

APPENDICES
for the
**Protocol for Developing Terrestrial Ecosystem
Current Landscape Condition Assessments**



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APPENDIX A

Outline for Terrestrial Ecosystem Assessments Current Landscape Condition

I. Chapter 1 – Introduction

A. Background, Context, and Application

1. Introductory paragraph describing the regional approach to assessments and identifying the connection between this assessment and the Region 2 Species Conservation Project.
2. Paragraph describing how and where this assessment will be applied – e.g., Forest Plan revision, NFP implementation (background for Focused Area Assessments), Healthy Forest Initiative, project planning, range allotment planning, etc.

B. Assessment Components

1. Identify and briefly describe the major terrestrial assessment components and explain the link between them
 - a. Historic Range of Variation (HRV) Assessments
 - b. Current Landscape Condition (CLC) Assessments
2. Identify the overall goals of this CLC Assessment

C. CLC Assessment Objectives

1. Identify broad issues relevant to the assessment area
 - a. Biological diversity and species viability
 - b. Forest and rangeland health
 - c. Natural disturbances and disturbance hazard and risk
 - d. Roadless areas, wilderness, special areas
 - e. Risk associated with land use practices and vegetation management
 - f. Other issues that are relevant to the assessment area
2. Describe the CLC Assessment Chapters and Modules – e.g., the organization of the assessment and the content of each section for a roadmap of the document

D. Description of the Assessment Area

1. Define the assessment area (e.g., geographic extent) and scales of assessment, with reporting units (e.g., vegetation type) for each scale identified
2. Discuss the national and regional ecological significance of the assessment area

II. Chapter 2 – Ecological and Socio-economic Context of the Assessment Area

Objective: Describe the ecological context of the assessment area, identifying the physical and/or biological factors that create ecological patterns and provide a foundation for interpreting the current ecological condition. Describe the social and economic context of the assessment area, identifying known primary socioeconomic factors that serve as a basis for interpreting ecological condition. Summarize important broad scale patterns of resource management and land uses that influence vegetation condition, landscape pattern, and ecosystem function.

A. Biogeographic Significance

1. Describe the broad-scale biogeographic significance of the assessment area. How is the assessment area important in an ecoregional context in providing for species?

B. Climate

1. Macro-topographic influences
2. Precipitation amounts and season – map and summary
3. Temperature ranges and means
4. Wind patterns
5. Historic climate change patterns

C. Physiography

1. Geology
2. Soils
3. Geography (or Ecological hierarchy)
 - a. Background
 - b. Maps from Province or Subcontinental level to lowest available level
 - c. Map unit summaries

D. Vegetation

1. Background on Potential Natural Vegetation (PNV)
2. Summary of major PNV types, including maps and brief descriptions of types with references to available literature describing the types
3. Brief summary of disturbance regimes, including expected ranges of frequency, intensity, extent, and severity of disturbance events, from Historic Range of Variation (HRV) assessment

E. Wildlife.

1. General description of current conditions and major changes in faunal species that are considered to be drivers of ecosystem condition, including a description of changes in species composition and population levels
2. Identify, by species, expected influences on ecosystem conditions. Discuss changes in vegetation structure and composition due to species changes.
3. Describe the implications of missing species or reduced/increased populations.

F. Anthropogenic

1. Historical context and influences – identify important factors that were not addressed in the HRV assessment
2. Social and economic values that may affect ecological condition – regional and local
3. Social and economic data – (e.g., population, age, employment, income, education, poverty, ethnic origins, etc.)
4. Projected changes in demographic trends, including population growth or decline, economic growth or decline, changes in social values, and resulting expected changes in resource uses
5. Land ownership and land use patterns – private, federal, state, county
 - a. Maps of anthropogenic land cover (e.g., agricultural land, urban areas, developments, managed vegetation, etc.)
 - b. Maps and descriptions reflecting the way in which the land is managed
 - c. Summaries of extractive uses (e.g., timber, range, etc.) and non-commodity uses

G. Summary of Significant Information Gaps

1. Inventory needs
2. Monitoring needs
3. Research needs

III. Chapter 3 - Existing Vegetation Condition

Objective: Describe the current composition, structure, function, and spatial distribution of the vegetation, by major cover type, of the assessment area. Emphasis will be on ecosystem structure and composition due to limited information on ecological function. Rely on current inventory data to the extent they are available. Evaluate the current condition in the context of what is known about the historic range of variation. Organize the description by major vegetation types.

A. Module 3A - Forests and Woodlands

1. Spruce-Fir Forests (*outline also applies to other forested types- Items 2-7 below*)
 - a. Composition
 - i. Spatial distribution in the section and on the Forest
 - ii. Characteristic dominant species and associations in each type
 - iii. Successional characteristics associated with composition
 - iv. PNV application including discussion of successional pathways, driving influences, spatial distribution, etc.
 - b. Structure
 - i. Stand age distributions
 - ii. Diameter-class distributions
 - iii. Distribution of habitat structural stages
 - iv. Stand density
 - v. Old growth/older forests – amounts, distributions, and characteristic features
 - vi. Patterns of variation within stand structural components
 - (a) Snags
 - (b) Coarse woody debris
 - (c) Canopy cover
 - (d) Canopy layers
 - c. Function
 - i. Net Primary Production
 - ii. Carbon storage
 - iii. Habitat
 - d. Ecological integrity – degree of presence or absence of expected elements of the vegetation
 - e. Summary of key findings and significant information gaps

2. Lodgepole Pine Forests
3. Aspen Forests
4. Douglas-fir Forests
5. Ponderosa Pine Forests
6. Limber Pine Woodlands
7. Juniper Woodlands
8. Other forest types that are relevant for the assessment area

B. Module 3B - Grasslands and Shrublands

1. Sagebrush Shrubland (*outline also for other non-forested types- Items 2-8 below*)
 - a. Composition
 - i. Spatial distribution in the section and on the Forest
 - ii. Characteristic dominant species and associations in each type
 - iii. Successional characteristics
 - iv. PNV application including discussion of successional pathways, driving influences, spatial distribution, etc.
 - b. Structure
 - i. Age and/or height class descriptions for shrubs
 - c. Function
 - i. Productivity
 - ii. Carbon storage
 - iii. Habitat
 - d. Ecological integrity – degree of presence or absence of expected elements of the vegetation
 - e. Summary of key findings and significant information gaps
2. Black Sagebrush Shrubland
3. Xeric Shrubland
4. Idaho Fescue Grassland
5. Bluebunch Wheatgrass Grassland
6. Little Bluestem Grassland
7. Alpine Tundra
8. Other species that are relevant for the assessment area

IV. Chapter 4 – Influences on Landscape Condition

A. Module 4A - Wildfire, Insects, and Disease

Objective: *Provide a spatial representation of expected historic fire regimes. Display the current condition as a measure of the departure from historic conditions. Map areas at high risk for fire. Describe the current condition of insect and disease within the assessment area. Map areas at high risk for insect and disease activity. Identify and map ecological risks associated with the interaction of wildfire with old growth/older forests, insects and disease. To the extent possible given information limitations, discuss the ecological implications of the current condition.*

1. Summary of current and expected natural disturbance agents
2. Map of historic fire regimes (e.g., fire return interval, fire intensity) – by major vegetation type
3. Map reflecting departure from historic fire regime
4. Maps reflecting current fire hazard conditions under different climate scenarios
5. Summary of current condition of insect and disease
6. Maps reflecting insect activity and risk of insect activity
7. Influences of fire, insects, and disease on major vegetation types
8. Identify and discuss risks associated with the interaction of wildfire with old growth/older forests
9. Identify and discuss risks associated with the interaction of fire with insects and disease
10. Summary of key findings and significant information gaps

B. Module 4B – Management of Forest and Woodland Ecosystems

Objective: *Describe the spatial and temporal patterns of management activities on forest ecosystems within the assessment area. Identify and map ecological risks associated with the interaction of management with wildfire, insects, and disease. To the extent possible given information limitations, discuss the ecological implications of the current condition.*

1. Spatial and temporal patterns of current and historic management activities
 - a. Temporal patterns in silvicultural practices by vegetation type
 - b. Spatial and temporal patterns of clearcuts
 - c. Impacts to particular vegetation types and structural conditions (are there disproportionate influences?)
 - d. Relevant summary information from HRV or evaluation in the context of what is known about HRV
2. Identify and discuss risks associated with the interaction of silviculture with wildfire
3. Identify and discuss risks associated with the interaction of silviculture with insects and disease
4. Summary of key findings and significant information gaps

C. Module 4C – Management of Grassland and Shrubland Ecosystems

Objective: *Describe the spatial and temporal patterns of management activities on grassland and shrubland ecosystems within the assessment area. To the extent possible given information limitations, discuss the ecological implications of the current condition.*

1. Spatial and temporal patterns of current and historic management activities
 - a. Livestock grazing
 - i. Allotment distribution
 - ii. Livestock type
 - iii. Stocking rates
 - iv. Season of use
 - v. Range condition
 - b. Influences of management on major grassland and shrubland vegetation types

- i. Changes in patterns of seral conditions
 - ii. Vegetation type conversions associated with land use practices
2. Relevant summary information from HRV or evaluation in the context of what is known about HRV
3. Summary of key findings and significant information gaps

D. Module 4D - Invasive Plant Species

Objective: *Identify current concerns regarding the distribution of exotic or invasive plant species. Depending on the availability of current systematic inventory data, map known locations of invasive plant species. Identify areas of probable vulnerability to invasion. Identify and map ecological risks associated with the interaction of invasive plant species with fire and forest and woodland vegetation management. Address the ecological consequences of the current condition and probable trends.*

1. Known occurrences and current distributions of invasive plant species -- summaries and map
2. Biophysical and anthropogenic influences that contribute to invasibility
3. Map of areas of probable vulnerability to invasion
 - a. Physiographic vulnerability model
 - b. Areas of critical concern for invasibility (e.g., "hot spots" of invasibility)
4. Identify and discuss risks associated with the interaction of invasive plant species with fire
5. Identify and discuss risks associated with the interaction of invasive plant species and forest and woodland vegetation management
6. Discussion of ecological consequences
7. Summary of key findings and significant information gaps

E. Module 4E - Roads and Trails

Objective: *Describe the current patterns of the distribution of roads and trails in the assessment area. Evaluate the relative impacts of these patterns on the vegetation types in the assessment area. Identify and map ecological risks associated with the interaction of roads and trails with invasive plant species. To the extent possible, given information limitations, discuss the ecological implications of the current condition.*

1. Roads distribution and density – summaries and spatial patterns
 - a. Roads in assessment area
 - b. Forest roads and trails, by class of use
 - c. Buffered roads to reflect a gradient of road impact
2. Identify and discuss risks associated with the interaction of roads and trails with invasive plant species
3. Influences of roads and trails on major vegetation types
4. Summary of key findings and significant information gaps

F. Module 4F - Recreation and Exurban Development

Objective: Describe the current patterns of the distribution of recreation and exurban development features in the assessment area. Evaluate the relative impacts of these patterns to each of vegetation types in the assessment area. Identify and map ecological risks associated with the interaction of recreation and exurban development with invasive plant species. To the extent possible given information limitations, discuss the ecological implications of the current condition.

1. Distribution (ski areas, campgrounds, summer homes, picnic areas, utilities, resorts, OHV areas, cow camps, etc)
2. Uses and trends
3. Identify and discuss risks associated with the interaction of recreation and exurban development with invasive plant species
4. Influences of recreation and exurban development on major vegetation types
5. Summary of key findings and significant information gaps

G. Module 4G - Minerals, Oil, and Gas Exploration and Extraction

Objective: Describe the current patterns of the distribution of mineral, oil, and gas extraction in the assessment area. Evaluate the relative impacts of these patterns to each of vegetation types in the assessment area. To the extent possible given information limitations, discuss the ecological implications of the current condition.

1. Mineral
 - a. Historic mines
 - b. Current mineral extraction
 - c. Key industrial and ecological integrity concerns
2. Oil
 - a. Historic wells
 - b. Current oil extraction
 - c. Key industrial and ecological integrity concerns
3. Gas
 - a. Historic wells
 - b. Current gas extraction
 - c. Key industrial and ecological integrity concerns
4. Influences of mineral, oil, and gas extraction on major vegetation types and on ecological integrity and sustainability
5. Summary of key findings and significant information gaps

V. Chapter 5 - Landscape Patterns

A. Module 5A - Forest and Woodland

Objective: Describe key features of spatial pattern on the landscapes. Identify the effects of land uses and management activities on landscape pattern. Discuss the dynamic nature of pattern and the probable ecological implications of varying patterns. To the extent possible given information limitations, discuss the ecological implications of the current condition.

1. Geographic context of current patterns of forest and woodland distribution
 - a. Importance of Forest in the larger eco-regional landscape
 - i. Maps of dominant types in eco-region, eco-subregion and on Forest
 - ii. Tabular summary reflecting abundance or rarity of dominant forest and woodland types at different scales
 - b. Patterns of distribution of forest and woodland cover types and structural conditions among various land ownerships and broadly defined land use allocations (e.g. wildland, agriculture, urban development, etc)
2. Landscape patterns on the Forest
 - a. Patterns of distribution of forest and woodland cover types and habitat structural stages among various land use allocations
 - i. Habitat Structural Stage distribution –maps for major types and over all vegetation types
 - ii. Histogram of percent of each stage by type
 - iii. Expected ranges in variability of the amount of each habitat structural stage of dominant cover types under historic disturbance regimes
 - iv. Locations of and proportion of each vegetation type permanently excluded from harvesting activities
 - b. Expected variation in patterns under historic disturbance regimes and various harvesting scenarios (RMLANDS model output)
 - c. Analysis of existing landscape structure - consider forest fragmentation, habitat distributions (e.g. interior habitat), edge/interior ratios, etc
 - d. Old growth/older forests distribution and recruitment
3. Summary of key findings and significant information gaps

B. Module 5B - Grassland and Shrubland

Objective: Describe key features of spatial pattern on the landscapes. Identify the effects of land uses and management activities on landscape pattern. Due to the limited availability of data to describe and map grassland and shrubland patterns, Livestock Preference and Rangeland Resilience Models were developed to approximate existing patterns of rangeland condition. Discuss the dynamic nature of pattern and the probable ecological implications of varying patterns. To the extent possible given information limitations, discuss the ecological implications of the current condition.

1. Geographic context of current patterns of grassland and shrubland distribution
 - a. Importance of Forest in the larger eco-regional landscape
 - i. Maps of dominant types in eco-region, eco-subregion and on Forest
 - ii. Tabular summary reflecting abundance or rarity of dominant grassland and shrubland types at different scales
 - b. Patterns of distribution of grassland and shrubland cover types and

- structural conditions among various land ownerships and broadly defined land use allocations (e.g. wildland, agriculture, urban development, etc)
2. Current grassland and shrubland landscape condition
 - a. Summary of historical to present day influences (e.g. fire, grazing, wildlife)
 - b. Livestock preference and rangeland resilience – a modeling approach
 - i. Livestock preference model
 - ii. Rangeland resilience model
 - iii. Identify and discuss interactions of livestock preference with wildfire and invasive plant species
 3. Proportion of major grassland and shrubland vegetation types permanently protected from livestock grazing (show map for spatial context)
 4. Dynamics of the forest and woodland/grassland and shrubland ecotone
 5. Summary of key findings and significant information gaps

VI. Chapter 6 – Areas of Special Biodiversity Significance

***Objective:** Describe plant communities of special concern or other unique habitats of biodiversity significance. Discuss their ecological significance, display the spatial distributions of these habitats, identify anthropogenic influences or risk factors, and evaluate the ecological implications of the current condition. Evaluate the relationships among vegetation of these special areas and vegetation of the assessment area.*

1. Plant communities of special concern—descriptions and maps
 - a. Spatial distributions
 - b. Distribution of these types within the major vegetation cover of the assessment area
 - c. Anthropogenic influences or ecological risk factors
 - d. Ecological significance
2. Unique landscape features – caves, cliffs, talus
 - a. Spatial distributions
 - b. Distribution of these types within the major vegetation cover of the assessment area
 - c. Anthropogenic influences or ecological risk factors
 - d. Ecological significance
3. Conservation sites
 - a. Spatial distributions
 - b. Distribution of these types within the major vegetation cover of the assessment area
 - c. Anthropogenic influences or ecological risk factors
 - d. Ecological significance
4. Research Natural Areas, both existing and potential – descriptions and maps
 - a. Spatial distributions
 - b. Distribution of these types within the major vegetation cover of the assessment area
 - c. Anthropogenic influences or ecological risk factors
 - d. Ecological significance
5. Other areas as relevant within the assessment area (e.g., roadless areas, wilderness, wildlife corridors, etc.)
 - a. Spatial distributions
 - b. Distribution of these types within the major vegetation cover of the assessment area
 - c. Anthropogenic influences or ecological risk factors

- d. Ecological significance
6. Discussion of how well unique and common habitats are currently represented under special management in the assessment area
7. Summary of key findings and significant information gaps

VII. Chapter 7 – Synthesis

Objective: *Summarize the key findings of the assessment. Develop a synthetic understanding of ecological integrity and ecological sustainability concerns of the assessment area. Examine the cumulative impacts of anthropogenic influences and ecological disturbance across the assessment area. Map “high integrity” and “low integrity” landscapes. Identify places that may serve as reference for developing ecological restoration approaches and monitoring. Identify the opportunities and needs for ecological restoration, including places of concern. Identify and prioritize information gaps, inventory needs, and research needs and provide suggestions for applying and maintaining the assessment.*

1. Summary of key findings presented by major management activities or issues
 - a. Wildfire, insects, and disease
 - b. Forest vegetation management
 - c. Rangeland management
 - d. Invasive plant species
 - e. Roads and trails
 - f. Recreation and exurban development
 - g. Minerals
 - h. Special management areas
2. Ecological Integrity and Sustainability
 - a. Definitions and explanation of application in this assessment
 - b. Key issues of ecological integrity and sustainability
 - c. Areas of ecological integrity concerns in the assessment area
 - d. Areas of high ecological integrity in the assessment area
 - e. Reference areas
3. Conclusions – what is next
 - a. Identify working hypotheses for adaptive management application of the assessment findings
 - b. Highlight interpretation risks associated with the quality or level of available information
 - c. Summarize critical inventory, monitoring, and research needs
 - d. Recommend ecological indicators for ecosystem monitoring
 - e. Provide suggestions for updates or revisions of the assessment

APPENDIX B

Review of Policy Regarding the Development of Management Recommendations in Species Assessments for the Region 2 Species Conservation Project

This paper provides background and rationale for decisions on the use of management recommendations in species assessments. (See the final section “Suggested Approach for R2 Species Conservation Assessments” for direction regarding use of management recommendations in species assessments).

Should Region 2 Ecological Assessments and Species Assessments Include Management Recommendations?

Note: This paper is not in the format for final assessments.

Analysis prepared for the Species Conservation Project Steering Group By Chris Liggett, Greg Hayward, and Nancy Warren

Problem Statement

The Species Conservation Assessment Project is designed to provide regional context and guidance in support of forest planning. Assessments will be completed for aquatic and terrestrial ecosystems and for a broad array of plant and animal species. The purpose of this white paper is to explore the question of whether or not the assessment(s) should contain management recommendations.

By “management recommendations,” we mean a statement that establishes a rule or specifies a definite condition that must be attained. Assessments are expected to provide factual information, predictions, estimates, etc. Here we consider whether they should include or advocate particular recommendations.

Background

This section contains relevant background information. First, we contrast the Species Conservation Project with earlier efforts to emphasize differences between planning and

scientific assessments. We then examine definitions of assessments and related topics, especially in light of the planning rule published in November 2000.

(1) Science and Planning in Relation to the Species Conservation Project.

Scientific assessments, and this project in particular, differ from the previous round of planning in several important ways:

- Emphasis on collaboration and scientific peer review.
- The order in which we do things.
- The way in which we define “decision space.”

Forest planning under the 1982 regulations began with an Analysis of the Management Situation (AMS). The AMS was prepared strictly in-house, and did not cover many important characteristics of the environment being managed. Population viability was evaluated much later, as part of the analysis of alternatives in the EIS. In the current forest plan revisions, assessments will provide scientific information that may assist forests in completing the necessary evaluation steps when initiating revision. These steps include summarizing new information, describing ecosystem and species diversity, and evaluating the effectiveness of the current plan in contributing to sustainability.

(2) Types of Assessments

The FY2001 Program Direction and Initial Operating Plan (PD) defines assessments as “characterizations of ecosystems above the project-level ... conducted at a variety of scales” (PD, p. 217). Two scales are then defined: *broad-scale assessments*, which cover “ecosystems that cross many watersheds and may cross several state boundaries,” and *watershed/landscape assessments*, which are

focused on “watersheds and landscapes ranging from 40-100,000 acres in size” (PD, p. 218).

Broad-scale assessments provide a synthesis of current scientific information, including a description of uncertainties and assumptions, to characterize historical conditions, current status, and future trends of ecological, social, and/or economic conditions, their relationship to sustainability, and the principal factors contributing to these conditions and trends (36 CFR219.5(a)(1)(i) and FSM 1920.5).

In 1999, a Committee of Scientists was convened to provide input for revising the planning regulations. Their report discussed assessments at length. They stated that “assessments, the assembling of a shared and scientifically grounded body of information, provide the foundation of information from which policies, strategies, and decisions can be built, evaluated, and changed ... The purpose of assessments is to understand the current conditions and trends regarding the land, resources, and people in an area in light of their history and the forces of change” (Committee of Scientists 1999:85-86). They saw the assessment process as distinct from decision-making, as practiced by federal agencies: “Most critically, assessments do not produce decisions and, therefore, should not be made to function under the NEPA processes associated with decision making” (Committee of Scientists 1999:95).

There are many recent examples of broad-scale assessments. These include the Sierra Nevada Ecosystem Project, Interior Columbia Basin Ecosystem Management Project, Southern Appalachian Assessment, Great Lakes Assessment, and the Northwest Forest Plan. Each of these assessments examined a broader geographic area than the ecological assessments envisioned for the Region 2 Species Conservation Project.

Species assessments are science products developed to assist managers in designing conservation programs for individual species. These documents provide managers, researchers, and the public with a thorough discussion of the biology, ecology,

management considerations, and status of a species or system in a defined geographic area. As a comprehensive, state-of-knowledge document, a species assessment is based on scientific knowledge accumulated prior to the initiation of the assessment. Conclusions concerning conservation status stem from the scientific information summarized in the assessment. Scientific assessments have been completed for a variety of fish and wildlife species, such as the inland cutthroat trout (Young et al. 1996), forest owls (Hayward and Verner 1994), and the Canada lynx (Ruggiero et al. 2000).

(3) Comparison of Region 2 Assessments with Other Assessments

The various broad-scale and species assessments described above have been designed to fulfill somewhat different purposes. Each differs in terms of the number of state and federal agencies involved, their relative level of participation, the geographic extent of the assessment, and the extent to which both scientists and managers were involved. Some offer management recommendations or conservation approaches, while others do not.

The Species Conservation Project is designed to incorporate terrestrial and aquatic ecosystem assessments, species assessments, reference models, and species conservation strategies into an overall framework that will ensure a thorough evaluation of species viability. Following is a description of the purpose and content of each of the documents that we envision.

Ecological Assessment: Characterizes physical, biological, and ecological components of terrestrial and aquatic ecosystems; describes the natural disturbance regimes and dynamics of ecosystems; and compares current with historical conditions to provide context and understanding of broad trends; examines the relationships between dominant management activities and ecological pattern and process; identifies inventory and monitoring methods; and identifies information gaps.

Species Assessment: Documents the species status, dominant ecological relationships, threats, inventory and monitoring methods, proven management practices, and information needs for a broad array of plant and animal species.

Conservation Strategy: Provides guidance and recommendations to address risk factors identified in a conservation assessment, to ensure species viability, and to preclude the need for federal listing under the Endangered Species Act. Conservation strategies will be developed for certain species listed as sensitive and for other species at risk.

Reference Models of Sustainability: Integrates the ecosystem and species assessments to identify the boundaries to ecosystem integrity and sustainability. This will help identify regional priorities for conservation or restoration, establish appropriate consistency in management strategies, and define the limits within which land and resource management will be sustainable.

We recognize a clear distinction between Conservation Assessments, which compile and synthesize scientific information, and Conservation Strategies and the Reference Models of Sustainability, which integrate information from the assessments. Furthermore, we suggest that the Region 2 Ecological Assessments and Species Assessments are neither 'broad-scale assessments' nor 'watershed assessments' as defined by the revised planning rule. The Region 2 Ecological Assessments examine spatial extents between those described in the planning rule. The Species Assessments do not assess species at particular spatial extents but instead examine the biology, ecology, and management of species at an array of spatial scales.

(4) The Case for Recommendations

Agency advice contains contradictory direction regarding use of recommendations in assessments. Strong arguments for including recommendations relate to efficiency and the role assessments should play in developing

consistent, credible, forest plans. The specific case for recommendations includes:

- Agency direction.
- Advice from the Committee of Scientists to produce assessments that are synthetic.
- Increasing credibility.
- Increasing consistency among forests.
- Increasing efficiency.

In the next few paragraphs we discuss the case for including recommendations in assessments for the Region 2 Species Conservation Project.

The FY2001 Program Direction and Initial Operating Plan (PD) begins by noting that "assessments do not produce decision documents, but do identify options that managers can evaluate during formal planning activities" (PD, p. 217). Specifically regarding broad-scale assessments, the PD says only that they "provide the context for land and resource management plan revision and include determinations of ... sustainability under existing management direction." Watershed or landscape assessments, on the other hand, are "to identify and prioritize restoration and land management actions necessary to achieve management objectives" and may include "identifying management issues and making recommendations based on the assessment" (PD, p. 218).

The Committee of Scientists felt that assessments must do more than simply discuss current conditions: "Assessments are not just 'buckets of facts.' Rather, assessments provide the context for proposing ways to achieve long-term goals of sustainability. To inform the development of desired future conditions and develop potential strategies and pathways of management to achieve them, one necessary result of the assessment process is the identification of elements for conservation strategies along with scientifically credible procedures for evaluating the effectiveness of strategies in achieving sustainability." (Committee of Scientists. 1999). Bioregional assessments should be designed to, among other things, "suggest elements necessary for

developing conservation strategies for species and ecosystems during the policy- and decision-making processes.” The Committee had a slightly different concept for smaller-scale assessments: “Small-scale assessments generally come after the development of a strategic direction for a larger landscape. They refine the estimates of management opportunities made during large-landscape planning to move the current conditions in the watershed toward the desired future condition.” (Committee of Scientists 1999:95)

There would be several benefits in having subject matter experts who participate in developing the assessments formulate management recommendations. First, there would be far less potential for misinterpretation of the information by individual managers. Recommendations by the scientists would have high credibility with the public and other agencies.

Consistency in approaches is important in dealing with region-wide issues such as species viability. Including management recommendations as part of the assessments would provide a greater degree of certainty to the public, cooperating agencies, and adjoining forest service units as to what to expect in the revised forest plans.

Preparing management recommendations early in the process may save time and prevent unnecessary effort by avoiding alternatives that clearly will not comply with laws and regulations. Including this within the assessments may also significantly reduce the burden on each individual forest to conduct these analyses and document the basis for the management recommendations, although this could be provided to some extent through a less explicit discussion of management implications.

(5) The Case against Recommendations

Although agency advice regarding use of recommendations is contradictory, several agency documents present strong arguments against incorporating recommendations in assessments. General arguments against use of recommendations center around:

- Agency direction.
- Protecting the objectivity of scientists and maintaining the separation between science and management.
- Acknowledging significant variability in the willingness and experience of scientists to write management recommendations.
- Acknowledging the chilling effect of published recommendations on management innovation.
- Conflicting direction that results from multiple recommendations articulated in different assessments.

Recent publications addressing the challenges of science/management collaboration provide useful perspectives on this question. Following two national workshops devoted to integrating science in decision-making, the U.S. Forest Service published a brief set of guidelines (USDA Forest Service 1997). One of the guidelines (#10) stated that collaborators must “Clearly identify roles and responsibilities”. Research is charged with producing information and generating management options, while land managers make management and policy decisions. While elaborating on these roles, the authors explicitly stated that researchers should “Avoid recommending a preferred policy option or taking positions on options.”

Mills et al. (1998) also discussed the challenge of integrating research and management cultures. They emphasized the need to clearly separate roles. Based on lessons learned in the Tongass Forest Plan revision, they suggested that collaborators “Define the science role carefully and always stay within it” and suggested that scientists “refrain from making management recommendations.”

Unger and Ross (Agency letter distributed in 1992) defined the role of assessments quite conservatively. In their view, assessments “are to be prepared as technical documents from which information can be drawn for management deliberations and decision making. The assessments themselves must be restricted to technical information and

interpretation. Management considerations are acceptable.”

The guidance articulated by USDA Forest Service (1997) and Mills et al. (1998) was written in the context of promoting collaboration, rather than an evaluation of the role of recommendations in assessments. However, to the extent that assessments represent science documents, the guidance is applicable to the Species Conservation Project.

Assessments produced for the Species Conservation Project will be written by a wide array of scientists from agencies and academia. These scientists will vary in their willingness to provide management recommendations, leading to very uneven treatment of this topic among assessments. Reluctance to provide recommendations will stem, in part, from a strong need to remain objective as suggested by Mills et al. (1998). Equally important, scientists are aware that scientific knowledge is never complete and understanding of nature is constantly changing. This perception of knowledge leads to greater skepticism. Therefore, many scientists feel uncomfortable making recommendations based on scientific knowledge alone, in part because information is never complete. In addition, effective recommendations must explicitly consider context -- ecological, social, and political.

Some scientists, while expert in their field, may not have the same depth of understanding of current land management practices. This may limit their ability to provide practical and appropriate management recommendations. Even where all participants in an assessment and planning process are fully competent and knowledgeable, differences in professional norms can frustrate attempts to translate scientific findings into practical management recommendations. Differences in understanding and use of terminology such as *conservation approaches*, *management recommendations*, *standards*, *guidelines*, *conservation measures*, and *management objectives* can cause confusion.

Once established, management recommendations may limit the range of alternatives considered. Any list of recommendations will likely be incomplete due to the limitations of scientific knowledge, yet once they are published; it may be difficult to justify using a different approach. This can create difficulties in using the assessment findings in subsequent program and project proposals, which must be evaluated under the National Environmental Policy Act. One of NEPAs most important provisions compels agencies to generate and evaluate alternatives to the proposed action. Scientific determinations, even when couched as “recommendations” carry an aura of authority (especially with the public) that curtail, if not halt, the search for options and alternatives. Furthermore, assessments with strong recommendations could unwittingly undermine agency policy.

Forest plans must integrate management of multiple resources and many species within the context of the particular features of a specific National Forest or Grassland. Integration will be more difficult if forests must consider many species assessments, each providing specific management recommendations that are likely to conflict. However, the difficult process of integration may be facilitated by assessments that thoroughly examine the implications of potential environmental changes and that describe a range of conservation approaches to address the major threats faced by species. The conflicts among recommendations contained in various species assessments are problematic, in part, because of the special status that recommendations hold when expressed by scientific experts.

Suggested Approach for R2 Species Conservation Assessments

We suggest that assessments produced for the Region 2 Species Conservation Project not include explicit management recommendations. This suggestion is based largely on arguments developed in recent documents published by senior managers and scientists in the Forest Service (e.g. United States Department of Agriculture 1997,

Everest et al. 1997, Mills et al. 1998) and reviewed earlier in this document. Assessments envisioned for the Species Conservation Project will be used to help develop numerous forest plans and projects over an extended period of time. The assessments will serve planning most effectively if they provide a strong science base from which to build plan alternatives without directing management.

To comply with NFMA, forest plans must demonstrate that management direction will provide ecological conditions with a high likelihood of maintaining viable populations of all native and desired non-native vertebrate species. Therefore, forest plans must: 1) identify species for which there is a risk that well-distributed populations will not be maintained; 2) identify approaches that would contribute to conservation of species at risk; 3) develop a range of alternatives; and 4) assess and document how the alternatives affect the likelihood of maintaining viable populations. The Species Conservation Project is designed to address the first two of these objectives by providing a regionally consistent set of information to identify species at risk and to provide for their viability.

Assessments completed for the Species Conservation Project will identify cause-effect relationships, prioritize threats to viability that result from land management planning, and describe potential conservation approaches. A thorough analysis of the implications of various management options will provide managers information to evaluate the outcome of management decisions. By not specifying particular management recommendations, these analyses will give forests and the public the opportunity to craft management direction that integrates a variety of approaches, including approaches not envisioned during development of the regional assessments.

Having suggested that Region 2 assessments avoid making management recommendations, we strongly suggest that assessments include thorough syntheses of the scientific knowledge reviewed in the assessment. Assessments should not represent merely a 'bucket of facts' but a synthetic understanding of nature that contributes to management. Assessments will be most useful when they clearly describe the consequences of changes in the environment that result from management. Furthermore, assessments will not result in significant contributions to management unless they describe and cite management recommendations proposed elsewhere. When others have implemented certain management recommendations, the assessment should examine the success of the implementation. For example, a synthetic assessment might examine the changes in biodiversity, stream function, and nutrient cycling that will result from removal of woody material from streams. It would include a review of approaches tried by other managers or scientists and the actual or predicted outcomes. Managers will then be able to apply that knowledge to choices they might be facing regarding riparian management.

A review of conservation approaches (Wisdom et al. 2000) provides another means of synthesis. Conservation approaches can identify options to address conditions that have caused the species (or group of species) to be at risk (Wisdom et al. 2000). Such conservation approaches are not the same as management direction. For example, they would not attempt to prescribe a specific minimum number of logs per acre to be retained within timber harvest units. Rather, they might identify the importance of down wood to a particular species or group. Depending on the management objectives for an area, managers and the public could search for innovative ways to satisfy species requirements while meeting other goals.

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APPENDIX C

Potential Natural Vegetation Model

Modeling of PNV

Modeling of PNV is a last resort necessity of much of the R2 data sets. Conspicuously absent in the region are comprehensive potential vegetation classifications that are backed by data and are consistent across geographic areas. To fill the gap in knowledge models can be used. PNV modeling should be undertaken by individuals who thoroughly understand (1) concepts vegetation classification and (2) understand the limitations of the data sets available. Six steps should be followed.

- (1) The first step is literature review. Potential sources of information include: The Nature Conservancy (TNC), state heritage programs, universities, other agencies (NPS, BLM), and local Forest knowledge. Barry Johnston's literature review of "Plant Associations of Region 2" is an excellent starting point.
- (2) The second step is to review potential GIS data sets with the Forest GIS specialist. A review of scales, data sources, and data attributes should be conducted. Polygon data typically include soils, National Ecological hierarchy (section, subsection, land type association), climate, geology, common vegetation unit (CVU), common land unit (CLU), resource information data (RIS), fire history, range type, and timber sale maps. Grid layers include digital elevation models (DEM), land cover derived from satellite imagery, and State GAP program data. Point data sources include Stage 2 data, FIA data plots, range transect data locations, and ecological classification data plots.
- (3) The third step is make decisions on the appropriate level of classification to be modeled. Should the model be at the "series", plant association, or grouped by logical combinations of potential vegetation types?
- (4) The fourth step is to develop relationships between PNV and the data sets using local expert knowledge and results of the literature review.
- (5) The fifth step is to build a process flow chart with the GIS analyst. What order should the data be developed? What are the key data layers or attribute fields?
- (6) The sixth step is to test the model. This can be either a statistical or a subjective approach. A statistical approach involves the use of "point data" to validate model results. Data points must be evenly spread across the landscape and not clustered in a few locations. A subjective strategy involves using local knowledge and digital ortho images to assess model results.

Bighorn Physiographic Model

- (1) Literature review suggested the use of Despain's 1972 ecological monograph on the "Vegetation of the Bighorn Mountains, in Relation to Substrate and Climate"; Hoffman and Alexander's 1976 publication "Forest Vegetation of the Bighorn Mountains, Wyoming: A Habitat Type Classification"; Nessor's 1986 "Soil Survey of the Bighorn National Forest"; Wyoming Natural Diversity Database reports; The Nature Conservancy ecological data bases; Girard's 1997 "Riparian Classification of the Bighorn National Forest", and other appropriate nearby vegetation classifications.
- (2) It was determined the best GIS data sources were the Bighorn common vegetation unit (CVU), Bighorn common land unit (CLU), 30m DEM, and Wyoming and Montana GAP Land Cover Types.

- (3) After a review of data sources and available information the decisions was made to attempt to model PNV at the “series” level.
- (4) Relationships were developed between PNV and the data sets using local expert knowledge and results of the literature review. Examples of this are: (1) the black sage (*Artemisia nova*) series is related to “sagebrush” on CVU data and Soil map unit 20 and (2) the CVU “species mix” field can be used to develop shade tolerance rules for forest series level classification.
- (5) An analysis process was developed to guide the sequence of query development. This is described in detail under the GIS Query Steps below.
- (6) The Bighorn PNV model was subjectively reviewed by local Forest Service experts using digital orthophoto quads. Point data was not available to statistically assess the model.

Bighorn GIS Queries

In order to keep the GIS modeling simple, we identified two map-derived, environmental attributes as predictors of the potential natural vegetation (PNV): the current vegetation species mix and the concurrent soil type (Houston, personal communication). The Bighorn National Forest Common Vegetation Unit (CVU) and Common Land Unit (CLU) coverages were the primary datasets used in the model. Elevation and GAP land cover type were used as supplemental data sources.

Data layers used:

- Bighorn Common Vegetation Unit
- Bighorn Common Land Unit
- 30m DEM clipped to the Bighorn National Forest boundary
- Wyoming and Montana GAP Land Cover Types

GIS Queries:

- (1) Summarize the Species Mix field in the CVU layer. Then using local knowledge, select the most shade tolerant species of the mix for each polygon.
- (2) Intersect the CVU and CLU coverages to show the relationship between cover type species mix and soil types. Summarize the tabular results of the intersection for easier comprehension. Use the soil data to verify that the results from Step 1 were ecologically correct.
- (3) Assign a PNV type to those polygons where no species mix was identified in the attributes and to polygons that were simply labeled “grass”, “forb”, or “shrub”. This process involves several steps.
 - a) Grass, Forb, and Shrub: Summarize the remaining grass, forb, and shrub types and their corresponding soil types in a spreadsheet table. Assign a PNV type to each combination based on local expert knowledge about what vegetation would be expected if the grass/shrub/forb fell on a particular soil type.
 - b) Alpine and Meadow Tundra: The GAP land cover codes 82001 (Meadow Tundra) and 74002 (Alpine exposed rock/soil) are used to refine the meadow tundra and alpine areas coded as grass/forb and add more meaning to the types coded as bare or bare rock. The CVU/CLU polygons that fall within GAP codes 82001 and 74002 (above 2990m) become alpine tundra or alpine rock PNV types, respectively. The exception for this are series coded as a tree or wetland type, which stay as their original type. The rest of the various “B” codes get recoded as well:

Table C.1.

CVU SPECIES MIX	PNV TYPE	CVU SPECIES MIX	PNV TYPE	CVU SPECIES MIX	PNV TYPE	CVU SPECIES MIX	PNV TYPE	CVU SPECIES MIX	PNV TYPE
ABLA	abla	FEID	feid	PIEN	pien	PIPO	pipo	PSME	psme
ABLA:PICO	abla	FEID:AGROP2	feid	PIEN:ABLA	abla	PIPO:ACNE2:BETUL	pipo	PSME:ABLA	abla
ABLA:PICO:PIEN	abla	FEID:AGSP	feid	PIEN:ABLA:PICO	abla	PIPO:JUNIP	pipo	PSME:ABLA:JUNIP	abla
ABLA:PICO:PIFL2	abla	FEID:CAEL3	feid	PIEN:ABLA:PIFL2	abla	PIPO:JUNIP:PSME	psme	PSME:ABLA:PICO	abla
ABLA:PICO:PSME	abla	FEID:CAREX	feid	PIEN:ABLA:PIPO	abla	PIPO:PICO	pipo	PSME:ABLA:PIEN	abla
ABLA:PIEN	abla	FEID:CAREX:STIPA	feid	PIEN:ABLA:POTR5	abla	PIPO:PICO:JUNIP	pipo	PSME:ABLA:PIFL2	abla
ABLA:PIEN:PICO	abla	FEID:DAIN	feid	PIEN:ABLA:PSME	abla	PIPO:PICO:PIEN	pien	PSME:JUNIP	psme
ABLA:PIEN:PIFL2	abla	FEID:ELYMU	feid	PIEN:BETUL:POTR5	dmixed	PIPO:PICO:POPUL	pipo	PSME:JUNIP:PIFL2	psme
ABLA:PIEN:PIPO	abla	FEID:POA	feid	PIEN:PICO	Pien	PIPO:PICO:POTR5	pipo	PSME:JUNIP:PIPO	psme
ABLA:PIEN:POTR5	abla	FEID:POPR	feid	PIEN:PICO:ABLA	Abla	PIPO:PICO:PSME	psme	PSME:JUNIP:POTR5	psme
ABLA:PIEN:PSME	abla	FEID:STIPA	feid	PIEN:PICO:PIFL2	Pien	PIPO:PIEN	pien	PSME:JUOS:PIFL2	psme
ABLA:PIFL2	abla	FEID:STIPA:POA	feid	PIEN:PICO:PIPO	Pien	PIPO:PIEN:PSME	pien	PSME:JUSC2	psme
ABLA:PIFL2:PICO	abla	HEKI:CAREX	feid	PIEN:PICO:POTR5	Pien	PIPO:POPUL	pipo	PSME:JUSC2:PIFL2	psme
ABLA:PIFL2:PIEN	abla	HEKI:FEID:AGROP2	feid	PIEN:PICO:PSME	Pien	PIPO:PIFL2:POTR5	pipo	PSME:PICO	psme
ABLA:PIFL2:PSME	abla	JUCO6	junip	PIEN:PIFL2	Pien	PIPO:PIFL2:PSME	psme	PSME:PICO:ABLA	abla
ABLA:PIPO	abla	JUCO6:ARTEM	artr	PIEN:PIFL2:ABLA	Pien	PIPO:POAN3	pipo	PSME:PICO:JUNIP	psme
ABLA:POTR5	abla	JUCO6:ARTR2	artr	PIEN:PIFL2:POTR5	Pien	PIPO:POAN3:POTR5	pipo	PSME:PICO:JUSC2	psme
ABLA:POTR5:PIEN	abla	JUCO6:CELE3	cele3	PIEN:PIFL2:PSME	Pien		pipo	PSME:PICO:PIEN	pien
ABLA:PSME	abla	JUCO6:CELE3:ARTR2	cele3	PIEN:PIPO:ABLA	Abla	PIPO:POPUL:JUNIP	pipo	PSME:PICO:PIFL2	psme
ABLA:PSME:PIEN	abla	JUCO6:PHMO4	psme	PIEN:PIPO:PIFL2	Pien	PIPO:POPUL:PSME	psme	PSME:PICO:PIPO	psme
ABLA:PSME:PIFL2	abla	JUCO6:SALIX	salix	PIEN:POAN3:POTR5	Pien	PIPO:POTR5	pipo	PSME:PICO:POTR5	psme
ARSC	alpine	PEFL15	pefl15	PIEN:POTR5	Pien	PIPO:POTR5:PICO	pipo	PSME:PIEN	pien
ARTEM	artr	JUNIP	junip	PIEN:POTR5:ABLA	Abla	PIPO:POTR5:PIEN	pien	PSME:PIEN:ABLA	abla
ARTEM:ARTR2	artr	JUNIP:ARTR2	junip	PIEN:POTR5:PICO	pien	PIPO:POTR5:PIFL2	pipo	PSME:PIEN:JUNIP	pien
ARTEM:CELE3	cele3	JUNIP:ARTR2:CELE3	junip	PIEN:POTR5:PSME	pien	PIPO:POTR5:POAN3	pipo	PSME:PIEN:PICO	pien
ARTEM:JUNIP:CELE3	cele3	JUNIP:PIFL2	pifl2	PIEN:PSME	pien	PIPO:POTR5:PSME	psme	PSME:PIEN:PIFL2	pien
ARTEM:PHMO4	artr	JUNIP:PIFL2:PIPO	pipo	PIEN:PSME:ABLA	abla	PIPO:PSME	psme	PSME:PIEN:PIPO	pien
ARTEM:PHMO4:RIBES	artr	JUNIP:PIFL2:PSME	psme	PIEN:PSME:PICO	pien	PIPO:PSME:JUNIP	psme	PSME:PIEN:POTR5	pien
ARTEM:RIBES	artr	JUNIP:PIPO	pipo	PIEN:PSME:PIFL2	pien	PIPO:PSME:PICO	psme	PSME:PIFL2	psme
ARTEM:RIBES:JUCO6	artr	JUNIP:PIPO:PIFL2	pipo	PIEN:PSME:PIPO	pien	PIPO:PSME:PIEN	pien	PSME:PIFL2:ABLA	abla

Table C.1.

CVU SPECIES MIX	PNV TYPE	CVU SPECIES MIX	PNV TYPE	CVU SPECIES MIX	PNV TYPE	CVU SPECIES MIX	PNV TYPE	CVU SPECIES MIX	PNV TYPE
ARTEM:SALIX	salix	JUNIP:PIPO:PSME	pipo	PIEN:PSME:POAN3	pien	PIPO:PSME:PIFL2	psme	PSME:PIFL2:JUNIP	psme
ARTR2	artr	JUNIP:PSME	psme	PIEN:PSME:POTR5	pien	PIPO:PSME:POPUL	psme	PSME:PIFL2:JUOS	psme
ARTR2:ARNO4	arno	JUNIP:PSME:PICO	psme	PIFL2	pifl2	PIPO:PSME:POTR5	psme	PSME:PIFL2:JUSC2	psme
ARTR2:CELE3	cele3	JUNIP:PSME:PIFL2	psme	PIFL2:ABLA	abla	POA:CAREX	wetland	PSME:PIFL2:PICO	psme
ARTR2:CELE3:JUNIP	junip	JUNIP:PSME:PIPO	psme	PIFL2:ABLA:PICO	abla	POAN3:JUSC2	cottonwood	PSME:PIFL2:PIEN	pien
ARTR2:CEMO2	cemo2	JUOS:PIFL2	pifl2	PIFL2:ABLA:PIEN	abla	POAN3:PIEN	pien	PSME:PIFL2:PIPO	psme
ARTR2:CHNA2	artr	JUOS:PSME	junip	PIFL2:ACER	dmixed	POAN3:PIPO:PSME	psme	PSME:PIFL2:POPUL	psme
ARTR2:CORNU:CHNA2	artr	JUSC2	junip	PIFL2:ACER:BEOC2	dmixed	POAN3:PSME	psme	PSME:PIFL2:POTR5	psme
ARTR2:JUCO6	artr	JUSC2:PICO:PSME	psme	PIFL2:JUNIP	pifl2	POAN3:PSME:PIFL2	psme	PSME:PIPO	psme
ARTR2:JUCO6:CELE3	cele3	JUSC2:PSME:PIFL2	psme	PIFL2:JUNIP:PSME	psme	POFR4:ARTR2	artr	PSME:PIPO:JUNIP	psme
ARTR2:JUCO6:SALIX	salix	PEFL15:ARTR2	pefl15	PIFL2:JUOS	pifl2	POFR4:SALIX	salix	PSME:PIPO:PICO	psme
ARTR2:JUNIP	junip	PEFL15:ARTR2:JUCO6	pefl15	PIFL2:JUSC2	pifl2	POPR	feid	PSME:PIPO:PIEN	pien
ARTR2:JUNIP:CELE3	junip	PHMO4	psme	PIFL2:JUSC2:PSME	psme	POPR:FEID	feid	PSME:PIPO:PIFL2	psme
ARTR2:JUNIP:JUCO6	junip	PHMO4:RHTR:RIBES	psme	PIFL2:PICO	psme	POPUL	cottonwood	PSME:PIPO:POPUL	psme
ARTR2:PHMO4:RHTR	rhtr	PHYSO	psme	PIFL2:PICO:ABLA	abla	POPUL:PIEN:PSME	pien	PSME:PIPO:POTR5	psme
ARTR2:POFR4	artr	PICO	pico	PIFL2:PICO:PIEN	pien	POPUL:PIPO	pipo	PSME:POAN3	psme
ARTR2:PRVI:RHTR	rhtr	PICO:ABLA	abla	PIFL2:PICO:POPUL	psme	POPUL:PIPO:PICO	pipo	PSME:POAN3:PIEN	pien
ARTR2:RHTR	rhtr	PICO:ABLA:PIEN	abla	PIFL2:PICO:PSME	psme	POPUL:PIPO:PSME	psme	PSME:POAN3:PIFL2	psme
ARTR2:RIBES	artr	PICO:ABLA:PIFL2	abla	PIFL2:PIEN	pien	POPUL:POTR5	cottonwood	PSME:POAN3:POTR5	psme
ARTR2:RIBES:ROSA3	artr	PICO:ABLA:POTR5	abla	PIFL2:PIEN:ABLA	abla	POPUL:POTR5:PIPO	pipo	PSME:POPUL	psme
ARTR2:RIBES:VASC	artr	PICO:ABLA:PSME	abla	PIFL2:PIEN:POTR5	pien	POPUL:POTR5:PSME	psme	PSME:POPUL:JUNIP	psme
ARTR2:SALIX	salix	PICO:PIEN	pien	PIFL2:PIEN:PSME	pien	POPUL:PSME	psme	PSME:POPUL:PIFL2	psme
ARTR2:SAVE4	save4	PICO:PIEN:ABLA	abla	PIFL2:PIPO	pipo	POPUL:PSME:POTR5	psme	PSME:POTR5	psme
ARTR2:VASC:JUCO6	artr	PICO:PIEN:PIFL2	pien	PIFL2:PIPO:JUNIP	pipo	POTR5	potr5	PSME:POTR5:JUNIP	psme
BASA3	feid	PICO:PIEN:PIPO	pien	PIFL2:PIPO:POTR5	pipo	POTR5:ABLA	abla	PSME:POTR5:JUSC2	psme
CAAQ	wetland	PICO:PIEN:POTR5	pien	PIFL2:PIPO:PSME	psme	POTR5:ABLA:PICO	abla	PSME:POTR5:PICO	psme
CAREX	wetland	PICO:PIEN:PSME	psme	PIFL2:POAN3	cottonwood	POTR5:ABLA:PIEN	abla	PSME:POTR5:PIEN	pien
CAREX:DECE	wetland	PICO:PIFL2	abla	PIFL2:POTR5	psme	POTR5:ACGL:PRVI	dmixed	PSME:POTR5:PIFL2	psme
CAREX:FEID	wetland	PICO:PIFL2:ABLA	abla	PIFL2:POTR5:ABLA	abla	POTR5:ACNE2	potr5	PSME:POTR5:PIPO	psme
CAREX:JUNCU	wetland	PICO:PIFL2:PIEN	pien	PIFL2:POTR5:PIPO	pipo	POTR5:JUNIP:PIPO	pipo	RHTR:ARTR2	rhtr

Table C.1.

CVU SPECIES MIX	PNV TYPE	CVU SPECIES MIX	PNV TYPE	CVU SPECIES MIX	PNV TYPE	CVU SPECIES MIX	PNV TYPE	CVU SPECIES MIX	PNV TYPE
CELE3	cele3	PICO:PIFL2:PSME	psme	PIFL2:POTR5:PSME	psme	POTR5:PICO	abla	RHTR:PRVI:RIBES	rhtr
CELE3:ARTEM	cele3	PICO:PIPO	pipo	PIFL2:PSME	psme	POTR5:PICO:PIEN	pien	RIBES	dmixed
CELE3:ARTR2	cele3	PICO:PIPO:JUNIP	pipo	PIFL2:PSME:ABLA	abla	POTR5:PICO:PIPO	pipo	RIBES:SALIX:JUCO6	salix
CELE3:ARTR2:JUCO6	cele3	PICO:PIPO:PIEN	pien	PIFL2:PSME:JUNIP	psme	POTR5:PICO:PSME	psme	SALIX	salix
CELE3:ARTR2:JUNIP	junip	PICO:PIPO:PIFL2	pipo	PIFL2:PSME:JUSC2	psme	POTR5:PIEN:ABLA	abla	SALIX:ARTEM	salix
CELE3:JUCO6	cele3	PICO:PIPO:POAN3	pipo	PIFL2:PSME:PICO	psme	POTR5:PIEN:PICO	pien	SALIX:ARTR2	salix
CELE3:JUNIP	junip	PICO:PIPO:POTR5	pipo	PIFL2:PSME:PIEN	pien	POTR5:PIEN:PIFL2	pien	SALIX:JUCO6:SHEPH	salix
CELE3:JUNIP:ARTEM	junip	PICO:PIPO:PSME	psme	PIFL2:PSME:PIPO	psme	POTR5:PIEN:PIPO	pien	SALIX:PEFL15	salix
CELE3:JUNIP:ARTR2	junip	PICO:POTR5	abla	PIFL2:PSME:POPUL	psme	POTR5:PIEN:PSME	pien	SALIX:PIEN	salix
CELE3:PRVI:COSES	dmixed	PICO:POTR5:ABLA	abla	PIFL2:PSME:POTR5	psme	POTR5:PIFL2	pifl2	SAPL2:SAGE2	salix
CELE3:RHTR:COSES	dmixed	PICO:POTR5:JUNIP	psme			POTR5:PIFL2:JUNIP	pifl2	STVI4:CAEL3	feid
CEMO2:ARTR2	cemo2	PICO:POTR5:PIEN	pien			POTR5:PIFL2:PIEN	pien	VASC	abla
CHNA2	artr	PICO:POTR5:PIFL2	abla			POTR5:PIFL2:PSME	psme		
DAIN:JUPA	feid	PICO:POTR5:PIPO	pipo			POTR5:PIPO	pipo		
DECE:CAREX	wetland	PICO:POTR5:PSME	psme			POTR5:PIPO:PIFL2	pipo		
ELSP3:SPCR	elsp3	PICO:PSME	psme			POTR5:PIPO:POAN3	pipo		
		PICO:PSME:ABLA	abla			POTR5:PIPO:POPUL	pipo		
		PICO:PSME:PIEN	pien			POTR5:PIPO:PSME	psme		
		PICO:PSME:PIFL2	psme			POTR5:POAN3	cottonwood		
		PICO:PSME:PIPO	psme			POTR5:POAN3:ABLA	abla		
		PICO:PSME:POTR5	psme			POTR5:POAN3:PIEN	pien		
						POTR5:POPUL	cottonwood		
						POTR5:PSME	psme		
						POTR5:PSME:PICO	psme		
						POTR5:PSME:PIEN	pien		
						POTR5:PSME:PIFL2	psme		
						POTR5:PSME:PIPO	psme		

Table C.2.

CLU Soil MUID	CVU Cover Type	PNV Type	CLU Soil MUID	CVU Cover Type	PNV Type	CLU Soil MUID	CVU Cover Type	PNV Type
10	BWO	PICO	26	S	SALIX	43	BWO	PICO
10	F	FEID	27	BWO	FEID	43	F	FEID
10	G	FEID	27	F	FEID	43	G	FEID
10	S	ARTRV	27	G	FEID	43	S	ARTRV
11	BWO	PIEN	27	S	ARTRV	61	G	ELSP3
11	F	FEID	28	F	FEID	62	G	ELSP3
11	G	FEID	28	G	FEID	63	G	FEID
11	S	ARTRV	29	F	FEID	64	G	FEID
12	F	ELSP3	29	G	FEID	65	G	FEID
12	G	ELSP3	29	S	ARTRV	66	G	ELSP3
13	F	MEADOW TUNDRA	30	F	FEID	67	G	ELSP3
13	G	MEADOW TUNDRA	30	G	FEID	68	G	ELSP3
14	BWO	PSME	30	S	ARTRV	71	G	FEID
14	F	FEID	31	BWO	FEID	72	G	FEID
14	G	FEID	31	F	FEID	73	G	FEID
14	S	ARTRV	31	G	FEID	74	F	FEID
15	F	ELSP3	31	S	ARTRV	74	G	FEID
15	G	ELSP3	32	F	FEID	78	F	FEID
15	S	ARTRV	32	G	FEID	78	G	FEID
16	F	DECA/CAREX	32	S	ARTRV	79	F	ELSP3
16	G	DECA/CAREX	33	F	MEADOW TUNDRA	80	F	FEID
16	S	SALIX	33	G	MEADOW TUNDRA	80	G	FEID
17	F	FEID	33	S	SALIX	81	F	FEID
17	G	FEID	34	F	FEID	81	G	FEID
17	S	ARTRV	34	G	FEID	82	F	FEID
18	BWO	FEID	34	S	ARTRV	82	G	FEID
18	F	FEID	35	F	ELSP3	83	F	FEID
18	G	FEID	35	G	ELSP3	83	G	FEID
19A	BWO	PICO	35	S	CELE3	90	F	SCSC
19A	F	FEID	36	F	MEADOW TUNDRA	90	G	SCSC
19A	G	FEID	36	G	MEADOW TUNDRA	90	S	ARTRV
19B	BWO	PIEN	36	S	ARTRV	91	F	FEID/ELSM3
19B	F	FEID	37	F	MEADOW TUNDRA	91	G	FEID/ELSM3
19B	G	FEID	37	G	MEADOW TUNDRA	91	S	ARTRV
20	F	ELSP3	37	S	SALIX	92	S	ARTRV
20	G	ELSP3	38	BWO	PICO	93	F	FEID
21	F	FEID	38	F	FEID	93	G	FEID
21	G	FEID	38	G	FEID	93	S	SALIX
21	S	ARTRV	38	S	ARTRV	95	F	DECA/CAREX
22	F	FEID	39	F	FEID	95	G	DECA/CAREX
22	G	FEID	39	G	FEID	95	S	SALIX
22	S	ARTRV	39	S	ARTRV	97	F	FEID
23	F	FEID	40	BWO	PICO	97	G	SCSC
23	G	FEID	40	F	FEID	98	F	FEID
24	F	FEID	40	G	FEID	98	G	SCSC
24	G	FEID	41A	F	FEID	98	S	ARTRW

Table C.2.

CLU Soil MUID	CVU Cover Type	PNV Type	CLU Soil MUID	CVU Cover Type	PNV Type	CLU Soil MUID	CVU Cover Type	PNV Type
25	BWO	FEID	41A	G	FEID	99	F	FEID/ELSM3
25	F	FEID	41B	F	FEID	99	G	FEID/ELSM3
25	G	FEID	41B	G	FEID	99	S	ARTRV
25	S	ARTRV	42	F	ELSP3	W	G	WATER
26	F	MEADOW TUNDRA	42	G	ELSP3			
26	G	MEADOW TUNDRA	42	S	ARTRV			

B= rock outcrop/bare soil PNV
 BBS= rock outcrop/bare soil PNV
 BIC= ice/snow PNV
 BRO = rock outcrop/bare soil PNV
 BRS= rock outcrop/bare soil PNV

c) Water and Wetlands: At this point, all of the polygons coded as CVU Species Mix type “W” (water) were coded PNV Type Water. All of the Deca/Carex polygons were also recoded to PNV type “wetland”

(4) Create a summary table to show all of the polygons currently in HSS 1T and 2T. This is done to check for any stands that are in a temporary type conversion, due to fire, logging, or other recent disturbance. Using local knowledge, recode PNV types for any necessary polygons. The following CVU fields are used to help the local expert determine the correct PNV type.

Table C.3.

PNV TYPE	Species Mix	HSS	Cover Type	Tree Species Present	Shrub Species Present
abla	No Data	1T	F	ABLA	No Data
abla	No Data	1T	F	ABLA	ARTR2:JUCO6
abla	No Data	1T	F	ABLA	SALIX
abla	No Data	1T	F	ABLA:PICO:PIEN	ARTEM:SALIX
abla	No Data	1T	F	ABLA:PIEN	No Data
abla	No Data	1T	F	ABLA:PIEN	SALIX
abla	No Data	1T	F	ABLA:PIEN:PICO	No Data
abla	No Data	1T	F	ABLA:PIEN:PICO	ARTR2
abla	No Data	1T	F	ABLA:POTR5:PIEN	No Data
abla	No Data	1T	F	PICO:ABLA	ARTR2
abla	No Data	1T	F	PICO:ABLA:PIEN	No Data
abla	No Data	1T	F	PICO:PIEN	No Data
abla	No Data	1T	F	PICO:PIEN:ABLA	VASC
abla	No Data	1T	F	PIEN:ABLA	No Data
abla	No Data	1T	F	PIEN:ABLA	ARTEM
abla	No Data	1T	F	PIEN:ABLA	ARTR2
abla	No Data	1T	F	PIEN:ABLA	SALIX
abla	No Data	1T	F	PIEN:ABLA	SALIX:ARTR2
abla	No Data	1T	F	PIEN:ABLA	SAPLM
abla	No Data	1T	F	PIEN:ABLA:POTR5	No Data
abla	No Data	1T	F	PIEN:PICO	ARTR2
abla	No Data	1T	F	PIEN:PICO:ABLA	SALIX
abla	No Data	1T	F	POTR5:ABLA	JUCO6:ARTR2
abla	No Data	1T	G	ABLA	No Data
abla	No Data	1T	G	ABLA	ARTR2
abla	No Data	1T	G	ABLA	SALIX
abla	No Data	1T	G	ABLA:PICO:PIEN	No Data

Table C.3.

PNV TYPE	Species Mix	HSS	Cover Type	Tree Species Present	Shrub Species Present
abla	No Data	1T	G	ABLA:PIEN	No Data
abla	No Data	1T	G	ABLA:PIEN	ARTEM
abla	No Data	1T	G	ABLA:PIEN	ARTR2
abla	No Data	1T	G	ABLA:PIEN	SALIX
abla	No Data	1T	G	ABLA:PIEN:PIFL2	ARTR2
abla	No Data	1T	G	PICO:PIEN:ABLA	No Data
abla	No Data	1T	G	PICO:PIEN:ABLA	SALIX
abla	No Data	1T	G	PIEN:ABLA	No Data
abla	No Data	1T	G	PIEN:ABLA	ARTEM
abla	No Data	1T	G	PIEN:ABLA	ARTR2
abla	No Data	1T	G	PIEN:ABLA	SALIX
abla	No Data	1T	G	PIEN:ABLA	SALIX:ARTEM
abla	No Data	1T	G	PIEN:ABLA	VASC
abla	No Data	1T	G	PIEN:ABLA:PICO	No Data
abla	No Data	1T	G	PIEN:ABLA:PICO	ARTR2
abla	No Data	1T	G	PIEN:ABLA:PICO	SALIX
abla	No Data	1T	G	PIEN:ABLA:POTR5	No Data
abla	No Data	1T	G	PIEN:PICO:ABLA	ARTEM
abla	No Data	1T	G	PIEN:PSME:ABLA	ARTEM
abla	No Data	1T	G	POTR5:PIEN:ABLA	SALIX
abla	No Data	1T	G	PSME:ABLA:PIFL2	ARTEM
abla	No Data	1T	G	PSME:PIEN:ABLA	CELE3
abla	No Data	2T	S	ABLA	No Data
abla	No Data	2T	S	ABLA:PIEN	No Data
abla	No Data	2T	S	PIEN:ABLA	No Data
abla	ABLA	2T	T206	ABLA	No Data
abla	ABLA:PICO	2T	T206	ABLA:PICO	No Data
abla	ABLA:PICO	2T	T206	ABLA:PICO	ARTR2
abla	ABLA:PICO:PIEN	2T	T206	ABLA:PICO:PIEN	No Data
abla	ABLA:PIEN	2T	T206	ABLA:PIEN	No Data
abla	ABLA:PIEN	2T	T206	ABLA:PIEN	ARTR2
abla	ABLA:PIEN:PICO	2T	T206	ABLA:PIEN:PICO	No Data
abla	ABLA:PIEN:PICO	2T	T206	ABLA:PIEN:PICO	VASC
abla	ABLA:PIEN:PSME	2T	T206	ABLA:PIEN:PSME	No Data
abla	ABLA:PSME	2T	T206	ABLA:PSME	No Data
abla	ARTEM	2T	S408	PIEN:ABLA	ARTEM
abla	ARTR2	2T	S401	ABLA:PIEN	ARTR2
abla	ARTR2:JUCO6	2T	S401	ABLA:POTR5	ARTR2:JUCO6
abla	ARTR2:JUCO6	2T	S401	PSME:PIEN:ABLA	ARTR2:JUCO6
abla	ARTR2:SALIX	2T	S401	PIEN:ABLA	ARTR2:SALIX
abla	CAREX	1T	G313	ABLA:PIEN	SALIX:ARTEM
abla	CAREX	1T	G313	PIEN:ABLA:PICO	SALIX
abla	FEID	1T	G613	PIEN:ABLA:PSME	ARTR2
abla	PICO	2T	T218	PICO	No Data
abla	PICO:ABLA	2T	T218	PICO:ABLA	No Data
abla	PICO:ABLA	2T	T218	PICO:ABLA	ARTR2
abla	PICO:POTR5	2T	T218	PICO:POTR5	No Data
abla	PIEN:ABLA	2T	T206	PIEN:ABLA	No Data
abla	PIEN:ABLA	2T	T206	PIEN:ABLA	ARTR2
abla	PIEN:ABLA	2T	T206	PIEN:ABLA	VASC:RIBES
abla	PIEN:ABLA:PICO	2T	T206	PIEN:ABLA:PICO	No Data
abla	PIEN:ABLA:PIFL2	2T	T206	PIEN:ABLA:PIFL2	No Data
abla	PIEN:ABLA:PIFL2	2T	T206	PIEN:ABLA:PIFL2	ARTR2
abla	PIEN:ABLA:PSME	2T	T206	PIEN:ABLA:PSME	No Data
abla	PIEN:ABLA:PSME	2T	T206	PIEN:ABLA:PSME	CELE3
abla	PIEN:PICO:ABLA	2T	T206	PIEN:PICO:ABLA	No Data

Table C.3.

PNV TYPE	Species Mix	HSS	Cover Type	Tree Species Present	Shrub Species Present
abla	PIFL2:PIEN:ABLA	2T	T219	PIFL2:PIEN:ABLA	No Data
abla	POA:CAREX	1T	G	ABLA	No Data
abla	POPR:FEID	1T	G106	PSME:ABLA:PIEN	ARTR2
abla	POTR5:PICO	2T	T217	POTR5:PICO	No Data
abla	PSME:PIEN:ABLA	2T	T210	PSME:PIEN:ABLA	No Data
abla	PSME:PIFL2:ABLA	2T	T210	PSME:PIFL2:ABLA	ARTR2
abla	SALIX	2T	S921	ABLA	SALIX
abla	SALIX	2T	S921	ABLA:PIEN	SALIX
abla	SALIX	2T	S921	PIEN:ABLA	SALIX
cele3	ARTEM:CELE3	2T	S408	JUNIP:PSME:PIEN	ARTEM:CELE3
cele3	ARTR2:CELE3	2T	S401	JUNIP	ARTR2:CELE3
cele3	CELE3	2T	S322	JUNIP:PSME	CELE3
cele3	CELE3	2T	S322	PSME	CELE3
cele3	CELE3:ARTR2	2T	S322	JUNIP:PSME	CELE3:ARTR2
cele3	CELE3:ARTR2	2T	S322	JUNIP:PSME:PIFL2	CELE3:ARTR2
cele3	CELE3:ARTR2	2T	S322	POTR5:JUNIP	CELE3:ARTR2
cele3	CELE3:ARTR2	2T	S322	PSME:JUNIP	CELE3:ARTR2
cottonwd	No Data	1T	F	POPUL	No Data
cottonwd	No Data	1T	G	POPUL	No Data
cottonwd	No Data	1T	G	POTR5:POPUL	ARTEM
cottonwd	No Data	1T	G	POTR5:POPUL:PIPO	No Data
cottonwd	ARTR2:SALIX	2T	S401	POPUL:JUNIP	ARTR2:SALIX
junip	ARTEM	2T	S408	JUNIP	ARTEM
pico	No Data	1T	F	PICO	No Data
pico	No Data	1T	F	PICO	ARTR2
pico	No Data	1T	F	PICO	JUCO6
pico	No Data	1T	F	PICO	SALIX
pico	No Data	1T	F	PICO:POTR5	No Data
pico	No Data	1T	F	PICO:POTR5	PEFL15
pico	No Data	1T	G	ABLA:PIEN:PICO	No Data
pico	No Data	1T	G	PICO	No Data
pico	No Data	1T	G	PICO	ARTR2
pico	No Data	1T	G	PICO	JUCO6
pico	No Data	1T	G	PICO	PEFL15:SALIX
pico	No Data	1T	G	PICO	SALIX
pico	No Data	1T	G	PICO	SALIX:ARTR2
pico	No Data	1T	G	PICO:POTR5	No Data
pico	No Data	1T	G	PIEN:PICO:ABLA	ARTEM
pico	No Data	1T	G	POTR5:PICO	No Data
pico	No Data	1T	G	POTR5:PICO	PEFL15:JUCO6
pico	No Data	1T	G	POTR5:PICO	SALIX
pico	No Data	1T	G	POTR5:PICO	SALIX:JUCO6
pico	ARTEM	2T	S408	PICO	ARTEM
pico	ARTR2	2T	S401	PICO	ARTR2
pico	ARTR2	2T	S401	POTR5:PICO	ARTR2
pico	ARTR2:JUCO6	2T	S401	POTR5:PICO	ARTR2:JUCO6
pico	ARTR2:VASC:JUCO6	2T	S401	PICO	ARTR2:VASC:JUCO6
pico	CAREX	1T	G313	PICO:POTR5	SALIX
pico	FEID	1T	G613	PICO	ARTEM
pico	PICO	2T	T218	PICO	No Data
pico	PICO	2T	T218	PICO	ARTEM
pico	SALIX	2T	S921	PICO	SALIX
pico	SALIX:PEFL15	2T	S921	POTR5:PICO	SALIX:PEFL15
pien	No Data	1T	F	ABLA:PIEN	No Data
pien	No Data	1T	F	PICO:PIEN	SALIX
pien	No Data	1T	F	PIEN	No Data

Table C.3.

PNV TYPE	Species Mix	HSS	Cover Type	Tree Species Present	Shrub Species Present
pien	No Data	1T	F	PIEN	ARTR2
pien	No Data	1T	F	PIEN	SALIX
pien	No Data	1T	F	PIEN:PICO	No Data
pien	No Data	1T	F	PIEN:PICO	ARTR2
pien	No Data	1T	F	PIEN:PICO	JUCO6
pien	No Data	1T	F	PIEN:POTR5	JUCO6
pien	No Data	1T	G	PICO:PIEN	No Data
pien	No Data	1T	G	PICO:PIEN	ARTEM
pien	No Data	1T	G	PICO:PIEN	ARTR2
pien	No Data	1T	G	PICO:PIEN	SALIX
pien	No Data	1T	G	PICO:PIEN	SAPL2
pien	No Data	1T	G	PIEN	No Data
pien	No Data	1T	G	PIEN	ARTR2:SALIX
pien	No Data	1T	G	PIEN	SALIX
pien	No Data	1T	G	PIEN:PICO	No Data
pien	No Data	1T	G	PIEN:PICO	SALIX
pien	No Data	1T	G	PIEN:POTR5	No Data
pien	No Data	1T	G	PIEN:POTR5	SALIX
pien	No Data	1T	G	POTR5:PIEN	No Data
pien	No Data	1T	G	POTR5:PIEN	ARTR2
pien	No Data	1T	G	POTR5:PIEN	SALIX
pien	No Data	1T	G	PSME:PIEN	No Data
pien	No Data	2T	S	PICO:PIEN	No Data
pien	ARTEM	2T	S408	ABLA:PIEN:PSME	ARTEM
pien	ARTR2	2T	S401	PIEN	ARTR2
pien	ARTR2	2T	S401	PIEN:ABLA	ARTR2
pien	CAREX	1T	G313	PIEN	SALIX
pien	PICO:PIEN	2T	T218	PICO:PIEN	No Data
pien	PICO:PIEN:POTR5	2T	T218	PICO:PIEN:POTR5	No Data
pien	PIEN	2T	T206	PIEN	No Data
pien	PIEN:PIFL2	2T	T206	PIEN:PIFL2	No Data
pien	PIEN:PIPO:PIFL2	2T	T206	PIEN:PIPO:PIFL2	CELE3
pien	PIEN:PSME	2T	T206	PIEN:PSME	No Data
pien	PIEN:PSME:PICO	2T	T206	PIEN:PSME:PICO	CEANO:PHMO4:RIBES
pien	PIEN:PSME:PIFL2	2T	T206	PIEN:PSME:PIFL2	No Data
pien	PIFL2:PIEN	2T	T219	PIFL2:PIEN	No Data
pien	SALIX	2T	S921	PICO:PIEN	SALIX
pien	SALIX	2T	S921	PIEN	SALIX
pien	SALIX	2T	S921	PIEN:PICO	SALIX
pifl2	No Data	1T	G	PIFL2	No Data
pifl2	PIFL2	2T	T219	PIFL2	No Data
pipo	No Data	1T	F	POTR5:PIPO	No Data
pipo	No Data	1T	G	JUNIP:PIPO	ARTR2
pipo	No Data	1T	G	PIPO	No Data
pipo	No Data	1T	G	PIPO	ARTEM:RIBES
pipo	No Data	1T	G	PIPO:POTR5	No Data
pipo	No Data	1T	G	PIPO:POTR5	SALIX
pipo	No Data	1T	G	POTR5:PICO:PIPO	SALIX
pipo	No Data	1T	G	POTR5:PIEN	SALIX
pipo	No Data	1T	G	POTR5:PIPO	No Data
pipo	No Data	1T	G	POTR5:PIPO:PICO	ARTR2:SALIX
pipo	No Data	2T	S	PIPO	No Data
pipo	ARTEM	2T	S408	PIPO	ARTEM
pipo	PICO:PIPO:POAN3	2T	T218	PICO:PIPO:POAN3	No Data
pipo	POTR5:PIPO	2T	T217	POTR5:PIPO	No Data
potr5	No Data	1T	F	POTR5	SALIX

Table C.3.

PNV TYPE	Species Mix	HSS	Cover Type	Tree Species Present	Shrub Species Present
potr5	No Data	1T	G	POTR5	No Data
potr5	No Data	1T	G	POTR5	ARTEM
potr5	No Data	1T	G	POTR5	ARTR2
potr5	No Data	1T	G	POTR5	ARTR2:POFR4
potr5	No Data	1T	G	POTR5	ARTR2:SALIX
potr5	No Data	1T	G	POTR5	SALIX
potr5	ARTEM	2T	S408	POTR5	ARTEM
potr5	ARTR2	2T	S401	POTR5	ARTR2
potr5	ARTR2:JUCO6	2T	S401	POTR5	ARTR2:JUCO6
potr5	CAREX:JUNCU	1T	G313	POTR5	No Data
potr5	POTR5	2T	T217	POTR5	No Data
potr5	POTR5	2T	T217	POTR5	SALIX
potr5	SALIX	2T	S921	POTR5	SALIX
psme	No Data	1T	F	PIFL2:POTR5	ARTR2
psme	No Data	1T	F	PIFL2:PSME	ARTR2:JUCO6
psme	No Data	1T	F	PSME	ARTEM
psme	No Data	1T	F	PSME:PIFL2	ARTR2
psme	No Data	1T	G	PICO:POTR5:PSME	No Data
psme	No Data	1T	G	POTR5:PSME:JUNIP	ARTR2:RIBES:JUCO6
psme	No Data	1T	G	POTR5:PSME:PIFL2	No Data
psme	No Data	1T	G	PSME	No Data
psme	No Data	1T	G	PSME:PIFL2	ARTEM
psme	No Data	1T	G	PSME:PIFL2	ARTR2
psme	No Data	1T	G	PSME:PIFL2	PEFL15
psme	No Data	1T	G	PSME:POTR5:PIFL2	ARTEM:JUCO6
psme	No Data	1T	G	PSME:POTR5:PIPO	ARTR2:JUCO6
psme	No Data	2T	S	PSME	No Data
psme	No Data	2T	S	PSME:POTR5	No Data
psme	ARTEM	2T	S408	PSME:JUNIP	ARTEM
psme	ARTEM	2T	S408	PSME:PIFL2	ARTEM
psme	ARTEM	2T	S408	PSME:PIPO	ARTEM
psme	ARTEM	2T	S408	PSME:POTR5	ARTEM
psme	ARTEM:SALIX	2T	S408	PSME:PIFL2	ARTEM:SALIX
psme	ARTR2	2T	S401	PIFL2:PSME	ARTR2
psme	ARTR2	2T	S401	PSME	ARTR2
psme	ARTR2	2T	S401	PSME:PIFL2	ARTR2
psme	ARTR2	2T	S401	PSME:PIFL2:JUNIP	ARTR2
psme	ARTR2	2T	S401	PSME:PIFL2:PICO	ARTR2
psme	ARTR2	2T	S401	PSME:PIFL2:POTR5	ARTR2
psme	ARTR2	2T	S401	PSME:POTR5	ARTR2
psme	PIFL2:PSME	2T	T219	PIFL2:PSME	No Data
psme	PSME:PIFL2:JUSC2	2T	T210	PSME:PIFL2:JUSC2	JUCO6:ARTR2

(5) Perform supplemental queries to complete the PNV map.

a) Shrublands

1. Sagebrush – Sagebrush was not separated in the CVU. Therefore, splitting out the Mountain and the Wyoming Big Sagebrush PNV types required several additional queries.

a. CVU type “S” and soil type 90, 97, 98, 66, 67, 68, 69, 75, 77, or 79 = Wyoming Big Sagebrush PNV Type

b. CVU type “S” or preliminary PNV type “Artr” and soil type 17, 29, 30, 41a, 41b, 70, 78, 80, 81, 82, 72, 83, or 64 = Mountain Big Sagebrush PNV Type.

c. CVU type “S” and GAP vegetation code “32006” = Mountain Big Sagebrush PNV Type

d. CVU type “S” and GAP vegetation code “32007” = Wyoming Big Sagebrush PNV Type

e. Sort any remaining sagebrush polygons using the DEM. Those polygons above 8,000 ft are coded Mountain Big Sagebrush PNV Type and those below 8,000ft are coded Wyoming Big Sagebrush.

2. Other shrub types – CVU type “S” and soil type 20 = Arno PNV type

b) Non-Vegetation – Any remaining CVU codes “B” and “BRS” are coded PNV type “Rock outcrop/bare soil”

c) Riparian – Combine riparian PNV types “wetland”, “salix”, “pefl15” into merged PNV type “Grass and Shrub Riparian”

(6) Develop an additional map showing seral lodgepole pine type vs. climax lodgepole pine type.

a) Lodgepole on soil types 10, 19a, 21, 40, 43, or 38 are climax lodgepole type.

b) Lodgepole on any other soil type are seral and will change to an abla/pien

APPENDIX D

Invasive Species Mapping

Mapping Known Occurrences

Data sources that were available for the pilot assessment for the Bighorn National Forest are documented in Table 3.12 of the Module VII description. There are additional potential data sources that may be utilized for future assessments (Table D.1).

Modeling Ecosystem Invasibility

Distribution maps and inventory data are far from complete for most areas. Predictive tools could be useful in developing efficient inventory schemes. Even where solid inventory data exist, predictive tools would be useful for developing early detection methods, identifying places at high risk so that the implications of land use practices can be evaluated, and developing appropriate monitoring schemes. Management is typically directed at controlling the spread of invasive species after they have already become established. Proactive approaches depend on the ability to predict areas at high risk for invasion so that preventative measures can be adopted.

The development of predictive models requires an understanding of factors contributing to invasions. Several studies have explored the subject of ecosystem invasibility in an attempt to identify driving factors. The studies are

summarized in Table D.2, from Stohlgren 2002. Identified factors include:

- (1) Species diversity with both positive correlations (Robinson et al. 1995; Planty-Tabacchi et al. 1996; Wisser et al. 1998; Smith and Knapp 1999; Stohlgren et al. 1999a) and negative correlations (Elton 1958; Fox and Fox 1986; Tilman 1997; Levine and D'Antonio 1999; Duker 2001) identified.
- (2) Exogenous disturbances with positive correlations identified (Fox and Fox 1986; Hobbs and Huenneke 1992; Smith and Knapp 1999, 2001)
- (3) Roads, trails, and other factors related to accessibility with positive correlations (MacDonald et al. 1989; Tyser and Worley 1992; Greenburg et al. 1997; Lonsdale 1999)
- (4) Soil nutrient status with positive correlations on more nutrient-rich soils (Huenneke et al. 1990; Harrison 1999; Stohlgren et al. 1999a, 1999b)
- (5) Community types with riparian areas (Planty-Tabacchi et al. 1996; Kotanen 1997; Stohlgren et al. 1998; Levine 2000; Larson et al. 2001) and rare habitats (Stohlgren et al. 1999a, Stohlgren et al. 2001) commonly invaded.

Table D.1. Data Sources for Mapping Known Occurrences of Invasive Plant Species.

Source	Dataset
US Forest Service	Forest Inventory Data
Biota of North America Program	Non-native plant species by county for the US
Forest Health Monitoring Program	Point data (presence and cover) from USFS lands
NPS Species	Non-native species lists for National Park units
Colorado State University Cooperative	Point data
University of Wyoming Spatial Data Visualization Center (?)	
State Heritage Programs	Non-native plant point data
State Natural Resources or Agriculture	Quarter quad data for at least 20 non-native species
County Inventories (?)	
US Fish and Wildlife Service	Survey response from refuges
Center for the Ecological Management of Military Lands	Species lists for land management units
US Geological Survey (Mid-continent Ecological Science Center) and the Natural Resource Ecology Laboratory at Colorado State University	Modified Whittaker plot data (presence and cover)

Table D.2. Summary of Findings of Studies of Factors Contributing to Ecosystem Invasibility.

Study	Type	Scale	Results
(Bergelson et al. 1993)	Experiment	Multiple	Rate of spread of a weed changes with different spatial patterns of disturbance
(Burke and Grime 1996)	Experiment	Local	Limestone grassland in United Kingdom. Most invasible with high levels of disturbance. Even more invaded when disturbance associated with eutrication.
(Dukes 2001)	Experiment	Local	Grassland community microcosms invasibility by yellow star-thistle (<i>Centaurea solstitialis</i>). High functional diversity decreased success. Species diversity not correlated with invasibility. Species diversity positively correlated with persistence of species after invasion
(Fox and Fox 1986)	Review	None	Invasion occurs with at least minimal alteration of endogenous disturbance regimes
(Greenburg et al. 1997)	Observation	Local	Compared invasion along roadsides with native and non-native soils and clearcuts to hold disturbance constant in xeric Florida sand pine scrub. Modified soil type was more invaded than native, even with disturbance. Roadways facilitate non-native propagule transport.
(Harrison 1999)	Observation	Local	California serpentine and non-serpentine grasslands compared indicate that invasion is less in poor soils (but whether because poor soils are less invasible or because current non-natives are unsuited is unknown).
(Hobbs and Huenneke 1992)	Review	None	Exogenous disturbance such as fire, grazing, and soil disturbance outside of the natural cycle (either greater or less) leads to increased invasibility
(Huenneke et al. 1990)	Experiment	Local	Applied nitrogen and phosphorus to plots in Californian annual serpentine grassland. Grazing exclusion resulted in decreased native forb presence. Adding nutrients resulted in increased invasion (reduced total richness, increased non-native dominance).
(Larson et al. 2001)	Observation	Regional	Mixed grass prairie (THRO, both units, 11 plant communities). Vegetation type explained more variance in invasibility than disturbance or park unit. Three way model with vegetation type, park unit, and disturbance best explains frequency and number of non-natives in aggregate- perhaps a reflection of nitrogen and water availability differences. Riparian zones are more invaded. Different species respond differently to disturbance and to vegetation type.
(Levine 2000)	Experiment	Local	California riparian area diversity is positively correlated with invasibility.

Table D.2 (continued). Summary of Findings of Studies of Factors Contributing to Ecosystem Invasibility.

Study	Type	Scale	Results
(Levine and D'Antonio 1999)	Review		Generally, species rich communities are more invasible than species-poor communities.
(Lodge 1993)			
(Lonsdale 1999)	Observation	Global	Variances in non-native species number explained by number of native species, island or mainland status, and reserve or not reserve status. On the mainland, degree of invasion increased with latitude. In reserves, number of visitors also explained number of non-native species.
(MacDonald et al. 1989)			North American nature reserves
(Planty-Tabacchi et al. 1996)	Observation	Watershed and patch	Studied Adour River in southwestern France, McKenzie River in Oregon, and the Dungeness and Hoh Rivers in Washington. The McKenzie and Adour similarities indicated that invasion along riparian areas can be predicted by species richness. At the patch scale, riparian zones are more invaded than upland zones.
(Rejmanek and Richardson 1996)	Review	Global	Island isolation from the mainland is correlated with their invasibility. Species rich islands are more invaded, but could result because they are more suited to agriculture.
(Robinson et al. 1995)	Experiment	Community	California winter annual grassland with plots 2m ² to 32m ² . Invaded plots typically had greater disturbance (trampled vegetation, bare soil), lowers levels of dominance, and higher species richness. Plot size was not significant. However, 70% of the variation was not explained.
(Smith and Knapp 1999)	Experiment	~60ha	Northeaster Kansas Kanza Prairie, C4 dominated grassland. Frequent fire reduced the number of non-natives found (e.g., invasibility). Non-native richness negatively correlated with ANPP and aboveground grass production. Grazing treatments both showed a positive correlation between native and non-native species richness.
(Smith and Knapp 2001)	Experiment	Local	Kanza Prairie. Fire reduced invasibility. Size of the local pool of non-native species was positively correlated with non-native species, and appears to counter the negative effect of fire on number of non-natives.
(Stohlgren et al. 1998)	Observation	Multiple	Central grassland riparian versus upland areas with similar grazing intensities. 1m ² scale no patterns. 1000m ² scale showed riparian zones had higher native and non-native richness than upland sites.
(Stohlgren et al. 1999a)	Observation	Multiple	Rocky Mountains and central grasslands. At the 1m ² scale, non-native species richness was negatively correlated with plant species richness and cover. At the 1000m ² scale, non-native species richness correlated with soil % N and native cover. At the landscape scale, non-native species cover correlated to total foliar cover, mean soil % N, and total number of non-native species.
(Stohlgren et al. 1999b)	Observation	Multiple	Central grassland grazed and grazing enclosure areas. At 1m ² and 1000m ² scales across all areas, grazed and ungrazed plots did not differ significantly in non-native species richness. Elevation was strongly correlated with non-native diversity. Non-native species richness was positively correlated with soil % N.
(Tyser and Worley 1992)	Observation	Community	Glacier National Park invasion of roadsides and trails in the backcountry. Non-natives decrease with distance from roadsides. Trails exhibited a similar trend, though the effect extended less distance.

Several modeling approaches have been applied to predict the distribution (e.g., presence or absence) of individual species (Higgins and Richardson 1996; Higgins et al. 1996; Higgins et al. 2000; Wadsworth et al. 2000; and Peterson and Vieglia 2001). None of the models quantifies the abundance of any one species or non-native species richness, and none attempt to identify areas vulnerable to invasion. However, quantitative models that predict areas susceptible to invasion as well as application tools for land managers concerned with invasive species are currently being developed through the Colorado Invasive Species Mapping Project of the US Geological Survey National Institute of Invasive Species Science (Stohlgren 2002).

In the immediate absence of quantitative tools that will provide predictions about areas vulnerable to invasion, we developed a simple, qualitative spatial representation that should help managers identify areas of risk. The model is meant to depict the level of potential for invasion by any number of weedy species that are known to occur in the assessment area. The model is not an individual species distribution model. The modeling approach involves two major steps. First, a physiographic model is developed to illustrate sites that are at high risk for weed invasion due to their basic ecological potential. Then, factors that are known to serve as weed vectors or otherwise exacerbate the risk of weed invasion are considered in the context of the basic

physiographic template to identify hot spots of invasive species concern.

Physiographic Model

In order to keep the GIS modeling simple and tractable, we identified three environmental attributes, all map derived, as predictors of weed risk. Much of the recent literature suggests a positive relationship between resource richness and invasibility. Moisture, light, and temperature were the three resource factors we determined to be most important in building the model (Stohlgren, personal communication). Moisture is the usually the resource most limiting to plant growth in western ecosystems and may explain much of the variation in expected patterns of weed distribution. We modeled moisture by using slope position and aspect as surrogates for a coarsely scaled moisture gradient. Canopy closure is another important component of weed invasion and spread. Most weeds are not well adapted to low light conditions of closed canopies and invade and spread most efficiently in open to no canopy cover situations. Finally, the model incorporates elevation as a geographic surrogate for temperature. Cold temperatures and short growing seasons associated with high elevation environments may be limiting to weed success. Most weedy species perform better at lower elevations. The model rule set is described in Table D.3. A matrix was developed for all possible combinations of these variables (Table D.4) and risk rankings were assigned (Table D.5).

Table D.3. Physiographic Parameters for Estimating the Risk of Invasibility by Weedy Plant Species.

	Symbol	Risk Rank
Elevation		
High > 10,000 ft	H	L
Mid 8,000 – 10,000 ft	M	M
Low < 8,000 ft	L	H
Canopy Closure		
High 61-100%	1	L
Medium 20-60%	2	M
Low <20%	3	H
Moisture		
Riparian/Valley Bottom	W	H
N, NE, NW aspects	M	M
S, SE, SW, W, E aspects	D	L
Flat aspects	F	M

Table D.4. All Possible Symbols and Rank Combinations.

Symbol	Rank Combination	Symbol	Rank Combination
H1W	LLH	M1D	MLL
H2W	LMH	M2D	MML
H3W	LHH	M3D	MHL
H1M	LLM	M1F	MLM
H2M	LMM	M2F	MMM
H3M	LHM	M3F	MHM
H1D	LLL	L1W	HLH
H2D	LML	L2W	HMH
H3D	LHL	L3W	HHH
H1F	LLM	L1M	HLM
H2F	LMM	L2M	HMM
H3F	LHM	L3M	HHM
M1W	MLH	L1D	HLL
M2W	MMH	L2D	HML
M3W	MHH	L3D	HHL
M1M	MLM	L1F	HLM
M2M	MMM	L2F	HMM
M3M	MHM	L3F	HHM

Table D.5. Weed Model Risk Rankings.

Red –Very High Risk		
Orange – High Risk		
Yellow – Moderate Risk		
Green – Low Risk		
Blue –Very Low Risk		
HHH	MHH	LHH
HHM	MHM	LHM
HMH	MMH	LMH
HHL	MHL	LMM
HLH	MMM	LHL
HMM	MLH	LML
HML	MML	LLH
HLM	MLM	LLM
HLL	MLL	LLL

Data Layers Used:

- (1) Common Vegetation Unit (CVU) - used for the canopy closure attribute
- (2) 30m DEM clipped to the National Forest boundary - used for calculating elevation and deriving aspect
- (3) Aquatic, Riparian, and Wetland Assessment model for calculating valley bottoms - used for the moisture component

GIS Queries:

- (1) Reclassify the 30m DEM data into three elevation categories:

Elevation	Symbol	Risk Rank
High > 10,000 ft	H	L
Mid 8,000 – 10,000 ft	M	M
Low < 8,000 ft	L	H

- (2) Calculate the aspect using ArcView Spatial Analyst and the 30m DEM. Reclassify the results into three moisture categories. Intersect the valley bottoms coverage with aspect to create the final moisture layer:

Moisture	Symbol	Risk Rank
Riparian/Valley Bottom	W	H
N, NE, NW aspects	M	M
S, SE, SW, W, E aspects	D	L
Flat aspects	F	M

- (3) Reclassify the CVU data into three canopy closure categories.

Canopy Closure	Symbol	Risk Rank
High 61-100%	1	L
Medium 20-60%	2	M
Low <20%	3	H

- (4) Union canopy closure, moisture, and elevation.
- (5) Concatenate the three symbol values (canopy closure, moisture, and elevation).
- (6) Assign the corresponding risk code to the symbol values.
- (7) Assign risk ranking based on the rank combination using the risk rank table.

Outputs from Step 1:

- (1) Map depicting degree of risk of weedy plant invasion based on physiographic template.
- (2) Tabular summaries to reflect portions or places on the landscape most vulnerable to invasion by weedy plants.
 - a) Relationships among weed risk categories and vegetation cover type for the entire Section (GAP cover types) and for the Forest (CVU cover types).
 - b) Relationships among weed risk categories and Land Type Associations.

Invasive Species Hot Spots

The map created from the physiographic model will reflect a qualitative estimate of vulnerability of a site, based on ecological potential, to invasion by plant species. We further identify weed risk by combining this physiographic model with locations of factors known to contribute to or exacerbate weed risk through either increasing resource availability by disturbance and/or serving as dispersal vectors. This step involves developing overlays of the following on the weed vulnerability map:

- (1) Roads – with the following rankings:
 - a) High risk - < 200 feet each side of the road
 - b) Medium risk – 200 – 400 feet each side of the road
 - c) Low risk - > 400 feet each side of the road
- (2) Burns – areas burned within the last 20 years are high risk
- (3) Areas of livestock concentration – based on livestock preference model (see **Module X**), livestock stocking levels, and locations of corrals, water developments, and stock driveways

- (4) Areas of intensive recreation – campgrounds, picnic grounds, ski areas are high risk
- (5) Existing weed infestations – areas are high risk within 400 yards of an existing infestation
- (6) Timber harvests - areas cut within the last 20 years are high risk
- (7) Trails and trail heads – motorized trails are high risk; areas where horses enter the Forest are high risk
- (8) Private inholdings, summer home groups, Forest Service administration sites, etc. – high risk within 400 yards of these areas

Data Layers Used:

- (1) Forest Plan Watershed Units Coverage
- (2) Forest Travel Routes – used for roads and trail data
- (3) Forest Large Fires History Coverage – used for recently burned areas
- (4) Forest Activities Database and Coverage – used for recently logged areas
- (5) Campground locations, ski area locations, summer home locations, resorts locations all from the forest
- (6) Existing weed data from the forest

Queries:

Union each hotspot layer with the weed risk layer to calculate weed risk levels associated with the hotspot.

Outputs from Step 2:

- (1) Maps reflecting weed risk hot spots – overlays of each risk factor on the weed vulnerability map for a total of eight maps

(2) Summary maps reflecting the degree of high risk in each geographic unit (the Forest plan watersheds – mid-scale planning areas)

(3) Summary reflecting relative importance of the hot spot creating factors

APPENDIX E

Natural Disturbance Patterns – Fire

Spatial Distribution of Historic Fire Regimes

A map to depict the spatial distribution of historic fires regimes was created by assigning fire disturbance regimes to each major native plant community. These assignments were made based on fire history studies on the Bighorn National Forest and on studies on similar native plant communities in the Rocky Mountains. The Potential Natural Vegetation map described on [page ___](#) of this assessment was used to approximate the HRV reference period native plant communities. A panel of

experts reviewed the fire disturbance regime assignments and made modifications to better reflect pre-European fire on the Bighorn National Forest. Native plant communities that occur over a wide range in elevation were assigned to two different fire disturbance regimes. Higher elevation forests are more mesic and have longer intervals between fires. An 8,000-foot elevation break was used to divide lodgepole pine, spruce, and subalpine fir, each into two different fire disturbance regimes (Table E.1).

Table E.1. Initial Fire Disturbance Regime Assignments to Vegetation Types.

Potential Natural Vegetation-Cover	Fire Disturbance Regime Assignment	Acres
Alpine Rock	N/A; Does not burn	6281
Alpine Tundra	>300 years; low intensity	76596
Aspen	125-300 years; mixed intensity	4704
Black Sagebrush	10-35 years; mixed intensity	77
Blue Bunch Wheat Grass	<=10 years; low intensity	6691
Cottonwood	125-300 years; low intensity	496
Douglas Fir	35-100 years; mixed intensity	109674
Grass & Shrub Riparian	10-35 years; mixed intensity	26847
Greasewood	10-35 years; mixed intensity	238
Ice/snow	N/A; Does not burn	12
Idaho Fescue	<=10 years; low intensity	169231
Juniper Woodland	>300 years; high intensity	5067
Limber Pine Woodland	35-100 years; mixed intensity	3204
Little Bluestem	<=10 years; low intensity	504
Lodgepole Pine > 8,000 ft. elevation	>300 years; high intensity	100120
Lodgepole Pine < 8,000 ft. elevation	125-300 years; high intensity	73408
Mixed Deciduous Shrub	10-35 years; mixed intensity	1416
Mountain Mohogany	10-35 years; mixed intensity	7592
Mountain Sagebrush	10-35 years; mixed intensity	3393
Ponderosa Pine	35-100 years; mixed intensity	34760
Rock outcrop/Bare Soil	N/A; Does not burn	59114
Sagebrush	10-35 years; mixed intensity	71944
Spruce > 8,000 ft. elevation	>300 years; high intensity	78853
Spruce < 8,000 ft. elevation	125-300 years; high intensity	81410
Subalpine Fir > 8,000 ft. elevation	>300 years; high intensity	225855
Subalpine Fir < 8,000 ft. elevation	125-300 years; high intensity	80346
Water	N/A; Does not burn	26
Wyoming Sagebrush	10-35 years; mixed intensity	260

Spatial Patterns of Departure From Historic Fire Regime

To estimate departure from historic fire regimes the assumption is made that today’s climate and physical conditions are similar to those that existed during the HRV reference period and that modern fires burned similarly to past fires and have similar ecological results. Without human intervention only minor shifts in ecological components, processes, and functions would be evident on today’s landscapes. Most major shifts in ecological components, processes, and functions are due to human activities that were absent during the reference period.

To map departure, a modern (post-European settlement) fire disturbance regime map for the Bighorn National Forest was compared to the spatial distribution of historic fire regimes map. The modern fire disturbance regime map consisted of a GIS cover depicting the last 100 years of large fire history. The following departure classes from Hardy, 2001 were used to assign departure to each polygon.

Departure Classes

(1) Little Departure (Condition Class 1). Historical ecosystem attributes of disturbance regimes (patterns and frequencies of insect, disease and fire), disturbance agents, smoke production, hydrologic function (sedimentation, stream flow, etc.), and vegetative attributes (composition, structure, and resilience to disturbance agents) are largely intact and functioning within an historical range. These areas can be maintained in a natural fire regime by prescribed fire with minimal if any mechanical treatment.

(2) Significant Departure (Condition Class 2). Historical ecosystem attributes have been moderately altered. One or more fire return intervals have been missed, resulting in increased fire sizes, intensities, severities, and

coarser landscape patterns, or fire frequency and intensities have increased due to the introduction and establishment of exotic plant species. These areas may need some mechanical treatments in addition to prescribed fire to be restored to natural fire regimes.

(3) Extreme Departure (Condition Class 3). Ecosystem attributes have been significantly altered. Multiple fire return intervals have been missed resulting in dramatic departures from historical conditions, or fire frequency and intensities have increased due to the introduction and establishment of exotic plant species. Mechanical treatment must be implemented to these areas before prescribed fire can be introduced.

(4) Not Applicable; Does Not Burn (Condition Class 0). Cover is rock, water, bare soil, ice and snow.

The following rules were used to determine to what Departure Class a polygon was assigned.

Step 1

All N/A; Does Not Burn were assigned “0”
All disturbance regimes with >125-year fire intervals were assigned “1”
All disturbance regimes with <100 year intervals were assigned “2”
All grass and shrubland units were assigned “3”

Step 2

Reclassify the polygons assigned “2”, using large fire history for the past 100 years.

<10 Year Fire Interval

If there was a fire during the past:

- 0 to 10 years – those polygons were assigned “1”
- 11 to 20 years – those polygons were assigned “2”
- 21 + years - those polygons were assigned “3”

•

10 to 35 Year Fire Interval

If there was a fire during the past:

- 0 to 35 years – those polygons were assigned “1”
- 35 to 70 years – those polygons were assigned “2”
- 71 to 99 years - those polygons were assigned “3”

35 to 100 Year Fire Interval

If there was a fire during the past:

- 0 to 100 years – those polygons were assigned “1”
- >100 years – those polygons were assigned “2”

The final assignments of Fire Disturbance Regime are shown in Table E.2.

Table E.2. Final Fire Disturbance Regime Assignments To Vegetation Types.

Potential Natural Vegetation/Cover	Fire Disturbance Regime	Departure Class	Acres
Alpine Rock	N/A; Doesn't burn	0	6,281
Alpine Tundra	>300 years; low intensity	1	76,596
Aspen	125-300 years; mixed intensity	1	4,704
Black Sagebrush	10-35 years; mixed intensity	2	77
Blue Bunch Wheat Grass	<=10 years; low intensity	3	6,691
Cottonwood	125-300 years; low intensity	1	496
Douglas Fir	35-100 years; mixed intensity	1	39,674
Douglas Fir	35-100 years; mixed intensity	2	73,387
Grass & Shrub Riparian	10-35 years; mixed intensity	3	26,847
Greasewood	10-35 years; mixed intensity	3	238
Ice/snow	N/A; Doesn't burn	0	12
Idaho Fescue	<=10 years; low intensity	3	169,231
Juniper Woodland	>300 years; high intensity	1	5,067
Limber Pine Woodland	35-100 years; mixed intensity	1	3,516
Limber Pine Woodland	35-100 years; mixed intensity	2	11,131
Little Bluestem	<=10 years; low intensity	3	504
Lodgepole Pine > 8,000 ft. elevation	>300 years; high intensity	1	100,120
Lodgepole Pine < 8,000 ft. elevation	125-300 years; high intensity	1	73,408
Mixed Deciduous Shrub	10-35 years; mixed intensity	3	1,416
Mountain Mohagony	10-35 years; mixed intensity	3	7,592
Mountain Sagebrush	10-35 years; mixed intensity	3	3,393
Ponderosa Pine	35-100 years; mixed intensity	1	1,199
Ponderosa Pine	35-100 years; mixed intensity	2	35,678
Rock outcrop/Bare Soil	N/A; Doesn't burn	0	59,114
Sagebrush	10-35 years; mixed intensity	3	71,944
Spruce > 8,000 ft. elevation	>300 years; high intensity	1	78,853
Spruce < 8,000 ft. elevation	125-300 years; high intensity	1	81,410
Subalpine Fir > 8,000 ft. elevation	>300 years; high intensity	1	225,855
Subalpine Fir < 8,000 ft. elevation	125-300 years; high intensity	1	80,346
Water	N/A; Doesn't burn	0	26
Wyoming Sagebrush	10-35 years; mixed intensity	3	260

BehavePlus Modeling Approach:

The above approach used to map departure from historic fire regimes compared the last 100 years of recorded fire occurrence with a map of historic fire regimes. Another approach is to quantify the structural stage composition of a landscape subjected to disturbances characteristic of historic fire regimes. This HRV structural stage composition can then be compared to current structural stage composition (Hann, 1999).

Spatial Patterns of Fire Hazard Conditions

The objective for creating a fire hazard map was to display potential differences in fire behavior among different geographic areas of the Bighorn National Forest under a given severe fire weather scenario. It was not to predict the array of expected fire behaviors that could occur under different weather scenarios. Fuel moisture, atmospheric humidity, temperature, and wind all powerfully influence fire behavior and their endless combinations could result in numerous arrays of potential fire behaviors.

The process selected to map fire hazard was adopted from *A Wildfire Hazard Assessment and Map for La Plata County, Colorado*, Romme, 2001. The objective of Romme's study was to assess and map the hazard of

fire within a representative southwestern Colorado landscape. To accomplish this he used BEHAVE to analyze resource data layers to predict total potential heat release, rate of fire spread, and flame length under severe fire weather conditions, for each polygon in the vegetation layer.

Topography was integrated into the process by using 30-meter digital elevation model data from the U. S. Geological Survey. The vegetation and topography data layers were combined producing a raster base map of vegetation/slope units.

BEHAVE does not directly simulate the effects of aspect, but aspect is an important modifier of fire behavior. For this analysis, we divided aspect into three weighted classes and assigned a multiplier value to each of the three classes. We used the multipliers from Romme, 2001. These multipliers can be adjusted to reflect local experience.

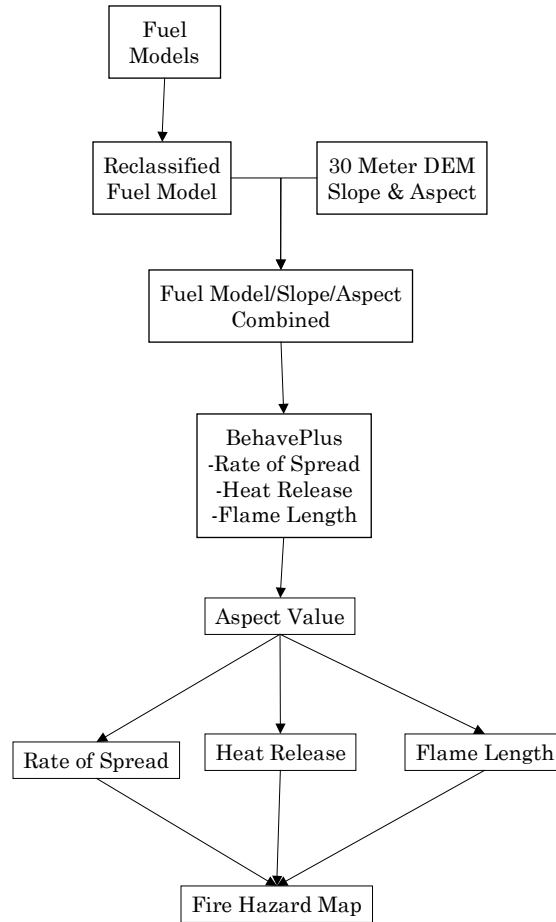
Data Used:

1. Fuel Model Coverage – From Biastock, 1994
2. Slope and Aspect – Derived from a USGS 30m DEM

Software Used:

1. BehavePlus Fire Modeling System Version 1.00.00 (December 2001)
2. ArcView 3.2a

Model Overview



Step 1. Fuel Model Classification

Each vegetation unit on the Bighorn National Forest had been assigned a fuel model type (Biastock, 1994). These fuel models were reclassified to fit into the standard fuel model types used by the Behave-Plus Fire Modeling System. The

reclassification was conducted on the Biastock's (1994) fuel models 16, 17, and 98. They were reclassified by examining the RIS cover types that encompassed by the fuel model. All of the other fuel models were left as they were (Table E.3).

Table E.3. Fuel Model Classification.

Fuel Model (Biastock, 1994)	NFDRS Fuel Model	RIS Cover Type	Reclassified Fuel Model
16	R	TCW	1
16	W	GHA, GKO, GPO, GRE, GRG, GWE, SWI, FWI	1
17	0	NDV	0
98	0	WAT, WET, WLK, WRE, WST	0

Step 2. Slope and Aspect

Slope and aspect were calculated for the Bighorn National Forest using 30-m DEM. The values for slope and aspect were then reclassified into three classes as identified in the table below. The aspect, slope, and fuel model layers were then overlaid to compose a composite layer.

Slope (%)	Class
0 – 20	1
20 – 40	2
40 +	3

Aspect (degrees)	Class
292.5 – 67.5	1
67.5 – 157.5	2
247.5 – 292.5	3

Step 3. BehavePlus

BehavePlus (2001) was used to predict total potential heat release, rate of fire spread, and flame length. It was run using the standard fuel model inputs for fuel models 1, 2, 5, 6, 8, 9, 10. Two weather scenarios were modeled to compare the results. The inputs are in the Table E.4. Run 1 was done using the same values as Romme, 2001. The results are shown in Table E.5 and E.6.

Table E.4.

	Run 1	Run 2
	Dry	Moderate
1-Hour Fuel Moisture	2.0%	7.0%
10-Hour Fuel Moisture	5.0%	10.0%
100-Hour Fuel Moisture	10.0%	18.0%
Live Woody Moisture	50.0%	100.0%
Live Herbaceous Moisture	50.0%	100.0%
Midflame Wind Speed	0.0 MPH	8.0 MPH

Table E.5. RUN 1 - Results from BehavePlus Using a Dry Conditions Scenario.

Fuel Model 1			
Slope	ROS (max)	Heat per Unit Area	Flame Length
%	ch/h	Btu/ft²	ft
0 - 20	6.2	116	1.5
20 - 40	16.5	116	2.3
40 +	47.3	116	3.7
Fuel Model 2			
Slope	ROS (max)	Heat per Unit Area	Flame Length
%	ch/h	Btu/ft²	ft
0 - 20	3.7	605	2.5
20 - 40	7.4	605	3.4
40 +	18.5	605	5.2
Fuel Model 5			
Slope	ROS (max)	Heat per Unit Area	Flame Length
%	ch/h	Btu/ft²	ft
0 - 20	2.3	822	2.3
20 - 40	5.2	822	3.3
40 +	13.9	822	5.3
Fuel Model 6			
Slope	ROS (max)	Heat per Unit Area	Flame Length
%	ch/h	Btu/ft²	ft
0 - 20	2.6	600	2.1
20 - 40	5.5	600	3
40 +	14.4	600	4.6
Fuel Model 8			
Slope	ROS (max)	Heat per Unit Area	Flame Length
%	ch/h	Btu/ft²	ft
0 - 20	0.3	239	0.5
20 - 40	0.5	239	0.7
40 +	1.1	239	0.9
Fuel Model 9			
Slope	ROS (max)	Heat per Unit Area	Flame Length
%	ch/h	Btu/ft²	ft
0 - 20	1.3	488	1.4
20 - 40	2.1	488	1.7
40 +	4.6	488	2.5
Fuel Model 10			
Slope	ROS (max)	Heat per Unit Area	Flame Length
%	ch/h	Btu/ft²	ft
0 - 20	1.5	1622	2.6
20 - 40	2.5	1622	3.3
40 +	5.7	1622	4.8

Table E.6. RUN 2 - Results from BehavePlus Using a Moderate Conditions Scenario.

Fuel Model 1			
Slope	ROS (max)	Heat per Unit Area	Flame Length
%	ch/h	Btu/ft2	ft
0 - 20	307.2	103	8.4
20 - 40	316	103	8.5
40 +	342.3	103	8.8
Fuel Model 2			
Slope	ROS (max)	Heat per Unit Area	Flame Length
%	ch/h	Btu/ft2	ft
0 - 20	112.2	552	11.5
20 - 40	115.4	552	11.6
40 +	124.7	552	12
Fuel Model 5			
Slope	ROS (max)	Heat per Unit Area	Flame Length
%	ch/h	Btu/ft2	ft
0 - 20	73.4	763	10.9
20 - 40	75.7	763	11.1
40 +	82.6	763	11.5
Fuel Model 6			
Slope	ROS (max)	Heat per Unit Area	Flame Length
%	ch/h	Btu/ft2	ft
0 - 20	82.4	558	10
20 - 40	85	558	10.1
40 +	93	558	10.5
Fuel Model 8			
Slope	ROS (max)	Heat per Unit Area	Flame Length
%	ch/h	Btu/ft2	ft
0 - 20	5.1	223	1.8
20 - 40	5.3	223	1.8
40 +	5.8	223	1.9
Fuel Model 9			
Slope	ROS (max)	Heat per Unit Area	Flame Length
%	ch/h	Btu/ft2	ft
0 - 20	25.3	449	5.2
20 - 40	26	449	5.3
40 +	28.2	449	5.5
Fuel Model 10			
Slope	ROS (max)	Heat per Unit Area	Flame Length
%	ch/h	Btu/ft2	ft
0 - 20	24.4	1510	9
20 - 40	25.2	1510	9.2
40 +	27.8	1510	9.6

Step 4. Aspect Multiplier

The outputs from BehavePlus were appended to the combined Veg/Slope/Aspect coverage and then adjusted to reflect the affects of aspect. The ROS, heat, and flame length values were multiplied by a number dependent on its related aspect class as depicted in Table E.7.

Table E.7.

Aspect (degrees)	Class	Multiplier
292.5 – 67.5	1	1
67.5 – 157.5	2	1.33
247.5 – 292.5		
157.5 – 292.5	3	1.66

Step 5. Fire Hazard Index

The new values for ROS, Heat, and Flame length were then normalized to a scale of 0 to 1. Next, the three values were summed to create the fire hazard index.

$$\text{ROS} + \text{Heat} + \text{Flame length} = \text{Fire Hazard Index}$$

Step 6. Fire Hazard Classification

The fire hazard Index is was then classified into four hazard classes based on expert opinion (Shadis 2002) (Table E.8).

Table E.8. Fire Hazard Class Using Fire Hazard Index.

Index Range	Fire Hazard Class
0	None
0 – 0.075	Low
0.075 – 0.172	Medium
0.172 – 0.423	High

ArcView was used to display maps of fire hazard for each simulation (weather condition).

CAUTION: This approach to mapping fire hazard has one fire weather scenario across the entire Bighorn National Forest. This is unrealistic since the probability of a subalpine forest experiencing the dry fire weather in our scenario is much less likely than a lower montane forest experiencing it. To compare fire hazard between different portions of the Forest requires us to estimate and compare the probability that

each area will experience the specified fire weather.

Additional Modeling Approaches:

The Fire and Fuels Extension of the Forest Vegetation Simulator

This model computes flame length and fire type (surface, passive crown fire, or active crown fire). In addition, it reports the torching and crowning indexes.

FlamMap

This model will produce maps of an area for any modeled value such as fuel moisture, fireline intensity, scorch height, or fuel consumption. FlamMap output can be used to calculate an index of fuel hazard for a given area.

Spatial Patterns of Ecological Risks Associated with Fire

Four areas of ecological risk associated with wildfire hazard that were evaluated are: TNC conservation sites, old growth forests, research natural areas, and vulnerability to invasive species following fire.

Maps of TNC conservation sites, old growth forests, research natural areas, and sites with known locations of invasive species were all compared with the fire hazard map. They were given a relative rank based on the proportion of the area in fire hazard classes of high, medium, low, and none.

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APPENDIX F

Range of Natural Variability in Subalpine Landscape Structure on the Bighorn National Forest, Wyoming: A Hypothesis

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Natural resource stewardship on federal lands is entering a new era of ecosystem management, in which the emphasis is on maintaining all of the biodiversity, ecological processes, and evolutionary legacies that make up these systems, while still producing necessary goods and services for the human component of the ecosystem (Kaufmann et al. 1994, Christensen et al. 1996, Vogt et al. 1997, Meyer and Knight 2001). One important component of ecosystem management involves understanding the history of the ecosystems being managed, and in particular the role of natural disturbance processes in shaping and maintaining ecological structure and function (Swetnam et al. 1999). To evaluate current ecological conditions, we need a benchmark or reference period of ecological integrity to compare with the present (Leopold 1966). For most of the Rocky Mountain region, the several hundred years just prior to the arrival of European settlers in the mid to late nineteenth century provides such a benchmark (Romme et al. 2002).

In this report, I attempt to reconstruct the range of natural variability in subalpine landscape structure that existed before 1900 in the Bighorn Mountains of north-central Wyoming. Many types of natural disturbances influenced landscape structure and dynamics, but the most important disturbance appears to have been fire (Veblen 2000, Meyer and Knight 2001). Therefore, my reconstruction focuses on the effects of fire and post-fire successional processes on landscape structure in high-elevation forests of the Bighorn Mountains. I also focus just on high-severity, stand-

replacing fires, because these appear to burn far larger areas and to have far greater impact on the structure and function of subalpine landscapes in the Rocky Mountains than do low-severity fires (Romme and Despain 1989, Veblen 2000).

A reconstruction of this kind is challenging in any ecosystem, but especially so for the Bighorn National Forest, where very little fire history research has been conducted (but see Bornong 1996 and Meyer and Knight 2001). My approach was to extrapolate from the subalpine landscape of Yellowstone National Park (YNP), where conditions are generally similar and where a substantial body of fire-related research findings is available. The subalpine forests of YNP and the Bighorns are at almost identical latitude, at similar elevations (ca 2,100 – 3,000 m in YNP, and 2,150 – 2,900 m in the Bighorns), and on similarly infertile geologic substrates (rhyolite and tuff in YNP, and granite in the Bighorns). Climatic conditions within the subalpine zone also are roughly similar, with cold snowy winters, cool summers, a precipitation peak in late winter / early summer and usually low precipitation in late summer / fall (see climographs for West Yellowstone, MT, the Northeast Entrance of YNP, and Burgess Junction in the Bighorns, in Figure 9 of Meyer and Knight (2001)). Nevertheless, I must strongly emphasize the tenuous nature of the interpretations and conclusions that are presented in this report. This analysis may be adequate for preliminary, strategic planning purposes – but it must be clearly recognized that additional fire history research is needed in the Bighorn Mountains to test the

hypotheses that I offer here and to revise the interpretations accordingly.

My reconstruction of historic landscape structure (pre-1900) in subalpine forests of the Bighorn Mountains is summarized in Table F.1. Please see the Methods section (below) for details on how I arrived at the numbers in Table F.1, as well as the Discussion section for important caveats and tentative recommendations about possible applications of this information.

I. Methods

The empirical data sets for reconstructing the range of natural variability in subalpine landscapes of the Bighorn National Forest are Romme and Despain's (1989) reconstruction of fire history and landscape structure in Yellowstone National Park, and Renkin and Despain's (1992) analysis of fires in YNP that were allowed to burn without interference from 1972 – 1987. As explained above, the Yellowstone system seems a reasonable surrogate for portions of the Bighorn system. In particular, the nearly continuous lodgepole pine forests on infertile rhyolite substrates of the central, southern, and western portions of YNP (Romme and Despain's study area) appear generally comparable to the nearly continuous lodgepole pine and spruce-fir forests on infertile granitic substrates in the southern part of the Bighorns. However, Romme and Despain's study area probably is not comparable to the more heterogeneous forest / grassland landscape on sedimentary substrates in the northern Bighorns (Meyer and Knight 2001). These interpretations are offered tentatively, and need additional critical evaluation.

The size of a study area has a powerful influence on quantitative descriptors of fire history and landscape structure. Generally, fire intervals and landscape structural variability increase as the size of the study area decreases. The estimates of pre-1900 landscape structure presented in Table 1 are for an area of ca 100,000 ha within the forested subalpine zone. Such an area is comparable in size to Romme and Despain's

study area in YNP (125,000 ha). Thus, the estimates in Table 1 might refer to all of the lodgepole pine & spruce-fir zone lying south and east of Cloud Peak, or to all of the area on granitic soils lying north and east of Cloud Peak. Smaller subunits of this large area would be expected to exhibit wider ranges of variation in all of the parameters listed in Table 1.

Definitions of Structural Stages on the Bighorn National Forest (Column 1 in Table 1):

The classification of forest structural stages used by the Bighorn National Forest is only roughly comparable to the classification of successional stages and stand age classes used in Romme and Despain's study. Thus, caution is needed in translating from one classification system to the other. Because the Bighorn National Forest's structural stage classification is well established and used in all of its databases and land management planning processes, I have attempted to correlate the Bighorn National Forest classification system with Romme and Despain's system (Table 2). My interpretations in Table 2 need to be assessed critically, and the numbers in Table 1 may require revision if any of my interpretations are seriously in error. In addition, maps of forest structural stages, based on interpretation of aerial photographs, may contain errors, in part because tree size and age are only partially correlated.

Derivation of the Numbers in Column 2 of Table 1 ("Ordinary" Conditions)

"Ordinary" climatic conditions are those that prevail most of the time. In YNP, "ordinary" conditions would apply to all of the twentieth century, except 1988 which was an extreme year (see below). Even if no fire suppression occurred, *most fires would remain small (< 100 ha)* because of wet weather conditions throughout most fire seasons (Renkin and Despain 1992). However, *moderate to large sized fires (> 100 ha) would be expected in 2 – 4 years out of every decade.* This estimate is based on the

observed occurrence of 5 fires of this size during the 15-year period from 1972 – 1987 in YNP when no fire suppression actions were taken (Meyer and Knight 2001;39). In addition, *moderately severe fire seasons (> 500 ha burned / 100,000 ha forest) would occur once every 2 – 3 decades*. This estimate is based on the observed occurrence of 3 fires of this size from 1900 – 1970 in YNP (Meyer and Knight 2001;40). A large landscape (e.g., 100,000 ha) may exist in a quasi-equilibrium state under this “ordinary” fire regime (Turner et al. 1993), i.e., proportions of each successional stage will vary within a relatively limited range as indicated in the table. However, such an equilibrium is unlikely to characterize the landscape over long periods of time, because of rare extreme fire events (described below, and in Column 3 of Table 1).

To obtain the numbers in Column 2 of Table 1, I examined the reconstruction of landscape structure presented in Romme and Despain (1989) and reprinted in Figure 40 of Meyer and Knight (2001). I assumed that the period of “ordinary” fire history was ca. 1780 – 1940 (a period of 160 years). I selected these dates because large fires in the early 1700s left a strong imprint on the landscape for several decades thereafter, and because consistently effective fire suppression began after World War II. Between 1790 and 1940, the legacy of the early 1700s fires was gradually diluted by variable rates of succession in the burned areas, and by new but relatively small fires burning throughout the study area.

Thus, the numbers in Column 2 of Table 1 for grass/forb and shrub/seedling stages represent the range of values for LP0 stages between 1780 and 1940 in Romme and Despain’s landscape reconstruction of YNP (note that grass/forb and shrub/seedling stages appear to best correspond to the LP0 stage, Table 2). Similarly, the values in Column 2 of Table 1 for the various sapling/pole stages, which correspond with LP0 or LP1, or with only LP1 (Table 2), represent the range of values observed between 1780 and 1940 for LP0 + LP1 combined or for only LP1, depending on the

particular sapling/pole stage being considered. The values for all of the other structural stages are derived in similar manner.

Derivation of the Numbers in Column 3 (“Extreme Fire Events”)

“Extreme” fire events are exemplified by the 1988 Yellowstone fires, and also by the extensive fires that occurred in YNP in the early 1700s. Such conditions may occur only once or twice in every century or two. These fires, though infrequent, will create long-lasting legacies in landscape structure by burning as much as 25 – 50 % of the landscape area, and will likely cause even large landscapes (e.g., 100,000 ha) to function over long time periods as non-equilibrium systems (Johnson 1992, Turner et al. 1993). It should be emphasized that extreme fire events like the 1988 Yellowstone fires are *not* “unnatural” or “abnormal” for subalpine ecosystems like those in YNP or the Bighorns. They are natural and normal, but occur at such long intervals that they may appear extraordinary when viewed within a limited time scale (Romme and Despain 1989).

To estimate the values in Column 3 of Table 1, I used the proportions of each successional stage existing in Romme and Despain’s study area immediately after the 1988 Yellowstone fires. [*Note: I have not actually measured these proportions, though I could do so easily with a GIS. For this report, I have estimated these values from inspection of the 1988 fire map. We may wish to do the GIS analysis to verify or revise these numbers.*] Column 3 of Table 1 contains the maximum value for younger stages (LP0 and LP1) or the minimum value for older stages (LP2 and LP3), because large fires create extensive tracts of young forests at the expense of old forests.

Derivation of the Numbers in Column 4 (“Long Fire-Free Periods”)

Very long fire-free periods occur naturally in high-elevation Rocky Mountain forest systems, probably because of long-term,

regional climatic variability (Veblen 2000). For example, there were no extensive fires in Romme and Despain's YNP study area from the late 1700s through mid 1800s – a period long before any kind of fire suppression efforts. Similarly, large fires were rare in mid to high elevation forests in the southern Rocky Mountains and southwest from the late 1700s through early 1800s (Swetnam and Betancourt 1998, Veblen 2000, Romme et al. 2002). “Fire-free” in this context refers only to the absence of *very large* fires. Fires still are ignited every year, but never grow to large size, probably because of wet weather conditions.

To estimate these values in Column 4 of Table 1, I used the proportions of the landscape covered by each successional stage in Romme and Despain's YNP study area in 1980 – just before the large 1988 fires. This represents a time when no large fires had occurred for ca. 250 years, which may be about the longest free-fire interval that could occur naturally in this system. The length of this fire-free period may have been increased somewhat by the effective fire suppression that occurred between about 1945 and 1972. However, even though some of the fires in the 1940's – 1960's undoubtedly would have been substantially larger had they not been suppressed, it is unlikely that any of those fires would have been of the magnitude of the 1988 fires. I say this because very large fires occur only in summers of extreme fire weather conditions. If weather like that in 1988 had occurred earlier in the twentieth century, fires could not have been suppressed any more effectively than were the fires in 1988.

II. Discussion

The hypothesized proportions of successional stages covering the subalpine landscape of the Bighorn Mountains prior to 1900 (Table 1) exhibit very broad ranges. This high variance reflects the non-equilibrium nature of high-elevation ecosystems in the Rocky Mountains. The lack of equilibrium is a result of infrequent

but large fire events that shape landscape structure over long periods of time (Johnson 1992, Turner et al. 1993). During shorter time periods, e.g., half a century, the system may exhibit a quasi-equilibrium state, as relatively small fires burn within a relatively large landscape. Such a quasi-equilibrium probably has characterized the Bighorn National Forest during the latter half of the twentieth century, when even the biggest fire – 5,300 ha in 1988 (Meyer and Knight 2001;40) – was still relatively small compared with the total extent of subalpine forest. Under these “ordinary” climatic conditions, fire suppression can be very effective. However, even without fire suppression, the great majority of fires tend to burn a relatively small area.

Despite the absence of very large fires on the Bighorn National Forest throughout the last century, managers and the public must recognize that immense fires -- like those in Yellowstone in 1988 -- probably have occurred in the Bighorns in the more distant past, and probably will occur again in the future. We also must recognize that such large fires probably cannot be prevented, either by direct fire-fighting efforts when they occur or by pro-active fuel reduction efforts before they occur, because large fires are controlled overwhelmingly by broad-scale weather phenomena (Bessie and Johnson 1995, Weir et al. 1995, Agee 1997). Infrequent but very large fires appear to be the norm for high-elevation ecosystems in the Rocky Mountains, and there is little that we can do to change this natural fire regime.

The ranges depicted in Table 1 may be compared with current landscape structure to assess current ecosystem “health” in a coarse-filter mode, and to develop targets for desired landscape condition -- but these comparisons should be made only in a very general sense, given the uncertainties of my analysis. We should be especially careful not to assume that the “ordinary” climatic conditions of the last century will necessarily characterize the next century. We must acknowledge the non-equilibrium nature of this system and expect “surprises”, e.g., fires much larger than any seen in the

last century. Considering the potential for very large, uncontrollable wildfires in the future, we probably should be conservative in our manipulation of current Rocky Mountain landscapes. With this in mind, I offer a few recommendations about applying the numbers in Table 1 to forest planning on the Bighorn National Forest, particularly with regards to the abundance and distribution of very old and very young forests. Because I have not studied the current state of the Bighorn National Forest landscape in any detail, I intend the following recommendations to be general rather than specific.

Regarding old forests, I suggest that we should strive to maintain their proportions near the maximum levels in Table 1 rather than being satisfied if older forests are merely above the minimum levels. I say this for two reasons. First, we can always create young forests by disturbing older forests, e.g., by logging or prescribed fire. However, we cannot create old forests; they must develop slowly over very long time periods without major disturbance. Second, we should anticipate increasing fire frequency and fire extent over the next several decades, as the climate warms overall and extreme weather conditions (including droughts) become more frequent (Overpeck et al. 1990, Balling et al. 1992, Flannigan and Van Wagner 1991, Gardner et al. 1996). The probability of controlling wildfires in the twenty-first century as effectively as we controlled them in the twentieth century is slight. Therefore, we must recognize that much of the older forest that we retain in current land use plans may be lost to uncontrollable fires in the next century – regardless of fire policy. The less old forest remaining in the landscape, the more critical will be future losses to uncontrollable wildfire for species and ecological processes dependant on old forests.

I further suggest that one or more extensive tracts of mature and old-growth forests should be identified and preserved. Large patches of mature forest are beneficial or even essential to many old-growth species

and ecological processes (Knight et al. 2000). However, because a single tract of mature forest is vulnerable to nearly complete loss in a future uncontrollable wildfire, it would be desirable to have more than one such area within the Bighorn National Forest. These large patches of mature forest also should include productive as well as unproductive stands, i.e., should include some stands that could potentially be harvested for wood products as well as stands on steep slopes and other poor sites. This is because recent meta-population theory suggests that the more productive forests may support the critical “source” populations that sustain many wildlife species throughout their ranges. I offer these recommendations in a *general* sense, recognizing that their implementation obviously will be constrained by the natural spatial pattern of forests in the Bighorn Mountains, the legacies of past land use, and other management objectives.

I also urge careful consideration of the extent and quality of early post-fire successional stages on the Bighorn National Forest. Although past timber harvest has created numerous patches of young forest in the grass-forb, shrub/seedling, and sapling/pole classes, not all of these patches are necessarily equivalent to young post-fire stands. Meyer and Knight (2001, pages 82-85 and 108-112) summarize the major ecological differences between burned and harvested stands -- differences related to forest floor conditions, coarse woody debris, snags, patch size and shape, and frequency of patch creation. For many species and ecological processes, these differences probably are not very important, e.g., large ungulates probably benefit equally from increased forage availability in either harvested or burned areas. However, other species may be strongly affected, e.g., three-toed woodpeckers and other cavity-nesting birds dependant on snags, and some soil microbial processes. Therefore, even if assessments of current landscape structure reveal an adequate extent of young forests on the Bighorn National Forest, when compared with the values in Table 1, additional prescribed burning, or timber

harvesting that mimics the salient ecological effects of burning, may still be necessary to provide adequate habitat for early successional, fire-dependant species.

The final and most important recommendation that emerges from this reconstruction of pre-1900 subalpine landscape structure on the Bighorn National Forest is that we need additional research into local fire history and landscape dynamics. At least two kinds of new research can provide site-specific data with which to evaluate the numbers in Table 1. These are (i) empirical field research on fire history and landscape structure at a broad spatial scale, and (ii) simulation modeling experiments such as those currently underway for the San Juan and GMUG National Forests in Colorado, using the spatially explicit landscape model RMLANDS (K. McGarigal and W. H. Romme, work in progress). I cannot over-emphasize that the numbers in Table 1 of this report represent at best a *hypothesis* -- a hypothesis in urgent need of critical testing and revision.

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Table F.1. Estimated range of natural variability in landscape structure on the Bighorn National Forest, Wyoming, prior to 1900. Estimates are for a 100,000 ha subalpine landscape on granitic substrates dominated by lodgepole pine and spruce-fir forests. See the Methods section in the text for details on how these numbers were derived, and the Discussion section for important caveats.

(1) Structural Stage on the Bighorn National Forest (note the suggested cross-classification and apparent overlaps in structural stages in Table 2)	(2) % of the subalpine landscape during “ordinary” climatic conditions *	(3) Maximum / minimum % of the landscape for several decades after “extreme” fire events **	(4) Maximum / minimum % of the landscape towards the ends of very long fire-free periods ***
Grass/Forb	5 - 15 %	50 % maximum	3 % minimum
Shrub/Seedling	5 - 15 %	50 % maximum	3 % minimum
Sapling/Pole (<40% crown cover)	5 - 45 %	50 % maximum	3 % minimum
Sapling/Pole (40-70% crown cover)	15 - 45 %	50 % maximum	5 % minimum
Sapling/Pole (>40% crown cover)	15 - 45 %	50 % maximum	5 % minimum
Trees >9” DBH (<40% crown cover)	N/A ****	N/A ****	N/A ****
Trees >9” DBH (40-70% crown cover)	15 - 50 %	15 % minimum	50 % maximum
Trees >9” DBH (>40% crown cover)	15 - 50 %	15 % minimum	50 % maximum
Old Growth	15 - 30 %	15 % minimum	40 % maximum

* “Ordinary” climatic conditions are those that prevail most of the time. In YNP, “ordinary” conditions prevailed throughout the twentieth century -- *except* in 1988. (See the Methods section in the text for additional explanation.)

** “Extreme” fire events are exemplified by the 1988 Yellowstone fires or by the extensive fires that occurred in YNP in the early 1700s and 1860s). (See the Methods section in the text for additional explanation.)

*** Very long fire-free periods occur naturally high-elevation Rocky Mountain forest systems, e.g., from the late 1700s – mid 1800s in YNP, and from the late 1700s – early 1800s in Colorado. “Fire-free” in this context refers only to the absence of *large* fires. Fires still are ignited every year, but never grow to large size, probably because of wet weather conditions. (See the Methods section in the text for additional explanation.)

**** This type probably is controlled by edaphic conditions rather than disturbance, and occupies a more or less constant proportion of the landscape over time (Table F. 2).

Table F.2. Suggested comparison of classifications of post-fire successional stages / age classes with classification of structural stages in databases of the Bighorn National Forest.

Structural Stage (Bighorn National Forest)	Structural/Successional Stage and Range of Stand Ages*** for each Stage (Romme & Despain 1989)
Grass/Forb	LP0 (0-40 years)
Shrub/Seedling	LP0 (0-40 years)
Sapling/Pole (<40% crown cover)	LP0 (0-40 years) or LP1 (40-150 years)
Sapling/Pole (40-70% crown cover)	LP1 (40-150 years)
Sapling/Pole (>40% crown cover) *	LP1 (40-150 years)
Trees >9" DBH (<40% crown cover)	persistent low-density forest on poor sites (e.g., steep slopes or margins of wet meadows) ... rarely burn ... all-aged
Trees >9" DBH (40-70% crown cover)	LP2 (150-250 years) or LP3 (>250 years)
Trees >9" DBH (>40% crown cover) **	LP2 (150-250 years) or LP3 (>250 years)
Old Growth	LP3 (>250 years)

* Note: I am not sure how "Sapling/Pole (>40% crown cover)" is different from "Sapling/Pole (40-70% crown cover)" ... these classes appear to overlap.

** Note: I am not sure how "Trees >9" DBH (>40% crown cover)" is different from "Trees >9" DBH (40-70% crown cover)" ... these classes appear to overlap.

*** Stand age refers to time since the last stand-replacing fire, not to the average age of extant trees in a stand. For young and middle-aged stands (dominated by the pioneer tree cohort that established after the last fire), stand age and average tree age are usually similar. However, in old stands (containing only a remnant of the pioneer cohort plus numerous younger cohorts) the average tree age is usually much less than the stand age.

APPENDIX G

Simulating the Dynamics in Landscape Structure and Wildlife Habitat in Rocky Mountain Landscapes: The Rocky Mountain Landscape Simulator (RMLANDS) and Associated Models

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The Rocky Mountain Landscape Simulator (RMLANDS) is a spatially explicit disturbance-succession simulation model linked to a landscape pattern analysis program (FRAGSTATS) and wildlife habitat capability model (HABICAP). These models are being developed as an aid to ecological assessments and resource planning, and to aid land managers in addressing the following specific questions:

- What is the range and pattern of variability in landscape structure under “natural” and anthropogenic disturbance regimes? RMLANDS provides a mechanistic approach for evaluating disturbance and succession processes over broad spatial (100,000's of ha) and temporal scales (100's of years) not possible or practical with empirical field studies. Moreover, RMLANDS allows us to ask “what if” questions associated with altered disturbance regimes (e.g., climate change, modified fire regimes, various timber management scenarios) and explore the potential affects on landscape structure dynamics. RMLANDS provides a quantitative framework for understanding the ecological significance of landscape structure measured at one point in time (e.g., current landscape condition).
- How does the range and pattern of variability in landscape structure vary in relation to spatial and temporal scale? RMLANDS provides a method for quantitatively assessing these scaling relationships and identifying potential threshold behavior. For example, at what

spatial scale (i.e., landscape extent) does the landscape exhibit shifting-mosaic, steady-state equilibrium conditions, if at all? Answers to this question will help determine the appropriate scale(s) for monitoring landscape structure change over time.

- How does the range and pattern of variability in landscape structure affect landscape function (e.g., ability to support viable wildlife populations) under various disturbance regimes? RMLANDS provides a method for evaluating the differential impacts of landscape changes on wildlife species with different habitat associations and life history characteristics, and identifying potential source habitats important to the long-term persistence of each species. In addition, RMLANDS provides a framework for evaluating the biological significance of short-term wildlife population/habitat trends derived from monitoring.

Answers to these and other questions will provide land managers a quantitative understanding of landscape dynamics that can serve as the basis for designing land management strategies, provide a scale-dependent context for interpreting landscape structure and wildlife habitat patterns, and provide a means to assess the impacts of alternative land management scenarios.

Conceptual Overview of RMLANDS

RMLANDS is a grid-based, spatially explicit, stochastic landscape simulation model designed to simulate disturbance and succession processes affecting the structure

and dynamics of Rocky Mountain landscapes. RMLANDS simulates two key processes: succession and disturbance. These processes are fully specified by the user (i.e., via model parameterization) and are implemented sequentially within 10-year time steps for a user-specified period of time. Succession occurs at the beginning of each time step in the simulation and represents the gradual growth and/or development of vegetative communities over time. Succession is implemented using a stochastic state-based transition approach in which vegetation cover types transition probabilistically between discrete states (conditions). Transition pathways and rates of transition between states are defined uniquely for each cover type and are conditional on several attributes of a vegetation patch. These patches, as defined for succession, represent spatially contiguous cells having the same cell attributes (e.g., identical disturbance history, age). Most cover types progress through a series of stand conditions (states) over time as a result of successional processes (albeit at different rates due to the stochastic nature of succession). In some cases, these transitions are affected by the occurrence of certain disturbances (e.g., low severity fire) or are regulated by management (e.g., silviculture). Other cover types (e.g., meadows, barren, water) are treated as having a single, static condition and are not affected over time by the interplay of disturbance and succession.

RMLANDS simulates a variety of natural and anthropogenic disturbances. Natural disturbances include wildfire, a variety of insects/pathogens (pinyon decline [pinyon ips beetle and black stain root rot], mountain pine beetle, Douglas-fir beetle, spruce beetle, and spruce budworm), and prairie dogs. Each natural disturbance process is implemented separately, but effects and is effected by other disturbance processes operating concurrently to effect changes in landscape conditions. For example, the occurrence of beetle-killed trees derived from the spruce beetle disturbance process can affect the local probability of ignition and spread of wildfire.

Each natural disturbance is modeled as a

stochastic process; that is, there is an element of chance (or uncertainty) associated with the initiation, spread, and ecological effects of the disturbance. The disturbance algorithm is common among all natural disturbance processes; however, it is parameterized differently for each process and consists of the following key components:

- Climate.—Climate plays a significant role in determining the temporal and spatial characteristics of the disturbance regime. Climate is specified as a global parameter that effects initiation, spread, and mortality of all disturbances within a time step. Climate can be specified as constant with a user-specified level of temporal variability, a trend over time (with variability), or as a user-defined trajectory - perhaps reflecting the climate conditions during a specific reference period.
- Initiation.—Disturbance events are initiated at the cell level. Each cell has a probability of initiation in each time step that is a function of its susceptibility to disturbance and, optionally, its proximity to other disturbance events or landscape features (e.g., roads). Susceptibility to wildfire, for example, is a function of cover type, stand condition, time since last fire, time since last insect outbreak, elevation, aspect, slope, and road proximity - factors that influence fuel mass and moisture and risk of human-caused ignition.
- Spread.—Once initiated, disturbance spreads to adjacent cells in a probabilistic fashion. Each cell has a probability of spread that is a function of its susceptibility to disturbance (as above), which is modified by its relative position (e.g., relative elevation or wind direction) and the influence of potential barriers (e.g., roads and streams). The probability of spread is further modified to reflect variable weather conditions associated with the disturbance event. This event modifier effects the final size of the disturbance and is specified as a user-defined size distribution. In addition,

there is an optional provision for the 'spotting' of disturbances during spread so that disturbances are not constrained to contiguous spread only.

- Mortality.—Following spread into vegetation patches for purposes of determining mortality response, where patches are defined as spatially contiguous cells having the same cell attributes (e.g., identical disturbance history, age).
- Transition.—Following mortality determination, each high mortality vegetation patch is evaluated for potential immediate transition to a new stand condition (state). Transition pathways and rates of transition between states are defined uniquely for each cover type and are conditional on several attributes at the patch level. Note, these disturbance-induced transitions are differentiated from the successional transitions that occur at the beginning of each time step in response to gradual growth and development of vegetation over time.

RMLANDS simulates a variety of anthropogenic disturbances, or treatments. Treatments are implemented via management regimes defined by the user. Management regimes are uniquely specified within management zones, or user-defined geographic units (e.g., urban-wildland interface versus interior). Management zones are further divided into one or more management types based on cover type. Each cover type can be treated separately or it can be combined with other cover types to form aggregate management types. Each management type is then given a unique management regime, which consists of one or more treatment types and associated spatial and temporal constraints. Specifically, each management regime is defined by the following components:

- Spatial constraints and priorities.—Spatial constraints limit where treatment is allowed. Spatial constraints can be defined on the basis of suitability (e.g.,

timberland suitability), road proximity, ownership, and riparian buffer zones. Each of these factors alone or in combination can restrict the allowable treatment area. In addition, the initiation of treatment units within the allowable area can be prioritized based on these factors. These spatial constraints and priorities are static; that is, they do not change over the course of the simulation.

- Treatment types and attributes.—Treatments include a variety of vegetation management practices, including silvicultural systems associated with commercial timber harvest and regeneration (clearcutting, shelterwood, group selection, individual tree selection), restoration treatments associated with ponderosa pine forest restoration, mechanical and chemical control of woody vegetation in shrubland and pinyon-juniper cover types, and prescribed fire. Each treatment is implemented according to a prescription that includes a treatment schedule, including a rotation period and/or treatment cycle, and spatial and temporal constraints on unit size and adjacency considerations.
- Treatment allocation.—Treatments are implemented according to an allocation scheme in which a specified proportion of the total treatment area is allocated to each treatment type.
- Treatment intensity.—Treatment intensity is controlled by treatment area; that is, within each time step treatments are implemented subject to the availability of suitable area and a maximum treatment area constraint. In addition, treatment intensity is subject to restriction based on specified watershed constraints. Specifically, once a watershed exceeds a specified disturbance threshold, all further treatments are prohibited in that watershed. The watershed disturbance threshold is defined in terms of clearcut equivalence and is designed to reflect the impact of disturbances (both natural and anthropogenic) on water

quality. Each disturbance type is given a clearcut equivalent coefficient and recovery trajectory over time.

- Treatment unit dispersion.--Treatment units can be dispersed in a random, aggregated, or dispersed fashion within user-defined timber management units (e.g., watersheds).

Given the management regime specified above, anthropogenic treatments are implemented much the same way as natural disturbances; that is, treatments are initiated at the cell level. Once initiated, treatment units are created by spreading outward from the initiation cell according to rules that seek to create logical treatment units based on land cover and terrain. Following spread, each vegetation patch is evaluated for potential immediate transition to a new stand condition (state). Transition pathways and rates of transition between states are defined uniquely for each cover type and are conditional on several attributes at the patch level. Treatment units remain under management for one full "rotation" (i.e., schedule of individual treatments), after which they are returned to the pool of unmanaged land.

Technical Overview of RMLANDS

RMLANDS is stand-alone program written entirely in Visual C++ for use in a Microsoft Windows Operating System environment. RMLANDS expects input grids in Arc Grid (ESRI) format and requires libraries from either ArcGIS or ArcView Spatial Analyst. RMLANDS was designed to make full use of the USDA Forest Service Integrated Resources Inventory (IRI) database. Consequently, all required input grids can be derived from the IRI database, although other data sources are acceptable. RMLANDS can be classified as a hybrid statistical/probabilistic model with the following distinguishing characteristics:

- Grid-based.--RMLANDS utilizes a grid-based data model in which the landscape is represented in a regular grid lattice structure. The grid structure allows for efficient and powerful spatial

processing. Each grid cell (pixel), representing a fixed geographic area, possesses a number of ecological attributes (e.g., cover type, age). Attributes possess multiple states (i.e., unique values), many of which change over time in response to succession and disturbance.

- Spatially explicit.--Consistent with the grid structure, RMLANDS is a spatially-explicit model; grid cells are geographically explicit and topological relationships are important in all processes (e.g., disturbance initiation and spread).
- Stochastic.--RMLANDS is a stochastic model; that is, there is an element of chance (or uncertainty) associated with the outcome of each process. For example, each cell has a probability of initiation for each disturbance process that is contingent on several cell attributes. A probability less than 1 means that there is only a chance of a disturbance initiating. Thus, given the same cell attributes, some cells will initiate while others will not. There is a stochastic element to nearly all processes in RMLANDS.
- Spatial scale.--The grid can be defined at any spatial resolution, although current applications utilize a high resolution (25 m cell size) grid that allows for detailed representation of landscape patterns. In addition, while RMLANDS does not limit the extent of the landscape, it is most applicable to landscapes between 10,000-1,000,000 ha.
- Temporal scale.--RMLANDS currently operates on a 10-yr time step and is most applicable to simulating landscape dynamics over 100's of years.

Applications

RMLANDS in concert with the other model components being developed (FRAGSTATS and HABICAP) can be used to help provide answers to the questions raised in the

introduction. For example, in a pilot study on the San Juan National Forest (SJNF) in southwest Colorado, we used an early version of these models to quantify the range of variation in landscape structure under wildfire disturbance regimes characteristic of the pre-European settlement period (Question 1). Specifically, we quantified the change in seral stage distribution of high elevation forest types and the spatial configuration of focal cover classes (e.g., late-seral coniferous forest) under a range of wildfire disturbance regimes (Figure G.1). The model output lends itself well to simple summary statistics associated with the composition and configuration of the landscape, as well as more synthetic or integrative multivariate representations of landscape structure dynamics (Figure G.2). Such statistical summaries make it possible to quantitatively evaluate the impact of altered disturbance regimes on landscape behavior, and thus provide a means to explore “what if” scenarios related to alternative land use policies. In addition, these statistical summaries provide an effective means of communicating to stakeholders the concept of landscape dynamics - an important principle underpinning ecosystem management.

RMLANDS and associated models can also be used to explore the scale-dependent nature of landscape dynamics (Question 2). In the SJNF pilot study, we quantified landscape structure dynamics across a range of landscape extents and detected threshold-like behavior. Specifically, the range of variability in landscape structure (integrating many components of structure) increased nonlinearly as the spatial extent of the landscape decreased (Figure G.3). At relatively large extents, say > 40,000 ha, landscape structure variability was extremely small, suggesting that the landscape was being maintained in a very narrowly bounded, shifting-mosaic, steady-state condition. On the other hand, at finer landscape extents, variability was quite large and unstable (i.e., nonconstant mean), suggesting nonequilibrium conditions. While the exact position of the threshold undoubtedly reflects our choice of model parameterization, it nonetheless indicates that threshold-like

behavior is likely to exist. Identifying these thresholds has important management implications, especially with respect to identifying meaningful scales for ecological assessments and monitoring.

Finally, RMLANDS and associated models can be used to explore the consequences of landscape dynamics to wildlife species of concern (Question 3). In the SJNF pilot study, we modeled the spatial and temporal distribution of capable habitat for four indicator species, representing a range of life history attributes and habitat associations, under a wildfire disturbance regime representing the pre-European settlement conditions. Among other things, the model results visually portray the patchy distribution of each species' habitat (Figure G.4) and the shifting mosaic nature of ephemeral habitats (Figure G.5). Although not part of the pilot study, these models can be used to explore questions associated with the potential impact of alternative land use scenarios on species of concern. In addition, these models can be used to identify stable habitat areas that may function as source habitats important to the long-term persistence of each species.

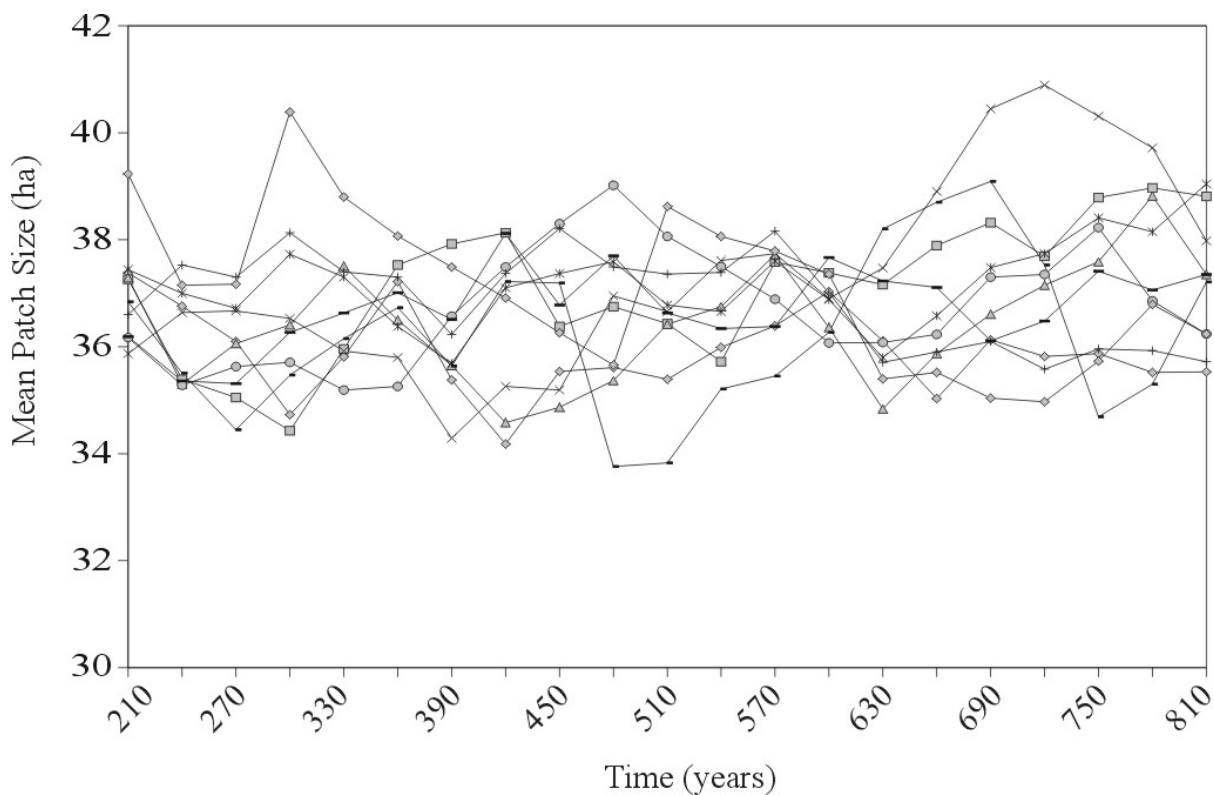
Although RMLANDS and associated models have broad application in the context of ecological assessment and resource planning, they are not without their limitations. These limitations largely relate to the abstraction of the landscape in the models and the heavy dependence on user-specified model parameters that influence outcomes. No model is immune to these issues. However, these models have been developed in collaboration with the US Forest Service and other partners to ensure that the level of abstraction is acceptable given the intended use. Perhaps the greatest limitation of these models is the heavy burden on model parameterization and the limited scope of scientific data available in this regard. For this reason, there is considerable “expert” opinion required to parameterize the models. Hence, these models are properly thought of as expert knowledge-based. Given these limitations, these models are not intended to provide the sole source of information needed to answer the questions

raised above. Rather, these models are intended to complement other approaches, including empirical field studies (e.g., fire history studies, wildlife habitat relationship studies, etc.) and literature reviews, and together provide for more informed ecological assessments and resource planning decisions.

Current Status

RMLANDS and associated models are currently being developed for application on the San Juan National Forest (SJNF) and Grand Mesa-Uncompahgre-Gunnison National Forest (GMUG) to aid broad scale ecological assessments as part of the land management planning process. Although these models are constantly changing in response to needs and capabilities, upon completion of these initial projects, these models will be poised for broad scale application throughout the Rocky Mountain region. Portability to any other forest will require completing the following tasks over a period of approximately one year.

- (1) Compile required GIS data.
- (2) Review and modify succession-disturbance pathways as needed for local conditions.
- (3) Compile literature, summarize local empirical data, and gather expert knowledge as needed for model parameterization.
- (4) Conduct preliminary analyses of natural disturbance regimes (i.e., historical range of variability assessment).
- (5) Conduct final analyses of natural disturbance regimes after review and feedback on preliminary results.
- (6) Conduct preliminary analyses of anthropogenic disturbance regimes to explore risks (in terms of potential impacts to landscape structure and wildlife habitat) associated with anthropogenic changes.
- (7) Conduct final analyses of anthropogenic disturbance regimes.
- (8) Summarize results of final analyses and present findings.



* Similar symbols represent same model run.

Figure G. 1. Trajectory of change in mean patch size of late-seral conifer patches for 10 model runs under a wildfire disturbance representing the pre-1900 (i.e., pre-Euro-American settlement) reference period on the Pagosa Ranger District of the San Juan National, Colorado. This family of trajectories depicts the range of variability in mean patch size over a 600-year period under this particular disturbance scenario. All other metrics were less dynamic than mean patch size, revealing the relatively narrow range of variability in landscape structure at the scale of the full landscape (~228,000 ha).

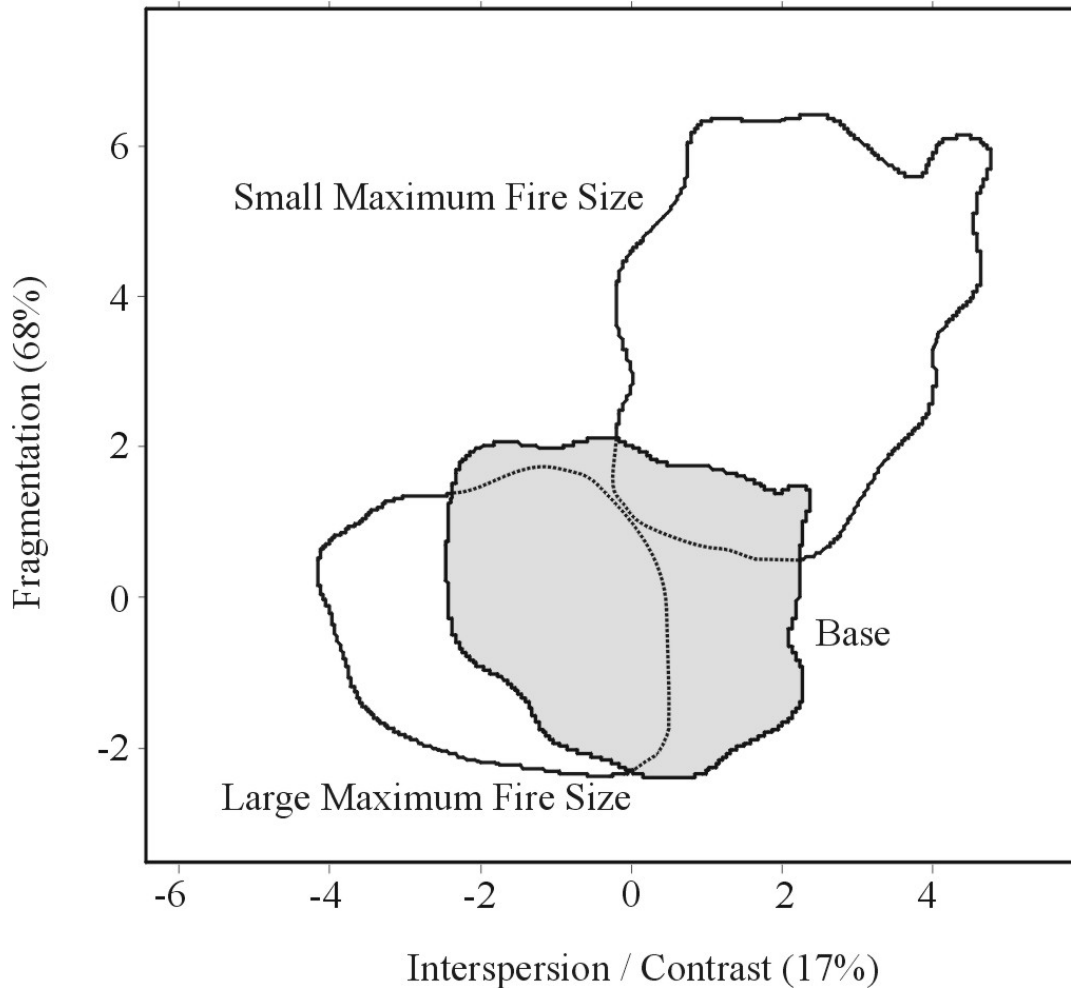


Figure G. 2. Ordination kernels depicting the 95% range of variation in landscape structure for late-seral coniferous forest under a three different wildfire disturbance regimes on the Pagosa Ranger District of the San Juan National Forest, Colorado. The “base” disturbance scenario represents the pre-1900 (i.e., pre-Euro-American settlement) reference period and is compared to a “large maximum fire size” scenario, in which wildfires were allowed to grow 25% larger, and a “small maximum fire size” scenario, in which wildfires were constrained to grow 25% smaller. The x-axis represents a gradient in late-seral coniferous forest interspersion and contrast with other cover types; the y-axis represents a general gradient in fragmentation (subdivision and isolation) of late-seral coniferous. The kernels depict the “landscape structure space” within which the landscape varied over time under simulated conditions; 85% of the variation in landscape structure over time was described by this 2-dimensional space. The enlargement and shift of the kernels under the “small maximum fire size” indicates that suppression of the largest wildfires caused late-seral coniferous forest to become more fragmented on average and vary more dramatically over time than under the “base” scenario.

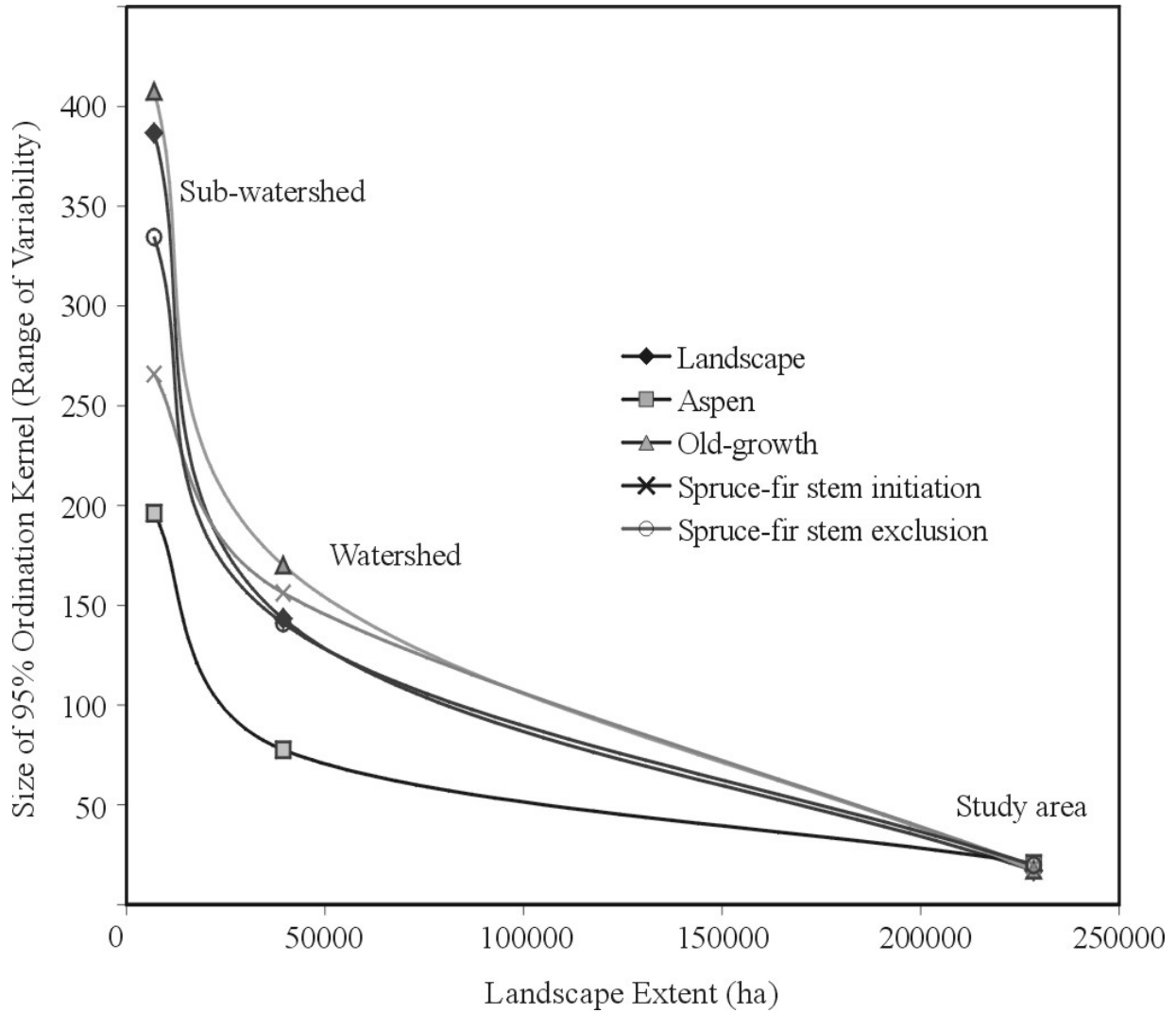


Figure G. 3. Relationship between the 95% ordination kernel area (see figure 2 for a description), representing the range of variation in landscape structure, and landscape extent for the overall landscape and several focal cover classes under a wildfire disturbance regime representing the pre-1900 (i.e., pre-Euro-American settlement) reference period on the Pagosa Ranger District of the San Juan National Forest, Colorado. The graph indicates a consistent threshold-like relationship in which the range of variation in landscape structure is diminished considerably when landscape extent exceeds 40,000 ha.

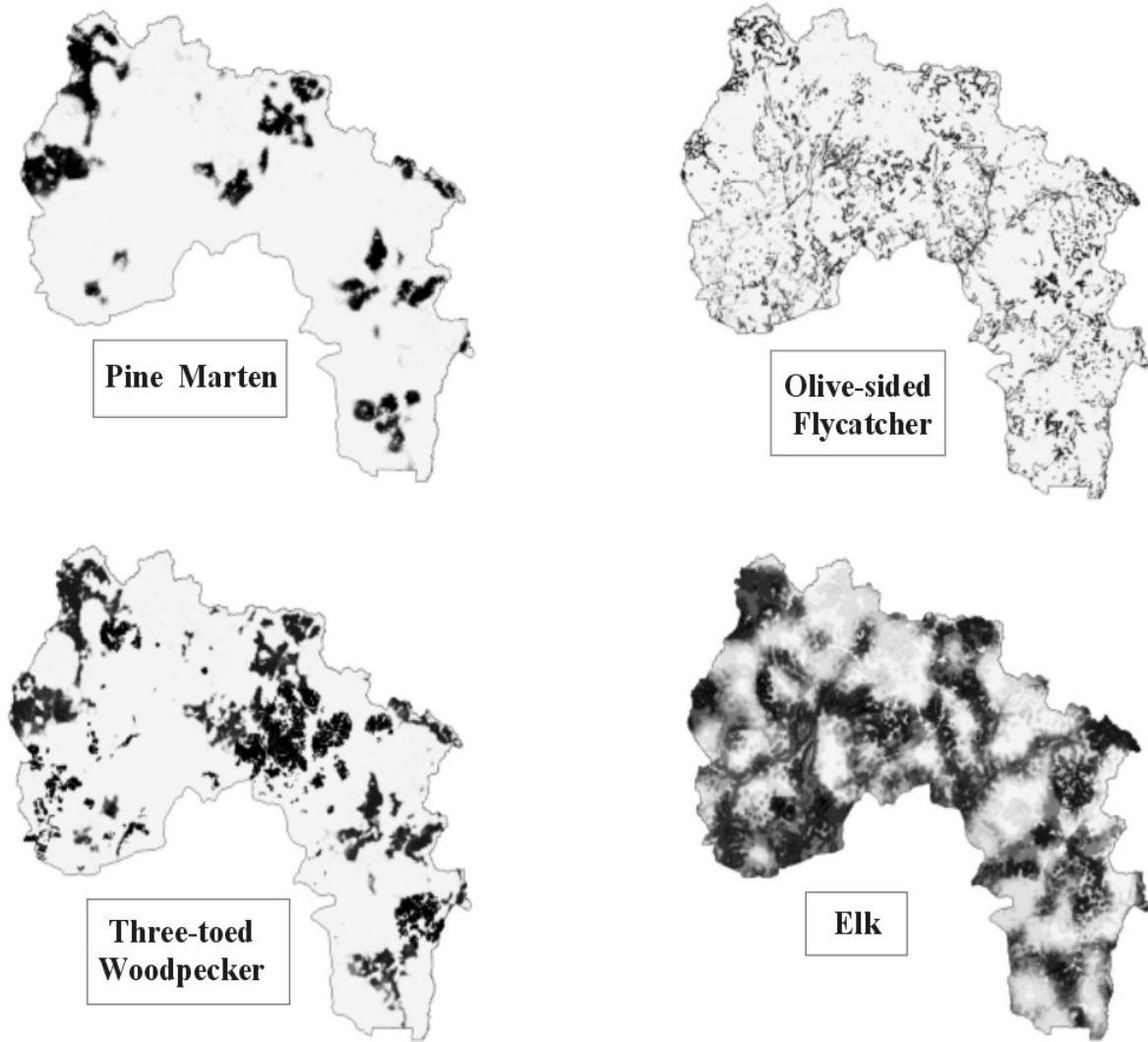


Figure G. 4. Four simulated landscapes depicting the patchy distribution of capable habitat for four wildlife indicator species on the 228,000 ha Pagosa Ranger District of the San Juan National Forest, Colorado. Each landscape represents one snapshot of habitat conditions during a 600-year landscape simulation under a wildfire disturbance regime representing the pre-1900 (i.e., pre-Euro-American settlement) reference period. Black represents habitat with the highest capability of meeting the species' needs for reproduction and survival, grey represents habitat with intermediate capabilities, and white represents areas not likely to serve as habitat.

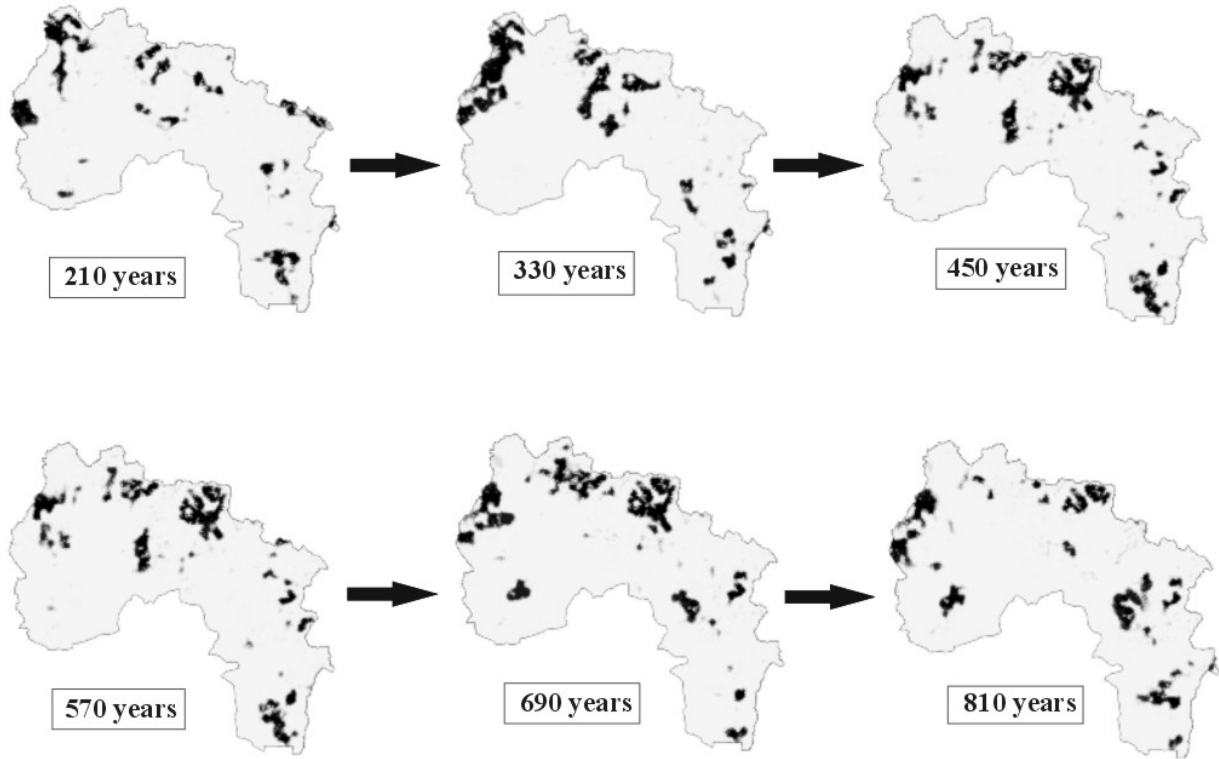


Figure G. 5. Six simulated landscapes demonstrating the shifting pattern of pine marten habitat over on the 228,000 ha Pagosa Ranger District of the San Juan National Forest, Colorado. Each landscape represents a snapshot of habitat conditions at 120-year intervals over a 600-year landscape simulation under a wildfire disturbance regime representing the pre-1900 (i.e., pre-Euro-American settlement) reference period. Black represents habitat with the highest capability of meeting the species' needs for reproduction and survival, grey represents habitat with intermediate capabilities, and white represents areas not likely to serve as habitat.

APPENDIX H

Predicted Cattle and Sheep Preference Patterns and Rangeland Resiliency Models

Predicted Cattle Preference Patterns Model

In order to keep the GIS modeling simple and tractable, we identified three environmental attributes, all map derived, as predictors of cattle preference. Distance to water, slope, and conifer or tall shrub canopy cover were

the three resource factors we determined to be most important in building the model. The model rule set is described in Table H.1. We developed a matrix of all possible combinations of these variables (Table H.2) and preference rankings were assigned (Table H.3).

Table H.1. Parameters for Predicting Cattle Preference Patterns.

	Symbol	Rank (H=high, M=medium, L=low)
Distance to water		
0 - 250 yards	W	H
251 – 880 yards	M	M
881 – 1760 yards	D	L
> 1760 yards	A	L
Slope		
0 – 10%	F	H
11 – 30%	G	M
31 – 40%	H	L
> 40%	M	L
Conifer or tall shrub canopy cover		
0 – 20%	1	H
21 – 40%	2	M
41 – 60%	3	L
> 60%	4	L

Table H.2. All Possible Symbols and Rank Combinations.

Symbol	Rank Combination	Symbol	Rank Combination
WF1	HHH	DF1	LHH
WF2	HHM	DF2	LHM
WF3	HHL	DF3	LHL
WF4	HHL	DF4	LHL
WG1	HMH	DG1	LMH
WG2	HMM	DG2	LMM
WG3	HML	DG3	LML
WG4	HML	DG4	LML
WH1	HLH	DH1	LLH
WH2	HLM	DH2	LLM
WH3	HLL	DH3	LLL
WH4	HLL	DH4	LLL
WM1	HLH	DM1	LLH
WM2	HLM	DM2	LLM
WM3	HLL	DM3	LLL
WM4	HLL	DM4	LLL
WF1	MHH	AF1	LHH
WF2	MHM	AF2	LHM
WF3	MHL	AF3	LHL
WF4	MHL	AF4	LHL
WG1	MMH	AG1	LMH
WG2	MMM	AG2	LMM
WG3	MML	AG3	LML
WG4	MML	AG4	LML
WH1	MLH	AH1	LLH
WH2	MLM	AH2	LLM
WH3	MLL	AH3	LLL
WH4	MLL	AH4	LLL
WM1	MLH	AM1	LLH
WM2	MLM	AM2	LLM
WM3	MLL	AM3	LLL
WM4	MLL	AM4	LLL

Table H.3. Cattle Preference Rankings.

Green = High; Light Yellow = Moderate; Gold = Low; Pink = No Preference

HHH	MHH	LHH
HHM	MHM	LHM
HHL	MHL	LHL
HMH	MMH	LMH
HMM	MMM	LMM
HML	MML	LML
HLH	MLH	LLH
HLM	MLM	LLM
HLL	MLL	LLL

Data Layers Used:

- (1) Hydrography and INFRA structural improvements – used to identify distance to live streams, ponds, troughs, wells, and other sources of water.
- (2) 30 m DEM clipped to the Bighorn National Forest boundary – used to determine slope.
- (3) Bighorn Common Vegetation Unit – IRI – used to determine conifer or tall shrub canopy cover.

GIS Queries:

- (1) Classify distance to water into four categories, using hydrography and INFRA layers:

Distance to Water	Symbol	Rank
0 - 250 yards	W	H
251 – 880 yards	M	M
881 – 1760 yards	D	L
> 1761 yards	A	L

- (2) Classify slope into four categories:

Slope	Symbol	Rank
0 – 10%	F	H
11 – 30%	G	M
31 – 40%	H	L
> 40%	M	L

- (3) Reclassify the CVU data into four canopy closure categories.

Conifer or Tall Shrub Canopy Cover	Symbol	Rank
0 – 20%	1	H
21 – 40%	2	M
41 – 60%	3	L
> 60%	4	L

- (4) Union canopy closure, slope, and distance to water.
- (5) Concatenate the three symbol values (canopy closure, slope, and distance to water).
- (6) Assign the corresponding preference code to the symbol values.
- (7) Assign preference ranking based on the rank combination using the preference rank table. The breaks between consolidated ratings may be modified for each specific landscape based on local expertise.
- (8) The model is run for vacant allotments the same as for the active allotments to portray the potential maximum effect if all current vacant allotments were to be stocked with cattle.
- (9) Finally, the model is run for allotments not currently used, but used in the past. Historically most suitable and even non-suitable areas were grazed by cattle or sheep during periods of extreme stocking. The model portrays a possible scenario of historic effects.

Outputs from Predicted Cattle Preference Model:

(1) Map showing:

- a) Where allotment status equals 'active' and where suitability equals 'suitable' for each preference value (high, medium, low, and none) - with each preference assigned a separate color.
- b) Where allotment status equals 'active' and where suitability equals 'non-suitable' as a separate color.
- c) Where allotment status equals 'vacant' and where suitability equals 'suitable' for each preference value (high, medium, low, and none) - with each preference assigned a separate color.
- d) Where allotment status equals 'vacant' and where suitability equals 'non-suitable' as a separate color.

- e) Where allotment status equals 'non-allotment' (e.g. neither 'active' nor 'vacant') and where suitability equals 'suitable' as a separate color.

(2) Tabular summary showing:

- a) acres where allotment status equals 'active' and suitability equals 'suitable' for each preference value (high, medium, low, and none).
- b) acres where allotment status equals 'active' and suitability equals 'non-suitable'.
- c) acres where allotment status equals 'vacant' and suitability equals 'suitable' for each preference value (high, medium, low, and none).
- d) acres where allotment status equals 'vacant' and suitability equals 'non-suitable'.

Table H.4. Livestock Preference Rankings for Cattle for Active and Vacant Allotments.

Active Allotment Livestock Preference Ratings						
	Non-suitable	Suitability None	Suitability Low	Suitability Moderate	Suitability High	Total
Acres						
Percent						
Vacant Allotment Livestock Preference Ratings						
	Non-suitable	Suitability None	Suitability Low	Suitability Moderate	Suitability High	Total
Acres						
Percent						

Predicted Sheep Preference Patterns Model

We identified the same three environmental attributes as predictors of sheep preference: distance to water, slope, and conifer or tall

shrub canopy cover. The model rule set is described in Table H.5. We developed a matrix of all possible combinations of these variables (Table H.6) and preference rankings were assigned (Table H.7).

Table H.5. Parameters for Predicting Sheep Preference Patterns.

	Symbol	Rank (H=high, M=medium, L=low)
Distance to water		
0 - 880 yards	W	H
881 - 1760 yards	M	M
1761 - 3520 yards	D	L
> 3520 yards	A	L
Slope		
0 – 25%	F	H
26 – 45%	G	M
46 – 60%	H	L
> 60%	M	L
Conifer or tall shrub canopy cover		
0 – 20%	1	H
21 – 40%	2	M
41 – 60%	3	L
> 60%	4	L

Table H.6. All Possible Symbols and Rank Combinations.

Symbol	Rank Combination	Symbol	Rank Combination
WF1	HHH	DF1	LHH
WF2	HHM	DF2	LHM
WF3	HHL	DF3	LHL
WF4	HHL	DF4	LHL
WG1	HMH	DG1	LMH
WG2	HMM	DG2	LMM
WG3	HML	DG3	LML
WG4	HML	DG4	LML
WH1	HLH	DH1	LLH
WH2	HLM	DH2	LLM
WH3	HLL	DH3	LLL
WH4	HLL	DH4	LLL
WM1	HLH	DM1	LLH
WM2	HLM	DM2	LLM
WM3	HLL	DM3	LLL
WM4	HLL	DM4	LLL
WF1	MHH	AF1	LHH
WF2	MHM	AF2	LHM
WF3	MHL	AF3	LHL
WF4	MHL	AF4	LHL
WG1	MMH	AG1	LMH
WG2	MMM	AG2	LMM
WG3	MML	AG3	LML
WG4	MML	AG4	LML
WH1	MLH	AH1	LLH

WH2	MLM	AH2	LLM
WH3	MLL	AH3	LLL
WH4	MLL	AH4	LLL
WM1	MLH	AM1	LLH
WM2	MLM	AM2	LLM
WM3	MLL	AM3	LLL
WM4	MLL	AM4	LLL

Table H.7. Sheep Preference Rankings.		
Green = High; Light Yellow = Moderate; Gold = Low; Pink = No Preference		
HHH	MHH	LHH
HHM	MHM	LHM
HHL	MHL	LHL
HMH	MMH	LMH
HMM	MMM	LMM
HML	MML	LML
HLH	MLH	LLH
HLM	MLM	LLM
HLL	MLL	LLL

Data Layers Used:

- (1) Hydrography and INFRA structural improvements – used to identify distance to live streams, ponds, troughs, wells, etc.
- (2) 30 m DEM clipped to the Bighorn National Forest boundary – used to determine slope
- (3) Bighorn Common Vegetation Unit – IRI – used to determine conifer or tall shrub canopy cover

GIS Queries:

- (1) Classify distance to water into four categories, using hydrography and INFRA layers:

Distance to Water	Symbol	Rank
0 - 880 yards	W	H
881 - 1760 yards	M	M
1761 - 3520 yards	D	L
> 3520 yards	A	L

- (2) Classify slope into four categories:

Slope	Symbol	Rank
0 – 25%	F	H
26 – 45%	G	M
46 – 60%	H	L
> 60%	M	L

(3) Reclassify the CVU data into four canopy closure categories.

Conifer or Tall Shrub Canopy Cover	Symbol	Rank
0 – 20%	1	H
21 – 40%	2	M
41 – 60%	3	L
> 60%	4	L

(4) Union canopy closure, slope, and distance to water.

(5) Concatenate the three symbol values (canopy closure, slope, and distance to water).

(6) Assign the corresponding ranking code to the symbol values.

(7) Assign preference ranking based on the rank combination using the preference rank table. The breaks between consolidated ratings may be modified for each specific landscape based on local expertise.

(8) The model is run for vacant allotments the same as for the active allotments to portray the potential maximum effect if all current vacant allotments were to be stocked with sheep.

(9) Finally, the model is run for allotments not currently used, but used in the past. Historically most suitable and even non-suitable areas were grazed by cattle or sheep during periods of extreme stocking. The model portrays a possible scenario of historic effects.

Outputs From Predicted Sheep Preference Model:

(1) Map showing:

- a) Where allotment status equals ‘active’ and where suitability equals ‘suitable’ for each preference value – high, medium, low, and none with each preference assigned a separate color.
- b) Where allotment status equals ‘active’ and where suitability equals ‘non-suitable’ as a separate color.
- c) Where allotment status equals ‘vacant’ and where suitability equals ‘suitable’ for preference value – high, medium, low, and none with each preference assigned a separate color.
- d) Where allotment status equals ‘vacant’ and where suitability equals ‘non-suitable’ as a separate color.
- e) Where allotment status equals ‘non-allotment’ (e.g. neither active nor vacant) and where suitability equals ‘suitable’ as a separate color.

(2) Tabular summary showing:

- a) Acres where allotment status equals ‘active’ and suitability equals ‘suitable’ for each preference value (high, medium, low, and none).
- b) Acres where allotment status equals ‘active’ and suitability equals ‘non-suitable’.

- c) Acres where allotment status equals ‘vacant’ and suitability equals ‘suitable’ for each preference value (high, medium, low, and none).
- d) Acres where allotment status equals ‘vacant’ and suitability equals ‘non-suitable’.

Rangeland Resiliency Model

In an attempt to keep the model simple, we identified three parameters that appear to be notable drivers in rangeland resiliency: aspect, soil depth, and parent material. We made the following assumptions regarding these parameters:

Aspect – southerly aspects are typically harsher sites and may have a lower resiliency.
 Soil Depth – (to bedrock or an impermeable layer) – shallower (< 20”) soils might have a lower resiliency than deeper soils (> 20”).
 Parent Material – granitic materials have lower resiliency than sedimentary materials; alluvial and fluvial soils tend to be resilient.

The model rule set is described in Table H.9. We developed a matrix of all possible combinations of these variables (Table H.10.) and resiliency rankings were assigned (Table H.11.).

Table H.8 Livestock Preference Rankings for Sheep for Active and Vacant Allotments.

i. Active Allotment Livestock Preference Ratings						
	Non-suitable	Suitability None	Suitability Low	Suitability Moderate	Suitability High	Total
Acres						
Percent						
ii. Vacant Allotment Livestock Preference Ratings						
	Non-suitable	Suitability None	Suitability Low	Suitability Moderate	Suitability High	Total
Acres						
Percent						

Table H.9. Parameters for Estimating Rangeland Resiliency.

	Symbol	Rank (H=high, L=low)
Parent Material		
Alluvial or fluvial	A	H
Sedimentary	S	H
Granitic	G	L
Aspect		
All (for alluvial or fluvial sites)	1	H
NE, N, NW	2	H
S, SE, SW, W, E	3	L
Soil Depth		
Deep	D	H
Shallow	S	L

Table H.10. All Possible Symbols and Rank Combinations.

Symbol	Rank Combination
A1D	HHH
S2D	HHH
S2S	HHL
S3D	HLH
S3S	HLL
G2D	LHH
G2S	LHL
G3D	LLH
G3S	LLL

Table H.11. Rangeland Resiliency Rankings.

Green = High; Light Yellow = Moderate; Gold = Low Resiliency

HHH	LHH
HHL	LHL
HLH	LLH
HLL	LLL

Data Layers Used:

- (1) Local soil survey or IRI-CLU – used for parent material and soil depth
- (2) IRI-CVU – used for aspect

GIS Queries:

- (1) Classify parent material into three categories:

Parent Material	Symbol	Rank
Alluvial or fluvial	A	H
Sedimentary	S	H
Granitic	G	L

- (2) Classify aspect into three categories:

Aspect	Symbol	Rank
All (for alluvial or fluvial sites)	1	H
NE, N, NW	2	H
S, SE, SW, W, E	3	L

- (3) Classify soil depth as either deep or shallow:

Soil Depth	Symbol	Rank
Deep	D	H
Shallow	S	L

- (4) Union parent material, aspect, and soil depth.
- (5) Concatenate the three symbol values (parent material, aspect, and soil depth).
- (6) Assign the corresponding ranking code to the symbol values.
- (7) Assign resiliency ranking based on the rank combination using the resiliency rank table. The breaks between consolidated ratings may be modified for each specific landscape based on local expertise.

Outputs From Rangeland Resiliency Models

- (1) Map showing rangeland resiliency with each ranking assigned a separate color.
- (2) Overlay the rangeland resiliency map with the map of livestock preference and show the combinations as nine separate colors grading from low preference/high resiliency at green, to high preference/low resiliency at red.

Table H.12. Livestock Preference/Rangeland Resiliency Combinations.

		Resiliency		
		High	Moderate	Low
Preference	High			
	Moderate			
	Low			

- (3) Tabular summary showing acreages of each livestock preference/rangeland resiliency combination.

Table H.13. Acres Covered by Each Livestock Preference/Rangeland Resiliency Combination.

		Resiliency		
		High	Moderate	Low
Preference	High	Acres	Acres	Acres
	Moderate	Acres	Acres	Acres
	Low	Acres	Acres	Acres

- (4) Overlay the map derived in Step 2 above with either LTAs or existing cover type, as available. Evaluate to determine how much of each plant community is represented within each of the nine combinations derived in Step 2. Show as acres of plant community within each preference/resiliency combination.

Table H.14. Acres of Each Plant Community Covered by Each Livestock Preference/Rangeland Resiliency Combination.

	Rangeland Resiliency/Livestock Preference Combination								
Plant Community	H/H	H/M	H/L	M/H	M/M	M/L	L/H	L/M	L/L
Mountain big sagebrush									
Aspen									
Etc.									

APPENDIX I

Areas of Ecological Concern

Low and High Integrity and Reference Areas

The objective of this appendix is to show an example of how to utilize key findings and data from previous modules to identify locations within the assessment area that may be characterized as having either high or low

ecological integrity. Additionally, the appendix identifies places on the landscape that may serve as reference areas based on their high ecological integrity.

Table I.1. The seven evaluation criteria or reference components identified to determine areas of ecological concern for the Bighorn National Forest. The table also identifies the GIS data and queries that were used for the analysis.

Evaluation Criteria for Areas of Ecological Concern	Spatial Data Source	Analysis Procedure
High road density	Road density coverage	Selected all areas with a road density value greater than 0.95 miles/m ² .
Timber activity	Timber harvesting	Selected timber harvests and buffered clearcuts by 100m and 50 m for all other harvesting activities.
Intensive recreation	Campgrounds, ski areas, summer homes, resorts, cow camps	0.5 mile buffer was added around all of the recreation points.
Intensive grazing activity and low resilience	High stocking, high preference, and low resilience	The intersection of high stocking (0 - 2 acres/AUM), high grazing preference for sheep and cattle, and low resilience.
Intensive grazing activity and high weed invasibility	High invasibility, high stocking, and high preference	The intersection of very high/high weed invasibility, high stocking (0 - 2 acres/AUM) and high grazing preference for sheep and cattle.
Intensive grazing activity and high fire hazard	High hazard, low resilience, high preference, high stocking	The intersection of high fire hazard, low resilience, high grazing preference for sheep and cattle, and high stocking (0 - 2 acres/AUM).
Fire Condition Class 3	Condition Class 3	Condition Class 3 selected from the current Condition Class map.

Areas of Low Integrity

After reviewing the key findings from each module, seven evaluation criteria were selected to identify areas of low ecological integrity on the Bighorn National Forest

The seven components of low ecological integrity, as determined for the Bighorn National Forest shown in Table I.1 are high road density; extensive silvicultural activity; a

coincidence of low rangeland resilience, high preference, and high livestock stocking; high weed invasibility or occurrence of invasive species; high departure from historical disturbance regimes; high impact recreation or the presence of utility corridors. Seven spatial coverages were then created to illustrate the evaluation criteria.

Each of the seven coverages was then converted into a binary coverage to indicate

whether the disturbance was taking place at a location or not. A value of one was assigned to polygons where there is presence of the activity and zero where the activity is not occurring.

Next, the seven coverages were combined and a new field called “concern” was added to the coverage (Fig. I.1). The 0 or 1 values for all seven disturbances were added together for each polygon to give a disturbance value between 0 and 7. A value of 7 would indicate that all seven-evaluation criteria for areas of ecological concern were taking place at that

point on the landscape. A location was considered to have low ecological integrity if it was characterized by at least six of the seven low integrity components listed above. Similarly, a location was considered to have moderately low ecological integrity if it was characterized by at least four of the seven components. The seven components were not ranked or weighted.

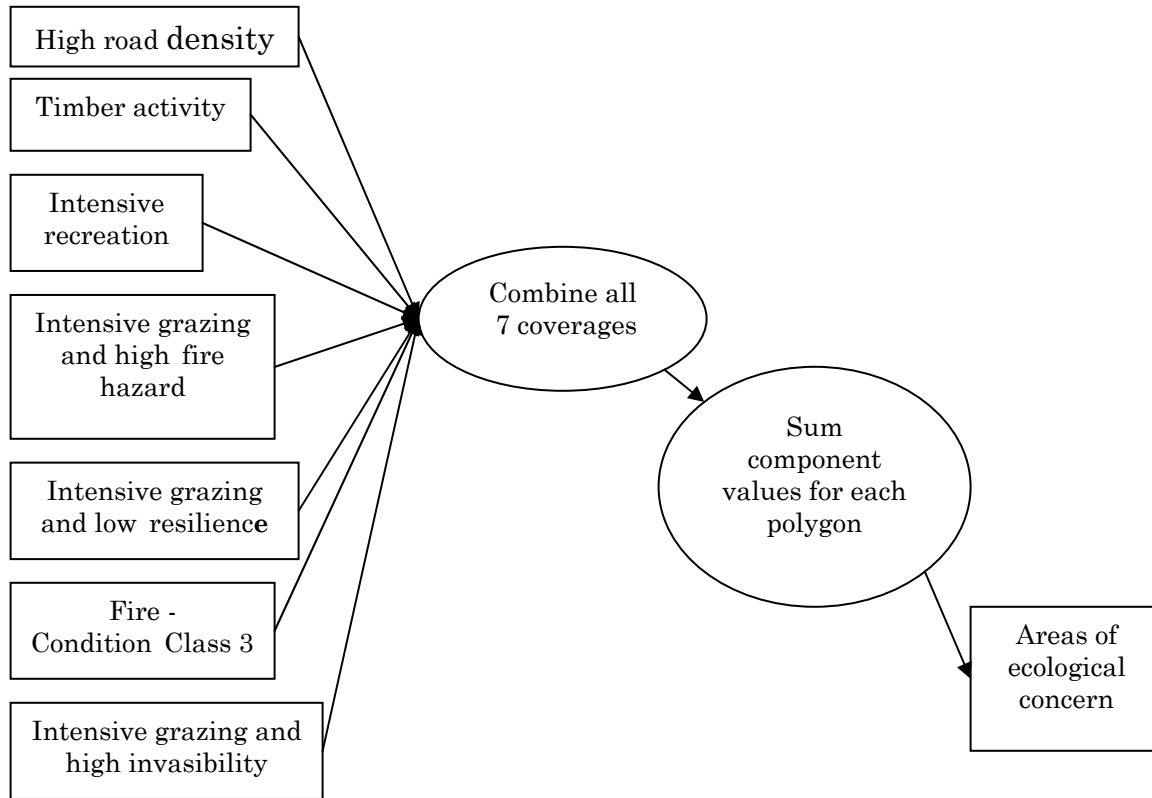


Figure I.1. Flow chart illustrating the process for determining areas of ecological concern.

Areas of High Integrity and Reference Areas

After reviewing the key findings from each module, seven evaluation criteria were selected to help identify locations that may be considered as areas of high integrity on the Bighorn National Forest.

The seven positive components of high ecological integrity, as determined for Bighorn National Forest are: low road density; no silvicultural activity; no intensive recreation; no know weeds; no domestic grazing; low or no departure from historical disturbance regimes; and no utility lines (Table I.2).

Seven spatial coverages were then created to illustrate the evaluation criteria. Each of the seven coverages was then converted into a binary coverage to indicate whether the disturbance was taking place at a location or not. A value of 1 was assigned to polygons where there was no presence of the activity and zero where the activity is occurring.

Next, the seven evaluation criteria coverages were combined and a new field called "reference" was added to the coverage. The 0 or 1 values for all seven disturbances were added together for each polygon to give a disturbance value between 0 and 7. A value of

7 would indicate that all of the seven evaluation criteria for areas of high integrity occur at that point on the landscape and therefore would indicate a high level of integrity. A location was considered to have high ecological integrity if it was characterized by at least six of the seven high integrity components listed above. Similarly, a location was considered to have moderately high ecological integrity if it was characterized by at least four of the seven components. The seven components were not ranked or weighted.

The next step in this process was to develop reference areas using our definitions of ecological integrity as described above (Fig I.2). All of the polygons with a value of 7 and other polygons, which were completely surrounded by value 7 polygons, were selected and converted into a new coverage. The coverage was then dissolved to form contiguous polygons. The four largest polygons became the suggested reference areas.

Table I.2. Seven evaluation criteria or reference components identified to determine areas of high ecological integrity for the Bighorn National Forest. The table also identifies the GIS data and the queries that were used for the analysis.

Evaluation Criteria for High Integrity Areas	Spatial Data Source	Analysis Procedure
Low road density	Road density coverage	Selected all areas with a road density value less than 0.95 miles/m ² .
No timber activity	Timber harvesting and Bighorn NF boundary	Selected timber harvests and buffered clearcuts by 100 m and 50 m for all other harvesting activities. That coverage was then merged with the Bighorn NF boundary so that all of the areas outside the buffered harvests could be selected.
No intensive recreation	Campgrounds, ski areas, summer homes, resorts, cow camps, and Bighorn NF boundary	0.5 mile buffer was added around all of the recreation points. That coverage was then merged with the Bighorn NF boundary so that all of the areas outside the buffered recreation sites could be selected.
No known weeds	Weed point and polygon coverages and Bighorn NF boundary	400 m buffer was added around known weed locations. Then that coverage was merged with the Bighorn NF boundary so that all of the areas outside the buffered weed locations could be selected.
No domestic grazing	Bighorn allotments	Selected all of the allotments with no current grazing (closed, vacant, and recreation allotments, etc.).
Fire Condition Class 0 and 1	Condition Classes 0 and 1	Selected Condition Classes 0 and 1 from the current Condition Class map.
No utilities lines	Utility coverage and Bighorn NF boundary	200 m buffer was added around utilities lines. That coverage was then merged with the Bighorn NF boundary so that all of the areas outside the buffered utilities lines coverage could be selected.

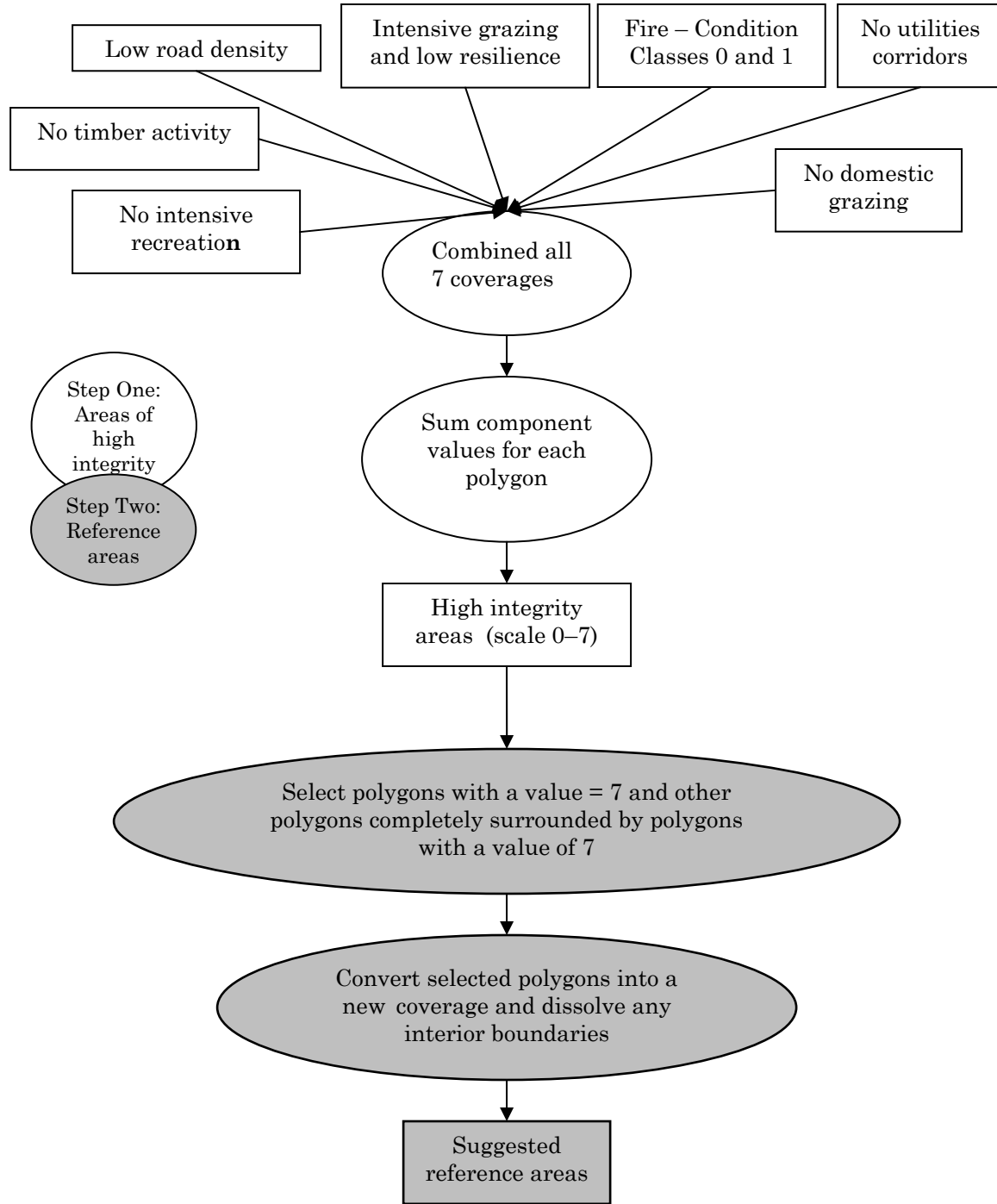


Figure I.2. Flow chart illustrating the process for determining areas of high ecological integrity and reference areas.