4

Where the Wild Things Roam

The human history of the Yellowstone region goes back to an undesignated time in tribal oral history, more than 11,000 years ago[1] when many groups of Native Americans, including the Blackfeet, Apsáalooke (Crow), Shoshone, and the original Sheep-Eaters, used the park as their home, hunting ground, and source for gathering medicinal plants.[2] These traditional uses of Yellowstone lands continued until the first explorers and trappers of European descent found their way into the region, returning home recounting tales of a bountiful land full of natural wonders where "fire and brimstone" gushed up from the ground.

In March 1872, President Ulysses S. Grant signed into law a congressional act making Yellowstone the first national park in the world, an area so extraordinary that it was set aside and protected in perpetuity for the enjoyment of future generations.

Thanks to its early designation and protection, Yellowstone National Park is one of the few remaining intact large ecosystems in the northern temperate zone of the earth. Native flora is allowed to progress through natural succession with little direct management. The park's bison are the only wild, continuously free-ranging bison remaining of

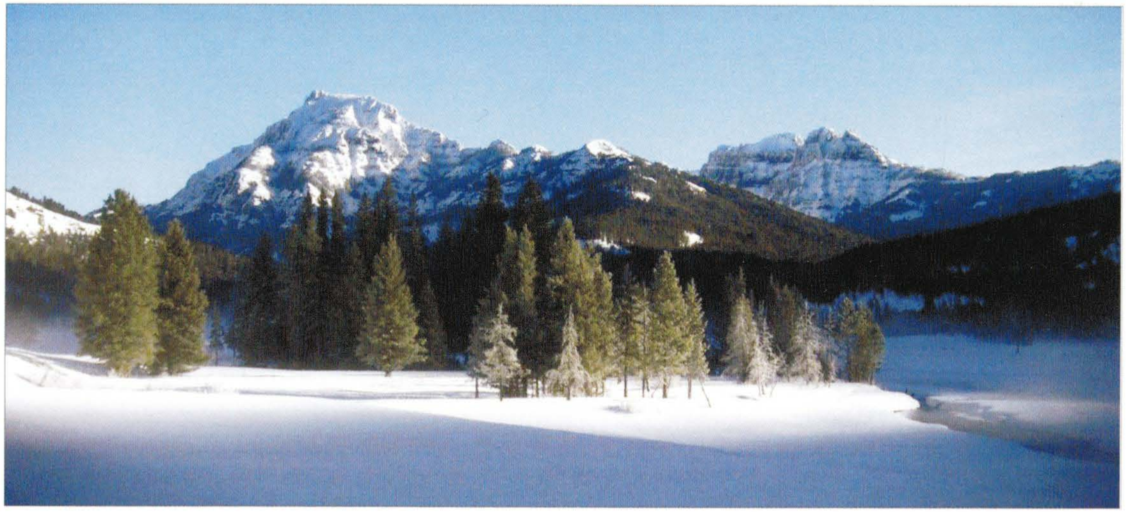

Figure 4.1: A winter morning on the prairie. (Photo courtesy of Hamilton Greenwood)

the vast herds that once covered the plains,[3] and in 1995 and 1996, gray wolves were reintroduced to the wild here, reestablishing an important predator-prey balance to the ecosystem.

In recent years, managing these resources has become increasingly challenging. Drought, wildfire, habitat fragmentation, contaminants, invasive species, disease, and a rapidly changing climate have begun to threaten human populations as well as native species and their habitats. To plan for this uncertainty, a dedicated group of ecologists are using ArcGIS, statistical analyses, and a geodesign workflow to measure the impact of potential land-use change before it happens.

Ecological Forecasting

The Yellowstone Ecological Research Center (YERC), a private, nonprofit organization located in Montana, spends much of its time conducting long-term, large-scale, collaborative ecological research and education in concert with both public and private organizations.[4] Historically, that work has relied heavily on ArcGIS to help organize, analyze, and visualize data on the health and status of native species and the land and water on which they survive. But what happens to protected species if annual temperatures increase by 2 degrees Fahrenheit? What happens to a species if a new road is built through a prime feeding ground?

To answer these questions, legacy environmental and species data can be used to identify historic population trends in the hopes of projecting or predicting future outcomes. It is not possible to predict the future with certainty, but you can plan ahead for probable events. If the weather station forecasts an 80 percent chance of rain tomorrow, most people grab an umbrella or change their plans. Following that analogy, YERC ecologists use the term *ecological forecasting* to represent the method they use to plan for any number of alternative what-if scenarios that might adversely impact the landscape or habitat of a protected species.

Figure 4.2: The prairie supports bison, pronghorn antelope, coyote, and an assortment of other creatures. (Photos courtesy of Hamilton Greenwood)

YERC ecologists use the term *ecological forecasting* to represent the method they use to plan for any number of alternative what-if scenarios that might adversely impact the landscape or habitat of a protected species.

Simulating ecological system dynamics is a complex undertaking. The sheer volume, variety, and complexity of geospatial data has grown exponentially in recent years, requiring the

Geodesign, in essence, is a decision support methodology that closely couples design activities with near real-time impact simulations informed by geographic knowledge — information on the physical aspects of the environment and human values.

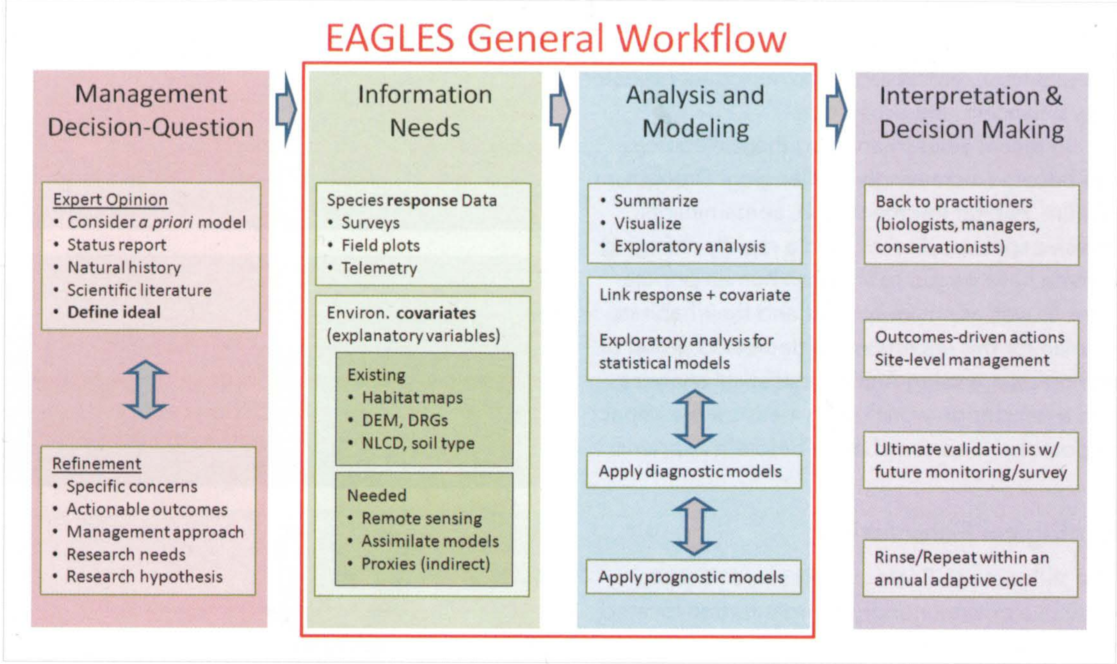

Figure 4.3: The EAGLES workflow schematic diagram. (Courtesy of the Yellowstone Ecological Resource Center)

development of new tools and efficient workflows to help decision makers spend more time on the issues, not sorting through data. More importantly, decision makers need to be able to synthesize this data into *standardized*, *transparent*, and *defensible* information to support the management needs of today while preparing for the needs of tomorrow. And that means having a *repeatable* process, a core tenet of scientific inquiry.

To support the entire process of ecological forecasting, YERC ecologists, statisticians, and GIS analysts created the Ecosystem Assessment, Geospatial Analysis and Landscape Evaluation System, known as EAGLES. EAGLES is an integrative workflow architecture that organizes vast amounts of historic spatial data, some covering the entire United States, with modeling routines to create predictive ecosystem and species models. ArcGIS is a key component of EAGLES, providing a mapping platform to make the data easily understandable to decision makers.

EAGLES—Geodesign at an Ecosystem Scale

EAGLES is essentially geodesign at an ecosystem scale. Geodesign, in essence, is a decision support methodology that closely couples design activities with near real-time impact simulations informed by geographic knowledge—information on the physical aspects of the environment and human values. In this case, design has more to do with adaptive management planning in response to possible land-use changes due to natural events,

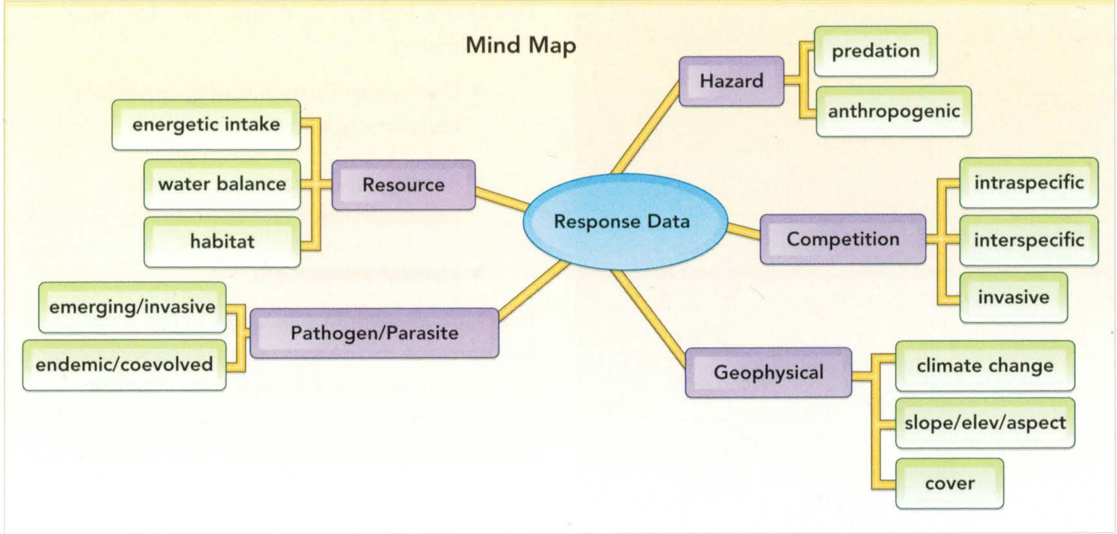

Figure 4.4: A mind map is a quick way to display potential factors affecting variation in a focal species response, for example, the health and vitality of a population. The mind map could be based on present-day data or legacy datasets, either of which helps visualize the narrative model, which can get rather complex.[5] The narrative model will eventually be used to create a quantitative model to support statistical analytics that occur later in the workflow. (Courtesy of the Yellowstone Ecological Resource Center)

although it can also be applied to local man-made events like the building of a new road or some other development.

The EAGLES workflow closely parallels Steinitz's geodesign framework using a workflow that guides practitioners through both assessment and intervention models. ArcGIS for Desktop tools and web-enabled environments provide a systematic yet flexible architecture for the integration of species data with environmental data to assess condition, create model parameters, and simulate impact of various scenarios. As each model is run, it is tested statistically against real data until the models "fit" reality well enough that they can be used to forecast probable future impacts.

The following is a breakdown of how a typical project might proceed through the EAGLES workflow.

Define the Management Decision or Question to Be Investigated

The workflow begins with the assembly of experts with a strong knowledge of the organism of interest, including physiological drivers, feeding habits, predator-prey relationships, competitive interactions, and habitat. Additionally, this effort can integrate pathogens, parasites, or other hazards. These experts help develop a conceptual model of key issues and management objectives. The conceptual modeling process begins with a verbal description of important relationships between the species of interest and its environment. The verbal description is then used to help select a set of hypothetical drivers to be considered for inclusion in the model. Here, we refer to the environmental variables (i.e., covariates) and their relationship to the species of interest (i.e., response data) as a narrative model using a mind map (figure 4.4).

ArcGIS for Desktop tools and web-enabled environments provide a systematic yet flexible architecture for the integration of species data with environmental data to assess condition, create model parameters, and simulate impact of various scenarios.

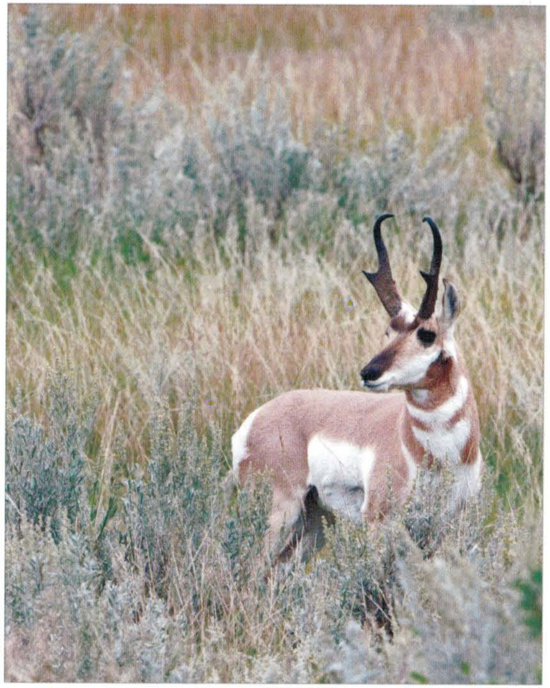

Figure 4.5: Pronghorn antelope. (Photo courtesy of Hamilton Greenwood)

Considering all possible risks and rewards based on expert opinion, research, and natural history helps avoid making inadequate models. Ideally, the mind map model and subsequent quantitative models represent factors that may affect populations, in the context of postulated mechanisms leading to testable hypotheses and management decisions.

For example, the Yellowstone National Park (YNP) pronghorn antelope (*Antilocapra americana*) faces a suite of risks characteristic of small populations with geographic/demographic isolation, low abundance, and low recruitment. Decision makers need a management plan based on demographic monitoring of abundance, especially species vitality rates. This study, led by P.J. White, YNP, focused on the following:

- Demographic monitoring, especially recruitment and survival
- Ecological interactions, especially predation rates and recruitment
- Habitat assessment

The issue assessment resulted in the creation of two narrative models, one representing *birthing arenas* and another for *resource selection* (involving the identification and use of viable habitats). In this case, species vitality could be explained by forage availability, predator intensity, geophysical context, and climatic variables; for example, the more rain, the more food, the more newborns, the healthier the population might become.

Information Needs

Once the narrative models have been created, the next step is the identification and gathering of relevant datasets (*representation models*) to support the development of numerous *process* and *evaluation models*. Data inputs can be classified into two broad groups: (1) spatially explicit and/or time series species observation data (i.e., response data), including locations, sightings, nest sites, GPS, telemetry data, sign, mortality sites, survey and transect data, and (2) environmental geospatial data (i.e., explanatory data). Environmental geospatial data can be static variables such as slope, aspect, elevation, existing habitat, and vegetation cover, or it can be dynamic variables that vary over time such as climatic metrics (such as minimum or maximum temperature, fire intensity, flooding, percent surface water, and forage biomass).

The following environmental geospatial data was needed to answer questions regarding road, predator, and range condition impacts on pronghorn antelope:

Abiotic

- Elevation
- Slope
- Topographic complexity

Biotic: Productivity

- Forage
- Net primary production (NPP)[6]

Biotic: Land cover

- Percent forest cover
- Percent sagebrush cover
- Percent herbaceous cover
- Percent soil cover

Biotic: Predation

- Coyote intensity of use
- Wolf intensity of use
- Small mammal (prey) prevalence

Human Influenced

- Distance to roads

One of the big advantages of EAGLES is the ease with which relevant geospatial data can be found, processed, and made ready for use in ArcGIS. A wiki provides an index of existing geospatial data, as well as information on its content and generation,[7] and COASTER (Customized Online Aggregation & Summarization Tool for Environmental Rasters)[8] allows anyone to customize climatic variables for a particular area, period of time, and spatial resolution and download them for immediate use with ArcGIS (figure 4.7). The climatic data comes from National Aeronautics and Space Administration (NASA) and spans over 30 years, with more data added daily.

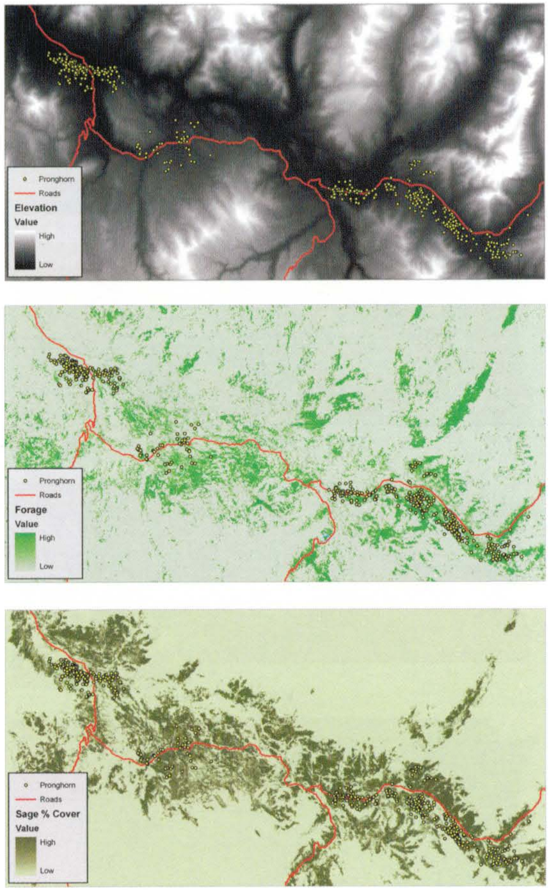

Figure 4.6: Environmental maps representing (a) elevation, (b) forage, and (c) percent sage cover overlaid with pronghorn locations shown as yellow dots and roads as red lines. (Figures courtesy of the Yellowstone Ecological Resource Center; data courtesy of YERC, NPS, USGS, ArcUSA, and Esri)

Data Integration

Preparing GIS data for use on any project can be time-consuming and frustrating. EAGLES simplifies the integration of species data with environmental datasets by using the Resource Selection

One of the big advantages of EAGLES is the ease with which relevant geospatial data can be found, processed, and made ready for use in ArcGIS.

COASTER (Customized Online Aggregation & Summarization Tool for Environmental Rasters) allows anyone to customize climatic variables for a particular area, period of time, and spatial resolution and download them for immediate use with ArcGIS.

Once the data is prepared, describing the landscape and defining how it operates, the evaluative modeling can occur (*evaluation models*) to determine whether the landscape is working well.

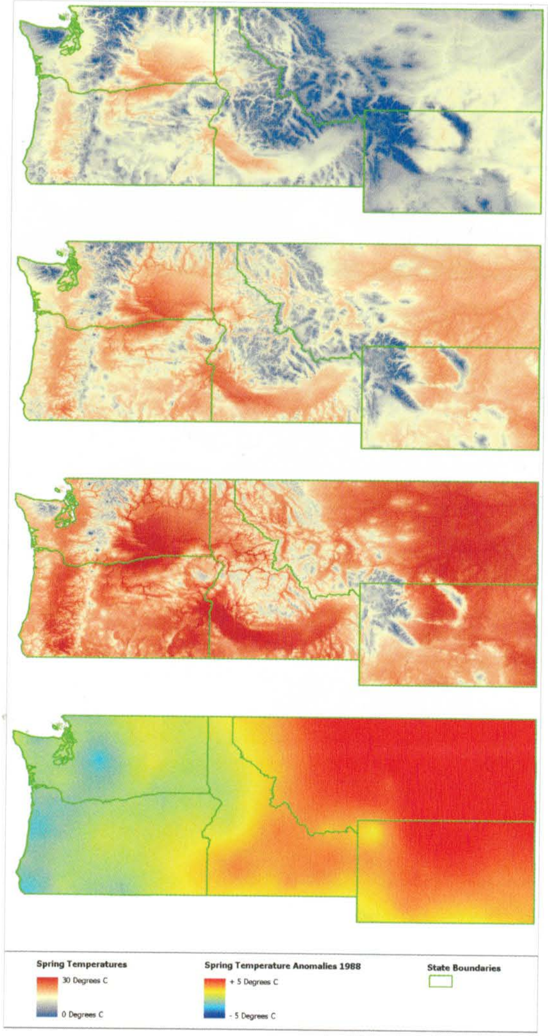

Figure 4.7: COASTER was used to produce an assessment of spring temperature anomalies for five western states (bounded by green line work). A blue-yellow-orange-red color ramp displays variation from -5C to +5C, signifying cooler to warmer temperature changes. (Figure courtesy of the Yellowstone Ecological Resource Center; data courtesy of YERC, USGS, NASA Ames Research Center, ArcUSA, US Census, and Esri)

Probability Function (RSPF). The tool, based on ArcGIS, helps organize and resample data to user-defined grid resolutions and supports the creation of merged data arrays (MDA)—basically a table created from the intersection of all environmental values by spatial location—great for use in statistical programming environments. The RSPF tool combines a number of tedious steps involved in preparing data for export, greatly streamlining an otherwise time-consuming process.

In the case of the pronghorn antelope study, the species observations included 762 telemetry fixes from 26 collared animals from May to July of 2005 (visible as the top layer of the data integration stack in figure 4.8). The *spatial extent* of analysis was defined by this data in combination with expert knowledge of known habitat use. The *spatial resolution* for all environmental data was a 100-meter grid produced by resampling of the data as appropriate.

Various modeling techniques were used to create forage, herbaceous, sage, soil, and cumulative NPP layers (*process models*). Additional models using empirical field data created coyote and wolf intensity of use and small mammal biomass layers. Finally, *available space* layers were created using one-kilometer buffers around each pronghorn location in which points were randomly generated over that space to simulate potential habitat use. Since the spatial scale at which pronghorn select their habitat was unknown, this process was repeated at three kilometers and five kilometers for comparative analysis.

Analysis and Modeling

Once the data is prepared, describing the landscape and defining how it operates, the evaluative modeling can occur (*evaluation models*) to determine whether the landscape is working well. This involves a number of statistical analyses that occur in the open source statistical programming environment R, which is accessed from within the

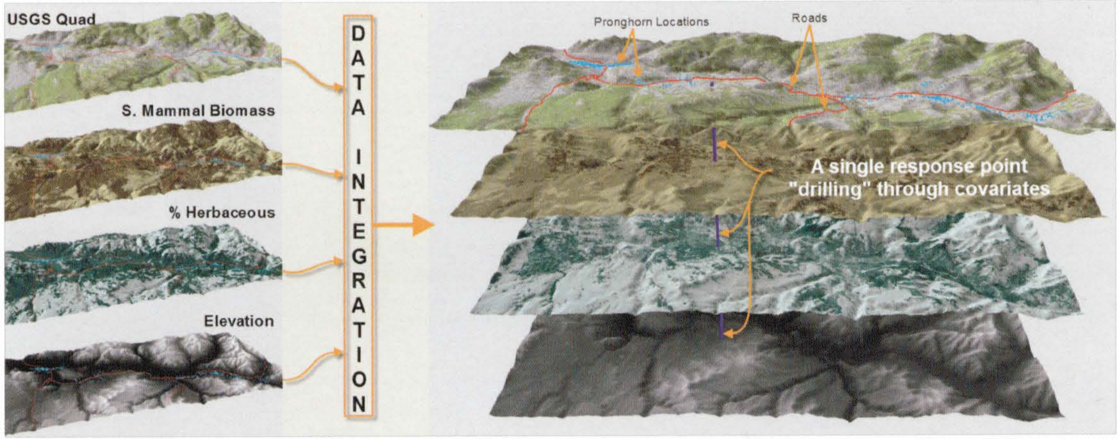

Figure 4.8: When all data is referenced to a common coordinate system, the referential link gives the scientist or manager the ability to investigate all the various interdependencies of a single point to all other data, increasing the efficiency and quality of inquiry. (Figure courtesy of the Yellowstone Ecological Resource Center; data courtesy of YERC, NPS, USGS, ArcUSA, and Esri)

ArcGIS environment. EAGLES uses the RSPF tool to create species distribution models and a statistical model for intensity of use. Optimization routines (e.g., Nelder-Mead, simulated annealing) are used to "fit" the model to the available data and associated assumptions (figure 4.9).

Model Assessment and Interpretation

Results from the preliminary data exploration and analysis both require a degree of statistical understanding to effectively build a model and interpret the results. For a model to be scientifically defensible, it should meet two criteria: (1) it should be the best model of a suite of candidate models, and (2) it should provide an adequate overall fit to the data.

The EAGLES tools provide users with a number of statistical mechanisms for addressing these criteria. The intent of EAGLES is to provide users with access to a powerful modeling and visualization framework without requiring extensive statistical programming knowledge.

Examining Alternative Futures—Ecological Forecasting

EAGLES has a tool called the Swap tool that enables users to build alternative scenarios (*change models*) using an already constructed model and change only one attribute while holding all else constant to examine the effects of that change on the model. This approach allows a transparent investigation of the changes in levels of treatments such as geophysical layer alterations, changes in forage availability, or more sophisticated modeled input layer substitutions. The goal is to apply a model previously fit to observed data to a potential scenario, in an effort to make projections about the ecological ramifications of a given landscape change (*impact models*).

> The goal is to apply a model previously fit to observed data to a potential scenario, in an effort to make projections about the ecological ramifications of a given landscape change (*impact models*).

For example, a forecast about the impact of building a new road through a habitat would rely on the input of a new layer that contains the proposed road (figure 4.10). The user can then apply the fitted RSPF model to the new road

Geodesign starts by defining key issues of concern that frame the question or hypothesis to be considered to meet management objectives.

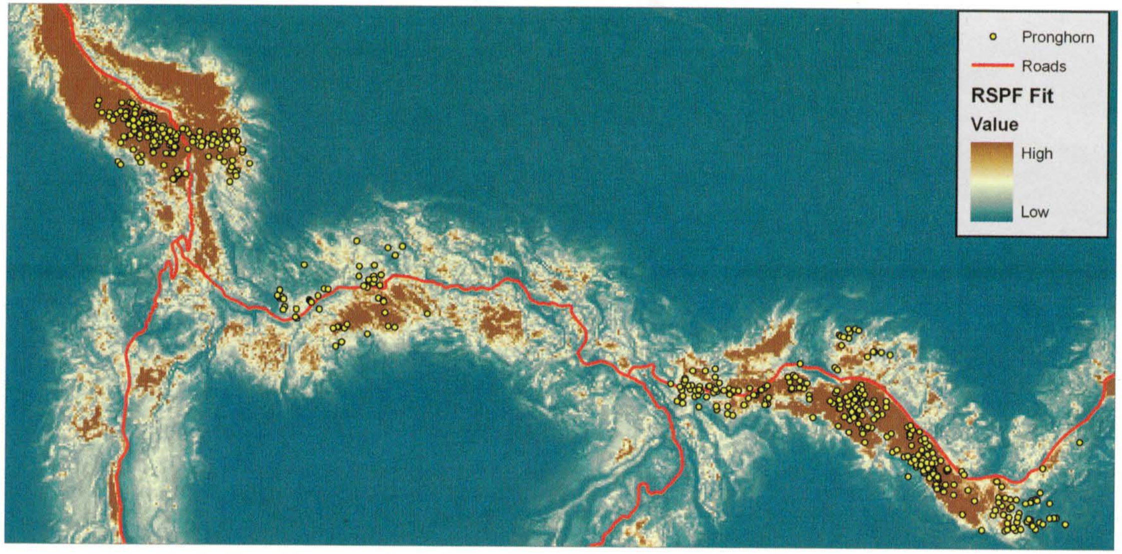

Figure 4.9: The final component of the RSPF output is the predicted RSPF surface for the best model, which is fitted and displayed in ArcGIS. Again, pronghorn observations are represented by yellow dots and roads as red lines. Percent of species/habitat model fit from high to low is represented by a color ramp that goes from brown to yellow to blue, with brown being a good fit and blue being a low fit. The prediction for pronghorn habitat use looks reasonable based on biological knowledge of this system: the large swatch of good habitat that is apparently not used in the upper left-hand corner of the surface is a traditional winter range. (Figure courtesy of the Yellowstone Ecological Resource Center; data courtesy of YERC, NPS, USGS, ArcUSA, and Esri)

layer (instead of the original layer) and view the response surface under the changed landscape. Such projections allow a measured assessment of habitat change. Visualization of the resulting surface occurs in GIS, and the resulting equations and models can be examined statistically as well. The intent is to provide a utility for planning for landscape change.

The Swap tool resides within the RSPF functionality and can be applied to an RSPF model and surface once a hypothesized alteration to the landscape has been built. Additional types of alternate landscape conditions include products such as expected forest density after thinning, forage production after burning, or NPP change under a future climate scenario.

Discussion

The EAGLES workflow closely parallels the geodesign workflow fulfilling both the *assessment* and *intervention* phases of Steinitz's model. It starts by defining key issues of concern that *frame* the question or hypothesis to be considered to meet management objectives. This in turn identifies the data needs and drives data collection and integration using customized search and data integration techniques that streamline the compilation of species and environmental geospatial datasets. This data (*representation models*) forms the backbone of the *assessment* phase.

In addition, EAGLES includes a number of procedures for the creation of *process models* that describe both static and temporal aspects of ecosystem processes. Elevation, slope, soil, wetness, productivity, forage, and vegetation cover are all derived from a multitude of datasets that represent the physical processes of the environment. These, as well as other datasets and tools like COASTER, are used to create assessment models that evaluate the condition or suitability of the environment, particularly with respect to capacity, hazards, or resources for a given species (*evaluation models*).

EAGLES is designed to aid resource management decision making by providing support for species habitat planning efforts that integrate changing landscape conditions with demographic responses. Managers seeking to evaluate multiple development plan proposals can use this system to compare alternative scenarios (*change models*), including changes in land-use practices, and explore their implications using hypothetical what-if scenarios (*impact models*). For example, managers can use this set of tools to investigate how a species of concern currently uses a portion of landscape and how that use pattern might change when the landscape is altered (e.g., through fire, flood, or development).

Lessons Learned

One of the obstacles to rapid adoption of the geodesign concept by the design disciplines is the time it takes to find, compile, and integrate relevant data into a common format for use in analyses. A second stumbling block occurs in the difficulty of tracking, archiving, and making available the complex data inputs that feed into ecological and species modeling efforts. One benefit of the EAGLES toolset is that it actually streamlines this process by allowing users to identify the geospatial data inputs, the region of interest, the scale, a common data resolution, and even a temporal resolution to make it easier to assemble available national datasets into a common georeferenced coordinate system using ArcGIS. Applying such a workflow to standardized datasets across the United States would help propel the adoption of geodesign.

Managers seeking to evaluate multiple development plan proposals can use this system to compare alternative scenarios, including changes in land-use practices, and explore their implications using hypothetical what-if scenarios.

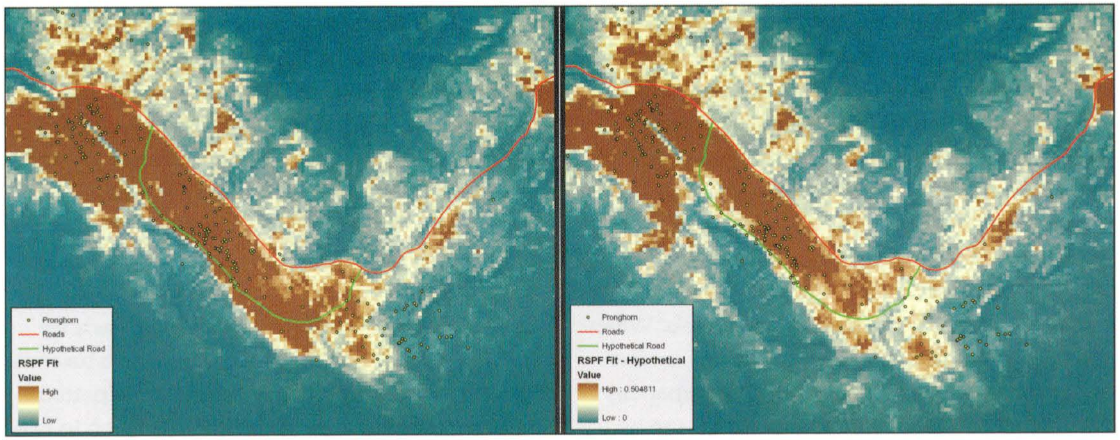

Figure 4.10: The map on the left displays a portion of the original RSPF model showing predicted habitat use for pronghorn in Yellowstone National Park. The Swap tool was used to apply the RSPF model to a hypothetical road addition (shown in green). The new prognostic RSPF model output for pronghorn (right) indicates that pronghorn would be excluded from portions of their original selected habitats. (Figures courtesy of the Yellowstone Ecological Resource Center; data courtesy of YERC, NPS, USGS, ArcUSA, US Census, and Esri)

When changes to the landscape are proposed, or seen as inevitable, in the case of natural disturbances or climate change, alternative scenarios can be considered and plans put in place to minimize the projected impacts. This is the power of geodesign for natural resource planning, which typically requires a strategy of adaptive management.

Figure 4.11: A braided stream of snowmelt winding its way through the valley. (Photo courtesy of Hamilton Greenwood)

Another benefit of EAGLES is the integration of scientific, domain-specific statistical analytics within the ArcGIS for Desktop platform. Species, habitat, and ecosystem modeling is based on complex system dynamics that often require analyses in statistical packages that run outside the GIS environment. But that's only part of the puzzle. When this data interacts with geospatial data, the synthesis of the various combinations and the visualization of the data over the landscape inform and improve the models. When changes to the landscape are proposed, or seen as inevitable, in the case of natural disturbances or climate change, alternative scenarios can be considered and plans put in place to minimize the projected impacts. This is the power of geodesign for natural resource planning, which typically requires a strategy of adaptive management.

As the degree of complexity in statistical analyses and remote sensing data increases, a set of standardized techniques and common data protocols becomes more essential, especially when supporting repeatable, transparent methods for ecological modeling. The successful intersection of these two domains requires workflow architectures that are simple enough to be widely adopted yet sophisticated enough to meet the criteria for decision-making standards. This requires a balance between high-level thinking of ecological pattern detection alongside the necessary attention to fine detail that allows researchers to model the ecological world accurately.

Finding solutions to major ecological challenges will require *new ways of thinking.* It is no longer humans *against* nature or humans *in* nature—it is humans *with* nature. Whether it's Yellowstone's pronghorn antelope, grizzly bear populations, or the collapse of Pacific Northwest salmon runs, science and GIS have lifted each of these issues—and many others like them—from subjective opinion and polarization to a place where decisions could be made on the basis of facts.

The work done by YERC is a significant contribution to the field of geodesign, which seeks to integrate the two most complex systems on earth—human social systems and ecological systems—directly into the acts of design and planning.

Key Links

Yellowstone Ecological Research Center
http://www.yellowstoneresearch.org/index.html

Yellowstone National Park
http://www.nps.gov/yell/index.htm

NASA
http://www.nasa.gov/

US Fish and Wildlife Service
http://www.fws.gov/

Acknowledgments

Special thanks to Robert Crabtree, Jennifer Sheldon, Brandt Winkelman, Yellowstone Ecological Research Center, and P.J. White, Yellowstone National Park. A good deal of the chapter content came from the *EAGLES User Manual.*[9] Thanks also to Hamilton Greenwood for permission to use his lovely photographs of species, adding greater meaning and context to the chapter.

Notes and References

[1] Paul Schullery, *Searching for Yellowstone: Ecology and Wonder in the Last Wilderness* (New York: Mariner Books, 1999), 7.

[2] Native American Tribes of Montana website, http://www.native-languages.org/montana.htm.

[3] "Yellowstone National Park," UNESCO World Heritage Centre web page. Retrieved May 6, 2011, from http://whc.unesco.org/en/list/28.

[4] Yellowstone Ecological Research Center website. Retrieved May 11, 2011, from http://www.yellowstoneresearch.org/about_mission.html.

[5] J. Beel, B. Gipp, and C. Müller. "'SciPlore MindMapping'—A Tool for Creating Mind Maps Combined with PDF and Reference Management," *D-Lib Magazine*, November/December 2009.

[6] Net primary production is the rate at which all the plants in an ecosystem produce net useful chemical energy. Retrieved May 16, 2011, from http://en.wikipedia.org/wiki/Primary_production#GPP_and_NPP.

[7] EAGLES geospatial wiki, http://geospatialdatawiki.wikidot.com/.

[8] COASTER, http://www.coasterdata.net/.

[9] K. R. Manlove, D. J. Weiss, and J. W. Sheldon, *EAGLES User Manual* (Bozeman, MT: Yellowstone Ecological Research Center, 2011). Retrieved May 16, 2011, from http://www.yellowstoneresearch.org/download/EAGLES_Manual.pdf.