# A Biological Conservation Assessment for the Greater Yellowstone Ecosystem

## Executive Summary

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# EXECUTIVE SUMMARY

This report presents a conservation assessment of the Greater Yellowstone Ecosystem, as requested by the Greater Yellowstone Coalition. It is complementary to a report to The Nature Conservancy on the Utah-Wyoming Rocky Mountains Ecoregion, which includes the Bighorn, Uinta, and Wasatch ranges as well as the Greater Yellowstone Ecosystem.

The approach taken in this study is representative of regional-scale conservation planning, which has become the standard approach for organizations and agencies worldwide interested in the conservation of biodiversity. Regional conservation planning differs from conventional land-use planning in that regions are defined ecologically rather than politically. The Greater Yellowstone Ecosystem (GYE; Fig.E1) was first defined by John and Frank Craighead as an area large enough to sustain the disjunct Yellowstone population of grizzly bears. That definition has expanded to encompass other qualities of the ecosystem, including intact watersheds and mountain ranges.

A fundamental quality of regional conservation planning is that it is systematic and, therefore, superior in many ways to opportunistic or politically-biased planning. Among the key attributes of systematic conservation planning are explicit goals and quantitative targets, objective methods for locating new reserves to complement existing ones, and explicit criteria for implementing conservation action.

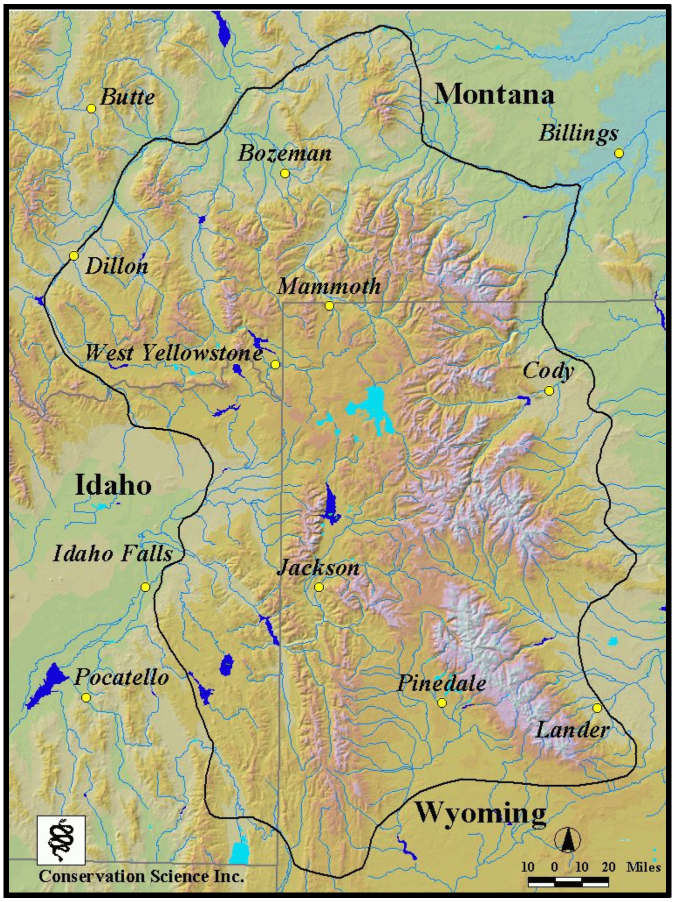

**Figure E1**. The Greater Yellowstone Ecosystem.

## Approach

We sought to identify high-priority sites within the Greater Yellowstone Ecosystem that have the most to lose, in terms of biodiversity, if not protected. These sites are often irreplaceable, in that the values they contain cannot be replicated elsewhere. Across much of the GYE and the West in general, measures other than the traditional "fee simple" acquisition have become the primary tools of the conservation community. Partnerships with private landowners (e.g., ranchers), conservation easements, and agency designations are among the tools available. Nevertheless, on private lands of very high biodiversity value or at immediate risk of degradation by development, acquisition by a public or private conservation authority is often the most appropriate action.

The methodology for the current assessment is a refinement of previous assessments and reserve selection and design projects conducted by our research group and others. Our "three-track method," first applied to the Klamath-Siskiyou ecoregion of northwestern California and adjacent Oregon, seeks to serve several basic goals of biological conservation:

- Representing all kinds of ecosystems, across their natural range of variation, in protected areas;
- Maintaining viable populations of all native species in natural patterns of abundance and distribution;
- Sustaining ecological and evolutionary processes within their natural ranges of variability; and
- Building a conservation network that is adaptable to environmental change.

In order to serve these goals, our methodology integrates three basic planning approaches that conservation biologists have pursued over the last several decades (albeit these approaches have usually been pursued separately rather than jointly):

- Protection of special elements—identifying, mapping, and protecting rare species occurrences (and particularly "hotspots" where occurrences are concentrated), watersheds with high biological values, imperiled natural communities, and other sites of high biodiversity value;
- Representation of habitats—inclusion of a full spectrum of habitat types (e.g., vegetation, abiotic habitats, aquatic habitats) in protected areas or other areas managed for natural values;
- Conservation of focal species—identifying and protecting key habitats of wide-ranging species and others of high ecological importance or sensitivity to disturbance by humans.

Together, these three tracks constitute a comprehensive approach to biological conservation. Integrating the results of site-selection algorithms, population models, and other quantitative approaches with qualitative data and the experience and intuition of biologists and managers, is a defensible strategy for the protection of biodiversity.

Our three-track method for selecting and designing a conservation network is an extension of the "fine filter/coarse filter" approach of The Nature Conservancy. The fine filter focuses on rare species and communities and is represented by our special elements track. The coarse filter is our second track. Also known as the representation approach, the coarse filter seeks to protect high-quality examples of all natural communities or ecosystems in a region. Especially when applied on a landscape scale, with the notion of representing all ecosystems in a region across their natural range of variation, the coarse filter is complementary to rare-species conservation. It may be especially useful for capturing species groups that have been poorly inventoried. The Nature Conservancy has estimated that 85-90% of all species can be protected by the coarse filter. Species that fall through the pores of the coarse filter—such as narrow endemics—can be protected through the fine filter.

Consideration of species with demanding spatial requirements constitutes the third track in our approach—focal species. We selected four carnivores and one ungulate as the focal species for this assessment: grizzly bear, gray wolf, wolverine, lynx, and elk. Adequate data to construct regional-scale habitat models were available for these species. Our research suggests that these species, collectively, respond to a broad range of landscape features and provide ecological indicator and umbrella species values. The GYE is especially significant in terms of focal species, as it possesses what is probably the densest elk population in the world and is the most southerly area in North America with potentially viable populations of grizzly bear, wolf, and wolverine. Hence, our assessment places greater emphasis on focal species than most previous multi-criteria conservation plans.

The needs of focal species are often best considered through modeling. For species not expected to show strong area or connectivity limitations, given the relationship between their life-history characteristics (territory size, population density, dispersal ability) and current landscape condition, the optimal approach is often to select the highest quality habitat as identified by a static habitat suitability model. Species with very large area requirements or dispersal needs, however, are not adequately addressed by static models. To create a coherent regional-scale conservation strategy for these species, dynamic modeling that integrates life-history characteristics and habitat configuration (e.g., the size and spacing of habitat areas) is useful. These species usually have relatively low population density, require a large area of habitat, or do not disperse easily across the landscape matrix (e.g., developed or non-forested habitat). All of our focal species fit this description to one degree or another.

## Methods

### *Planning Units*

The building blocks of a conservation plan are the sites that are compared to one another in the conservation assessment. We used 6th-level watersheds as planning units because they are ecologically relevant and are of a convenient scale for regional planning. Among other advantages, using watersheds as planning units allows site selection algorithms to represent aquatic systems as intact and connected units. Nevertheless, 6th-level watersheds had not been delineated for most of the study area. Therefore, we created pseudo (modeled)-6th-level watersheds using the BASINS function in ArcInfo GRID geographic information system (GIS) software, based on a 90 m digital elevation model. To better conform the resulting polygons to recognized watersheds, we merged them with USGS 5th-level watersheds. We eliminated polygons smaller than 2,000 ha (4942 acres; leaving the official 5th-level watershed lines intact) and further divided several large polygons to avoid potential species-area effects, which could bias the site selection algorithm. To distinguish existing protected areas from other lands, we merged the watershed polygons with USGS Gap Analysis Program (GAP) management status 1 (strictly protected) and 2 (moderately protected) polygons. This procedure resulted in1908 planning units, ranging in size from 13 ha (32 acres) to 43,564 ha (107,647 acres) and averaging 5,692 ha (14,065 acres). (The smaller units were watersheds partly within existing protected areas. Only the portions of the watersheds that fell outside protected areas were considered planning units in this analysis, as we assumed that protected areas are, in fact, already protected.) GAP level 1 and 2 protected areas constitute 2.9 million hectares (7,165,900 acres), or 27%, of the 10.9 million hectare (26,933,900 acre) GYE study area.

### *The SITES Selection Algorithm*

Early conservation assessments and reserve designs depended on manual mapping to delineate sites and on simple scoring procedures to compare and prioritize sites. The large number of conservation targets and the large size and diverse types of data sets describing the targets in this study required the use of a more systematic and efficient site selection procedure. We used the site-selection software SITES (v1.0) to assemble and compare alternative portfolios of sites. SITES attempts to minimize portfolio "cost" while maximizing attainment of conservation goals in a compact set of sites. This set of objectives constitutes the "Objective Cost function:"

Cost = Area + Species Penalty + Boundary Length

where Cost is the objective (to be minimized), Area is the number of hectares in all planning units selected for the portfolio, Species Penalty is a cost imposed for failing to meet target goals, and Boundary Length is a cost determined by the total boundary length of the portfolio.

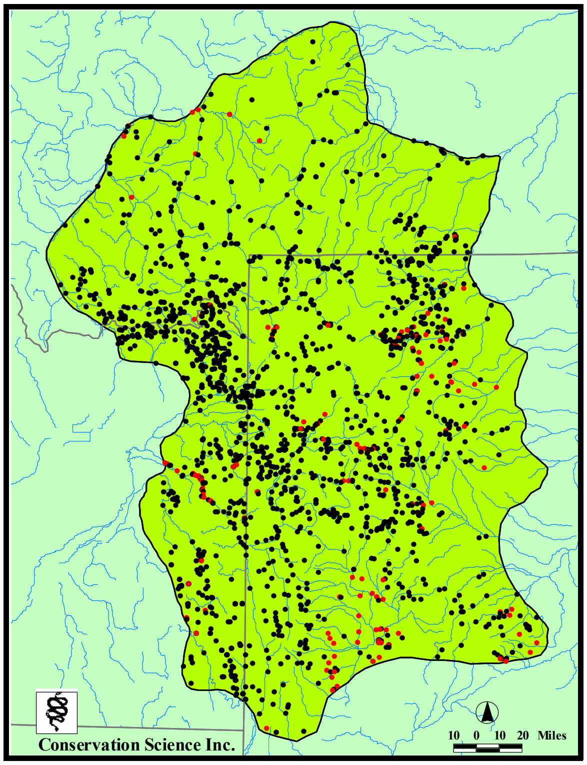

**Figure E2**. GYE natural heritage data. G1 and G2 in red, others black

We made numerous SITES runs, with varying quantitative goals, to determine alternative portfolios which met stated goals for the protection of target groups: local-scale imperiled species, bird species, aquatic species, and rare plant communities within the special elements track; vegetative, abiotic, and aquatic habitat types within the representation track; and high-quality habitat for the five species analyzed within the focal species track.

### *Special Elements*

We assembled element occurrence data for the study area from state heritage programs in Montana, Idaho, and Wyoming. After excluding occurrences of species or communities last observed prior to 1982, or ranked as non-viable or non-breeding occurrences by the heritage programs, 2303 occurrences of 435 species and communities remained (Fig. E2), 203 of them for the 55 species and communities with conservation status ranks of G1 (critically imperiled globally) or G2 (imperiled globally). We divided the occurrence data into four target groups for separate SITES analyses: local-scale species (class 1 targets in Appendix A), bird species (class 2), coarse- and regional-scale aquatic species (class 4), and plant communities (class 5). We set goals for 100% capture of the G1 and G2 occurrences in all target groups and 50% capture of occurrences of lower conservation status. A SITES portfolio had to meet these goals or was penalized as part of the cost function.

We made 10 repeat runs in SITES for each special elements target group, using the “sum runs” option. Each run consisted of one million iterations, the number of attempts the algorithm makes to find a solution. Output from the sum runs includes an indication of how many times each planning unit was included in the 10 different portfolios, as well as the “best” (lowest cost) portfolio solution of the 10. The number of times planning units were selected for in these runs was used in determining the irreplaceability of megasites in our preferred alternative portfolio (see below).

*Representation*

The Nature Conservancy (TNC) recommends the identification of “ecological systems”—dynamic spatial assemblages of ecological communities—that represent the entire range of ecosystems found within an ecoregion. The terrestrial ecological systems of the Greater Yellowstone Ecosystem have not been classified. Hence, we used a combination of vegetation types mapped by the state GAP programs and a new classification of abiotic (geoclimatic) habitats in an effort to represent terrestrial ecological communities across environmental gradients. Representing a broad spectrum of geoclimatic habitats and associated vegetation—ideally along intact environmental gradients—is a strategy for facilitating the shifts in distribution that species will need to make in response to climate change. For aquatic communities, we used the aquatic ecological systems classification developed by Mary Lammert, Aquatic Ecologist with TNC’s Freshwater Initiative. As with special elements, we used the sum runs option in SITES to determine how frequently planning units were selected for portfolio solutions to represent terrestrial and aquatic habitat types, then used that information in determining our preferred alternative portfolio megasite irreplaceability scores.

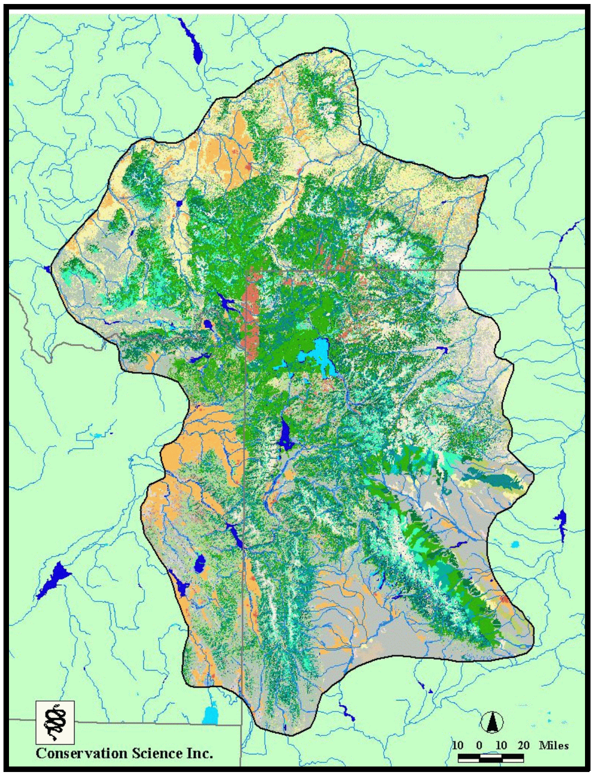

**Figure E3**. GYE Gap Analysis Program vegetation types.

The GAP program has mapped vegetation types in the three states included in the project. We merged the vegetation maps into a single map that includes 39 vegetation types in the study area (Fig. E3). These vegetation types correspond generally to the alliance level of classification hierarchy. We performed a gap analysis to judge how well the existing system of protected areas represents regional vegetation types. We used SITES to develop portfolios of planning units that would protect at least 25% of the area of each wetland vegetation type (lowland riparian, mountain riparian, water, wetland, wet meadow) and 15% of all others, with the justification that wetland types are of generally higher biological value in the region.

We performed the classification of physical habitats in ArcInfo GIS using the major components of climate variation in the study area: 1) mean annual precipitation; 2) spring precipitation; 3) mean annual low temperature; 4) mean annual high temperature; and 5) the difference between winter mean low temperature and summer mean high temperature. We also used mean annual growing degree days in the classification. Soil depth, water-holding capacity, and organic carbon content were all derived from the STATSGO soils database. The nine climate and soils variables were used in a cluster analysis which identified 38 physical habitat types in the study area (Fig. E4). We performed a gap analysis to judge how well the existing system of protected areas represents regional physical habitat types, then used SITES to develop portfolios that would protecting at least 15% of the area of each type.

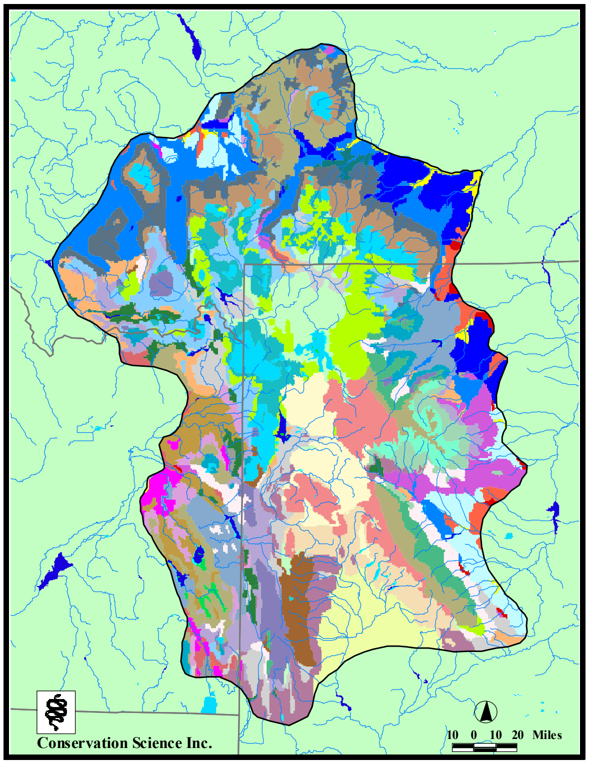

**Figure E4**. GYE physical habitat types

We applied two levels of aquatic habitat classification: 1) aquatic macrohabitats, identified at the stream reach level; and 2) aquatic ecological systems, identified at the watershed to basin level. Both classifications utilize four components: 1) stream size (headwater to large river); 2) elevation (low to alpine); 3) stream gradient (low to very steep); and dominant geology (coarse, porous, nonporous). Aquatic macrohabitats were classified by specific portions of the range of each of the four components, e.g., “very steep alpine headwater in coarse geology.” Aquatic ecological systems, being aggregations of macrohabitats, represent a greater range of component gradients, e.g., “alpine, includes moderate and low gradients, headwater and creek, granitic or volcanic.” We integrated aquatic ecosystems and nested macrohabitats as combined inputs to SITES, and set goals of representing at least 20% of each combined aquatic habitat type.

### *Focal Species*

We used GIS data on species distribution and habitat characteristics to construct new static habitat suitability models for our selected focal species in the region. These results were then compared with those from dynamic models that placed regional population dynamics within a larger multi-regional context. Species distribution data included sightings records of lynx and wolverine, grizzly bear radiotelemetry locations, and the boundaries of wolf pack territories. Habitat data included vegetation, satellite imagery metrics, topography, climate, and human-impact related variables (e.g., road density). We used multiple logistic regression to compare habitat variables at telemetry or sighting locations with those at random points. Predicted habitat values can be seen as map-based hypotheses subject to refinement and validation by future survey data.

We performed population viability analyses using the program PATCH. This program links the survival and fecundity of individual animals to GIS data on mortality risk and habitat productivity measured at the location of the individual or pack territory. The model tracks the population through time as individuals are born, disperse and die, predicting population size, time to extinction, and migration and recolonization rates. The model allows the landscape to change through time. This permits the user to quantify the consequences of landscape change for population viability, examine changes in vital rates and occupancy patterns that might result from habitat loss or fragmentation, and identify source and sink habitats within a landscape.

The landscape change scenarios used estimates of potential change in human-associated impact factors (e.g., roads and human population) during the period 2000-2025 given increased development on either private and non-protected public lands or on private lands only. Data layers from the focal species analysis were incorporated as additional targets in the SITES portfolio selection. We then compared alternative SITES solutions with results from the PATCH model to assess whether the portfolios ensured population viability and if not, what additional areas were suggested by the PATCH model.

### *Expert Assessment*

Quantitative data on which to evaluate conservation options are always limited. We sought to apply rigorous, objective measures of conservation value whenever possible, recognizing that a quantitative assessment would need to be supplemented by expert opinion. We chose a combined approach of one-on-one interviews during early phases of this work, followed by workshops to evaluate the draft results.

Expert opinion was sought to provide validation of element occurrence data from heritage programs and other sources and to expand the overall knowledge base. George Wuerthner identified a wide range of experts on various aspects of the Greater Yellowstone Ecosystem, then visited and interviewed these experts. Interviews were conducted during late 1999-2000 throughout the study region. People contacted included federal and state agency biologists, university faculty, staff of environmental groups, and others with knowledge of the region's biological attributes. Interviews included discussion of the person's qualifications and knowledge of the region, habitat conditions of the lands in question, status of rare or sensitive species, threats, and any monitoring, surveys, or management being implemented for the species or communities concerned.

Immediately after our draft report was produced, our team participated in two workshops to present our results, evaluate alternative portfolios, and identify the next steps for conservation of priority areas. The first workshop was organized by the Greater Yellowstone Coalition and held April 5-6, 2001, in Bozeman, Montana. This workshop concentrated on the Greater Yellowstone Ecosystem. The second workshop was organized by the Wyoming Field Office of The Nature Conservancy and held April 9-10, 2001 in Lander, Wyoming. This workshop examined the entire Utah-Wyoming Rocky Mountains Ecoregion, of which the Greater Yellowstone Ecosystem is the northwestern part.

### *Megasite Ranking*

We aggregated planning units into "megasites" for purposes of evaluation and priority setting. Megasites comprised contiguous planning units with sum runs values > 1. Boundaries of 4th level watersheds and other natural features were used to delineate boundaries between adjacent megasites. Hence, these larger sites are areas that "make sense" in terms of geography, land ownership, or other factors that must be considered in the process of implementing a conservation plan. We strove to keep the number of megasites reasonably low in order to allow comparative scoring and priority-setting. Areas in portfolios that lie outside of designated megasites are often valuable as linkages, buffer zones, or for other functions.

We relied on a key concept in conservation planning—irreplaceability—to prioritize megasites. Irreplaceability provides a quantitative measure of the relative contribution different areas make to reaching conservation goals. A site with an irreplaceability value of 100 for a particular class of targets is essential to meeting a particular goal; if that site is destroyed, the goal cannot be attained. An example might be a site that holds the only known occurrence of a species in the region, the world, or whatever other geographic area is under consideration. A site with an irreplaceability value of 0 has essentially infinite replacements.

Because our assessment considers multiple values of megasites and attempts to achieve a broad set of conservation goals, we assigned irreplaceability values to megasites based on 9 criteria:

1) Contribution to the goal of protecting 50-100% of viable occurrences of all imperiled, local-scale (class 1) species in the region (i.e., 100% of G1/G2 species, 50% of others).
2) Contribution to the goal of protecting 50% (or 100% for G1/G2 species) of viable occurrences of vulnerable and declining (class 2) bird species in the region.
3) Contribution to the goal of protecting habitat capable of supporting 50-75% of the population of each focal species (class 3) that currently could be supported in the region, as identified by habitat suitability modeling (i.e., 50% for elk, 75% for carnivores).
4) Contribution to the goal of maintaining viable populations (regionally and inter-regionally) of focal species over time, as determined by the PATCH dynamic model. Scores were an average of predicted lambda (population growth rate) values for grizzly bear, wolf, and

wolverine, weighted by the likelihood that a site was occupied by the species.

5) Contribution to the goal of protecting 50% (or 100% for G1/G2 species) of viable occurrences of coarse-scale and regional-scale aquatic species (class 4) in the region.

6) Contribution to the goal of protecting 100% of all viable occurrences of G1/G2 plant communities and at least 50% of the occurrences of other plant communities of high conservation interest (class 5).

7) Contribution to the goal of representing at least 25% of the area of each wetland vegetation type and at least 15% of the area of each other vegetation type in the region.

8) Contribution to the goal of representing at least 15% of the area of each abiotic (geoclimatic: climate and soils) habitat type in the region.

9) Contribution to the goal of representing at least 20% of the length of each aquatic (stream) habitat type in the region.

Each megasite was scored 0-10 for each of the 9 criteria. For criteria 1-3 and 5-9, the number of times (out of 10) individual planning units were selected in SITES sum runs were averaged and the area-weighted mean used as the score for each megasite. For criterion 4, entire megasites were scored as units. A total irreplaceability score was calculated for each megasite by summing the scores from the 9 criteria and rescaling the sums to range from approximately 1 to 100.

Another key consideration in conservation planning is threat or vulnerability. Based on expert opinion about the threats faced by each megasite, and taking into consideration quantitative threat data (e.g., human population growth, development trends), we assigned a vulnerability score of 0-100 to each megasite. Preliminary vulnerability scores were revised by participants in the workshop in Bozeman and those revised scores were rescaled to range from approximately 1 to 100. Megasites were then plotted on a graph of irreplaceability (y-axis) versus vulnerability (x-axis) and the graph divided into four quadrants. The upper right quadrant, which includes megasites with high irreplaceability and high vulnerability, comprises the highest priority sites for conservation. This top tier of megasites is followed by the upper left and lower right quadrants (2nd and 3rd tiers, which could be ordered differently depending on needs of planners), and finally, by the lower left quadrant, comprising megasites that are relatively replaceable and face less severe threats. Within quadrants, megasites were ranked for conservation priority using the sum of their irreplaceability and vulnerability scores.

## Results and Discussion

### *Proposed Portfolio*

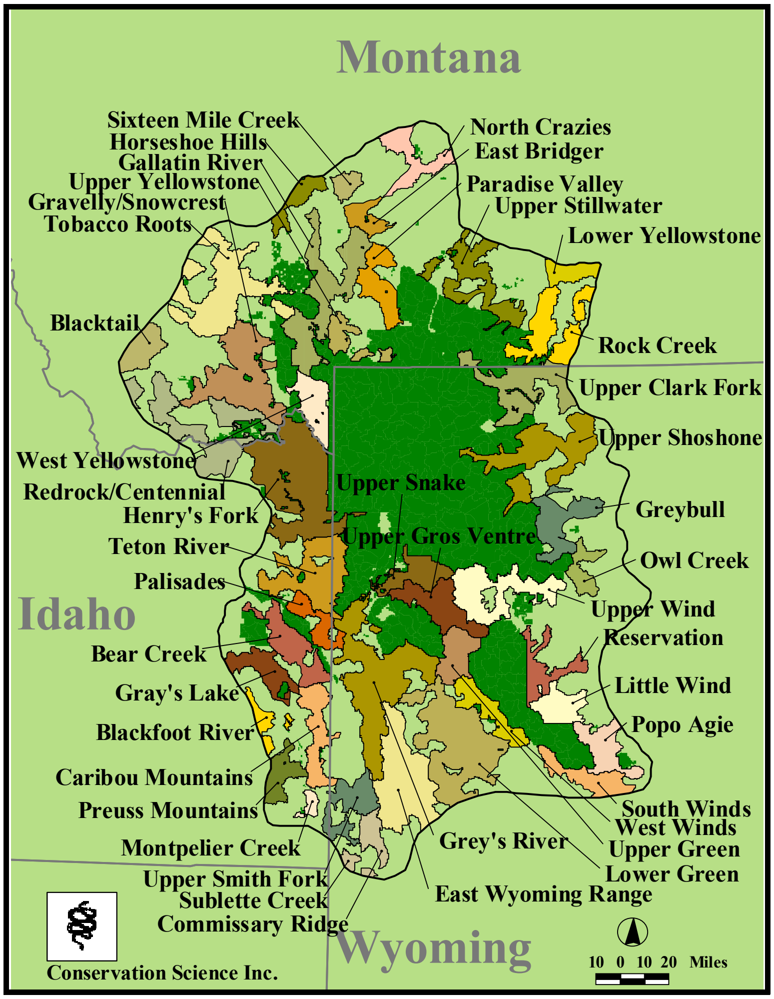

**Figure E5**. Proposed portfolio of conservation sites (existing protected areas dark green).

Our proposed portfolio (Fig. E5) is based on SITES sum runs results that included all components of the three tracks (special elements, representation, and focal species). The 43 megasites in the portfolio range in size from 28,000 to 780,000 acres (average size 270,000 acres) and total 11,300,000 acres (43% of the GYE). Private lands constitute 36% (4.1 million acres) of the total portfolio area.

Our proposed portfolio, if fully protected and combined with existing protected areas (totaling 7,140,000 acres), would bring the total protected area in the GYE to 18,440,000 acres, nearly 70% of the ecosystem. That protected areas network would encompass over 91% of special element occurrences, focal species habitat, and terrestrial and aquatic ecological systems within the study area (Table E1). As shown in the "Δ" column in Table 1, the proposed portfolio—if fully protected—would cover 43% more of the region than the current reserve network. For that 43% increment, there is a considerable "bang for the buck" for many elements—for example, a 70% increase (to 100%) in coverage of G1/G2 species, a 61% increase for all special elements combined, and a 50% increase for representation of ecological systems (vegetation, physical habitats, and aquatic habitats combined).

Table E1. GYE portfolio conservation target protection increases.

| | Current % | Plus Quad1 | Plus Quad2 | Plus Quad3 | Plus Quad4 | Total Δ (%) |
|---|---|---|---|---|---|---|
| Protected Area | 26.6 | 48.4 | 58.2 | 62.5 | 69.8 | +43.2 |
| Special Elements | | | | | | |
| All G1-G2 | 28.9 | 74.9 | 89.1 | 93.3 | 100 | +71.1 |
| Class 1–Local-Scale Species | 40.7 | 69.2 | 86.3 | 89.0 | 93.2 | +52.5 |
| Class 2–Birds | 26.0 | 67.4 | 80.3 | 83.7 | 85.6 | +59.6 |
| Class 4–Fish | 26.7 | 55.6 | 82.2 | 84.4 | 87.8 | +61.1 |
| Class 5–Plant Communities | 28.7 | 81.6 | 91.7 | 94.8 | 95.0 | +66.3 |
| Special Elements Average | 30.2 | 69.7 | 85.9 | 89 | 92.3 | +62.1 |
| Focal Species Resources | | | | | | |
| Elk Winter Range | 13.9 | 35.8 | 46.9 | 53.0 | 63.4 | +49.5 |
| Grizzly | 94.4 | 96.5 | 98.0 | 98.3 | 98.9 | +4.5 |
| Lynx | 36.3 | 60.6 | 73.1 | 77.2 | 84.6 | +48.3 |
| Wolf | 77.8 | 86.0 | 92.7 | 94.1 | 96.3 | +18.5 |
| Wolverine | 41.3 | 62.7 | 74.2 | 76.0 | 83.1 | +41.8 |
| Focal Species Average | 52.7 | 68.3 | 77.0 | 79.8 | 85.3 | +32.6 |
| Representation (Ecological Systems) | | | | | | |
| ≥ 15%–Vegetation Types | 61.5 | 89.7 | 92.3 | 92.3 | 100 | +38.5 |
| ≥ 15%–Physical Habitat Types | 41.0 | 89.7 | 92.3 | 94.9 | 100 | +59.0 |
| ≥ 20%–Aquatic Types | 44.3 | 74.5 | 90.5 | 95.9 | 98.0 | +53.7 |
| Representation Average | 48.9 | 84.6 | 91.7 | 94.4 | 99.3 | +50.4 |
| Total Average | 43.2 | 72.6 | 83.8 | 86.7 | 91.2 | +48.0 |

### *Focal Species Considerations*

Focal species do not receive as great a benefit from our proposed portfolio as special elements or ecological systems—only elk winter habitat and lynx habitat increase by more than the 43% in total area that would result from protecting the entire portfolio of megasites. For grizzly bear and wolf, only 4.5.% and 18.5%, respectively, more habitat would be protected. This relatively low added value reflects the fact that these carnivores find their highest quality habitat within existing protected areas—especially Yellowstone National Park and adjacent wilderness areas—which provide the low road density and other components of habitat security these animals require. Nevertheless, as discussed below, increasing the protected areas network in the GYE would help mitigate against the loss of habitat value that will occur as human population and associated developments increase in the region over the next several decades. Protection of roadless areas is especially important for these species.

The grizzly bear habitat suitability model showed a negative association of bears with roads, and a positive association with sloping terrain, elk winter range, and protected areas. The interaction of roads and trails with the wilderness management class has become more strongly negative with time, perhaps reflecting increased hunter-associated mortality.

The wolf model, though similar to that for the grizzly bear, differs in the strong negative association with slopes of above 20 degrees. The wolverine model also shows a positive association with wilderness and especially parks, making it similar to the models for the grizzly bear and wolf. Potential effects of adding the non-wilderness RARE II roadless areas to a protected areas network suggest that substantial areas of the southern and northwestern GYE show potential for enhancing carnivore populations under this scenario.

The GYE inner study region is predicted to lose a substantial percentage of its carrying capacity for carnivores in the next 25 years if current trends continue. The loss ranges from 15.7% for the wolverine to 17.1% for the wolf and 26.4% for the grizzly bear. If no new road construction occurs on public lands, the loss is reduced by approximately 50%, e.g., to 14.6% for the grizzly bear and 10.8% for the wolf. Although the presence of large core areas such as Yellowstone National Park buffers populations from complete extirpation, changing landscape conditions have strong impacts on both abundance and distribution of these and other carnivore species.

Under optimistic assumptions as to demographic rates under current landscape conditions, the PATCH model predicts that areas capable of supporting grizzly bears encompass most of the public lands core of the GYE and some private lands along the western edge of the Bighorn basin. Wolves could potentially occupy a larger area that is contiguous with the central Idaho population.

Under pessimistic future conditions core areas of the GYE remain occupied and are strong sources for grizzly bears, but they are no longer able to support the large areas of peripheral distribution. The core GYE is already surrounded by a ring of strong sink habitat, and this ring of sinks will intensify with increasing human population and road-building (Fig. E6). These forces will eliminate many non-core areas of the GYE as potential habitat. If habitat degradation does not occur on public lands—i.e., if roadless areas are protected—the reduction in demographic potential is not as severe. This contrast is especially evident in areas that are peninsular extensions of habitat from the core GYE.

The GYE grizzly bear population appears to be demographically isolated from other regions under most plausible landscape scenarios. This may pose long-term dangers from genetic isolation. Nevertheless, the dramatic impact of future landscape change on the potential distribution and size of the region's bear population suggest that the highest priority should be to prevent loss of connectivity within the region itself by protecting these at-risk areas. An enlarged recovery zone and improved roadless area management policy on public lands, when coupled with conservation strategies on private lands identified as critical population sinks, could potentially prevent much of this population decline and loss of habitat.

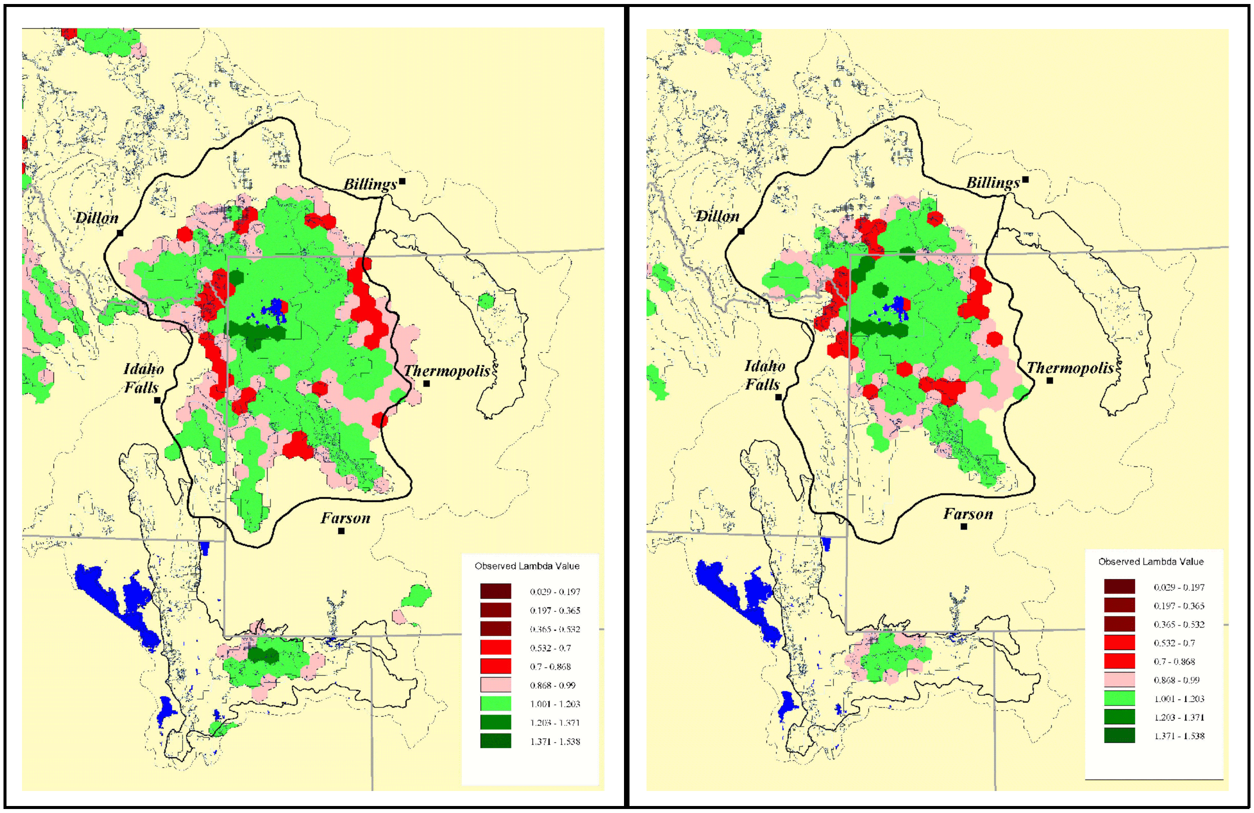

Fig. E6. Demographic potential and potential distribution of grizzly bears under current (a) and future (b) landscape conditions (scenario 2 - road development on both private and public lands) as predicted by the PATCH model. Sink areas are shown in red and source areas in green.

Because the wolf can inhabit semi-developed habitat outside the core GYE, it will be more dramatically affected by future development in those areas. Under current conditions the GYE wolf population should be able to form a connected metapopulation encompassing most public lands and some private lands in the GYE and adjacent regions. Under future scenarios, outlying areas become sink habitats for wolves, and although connectivity is maintained to central Idaho, the GYE becomes isolated from more distant populations in the Northern Continental Divide Ecosystem. If road development is limited on public lands, the viability of peripheral populations and connectivity to central Idaho is enhanced. Because demographic rescue from core areas would be important in sustaining wolves in matrix habitat, high priority should be given to maintaining habitat continuity between the GYE and central Idaho populations.

For the lynx, relatively low levels of population cycling are predicted to greatly increase extinction risk if the GYE region is isolated from boreal lynx populations. Further range contraction is predicted for all carnivore species without coordinated regional planning for habitat restoration.

We evaluated elk winter range, as delineated by species experts, as to viability based on road density and other human-impact factors. Areas of wintering habitat with high potential viability (low road density) on private lands were identified for inclusion in conservation portfolios. The elk winter range predictive model shows a positive association with well-vegetated areas that are somewhat sloping, southwest aspects. On a regional scale, these areas (Figure E7) do not overlap strongly with high quality habitat for the large carnivores, largely due to the human-associated factors that restrict carnivore distribution more than ungulate distribution.

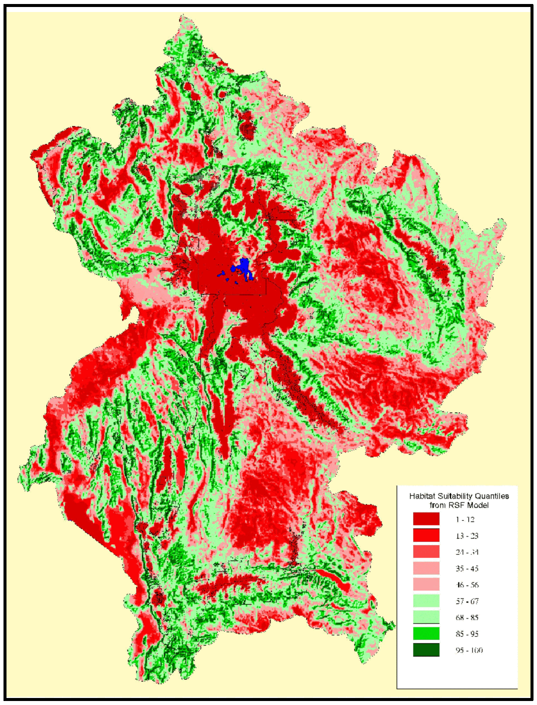

Fig. E7. Results of a logistic regression model predicting relative suitability as elk wintering habitat.

By linking demography to mapped habitat characteristics, our analysis helps reveal the regional mechanisms driving population viability as the GYE landscape changes over the next quarter century. The results suggest that despite the presence of large protected areas in the region, it will be challenging to conserve carnivores in the Greater Yellowstone Ecosystem as human populations grow. Many of the carnivore populations in the region are on the periphery of their range due to climatic or historical factors, or both, and, unlike more northern populations, cannot expect a large “rescue effect” from surrounding regions. As these carnivore populations rebound from historical eradication efforts, they will find their habitat options increasingly foreclosed by the rate of landscape change.

The GYE is unique in the western United States in that large core refugia lie in close proximity to rapidly growing human populations (Fig. E8). Currently, the core refugia of the park and adjacent wilderness areas can support carnivore populations in the extremities of the ecoregion. Because these outlying areas may not yet be occupied by expanding carnivore populations, they may not receive adequate conservation focus and may be more subject to competing land uses such as grazing than are areas within the core ecosystem. If current trends continue, a ring of development will increasingly surround the core with sink habitat, isolating it from the “arms and legs” of the ecoregion and weakening its ability to sustain carnivores in those outlying areas.

Given the contrasts between species, building a conservation strategy that combines priority areas for all focal species is challenging. Areas of high value for multiple species must combine both biological productivity and security from human impacts. Such areas (e.g., undeveloped riparian areas) are scarce in the GYE and tend to be highly threatened by development. Comparison of the results from our alternate future scenarios suggests that only about half of the loss in carnivore carrying capacity is linked to development on public lands. Even for wide-ranging species such as the grizzly bear that are closely associated with wilderness, conservation planning must address entire landscape mosaics of public and private lands.

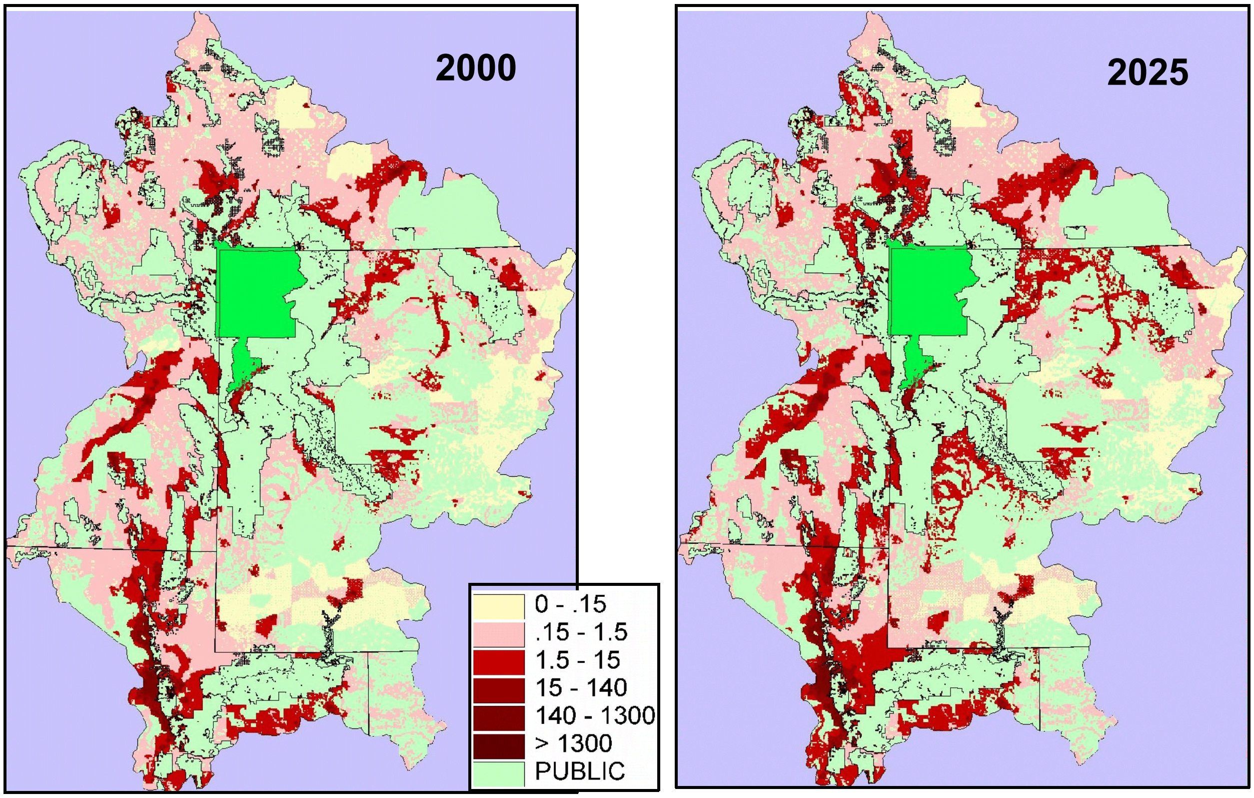

Figure E8. Current and predicted housing density per square kilometer (data from Theobald 2001)

Although our focal species studies were concentrated on just five species of large mammals, other species within the GYE deserve increased study. In particular, the living resource that may be most threatened and degraded in the ecosystem is its native fisheries. It is only because of its location at the headwaters of three major river systems–Green/Colorado, Snake/Columbia, Yellowstone/Missouri—hence upstream from most human disturbances and activities—that the GYE has retained habitat quality and some measure of protection for native fish populations. Indeed, a systematic study by Rob Van Kirk found that all watershed subunits with good natural function were either in the center of the ecosystem where park and wilderness protection dominates or along the Yellowstone River. Bank stabilization and channelization activities along all of the large rivers of the GYE are currently destabilizing fish habitat or have the potential to alter geomorphic processes and the integrity of riparian and aquatic communities. Thus, the trend for the ecosystem's native fish is generally downward, with a continual loss of habitat quality and population size.

*Megasite Ranking*

Megasite irreplaceability scores ranged from 0.3 to 99.5 (mean: 54.9), and vulnerability scores from 1.5 to 98.5 (mean: 50.3). Our irreplaceability vs. vulnerability prioritization resulted in 15 megasites totaling 5.9 million acres in the high irreplaceability-high vulnerability quadrant 1, giving them the highest priority for conservation action (Figures E9, E10). Ten megasites in quadrant 2 (high irreplaceability-low vulnerability, medium priority) cover 2.6 million acres; five megasites in quadrant 3 (low irreplaceability-high vulnerability, medium priority) cover 1.2 million acres; and 13 megasites in quadrant 4 (low irreplaceability-low vulnerability, lower priority) cover 1.9 million acres.

To compile an overall ranking of megasite conservation priority, we first combined their irreplaceability and vulnerability scores. We then ordered them within quadrants according to combined scores (Table E2).

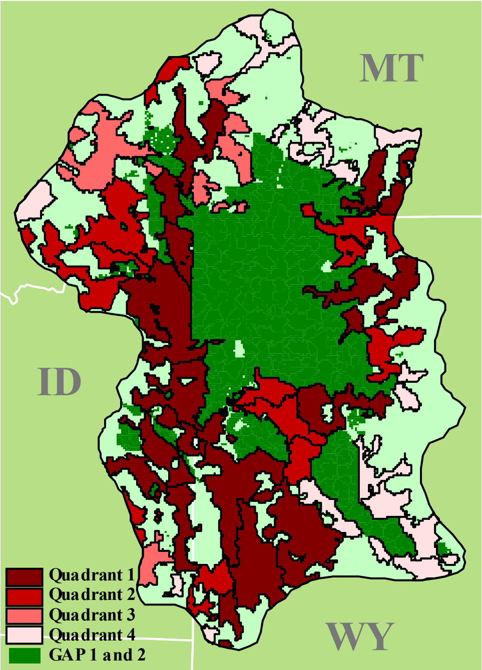

**Figure E10.** Megasite quadrants.

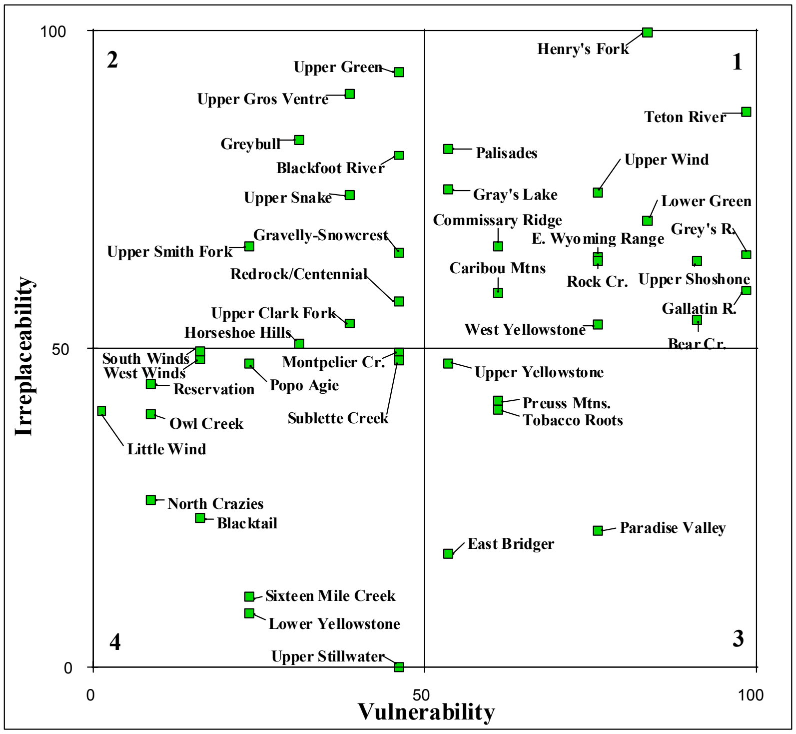

**Figure E9.** Megasite irreplaceability vs. vulnerability.

Table E2. Megasites list. Sites within each quadrant are ordered by their combined irreplaceabiilty and vulnerability scores.

| Rank | Name | Vulnerability | Irreplaceability | Irreplaceability + Vulnerability | Quadrant | Acres |
|---|---|---|---|---|---|---|
| 1 | Teton River | 98.5 | 87.24 | 185.7 | 1 | 401633 |
| 2 | Henry's Fork | 83.6 | 99.49 | 183.1 | 1 | 782870 |
| 3 | Grey's River | 98.5 | 64.89 | 163.4 | 1 | 708788 |
| 4 | Gallatin River | 98.5 | 59.13 | 157.6 | 1 | 512487 |
| 5 | Upper Shoshone | 91.0 | 63.79 | 154.8 | 1 | 466237 |
| 6 | Lower Green | 83.6 | 70.07 | 153.7 | 1 | 691779 |
| 7 | Upper Wind | 76.1 | 74.51 | 150.6 | 1 | 360682 |
| 8 | Bear Creek | 91.0 | 54.56 | 145.6 | 1 | 245821 |
| 9 | East Wyoming Range | 76.1 | 64.26 | 140.4 | 1 | 533591 |
| 10 | Rock Creek | 76.1 | 63.90 | 140.0 | 1 | 319089 |
| 11 | Palisades | 53.7 | 81.46 | 135.2 | 1 | 135526 |
| 12 | West Yellowstone | 76.1 | 53.77 | 129.9 | 1 | 182143 |
| 13 | Gray's Lake | 53.7 | 75.00 | 128.7 | 1 | 178334 |
| 14 | Commissary Ridge | 61.2 | 66.15 | 127.4 | 1 | 114184 |
| 15 | Caribou Mountains | 61.2 | 58.80 | 120.0 | 1 | 224160 |
| 16 | Upper Green | 46.3 | 93.43 | 139.7 | 2 | 172937 |
| 17 | Upper Gros Ventre | 38.8 | 89.93 | 128.7 | 2 | 255051 |
| 18 | Blackfoot River | 46.3 | 80.37 | 126.7 | 2 | 79757 |
| 19 | Greybull | 31.3 | 82.85 | 114.1 | 2 | 261782 |
| 20 | Upper Snake | 38.8 | 74.05 | 112.8 | 2 | 176685 |
| 21 | Gravelly/Snowcrest | 46.3 | 65.07 | 111.4 | 2 | 510726 |
| 22 | Redrock/Centennial | 46.3 | 57.65 | 103.9 | 2 | 487682 |
| 23 | Upper Clark Fork | 38.8 | 54.18 | 93.0 | 2 | 367334 |
| 24 | Upper Smith Fork | 23.9 | 66.26 | 90.2 | 2 | 206216 |
| 25 | Horseshoe Hills | 31.3 | 50.79 | 82.1 | 2 | 111294 |
| 26 | Preuss Mountains | 61.2 | 41.89 | 103.1 | 3 | 138282 |
| 27 | Tobacco Roots | 61.2 | 40.51 | 101.7 | 3 | 585864 |
| 28 | Upper Yellowstone | 53.7 | 47.87 | 101.6 | 3 | 120975 |
| 29 | Paradise Valley | 76.1 | 21.72 | 97.8 | 3 | 206257 |
| 30 | East Bridger | 53.7 | 17.96 | 71.7 | 3 | 104048 |
| 31 | Montpelier Creek | 46.3 | 49.44 | 95.7 | 4 | 36348 |
| 32 | Sublette Creek | 46.3 | 48.33 | 94.6 | 4 | 28234 |
| 33 | Popo Agie | 23.9 | 47.84 | 71.7 | 4 | 197398 |
| 34 | West Winds | 16.4 | 49.63 | 66.0 | 4 | 179760 |
| 35 | South Winds | 16.4 | 48.54 | 64.9 | 4 | 178588 |
| 36 | Reservation | 9.0 | 44.44 | 53.4 | 4 | 180259 |
| 37 | Owl Creek | 9.0 | 39.84 | 48.8 | 4 | 109934 |
| 38 | Upper Stillwater | 46.3 | 0.32 | 46.6 | 4 | 328326 |
| 39 | Little Wind | 1.5 | 40.40 | 41.9 | 4 | 161810 |
| 40 | Blacktail | 16.4 | 23.57 | 40.0 | 4 | 142995 |
| 41 | North Crazies | 9.0 | 26.24 | 35.2 | 4 | 187094 |
| 42 | Sixteen Mile Creek | 23.9 | 11.28 | 35.2 | 4 | 66335 |
| 43 | Lower Yellowstone | 23.9 | 8.52 | 32.4 | 4 | 102526 |

Progress toward conservation goals can be achieved most efficiently by protecting first the highest priority megasites (quadrant 1), then the medium priority megasites (quadrants 2 and 3), and finally the lower priority megasites (quadrant 4) (Fig.E11). The greatest incremental gains are achieved by protecting the 15 megasites in quadrant 1, resulting in an average increase of over 29% for the three tracks (43.2% currently to 72.6%). Protecting the ten megasites from quadrant 2 increases average protection for the three tracks another 11%, to 83.8%. Protecting the five megasites in quadrant 3 increases average protection to 90.6%, and protecting the 13 megasites in quadrant 4 results in 92.6% average protection for the three tracks.

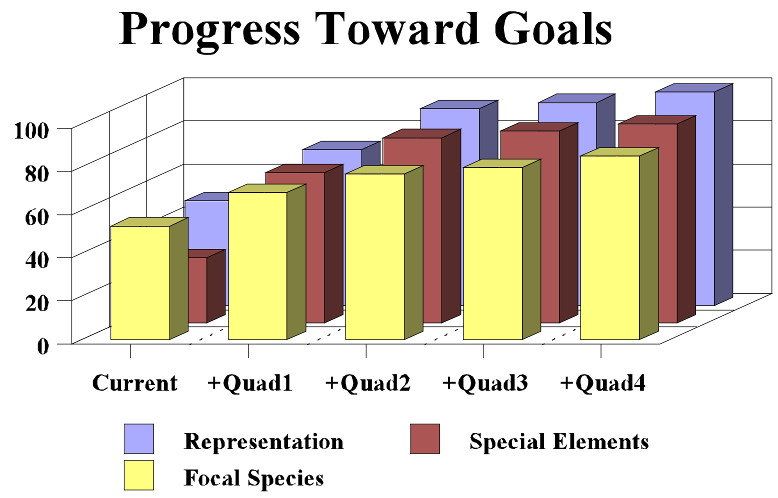

**Figure E11.** Increases in achieving conservation goals by incrementally protecting megasites in the four quadrants of the irreplaceability vs. vulnerability chart (Fig. 6).

In the real world, protection opportunities will not arise in an orderly sequence that corresponds to science-based priorities. For example, megasites in quadrants 2 or 3 may become available for protection before megasites in quadrant 1; if not protected quickly, some of these sites may be converted to subdivisions. Yet funds, or political capital, spent protecting these sites may preclude opportunities for protecting biologically more significant sites in the future.

What is the optimal course of action under such circumstances? We suggest that conservationists implement an informed opportunism, taking advantage of many conservation openings as they arise, but with explicit recognition of the trade-offs involved. Sometimes it will be better to act and other times to wait. Systematic conservation planning allows the effects of trade-offs to be quantified and considered in a biologically meaningful way. With information made transparent and explicit, decision-makers will be able to take actions which, we hope, are scientifically defensible and result in the most biodiversity conserved.

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