Climate Change Adaptation Strategies for BLM Resource Management in Southern Nevada

A Pilot Test of the Yale Mapping Framework

Final Report to Yale University

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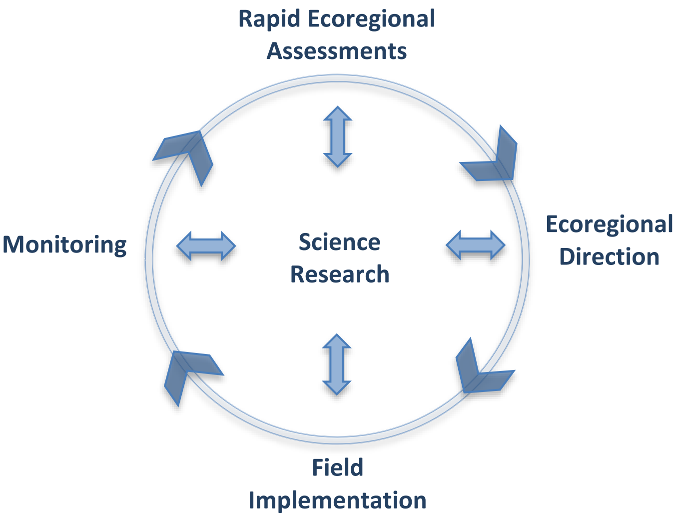

This pilot project investigated the potential application of Yale Framework analyses and approaches (http://databasin.org/yale) for public land management; where natural resource assessment aims to provide context and information for planning decisions. The project built upon current research carried out for the Department of Interior, Bureau of Land Management's (BLM) Rapid Ecoregional Assessments (REAs—see process diagram right) within the ecological transition between the Mojave Desert and Great Basin ecoregions of southern Nevada.[1] **Key stakeholders** for this project included BLM staff in state and field offices within Nevada with responsibilities for natural resource management planning. The BLM field offices of Tonopah, Caliente, and Las Vegas were emphasized. More broadly, this pilot should have relevance to other land managers and planners, especially if managing for 'multiple-use,' and where regulatory requirements apply under the National Environmental Policy Act (NEPA).

Adaptive management in natural resource conservation implies an iterative approach to decision making[2]. It presumes that knowledge remains incomplete and circumstances change continuously, so management is structured as an ongoing, learning process. Adaptive conservation commonly includes generalized phases of assessment, planning, implementation, and monitoring. This approach has been formalized by the BLM under their "Landscape Approach," where REAs provide contextual input to subsequent planning decisions. Assessments seek to understand past, current, and forecasted patterns among key resources and change agents across the entire ecoregion. They document trends that need to be addressed to achieve agency goals. Planning processes specify management goals and objectives, and commonly take shape within Resource Management Plans (RMPs) that determine areas of emphasis in conservation or extractive resource use, and provide guidelines for site-level activity including needed restoration and mitigation. Plans are typically developed within a given BLM field office but may be developed over larger landscapes. Monitoring focuses on key parameters identified within prior assessment and planning phases, and sets the stage for periodic iterations of the adaptive management cycle.

An adaptive approach is essential with a changing climate. Change is likely to accelerate and bring increasing levels of uncertainty to decision making. We now face the challenge of aligning assessment and planning processes to better foresee rapidly changing conditions and provide insights into the type,

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[1] Link to project area map Figure 2, and reference Appendix A on BLM REA background
[2] Link to website: http://structureddecisionmaking.org/index.htm

location, and timeframe for appropriate management action. The latter factor, - *timeframes* - tend to differ for assessment vs. planning. Timeframes for ecoregional assessments pertain to the prior century, current conditions, and forecasts extending over the coming 50 years. In contrast, planning decisions are taken within 1, 5, 10, or perhaps 15-year planning cycles. Therefore, a key challenge is to glean insights from assessments organized around longer timeframes that will inform the planning decisions of the coming decade. Determining which actions to take today, versus postponing them for subsequent cycles of assessment, will become an increasingly critical facet of natural resource management in the 21st century. Through this project, we aimed to explore these questions and test analyses suggested by the Yale Framework to assist BLM with their planning decisions.

Methods

The Yale Framework sets out a series of potential adaptation objectives. Some center on conserving current patterns of biodiversity and maintaining ecological processes; others emphasize forecasting future patterns and/or identifying potential climate change refugia. Potential analyses are organized around levels of ecological organization, including landscape, ecosystem, or species levels[3]. This framework therefore sets up a menu of approaches that, depending on user needs and capacities, provides a robust starting point for climate change adaptation.

We gathered BLM staff from the Nevada state office to review the framework and then identify which approaches were both feasible within a 6-month project timeframe and most likely to be informative for planning decisions[4]. We then formulated a series of specific management questions to be addressed by each analysis[5]. This facilitated clarification and agreement among the team on expected outputs and detailed focus of each analysis. This also provided an opportunity to clarify the expected utility of each analysis to various forms and stages of BLM resource decision making. Since many spatial analyses already completed for each ecoregional assessment fit neatly into the Yale Framework, we could build directly on those prior efforts. In other instances, we completed new analyses and adaptive actions specifically suited to Framework recommendations. Data sources, technical methods and tools under each analysis are briefly referenced below in the results section, but are explained in greater depth in Appendix C.

Following from methods applied in the REAs, we established a set of **conservation elements**, **change agents**, and **scenarios** that would be used in each analysis. Conservation elements include the natural resource values of conservation concern. Here we included a subset of representative ecological systems and habitats that characterize the regional transition from warm desert (Mojave) to cool desert (Great Basin). We also selected several landscape species, or species with relatively large home-ranges and migratory requirements as a second focus for analysis. Again, these included species that

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[3] Cite the framework master table elsewhere in the website

[4] See Table 2 for matrix of approaches utilized in this pilot.

[5] See

Table 1 for full listing of MQs addressed in this project.

characterize both southern (warm desert) and northern (cool desert) portions of the study area. Change agents include human land uses and effects that alter the natural ecological processes supporting our selected conservation elements. Besides the potential effects of climate change, urban and industrial development, invasive species, and altered natural fire regimes were selected for inclusion in these analyses. Scenarios are aimed at spatially representing land use, management, and other change agents for different timeframes to understand how conservation elements may be sustained at each timeframe. For this project, scenarios were derived from the REAs for current conditions (2012), along with forecasted land use and invasive species conditions *circa* 2025, and forecasted climate-change-influenced conditions *circa* 2060. Each scenario was cumulative of change agents from previous timeframes.

As each analysis was completed, BLM staff provided reviews via web meetings to evaluate and interpret results. This allowed staff to fully understand the data sources, technical tools, and outcomes from each analysis. A two-day workshop was then conducted to review the complete set of analyses results and to document their applicability to management planning. This documentation included the potential for each analysis to a) identify the need to change current management, b) identify, construct, and evaluate alternative management solutions, c) establish the potential timeframe for implementing the management action, and d) considerations for documenting uncertainty associated with each management alternative.

Results

We could address most components of the Yale Framework in this project. Because each analysis was applied to many distinct combinations of conservation elements, change agents, and land-use scenarios, we have included here just a representative cross-section of results for purposes of illustration.

Protect Current Patterns of Biodiversity – Managing for Ecological Integrity

This starting point in the Yale Framework follows common recommendations (e.g., Glick et al. 2011) to first focus on reducing current stressors on biodiversity to improve resilience for climate change effects. The first series of analyses within the Framework apply to current ecological pattern and process. Specifically, the Framework includes objectives of “protect current patterns of biodiversity,” “maintain ecological processes” and “maintain and restore ecological connectivity.” Clearly, the most urgent climate change adaptation strategy is to secure and maintain high-integrity ecosystems today. The novel ecosystems of the future will result from the transformations of today’s ecosystems. High-integrity ecosystems are more resilient to both the loss and novel introduction of individual species over time. Where ecological processes have already been disrupted, and species have already been lost, the chances of ecosystem collapse increase. Therefore, a clear focus today on maintaining and restoring composition and structure (where feasible) provides insurance against ecosystem collapse – and avoidable species extinction - with a changing climate.

We first addressed components of the framework specific to mapping the current location of ecosystem types and species habitats. We evaluated their relative representation within current and proposed conservation designations and then conducted a systematic evaluation of their ecological integrity and relative landscape connectivity. Finally, we assessed potential loss of biodiversity from current and future change agents through conflict analyses.

Ecosystems: Map Terrestrial and Aquatic Ecosystems and their Associated Services. Figure 1 depicts the current distribution of Inter-Mountain Basins Big Sagebrush Shrubland[6]. This type is classified and described by NatureServe as one of over 600 mid-scale terrestrial ecosystem types occurring within the conterminous U.S. (http://www.natureserve.org/explorer/). This classification was used as the basis for national mapping efforts by the USGS Gap Analysis Program and inter-agency LANDFIRE effort; and provides one practical scale for treating ecosystems in climate change adaptation. Common methods for mapping types based on existing vegetation include inductive modeling methods (see e.g., Ohmann and Gregory 2002; Lowry et al. 2007). With these methods, thousands of georeferenced field samples – each labeled to its classification type - are used to 'data mine' through multiple map layers, including spectral bands from satellite imagery, landform, soil, and other biophysical variables. The combination of mapped variables that best explain the distribution of field samples then form the basis for mapping that type. A very similar statistically based approach is deployed for individual species habitat maps[7]. Once maps were generated we could use the NatureServe Vista ArcGIS extension to map diversity as recommended in the Yale Framework under this section. This might be viewed as a specialized depiction of alpha diversity; where richness maps reflect the concentration of localities of elements selected using a coarse/fine filter approach. This information provided a visualization of useful biodiversity patterns within the region (Figure[8]).

For multiple-use planning, quantifying the relative representation of conservation elements within current and proposed protected areas is common practice. We completed a 'gap analysis' documenting the proportional distribution of each conservation element within GAP status 1 and 2 lands (i.e., high-levels of biodiversity protection) *vs.* lands identified as potential (but undesignated) conservation areas *vs.* all other lands within the study area. We also overlaid land ownership maps to further differentiate these distributions by land manager, and highlight the relative contributions by BLM field offices. This clarified areas where management change might be considered. For example, for Inter-Mountain Basins Big Sagebrush Shrubland, with over 2.5 million acres in the study area, 21% currently falls within designated protected areas, 24% falls within lands suggested for enhanced protection, and some 360,000 acres suggested for enhanced protection fall within BLM jurisdiction.

Ecosystems: Map Areas of High Ecological Integrity. Here we aimed to address one primary management question: ***What is the current ecological integrity of our key CEs and what changes to management might maintain or restore ecological integrity?*** Throughout the Rapid Ecoregional Assessment, relative effects of change agents on each conservation element (CE) were addressed by gauging ecological integrity. Conceptual models for each CE were used to document current knowledge about the primary change agents and their effects on each CE. The methods used here have been developed over the past decade by NatureServe and partners (see e.g., Schorr et al. 2000, Unnasch et al.

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[6] Link to sagebrush distribution map in the study area Figure 1

[7] See e.g., http://www.cs.princeton.edu/~schapire/maxent/

[8] Point to Conservation Value Summary Figure 7

2008, Faber-Langendoen et al. 2009; Rocchio and Crawford 2011). This method translates conceptual models into a “scorecard” of indicators for reporting on the ecological integrity of a given CE within a given location. Indicators are chosen to gauge a limited set of **key ecological attributes**, or ecological drivers, for each CE. Key ecological attributes may include natural characteristics, such as native species composition (with indicators typically measured in the field). Indicators may also be addressed through remote sensing and spatial modeling, these often focusing directly on known ecological stressors. Given the rapid and regional character of an REA, stressor-based indicators were relied upon. Indicators were selected that practically enabled reporting of CE integrity by 5th level watershed and 4 x4 km grid cells (the latter indicated by BLM as sufficient for most non-project specific planning applications). For this effort, we utilized results of three primary indicators of ecological integrity for each of our conservation elements. These included a spatial model of landscape condition, a predictive map of invasive annual grass abundance, and measures of wildfire regime departure. Figure4[9] shows the relative scores for invasive annual grasses, as related to the distribution of pygmy rabbit (*Brachylagus idahoensis*). While ecological integrity indicators from the REA aimed to provide an ecoregion-scale snapshot of current conditions, BLM planners and field staff indicated that this level of information would assist considerably in their resource allocations for ecological restoration and monitoring.

Species: Maintain and Restore Ecological Connectivity. Ecological connectivity can encompass a wide range of phenomena; all of which are important to climate change adaptation in natural resource management. Most commonly, “connectivity” relates to landscape linkages for individual species. A broader view of connectivity might simply be called “landscape permeability” aiming to more generally reflect the relative connectedness of any given place to other surrounding portions of the regional landscape. This concept and approach are generally NOT aiming to reflect needs or constraints of individual species, but instead provides a general indication of the potential for lateral connections from the perspective of many ecological phenomena. These could include generalized species movements for e.g., pollinators, birds, plants, or for disturbance dynamics, such as wildfires.

Here we posed a single management question: ***What does generalized landscape connectivity contribute towards the current ecological status of our key CE and where are current barriers to this connectivity?*** To address this question, we utilized an existing regional model of landscape permeability, and compared its output with a species-specific linkage surface developed for desert tortoise (*Gopherus agassizii*). While multiple approaches and tools have become available for analyzing these phenomena, we used *CircuitScape*[10] in both instances[11]. Even though desert tortoise occurs throughout the Mojave Desert, except for steep slopes and isolated mountain ranges, the specialized desert tortoise model provided much more specific information on sensitive linkage areas than did the generalized landscape permeability model, and was strongly preferred by BLM planning staff. In instances where at-risk species have large landscape requirements for movement among meta-populations, a specialized linkage model is likely to be necessary to inform management decisions.

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[9] Point to pygmy rabbit map Figure 4

[10] Link to *CircuitScape* software http://www.circuitscape.org/Circuitscape/Welcome.html

[11] Point to Desert Tortoise *CircuitScape* output Figure 5

Ecosystems and Species Conflict Assessments

These assessments utilized the NatureServe Vista ArcGIS extension to characterize scenarios as described above under Methods for current (2012) and 2025 (Figure[12]) to answer the management question: ***By 2025, what proportion of these key CE values is likely to be affected by renewable energy and other forms of urban/industrial development?*** The scenarios included current and proposed/planned developments (urbanization, infrastructure, and energy) as well as current and future forecast invasive species and current fire plus beneficial management/protection. The Vista DSS then uses expert information on response of conservation elements to change agents (Figure[13]) and management/protection practices to quantify areas of each conservation element as compatible or in conflict with scenario features for each timeframe (Figure maps[14][15] and reports[16]). Results indicate that while the ecoregion currently offers fairly high levels of support for conservation elements, future spread of invasive species coupled with transmission development pose significant threats to biodiversity. This approach is not a replacement for ecological integrity assessment, which provides a more specific and nuanced view of how change agents affect biodiversity but rather provides a rapid assessment of the sum of change agent conflicts on the distribution of conservation elements. The Vista tool can also accommodate landscape condition modeling which is one component of ecological integrity modeling. This approach and tool also support mitigation and adaptation planning which we illustrated through examples as further explained under the section below ***Protect Climate Refugia***.

Forecast Climate Change and Effects

To assess the degree of forecasted change in climates within the study area, temperature and precipitation values from climate models were compared to observed 20th century data (specifically, 1905-to-1980) derived from PRISM[17]. Because there may be a large degree of uncertainty in modeled projections of future climate, we mapped future climate as derived from seven climate models vetted for the IPCC's 4th Assessment Report (IPCC 2007) and downscaled to a 4X4km grid. This is the EcoClim data set developed by Dr. Healy Hamilton and colleagues. The time period representing future climate for this analysis was a 10-year period from 2050-2060. Only the A2 greenhouse gas emissions scenario is being examined in the climate forecasts. Using climate forecasts, we first attempted to address the management question: ***By 2060, what portion of BLM managed land is likely to occur with climate regimes significantly departed from 20th century character; and which climate variables might contribute most to that change?*** Using an analysis that we refer to as "climate space trends," we established a 20th century baseline by calculating mean and standard deviations on a per-pixel basis for monthly climate variables of average maximum temperature (TMax), average minimum temperature (Tmin), and total precipitation. Using the same calculation for mean values from the forecast models, we compared forecasted to baseline values and mapped pixels where 2050-2070 mean values are forecasted to occur outside of 1 and 2 standard deviations from the baseline means. This forecasted deviation, on a per-pixel basis, provides a spatially

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[12] Point to figure of scenario Figure 9
[13] Point to figure of Vista interface Figure 8
[14] Point to map of individual element impact map Figure 11
[15] Point to Compatibility Conflict map Figure 12
[16] Point to Scenario Evaluation Report Figure 10
[17] http://www.prism.oregonstate.edu/index.phtml

explicit indication of forecasted climate stress. Once identified, users can investigate exactly which variables explain the significant deviation(s). For example, a given 4X4 km pixel might indicate that 4 different variables are forecasted to deviate by 2 stdv by 2060. One could then clarify that those variables are in fact Tmax for the months of May, June, July, and August, or some other combination of monthly Tmax, Tmin, and Total Precipitation variables. Figure 5[18] one summary output where as many as six monthly maximum temperature values are forecasted to depart by > 2 stdv from the 20th century mean values. The months and forecasted changes in temperature highlighted by this analysis are available to planners within this data set. This pattern can be evaluated relative to the distribution of each BLM field office within the study area. These forecasts can be linked to other models, such as hydrologic models designed for local basins, or fire regime models, where temperature and precipitation trends can influence forecasts of fire return intervals.

The next management question we addressed was: ***By 2060, what proportion of the CE distributions are likely to occur within their 20th century climate regime, and what areas within and outside of those distributions might provide robust local-scaled refuge from a changing climate?*** To address these questions, we first developed forecasts of climate envelopes for our major conservation elements. By "climate envelope" we mean the combination of monthly temperature and precipitation variables that characterize the current distribution of each CE. Dr. Hamilton and colleagues used Maxent, a spatial distribution modeling tool, to developed statistical correlations between observed locality data and 20th century climate regimes for each CE, and then forecast the high-probability relationships to map 2060 envelope distributions based on future climate scenarios. This approach does not presume that current distributions delineate the full biophysical limits of each CE distribution, but rather that they reflect central tendencies within that distribution.

As many as six forecasted distributions were developed for each CE, applying results from multiple downscale forecast models organized within the EcoClim data set. This enabled further evaluation of model confidence, highlighting where more than one model forecast agreed. From these multiple forecasts, we identified all 4X4 km pixels where at least two models agreed that a) there was overlap between current and 2060 forecasted distribution, b) where forecasts indicate a contraction in distribution, and c) where models indicate an expansion in distribution. See Figure 14 [19] as an example where the climate envelope for pinyon-juniper woodlands, characteristic of the mountain ranges throughout the study area, are forecasted to contract in a general south-to-north direction throughout at nearly 50% of its current range within the study area. Similarly, forecasted expansion includes several mountain ranges, where an apparent move to higher elevation is indicated. Similar trends can be observed for other major types of upland vegetation, as well as for landscape species (Figures 15-20).[20] Clearly forecasted trends for a given CE differ across the study area, providing distinct perspectives for planners and managers in difference BLM field offices of this study area.

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[18] Map of climate space trends for Tmax departures Figure 6

[19] PJ woodland Figure 15

[20] Indicate climate envelope shift maps for other CEs Figure 16, Figure 17, Figure 18, Figure 19, Figure 20, Figure 21

By analyzing the **combination of climate envelope trend maps** for all major vegetation types in the study area, planners and field ecologists can formulate hypotheses about the nature of landscape change that are plausible for a given area. For example, the combination of envelope trend maps indicates that the western basins, currently dominated by desert playas and mixed salt desert scrub, appear to be quite vulnerable to severe contraction of current plant species. Playas might logically expand in extent and other areas could be encroached upon by related species from the adjacent Mojave Desert. From these multiple models, one can better anticipate that extreme xeric vegetation characteristic of most desert basins will expand at the expense of mid-elevation type, such as Joshua tree-blackbrush scrub in the Mojave Desert, and big sagebrush shrubland in the Great Basin. Species strongly tied to these habitats, such as desert tortoise, associated with creosotebush desert scrub to the south, or greater sage grouse, associated with big sagebrush shrubland to the north, indicate similar trends in their distribution.

Potential **refuge from climate change** may be identified in several ways. Forecasted climate envelopes, especially when developed for a cross-section of conservation elements in the area, can provide one means to do so. Figure 21[21]_ indicates the overlap of climate envelope forecasts from all major upland vegetation types within the study area. This technique provides a count for the number of types per pixel where individual models show an overlap between current and forecasted 2060 envelopes. For 21 vegetation types mapped, as many as eight types coincide at selected northern and high-elevation locations throughout the study area. This contrasts with western basins where no upland vegetation models indicate overlap between forecasted and current climate envelopes. A similar, albeit distinct pattern emerges with the same type of analysis of models for the seven targeted landscape species in the study area (Figure 22)[22].

Project Future Patterns of Biodiversity and Conflict

This analysis used identical approaches and tools as described earlier under Ecosystems and Species Conflict Assessments. In this case we assessed how future patterns of biodiversity may be impacted by cumulative development and invasive species change agents through 2025 to answer a variation of the management question posed in the previous conflict assessment as:

By 2025, what areas of climate-change refugia and potential CE expansion areas are likely to be affected by change agents, particularly renewable energy and other forms of urban/industrial development?

The key purpose of such analyses is to link current biodiversity retention and restoration with potential future biodiversity distribution to identify “robust” strategies (Glick et al. 2011) and avoid maladaptive responses. Essentially this means prioritizing areas to receive restoration that will provide current and likely future benefits as well as apply avoidance mitigation to new development that will reduce current impacts and relocating features will not conflict with expected areas of concentration for biodiversity refugia. To conduct this work, we assessed the maps of climate refugia and expansion areas described above against the 2025 scenario to understand how future development and invasives spread may

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[21] Climate refugia based on counts of veg envelope overlaps Figure 22

[22] Climate refugia based on counts of landscape species envelope overlaps Figure 23

impact such areas (Figure 13[23]). Next, we selected a sample of locations to illustrate how typical mitigation, restoration, and adaptation strategies can be expressed in a decision support tool. These examples included restoration of future core mule deer wintering habitat and two examples of using avoidance to relocate planned solar and transmission development from areas that would cause current and future conflicts to areas that would cause fewer current and future conflicts (Figure 14[24]). We emphasize that these mitigations and adaptations are for illustration purposes only and did not consider the full range of siting considerations and prioritization required.

Protect the Ecological Stage

Within the Yale Framework, the notion of mapping **"enduring features"** is included as an adaption strategy. There are several alternative approaches to mapping these units, and many more options for applying them to climate change adaptation. We chose to briefly explore several technical options for mapping enduring features for use in defining local-scale climate-change refugia within the study area. Our goal was to provide a robust measure of ecological heterogeneity in upland environments that could be used in combination with other maps of vegetation or species distributions, such as the 4 X 4km climate envelope maps previously mentioned.

We first developed a map of geophysical heterogeneity, following approaches commonly referred to as "ecological land units" or ELUs (Anderson and Ferree 2010). Utilizing a 10x10m digital elevation model for the study area, we applied one of many current algorithms to map a series of major landforms for the study area (Tagil & Jenness 2008) (Figure 25). Local-scale landform often drives vegetation pattern and finding a relatively small number of landforms typical to the basin and range physiography of the study area was not difficult. In a temperate desert environment, relative radiation input, or insolation is another very strong driver of vegetation pattern, with southerly-facing slopes receiving far more intense input that relatively protected north facing slopes. We developed a companion input to the landform model describing insolation using one of many useful modeling algorithms (McCune & Keon 2002). While physical and chemical properties of surficial geology and soils are often used in geophysical models of this type, we chose not to include them given the incomplete nature of soils information, and spatially coarse resolution of surface geology data within our study area. Weighing relative impacts on biotic response, especially in warm desert environments, these variables could be viewed as of secondary importance for our purpose.

A second readily available model suitable for this purpose is the national map of Biophysical Settings developed and maintained through the inter-agency LANDFIRE effort. We used this map to depict biophysical heterogeneity for the study area (Figure 25). This map, with an approximate minimum map unit of five hectares, depicts the predictive distribution of some 500 terrestrial ecological system types across the nation; given assumptions of natural disturbance processes. These concepts match our major vegetation types selected for analysis within our study area. While this map does not incorporate the same level of local detail derived from the landform model, it does readily incorporate climate-based

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[23] Point to refugia cumulative effects index map Figure 13

[24] Point to map of example adaptations/mitigations Figure 14

elevation gradients common to this basin and range physiography; where elevations span multiple life zones, from desert basin bottoms up through high montane elevations.

Anticipating the combination of our geo/biophysical heterogeneity models with 4X4 km climate envelope data, we chose a regular 4km^2 hexagon as a simple spatial index unit (Figure 26 and Figure 27)[25]. By simply totaling the number of classes from each hexagon, we created an index score for each, and a spatial index for the study area. To identify portions of the study with relatively high geo/biophysical heterogeneity, we simply calculated a mean value across all hexagons, and then selected all with above average scores from each index. The result, unsurprisingly, highlights the mountain ranges throughout the study area. Differences between the geophysical and biophysical index results are likely explain by the representation of elevation gradients within the biophysical model; although additional investigation might identify additional factors.

We then took the result of each model and overlaid each with the climate envelope trends maps for each CE (Figure 28)[26]. This indicates relatively high ecological heterogeneity across these distributions. This general type of application for using biophysical heterogeneity as a climate-change buffering aid in biodiversity reserve network design has a long history (see e.g., Nachlinger et al. 2001, Neely et al. 2001[27]). There is some reasonable potential that, as individual species respond to climate stress across this study area, areas with climate envelope overlap AND high local heterogeneity will likely provide the most secure climate change refuge. Those heterogeneous areas located within forecasted climate envelop contraction zones might have some additional time to move relative to less heterogeneous areas.

Evaluating the Framework

Our objective was not so much to reach conclusions from the assessment as to explore the “menu of approaches” in the Framework and develop information and a decision support system for integration into multiple scales and planning functions of BLM. Working through the modules with BLM provided information on the value of information products for BLM purposes. The most useful information identified by BLM is:

- Current location and ecological integrity of conservation elements.
- Species specific connectivity vs. general landscape permeability, the latter they found difficult to interpret and apply to decision making.
- Quantitative cumulative effects assessment of current, planned, potential stressors on biodiversity and the ability to readily propose and test mitigation/adaptation actions against conservation elements and climate refugia data.
- Individual species refugia and concentration areas and threats to those areas.

They found least utility in “protecting the ecological stage,” finding it too abstract to explain and utilize within a formal planning process (where defensibility is very important).

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[25] See map figures of each model, overlain with the hexagon grid; details of methods are found in the appendix Figure 25, Figure 26

[26] Reference sagebrush example Figure 27

[27] Methods for TNC portfolio design, including these methods http://conserveonline.org/workspaces/cbdgateway/era/standards/std_11

The framework provided an initial structure for comparison against data and analyses that could potentially be addressed by BLM within the Ecoregional Direction phase of their Adaptive Landscape Approach. It certainly suggested some analyses that BLM might not have otherwise considered. Prior to project start-up, BLM had identified a series of potential responses to climate change. While most of these responses fell into the Framework, several did not. These included species-based strategies, such as planning for assisted migration or translocation and adjusting seed mixes in anticipation of site restoration with climate-appropriate species. Others included evaluation of current monitoring investments to better anticipate climate-induced change. Still others suggested combining climate change mitigation (e.g., carbon sequestration) with adaptation strategies and/or development of new education, outreach, and policy-based strategies.

A key finding from this pilot was that the current framework was difficult for public land managers to comprehend and readily apply to their decision-making processes. We suspect this would be a common problem for all but a small group of organizations experienced in such analyses that could determine how to apply the menu of approaches to their work. In response, we developed an alternative matrix that more directly links the framework to public land management decision making processes (

Table 1 below). In this version, we replaced the strategies (the rows) with key management questions of BLM. The levels of ecological organization from the Yale Framework (the columns) with levels of decision making from national to project level. The right-hand columns of the matrix center on the types of decision making that each analysis could inform. These include broader aspects of issue identification or public education, informing regional (typically multi-partner) strategies, informing alternatives management directions, and local site-scale or activity plans. The latter two processes typically dovetail with planning under NEPA and other regulations governing public lands. In most instances, the spatial resolution of analyses we selected would have limited utility to local site or activity planning and/or require iteration with locally-available data. Input from the BLM Washington Office indicated the need for a 4th column to address national policy and budget decision making; to keep the matrix simple we suggest that function be captured in the Issue Identification column.

We added a column that identified the type of analyses conducted to answer the management questions and then populated the columns with an indication of how the analyses result applied at the level of decision making as:

- Direct: the results would be used directly in that stage of decision making
- Indirect: the result would provide information and context to the decision but the level of spatial resolution and uncertainty would not support direct use/reliance on the result. For example, BLM was very interested in the climate envelope modeling to inform whether a desert tortoise relocation site was suitable. While a site might be currently suitable and offer adequate connectivity to populations to the south, barriers to the north would prevent population migration if the climate envelope predicted that populations would need to migrate. Under those conditions, one might determine the site would not have long term viability.
- NA: not applicable to the decision level.

Additional specific findings and recommendations are provided in Appendix B.

Table 1. Framework adaptation for BLM application, see text for further description.

Management Questions Addressed	Analysis Type	Levels of Decision Making[28]			
		Issue ID	**Regional Strategy**	**Land Use Plans**	**Site or Activity Planning**
What proportion of CE values are currently found within lands with management aimed at their conservation?	Gap Analysis, CE & Conservation Value Mapping	**Direct**	**Direct**	**Direct**	**NA**
What is the current ecological integrity of CEs and what changes to management might maintain or restore ecological integrity?	Ecological Integrity Assessment	**Direct**	**Direct**	**Direct**	**Indirect**
What does connectivity contribute towards the current ecological integrity of our key CEs and where are current barriers to this connectivity?	Landscape Permeability and Linkages	**Direct**	**Direct**	**Direct**	**Indirect**
By 2025, what proportion of CEs are likely to be affected by renewable energy and other forms of urban/industrial development?	2025 Development	**Direct**	**Direct**	**Direct**	**Direct**
By 2060, what proportion of CE distributions are likely to occur outside current distributions, and what proportions might be affected by development by 2025?	2060 Climate Envelope & Forecasts	**Direct**	**Direct**	**Direct**	**Indirect**
By 2060, what portion of BLM managed land is likely to occur with climate regimes significantly departed from 20th century character? and…which climate variables might contribute most to that change?	2060 Climate Space Trends Analysis	**Direct**	**Direct**	**Indirect**	**Indirect**
By 2060, what proportion of CE distributions are likely to occur within their 20th century climate regime, and what areas within and outside of those distributions might provide robust local-scaled refuge from a changing climate?	2060 Climate Envelope Refugia and Linkages Biophysical Heterogeneity	**Direct**	**Direct**	**Indirect**	**Indirect**

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[28] Note that these levels of decision making apply to BLM, they can be generalized as follows: Issue Identification, Strategy Development; Planning, and Implementation

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Figures (for web page)

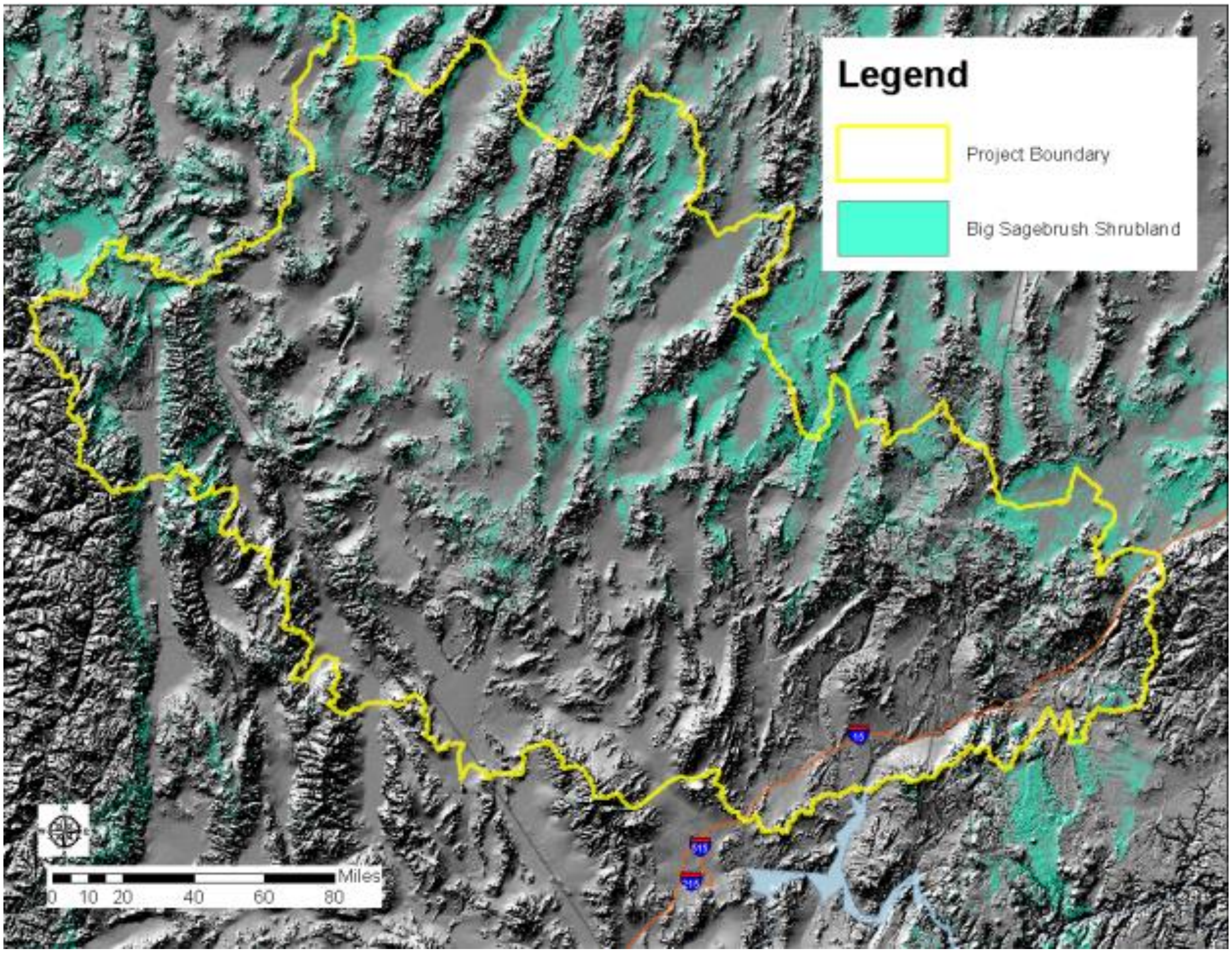


Figure 1. Distribution of Big Sagebrush Shrubland.

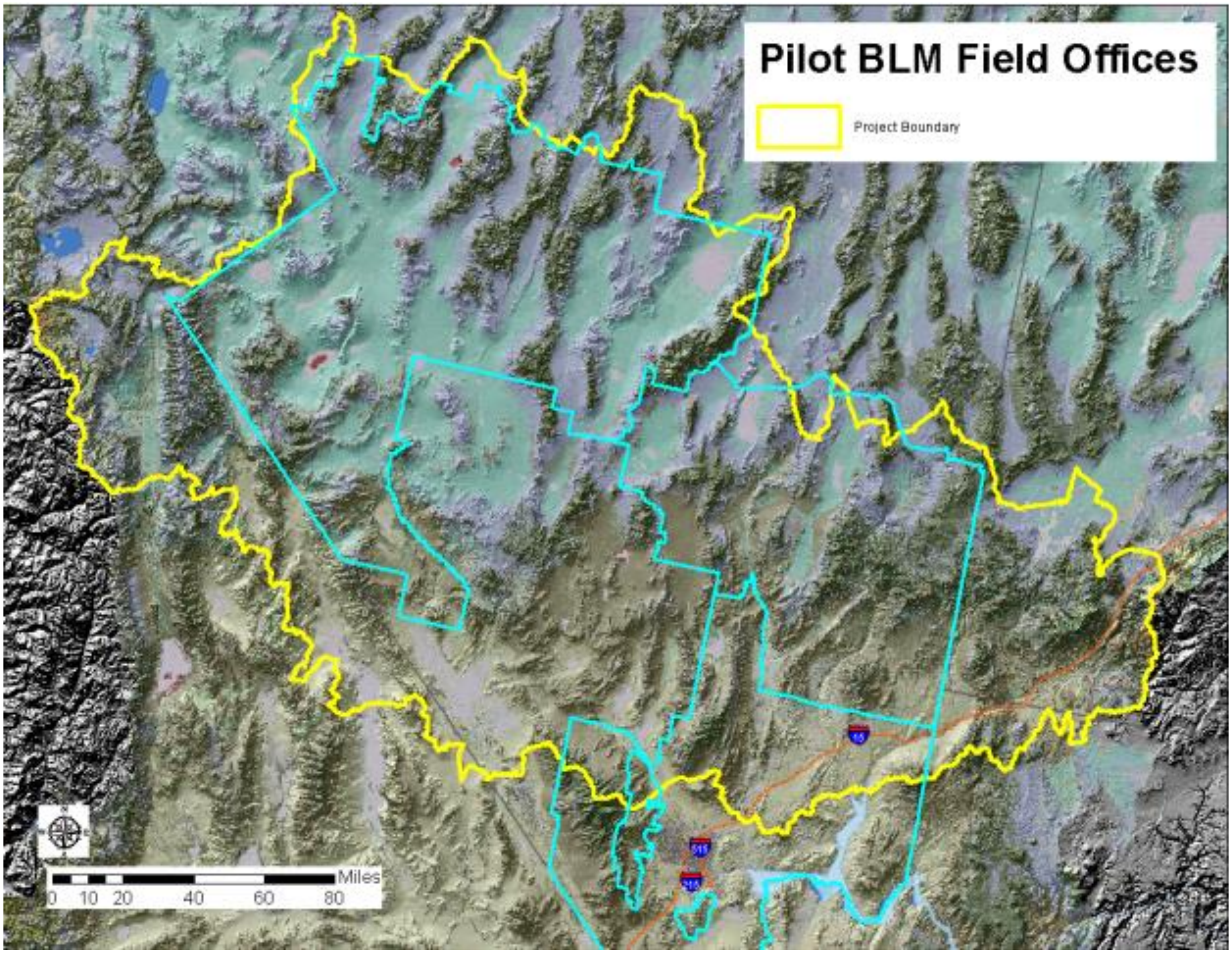


Figure 2. Project area: a watershed defined ecotone region between the Central and Mojave Basins.

Table 2. Yale framework and analyses utilized in this pilot (gray shaded cells).

Adaptation Approaches	**Levels of Ecological Organization**		
	Landscapes	Ecosystems	Species & populations
Protect current patterns of biodiversity (baseline)		map ecosystems & services	map species distributions
Project future patterns of biodiversity	land use forecasts	forecasted climate envelopes	forecasted climate envelopes
Maintain ecological processes	climate stress	ecological integrity	
Maintain and restore ecological connectivity	landscape permeability	landscape linkages	landscape linkages

Protect climate refugia	climate stress	forecasted climate envelopes	forecasted climate envelopes
Protect the ecological stage (enduring features)	ecol integrity; heterogeneity	ecol integrity; heterogeneity	

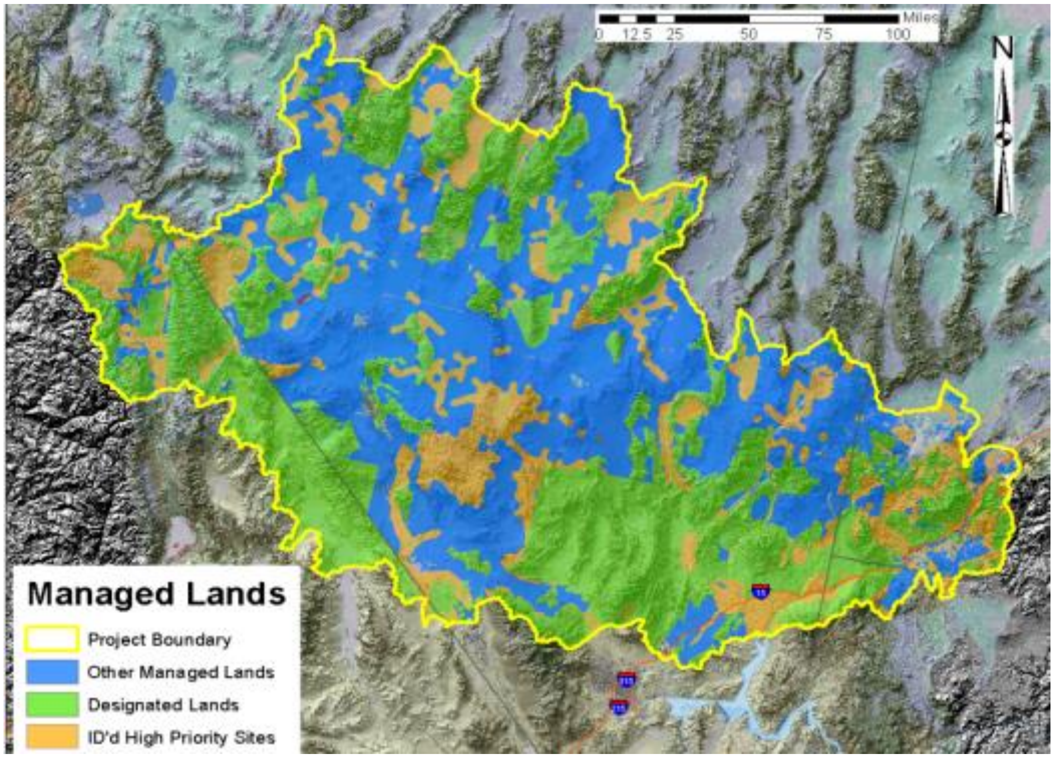


Figure 3. Managed lands in the pilot area.

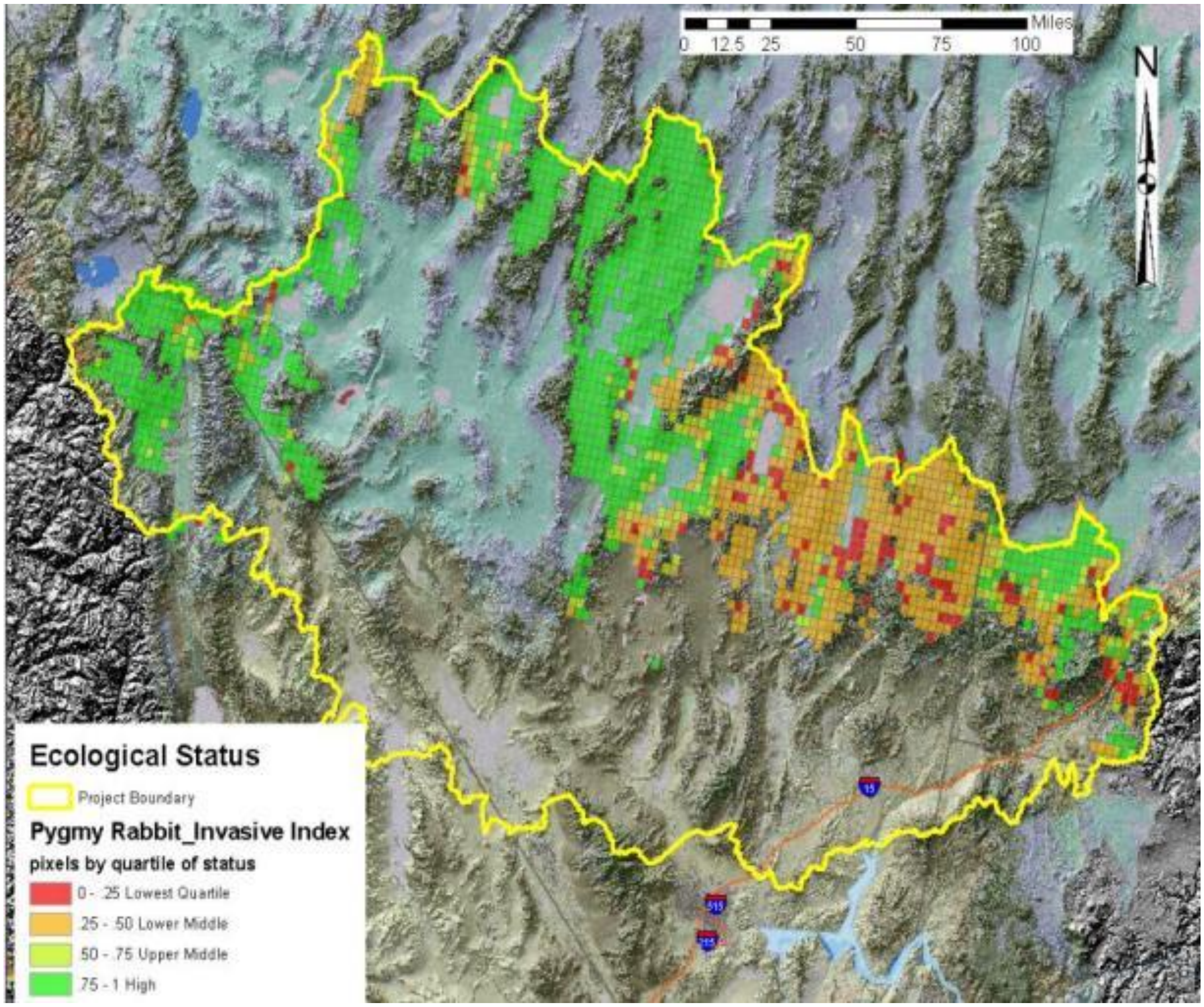


Figure 4. Example ecological status assessment.

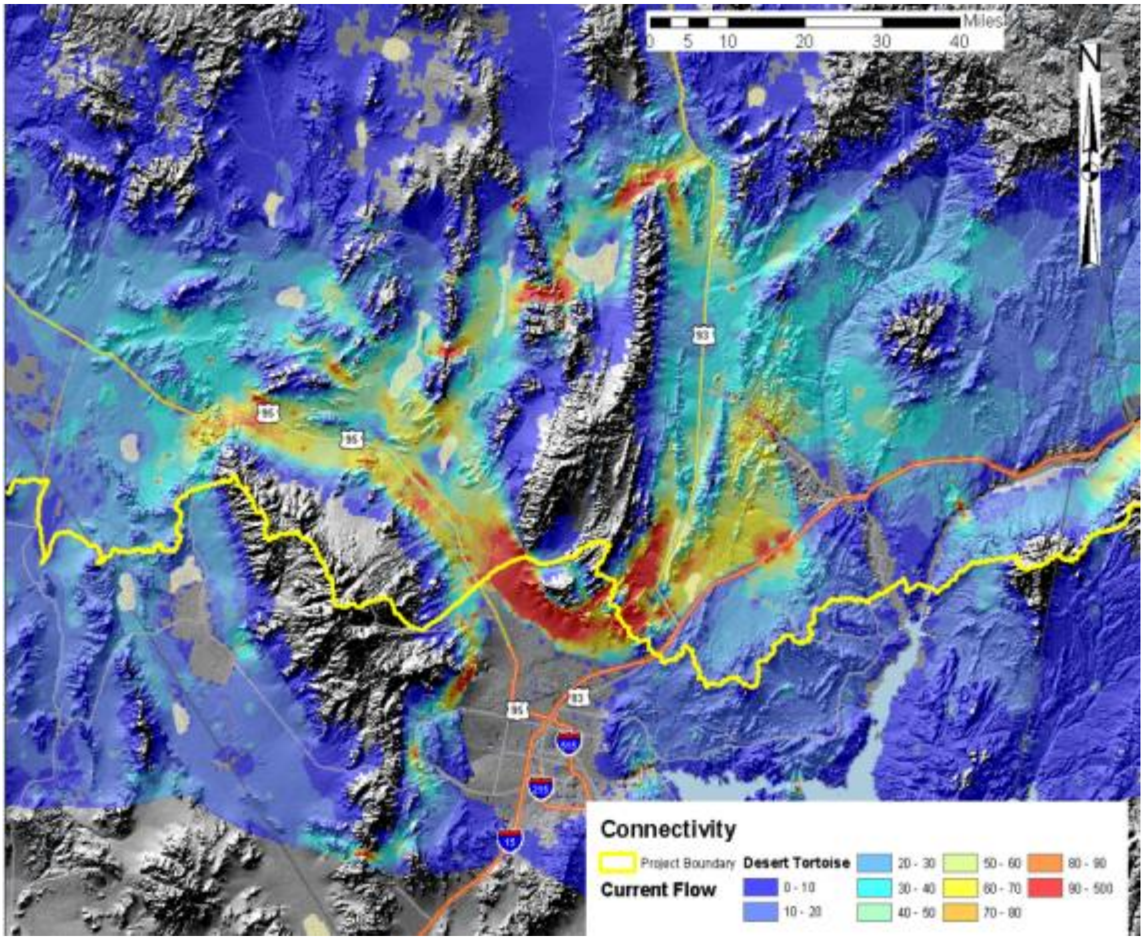


Figure 5. Example species connectivity model.

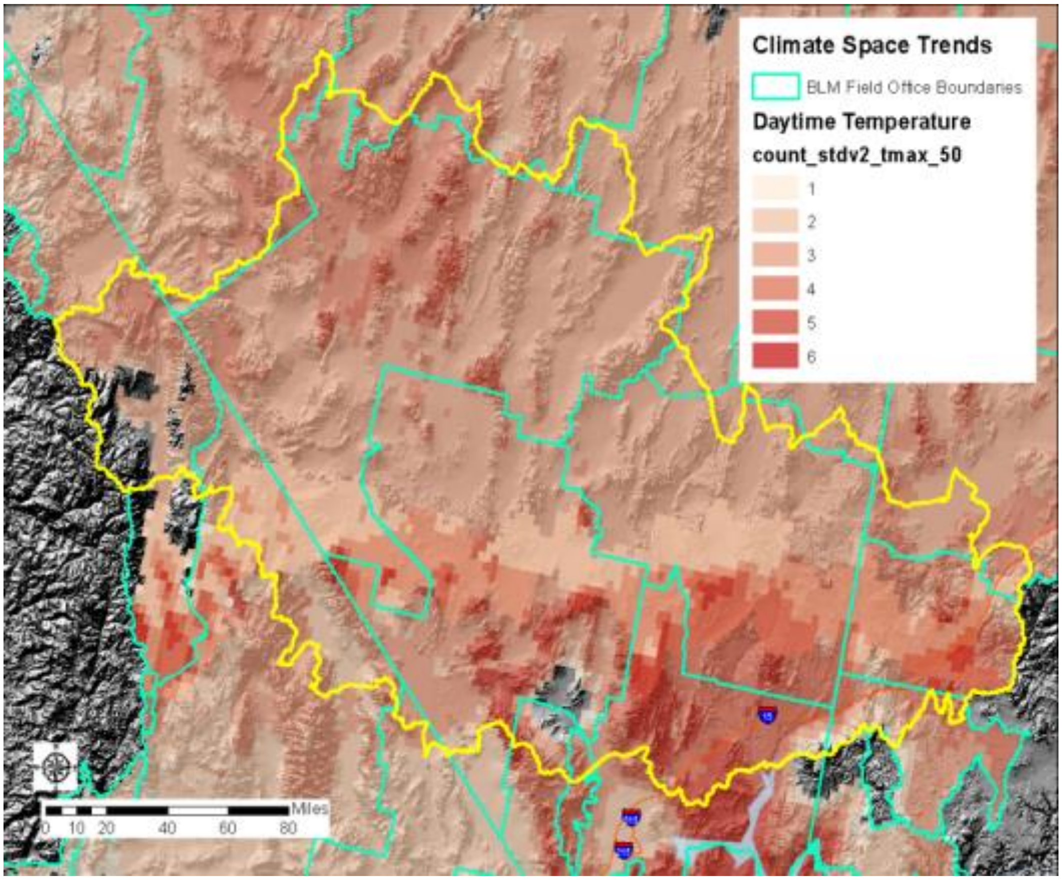


Figure 6. Example climate change model output: number of monthly maximum temperature forecast exceed 2 standard deviations of baseline value by 2060.

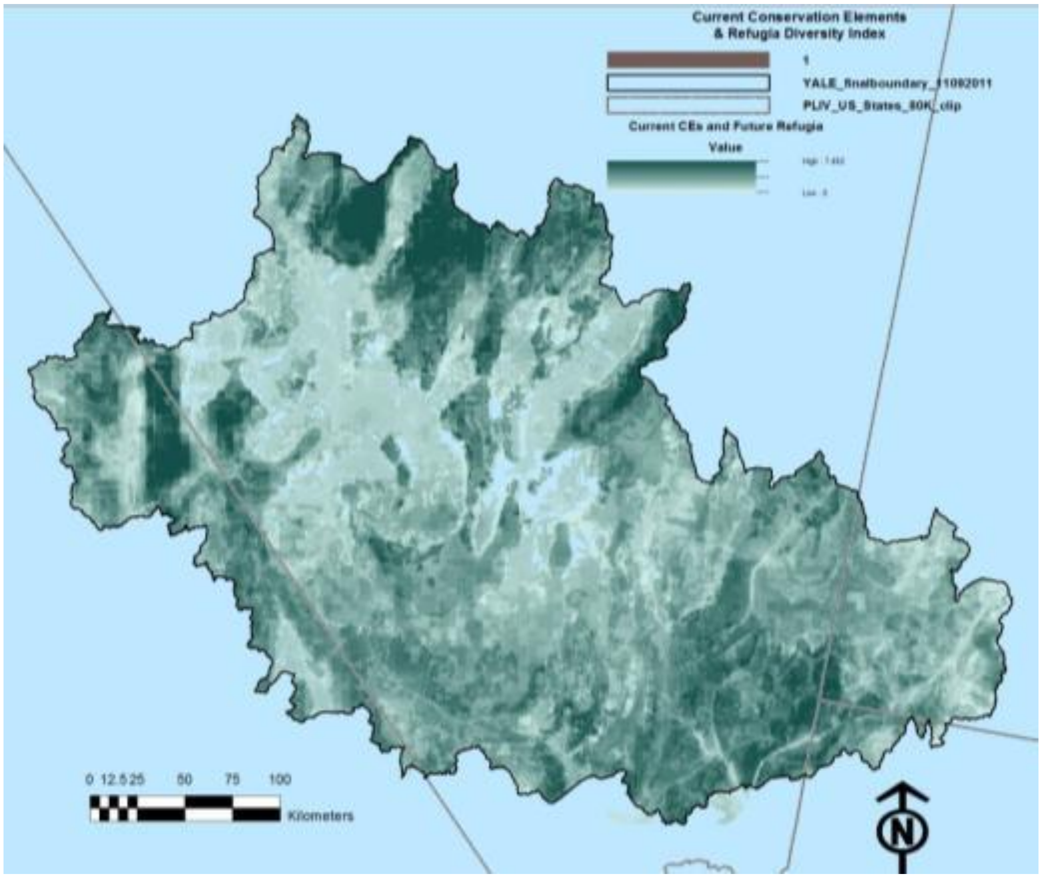
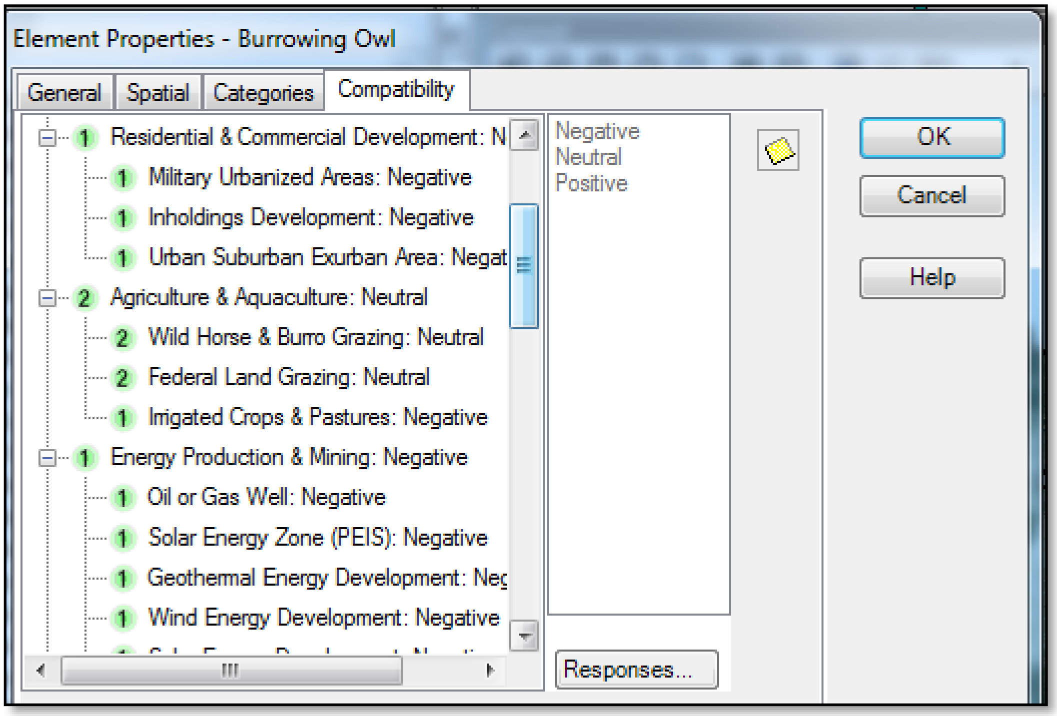


Figure 7. Conservation Value Summary (Diversity Index).



Element Properties - Burrowing Owl

- 1 Residential & Commercial Development: N
  - 1 Military Urbanized Areas: Negative
  - 1 Inholdings Development: Negative
  - 1 Urban Suburban Exurban Area: Negat
- 2 Agriculture & Aquaculture: Neutral
  - 2 Wild Horse & Burro Grazing: Neutral
  - 2 Federal Land Grazing: Neutral
  - 1 Irrigated Crops & Pastures: Negative
- 1 Energy Production & Mining: Negative
  - 1 Oil or Gas Well: Negative
  - 1 Solar Energy Zone (PEIS): Negative
  - 1 Geothermal Energy Development: Neg
  - 1 Wind Energy Development: Negative

Figure 8. Example Vista interface for assigning species response to change agents.

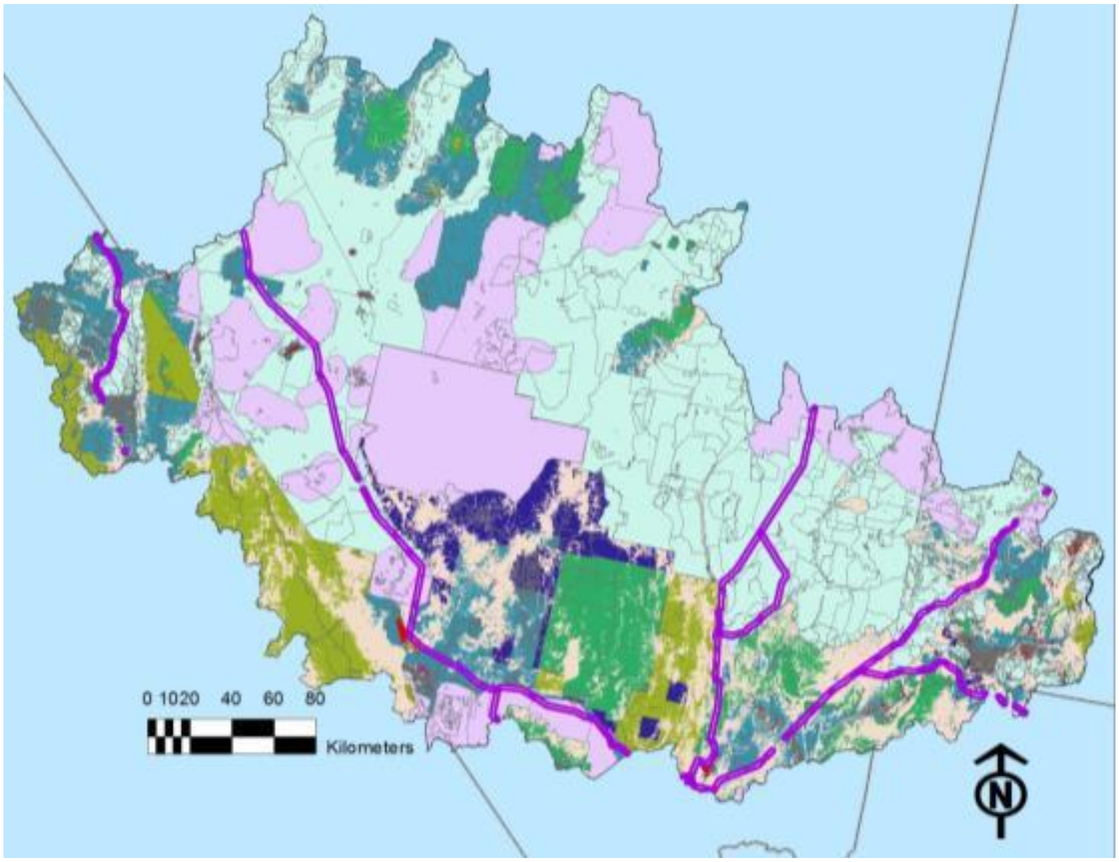
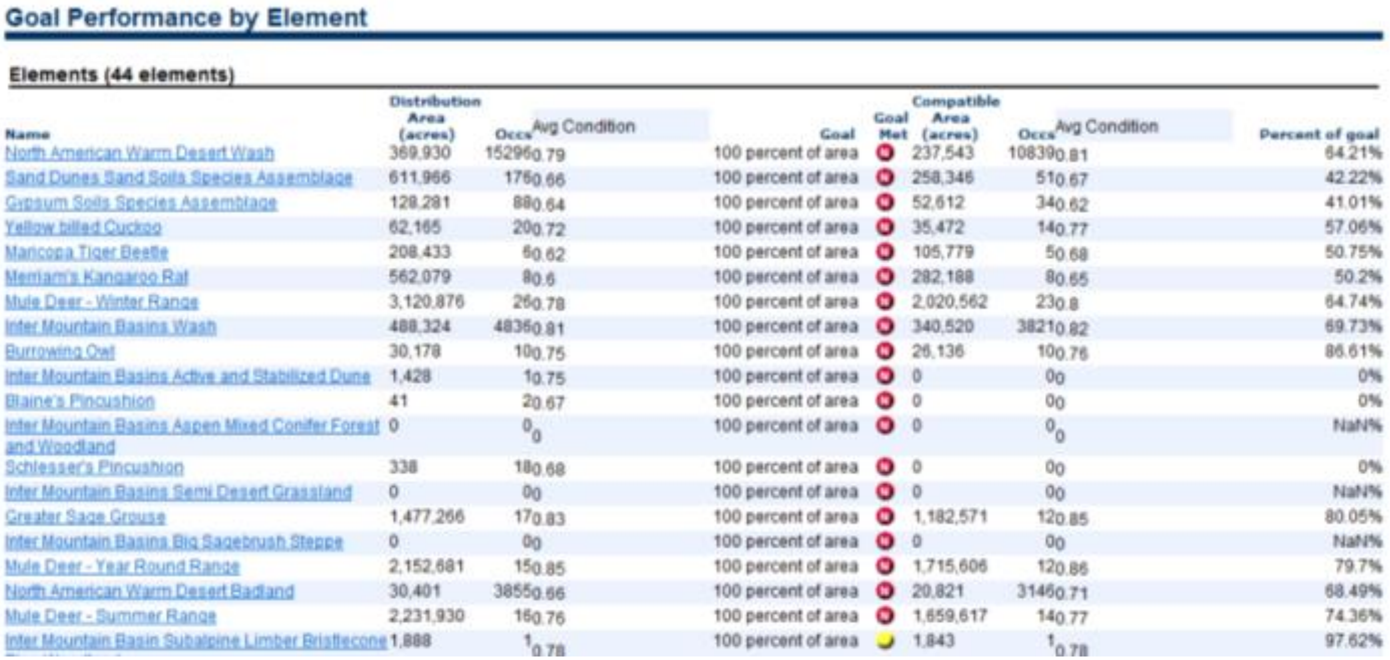


Figure 9. Example scenario data layers. Note that layers overlap so scenarios are comprised of a stack of layers.



Goal Performance by Element

Elements (44 elements)

Name	Distribution Area (acres)	Occs	Avg Condition	Goal	Goal Met	Compatible Area (acres)	Occs	Avg Condition	Percent of goal
North American Warm Desert Wash	369,930	15296	0.79	100 percent of area	🔴	237,543	10839	0.81	64.21%
Sand Dunes Sand Soils Species Assemblage	611,966	176	0.66	100 percent of area	🔴	258,346	51	0.67	42.22%
Gypsum Soils Species Assemblage	128,281	88	0.64	100 percent of area	🔴	52,612	34	0.62	41.01%
Yellow billed Cuckoo	62,165	20	0.72	100 percent of area	🔴	35,472	14	0.77	57.06%
Maricopa Tiger Beetle	208,433	6	0.62	100 percent of area	🔴	105,779	5	0.68	50.75%
Merriam's Kangaroo Rat	562,079	8	0.6	100 percent of area	🔴	282,188	8	0.65	50.2%
Mule Deer - Winter Range	3,120,876	26	0.78	100 percent of area	🔴	2,020,562	23	0.8	64.74%
Inter Mountain Basins Wash	488,324	4836	0.81	100 percent of area	🔴	340,520	3821	0.82	69.73%
Burrowing Owl	30,178	10	0.75	100 percent of area	🔴	26,136	10	0.76	86.61%
Inter Mountain Basins Active and Stabilized Dune	1,428	1	0.75	100 percent of area	🔴	0	0	0	0%
Blaine's Pincushion	41	2	0.67	100 percent of area	🔴	0	0	0	0%
Inter Mountain Basins Aspen Mixed Conifer Forest and Woodland	0	0	0	100 percent of area	🔴	0	0	0	NaN%
Schlesser's Pincushion	338	18	0.68	100 percent of area	🔴	0	0	0	0%
Inter Mountain Basins Semi Desert Grassland	0	0	0	100 percent of area	🔴	0	0	0	NaN%
Greater Sage Grouse	1,477,266	17	0.83	100 percent of area	🔴	1,182,571	12	0.85	80.05%
Inter Mountain Basins Big Sagebrush Steppe	0	0	0	100 percent of area	🔴	0	0	0	NaN%
Mule Deer - Year Round Range	2,152,681	15	0.85	100 percent of area	🔴	1,715,606	12	0.86	79.7%
North American Warm Desert Badland	30,401	3855	0.66	100 percent of area	🔴	20,821	3146	0.71	68.49%
Mule Deer - Summer Range	2,231,930	16	0.76	100 percent of area	🔴	1,659,617	14	0.77	74.36%
Inter Mountain Basin Subalpine Limber Bristlecone	1,888	1	0.78	100 percent of area	🟡	1,843	1	0.78	97.62%

Figure 10. Example cumulative effects report. Indicates current and remaining area of each element under the 2025 future scenario.

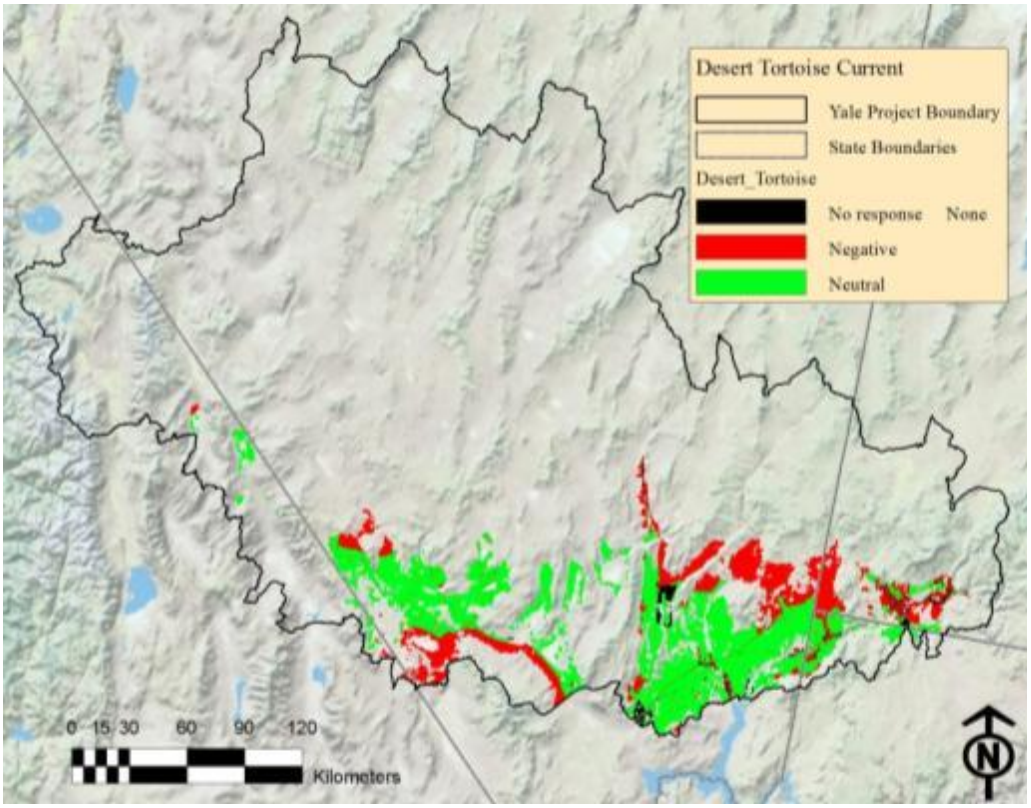


Figure 11. Example species cumulative effects impact map.

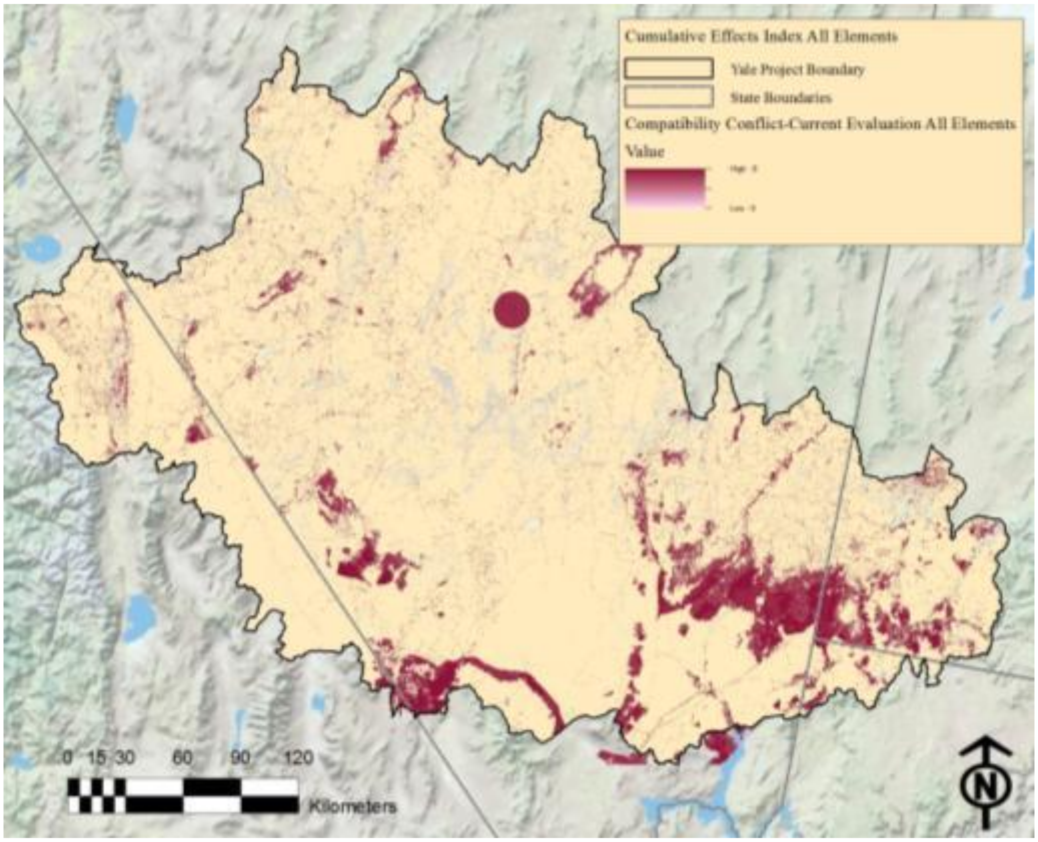


Figure 12. Cumulative effects index map.

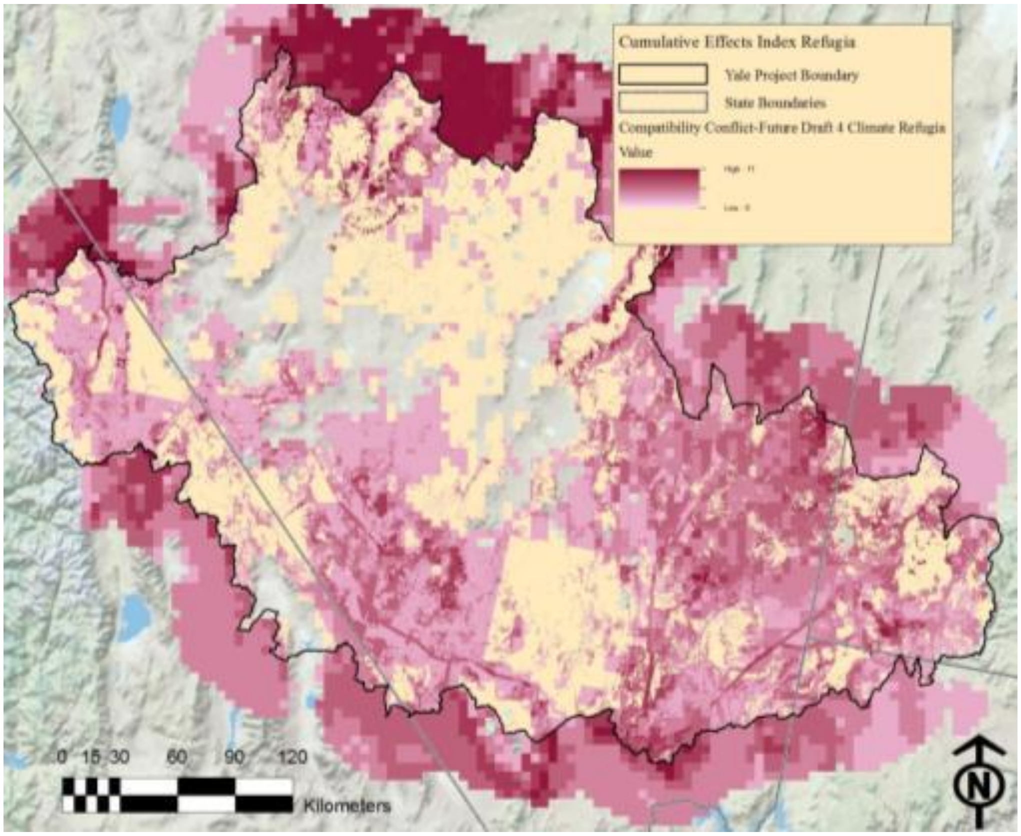


Figure 13. Cumulative effects index for refugia

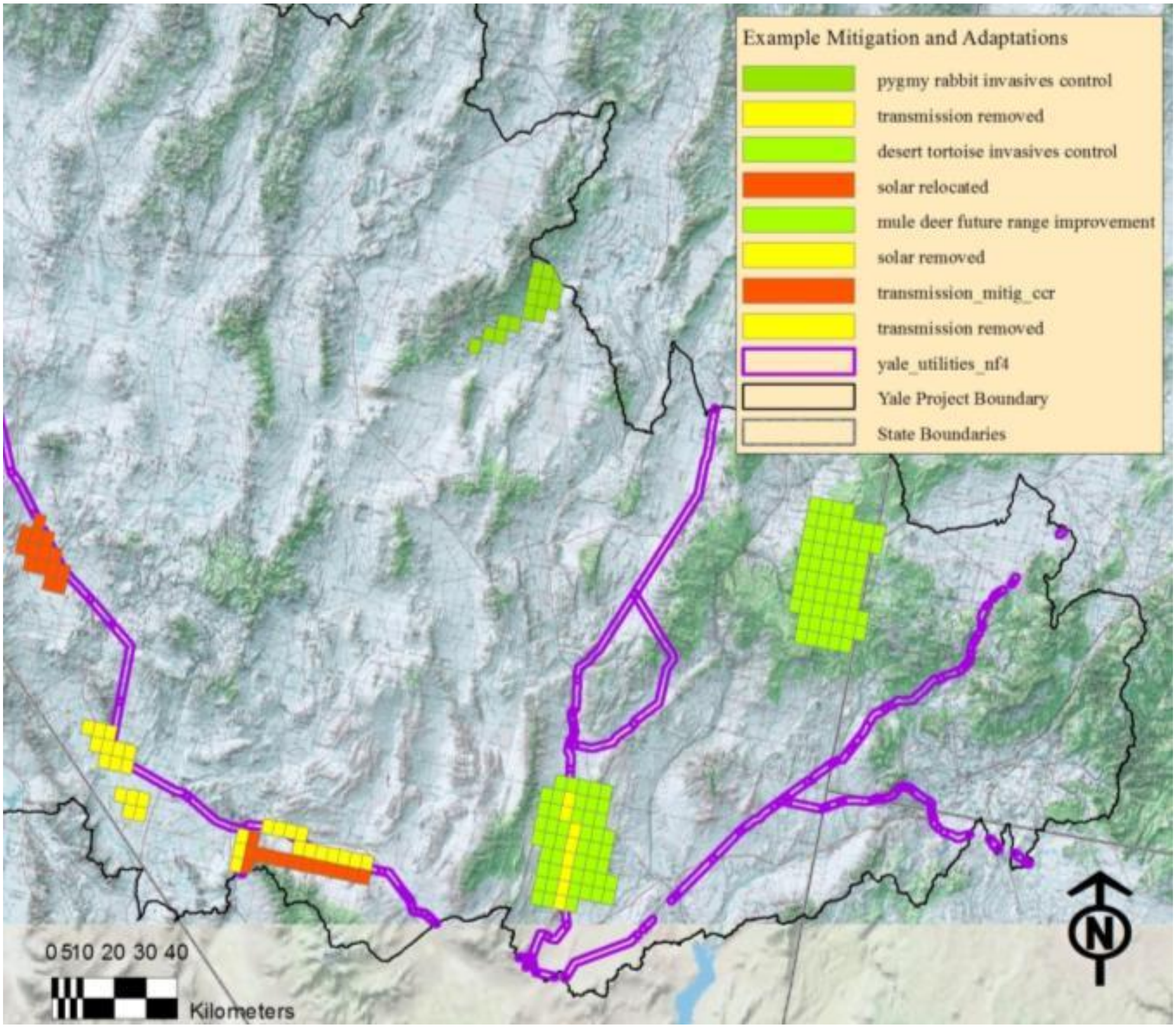


Figure 14. Example adaptation and mitigation features (for illustration purposes only).

Green areas indicate places to conduct restoration actions of burns and current and future invasive species spread. Yellow areas use avoidance to remove proposed solar plants and transmission lines from environmentally sensitive areas. Orange areas indicate where solar and transmission could be relocated to reduce impacts on current biodiversity patterns and future refugia concentrations. Mitigations conducted using NatureServe Vista Site Explorer tool.

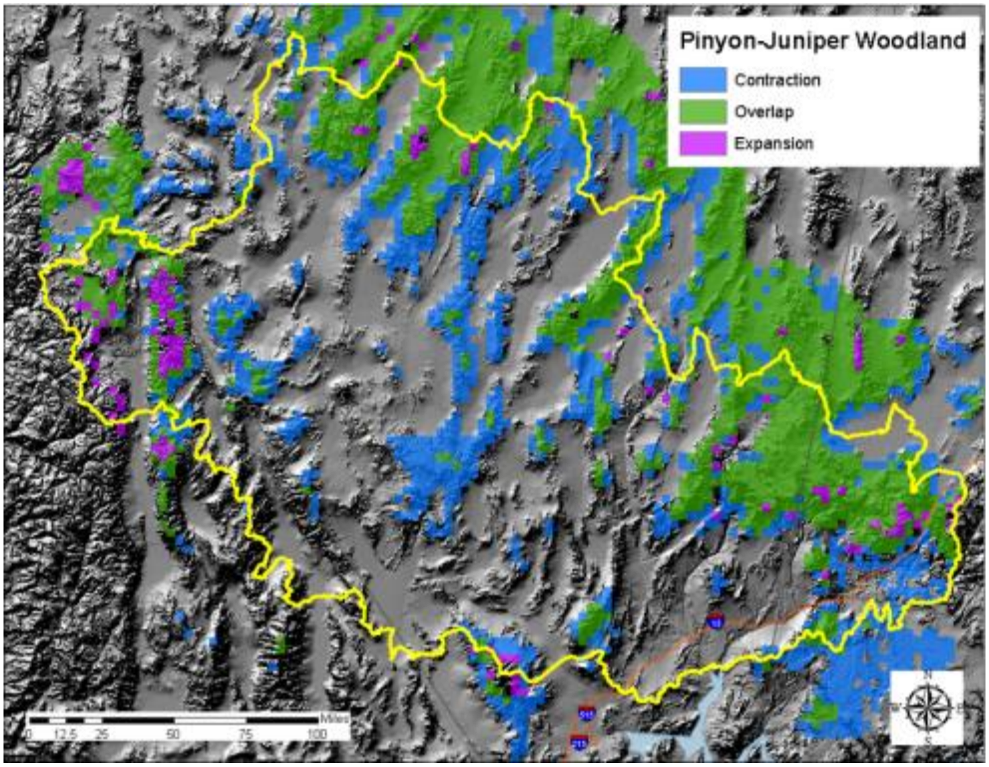


Figure 15. Climate envelope forecast for Pinyon-juniper woodland in the study area.

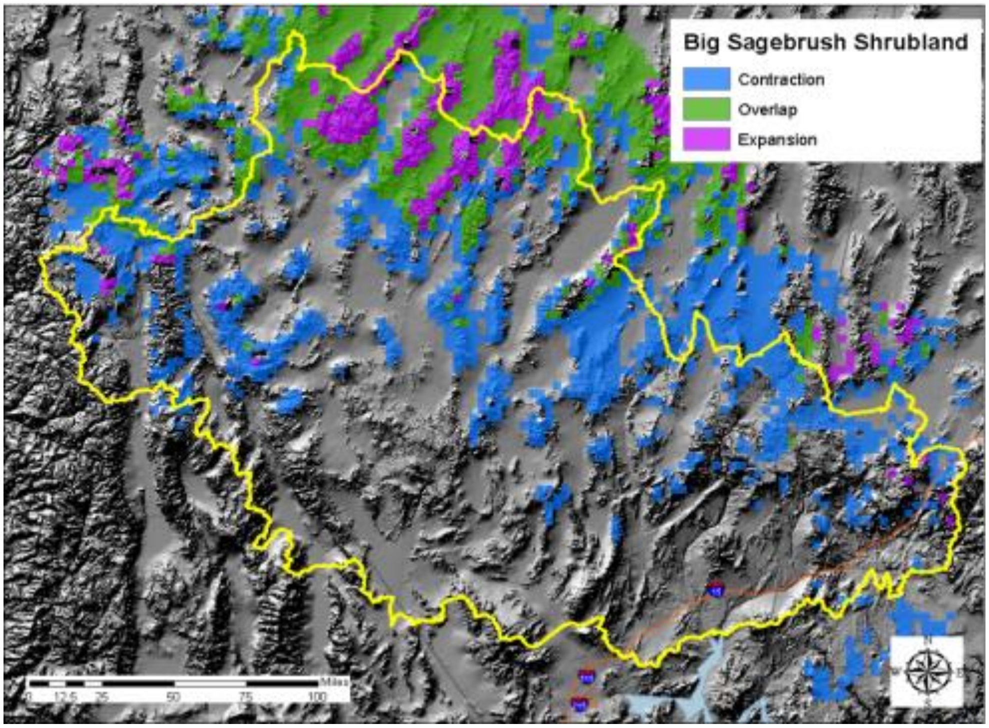


Figure 16. Climate envelope forecast for Big sagebrush shrubland in the study area.

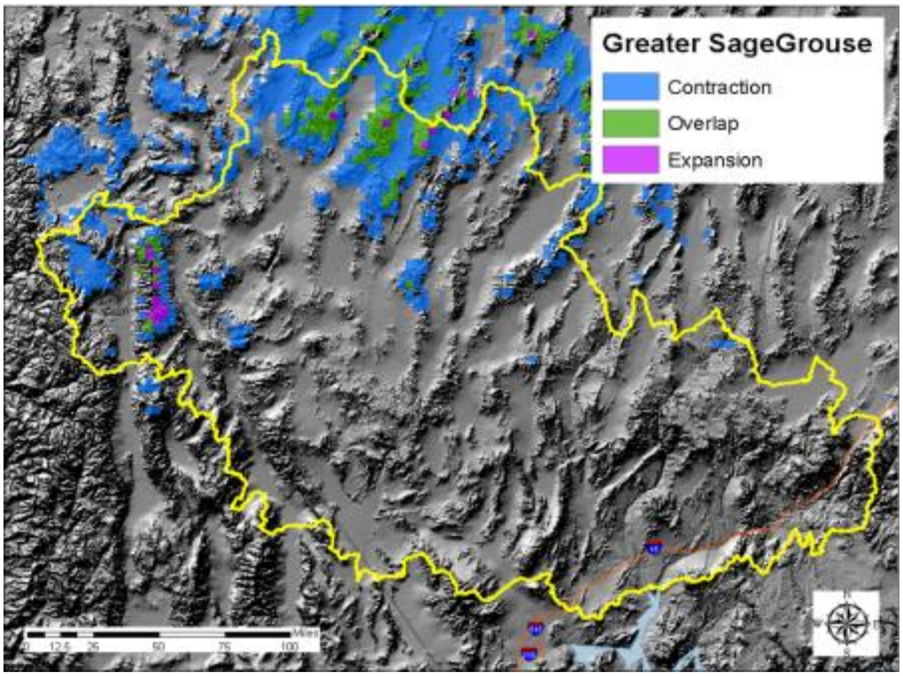


Figure 17. Climate envelope forecast for sage-grouse occupied habitat in the study area.

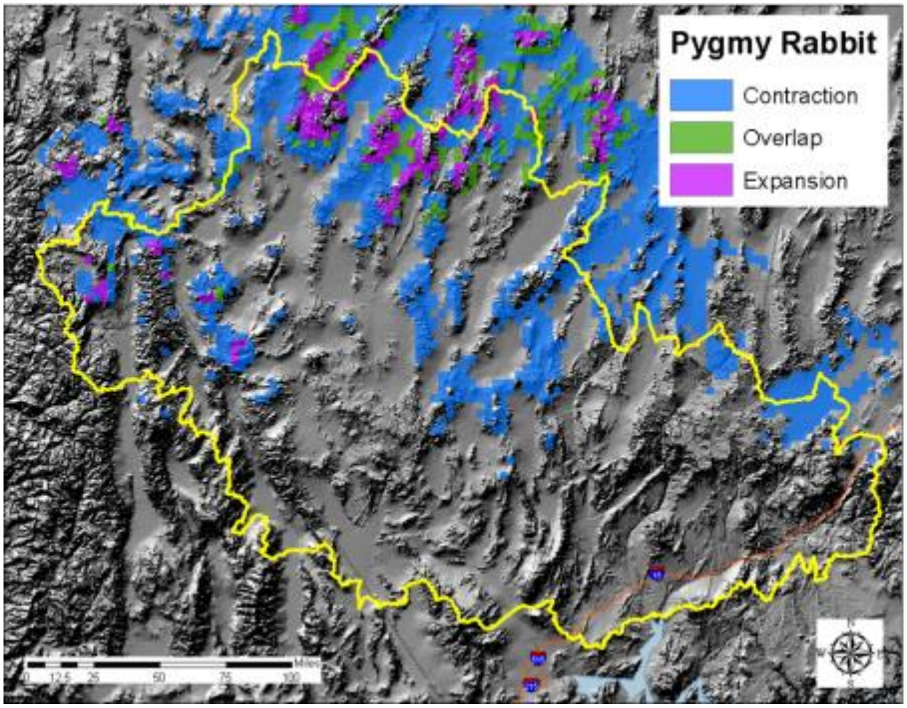


Figure 18. Climate envelope forecast for Pygmy rabbit in the study area.

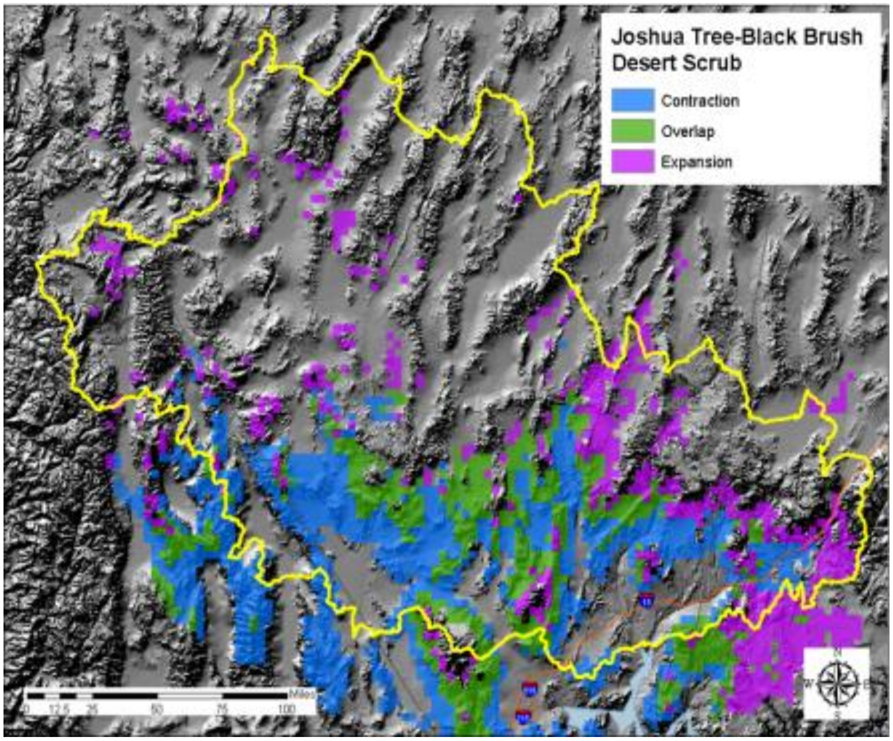


Figure 19. Climate envelope forecast for Joshua tree-blackbrush scrub in the study area.

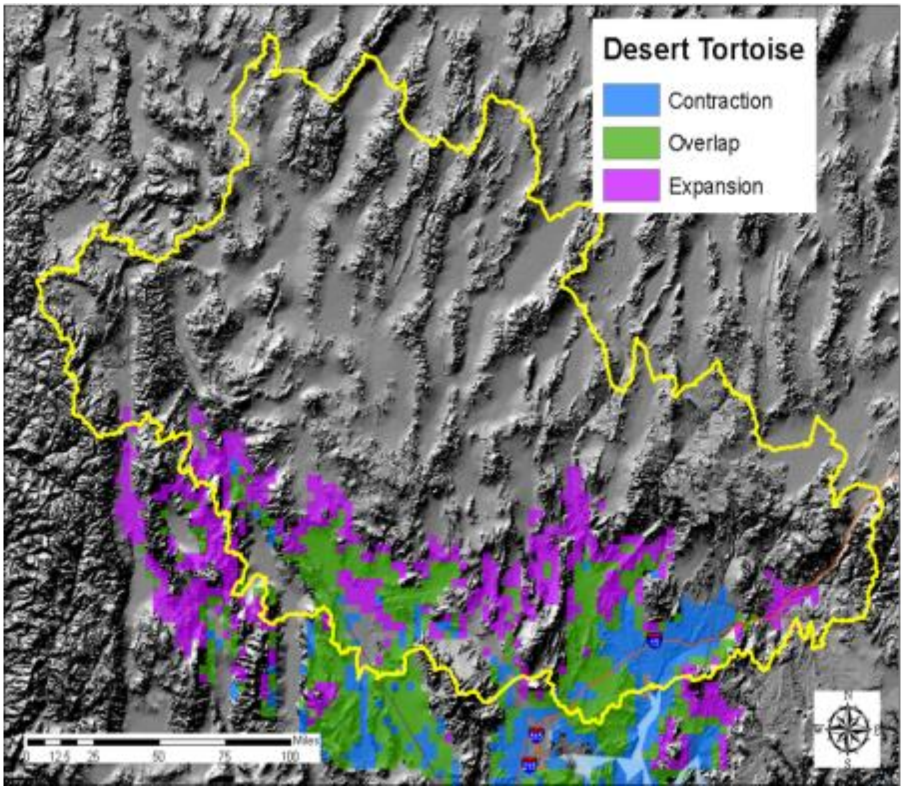


Figure 20. Climate envelope forecast for occupied Desert tortoise in the study area.

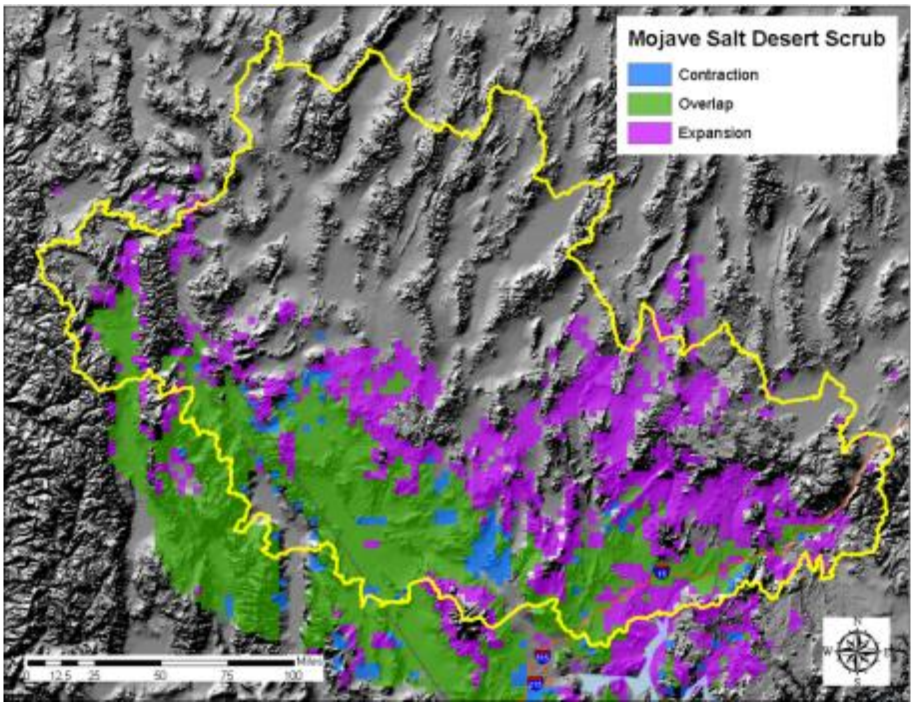


Figure 21. Climate envelope forecast for Salt desert scrub in the study area.

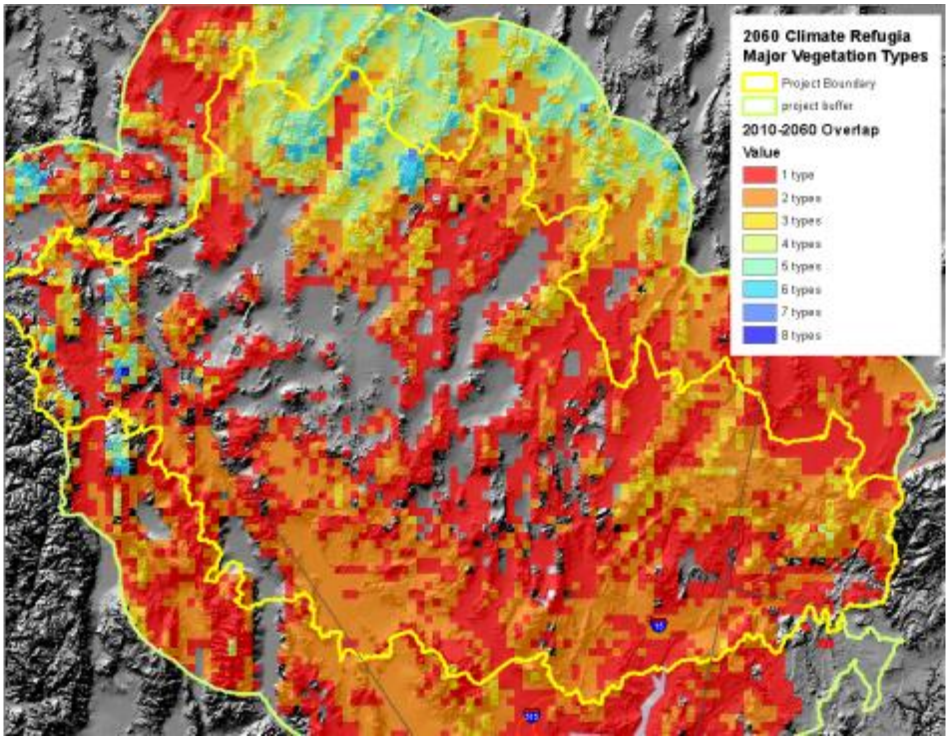


Figure 22. Combined climate envelope envelopes for major vegetation in the study area.

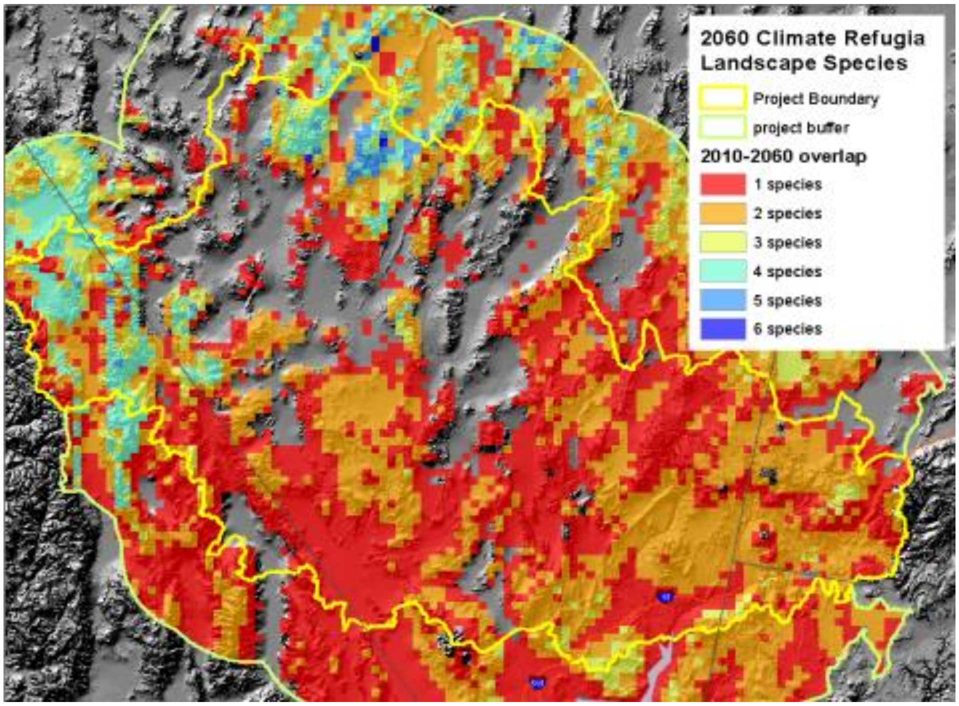


Figure 23. Combined climate envelope envelopes for selected landscape species in the study area.

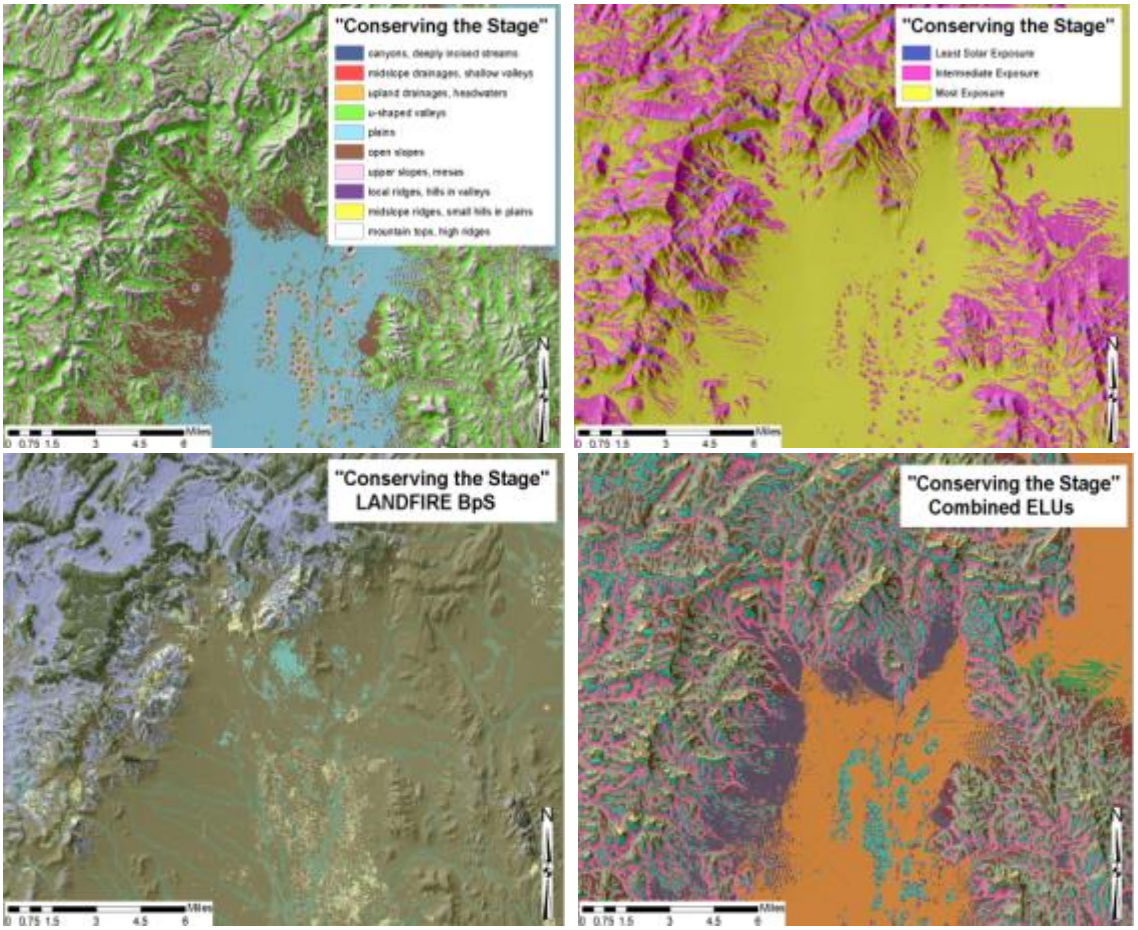


Figure 24. landform and insolation models as inputs to the combination Ecological land units (ELUs); with example LANDFIRE biophysical settings (BpS) map in the same area.

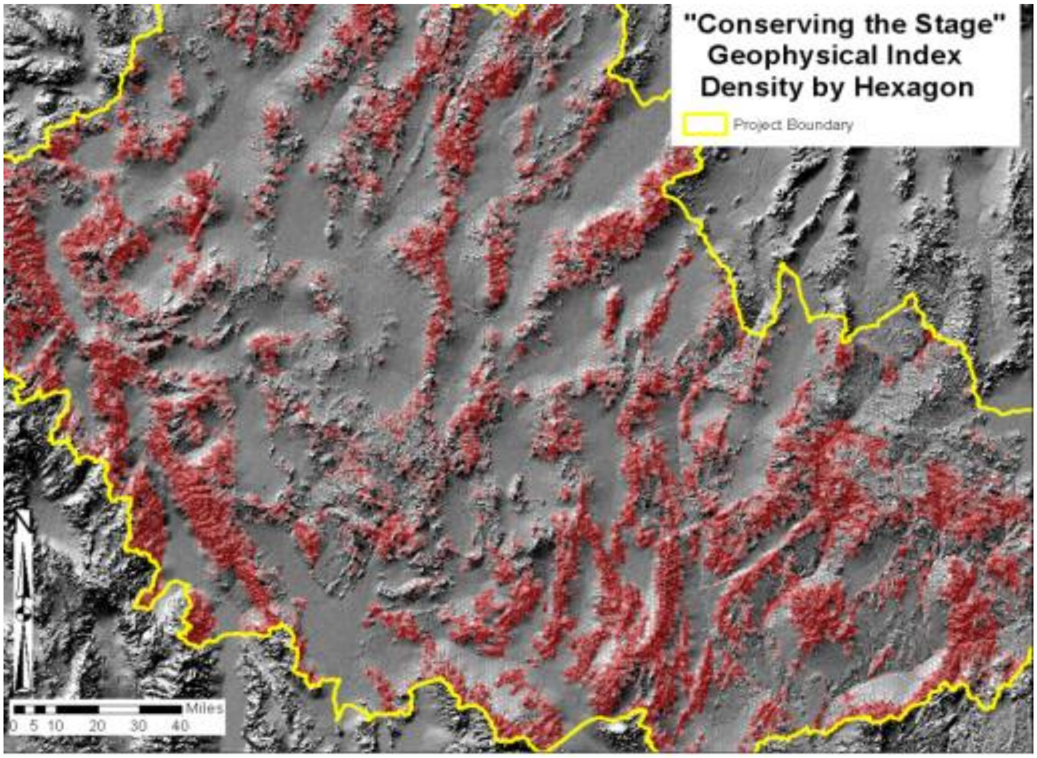


Figure 25. Geophysical heterogeneity index values, selected 4 km2 hexagons reflect above average densities of types.

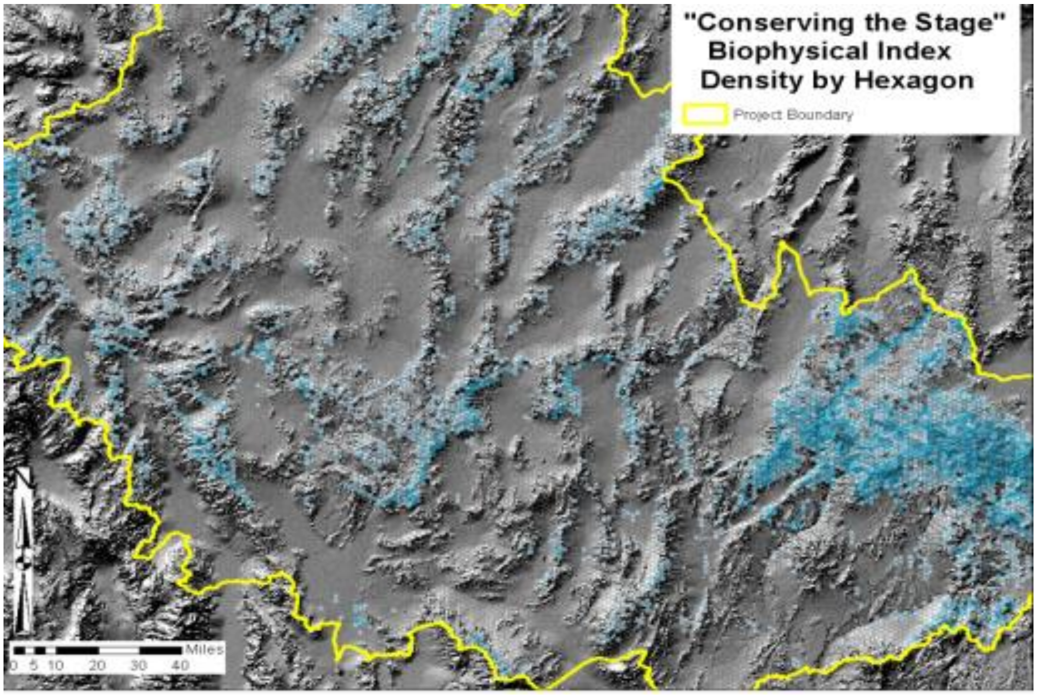


Figure 26. Biophysical heterogeneity index values, selected 4 km2 hexagons reflect above average densities of types.

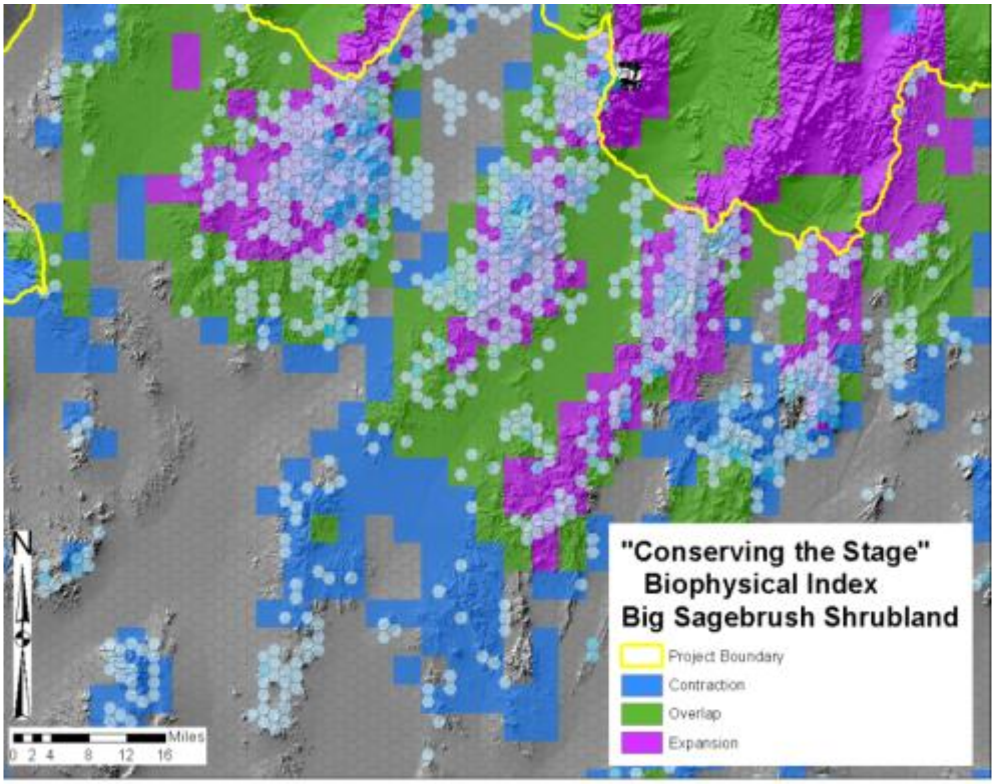


Figure 27. Overlay of biophysical heterogeneity index (w/ above average scores) on climate envelope forecasts for Big sagebrush shrubland.

Appendix A: REA Background

REAs integrate ‘wall-to-wall’ data on biodiversity and other key resources, such as representative vegetation, aquatic ecosystem types and sensitive species http://www.blm.gov/wo/st/en/prog/more/climatechange/reas.html. They also document change agents, such as urban/industrial development, invasive species, fire/hydrologic regime alteration, and climate change, and their effects on key resources. Each REA develops spatially-explicit land use scenarios, including documentation of current conditions and forecasted conditions for 2025 and 2060. Evaluation of current land use scenarios emphasizes documentation of relative ecological integrity for key natural resources. Forecasted land use trends (e.g., renewable energy development patterns) are emphasized in the analysis of the 2025 scenario, and climate change effects are emphasized in the 2060 scenario. The REA produces an updated perspective on the location (current and likely future) of key resources and change agents, and provides a contextual synthesis for use in subsequent management plan revisions.

Climate change adaptation must form one key facet of BLM management plan revision, especially in regional landscapes of the arid southwest, where climate change effects are predicted to be severe over the coming decades. This proposed project will take full advantage of REA results now coming available to chart a pathway for integrating this contextual information into BLM planning decisions. It will also provide a vehicle for clarifying multi-jurisdictional strategies with BLMs partners as the REA data and analyses are conducted for the complete ecoregion extent.

Appendix B. Framework evaluation & recommendations

Following we provide our key evaluation conclusions and recommendations organized into thematic areas of Structure, Content, and Usability. We include evaluation and recommendations in each thematic area.

Structure

Evaluation

Overall, the Yale Framework provides a unique "menu of approaches" rather than a more typical step-by-step framework such as UNEP's Ecosystem Based Adaptation Decision Support Framework (in process), USFWS/NatureServe's Refuge Vulnerability Assessment guide (in process), and WCS's climate adaptation framework. For organizations with established processes and ability to incorporate the approaches into their processes having a menu rather than a prescribed process may be appealing. For other organizations, the lack of sequential steps may lead to confusion about where to start and where to go next.

Recommendations

We adapted the table (Table 1 in body of report) to associate BLM's management questions to levels of decision making and assessments. We offer this approach for consideration to inform revision of the Yale Framework to address the process problems we encountered.

Content

Evaluation

General contribution to adaptation guidance

Specific content evaluation

Here we include our evaluation of the utility of the content based on discussion of value and utility of the results we provided using the Framework components.

1. Diversity mapping evaluation
    a. BLM generally found diversity maps expressed as "Conservation Value Summaries" in the NatureServe Vista DSS to be useful for understanding patterns of biodiversity and differences in diversity among areas.

2. Gap analysis evaluation:
    a. Generally, BLM found this product useful. They liked being able to see statistics on representation of conservation elements by district to understand which districts have the greatest proportion of certain elements. The results of the gap analyses, which flagged elements that are not well represented in designated lands and for which BLM has both a significant proportion of their distribution and a significant proportion in areas other institutions have identified as conservation priorities, provided BLM with useful flags to take a closer look at those conservation elements.

3. Conservation Element Status Assessment

4. Connectivity Assessment
    a. BLM strongly preferred individual conservation element (i.e., species) connectivity maps over general permeability analyses. They found the latter to be too abstract for decision making purposes.

5. Cumulative Effects Assessment & Mitigation/Adaptation Planning
    a. BLM found tremendous utility in the ability (as expressed with the NatureServe Vista DSS) to rapidly evaluate scenarios against conservation elements and get maps and quantitative reports of potential impacts. Due to time constraints, this project did not fully integrate the different assessments as much as desired which remains an area for further investigation.
    b. BLM found the planning capabilities useful, to be able to propose alternatives and identify maladaptive responses to current and future biodiversity patterns.

Recommendations

1. Practitioners like to receive products at their full resolution or some aggregation suitable to the extent of the planning region such that patterns can still be seen and decisions about management units can be made from the data. For the extensive area of this project, it was determined that results at a 4km pixel were sufficient but that all source data should retain its original resolution.

Usability

Evaluation

Usability is first influenced by structure; as discussed earlier, a lack of step-by-step guidance, or guidance on how to apply the menu of approaches to a defined process may hamper usability. For example, we needed to define a linear set of technical steps coupled with team and stakeholder interactions to make use of the Framework components. NatureServe has extensive experience in doing this that may not be typical of many organizations seeking to apply the Framework.

Recommendations

As outlined in the main report, we recommend aligning the framework to logical steps of planning as shown in the section on Structure above. For many organizations, however, it is unlikely that merely providing the framework will prove sufficient. Many planning organizations (at all levels of government as well as consultants that perform much of the work and NGOs) still lack a firm grasp of spatially-based planning let alone the very advanced GIS modeling work with, in some instances, very novel types of data and concepts. Therefore, some sort of technical assistance program is going to be necessary that would include a range of interventions suited to the level of assistance any organization requires:

- Informational interactive webinars to explain the framework in greater depth, illustrated with case studies, and allowing Q&A. These can also be recorded for online viewing.
- Modularized group or individual training. These can also be recorded for online viewing.

- Direct project assistance. Often organizations lack "the breathing room" to switch to new approaches, tools, and activities and thus prefer a transition period where a service provider conducts the heavy lifting and then provides a tech and knowledge transfer.

Additional Comments and Recommendations

The following items are not specific to the Yale Framework but may suggest some useful additions based on our experience on this pilot and other climate change work we have conducted.

Interaction

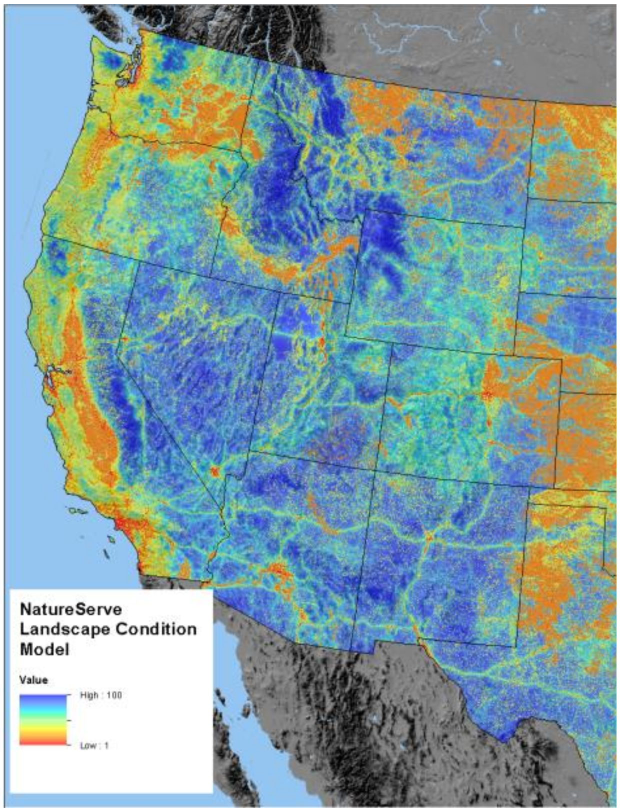
In this pilot and other similar projects conducted for FWS Refuges we have found that the amount of interaction time between the technical/scientific team and the planners/managers is critical to a successful project. Upfront understanding of the process greatly helps the recipients of the work to actively and productively participate and contribute data and knowledge to the process. Strategic meetings to review work and results to date maintains this involvement and understanding and keeps the technical team on track to produce needed products. A final hand off workshop ensures that the recipients understand the products and their appropriate use and boosts the chances the products will be applied in planning and implementation.

Specific to our pilot project with Yale, resource constraints and the short duration of the project limited interaction to a one day kickoff workshop, four 90-minute web meetings, and a 1.5-day final workshop. The final workshop in this case was not intended as a handoff but a time to review NatureServe's development of an adaptation alternative scenario and provide comment to guide a final iteration of it. The web meetings were meant to share the results and identify need for management change and strategies based on those results that could be incorporated into the adaptation plan alternative. The novelty and complexity of the products hampered most participants from sufficiently understanding them during those short meetings to provide the desired information. Ideally multiple in-person workshops will be conducted to review results from such complex studies and give ample time to digest and discuss the results and identify strategies. Funding limitations and availability of staff to make time for multiple meetings may preclude such an approach so we recommend creativity in solving this problem. One approach that is being used with some success in the BLM's Rapid Ecoregional Assessments is to have contractors conduct webinars on the products, then post the products on a secure portal where participants can access them according to their own schedules and post comments. A follow up webinar after a brief time could then allow group discussion of their thoughts on need for management change and strategies.

Appendix C: Detailed Methods and Results

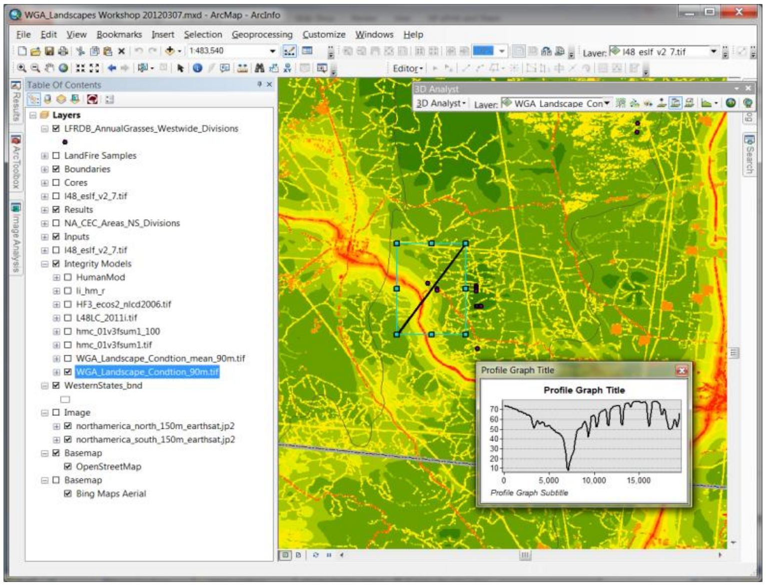
Manage For Ecological Integrity

Comer, P. J. & J. Hak. 2012. Landscape Condition in the Conterminous United States. Spatial Model Summary. NatureServe, Boulder, CO.



Conceptual Basis: Integrated, quantitative expressions of anthropogenic stress over large geographic regions can be valuable tools in environmental management. When they take the form of a map, they characterize ecological conditions on the ground; from highly disturbed to apparently unaltered conditions. They can be particularly helpful for identifying relatively intact landscape blocks or for screening ecological reference sites; i.e., a set of sites where anthropogenic stressors range from low to high. Ecological condition of reference sites is often further characterized in the field to determine how ecological attributes are responding to apparent stressors. This knowledge may then apply in other similar sites for all forms of environmental decision making.

This **Landscape Condition Model** integrates readily available spatial data to express common ecological stressors. The intent of the model is to enable spatial expression of common knowledge and experience regarding the relative effects of land uses on natural ecosystems and habitats. Expert knowledge forms the basis of stressor selection, and relative weighting in the model. This model has been calibrated westwide, and continues to be evaluated with field samples.



Technical Description: Table 1 includes a summary of data sets, settings, and assumptions included in this model. We selected a limited set of stress-inducing land use classes for which we have regionally consistent coverage. Our aim here is to characterize the primary local scale stressors. We have not attempted to factor in regional stressors, such as air pollutants or climate change. Stressors are organized into thematic groupings of Transportation, Urban and Industrial

Development, and Managed & Modified Land Cover. Transportation features, derived from ESRI StreetMap data circa 2006, depict roads of five distinct sizes and expected traffic volume. These data provide a practical measure of human population centers and primary transportation networks that link those centers. Ecological stress induced by built infrastructure (through habitat loss, fragmentation, altered ecological processes, etc.) are well known.

As a compliment to Transportation infrastructure, Urban and Industrial Development includes industrial (e.g., mines, energy development) and built infrastructure across a range of densities, from high density urban and industrial zones, to suburban residential development, to exurban residential and urban open spaces (golf courses, for outdoor recreation. These data were derived mostly from national land cover data through combined efforts of USGS (National Land Cover and Gap Analysis Programs) and the LANDFIRE effort. Other data sets included oil/gas well and transmission line right-of-way.

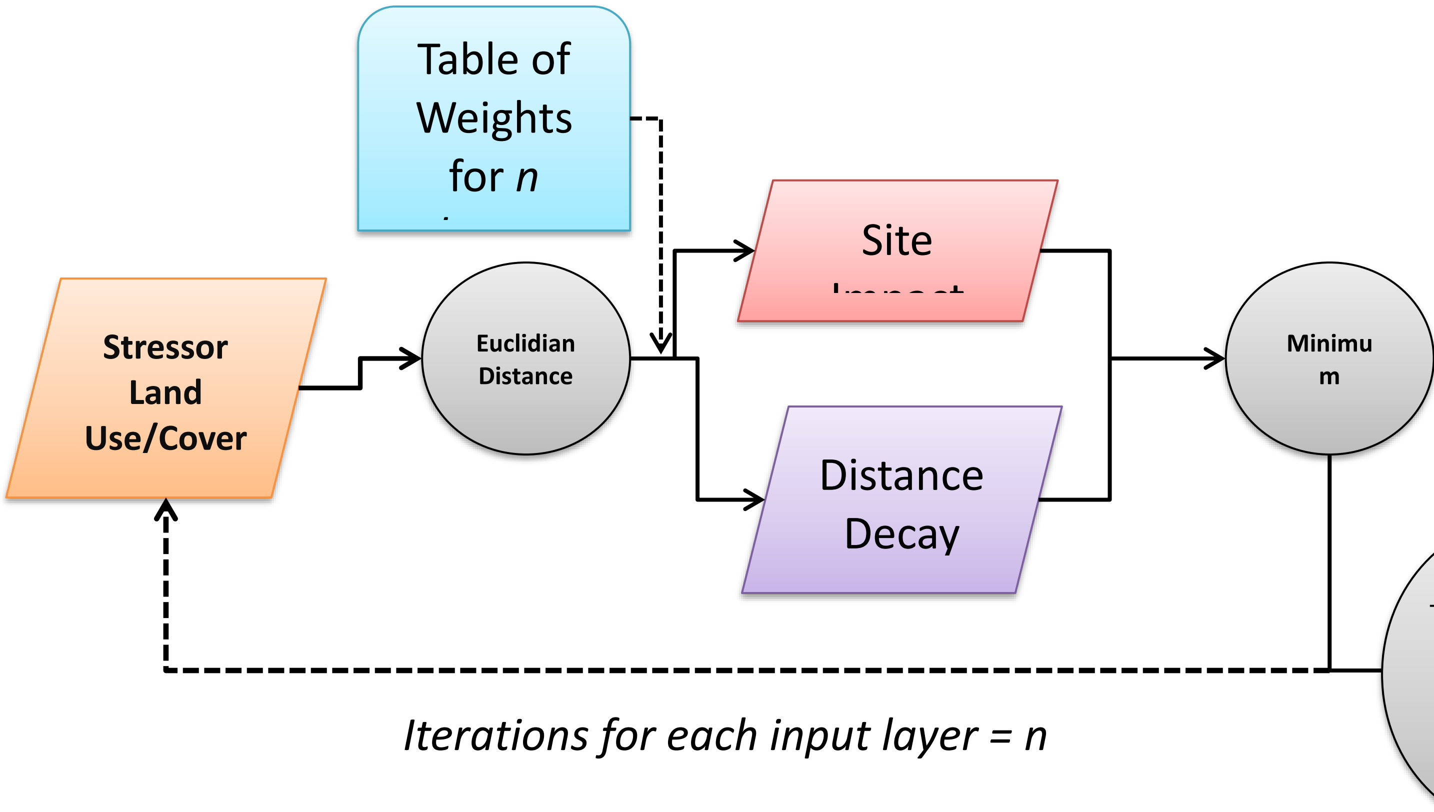
The third category, Managed and Modified Land Cover, includes the gradient of land cover types that reflect land use stressors at varying intensities. Again, national data from USGS and LANDFIRE provide a consistent depiction of these varying land cover classes, from intensive (cultivated and/or irrigated) agriculture, vineyards and timber tree plantations, various forms of introduced non-native vegetation in upland and wetland environments, and finally, areas where native vegetation predominates, but modifications have clearly taken place. These modifications include recently logged areas, or areas that have seen historic conversion, but have recovered some combination of mainly native vegetation (old fields, etc.).

Model Development: Each data layer is given a site impact value, scaled from 0.0 to 1.0 reflecting expert assumptions of the generalized ecological impact where the land use occurs, with values closer to 1.0 expressing relatively little ecological impact from the land use. A second 'distance decay' function calculates and applies a decreasing value for each input layer with distance away from its location. Therefore, a given land use, such as a road of a given size and presumed traffic volume will be given two values, one for its relative impact where it occurs, and a second for the rate of decay of its presumed impact with distance. The result for each input layer is a map surface indicating relative scores between 0.0 and 1.0. Distance decay settings may vary from 0.0 - effectively no presumed ecological impact within one pixel of its location - out to a maximum of 2,000 meters, where presumed effects of a given land use would finally reach zero.

Individual spatial models for each input layer are then combined and normalized to a 0.0 to 1.0 scale. Where the lowest individual layer score is lower than the resulting normalized score, that lower score overrides the normalized score. The combination of per-pixel scores results in a continuous map surface.

Table 1. Date inputs and values integrated together for the NatureServe Landscape Condition Model.

Theme	Impact Score	Presumed Relative Stress	Decay Score	Impact Decays to Zero
Transportation				
Dirt roads, 4-wheel drive	0.7	Low	0.5	200m
Local, neighborhood and connecting roads	0.5	Medium	0.5	200m
Secondary and connecting roads	0.2	High	0.2	500m
Primary Highways with limited access	0.05	Very High	0.1	1000m
Primary Highways without limited access	0.05	Very High	0.05	2000m
Urban and Industrial Development				
Low Density Development	0.6	Medium	0.5	200m
Medium Density Development	0.5	Medium	0.5	200m
Powerline/Transmission lines	0.5	Medium	0.9	100m
Oil /gas Wells	0.5	Medium	0.2	500m
High Density Development	0.05	Very High	0.05	2000m
Mines	0.05	Very High	0.2	500m
Managed and Modified Land Cover				
Ruderal Forest & Upland	0.9	Very Low	1	0m
Native Veg. with introduced Species	0.9	Very Low	1	0m
Recently Logged	0.9	Very Low	0.5	200m
Managed Tree Plantations	0.8	Low	0.5	200m
Introduced Tree & Shrub	0.5	Medium	0.5	200m
Introduced Upland grass & forb	0.5	Medium	0.5	200m
Introduced Wetland	0.3	High	0.8	125m
Cultivated Agriculture	0.3	High	0.5	200m



Invasive Annual Grass Models

Wildfire Regime Condition Class

Wildfire is a key natural process for many terrestrial CEs within each ecoregion but land use patterns commonly result in significant departure from expected fire frequency and intensity. In a limited way, we will develop spatial models of wildfire risk based on lightning strike and landscape information, as was completed in the Northern Basin and Range ecoregion. However, most aspects of these CAs are best addressed within the context of major coarse-filter CEs since existing knowledge and modeling centers around their characteristic fire regimes. This knowledge forms the basis for conceptual tabular and spatial models of fire regime departure and enables us to summarize these effects by appropriate landscape units (e.g., watersheds by 5th level hydrologic unit codes or HUC10). Fire regime models also provide one key mechanism for translating measured and predicted trends in climate regimes as they affect these critical ecological dynamics.

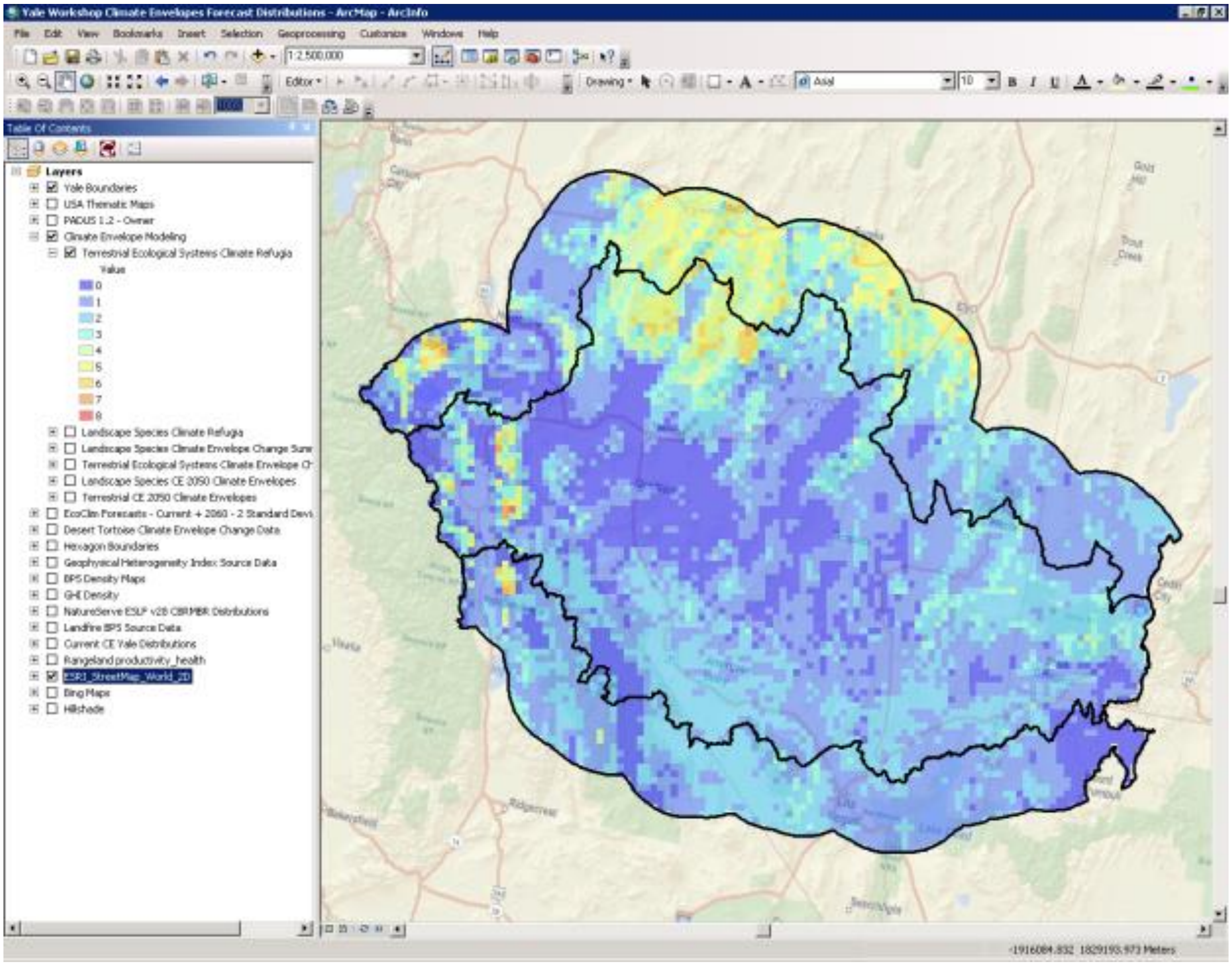
Manage for Climate Change Refugia

2060 Climate Refugia for Terrestrial Ecosystems

The 4 kilometer California Academy Terrestrial Ecosystem Climate Envelope change summary data, which predicts where vegetation ranges will contract, expand or remain the same, were used to create a 2060 terrestrial ecosystem climate refugia map. Fifteen terrestrial ecosystem species were evaluated (these are all the terrestrial ecosystems that were evaluated in the California Academy Climate Envelope project): Great Basin Pinyon Juniper, Great Basin Xeric Mixed Sagebrush Shrubland, Inter-Mountain Basins Aspen Mixed Conifer Forest and Woodland, Inter-Mountain Basins Big Sagebrush Shrubland, Inter-Mountain Basins Big Sagebrush Steppe, Inter-Mountain Basins Curl-leaf Mountain Mahogany Woodland and Shrubland, Inter-Mountain Basins Montane Sagebrush Steppe, Inter-Mountain Basins Mixed Salt Desert Scrub, Inter-Mountain Basins Semi-Desert Shrub Steppe, Inter-Mountain Basins Subalpine Limber Bristlecone Pine Woodland, Mojave Mid-Elevation Mixed Desert Scrub, Rocky Mountain Aspen Forest Woodland, Sonora Mojave Creosotebush White Bursage Desert Scrub, Sonora Mojave Semi Desert Chaparral, and Sonoran Mojave Mixed Salt Desert Scrub.

Each terrestrial ecosystem climate envelope change summary map was reclassified to identify the areas that are predicted to remain the same and assigned a value of 1, while all other pixels (areas of expansion or contraction or no occurrence) were assigned a value of 0.

In the Raster Calculator, each of the fifteen reclassified terrestrial ecosystem grids were added together to produce a terrestrial ecosystem climate refugia grid. Pixel values ranged from 0 to 8. The numeric value of a pixel represents how many different terrestrial ecosystems overlap; the higher the number the more terrestrial ecosystems that are predicted to remain in that location.



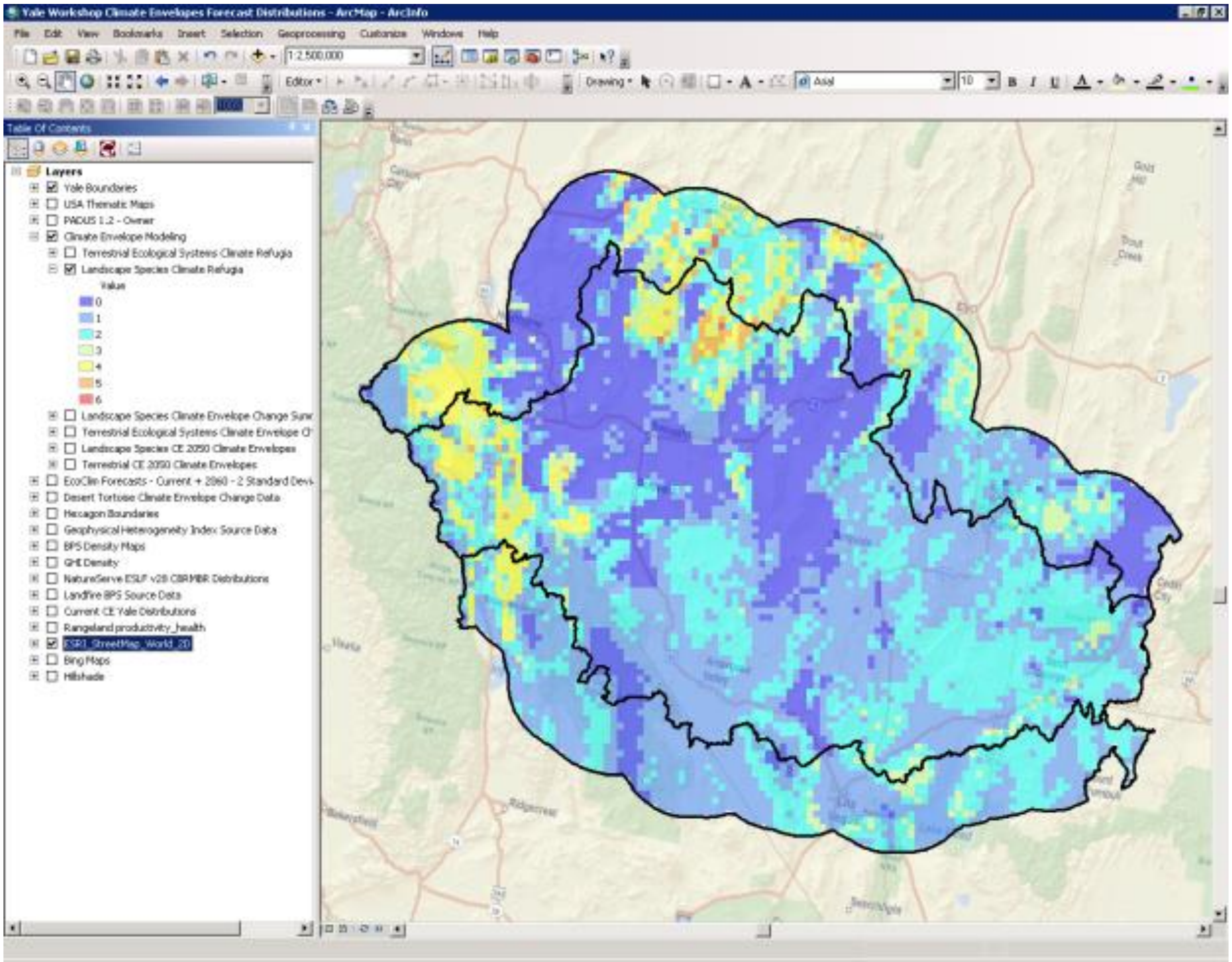
Layers
- ☑ Yale Boundaries
- ☐ USA Thematic Maps
- ☐ PADUS 1.2 - Owner
- ☑ Climate Envelope Modeling
  - ☑ Terrestrial Ecological Systems Climate Refugia
    - Value
    - 0
    - 1
    - 2
    - 3
    - 4
    - 5
    - 6
    - 7
    - 8
  - ☐ Landscape Species Climate Refugia
  - ☐ Landscape Species Climate Envelope Change Sum
  - ☐ Terrestrial Ecological Systems Climate Envelope Ch
  - ☐ Landscape Species CE 2050 Climate Envelopes
  - ☐ Terrestrial CE 2050 Climate Envelopes
- ☐ EcoClim Forecasts - Current + 2060 - 2 Standard Devi
- ☐ Desert Tortoise Climate Envelope Change Data
- ☐ Hexagon Boundaries
- ☐ Geophysical Heterogeneity Index Source Data
- ☐ BPS Density Maps
- ☐ GHI Density
- ☐ NatureServe ESLF v28 CBRMBR Distributions
- ☐ Landfire BPS Source Data
- ☐ Current CE Yale Distributions
- ☐ Rangeland productivity_health
- ☑ ESRI_StreetMap_World_2D
- ☐ Bing Maps
- ☐ Hillshade

2060 Climate Refugia for Landscape Species

The 4 kilometer California Academy Landscape Species Climate Envelope change summary data, which predicts where species range will contract, expand or remain the same, was used to create a 2060 landscape species climate refugia map. Eight landscape species are evaluated in the Yale study: bighorn sheep, desert tortoise Mojave, greater sage grouse, mule deer summer, mule deer winter, mule deer yearlong and pygmy rabbit.

Each landscape species climate envelope change summary map was reclassified to identify the areas that are predicted to remain the same and assigned a value of 1, while all other pixels (areas of expansion or contraction or no occurrence) were assigned a value of 0.

In the Raster Calculator, each of the eight reclassified landscape species grids were added together to produce a landscape species climate refugia grid. Pixel values ranged from 0 to 6. The numeric value of a pixel represents how many different landscape species overlap; the higher the number the more landscape species that are predicted to remain in that location.



Layers
- ☑ Yale Boundaries
- ☐ USA Thematic Maps
- ☐ PADUS 1.2 - Owner
- ☑ Climate Envelope Modeling
  - ☐ Terrestrial Ecological Systems Climate Refugia
  - ☑ Landscape Species Climate Refugia
    - Value
    - 0
    - 1
    - 2
    - 3
    - 4
    - 5
    - 6
  - ☐ Landscape Species Climate Envelope Change Sum
  - ☐ Terrestrial Ecological Systems Climate Envelope C
  - ☐ Landscape Species CE 2050 Climate Envelopes
  - ☐ Terrestrial CE 2050 Climate Envelopes
- ☐ EcoClim Forecasts - Current + 2060 - 2 Standard Devi
- ☐ Desert Tortoise Climate Envelope Change Data
- ☐ Hexagon Boundaries
- ☐ Geophysical Heterogeneity Index Source Data
- ☐ BPS Density Maps
- ☐ GHI Density
- ☐ NatureServe ESLF v28 CBRMBR Distributions
- ☐ Landfire BPS Source Data
- ☐ Current CE Yale Distributions
- ☐ Rangeland productivity_health
- ☑ ESRI_StreetMap_World_2D
- ☐ Bing Maps
- ☐ Hillshade

GEOPHYSICAL/BIOPHYSCIAL HETEROGENITY DENSITY MAPPING

Abstract Summary:

NatureServe modeled the relative complexity of the physical landscape across the Yale study area for use in identifying potential climate refugia. The assumption is that the more complex the underlying physical landscape, the more likely it will be able to sustain species in the future if when species ranges shift due to climate change (Anderson and Ferree 2010). A "Geophysical Heterogeneity Index" (GHI) map was derived from a combination of landform, solar radiation and flow accumulation maps. The relative density of the resultant GHI classes was then summarized in hexagon maps of varying scales (e.g. 1/2 km, 1 km, 4 km, 8 km, 16 km area hexagons) to identify the geophysical heterogeneity density (GHD) across the Yale landscape. In addition, a Biophysical Heterogeneity Density (BHD) map was produced from LANDFIRE Biophysical Setting vegetation data, to evaluate if the resultant maps are comparable to the Geophysical Heterogeneity Density (GHD) map, to evaluate if this readily available source of data on vegetation could be effectively utilized to identify climate refugia.

Methods and Results:

The landforms and solar radiation maps were produced using models (with slight modifications) from Jeff Jenness's Topographic Toolbox 9.3 (i.e. Landform Classification (Jenness).tbx and Solar Radiation (McCune 2002).tbx. The Flow accumulation map was modeled using standard ArcGIS hydrology modeling tools. These three maps were then combined to create a Geophysical Heterogeneity Index (GHI) map. The Geophysical Heterogeneity Density (GHD) hexagon map was created from a simple count of the total number of GHI classes within each hexagon. Detailed descriptions of the technical methodologies for modeling the landforms, solar radiation and flow accumulation maps, and producing the geophysical heterogeneity index map, and the final geophysical and biophysical heterogeneity density maps are provided in the appendix.

The landforms map effectively models the physical complexity of the Central Basin and Range / Mojave Basin and Range landscape into ten landform classes. The nuances of the landscape are well defined (see Map 1). However, the landform map tends to over-estimate the extent of the macro-scale landform classes (i.e. u-shaped valleys, plains, open slopes and upper slopes/mesas), as well as the extent of canyons/deeply incised streams, and mountain tops/high ridges, but tends to under-estimate the extent of micro-scale landforms (i.e. midslope drainages/shallow valleys, upland drainages/headwaters, local ridges/hills in valleys, and midslope ridges/small hills in plains). The model parameters were adjusted to provide the best compromise between reducing the macro-scale landforms and increasing the micro-scale landforms. On alluvial plains, upper slopes/mesas extend down too far into the open slopes, and should more correctly be identified as open slopes. This issue was unresolvable, and simply reflects that alluvial fan elevations are similar in structure to upper slopes/mesas, and therefore will tend to be incorrectly classified in this type of landform model using digital elevation model data.

The solar radiation map models the relative level of solar energy across the Yale study area (see Map 2). The solar radiation map is a continuous surface of predictive/modeled solar energy, unlike an aspect map which is a classified map of the eight cardinal directions of the compass (north, north/east, east, south/east, etc.), traditionally used in modeling as a proxy for solar radiation. The solar radiation map values match example values for similar latitudes/aspects from McCune and Keon's study (2002). However, this map should be reviewed because the Yale study area is relatively drier/hotter than other locations at similar latitudes, and therefore it could be expected that the relative solar radiation would likely be higher throughout the Yale study area. The McCune and Keon model is based solely on elevation and latitude and does not consider relative precipitation, temperature or biogeographic location.

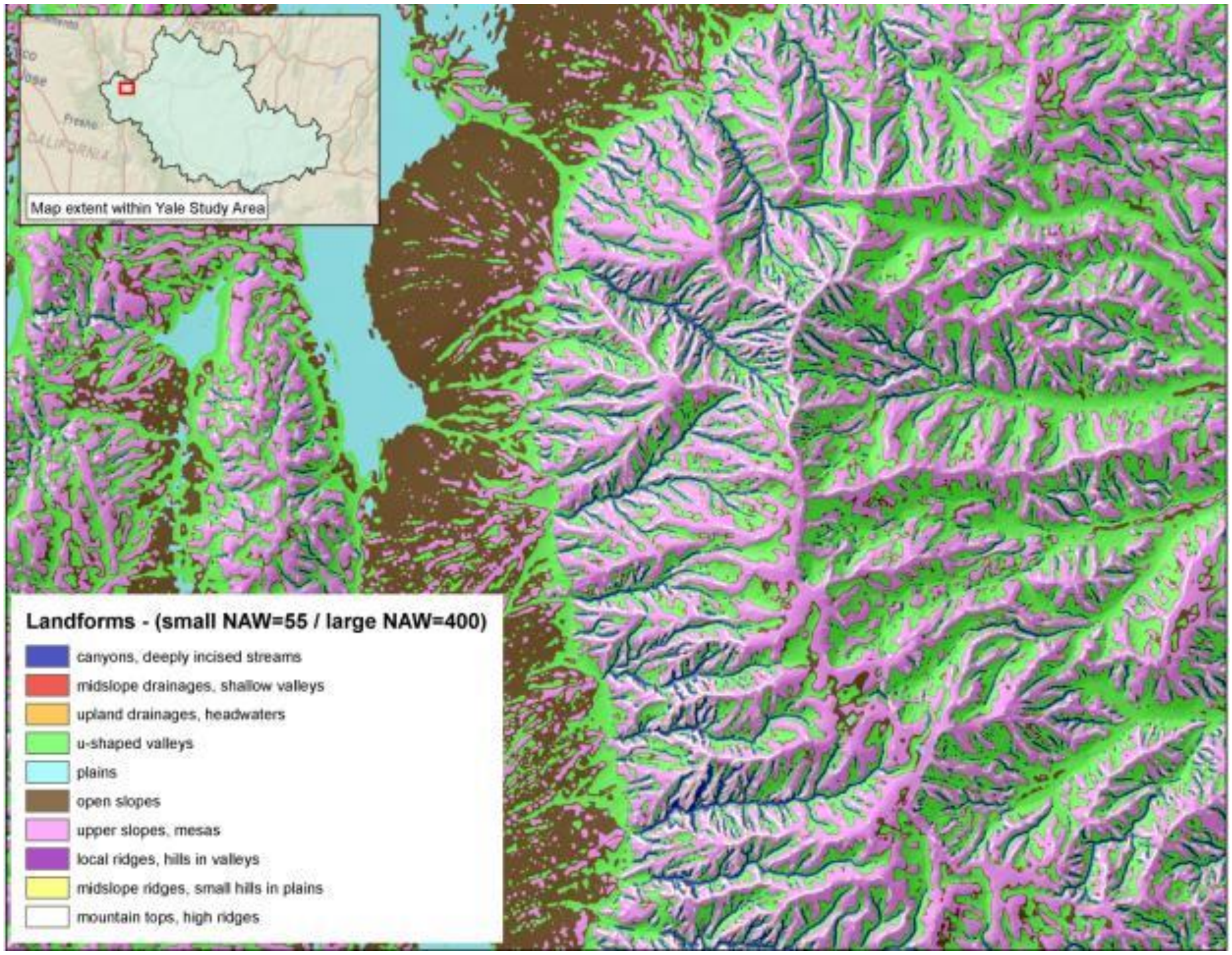
The Geophysical Heterogeneity Index (GHI) map is a combination of three physical characteristics of the landscape: landforms (10 classes), solar radiation (reclassified to 3 classes) and flow accumulation (reclassified to 2 classes) grid maps (see Map 3). For example, a site could be classified as a combination of "Upper Slope/Mesa landform +

South Facing Solar Radiation + no flow accumulation". The GHI map produced 46 unique classes (see the appendix for additional details about the values).

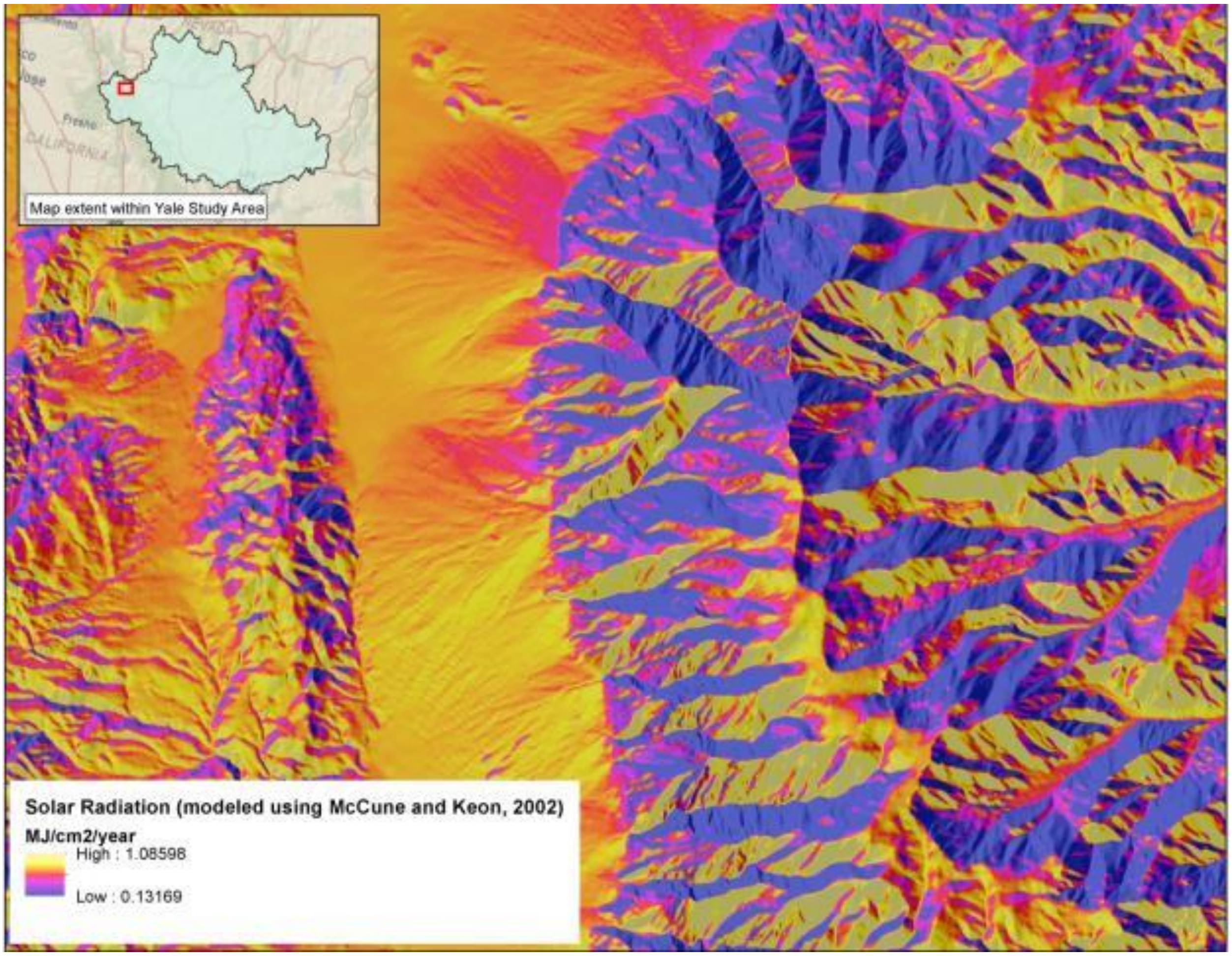
The Geophysical Heterogeneity Density (GHD) hexagon map aims to identify sites of relatively higher densities of geophysical heterogeneity (i.e. site of multiple physical characteristics). It was displayed by standard deviation to try and parse out hexagons with relatively higher densities of GHI classes (see map 4).

The Biophysical Heterogeneity Density (BHD) hexagon map aims to identify sites of relatively higher densities of ecosystem heterogeneity (i.e. sites of multiple vegetation types). It also was displayed by standard deviation to try and parse out hexagons with relatively higher densities of Landfire Biophysical Settings (BPS) vegetation classes (see map 5).

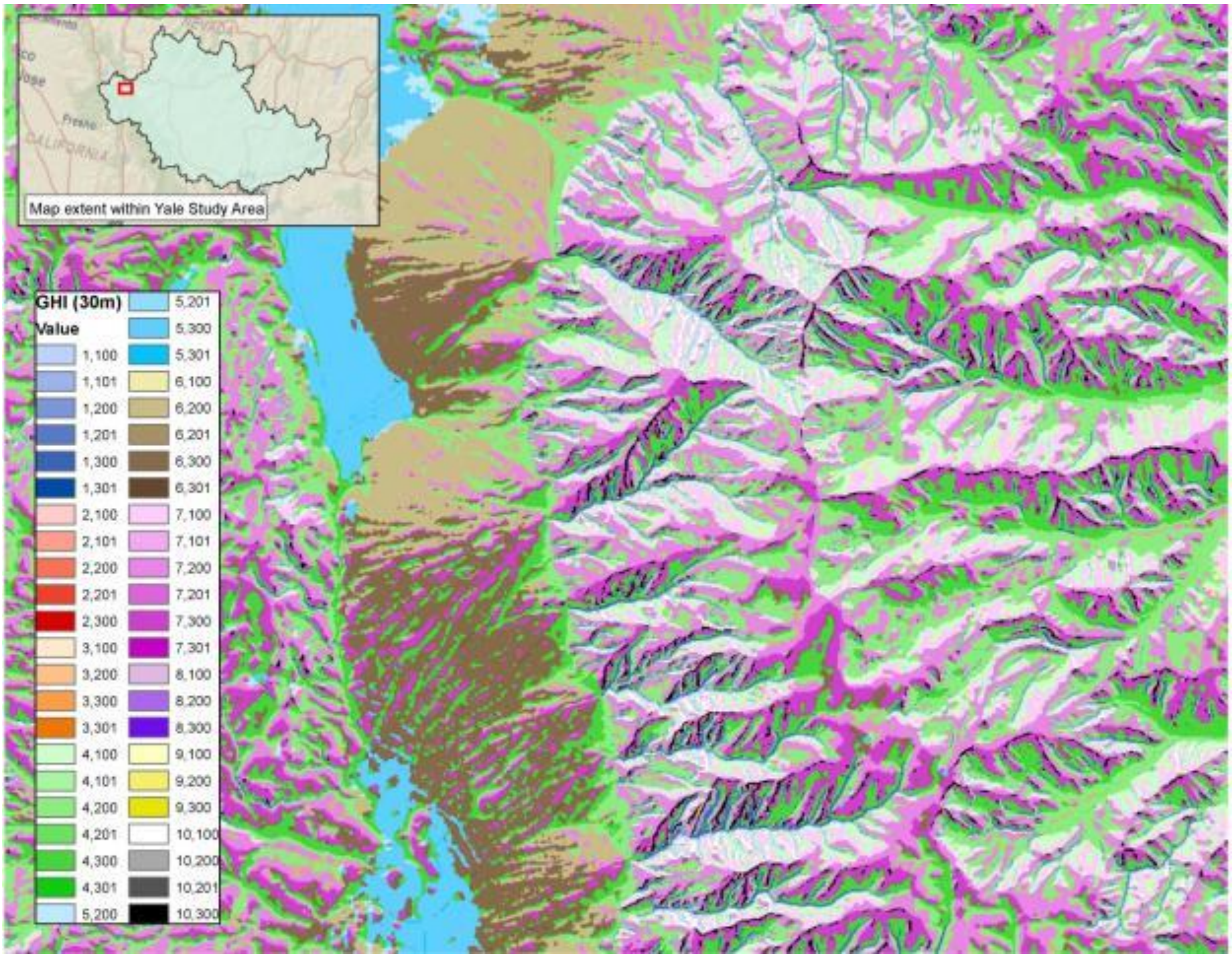
Map 1. Landforms, 1:100,000 (a small part of the Yale study area draped over a hillshade)



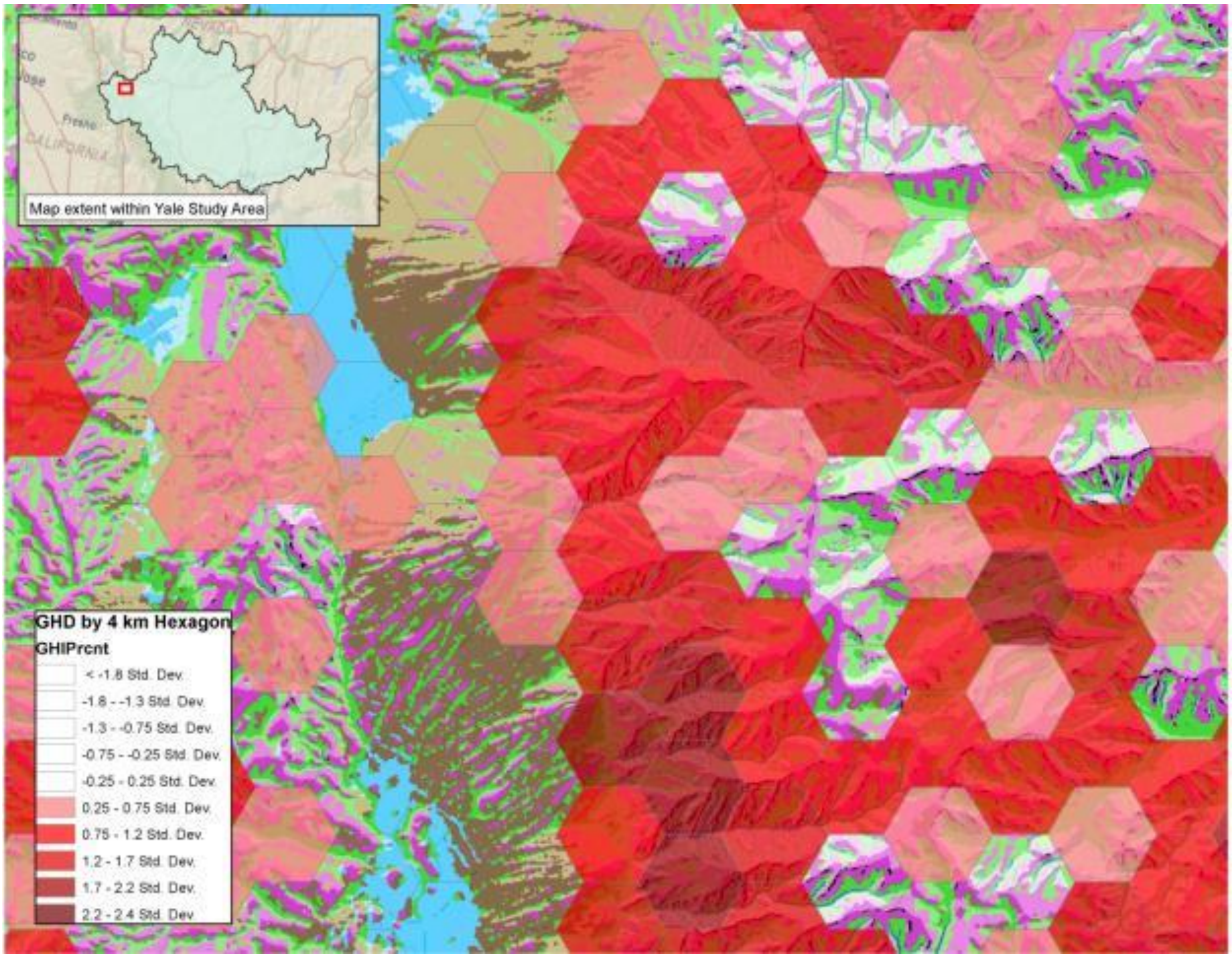
Map 2. Solar Radiation, 1:100,000 (a small part of the Yale study area, draped over a hillshade)



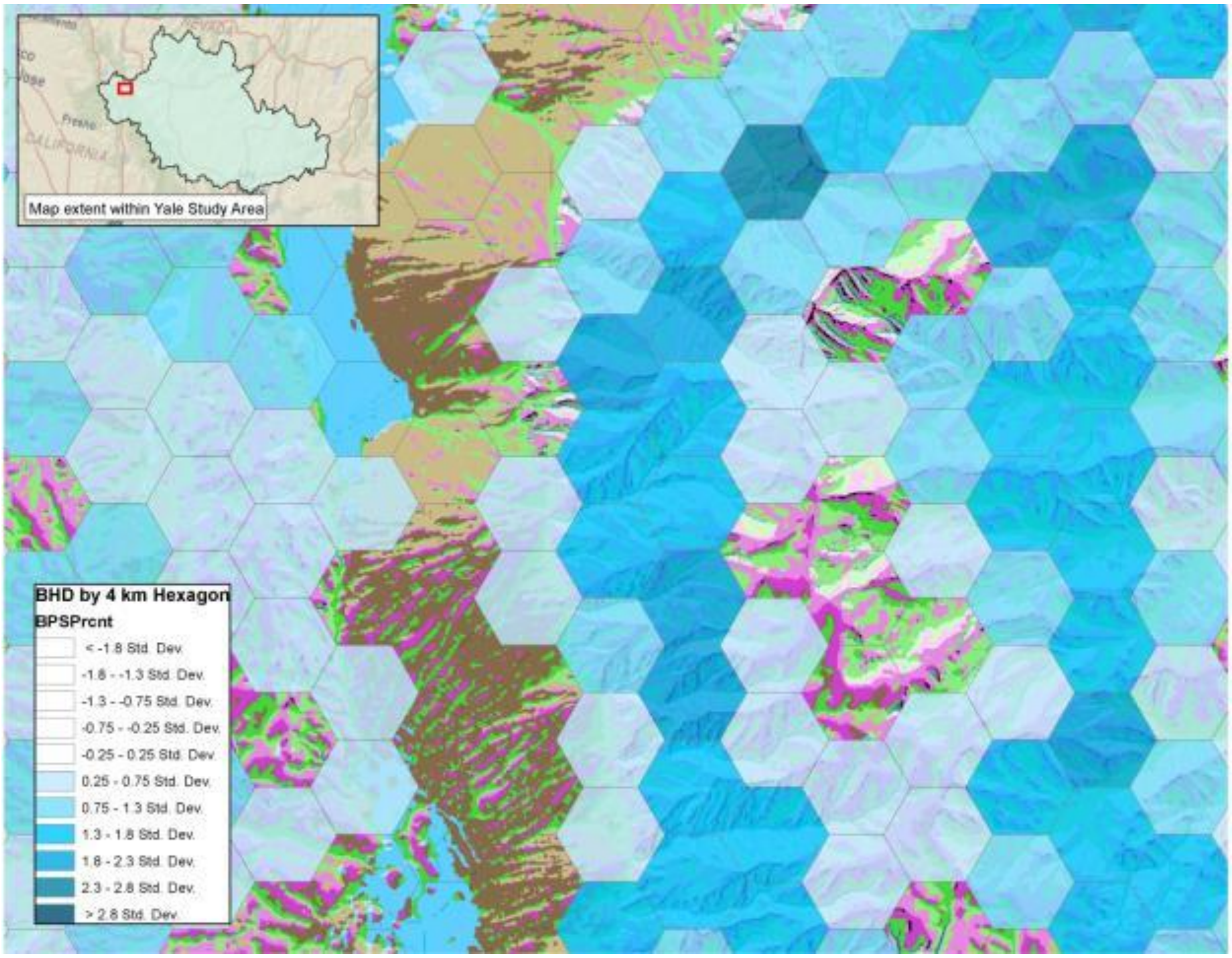
Map 3. Geophysical Heterogeneity Index (GHI) Map, 1:100,000 (a small part of the Yale study area NOT draped over hillshade)



Map 4. Geophysical Heterogeneity Density (GHD) map, displayed by standard deviation



Map 5. Biophysical Heterogeneity Density (BHD) map, displayed by standard deviation



APPENDIX:

Source Data Inputs:

- Yale Study Area boundary
- USGS NED 10 meter Digital Elevation Model

Landforms

A modified version of Jeff Jenness's Landform Classification Model (Tagil and Jenness, 2008) from Topography Tools 9.3 was used to model landforms. This tool models 10 landform classes using a digital elevation model (DEM) as source input. The 10 landform classes and their grid values (in parenthesis) include:

canyons, deeply incised streams (1)
midslope drainages, shallow valleys (2)
upland drainages, headwaters (3)
u-shaped valleys (4)
plains, less than 2% slope (5)
open slopes, over 2% slope (6)
upper slopes, mesa (7)
local ridges, hills in valleys (8)
midslope ridges, small hills in plains (9)
mountain tops, high ridges (10)

The USGS 10 meter NED digital elevation model was used as source data for modeling landforms in the Yale study area. This data has significant artifacts – banding/steps - that affect any derived topographic datasets (it creates significant salt and pepper in the derived grids rather than smooth continuous surfaces). It was necessary to first smooth the NED10 data using a filter to try and remove these artifacts (using a focal majority function where a moving window moves across the grid evaluating the majority value within a specified window). Smoothing will remove very high peaks and very low sinks. A 3x3 circular neighborhood analysis window (NAW) was moved over the NED10m to remove the artifacts, and this step was then repeated second time using the first smoothed DEM as input.

Jenness Landform Classification model uses a 5% slope threshold to distinguish between Plains and Open Slopes, but this value was modified to 2% based on expert opinion of how best to differentiate between Plains and Open Slopes landforms in the Yale study area.

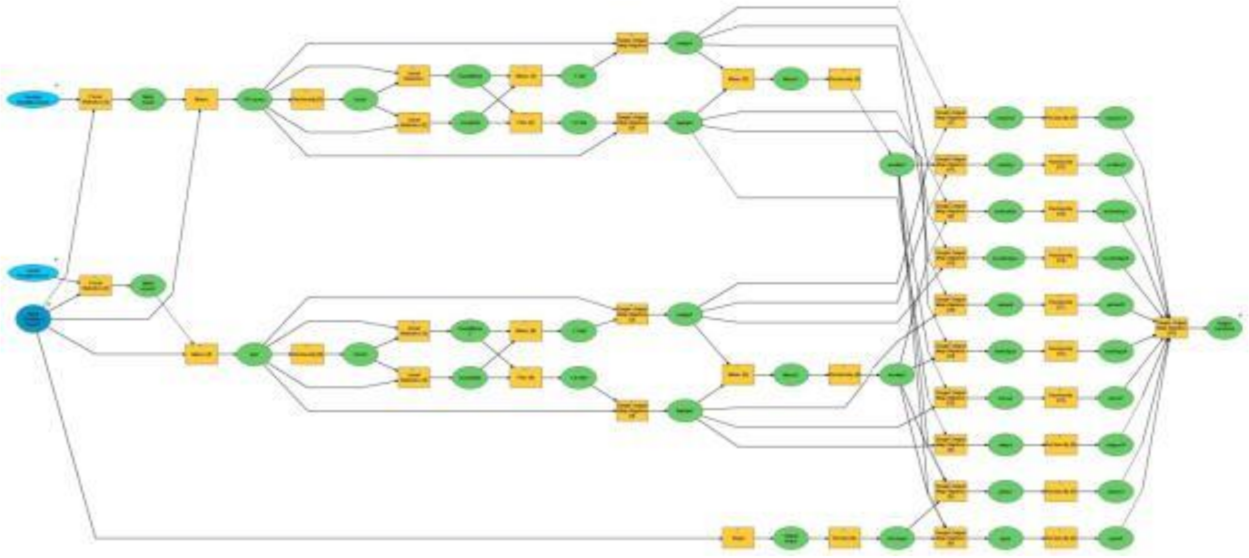
Jenness landform classification tool classifies landform based on Topographic Position Index (TPI). The TPI were calculated using a moving window and is the difference between a cell elevation value and the average elevation of the neighborhood around that cell. Positive cell values meant the cell was higher than surrounding cells, while negative cell values meant it was lower.

"Landform category can be determined by classifying the landscape using 2 TPI grids at different scales. The combination of TPI values from different scales suggest various landform types." "For example, a high TPI value in a small neighborhood, combined with a low TPI value in a large neighborhood, would be classified as a local ridge or hill in a larger valley, while a low small neighborhood TPI plus a high large-neighborhood TPI would be classified as an upland drainage or depression."

Various landform classification trials were conducted using different small and large NAW for calculating the 2 Topographic Position Index (TPI) maps, to try and identify optimal small and large NAWs for developing landforms in the Yale landscape.

The large NAW generally identifies the extensive/macro scale landform features: plains, open slopes, upper slopes/mesas, and u-shaped valleys. Using the twice smoothed DEM, as the size of the small NAW increased, it increased the extent of midslope drainages/shallow valleys, upland drainages/headwaters, local ridges/hills in valleys, and midslope ridges/small hills in plains. These classes are under-represented in the landform map and therefore it was desirable to see their extents expand. But when the small NAW increased, it ***also*** significantly increased the extent of canyons/deeply incised streams, and mountain tops/high ridges, as well as upper slopes/mesas and u-shaped valleys which was not desired. The best compromise between small NAW and large NAW – where it balances pulling out the former classes, without unduly expanding the latter classes – was a small NAW of 55 and a large NAW 400. The final landform dataset was reclassified with values in the 1000s to represent each landform (i.e. 1000 = canyons, deeply incised streams, 2000 = midslope drainages, shallow valleys, etc.)

Diagram 1. Landform Classification (Jenness) ArcGIS toolbox model from Jeff Jenness's Topography Tools 9.3 (zoom in to see detail).



Solar Radiation

A modified version of the McCune and Keon's Solar Radiation model (McCune and Keon 2002) from Jeff Jenness's Topography Tools 9.3 was used to model solar radiation. This tool presents a GIS version of McCune's model, using a digital elevation model and a grid of latitude (decimal degrees) as source data to derive slope, aspect (folded) and latitude to model potential annual direct solar radiation (MJ/cm2/year).

It is based on McCune and Keon's (2002) equation 1 for modeling solar radiation:

Exp(-1.467 + 1.582 * COS([Latitude Radians])*COS([Slope Radians]) - 1.5*COS([Aspect Radians]) * SIN([Slope Radians]) * SIN([Latitude Radians]) - 0.262 * SIN([Latitude Radians]) * SIN(Slope Radians]) + 0.607 * SIN([Aspect Radians]) * SIN([Slope Radians]))

Where
Latitude Radians = Latitude Raster * (pi/180)
Slope Radians = Slope Degrees * (pi/180)
Aspect Radians = Folded Aspect (180 – (Aspect-180)) * pi/180

But in their paper McCune and Keon present three equations for modeling solar radiation:

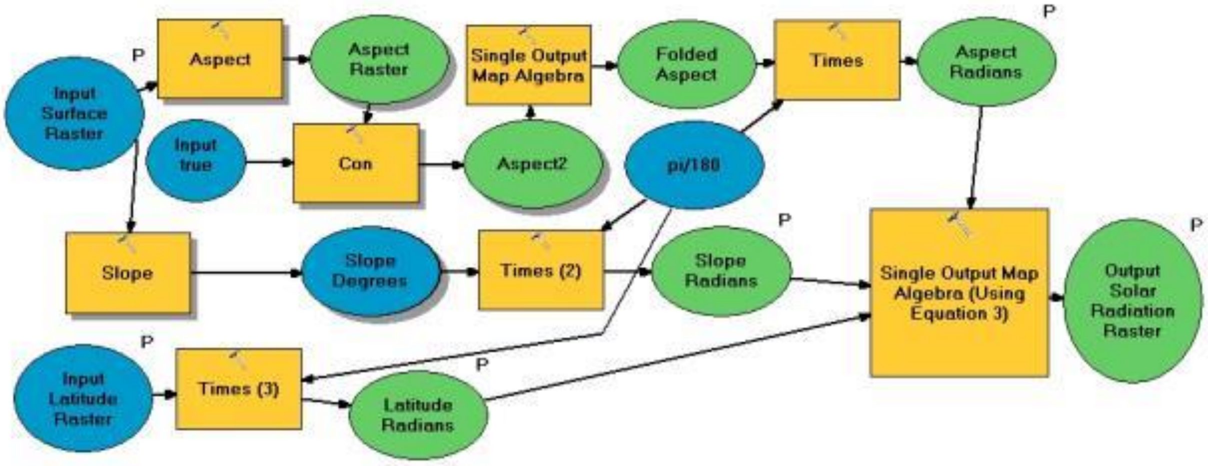
Equation 1 can be used anywhere on the planet, irrespective of slope and latitude.
Equation 2, however, can be implemented at any latitude, but only on dems with slopes from 0-60.
Equation 3 is the most restrictive, and can be utilized at latitudes from 30-60 and slopes from 0-60.

The study suggests that their equation 3 produces the most robust results and that it is generally a better option. Another researcher suggested if you are in the 30-60 latitudes it is best to reclassify any slope values over 60, to 60 degrees, and therefore can use equation 3. There were few slopes over 60 degrees in the Yale study area, therefore I followed the suggestion and reclassified these slopes to 60 degrees, and used equation 3.

McCune and Keon's equation 3 for modeling solar radiation:

0.339 + 0.808*COS([Latitude Radians])*COS([Slope Radians])-0.196*SIN([Latitude Radians])*SIN([Slope Radians])-0.482*COS([Aspect Radians])*SIN([Slope Radians])

Diagram 2. Solar Radiation (McCune 2002) ArcGIS toolbox model from Jeff Jenness's Topography Tools 9.3



The USGS NED 10-meter digital elevation model, and a 10-meter grid of latitude (decimal degrees), were used as the source data.

Within the model any slope over 60 was reclassified as 60 degrees (using the following CON statement (CON(Slope Degrees > 60), 60, Slope Degrees)) and replaced equation 1 with equation 3.

The resultant map is a 10-meter raster grid of potential annual direct solar radiation (MJ/cm2/year). Solar radiation is measured as a value of energy per unit area. In this case it is megajoules per cm2, per year. In the Yale study area, the values ranged from 0.131 to 1.086. The solar radiation map is a continuum from least potential annual direct solar radiation (0.131 - North facing slopes) to most potential solar radiation (1.086 - South facing slopes) (see map 2).

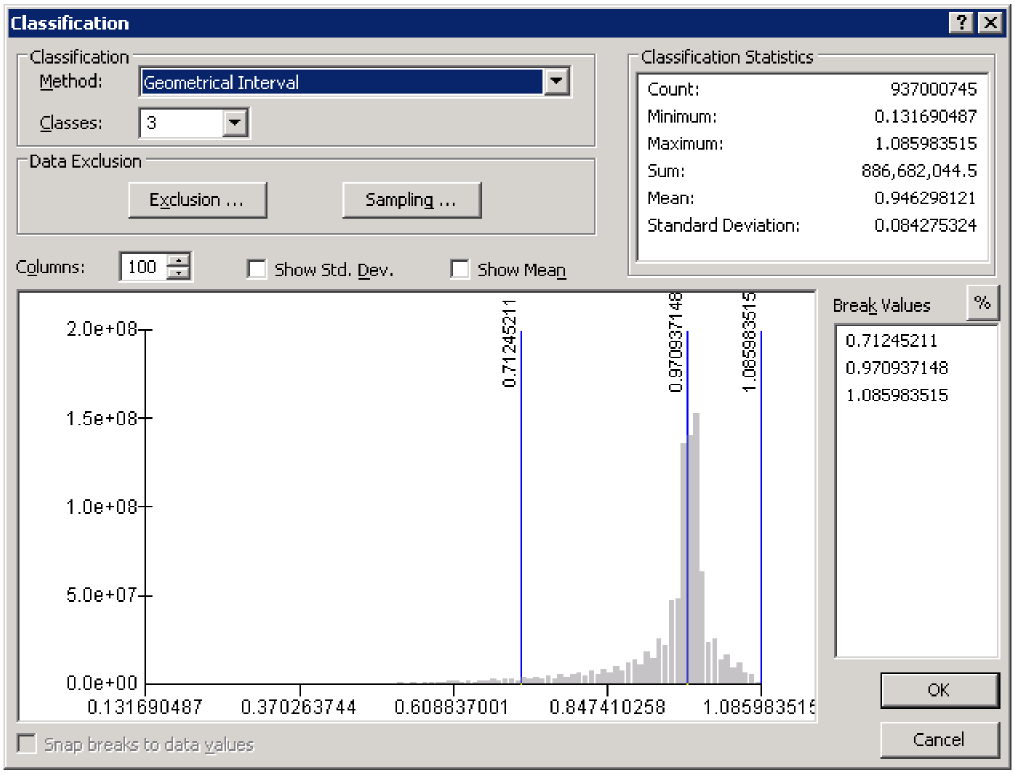
North Flat South
0.131--------------0.958--------------1.086

The result showed very good correlation with McCune and Keon's example values for equation 3:

From McCune and Keon (2002), page 605:

Latitude/Slope/Aspect	**McCune and Keon Example Values**	**Average Yale Example Values**
40N, 30 slope, N aspect	0.571	0.672
40N, 30 slope, S aspect	1.053	1.055
40N, Flat	0.958	0.967

The geometrical interval classification method in ArcGIS 9.3 was used to classify the solar radiation output into three classes. The geometrical interval classification is appropriate for continuous data that is not distributed normally (for more information see http://blogs.esri.com/esri/arcgis/2007/10/18/about-the-geometrical-interval-classification-method/)



Classification

Method: Geometrical Interval

Classes: 3

Columns: 100

☐ Show Std. Dev. ☐ Show Mean

Classification Statistics

Count:	937000745
Minimum:	0.131690487
Maximum:	1.085983515
Sum:	886,682,044.5
Mean:	0.946298121
Standard Deviation:	0.084275324

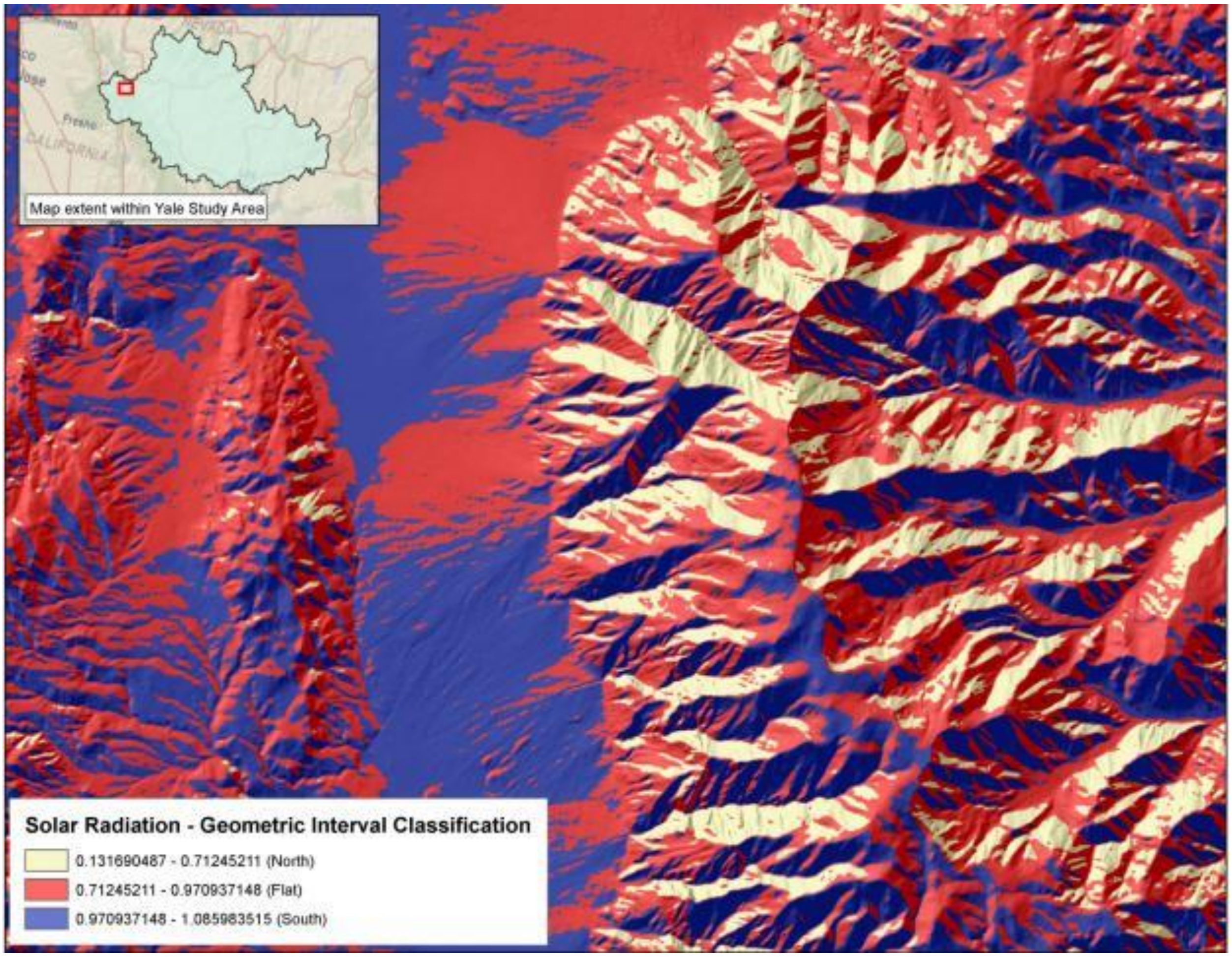
Break Values

0.71245211
0.970937148
1.085983515

☐ Snap breaks to data values

A visual review of the classified map draped over a hillshade shows that the geometric class breaks appear to be suitable thresholds for defining north aspect versus flat versus south aspect in the solar radiation grid. The solar radiation map was reclassified to three classes based on these threshold values (see map 6).

Map 6. Classified Solar Radiation Map (a small part of the Yale study area, draped over hillshade)



Flow Accumulation

The USGS NED 10-meter digital elevation model was used in the ArcGIS Flow Direction/Flow Accumulation tools to model accumulated flow within the Yale study area. Accumulated flow is the accumulated weight of all grid cells flowing into each downslope cell in the final raster.

Of note, this tool models all hypothetical stream networks based on the digital elevation model, regardless of whether a stream/river exists on the landscape. In this study area, many of the streams identified in this modeled flow accumulation map will not exist or be ephemeral.

A threshold for identifying a stream network (versus the surrounding upland) was identified in the resultant flow accumulation map based on a visual review of the data/expert opinion and the flow accumulation map was reclassified into two classes based on this class break threshold value (17).

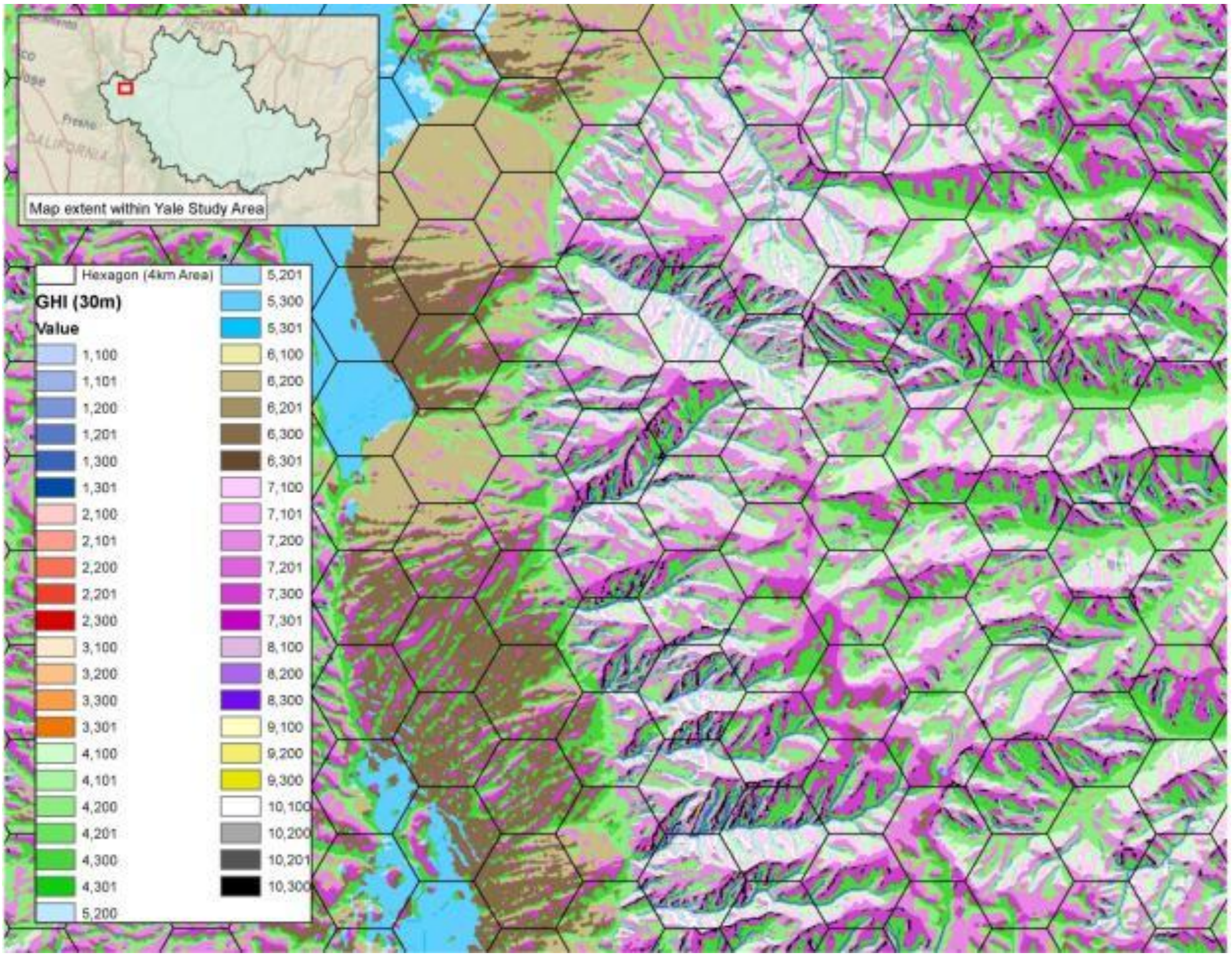
Geophysical Heterogeneity Index (GHI) Map

The landform, classified solar radiation and classified flow accumulation maps were then combined to create a geophysical heterogeneity index map. The landforms are represented by the 1000s values (1000 = canyon, deeply incised streams; 2000 = midslope drainages, shallow valleys; 3000 = upland drainages, headwaters; 4000 = u-shaped valleys; 5000 = plains; 6000 = open slopes; 7000 = upper slopes, mesas; 8000 = local ridges, hills in valleys; 9000 = midslope ridges, small hills in plains; 10000 = mountain tops, high ridges), the reclassified solar radiation are represented by the 100s values (100 = north facing, 200 = flat, and 300 = south facing) and the reclassified flow accumulation classes are represented by the 1s (1 = stream, 0 = non-stream)

Geophysical Heterogeneity Density (GHD) Map

A series of hexagon maps were created at various scales – 16km, 8km, 4 km, 1 km and ½ km – and the total number of GHI classes that occurred within each hexagon was calculated (see for example, Map 7).

Map 7. Hexagon Map – 4 km Area, displayed over the GHI map



The distribution of the resultant Geophysical Heterogeneity Density (GHD) hexagon map was then displayed by standard deviation to identify areas of relatively higher geophysical complexity/potential climate refugia (see for example, Map 4). The goal of mapping the densities at different scales was to try and find the scale at which the density per hexagon best reflected the heterogeneity on the ground. A very small hexagon would likely have occurrences of only 1 or 2 different GHI classes, whereas a very large hexagon could have occurrences of all 46 GHI classes. Both results are meaningless. The challenge is to identify the scale (sweet spot) somewhere in the middle of these two extremes that will model the geophysical heterogeneity of the landscape in a realistic manner.

Biophysical Heterogeneity Density (BHD) Map

A biophysical heterogeneity density map was created for comparison with the geophysical heterogeneity map, to see if this readily available vegetation map could be used as a proxy for identifying climate refugia. The Landfire Biophysical Settings map, which represents the vegetation that may have been dominant on the landscape prior to Euro-American settlement, was used as the source data for creating a biophysical heterogeneity density map. The same methodology used to create the Geophysical Heterogeneity density map was applied to produce the biophysical heterogeneity density map. The distribution of the resultant Biophysical Heterogeneity Density (BHD) hexagon map was then displayed by standard deviation to identify areas of relatively higher biophysical complexity/potential climate refugia (see, for example, Map 5).

Source References:

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Downloaded Testrad.xls - McCune and Keon's spreadsheet with constants and equations for potential annual direct incident radiation (from http://people.oregonstate.edu/~mccuneb/radiation.htm)

Sean Parks 2004. Solar Radiation ArcView Script (based on McCune and Keon, 2002) (asr_readme.txt ; http://arcscripts.esri.com/details.asp?dbid=13776)

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