Great Northern Landscape Conservation Cooperative

Science Plan, 2015-2019

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EXECUTIVE SUMMARY

The purpose of the Great Northern Landscape Conservation Cooperative (GNLCC) Science Plan is to provide a framework and explain the process for identifying science priorities in the context of landscape conservation which drives annual workplans. The GNLCC Science Plan builds off the Governance Charter and Strategic Conservation Framework (Chambers et al. 2013) to achieve landscape goals through an adaptive management approach. The GNLCC Science Plan describes:

- ecological relationships among conservation targets, threats, and actions as they relate to overall goals and vision
- a process for setting desired condition and quantifiable objectives for conservation targets and their use as a metric for progress
- how to assess conservation actions for effectiveness towards goals
- where and how Cooperative partners contribute to and benefit from shared conservation delivery

The Science Plan aligns GNLCC's goals and vision with standard conservation approaches and vocabularies and employs a dual-scaled approach to address those goals. The 31 Conservation Targets prioritized in the Conservation Framework will be linked to measures of ecological integrity through the development of a Landscape Integrity Index. This offers two levels of metrics that can be integrated. The Plan also suggests appropriate roles for participants (Steering Committee, Advisory Team, Science Community, Partner Forums, etc.) identified in the Governance Charter. In sum, The Science Plan sets a course for Partners to successfully develop and apply science, inform management and track progress of the GNLCC towards its collective vision and over-arching goal of Landscape Integrity.

Conservation Targets

The Science Plan describes a process that guides stakeholders toward informed, collaborative action on specific, conservation targets that effect landscape conservation (see Strategic Conservation Framework). To start, we explain a strategy and process (Fig. ES1) that employs new conservation paradigms, (e.g., Strategic Habitat Conservation, vulnerability assessments, conservation triage) in a logical progression that uses shared data and knowledge to target priority conservation action that is necessary to reach GNLCC goals, while acknowledging uncertainty. The process is intended as a heuristic approach, rather than a recipe, to guide partners toward achieving informed, effective action for conservation targets.

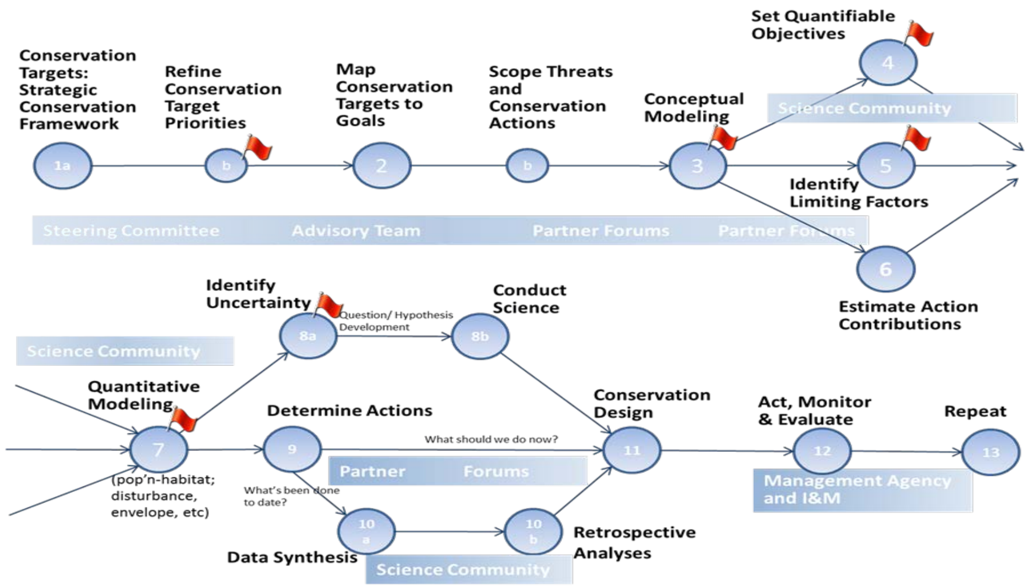

Figure ES1. Stepwise process for directly addressing priority GNLCC Conservation Targets. The process includes identifying science needs, developing applications, and estimating conservation action effectiveness for each target while delivering data, models, and conservation planning to support advancement of GNLCCs landscape goals. Each step is addressed in detail in the Science Plan and briefly described below. Red flags here postulate steps where science needs are identified. In practice specific science needs will vary with the target being addressed.

Steps:

1a: **Strategic Conservation Framework** – The first iteration of the GNLCC's Conservation Goals and priority Targets (see GNLCC Conservation Framework; Chambers et al. 2013).

1b: **Refine Conservation Target Priorities** – Within the 5 years of this Plan four states will deliver revised State Wildlife Action Plans, USFWS will implement a surrogate species approach, and multiple Forest (USFS) and Land Use (BLM) Plans will be approved; thus periodic review is an integral, iterative step.

2a: **Map Conservation Targets to Goals** – An explicit first step linking species, habitat/ecosystem and process targets to GNLCC landscape-scale goals. Partners and partnerships address targets from unique perspective; Step 2b works to resolve perspective and align programs.

2b: **Scope Conservation Threats and Actions** – Standardizes each conservation target to a lexicon as a means to consistently feed a Conceptual Model for each Conservation Target. We rely on the expertise exemplified by the Partner Forums to specify threats and actions in a structured discussion.

3: **Conceptual Models** – The next step is to develop common understanding of each Target's ecological relationships by building conceptual models.

4: **Set Quantifiable Objectives** – A critical task for the GNLCC and partner-driven conservation in general. Many social, political, economic, and biological factors influence how objectives are set. The Steering Committee is critical to promote agreed-upon objectives.

5: **Identify Limiting Factors** – These may be lacking for species that have not been specifically targeted by recovery planning. Also, because we lack quantifiable objectives for many targets, critical limits to achieving those objectives are unclear.

6: **Estimate Action Contributions** – Here the Plan invokes conservation triage to estimate the relative cost/benefits of conservation actions identified in Step 2b. Target metrics are refined by setting objectives and identifying limiting factors.

7: **Quantitative Modeling** – In this step, we develop predictive models as a means to understand and quantify uncertainty, and prioritize and evaluate management actions in terms of their benefit to achieving objectives.

8a: **Identifying Needs and Uncertainty** – These outcomes encompass a large proportion of GNLCC science needs and serve as primary guidance for developing Annual Workplans.

8b: **Conduct Science** – This stepwise and iterative process ensures our actions are well informed. They also ensure that our research investment precisely informs management action.

9: **Determine Conservation Actions** – The second outcome of the modeling exercise is the suite of conservation actions – an improved Managers' Toolbox – that are cost effective and predicted to be ecologically effective.

10a: **Data Synthesis of Legacy Conservation Actions** – To understand how much have we collectively changed the conservation options and outcomes and where those actions occur, we need to identify and compile data from multiple sources to document the cumulative status of past and current conservation actions.

10b: **Retrospective Analyses** – Data gathered and archived in Step 10a will be used to understand their contribution to GNLCC conservation targets.

11: **Landscape Conservation Design** – This is both a process and a product, where the process is science-based, iterative and adaptive with stakeholders, and the product results in a desired landscape condition as expressed through the integration of quantifiable biological, cultural, and physical resource objectives.

12: **Act, Evaluate, Monitor** – This important step is largely outside the scope of the Science Plan except for two important concepts: the design of conservation actions using an experimental approach and considerations and integration of sound monitoring protocols. However implementation and effectiveness require this step.

13: **Repeat** – Led by the GNLCC Steering Committee and Advisory Team, the process repeats in timeframes built around improved knowledge, technology, and conservation need.

Landscape Integrity Index

Landscape conservation is a challenge of scales: spatial, temporal, ecological, jurisdictional, and socio-political. Preceding conservation paradigms (i.e., FWS 2008) have successfully defined useful frameworks within a specified spatial scale. However, an LCC's challenge is to understand and address conservation objectives concurrently at different extents and resolutions. The GNLCC must roll up conservation actions aimed at specific targets to quantify advances toward landscape-scale subgoals which result in our collective vision. Thus, we need a cohesive means to describe and track landscape change and conservation outcome as a measure of landscape impact overall. We define landscape as a large area encompassing an interacting mosaic of ecosystems and human systems that is characterized by a set of common management concerns (Clement et al. 2014).

The four GNLCC goals (Chambers et al. 2013) embody the definition, maintenance, and advancement of ecological or landscape integrity. Thus forth, we will use landscape integrity to encompass this ideal. We characterize landscape integrity as the inverse of human modification (i.e., the 'H' index of Theobald 2013) and as a subset of ecological integrity as defined by Noss (1990) and Parrish et al. (2003). Areas of high ecological integrity have unfragmented natural landscapes, highly functioning biotic and abiotic processes and native biotic components within a natural range of variability, and few impacts from invasive species.

The GNLCC will use a Landscape Integrity Index (LII; Fig ES2) for the Great Northern region to serve as a 2014 baseline and provide the opportunity to monitor progress toward (or away from) desired conditions from this baseline. The LII estimates landscape-scale threats to Conservation Targets as using standard threat classes (Salafsky et al. 2008) and spatial modeling techniques (Theobald 2013).

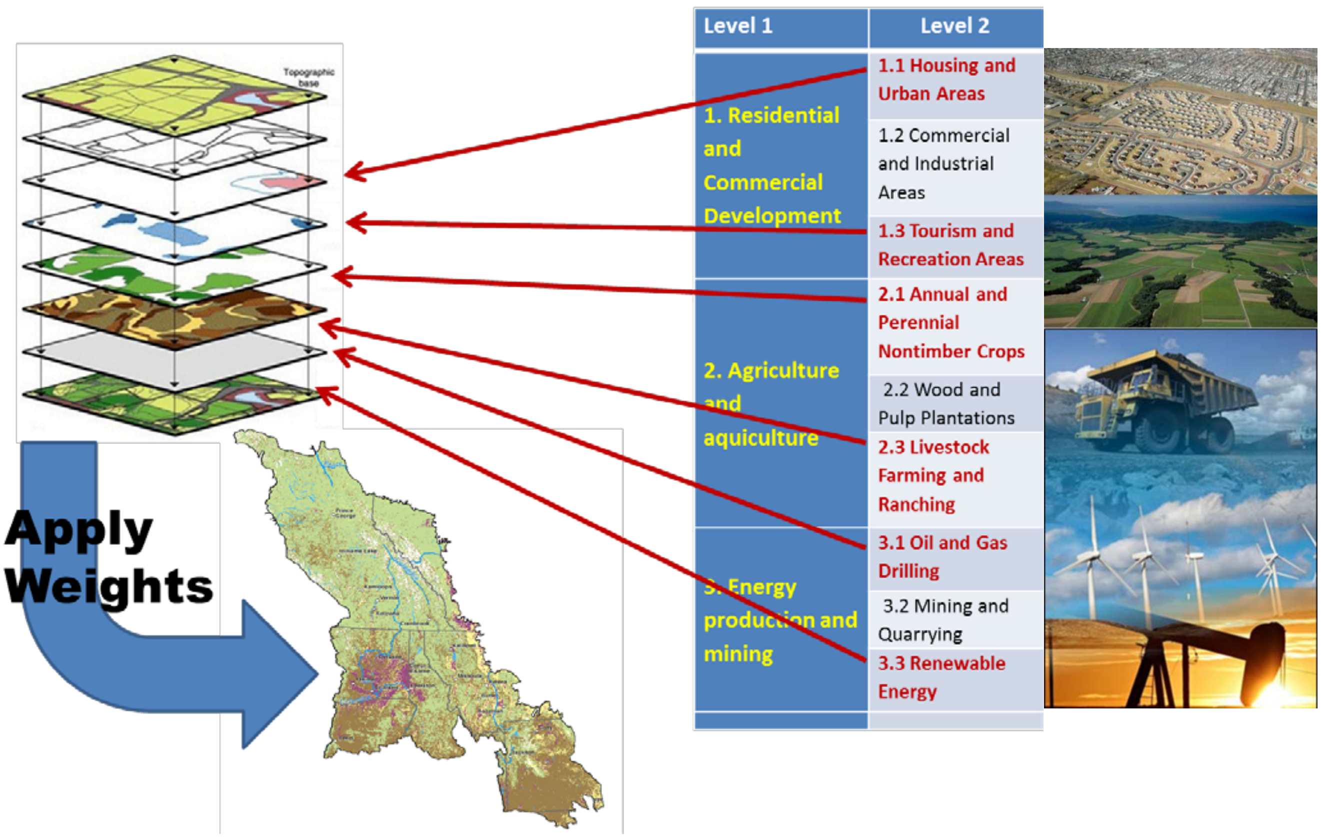

Figure ES2. The Landscape Integrity Index will identify priority conservation threats in GNLCC, refine spatial data describing those threats and apply threat- and target-specific estimates of intensity to characterize the GNLCC landscape. The process is collaborative and participatory ensuring stakeholders are invested in the result. It requires contributions from all partners and delivers a consistent estimate of landscape condition. The modeling process can repeated at intervals to estimate landscape trends in relation to goals.

The LII approach promotes an adaptive response n both spatial and temporal contexts and approximates a condition estimate that all GNLCC partners find relatable and can use. This first estimate will allow the GNLCC to track changes by land use impact over time and identify important data gaps that are specifically identified for conservation targets via the process described in Section 1. The LII map informs us where the more broadly effected human impact is occurring, and where there may be a high need to conserve or where certain systems may be lost and other areas should be prioritized to maintain desired conditions. If LII is remaining relatively stable or decreasing (less human impact) we assume that landscape integrity in the GNLCC is maintained or improved.

The GNLCC-wide Landscape Integrity map will inform annual workplans in terms of prioritizing data acquisition and focus the partnership on particularly sensitive or threatened locales and conservation targets that are in need of attention. Ideally, subsequent iterations will use updated spatial data generated through GNLCC workplans and science products and by partners developing other spatial data improvements (e.g., Crucial Habitat Assessment Tools [CHAT], Rapid Ecoregional Assessments [REA], State Wildlife Action Plans [SWAP]).

Action and Progress toward GNLCC Vision and Goals

The outstanding challenge to large landscape conservation is creating consensus, producing and delivering cross-scale, cross-jurisdictional information to best inform conservation decision and action as a coordinated effort from all participants. The Science Plan guides the GNLCC partnership to integrate quantifiable objectives on specific common conservation targets with landscape-scale desired outcomes by linking target metrics to estimates of landscape integrity (Fig. ES3).

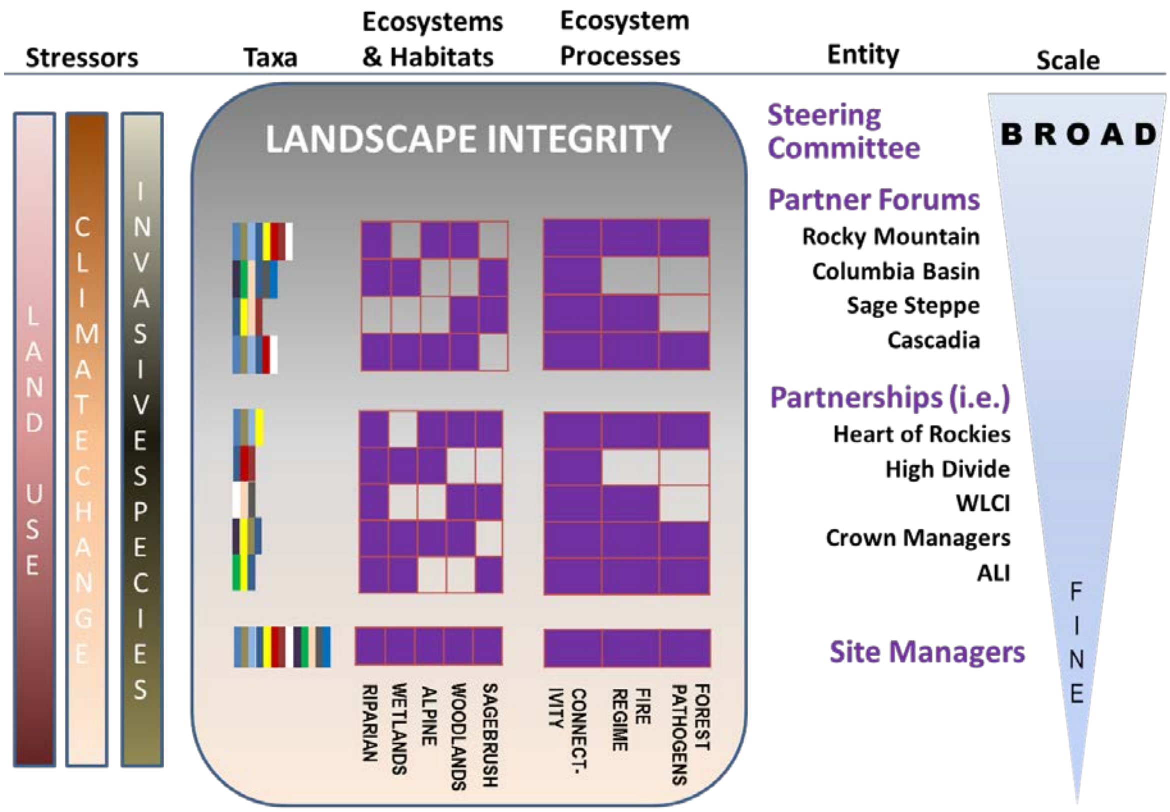

Figure ES3. Conceptual model for integrating across ecological scales from broad (Landscape Integrity) to finer (Taxa, Ecosystems and Habitats, Ecosystem Processes) extent conservation data to inform site managers and conservation partnerships on appropriate actions in the face of landscape-scale ecological stressors.

GNLCC seeks to integrate multi-scale data to increase manager's confidence that proposed actions will contribute to shared outcomes and coordinated evaluations that accurately measure trends (toward or away from) desired condition.

GNLCC Science Plan, 2015-2019

INTRODUCTION

About the Great Northern Landscape Conservation Cooperative

The Great Northern Landscape Conservation Cooperative (GNLCC) is an applied conservation science partnership that convenes science expertise and provides technical data, information and support to inform resource management and landscape conservation in the face of landscape stressors. GNLCC provides the landscape context for conservation planning and implementation towards a collective vision through an adaptive management framework (Holling 1978). We define landscape as a large area encompassing an interacting mosaic of ecosystems and human systems that is characterized by a set of common management concerns (Clement et al. 2014).

The Purpose of this GNLCC Science Plan

The purpose of the Great Northern Landscape Conservation Cooperative (GNLCC) Science Plan is to provide a framework and explain the process for identifying science priorities in the context of landscape conservation, which drives annual workplans. The GNLCC Science Plan builds on the GNLCC Strategic Conservation Framework (Conservation Framework; Chambers et al 2013). Using an adaptive management approach, the Science Plan (Plan) describes how partners to GNLCC collectively accomplish its vision for the landscape and how each individual and organization can contribute to that vision: *A landscape that sustains its diverse natural systems to support healthy populations of fish, wildlife and plants; sustains traditional land uses and cultural history; and supports robust communities* (Chambers et al. 2013).

The GNLCC Science Plan explains and instructs the GNLCC about how we intend to apply the GNLCC Strategic Conservation Framework to achieve landscape goals using an adaptive management approach by describing:

- *ecological relationships among* conservation targets, threats, and actions as they relate to overall goals and vision
- a process for setting desired condition and quantifiable objectives for conservation targets and their use as a metric for progress
- how to assess conservation actions for effectiveness towards goals
- where and how Cooperative partners contribute to and benefit from shared conservation delivery

The Conservation Framework (Chambers et al. 2013) describes a collective landscape vision, the over-arching goal of landscape integrity, four subgoals, 28 conservation targets and 3 priority landscape stressors. These commonalities are used to measure progress toward the goal and vision. The Science Plan describes how GNLCC intends to prioritize and synthesize ecological science and implement conservation practice across spatial and ecological scales – from species-specific conservation targets through quantifications of landscape integrity – to derive conservation outcomes and repeatable measures of effectiveness.

In Section 1, we use three conservation targets as proof-of-concept examples to illustrate a stepwise process for setting quantifiable objectives, evaluating and implementing conservation actions, and measuring progress toward goals. The examples describe ecological relationships and socio-economic factors influencing those targets and how they may be translated to support the stated goals. Throughout the iterative process, we highlight the science, data, and tools needed for effective planning, implementation, and monitoring of conservation actions by managers.

Section 2 addresses Landscape Integrity. Although resource managers don't generally implement conservation action at broad extents, value is gained from tracking landscape-scale change resulting from consumptive land use, invasive species spread (Beever et al. 2014), climate impacts, and more. Section 2 describes a geospatial approach to tracking landscape change that informs LCC partners on trends in processes and conditions (e.g., connectivity and ecosystem health).

Finally, Section 3 describes how these multi-scale approaches will be used to (a) track our collective progress toward stated goals and desired conditions, and (b) identify critical gaps in scientific information to guide GNLCC annual work plans and funding.

This Science Plan guides GNLCC investments to best provide landscape scale context. This enables the conservation and natural resource management community to achieve their respective missions and mandates while understanding how they affect and derive a landscape benefit from their local action..

Roles within the GNLCC Partnership

The roles of the various GNLCC partner groups are detailed below according to each step in the science process:

- The **Steering Committee** sets big-picture guidance and alignment for the GNLCC and approves science direction.
- The **Advisory Team** coordinates science needs, refines identified priorities, and leads the process of defining metrics for GNLCC success.
- **Partner Forums** consist of on-the-ground practitioners who have a major role in the GNLCC. Based on their local expertise, they identify priority conservation targets; link metrics describing conservation targets to the GNLCC landscapes; identify the extent and intensity of threats to those targets; ground-truth conceptual models; plan and deliver conservation actions; and share lessons learned.
- The **Science Community** develops and shares knowledge, expertise, and tools for practitioners; helps advance conceptual models; and provides analysis and synthesis.
- **Management Agencies and Land Owners/Resource Stakeholders:** These participants are especially important for delivery of conservation and resource management on the ground. They can ground-truth conceptual models for application to management decisions, their decisions result in management actions, and they monitor and evaluate impacts and the success of their conservation actions through adaptive management.
- The Science Plan describes a role for **inventory and monitoring specialists** that includes improved planning, implementation, and data coordination by GNLCC partner organizations and/or inter-organizational work teams.

LCCs are complex partnerships that transcend geographical, jurisdictional and institutional boundaries. LCCs require consistent engagement from stakeholders who affect large landscape conservation by employing a range of roles unique to their missions and mandates. Because each partner's capacity differs, the Science Plan provides a strategy on how these roles can best integrate across multiple resource management and jurisdictional levels (Figure 1). Key principles of the framework are:

- all partners can be engaged at some level throughout the cycle (as indicated by rings);
- the lead role changes throughout the cycle (as indicated by ring width); and
- science needs are identified throughout the cycle

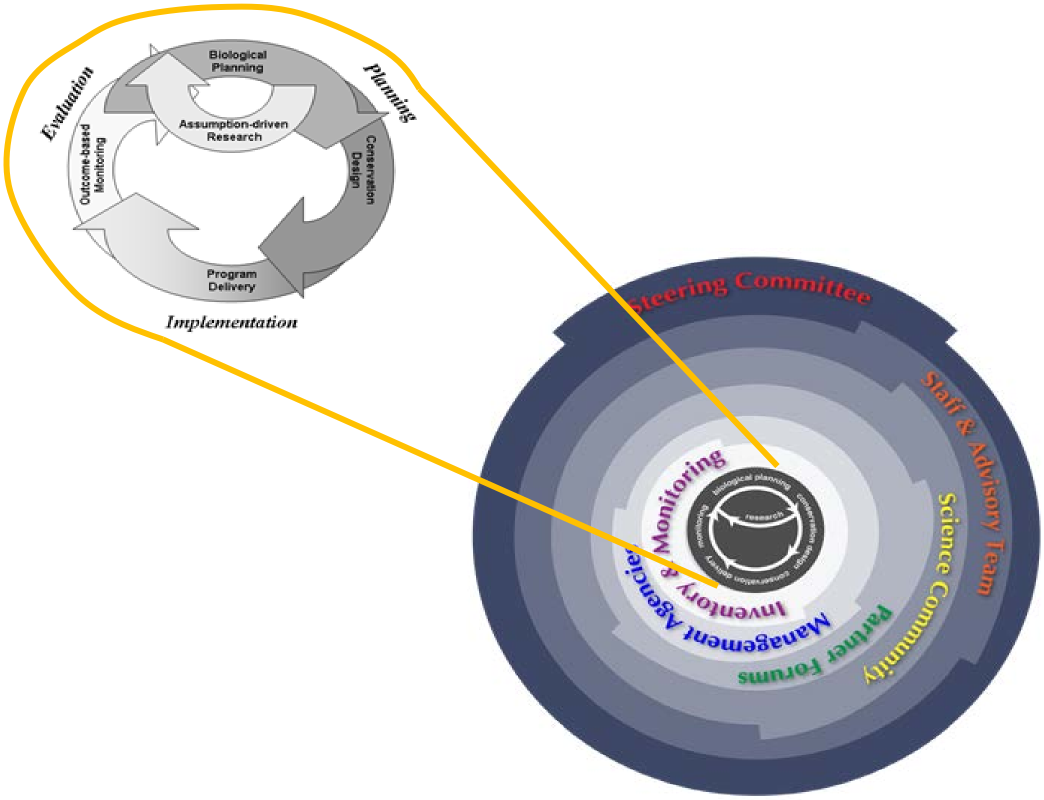

Figure 1: Linking GNLCC Partners and their contributions to adaptive management in the context of landscape conservation. The upper left circle depicts an adaptive management model (FWS 2008) describing iterative biological planning, conservation design and delivery, and monitoring informed by assumption-driven research. Sliding this model into the GNLCC partnership governance structure (lower right) helps visualize the relative timing of important contributions from each group contributing to landscape conservation in the Great Northern region.

Figure 2 represents the timing, level, and prominence of activity or engagement required by each group identified above through the adaptive management wheel. It is used in subsequent figures (i.e., Figs. 5, 6, and 9) to show shifts of role and responsibility. The timeline is relative and dependent on the specific conservation target(s). Thicker bars indicate where each group takes a leading role. This representation of functional roles will continue through this Science Plan describing the 'who' where it accompanies subsequent figures describing the 'what' of each element of the stepwise process.

Figure 2: Example of a relative 'progress bar' graphic depicting GNLCC Partners and their contributions to landscape conservation (see Fig. 1). The X-axis is a relative timeline, proceeding from right to left, that will vary in duration depending on the conservation target. See subsequent figures. Meaningful renditions of this example are paired with elements of the Stepwise Process (Section 1) in figures 5, 6, 9, 15 and 16. SC = Steering Committee; AT = Advisory Team; Sci = Science Community; PF = Partner Forums; Mgt = Management Agencies; M&E = Inventory and Monitoring specialists.

GNLCC Conservation Vision, Goals & Targets

The GNLCC partnership envisions:

> *"A landscape that sustains its diverse natural systems to support healthy and connected populations of fish, wildlife, and plants; sustains traditional land uses and cultural history; and supports robust communities."*

The GNLCC understands this vision is a stated desired future condition of ecological integrity across a landscape or Landscape Integrity (as defined herein) for the Great Northern geography. GNLCC defines this following Noss (1990): areas of high ecological integrity have un-fragmented natural landscapes, highly functioning biotic and abiotic processes, native biotic components within a natural range of variability, and few impacts from invasive species. These areas have the composition, structure, and function of less-altered landscapes (Noss 1990). The concept is explicitly encompassed in the GNLCC landscape integrity goal through four sub-goals (Chambers et al. 2013):

1. Maintain large, intact landscapes of naturally functioning terrestrial and aquatic community assemblages.
2. Conserve a permeable landscape with connectivity across aquatic and terrestrial ecosystems, including species movement, genetic connectivity, migration, dispersal, life history, and biophysical processes (recognizing this is species dependent, and recognizing in some circumstances connectivity is not desired).
3. Maintain hydrologic regimes that support native or desirable aquatic plant and animal communities in still and moving water systems.
4. Promote landscape-scale disturbance regimes that operate within a future range of variability and sustain ecological integrity.

The GNLCC addresses 31[1] taxa, habitats and ecosystems, and ecosystem processes as priority Conservation Targets (Table 1; Chambers et al. 2013). Targets were identified by a rigorous review of regional, national and international planning documents and vetted through the Steering Committee and Advisory Team.

Taxa	Ecosystems/Habitats	Ecosystem Processes
whitebark pine	riparian corridors	aquatic connectivity
salmon	riverine	connectivity
steelhead trout	wetlands	natural fire regimes
bull trout	alpine lakes	insects and forest pathogens
cutthroat trout	watershed uplands	
trumpeter swan	pothole lakes	
greater sage-grouse	alpine	
burrowing owl	sub-alpine	
white-headed woodpecker	woodland	
Lewis' woodpecker	dry fire adapted forests	
pygmy rabbit	sage shrub/grasslands	
pronghorn antelope		
mule deer		
grizzly bear		
wolverine		
Canada lynx		

Table 1: GNLCC Conservation Targets identified in GNLCC Strategic Conservation Framework (Chambers et al. 2013) and amended by vote at the Spring 2014 Steering Committee meeting.

[1] Three targets were added by Steering Committee, spring 2014.

Conservation Paradigms

Conservation Vocabulary

To promote consistency in process and outcome among the diverse LCC partnership, this Plan identifies with a standard conservation lexicon (Salafsky et al. 2008) which serves to structure and synthesize partner-driven conservation. The following definitions will be referenced throughout the Plan:

GNLCC Conservation Framework & Science Plan	Definition	Open Standards for the Practice of Conservation (Salafsky et al. 2008)
Goal	Any set of actions to achieve defined conservation goals and objectives; described as a chain linking targets, direct threats, contributing factors, and conservation actions	Conservation Project
Conservation Target	Species, community, ecosystem, or process	Focal Conservation Target
Stressor/Impact	Ultimate factors (usually social, economic, political, cultural) that enable direct threat; may be negative effect (commodity demand) or opportunity (planning goal)	Contributing Factor
Conservation Action	Intervention designed to reach an objective or goal; can be applied to contributing factor, direct threat, or to conservation target	Conservation Action
	Attribute of a conservation target's ecology; a degraded condition or "symptom"	Stress
Threat	The proximate human activity causing degradation of target. Threat may be historical, current, or likely to occur in future	Direct Threat

Table 2: Cross reference of conservation terms used in the GNLCC Strategic Conservation Framework (Chambers et al. 2013) and terms defined in Salafsky et al. (2008).

Adaptive Management

The GNLCC Science Plan draws upon the concepts of Strategic Habitat Conservation (SHC; USFWS 2008, Figure 3) a species population based adaptive management framework used by the US Fish and Wildlife Service. The SHC is used to structure our Conservation Target approach. Building on SHC, we outline an iterative, adaptive process to achieve a resource outcome. That outcome can be used as a subset of conservation targets to measure progress toward a stated desired condition or goal, in this case, the goal of maintaining or enhancing landscape integrity as achieved through the four subgoals.

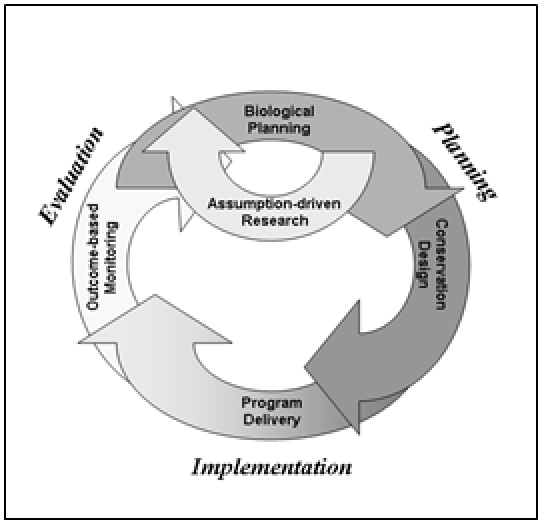

Figure 3. Strategic Habitat Conservation model (USFWS 2008).

SHC guidance provides basic questions that must be addressed in a science-based strategy. We modify those questions to guide the Science Plan as follows:

1. What is the trend in long-term average populations (or conservation target) and what direct threats and contributing factors are driving those trends? (Fig. 5, Steps 2b, 5)
2. What do we want to achieve (i.e., the desired condition) and how can we achieve it? (Fig. 5, Steps 4-7)
   - 2.1. What are our collective objectives and desired conditions for Conservation Target? (Fig. 5, Step 4)
   - 2.2. What factors are acutely limiting our ability to achieve the desired condition? (Fig. 5, Step 5)
   - 2.3. What conservation actions are available to overcome these limiting factors? (Fig. 5, Steps 2b, 6)
3. Where should we apply these conservation actions to effect the greatest change at the lowest possible total monetary and non-monetary costs to management agencies and societies? (Fig. 5, Steps 6, 9-10b)
4. How much of a particular type of conservation actions will be necessary to reach our stated desired condition?(Fig. 5, Steps 9-11)
5. What are the key uncertainties in the answers to questions 1-4 and what assumptions were made in developing the strategy? These will guide our research and monitoring activities (Fig. 5, Steps 7-8b).

The Science Plan does not directly address the Implementation element of SHC (Fig. 3), Program Delivery. Rather we focus primarily on the Planning and Research elements and, to a lesser degree, the Evaluation element. Subsequent documents will address GNLCC's role in those aspects of adaptive management and follow on implementation of this Plan.

Landscape Integrity

We define landscape integrity as ecological integrity at a landscape extent as interpreted by the ability of ecological systems to support and maintain communities of organisms that exhibit composition, structure, and function (after Noss 1990) comparable to those of natural habitats within an area (after Parrish et al. 2003). Herein, we use a Landscape Integrity Index (LII, described more completely in section 2) as the product of threat intensity and threat geographic footprint (Theobold 2013). Landscapes have high integrity where relatively intact natural core areas have low levels of human modification; there are linkages connecting those cores; and natural disturbance processes (e.g., wildland fire) support conservation targets. Because we are integrating local action with regional goals, we are using both a measure of conservation target population and status and a broad measure of desired condition related to human footprint to design and evaluate our collective progress towards meeting stated goals (See Section 2). The indices (a) measure impact and (b) measure conservation success. We will also link specific management strategies to conservation targets and threats to give conservation practitioners a way to assess how their local actions affect GNLCC goals. In Section 1, we describe this process for Conservation Targets (taxa, ecosystems, habitats, and ecosystem processes) and describe how they collectively inform goal advancement. In Section 2, we describe landscape integrity and how the LII will be a complimentary measure from a regional scale.

SECTION 1: Conservation Targets

The Science Plan describes a process that guides stakeholders toward informed, collaborative action on specific, conservation targets that effect landscape conservation (see Strategic Conservation Framework). To start, we explain a strategy and process (Fig. 4) that employs new conservation paradigms, (e.g., Strategic Habitat Conservation, vulnerability assessments, conservation triage) in a logical progression that uses shared data and knowledge to target priority conservation action that is necessary to reach GNLCC goals, while acknowledging uncertainty.

The process is intended as a heuristic approach, rather than a recipe, to guide partners toward achieving informed, effective action for each target that collectively contribute to the goal of landscape integrity. The process uses existing efforts and, where needed, new information to achieve quantitative outcomes as metrics of progress toward shared landscape outcomes (see Section 2).

To date, GNLCC partners have made varying levels of progress working on each of the focal targets. Thus, some examples include more information than others as is typical across the suite of conservation targets. This disparity is one of the challenges of bringing these together under a single, large-landscape framework. It also allows us to use a few examples to evaluate progress while using others to consider how we approach targets through hypothetical application. In this Science Plan, we use grizzly bear to demonstrate the process as a proof-of-concept example.

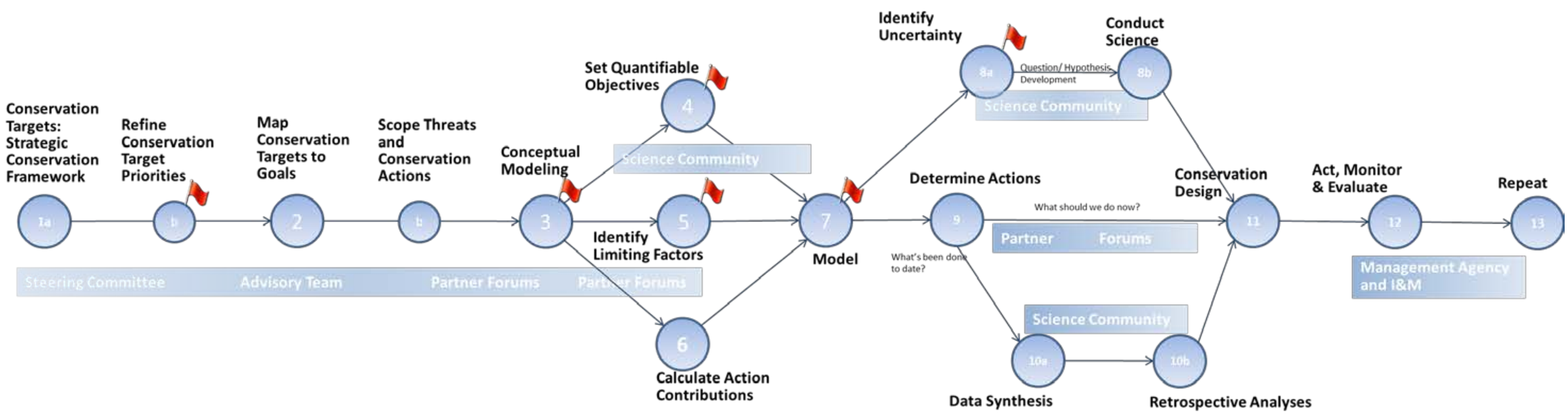

Figure 4: Process for directly addressing specific priority GNLCC Conservation Targets. This process includes assessing science needs, developing applications, and estimating conservation action effectiveness for each target while delivering data, models, and conservation planning to support attainment of collective landscape integrity objectives. Each step is addressed in detail below. The red flags represent steps where science needs are identified. In practice the specific needs will vary with the target being addressed.

Step 1a: Strategic Conservation Framework

The GNLCC Strategic Conservation Framework (Chambers et al. 2013) describes a conceptual example of the GNLCC's Conservation Goals as linked to a few priority Conservation Targets (see GNLCC Conservation Vision, Goals & Targets, above and (http://greatnorthernlcc.org/sites/default/files/documents/gnlcc_framework_final_small.pdf). Concepts in the Strategic Conservation Framework are based on an analysis of commonality of GNLCC conservation partners; the process for review and approval of the vision, goals, conservation targets and concepts are described in GNLCC meeting notes and institutional history (http://greatnorthernlcc.org/business). The Strategic Conservation Framework is intended to be adaptive and includes scheduled revision cycles and opportunity for interim adjustments including incorporation of emerging concerns by partners and Partner Forums (Step 1b).

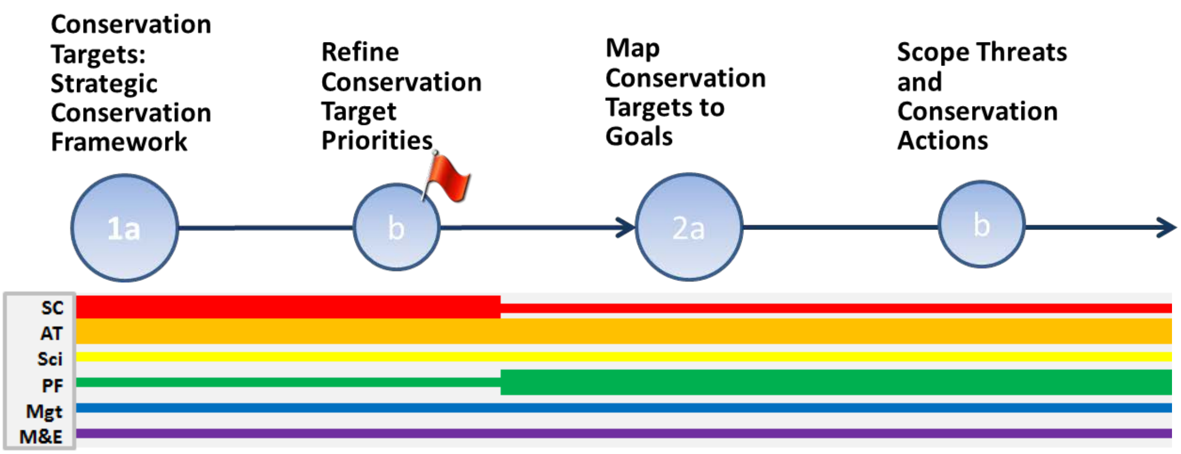

Figure 5. Steps 1 - 2 of GNLCC Science Plan stepwise process. SC = Steering Committee; AT = Advisory Team; Sci = Science Community; PF = Partner Forums; Mgt = Management Agencies; M&E = Inventory and Monitoring specialists. The X-axis is a relative timeline that will vary in duration depending on the focal Target. The red flags represent steps where science needs are identified. In practice the specific needs will vary with the target being addressed.

Step 1b: Refine Conservation Target Priorities

A more quantitative approach to linking Targets to priorities will lead to two immediate outcomes: 1) recognition of specific science needs to inform this early planning process and, 2) identification of important conservation targets that will help inform conservation goal achievement but are currently missing or improperly prioritized. This represents a first assessment in the iterative process to refine inputs and evaluate outputs. This is ideally handled by Partner Forums. Within the 5 years of this Plan four states will deliver revised State Wildlife Action Plans (SWAP; Wyoming revised its plan in 2013) and the USFWS will implement a surrogate species approach. GNLCC will recognize and integrate emerging prioritization approaches (i.e., Brock and Atkins 2013); thus periodic review is an integral, iterative step.

Step 2a: Map Conservation Targets to Goals

Because the ultimate objective is to measure the GNLCC partnership's progress toward meeting the GNLCC goals, we need to identify appropriate ways to measure this progress Suitable metrics for conservation targets must be logically linked to indices of landscape integrity and evaluated to estimate effectiveness. This task will be led by the Advisory Team but requires substantial local knowledge and discipline-specific expertise from Partner Forums. Partner Forum members – the recognized local experts with specific knowledge about which metrics best contribute and translate to landscape integrity – must lead the dialogue and prioritization process with regional planners and executives who set program priorities and align funding. Engaging Partner Forums builds capacity, expands the Cooperative, and guides responsiveness to on-the-ground questions and needs. Partners and partnerships (formalized relationships of partners with a stated purpose) address targets from unique perspective; Step 2b moves toward resolving perspective and aligning programs. Outcomes from this step are important inputs for steps 5, 7, and 9.

The first sub-step in this process is drafting *qualitative* links among Conservation Targets and Goals into a conceptual ecological model (Table 3 is an example). In practice the process is iterative and adaptive to ongoing planning and process.

Conservation Goal	**Sage Steppe Ecotype & Forum**	**Rocky Mountain Ecotype & Forum**	**Columbia Basin Ecotype & Forum**	**Cascadia Ecotype & Forum**
Large Intact Blocks	Greater-sage grouse Pygmy rabbit Sage Shrub/grasslands	Grizzly bear Wolverine Canada lynx	Salmon Rivers Sage shrub/grasslands	Wolverine Canada lynx Salmon Woodland Sub alpine
Connectivity / Permeability	Pronghorn Mule deer Sage shrub/grasslands Riparian Connectivity	Whitebark pine Bull trout Cutthroat trout Trumpeter swan Lewis' woodpecker Mule Deer Grizzly bear Wolverine Canada lynx Riparian Alpine	Salmon Steelhead Lewis' woodpecker White-headed woodpecker Mule deer Riparian River Dry, fire adapted forest Aquatic connectivity Connectivity	Whitebark pine Salmon Steelhead White-headed woodpecker Mule deer Riparian Alpine
Aquatic Integrity	Wetlands Rivers Pothole Lakes	Cutthroat Trout Bull Trout Wetlands Alpine Lakes	Salmon Steelhead Rivers Wetlands	Salmon Steelhead Rivers Wetlands
Disturbance within Future Range of Variability	Greater sage-grouse Burrowing Owl Natural fire regime Insects and forest pathogens	Whitebark pine Lewis' woodpecker Woodland Sub alpine Fire Regime Natural fire regime Insects and forest pathogens	White-headed woodpecker Lewis' woodpecker Wetlands Watershed Uplands Dry, fire adapted forest Natural fire regime	Whitebark pine White-headed woodpecker Dry, fire adapted forest Woodland Sub alpine Natural fire regime

			Insects and forest pathogens	Insects and forest pathogens

Table 3. A first approximation linking Conservation Targets to Goals. The Science Plan calls for subject matter expertise to augment this matrix. Ecosystem process targets crosscut all ecotypes.

Step 2b: Scope Conservation Threats and Actions

At Step 2b, we shift to specific Targets. Scoping conservation threats and conservation actions is a critical step as described by the Open Standards for the Practice of Conservation approach (http://www.conservationmeasures.org/; Salafsky et al. 2008). Because our traditional conservation practices have been multi-disciplinary, respective disciplines have developed their own terminology. A more integrative, inter-disciplinary approach calls for a standard lexicon (Salafsky et al. 2008) as a common language. The lexicon attempts to define the 'universe' of threats and conservation actions. Step 2b of the Science Plan standardizes each conservation target to the lexicon as a means to consistently feed a Conceptual Model (Step 3) for each Conservation Target. We rely on the expertise exemplified by the Partner Forums to specify threats and actions in a structured discussion framed by the Salafsky et al. (2008) lexicon.

Adopting the Salafsky et al. (2008) lexicon causes no loss of resolution from the Strategic Conservation Framework. For example, the Framework identifies 3 *landscape stressors*: Climate Change, Invasive Species, and Land Use Change (Chambers et al. 2013, page 7). These impact-scales are termed *contributing factors* (defined as: the ultimate factors, usually social, economic, political, institutional, or cultural, that enable or otherwise add to the occurrence or persistence of proximate direct threats) by Salafsky et al. (2008). To a degree, differences in terminology are semantic: GNLCC Steering Committee members agree these are the primary, high-level concerns in the geography. Discretely identifying them and other conservation threats and response actions serves to ensure the partnership is thinking and speaking in common terms.

Salafsky et al. (2008) describes a nested classification with 3 levels of threat. The highest (Table 4, left column) describes general human activities at a broad scale; the second level (the body of Table 4) provides activities that may impact a specific Conservation Target. The third level is an analysis of threats which link specific threats or explain stress conditions that impact the Conservation Targets. For example, Table 4 suggests (4) Transportation and Service Corridors – (4a) Roads and Railroads is a threat for grizzly bear through land use change. This could include collisions, increased human-bear interactions, and/or behavioral avoidance. Management responses to specific, high priority threats may differ. Therefore it becomes important to be specific where feasible to promote specific appropriate conservation action or response.

Goal 1: Maintain Large Intact Blocks

		Conservation Targets	
Level 1 Threats	Lever 2 Threats	Grizzly Bear	Connectivity
1. Residential and Commercial Development	1.1 Housing and Urban Areas	X	X
	1.2 Commercial and Industrial Areas	X	X

	1.3 Tourism and Recreation Areas		X
2. Agriculture and aquiculture	2.1 Annual and perennial nontimber crops		X
	2.3 Livestock farming and ranching	X	X
3. Energy production and mining	3.1 Oil and gas drilling		X
	3.3 Renewable energy		X
4. Transportation and service corridors	4.1 Roads and railroads	X	X
	4.2 Utility and service lines		X
5. Biological resource use	5.1 Hunting and Collecting Terrestrial Mammals		
	5.3 Logging and wood harvesting	X	X
	5.4 Fishing and harvesting aquatic resources	X	
6. Human intrusions and disturbance	6.1 Recreational activities	X	X
7. Natural system modifications	7.1 Fire and fire suppression		X
	7.2 Dams and water management/use	X	X
	7.3 Other ecosystem modifications	X	X
8. Invasive and other problematic species and genes	8.1 Invasive non-native/alien species	X	X
	8.2 Problematic native species	X	X
9. Pollution	9.1 Household sewage and urban waste water		X
	9.2 Industrial and military effluents	X	X
	9.3 Agricultural and forestry effluents	X	X
11. Climate change and severe weather	11.1 Habitat shifting and alteration		X
	11.2 Droughts	X	X
	11.3 Temperature extremes		X
	11.4 Storms and flooding	X	X

Table 4. Hypothetical example for identifying Conservation Threats [as classified by Salafsky et al. (2008)] that impact grizzly bear and bear habitat in terms of maintaining large blocks of intact habitat. First and second level threats (Salafsky et al. 2008) listed in columns 1 & 2. GNLCC conservation targets categorized by contributing factors (Stressors) listed in columns 3-7). 'X' indicates where a threat intersects a target/stressor. Only threats relevant to grizzly bear listed here.

Similarly, we identify conservation actions (Table 5). Again the Level 1 (left column) and Level 2 (Table 5, column 2) Actions are (probably) easily identified by GNLCC staff and the AT. The Level 3 actions address Conservation Targets within and beyond the Great Northern. The grizzly bear example (Table 5) is well documented. The third level following Action (3) Species Management – (3.2) Species Recovery entailed drafting a Recovery Plan (USFWS 2013a). Some GNLCC conservation targets have not reached this level of resolution.

Similar to Threats, which we prioritize through input from Partner Forums, a 'Managers Toolbox' of ongoing actions and innovative approaches can be tested or presented conceptually. Describing specific actions and their effect will provide a basis for the management elements.

Goal 1: Maintain Large Intact Blocks

		Conservation Targets	
Level 1 Actions	Level 2 Actions	Grizzly Bear	Connectivity
1. Land/water protection	1.1 Site/area protection	X	X
	1.2 Resource and habitat protection	X	X
2. Land/water management	2.1 Site/area management	X	X
	2.2 Invasive/problem species control		X
	2.3 Habitat and natural process restoration	X	X
3. Species management	3.1 Species management	X	
	3.2 Species recovery	X	
	3.3 Species reintroduction	X	X
4. Education and awareness	4.1 Formal education	X	X
	4.2 Training	X	X
5. Law and policy	5.1 Legislation	X	X
	5.2 Policies and regulations	X	X
	5.3 Private sector standards and codes	X	X
	5.4 Compliance and enforcement	X	X
6. Livelihood, economic and other incentives	6.1 Linked enterprises and livelihood alternatives		X
	6.3 Market forces	X	X
	6.4 Conservation payments	X	X
7. External capacity building	7.1 Institutional and civil society development	X	X
	7.2 Alliance and partnership development	X	X
	7.3 Conservation finance	X	X

Table 5. Hypothetical example for identifying Conservation Actions [as classified by Salafsky et al. (2008)] for grizzly bear and bear habitat specifically for the Goal of maintaining large blocks of intact habitat. In practice, actions need to be directly linked to stressors/threats from Table 4 by experts best facilitated through a Partner Forum.

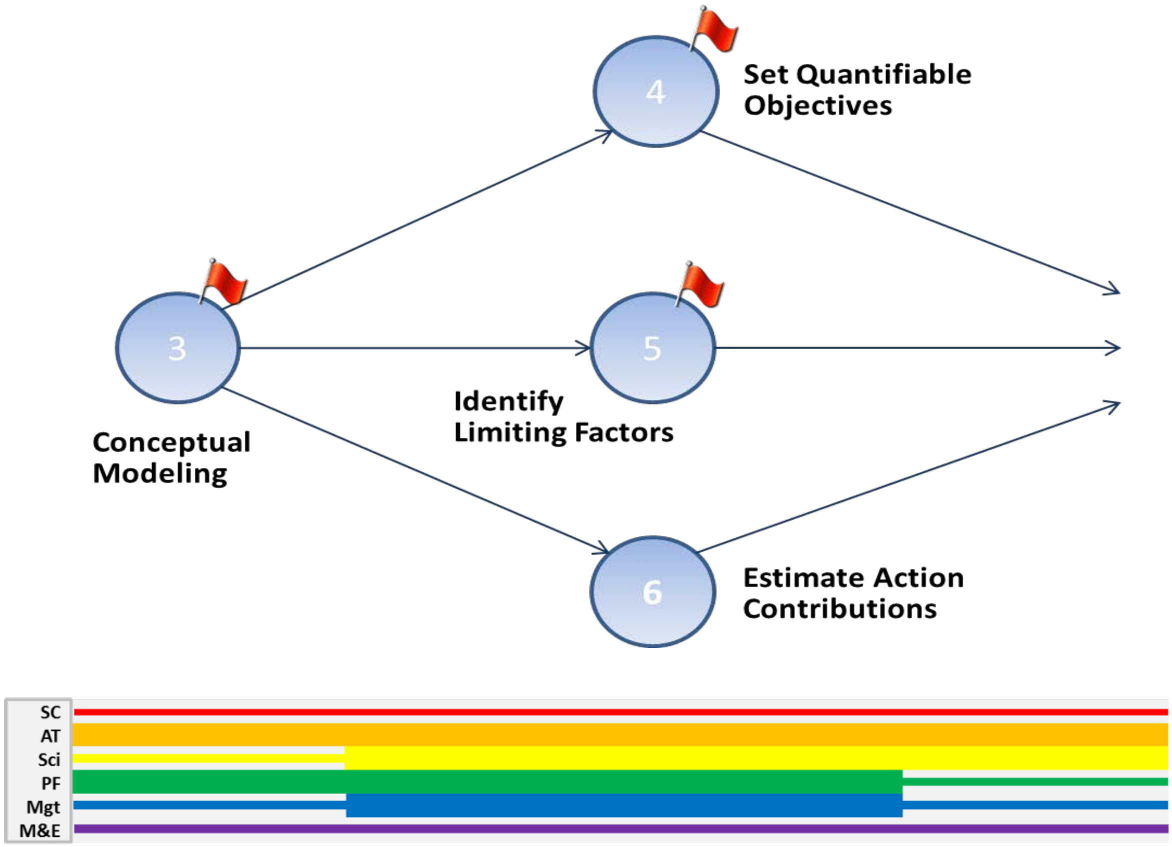

Figure 6. Steps 3 - 6 of GNLCC Science Plan stepwise process. SC = Steering Committee; AT = Advisory Team; Sci = Science Community; PF = Partner Forums; Mgt = Management Agencies; M&E = Inventory and Monitoring specialists. The X-axis is a relative timeline that will vary in duration depending on the conservation target. The red flags represent steps where science needs are identified. In practice the specific needs will vary with the target being addressed.

Step 3: Conceptual Models

After achieving consensus from partners with respect to concepts, terms, threats, and actions, it is important to begin adaptive management concepts to conservation delivery or management actions. The next step is to develop common understanding of the ecological relationships for each conservation target. We do this by building conceptual models (e.g., IAFWA 2011) that may start off fairly simple (Fig. 7) but can become complex (Fig. 8). At a minimum, a basic conceptual model is needed for each Conservation Target. Conceptual models provide the scientific/ecological background connecting priority Conservation Targets (Steps 2a and 2b), inform subsequent steps of Setting Quantifiable Objectives (Step 4, Fig. 6), Identifying Limiting Factors (Step 5), and Calculating Action Contributions (Step 6) for each Target. A conceptual model also provides the synthetic benefit of understanding how and when Threats, Limiting Factors and Conservation Actions align among two or more Targets which further informs Step 6,the relative contribution of Conservation Actions (see below). A conceptual model can also be a useful tool during collaborative planning, as it provides transparency among participants about assumptions for system and key drivers. .Conceptual models for some targets (Fig. 8) are well-developed and should be adopted and incorporated appropriately. Needed models will be best developed by species and ecosystem experts participating in Partner Forums.

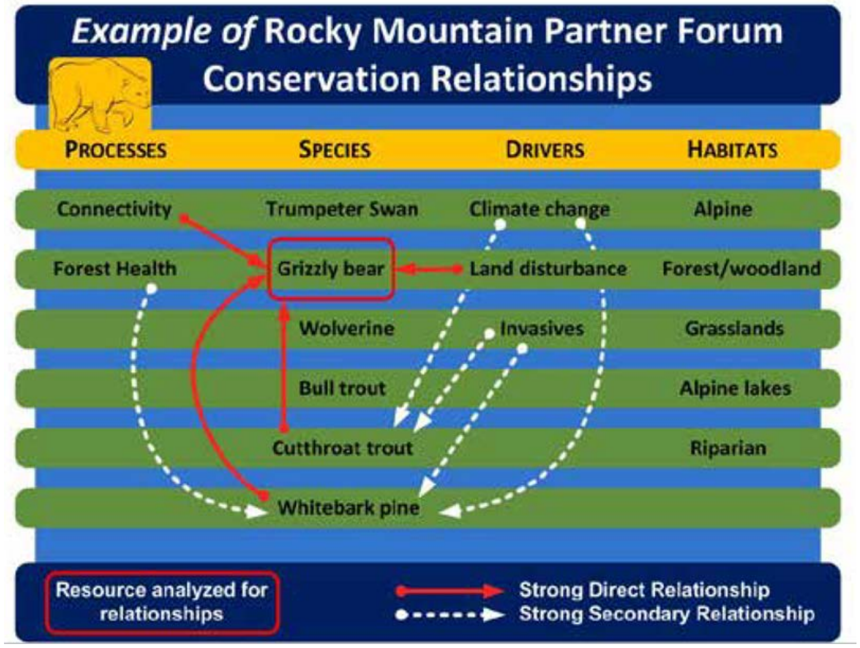

Figure 7. Example conceptual model of conservation relationships for grizzly bear (Chambers et al. 2013). This example incorporates the suite of priority conservation targets identified by the GNLCC. It shows, through simple relationship arrows, an example of the complexity of the inter-relationships among scaled conservation targets.

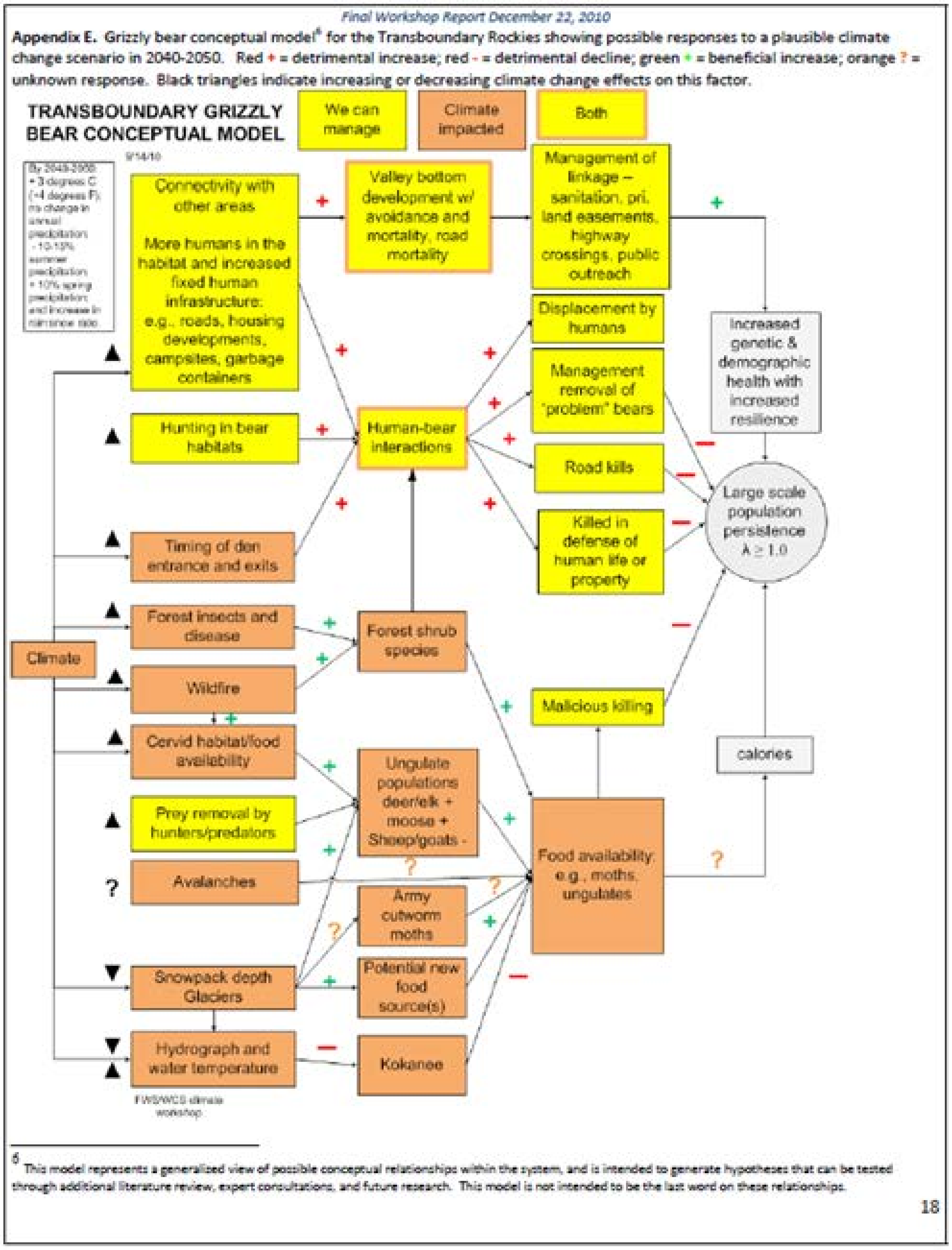

Figure 8. Transboundary Grizzly bear conceptual model from Servheen and Cross (2010). The level of detail here and in supporting data and information in Servheen and Cross (2010) are an example of the level of detail that can support Steps 4-6 of the Science Plan. Terms and concepts used here must be evaluated against the standard lexicon to enable synthesis with parallel models.

Step 4: Set Quantifiable Objectives

At this step, there is a transition from a conceptual to a quantitative approach by setting quantifiable objectives and devising explicit conservation strategies for Conservation Targets. Many social, political, economic, and biological factors influence how objectives are set; therefore, the GNLCC Steering Committee is critical to promote agreed-upon objectives. Our primary focus here is the biological factors.

Population (taxa) objectives are more useful if they comprise desired abundance (i.e., population size) and a performance indicator (i.e., recruitment). Abundance objectives enable estimation of how much habitat to maintain. Performance measures (typically a vital rate such as adult mortality or fecundity) describe the desired effect on the population (FWS 2008). Where impractical, we may elect to use an indicator (i.e., patch size, temporal trend, etc.). Performance indicator objectives often relate back to response of habitat or population management strategies. Thus, they represent assumptions that can help us develop Steps 7a-c, (Figure 14).

Grizzly Bear Example

Two of the four extant populations of grizzly bear in the US portion of the GNLCC have established, agreed upon quantifiable objectives established for recovery planning and post-delisting management (USFWS 2013a, 2013b). Multiple criteria are identified to provide sufficient information upon which to base management decisions. In general, the conservation strategies set both demographic goals, which may be difficult to quantify, and demographic standards, which are objective and measurable criteria of population status and health (USFWS 2013b). The goal of the agencies implementing grizzly bear conservation strategies is to maintain genetically diverse bear populations (USFWS 2013a) with a focus on maintaining minimum thresholds (population size, mortality rates) in recognition of social and political tolerance and management of human interaction.

Ecosystem	Demographic Goals		Demographic Standards	
	# Individuals	Females with cubs	Management Units Occupied	Mortality Limits
Northern Continental Divide	800		21 (of 23)	Females: ≤ 0.10 Males: ≤ 0.20 [per year?]
Greater Yellowstone	500	48	16 (of 18)	Calculated [annually?]

Table 6. Population-based objectives for two grizzly bear populations (extracted from USFWS 2013a, USFWS 2013b).

Habitat and Ecosystem-based targets

The conservation literature has extensive treatment on developing population species-based objectives but less emphasis on objective setting for non-species conservation targets. Where a species conservation target has been quantified for biological planning, habitat becomes the subject of the conservation design phase. Objectives can be set for habitats designed to relate to species objectives. This same relationship can be true for ecosystem process. Through conceptual models, each important conservation target is seen to inter-relate and can thereby be quantified in that context. For example, cutthroat trout to stream habitat to aquatic connectivity. Conservation delivery and monitoring follow.

Step 5: Identify Limiting Factors

Factors that limit populations, habitats, and ecosystem process must be well understood and agreed upon for GNLCC to successfully progress toward conservation goals. Limiting factors are best described for species of concern identified in National, State, and/or Provincial Recovery. Limiting factors tend to be lacking for species that have not been specifically targets by of such planning and for habitats, ecosystems and ecosystem processes. Because we lack quantifiable objectives for many targets, critical limits to achieving those objectives are also lacking. Further, in most instances we have not defined potential future limiting factors with any rigor.

Using grizzly bear as the example Conservation Target, GNLCC staff and the AT translate the conservation threats developed for Conceptual Models and lead the Partner Forums through a process to elaborate on the threats. Through identification of the threats (identified in Step 2b), those factors most limiting to progress toward target objectives (i.e., population abundance and vital rate) become clear. This serves to parameterize inputs for subsequent modeling (Step 7) and determine sources of uncertainty (Step 7a, Identify Uncertainties). This begins the structured approach to Step 6 as we consider ongoing management actions to evaluate objective attainment. An important institutional element is continuing Partner Forums engagement. In concept, this process opens the door to participation and helps participants recognize their contribution beyond institutional and jurisdictional boundaries.

Step 6: Estimate Action Contributions

Step 6 invokes conservation triage described by Botrill et al. (2008) as a way to estimate the relative costs and benefits of conservation actions identified in Step 2b and refined by setting objectives (Step 4) and identifying limiting factors (Step 5). Botrill et al. (2008) presents a simple, scalable formula for comparing conservation actions (defined here as *Relative Efficiency* of management actions) which we modify as:

$$\textbf{Relative Efficiency} = \frac{\text{p[success] * value * benefit}}{\text{cost}}$$

where:

P [success] = probability of success
Value = distinctiveness of the conservation target
Benefit = net increase toward quantifiable objective, and
Cost = of the action in dollars

Much of our conservation action across the landscape is initiated with minimal understanding of the relative value of each action's contribution to our shared objective. Part of this poor understanding is our lack of shared, quantified objectives. Thus, Steps 4-6 (setting objectives, identifying limiting factors, and estimating the effect of conservation action) are iterative with subsequent modeling exercises. It is important to acknowledge that the process for this step is likely to be more qualitative than quantitative, at least initially. Estimating the relative efficiencies of our collective current conservation actions is the final step of 'what we know'. This conservation triage approach sets the stage for 'what do we want to know' (i.e., Step 7, Quantitative Modeling) and initiates and informs the 'what should we do' question (Steps 8 – 9) by attempting to quantify how current actions are affecting targets. Another critical aspect of this step is that conservation triage incorporates societal, ecological, and economic value. This means including non-traditional sources and experts to understand how these factors are expressed and quantified. It calls on the full range of Management Agency and Science Community so that relative efficiency calculations are as realistic as possible. It also includes a predictive element of estimating how efficiently a given action, or suite of actions, will move us toward our objectives.

The probability of success, Pr(success), is the probability that a given conservation action will have an intended effect. This may be estimated or calculated in a number of ways. For example, calculating the probability of restoration success based on reseeding techniques (Knudson et al. 2014). Value is a relative score that accounts for the uniqueness of the conservation target. Botrill et al. (2008) considered a species evolutionary distinctiveness. For GNLCC, a measure of the targets ecological distinctiveness (i.e., wolverine is the only high alpine associated species target) may be more appropriate. The benefit function estimates the amount gained from that action in progress toward the stated goal (Botrill et al. 2008), and therefore depends on goals set and an actions' relationship to that goal. Step 6 proposes a novel approach which will require a series of applied trials to perfect its use.

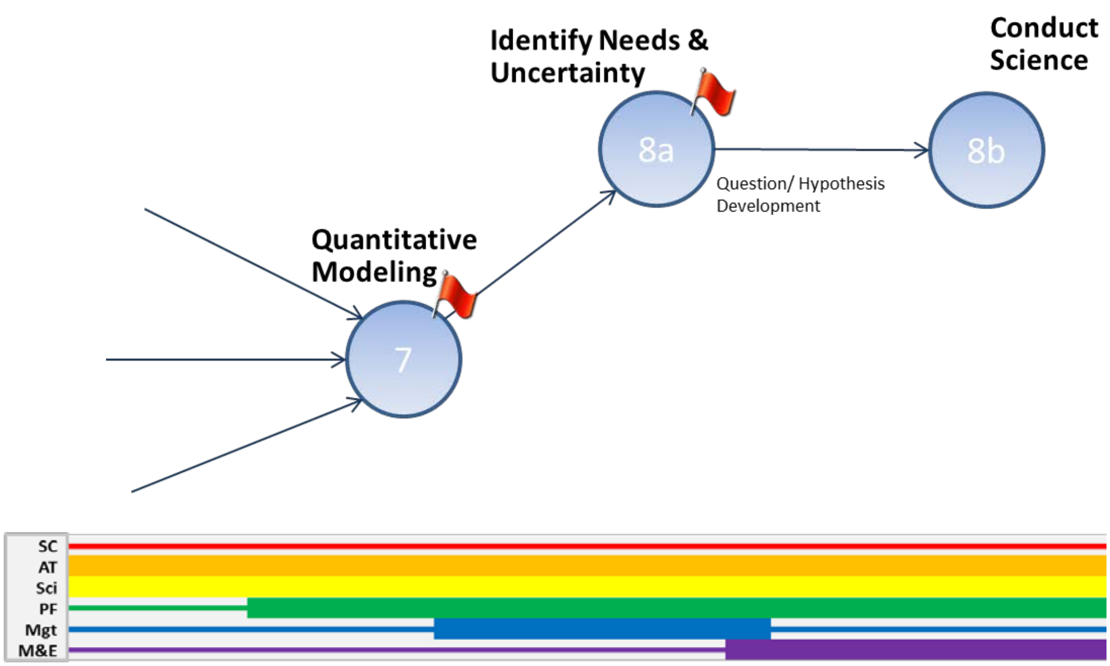

Figure 9. Steps 7 - 8 of GNLCC Science Plan stepwise process. SC = Steering Committee; AT = Advisory Team; Sci = Science Community; PF = Partner Forums; Mgt = Management Agencies; M&E = Inventory and Monitoring specialists. The X-axis is a relative timeline that will vary in duration depending on the focal Target. The red flags represent steps where science needs are identified. In practice the specific needs will vary with the target being addressed.

Step 7: Quantitative Modeling

Elements are now in place to advance conservation in a defensible, transparent, analytical process. We can now attempt to develop predictive models as a means to understand and quantify uncertainty (for Step 8a) and prioritize and evaluate management actions in terms of their relative benefit to achieving objectives (Step 9). Step 7 directly engages the GNLCC Science Community, evoking a broad range of analytical capabilities and shared capacity in response to identified needs. Model predictions might stop at concluding an interim condition (i.e., min canopy cover or % edge for a single target) that inform that next step of designing a management strategy or may more broadly encompass multiple stressors and targets. The obvious overarching question is: how can we achieve objectives through cost-effective conservation actions (e.g., Step 6)?

Models are a means of organizing science to aid in understanding:

- the relationship between populations (Step 4) and limiting factors (Step 5)
- how a system functions by expressing real relationships in simplified terms
- the relationship between independent and dependent variables by providing a structure for analytical manipulations (stressor v. habitat or species)

Modeling seeks to project future condition (population level, vital rate, extent or magnitude of disturbance, etc.) in response to changing land use patterns, climate, invasive species, or other contributing factors (stressors). The step calls upon specialists in the Science Community (i.e., Climate Science Centers, agency and NGO research divisions, academia) to provide data, expertise, and novel approaches to inform management action under a range of future conditions.

As a general guide, application of models to spatial data should target specific management treatments (Step 6) that can remediate limiting factor(s). Model predictions should be expressed in the same terms as quantitative objectives to (1) estimate the amount of management necessary to attain those objectives; and (2) facilitate estimates of project, program, or agency accomplishments and progress toward achieving those objectives. The process of explicitly stating a model enables critical evaluation of uncertainties and assumptions, determines confidence in the predictions (leading to Step 9), and targets information needs (leading to Step 8a).

Quality data and data management are hallmarks of useful model outputs. GNLCC designed the highly interoperable Landscape Conservation Management and Analysis Portal (LC MAP, Appendix 1) to facilitate data discovery, sharing and documentation. In addition to raw data, LC MAP delivers access to a vast array of data analysis and modeling tools and documentation and hosts the forum to facilitate collaborative, partner-driven science.

Step 8a: Identifying Needs and Uncertainty

One outcome of the stepwise process (modeling exercise and prior steps) is a developing picture of key information gaps (identified by red flags) and uncertainties (outcomes of modeling). These outcomes encompass a large proportion of GNLCC science needs (but see steps 10a-b) and serve as primary guidance for annual workplans.

Steps 7, 8a, and 8b represent another potential iteration or feedback loop, because objectives and outcomes of these steps are acutely linked if not inter-related. Modeling outcomes identify uncertainty (reducible, irreducible, etc) and generate additional research questions, and newly collected field data augments analysis and modeling. Science needs prioritization necessitates an understanding of existing and ongoing science.

Step 8a prioritizes which of those science needs (for example, Table 7) are most critical and defines how to most efficiently acquire the information (see Section 3).

Process Step	Need
1b. Refine Conservation Target Priorities	Re-assess priorities based on partner input & programs i.e., Surrogate Species, SWAP revisions, etc.
3. Conceptual Modeling	Conceptual models describing ecological roles, threats and action opportunities
4. Set Quantifiable Objectives	Standards and strategies for setting quantifiable objectives across range of targets
5. Identify Limiting Factors	Better (more quantitative & analytical) understanding of the factors limiting our objective achievement
7 Quantitative Modeling	Reliable models for many targets and synthetic models informing on multiple targets

Table 7. Example summary of science needs expressed through the stepwise process.

Step 8b: Conduct Science

One result of Step 8a is a prioritized list of science needs as identified by multiple, parallel conservation planning and science efforts. The GNLCC Science Community is engaged through the solicitation process that accompanies an annual workplan. The Science Community is multi-disciplinary, cross-organization (federal, provincial and state agency researchers, university and NGO scientists), and open. Science is proposed and conducted through a thorough peer-review process and with close collaboration with resource managers. Communication is facilitated through the Partner Forums, Steering Committee and Advisory Team.

Step 8b must include effective data management, processing, archive, delivery and dissemination of science products. The GNLCC Data Standard (http://greatnorthernlcc.org/sites/default/files/documents/gnlcc_datamgt_sharing_policy.pdf), LC MAP data portal (http://greatnorthernlcc.org/lcmap), and Communication Plan (http://greatnorthernlcc.org/document/communications-and-outreach-strategy-2012-14-draft) ensure efficient, transparent delivery of priority science outcomes.

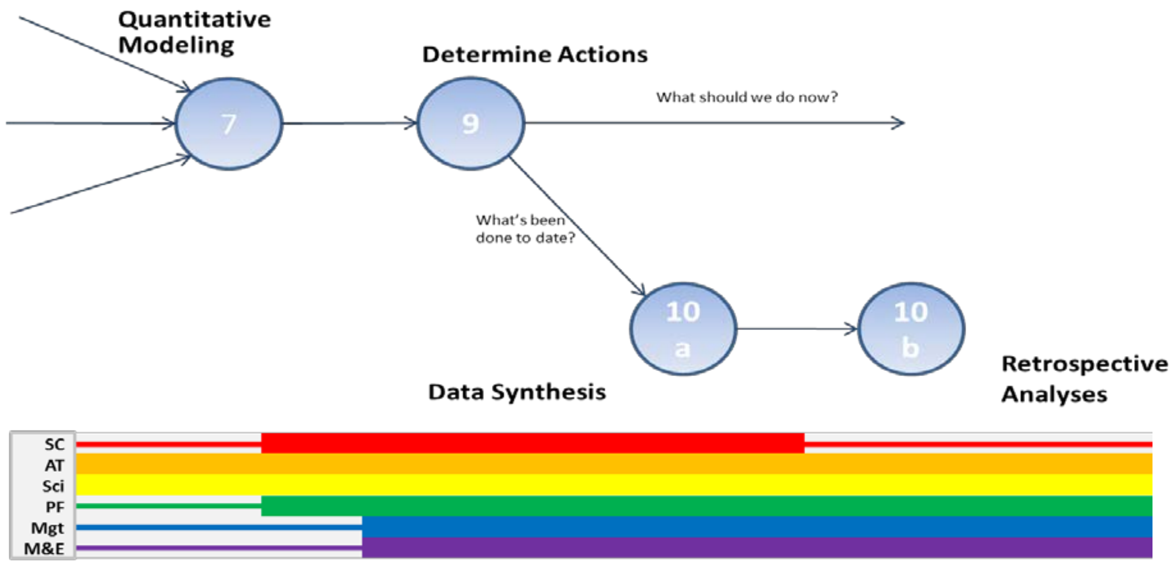

Figure 15. Steps 9 and 10 of GNLCC Science Plan stepwise process. SC = Steering Committee; AT = Advisory Team; Sci = Science Community; PF = Partner Forums; Mgt = Management Agencies; M&E = Inventory and Monitoring specialists. The X-axis is a relative timeline that will vary in duration depending on the focal Target.

Step 9: Determine Actions

The second outcome of the modeling exercise is identification and development of a suite of conservation actions that are cost effective and predicted to be ecologically effective. This set of vetted conservation actions provide an improved 'Managers Toolbox' (see Step 2b) which increase confidence that, when applied appropriately, will increase the likelihood of achieving GNLCC goals. Partner Forums will be critical to vet and refine high-value actions and communicate the process and outcome to resource managers. Management agency contributions during prior steps are leveraged by the improved Toolbox. Inventory and Modeling specialists are engaged to advise on management action and design monitoring. Steering Committee members would coordinate integration of vetted actions into agency decision processes. Tools in the improved toolbox are also critical components to design a strategy through Landscape Conservation Design (Step 11). The GNLCC does not direct or dictate action; rather, the GNLCC provides the context (vision, goals, rationale and steps) for how participants can respectively implement management action to result in a collective outcome. This step will be more explicitly described through coordination and implementation plans and not as part of this science plan.

Step 10a: Data Synthesis of Legacy Conservation Actions

Several prior steps (2b, 6) have addressed the legacy of management actions in terms of understanding what has been done to improve the trend of priority conservation targets. However, we've yet to address and compile the results of on-the-ground actions. How much have we collectively changed the opportunity and effectiveness of conservation action and where have those actions occurred? To understand this we need to identify and compile data from multiple sources to document the cumulative status of past and current conservation actions. Several such data integration efforts are underway (i.e., Protected Areas Database, National Conservation Easement Database, Land Treatment Digital Library) and interoperability tools (i.e., LC MAP (Appendix 1), Data Basin) are available to facilitate additional data discovery and synthesis. Data is expensive and becoming more so. The Science Plan directs GNLCC partners to maximize prior investments by ensuring legacy data are available to inform future Conservation Design.

Step 10b: Retrospective Analyses

Data gathered and archived in Step 10a will be used to understand their contribution to GNLCC conservation targets. Part of this challenge is technical and will require advanced information management practices to organize data in a way that gives a comprehensive view of the conservation impact and enables us to focus our current conservation needs, based on a retrospective perspective. Again, the Partner Forums provide a natural communication mechanism among Management Agencies and Science Community to ensure analyses are highly informative and actionable.

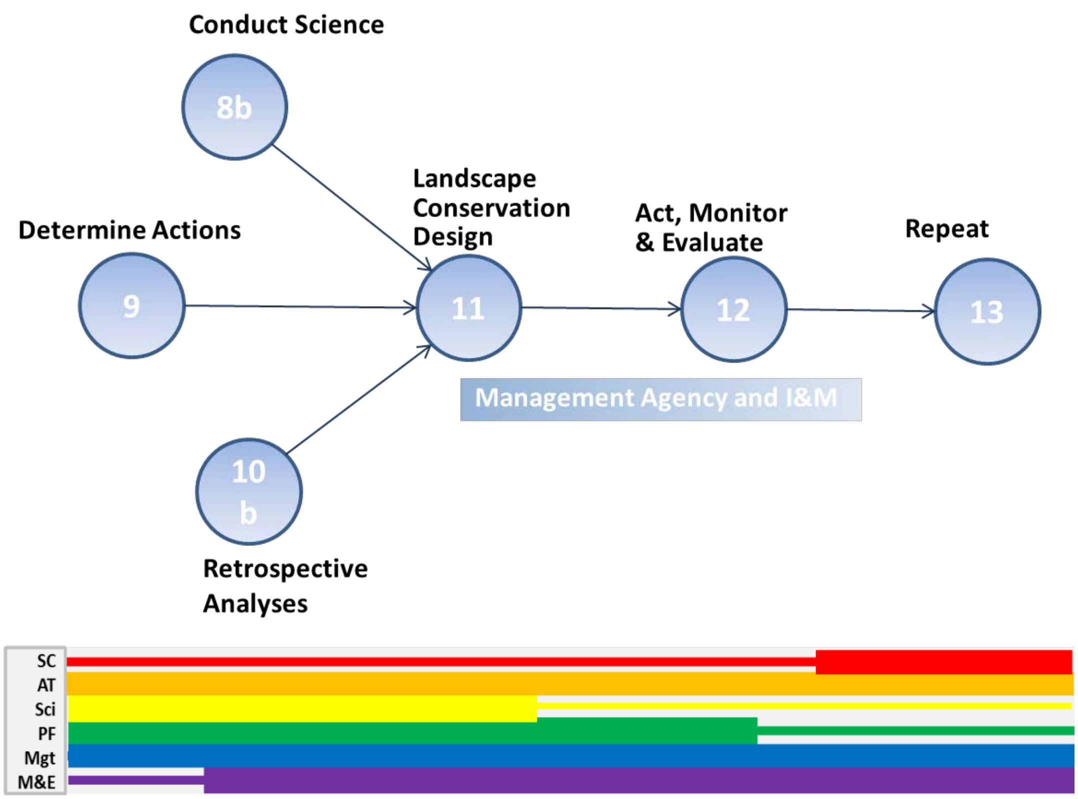

Figure 16. Steps 11 – 13 of GNLCC Science Plan stepwise process. SC = Steering Committee; AT = Advisory Team; Sci = Science Community; PF = Partner Forums; Mgt = Management Agencies; M&E = Inventory and Monitoring specialists. The X-axis is a relative timeline that will vary in duration depending on the focal Target.

Step 11: Landscape Conservation Design

Conservation design involves combining geospatial data with biological information and models to create tools, such as maps, that evaluate the potential of every acre of habitat to support a population, community, or ecosystem process. Using these tools, those involved can estimate the current habitat-acre capability — and what it needs to be – to achieve quantifiable objectives (Step 4) and desired condition. The tools guide collaborative decisions about the kind, quantity, and configuration of habitat needed, what activities (Step 9) to undertake and where.

Landscape Conservation Design (LCD) is a partnership-driven, science-based, technologically-advanced, holistic method to assess current and anticipated future conditions (biological and socioeconomic), offers a spatially-explicit depiction of a desired future condition, and helps inform management prescriptions for achieving those conditions. LCD is both a process and a product where the process is iterative and adaptive and the product results in a desired landscape condition as expressed through the integration of quantifiable biological, cultural, and physical resource objectives, assesses the current and projected landscape condition, analyzes the landscape's ability to achieve desired resource objectives under a variety of temporal and spatial scenarios, and identifies a variety of management strategies to achieve those objectives. LCD contains elements of both planning and design. (USFWS 2013c, ALI 2014, LCC Network, in prep). GNLCC partners have completed or are initiating LCD in the Columbia and Upper Green River basins (http://greatnorthernlcc.org/supported-science/317, http://greatnorthernlcc.org/updates/lccs-receive-funding-support-partner-conservation-efforts-green-river-basin). The process is expedited by existing data processing tools (Appendix A) but is dependent on close collaboration among practitioners and researchers through Partner Forums. Upon completion of the LCD, partners implement the strategies applicable to their organization. This may require each individual partner to conduct more detailed, site-specific planning prior to implementation. Over time, partners monitor and evaluate (Step 12) the effectiveness of their individual and collective implementation and reconvene (Step 13) to assess and revise the LCD on a periodic basis.

Landscape conservation design is the synthesis of the previous steps through a participatory, science-based, stakeholder driven process, led by species-, place- or issue-based partnerships for common outcomes. The GNLCC provides the overall context, continuity and fabric for how these efforts translate to landscape integrity. Upon completion of the LCD, partners implement the strategies applicable to their organization. Normally, this would require each individual partner to conduct more detailed, site-specific planning prior to implementation. Over time, partners monitor and evaluate the effectiveness (Step 12) of their individual and collective implementation and reconvene (Step 13) to assess and revise the LCD on a periodic basis.

Step 12: Act, Evaluate, Monitor

This Science Plan defines the process for partners to identify science needs for priority conservation targets and develop the roadmap to collaboratively design our conservation actions for the purpose of landscape integrity using the best available science. The next step (labeled Program Delivery in Fig. 3) is to apply conservation through a variety of on-the-ground actions, environmental education and awareness and, where necessary, regulation and enforcement. This important step, similar to conservation action, will be described as part of coordination or implementation plans that identify who is doing what towards what outcome. However, it is critical to note that the design of conservation actions must use an adaptive approach with sound monitoring protocols in order for conservation activities to deliver reliable, measurable information that can inform subsequent cycles. Subsequent GNLCC documents will address Program Delivery and how GNLCC can facilitate high value implementation.

Step 13: Repeat

Led by the GNLCC Steering Committee and Advisory Team, the process repeats in timeframes driven by improved knowledge, technology, and conservation need.

SECTION 2: Landscape Goals

Landscape conservation is a challenge that spans numerous boundaries and scales: spatial, temporal, ecological, jurisdictional, and socio-political. Preceding conservation paradigms (e.g., FWS 2008) have defined useful frameworks within a specified spatial scale. However, the challenge at hand is to understand and integrate conservation objectives concurrently at different scales and in the context of a collective landscape vision and goal.

The four GNLCC goals are, by definition, the maintenance, and improvement of landscape integrity. Areas with higher landscape integrity have unfragmented natural landscapes, highly functioning biotic and abiotic processes, native biotic components within a natural range of variability, and few impacts from invasive species. In other words, they have the composition, structure, and function of less-altered landscapes (Noss 1990). These areas are resilient to change, often contain large intact blocks of land, and sustain healthy and connected populations of fish, wildlife, and plants.

To attain a vision and explicit goal, there must be reasonable agreement on the desired condition for target resources when reaching that goal. For individual conservation targets, we look to quantifiable objectives (Section 1, Step 4). However, clearly articulated quantifiable objectives are often not as easy to define at broad ecological scales. For example, Goal 1 (maintain large intact landscapes of naturally functioning terrestrial and aquatic community assemblages) calls for desired condition of community elements and geospatial considerations (large intact landscapes) of multiple processes (i.e., naturally functioning). We may or may not achieve this goal by focusing on individual conservation targets, yet we would lack the ability to measure conservation action in terms of our landscape goals. There may be some instances where subgoal desired conditions are directly quantifiable, but to address other cases, the GNLCC will develop a Landscape Integrity Index (LII) as measure to track advancement toward desired conditions.

Increasingly, natural resource agencies and organizations are monitoring and evaluating the status and condition of their lands and waters by measuring some element of landscape integrity (e.g., Canada National Parks Act (2000), Lindenmayer et al. 2000, Fancy et al. 2007, Borja et al. 2008, US Forest Service Forest Planning Rule 2012, National Wildlife Refuge System Improvement Act of 1997). A measure of landscape integrity is used by the Bureau of Land Management's (BLM) Rapid Ecoregional Assessments (REA) when assessing the current status and likely future condition of conservation elements (http://www.blm.gov/wo/st/en/prog/more/Landscape_Approach/reas.html). Additional examples include the National Park Service's Natural Resource Condition Assessments (http://www.nature.nps.gov/water/nrca/), the Western Governors' Association (WGA) initiative on Wildlife Corridors and Crucial Habitat (www.westgov.org/initiatives/wildlife), and the US Department of the Interior's Landscape Conservation Cooperatives (LCCs; www.lccnetwork.org). Therefore, use of a landscape-scale index such as LII allows partners to measure and compare across disparate landscape programs.

Landscape Integrity Index

The GNLCC will develop and use LII (Fig. 18) for the Great Northern region to serve as a 2015 baseline and provide the opportunity to monitor movement toward (or away from) desired condition from this baseline. In this GNLCC Science Plan, we characterize landscape integrity as the inverse of human modification (i.e., the 'H' index of Theobald 2013) and as a landscape scale definition of ecological integrity as defined by Noss (1990) and Parrish et al. (2003).The LII estimates threats observable at the landscape-scale that are relevant to Conservation Targets as described by Salafsky et al. (2008) and modeled by Theobald (2013). Briefly, the LII is used to characterize every pixel on the landscape in terms of its relative landscape integrity on a scale of 0 – 1. Evaluating collections of pixels within ecological (i.e., hydrologic units, vegetation communities), ecotypic (i.e., Partner Forums, ecoregions), or socio-political (i.e., states) units will provide characterizations of the human footprint for those units. The LII approximates a universally relevant condition estimate that all GNLCC partners can identify with. This first measure will allow the Cooperative to track changes in extent and estimated intensity for stressors over time and identify important data gaps that are specifically identified at more localized scales via the process described above (Section 1).

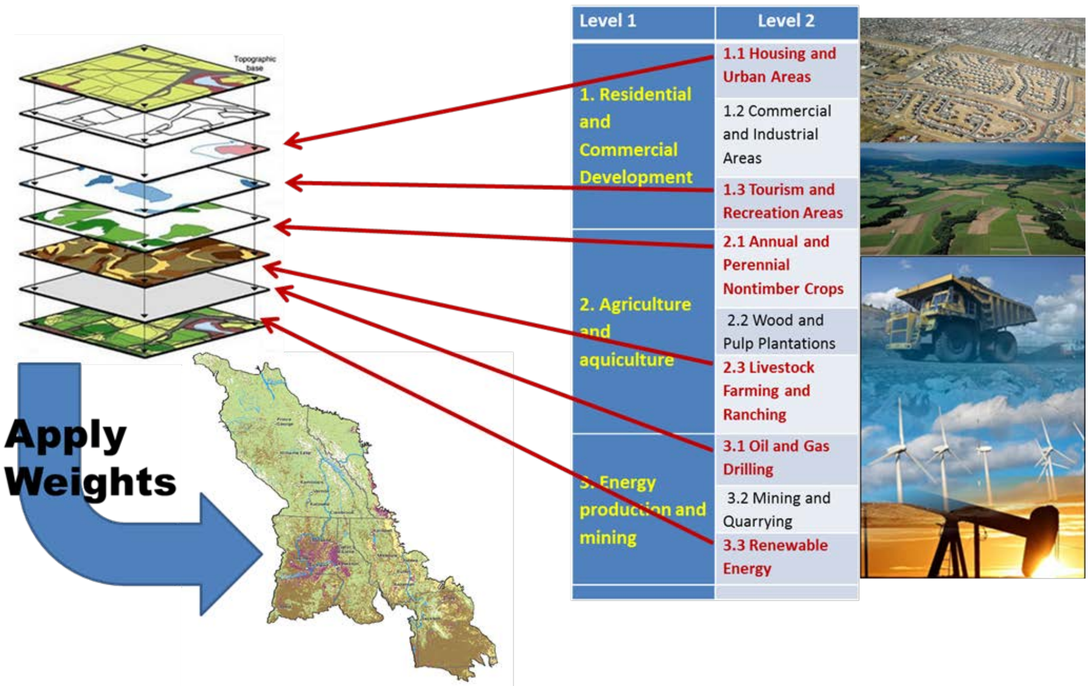

Figure 18. The Landscape Integrity Index will identify priority conservation threats in GNLCC, refine spatial data describing those threats and apply target-specific estimates of intensity to characterize the ecological integrity over broad extents. The process is collaborative, participatory and iterative. It requires contributions from all partners and delivers a consistent estimate of landscape condition.

GNLCC has identified climate change, land use change, and invasive species as priority landscape stressors (Chambers et al. 2013). Achieving our collective vision (expressed through subgoals and conservation targets) requires understanding effects of stressor status and trend on conservation targets. Data describing stressors vary (e.g., in their resolution and extensiveness of information) but in general are more available for land use change and climate and are less consistent or entirely largely lacking for invasive species. Our immediate, proximate conservation actions typically focus on land use change and invasive species, though conservation planning must account for changing climate. GNLCC will initially focus the LII on land use change (and, where data is available, invasive species) as an indicator of existing condition because the data and modeling strategies are best developed (Theobald 2013, Buttrick et al. 2014) and the threats are pressing. Climate change and the uncertainties inherent in climate models will be incorporated to project and interpret natural range of variability in the future. Developing the LII will rely on the broad multi-disciplinary expertise found in the GNLCC Science Community as well as data sources from many partners and partnerships.

The GNLCC-wide Landscape Integrity map can serve as a tool to inform annual workplans in terms of prioritizing data acquisition and provide information to help make decisions on where to focus the partnership on particularly sensitive or threatened locales and conservation targets that are in need of attention and ripe for conservation action. Subsequent measures, every 5 years, will use updated spatial data generated by GNLCC and tools and data generated by CHAT, REA, and other landscape programs and projects. Additional data layers such as the Protected Areas Database (USGS, http://gapanalysis.usgs.gov/padus), Conservation Easements Database (http://conservationeasement.us/), Land Treatment Digital Library (USGS, https://ltdl.wr.usgs.gov/) and others will serve as initial representations of Conservation Actions (*sensu* Salafsky et al. 2008; Section 1, Step 5). These data will be overlaid with the LII to inform partners regarding past and ongoing conservation activities. Theobald (2013) describe the technical approach to developing the LII; Fig. 18 describes the basic process of identifying landscape threats, overlaying source data, estimating relative univariate intensity, and synthesizing into a spatial LII.

Several examples show how a landscape index can be applied in management. The Washington Connected Landscapes Project, including Washington state and portions of Oregon, Idaho, and British Columbia, chose focal species to serve as "umbrellas" (*sensu* Launer and Murphy 1994; Sattler et al. 2014) that would encompass the diverse habitat needs of a broader array of species of conservation concern (http://waconnected.org/wp-content/themes/whcwg/docs/statewide-connectivity/2010DEC%2017%20WHCWG%20Statewide%20Analysis%20FINAL.pdf, Chapter 2), These species were selected based on their sensitivity to landscape features such as transportation infrastructure and urban development (WHCWG 2010). The team selected 11 focal species for the Columbia Plateau ecoregion, including Columbia sharp-tailed grouse, greater sage-grouse, black tailed jackrabbit, white-tailed jackrabbit, Townsend's ground squirrel, Washington ground squirrel, least chipmunk, mule deer, western rattlesnake, beaver, and tiger salamander (WHCWG 2012). Of these, greater sage-grouse and mule deer are also GNLCC conservation targets.

Type of CT	Conservation Target/Metric	Scale/Area							Objective set by:	Monitored by:
Stressor	Land Use/Invasives	GNLCC							Theobald (2013) Baseline	GNLCC
	Land Use/Invasives	Sage Steppe Forum		Rocky Mountain Forum			Columbia Basin F	Cascadia F	Theobald (2013) Baseline	GNLCC
	Land Use/Invasives	WY B	Columbia Plateau	High Divide	CoC	GYA	Columbia River	Cascades	Theobald (2013) Baseline	GNLCC
	AIS								Potential GNLCC AT Project	GNLCC
	Climate Change	Past and projected climate change described by area; impacts assessed per Conservation Target							Hostetler, CIG, etc	Climate Science Centers
Ecosystem Processes	Connectivity								Baseline CHAT model	WGA
	Wildland Fire								Baseline tracked by NIFC	NIFC
	Insect and Forest Pathogens								Baseline tracked by USFS	USFS
Hab or Ecosy	Wetlands								IMJV	GRYN NPS I&M
	Riverine								ALI/WA Conn	ALI/WA Conn
	Sage Steppe								WLCI/ALI/WA Conn	WLCI/ALI/WA Conn
	Whitebark Pine								Baseline tracked by NPS I&M; USGS; USFS	Baseline tracked by NPS I&M; USGS; USFS
Species	Grizzly Bear								IGBC	IGBC
	Sage-Grouse								???	???
	Cutthroat Trout								???	???
	Mule Deer								WA Conn	WA Conn
	Wolverine								???	USFS; WCS
	Sockeye Salmon								???	???
	Bull Trout								USFWS	USFWS

Table 8. Proposed matrix of conservation targets and stressors. Colored cells indicate where the indicator would be tracked. Yellow is an ecosystem process; Green is a habitat or ecosystem; Red are taxa; Blue are stressors. For reporting, this type of table could serve as a template. Partners could insert numbers and/or arrows to indicate trend. WY B (Wyoming Basins); GYA (Greater Yellowstone Area); CoC (Crown of the Continent).

In another example, the Crown Managers Partnership (CMP), covering the Crown of the Continent in portions of Montana, British Columbia, and Alberta, has adopted a Strategic Plan that strives for an ecologically 'healthy' ecosystem achieved by management actions of multiple agencies each operating within their own jurisdiction with common goals in mind. The Managing for Ecological Health Project identifies six broad indicators to describe ecological health in the Crown: landscapes, water quantity and quality, biodiversity, invasive species, air quality, and climate. CMP partners are developing coordinated cross-jurisdictional management outcomes for a suite of trans-boundary focal species using occupancy and abundance models for grizzly bear, wolverine, cutthroat trout, and bull trout, all of which are GNLCC Conservation Targets.

Another example is the Cascadia Partner Forum which fosters a network of natural resource practitioners working with the Landscape Conservation Cooperatives to build the adaptive capacity of the landscape and species living within it. Four priority issues within Cascadia have been identified by the Pilot Council for the Cascadia Partner Forum to focus on: 1) Habitat connectivity, 2) Water, 3) Iconic Species: Wolverine and Sockeye salmon, and 4) Access Management. They are preparing a report that provides a synthesis of existing information on these priority issues, discusses case studies within the Cascadia region on each topic, highlights success stories in Cascadia, and identifies funding needs for further information and climate adaptation actions.

A final example is the Wyoming Landscape Conservation Initiative (WLCI). WLCI is a long-term, science-based program to assess and enhance aquatic and terrestrial habitats at the landscape scale in southern Wyoming, while facilitating responsible development through local collaboration and partnerships. The WLCI works to ensure that wildlife and habitat remain viable across the landscape, even with significant development pressure. The priority objectives addressed within the focus communities are: fragmented habitats, invasive species, and water quality and quantity. Greater sage-grouse has been a focal species of the WLCI since Wyoming harbors approximately 36-40% of the rangewide population of the species.

Immediate Science Needs for Landscape Integrity Measures

Because of the urgent threat posed by invasive species, an evaluation and improvement of invasive species distribution and risk spatial data is a clear need; a database describing the distribution of terrestrial non-native and invasive plants database is incomplete; data for aquatic invasive species is missing entirely. Climate change projections can easily pared with LII Landscape Integrity Index to estimate impacts to landscape integrity as defined herein. Projected climate changes are expected to influence ecosystem composition, structure and function in many ways, though uncertainty in climate trend and ecosystem response is high. Appropriate incorporation of climate models will be an important consideration during LII development. Also, as it stands, the LII is a more robust tool within terrestrial systems than in aquatic systems.

The evaluation of progress by the LCC will require cumulative impact assessment that must be built upon data collected in a manner that will make it comparable to like data; i.e., collected using common protocols. By this simple step the LCC partners can foster the common currency of data that is a perquisite to the integration of data. Variation in data source quality, disposition, and extent are compounded by the international extent of the GNLCC geography. Though many partnerships are working on data integration issues, challenges remain and must be addressed for the LII to be useful. Furthermore, the LII seeks to quantitatively amalgamate estimates of numerous prominent land use effect into one value per pixel. Although the LII was ideologically 'tuned' for species particularly sensitive to land-use disturbance, the effect of a given landscape-level stressor will undoubtedly vary across species, geographies, and time (e.g., Beever et al. 2011), and thus may need re-calibration for greatest accuracy. In order to measure landscape integrity then, tools to understand spatial patterns of the LII, more robust data sources, and other indices will need to be developed and appropriately combined at meaningful spatial scales.

How Collaborator Management Actions and Strategies Influence these Indicators

Collaborators engage in management actions and strategies that, taken collectively, are intended to improve the condition of the landscape, including efforts to improve habitats, ecosystems, species, and ecosystem processes, and reduce the impact from human modification. These actions include protection (land acquisition, conservation easements, etc), restoration (reclamation, rehabilitation, etc.), species and habitat management, (see Safalsky et al 2008). Some collaborators such as the Interagency Grizzly Bear Committee and the Intermountain West Joint Venture take direct action that seeks to benefit a priority species, habitat or process. Some ecosystems groups, such as Arid Lands Initiative, Crown Managers Partnership, Greater Yellowstone Coordinating Committee, Wyoming Landscape Conservation Initiative, are a collection of partners that take individual actions that roll up into action at the ecosystem level (Table 9). Some groups, such as the Washington Connected Landscape Project, provide science that serve basis for management action. Some programs and organizations, such as the USGS and the agency Inventory & Monitoring programs, monitor these species, habitats, and processes to assess whether we are meeting objectives. Over time, the results of these actions will be reflected in the targets selected for the index and will thus contribute to the GNLCC collective vision of a landscape that sustains its diverse natural systems.

Effort	Extent	Metrics	Outcomes
Western Governors Association CHAT	18 Western States, including 5 states in GNLCC	Landscape Condition; Large Natural Areas; Landscape Connectivity; Freshwater Integrity	Landscape Integrity dataset released December 2013; no specific plan to update at regular intervals
Washington Wildlife Habitat Connectivity Working Group	State of Washington; Columbia Basin;	Landscape Integrity; Connectivity; Resistance	Coarse Scale evaluation for entire state complete; finer-scale evaluation for Columbia Basin Complete; finer-scale evaluation for Okanogan-Kettle underway
Crown Managers Partnership Ecological Health Monitoring	Crown of the Continent	Human Modification Index	Underway
Montana Connectivity Map	State of Montana	Connectivity; Species Modeling	Complete
Wyoming Landscape Conservation Initiative	Southwest and south central Wyoming	Integrated Assessment Index	Complete
BLM Wyoming Basins REA	Omenik's Wyoming Basins (Level III Ecoregion)	Terrestrial Development Index; Aquatic Development Index	Scheduled to be completed 2014; no schedule for revision or update
BLM Middle Rockies REA	Omerik's Wyoming Basins Level III Ecoregion	Terrestrial Intactness, Aquatic Intactness, Species status, Climate Change	Scheduled to be completed August 2014; no schedule for revision or update
Landscape Climate Change	National Parks in the	Ecosystem and Tree	Scheduled July 2015;

Vulnerability Project	Northern Rocky Mountains	Species Vulnerability	Management options for vulnerable ecosystem types and tree species within these focal parks

Table 9. Example partner efforts to measure landscape integrity.

SECTION 3: Integrating Filters to Understand Progress

The GNLCC Science Plan describes: (a) a way to track our collective progress toward stated goals and desired conditions, and (b) the process for identifying critical gaps in scientific information which then guide GNLCC annual work plans and funding strategies. The section summarizes these objectives.

Tracking Collective Progress toward Stated Goals

The outstanding challenge to large landscape conservation is delivering cross-scale information to best inform conservation decision and action. The Science Plan guides the GNLCC partnership to integrate quantifiable objectives with landscape-scale desired outcomes by linking many conservation target metrics to measures of landscape integrity. We acknowledge this element of the GNLCC Science Plan remains a work in progress – a challenge we can only adequately address as a cooperative partnership. Yet we recognize many elements are in place (e.g., Fig. 9, Table 9) and should be leveraged to measure and evaluate progress in relation to goals. GNLCC seeks to integrate multi-scale data to increase manager's confidence that proposed actions will contribute to shared outcomes and coordinated evaluations that accurately measure trends (toward or away from) desired condition. Conceptually, the integration is fairly straightforward (Fig. 19). In practice, GNLCC will rely on the coordinated interaction among management agencies, local partnerships, science organizations and the Partner Forums.

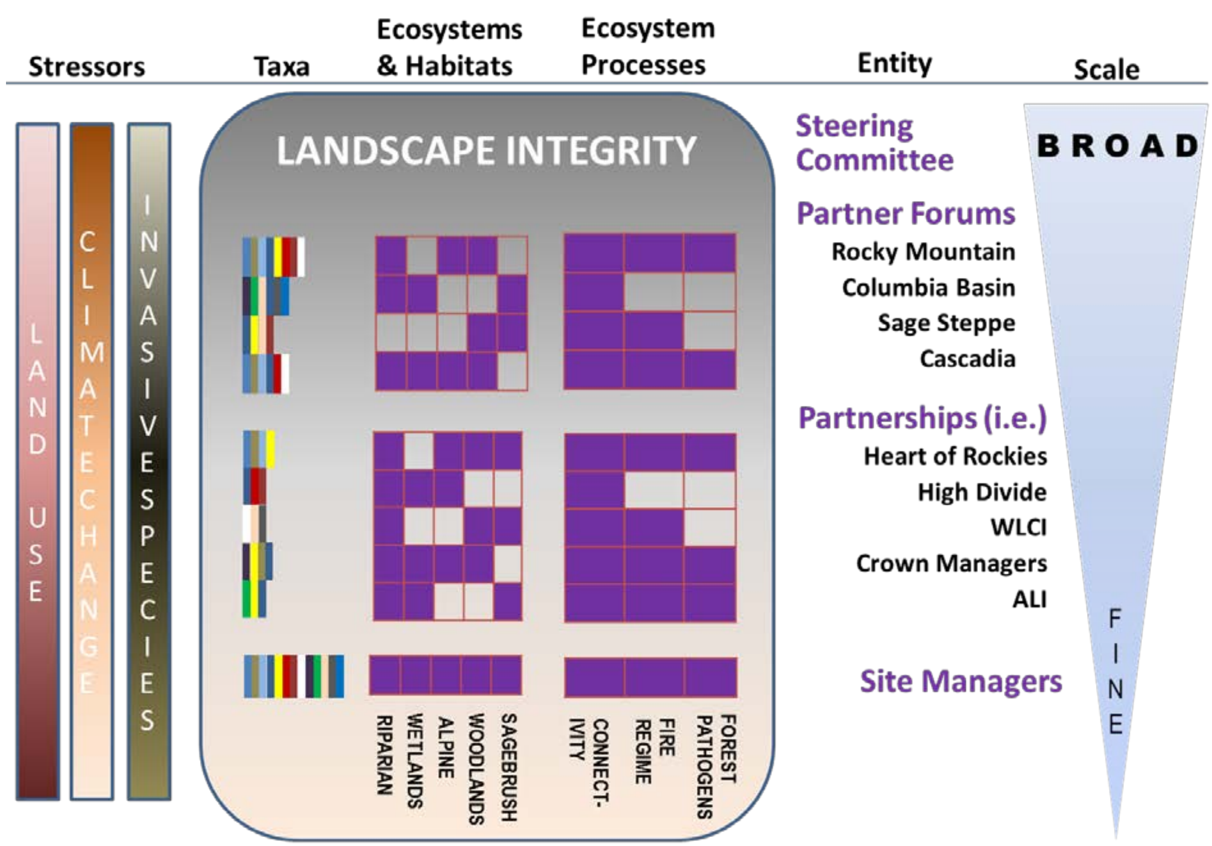

Figure 19. Conceptual model for integrating coarse (Landscape Integrity) and fine (Taxa, Ecosystems and Habitats, Ecosystem Processes) filter conservation data to inform site managers and conservation partnerships on appropriate actions in the face of landscape stressors.

A number of GNLCC Conservation Targets (Table 1) do not have the level of *in situ* conservation coordination and planning necessary for complete analysis at this time. GNLCC staff are assembling in-place elements as part of the Project Tracking System (Appendix A) as an early step. However, by understanding each target's conservation ecology, establishing quantifiable objectives for conservation targets, and measuring target-specific and landscape metrics, the GNLCC can collaboratively track progress and guide strategy adjustments.

Guiding Annual Workplans

The Science Plan's approach identifies numerous information and capacity gaps through the process of quantifying shared goals and objectives, characterizing desired condition, identifying limiting factors, recognizing important spatial data inadequacies, and disclosing needed analytical and decision-support tools. The Science Plan and accompanying annual workplans will reflect those interpretations supported by LC MAP, the GNLCC Project Tracking System, and the Communication Plan (see Appendix A). In its simple concept, the annual workplan entails collecting the flags as described in Step 8a (page 21). However, pursuing 31conservation targets, three landscape stressors, and characterizing multiple-scale status and trends will generate a broad spectrum of needs. Identified needs will be captured and summarized in annual reports but a prioritization process will guide work plans. Staff and the Advisory Team will lead the process and capture input from practitioners (via Partner Forums and partnerships), regional leadership (via Steering Committee) and through the iterative science process (Science Community). Staff and Advisory Team will identify and track parallel science delivery and on-going research to further refine gaps and cross-reference expressed needs among agency partners to identify a focal subset of high priority needs. These needs will be expressed as increasingly specific science calls that form a portion of the annual workplan and are appropriately interpreted in consequent funding guidance. Science solicitations may be direct requests from specific organizations with proprietary or jurisdictional rights or open for competition through a request for proposals.

A second element of the annual workplan is organizational objectives for GNLCC work teams. GNLCC Staff, through their parent agency, develop and achieve performance plans. These will be transferred to the GNLCC workplan. The Advisory Team will draft team-level objectives for the AT and Steering Committee which will approve both. Cursory evaluations of accomplishments at year end will inform subsequent annual workplans (Fig. 20).

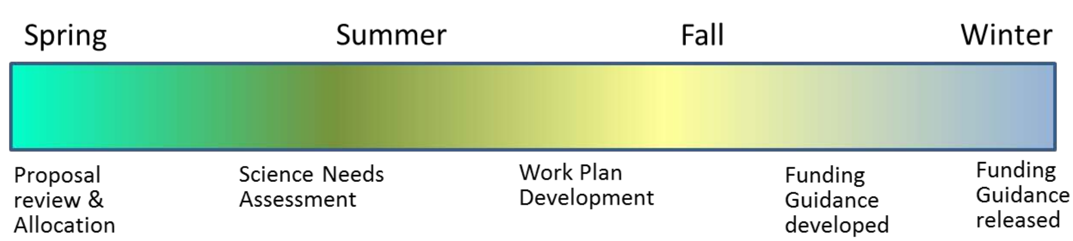

Figure 20. Basic workflow describing Annual Workplan development and implementation.

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APPENDIX A: Tools and Technological Resources Supporting the GNLCC Science Plan

Tools to Further Landscape Conservation Science
To facilitate the application of science and information exchange among those partners, the GNLCC has developed the following science communication tools:

A communication strategy (http://greatnorthernlcc.org/sites/default/files/temp/comm_outreach_strategy_draft_29apr.pdf; Fig. 1) for the GNLCC clearly spells out strategies to keep key groups of partners engaged in and connected through the GNLCC. Clear communication and engagement among partners is critical for the GNLCC to function.

The GNLCC website (http://greatnorthernlcc.org) provides a location for sharing information. Specifically, for the partner forums to exchange information regarding mutual goals and shared projects, access to the results from research projects supported by the GNLCC, new tools for managers, and webinars on research and conservation initiatives happening throughout the region.

A project tracking system (PTS) to house all science proposal, funded project and product information. The tool will serve as the point of reference for all projects GNLCC leads. The GNLCC website and other outreach sources will dynamically draw from the PTT fostering efficient, timely communication of GNLCC science and science support products. The PTT will also dynamically interact with data resources housed on LC MAP (see below). It will be integratable with National LCC Network and Climate Science Center project tracking resources (functional Dec. 2013).

LC MAP (or the Landscape Conservation Management and Analysis Portal; https://www.sciencebase.gov/catalog/?community=GNLCC) provides a collaborative virtual workspace for GNLCC partners to securely share, access, and analyze common datasets and information. It is a tool that facilitates data mining and discovery from the World Wide Web, uses mapping applications for data analysis, and advances collaborative research by providing a secure space for multiple partners to assess, edit, analyze, and model common data themes in near realtime - with advance data security and documentation functions.

Data standards ensure security and quality, and the ability to share and apply data throughout the region. See the document Data Management Standards for details.

These are a few of the tools developed to date to facilitate information exchange and science application among GNLCC partners. As this foundation is built, additional tools will be developed and the capacity for shared science will increase.

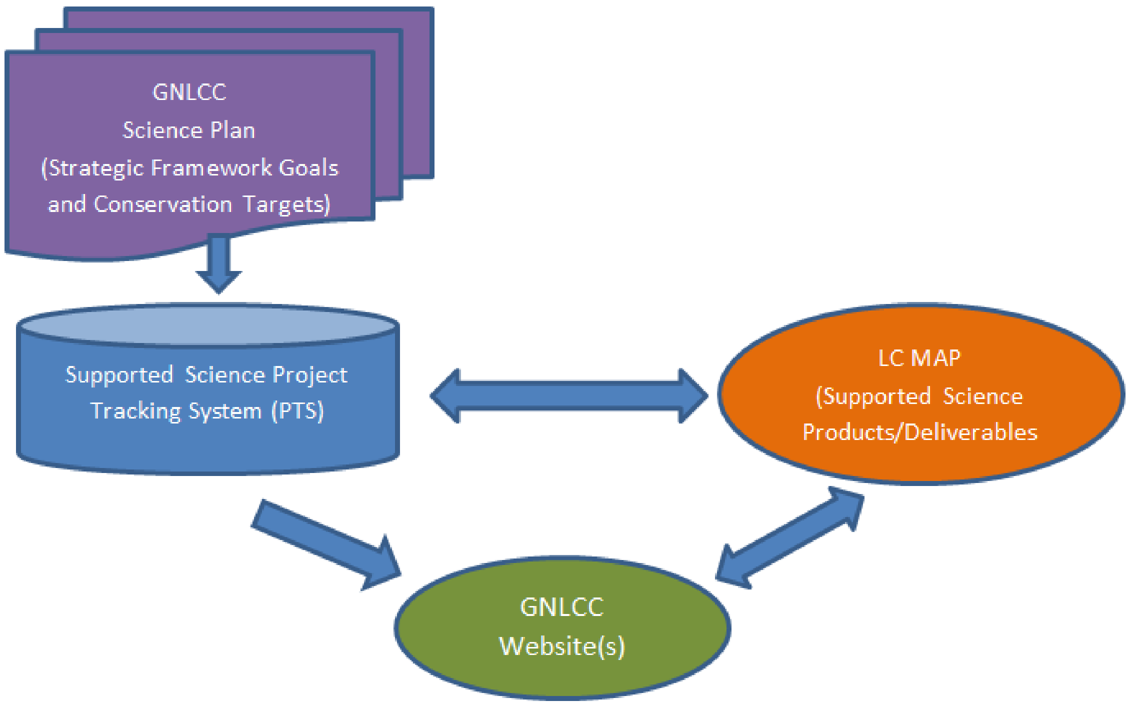

Figure A1.--Linking GNLCC Supported Science Product with GNLCC Science Plan components.

One function of the GNLCC project tracking system (PTS) is to serve as a data link between GNLCC science products and the GNLCC science plan and strategic framework components (conservation targets, strategic framework goals, and partner forum geographic areas). The linking provides the relationship for GNLCC audiences to navigate the science plan and GNLCC supported science products (data, tools, reports, etc.). The linkage includes products cataloged and archived on LC MAP, which has many robust features including a rich metadata repository. Various science plan meta-analysis reporting options can include GNLCC supported science trends, supported science gap analysis, breakdown of science products and related science plan components, spatial summarization of science plan components, etc.

- Supported Science Product Archiving and Cataloging

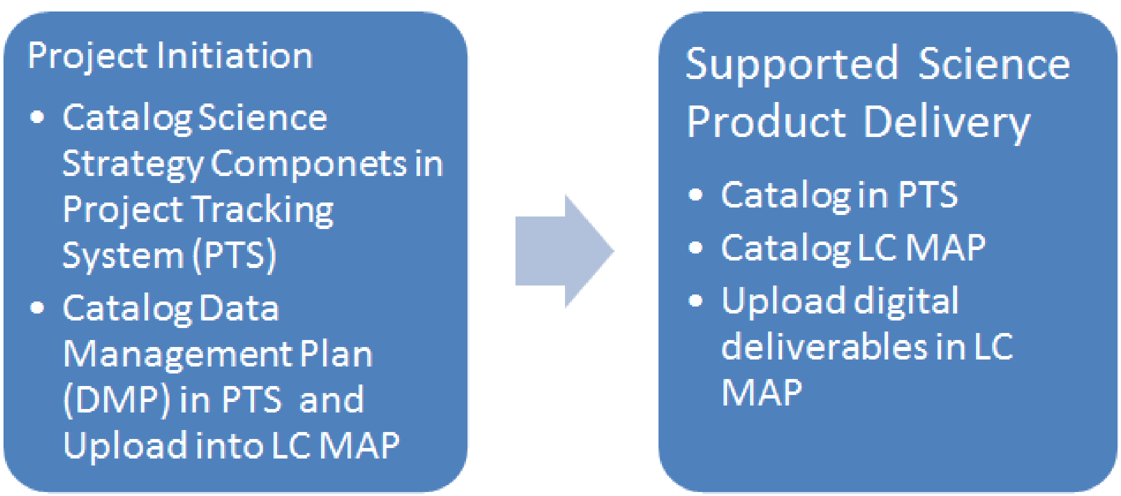

Figure A2.--Product Archiving and Cataloging.

GNLCC supported science products come in many forms (vector/raster/tabular data, tools, reports, etc.) and proper cataloging and archiving ensure sustained use and discoverability. As the backbone of the science strategy's supported science products, LC MAP is the GNLCC information system for cataloging and archiving. LC MAP has many functions including a cloud based data repository which includes robust data storage component. This repository is used as a cloud based archival repository for GNLCC deliverables. The primary repository for project information is in the project tracking system (PTS). The project and product cataloging and archiving is a two stage process starting at projects cataloged in the PTS. Projects may have one or many deliverables associated with it. At project initiation, the project background, science strategy components, and DMP are cataloged in the PTS and LC MAP. Next all supported science products are cataloged in the PTS and LC MAP and all digital data, files, and products is designed to be uploaded into LC MAP for archival. This process will be repeated if re-delivery of products is necessary or subsequent products are delivered. For more information on LC MAP visit greatnorthernlcc.org. For information on data management standards visit the Data Management Standards document.

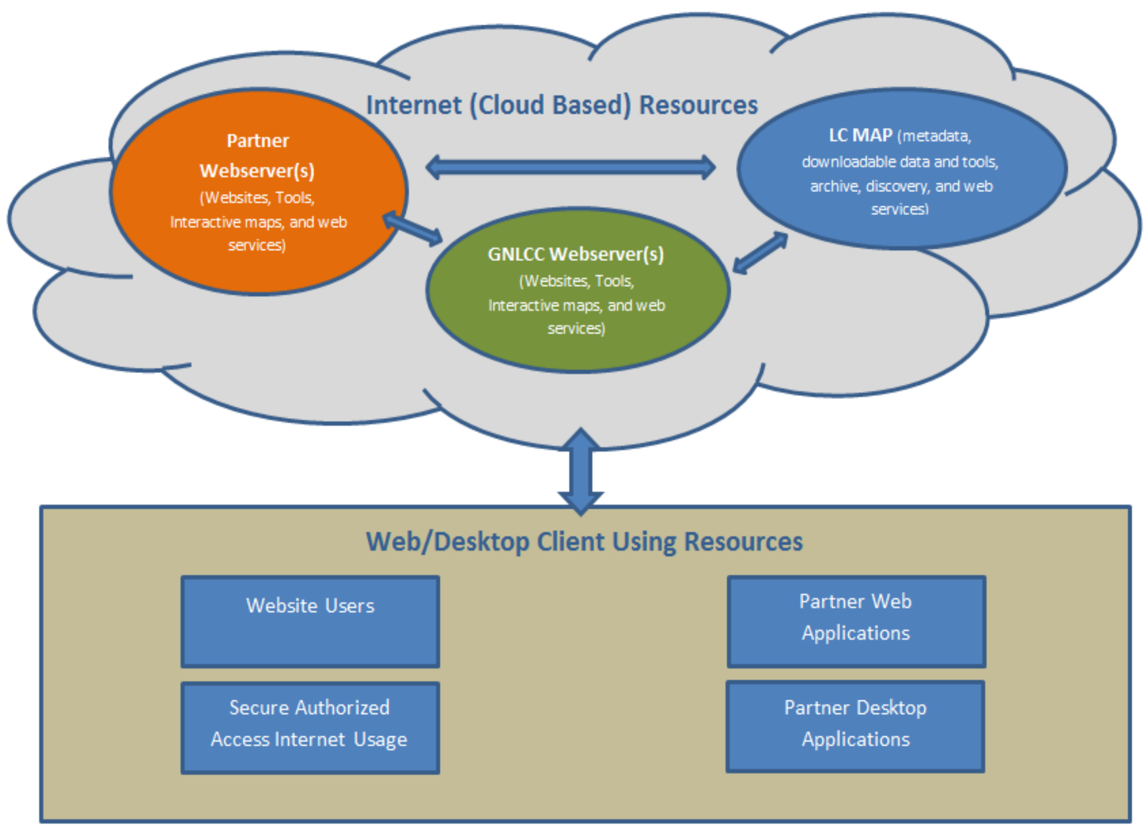

Figure A3.--Product Delivery and Information Integration.

The overall methodology of GNLCC science product delivery is through cloud based architecture. The cloud based architecture allows other users or user applications (clients) to consume information and tools transferred over the internet. LC MAP is a cloud based system that can store and serve (distribute) data/metadata to others or can be a place to catalog locations on other partner cloud based systems. This framework allows for GNLCC web apps or partner web apps to utilize each other and work to entities strengths, reducing redundancy and confusion inherent with information technology duplication. Over time new hubs (cloud based web resources) will emerge and some will fade away. This design handles flexibility and scaling, minimizing disruption and promoting cooperation and growth.

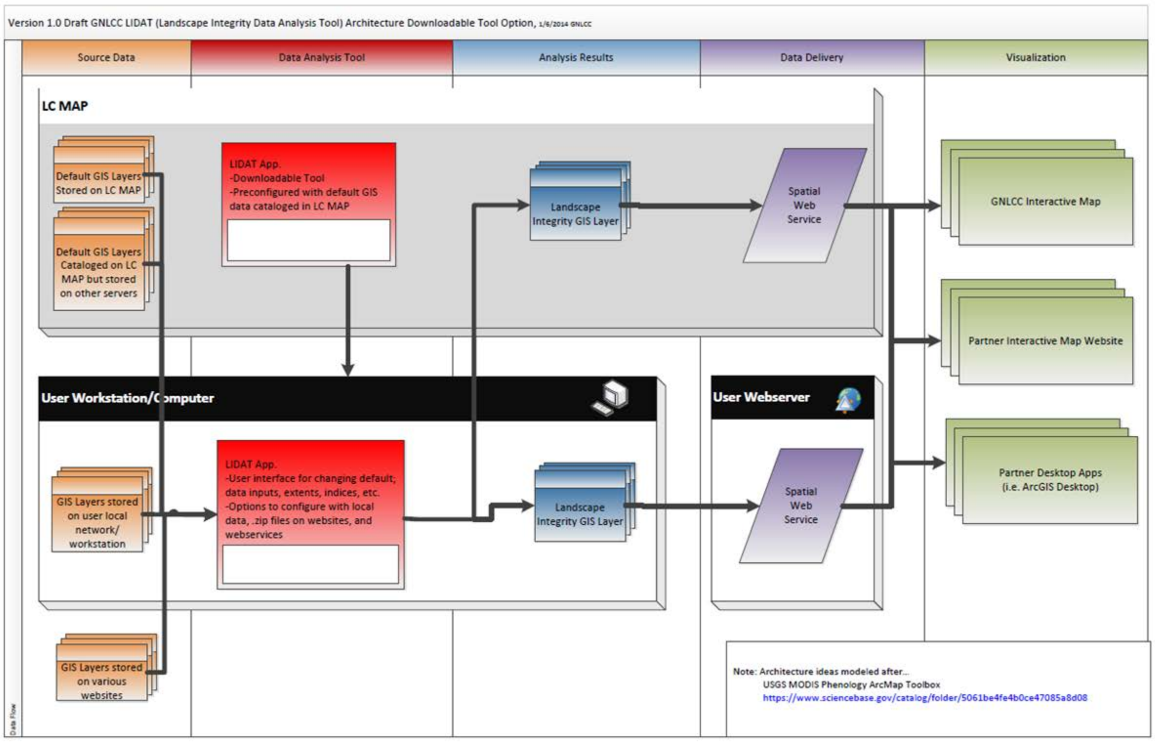

Figure A4.—Technical design for Landscape Integrity Index development.