Analyzing Risks to Protected Areas Using the Human Modification Framework: A Colorado Case Study

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Abstract

A framework that organizes natural and protected areas is often used to help understand the potential risks to natural areas and aspects of their ecological and human dimensions. The spatial (or landscape) context of these dynamics is also a critical, but, rarely considered, factor. Common classification systems include the U.S. Geological (USGS) Gap Analysis Program GAP) stewardship coding scheme, the International Union for the Conservation of Nature (IUCN) Protected Area Management Categories, and the American Planning Association (APA) Land-Based Classification Standards. The GAP and IUCN frameworks are coarse classifications (four to eight categories), whereas the APA focuses primarily on private land uses. To address these limitations, we develop here more refined implementation methods based on the human modification framework, which conceptually is rooted in characterizing the degree to which natural processes are free or controlled, and the degree to which landscape patterns are natural or artificial. To provide useful and tighter coupling of specific threats and spatial data surrogates, we refine the conceptual basis by identifying three primary types of human activities that cause modification of natural systems and patterns. These are land uses categorized as urban/built-up, recreation, and production/extraction. We detail specific metrics and common data used as surrogates that can provide a stronger basis for characterizing the degree of human modification. We illustrate our methods by presenting analysis results for a Colorado case study.

Keywords: Human modification, protected areas, threat assessment, landscape pattern, land use.

Introduction

Overview of Conceptual Frameworks

A number of general wilderness frameworks have been established to provide a conceptual basis to understand protected areas. One of the earliest was provided by Brown and others (1978) who developed the Recreational Opportunity Spectrum (ROS), an approach that was based on characterizing resource, social, and managerial conditions for parks and recreation areas. The ROS has less well-developed guidance for characterizing threats and conservation on working and private lands. In Australia, Lesslie and Taylor (1985) developed the wilderness continuum concept that provided the basis for developing an inventory of high-quality wilderness areas. More recently, Cordell and others (2005) provided a concise review of the two most widely accepted attributes of wildlands: naturalness and wildness.

A number of efforts have built on these conceptual frameworks to provide detailed characterizations of wilderness through fine-grained mapping. Lesslie and others (1988) provided an early mapping technique based on overlaying distance classes from settlement and road infrastructure. Kliskey (1998) developed a method to better link perception of wilderness to the ROS in a spatially explicit mapping framework. Aplet and others (2000) developed a nationwide map of wilderness by distinguishing managed from natural landscapes and mapping a multidimensional index at 1-km resolution. Building on earlier work in Australia and the United States, Sanderson and others (2002) mapped the human footprint for the entire globe at 1-km resolution.

More recently, scientists have been moving from employing general indicators of wilderness (or degree of human modification) to recognizing specific indirect and direct threats (e.g., to wilderness ecosystems by Cole and Landres 1996) and the relative degree to which different types of protected areas function to protect biodiversity. A common approach to categorizing or organizing different types of protections or threats has been to define categories based on whether land is managed for permanent biodiversity maintenance through some legal or institutional mechanism, or both. Both the World Conservation Union (IUCN) and the U.S. Geological Survey's (USGS) Gap Analysis Program (GAP) use this approach, though their protection categories differ somewhat (Davey 1998, Scott and others 1993). For example, the IUCN contains eight categories (IUCN 1994): I–scientific reserve/strict nature reserve; II–national park; III–natural monument/natural landmark; IV–managed nature reserve/wildlife sanctuary; V–protected landscapes; VI–resource reserve; VII–natural biotic area/anthropological reserve; and VIII–multiple-use management area/managed resource area.

The USGS GAP program found these too vague for their uses, and so they devised a stewardship classification with four status classes (Csuti and Crist 2000): (1) permanent protection from conversion of natural land cover, with natural disturbance events allowed; (2) permanent protection and some suppression of natural disturbance; (3) some extractive uses permitted; and (4) no protection from conversion of natural land cover.

The Land-Based Classification Standards (APA 2003) provide a multidimensional land use classification model based on five characteristics: activities (land use based on observable characteristics), functions (economic purpose), building types (structures), site development character (physical characteristics such as land cover types), and ownership constraints (private vs. public, or other legal devices to constrain use). They are richly developed for private land but are less directly applicable to public protected or conserved areas.

The IUCN categories have been revised substantially in the Conservation Measures Partnership, a collaborative effort mostly among nongovernmental organizations that includes The Nature Conservancy, World Wildlife Fund, and Conservation International, in addition to the IUCN. They recognize 11 classes of direct threats (IUCN-CMP 2006): residential and commercial development; agriculture and aquaculture; energy production and mining; transportation and service corridors; biological resource use; human intrusions and disturbance (e.g., recreation, war, etc.); natural system modifications (e.g., fire suppression); invasive species and genes; pollution; geologic events; and climate change and severe weather.

Several alternative approaches have recently emerged. For example, the human footprint (Sanderson and others 2002) represents, in a general way, the total footprint of all the human population's influence as a continuum stretched across the land surface. Implicit in nearly all these approaches is that if an area is of high value, and it is unprotected, then it is vulnerable. However, incorporation of threat directly into these frameworks is underdeveloped, and these approaches have been critiqued because they neglect a means to assess the relative imminence of the threat or urgency of conservation action need—Are some gaps more important than others, and, if so, which ones (Margules and Pressey 2000, Theobald 2003)?

Objectives

We find four main limitations of these existing frameworks. First, they are often based on ad hoc categories or classes, with little or minimal attention to establishing explicit measures of threat. Second, they are based on discrete categories or classes, and so cannot resolve small differences. Also, because they are based on class (or nominal) data, they cannot be easily integrated at different spatial scales to examine landscape context. Third, the surrogate spatial variables that are used as a basis for classifying are generally too coarse grained to capture fine-grain patterns, ultimately limiting detailed characterization. Finally, and, especially, most approaches examine the in situ landscape content of a park or protected area (PPA) using levels of threat or protection. Typically, an individual PPA receives a single score, regardless of size or the types of adjacent land uses. For example, although national parks often have an intensely used, built-up portion (e.g., Yosemite Valley in Yosemite National Park) directly adjacent with designated wilderness, typical protocols and methods result in only a single value being applied to the entire PPA. In addition to content, we believe that the landscape context of a PPA is important as well. This aligns analytical methods with

Table 1—Example land uses along human modification gradient for each factor. Each row provides an example of a possible human use along the "wild" (0.0) to human-dominated (1.0) gradient for each of the three factors (columns)

Value	Convert (urban/built-up)	Extract (production/extraction)	Visit (recreation/work)
0.0	Wilderness	Wilderness	Municipal watershed (no access)
0.1	Wilderness with trails	Gathering	Private preserve (guide d access)
0.2	Wilderness w/trails, bridges	Public grazing allotments	Wilderness area
0.3	Multiuse forest	-	Backcountry forest
0.4	Rural housing density	Timber selective cut	Multiuse forest
0.5	Campground	Hay meadow	Highuse trail/destination
0.6	Exurban housing density	Timber clearcut	Motorized recreation
0.7	Visitor center	Dryland crop	Cross-country ski resort
0.8	Suburban housing density	Oil/gas well	Downhill ski resort
0.9	Urban residential	Mine	Urban park
1.0	Commercial/industrial	Irrigated cropland	Sports stadium/complex

the growing concerns of land managers over these external threats. For example, two of the main threats to the National Forest System (loss of open space due to housing development and invasive species) are external (Bosworth 2004), and changes in surrounding land use are a leading threat to resources in United States national parks (GAO 1994).

We aim to address these limitations by building on the human modification framework (HMF) (Theobald 2004). The HMF is based on two dimensions: the degree to which natural processes are free or controlled, and the degree to which landscape patterns are natural or artificial. To provide useful and tighter coupling of specific threats and spatial data surrogates, we refine the conceptual framework by identifying three primary types of human activities that cause human modification of natural systems and patterns. These are land uses categorized as urban/built-up, recreation, and production/extraction. We detail specific metrics and common data used as surrogates that can be used to implement each of these factors to provide a stronger basis for characterizing the degree of human modification. Our overall goal in this paper is to develop a general yet simple method to characterize threats associated with human land use activities for managing landscapes and to provide metrics and more directly capture threats in a detailed, spatially explicit manner. Our objectives are to describe factors that can be used to refine the HMF, identify common surrogates of these factors that can be mapped at relatively fine grain, conduct a spatially explicit analysis of the landscape context, and illustrate these methods using a case study example for the State of Colorado.

Methods

Human Modification Framework

Here we further refine the HMF to emphasize three primary factors that can be used to characterize land use based on what human activities occur at a given location. Principally, humans go to an area to produce or remove natural resources (production/extraction), visit but do not extract significant resources (recreation/tourism), or concentrate or intensify resources by reconfiguring and constructing buildings and other infrastructure (urban/built-up). Each of these three factors begins with a value of 0.0 denoting no human influence (i.e., a wild location), and 1.0 representing an area that is strongly influenced (developed) by human activities. We seek to fully characterize the spatial heterogeneity of threats by characterizing land uses at a relatively fine grain (<1 km^2 cells or minimum mapping unit), rather than attributing an average or overall value across a broader spatial extent (e.g., a GAP stewardship value for an entire national park). We then can overlay our threat maps with a map of protected areas to assess gaps and opportunities.

For each factor, we explicitly place values for different levels of threat along a 0 to 1.0 axis (Table 1). Although these values are either assigned arbitrarily, based on expert opinion, mapped through surrogate variables, or quantified

Table 2—Possible surrogate spatial data for urban/built-up factor

Data	Source	Scale (extent/grain)	Notes
Housing density	Census Bureau; SERGoM v2 (Theobald 2005)	Nationwide/block Nationwide/1 ha	Better indicator of landscape change than population density
Population density	Census Bureau	Nationwide/block	Commonly used
Road density	Census TIGER; GDT; NavTec	Nationwide/1:100K	Need to identify the radius or size of the moving window in computing density. Major road types are often distinguished and weighted when computing road density. Need to extend to characterize road use (i.e., traffic volume) as well. Poor representation of rural, forest, park areas
Structures (houses, buildings, bridges)	Parcel-level National forest/park unit	County by county	Critical data for fine-grained analysis, but very limited availability etc.
Trail density	National forest/PPA	PPA/1:24K, GPS	Need to specify radius of moving window when computing density (~ 500 m) Can major differences in trail types, such as modes of use, use level be distinguished? Standardized, consistent data on trails are not available
Campground density	USFS	PPA/1:24K	Location of campgrounds, number of units/sites, and type of use
Dam density	National Inventory of Dams 1: 1,000,000	Nationwide/	For major dams (> 4 m in height); spatial precision issues; incomplete attributes such as year built, storage volume, etc.
Land cover	National Land Cover Data set (NLCD)	Nationwide/900 m^2	Urban/built-up classes (21, 22, 23)–update with NLCD 2001 when available

Each row provides an example of a possible spatial datum that is commonly used as a surrogate for this factor.
PPA = park or protected area.

using some combination of these, it is critical that we make our assumptions quantitatively explicit, at the very least to communicate how threats may affect a location and their relative importance to other threats. Also note that this approach is agnostic to land ownership—that is, land use activities for each of these factors can occur on both private and public lands (though some types may be more dominated than others). For example, although built-up is often associated with urban areas, some localized areas within protected areas (e.g., a national park visitor center) can be highly built-up as well. Table 2 proceedes a short, preliminary listing of surrogate maps that are commonly used to estimate these activities for the three factors—yet much work needs to be done to fill these critical data gaps. Again, we emphasize that often these values are arbitrary, but providing explicit values is a useful and important exercise.

Urban/Built-Up—

This factor characterizes the intensity to which humans occupy a given location. Human activities often concentrate or intensify resources by reconfiguring resources or constructing buildings and other infrastructure such as roads, dams, bridges, etc. Table 2 provides a list of useful data layers that can be used to measure the degree of the urban/built-up factor. Common surrogate spatial variables include population density and housing density. We prefer housing density because it more directly characterizes landscape and ecological changes on the ground, whereas population density is attributed typically only for primary residences. Data on residential land cover (e.g., from National Land Cover Data (NLCD) are often used to represent built-up areas, though additional data from the Census Bureau (or parcel level) are needed to characterize lower density development beyond the urban fringe. Commercial, industrial, and transportation land uses also are associated with high levels of human modification (e.g., high levels of impervious surface), population density (less direct), etc. Data on transportation infrastructure, such as road density (e.g., Theobald 2003), are also strong measures of land uses associated with built-up areas. We believe that housing density and road density provide complementary information—high density of roads can occur not only in urban areas but also in remote rural areas (e.g., forest logging roads). Recently, researchers are beginning to distinguish major road types (e.g., interstate vs. secondary roads) when computing road density, though more work to characterize road use rather than the existence of roads is needed. Improved data sets are needed to better identify the location and intensity of structures in rural areas, particularly bridges, culverts, roadway fences, utility corridors (e.g., power lines, pipelines, etc.).

Production/Extraction—
This factor characterizes the intensity of human activities associated with the amount and intensity of extracting or removing resources. Agricultural production, especially cropland, but, also, grazing and mining and timber activities are common forms of this activity type (Table 3). It is common to use land cover data to map production land uses that have caused land cover conversion, such as agricultural croplands and orchards. The intense changes in pattern and the high degree of modification of ecological processes mean that this is a critical component to map. A variety of also additional activities also contribute to human modification for which data are less commonly available. This would include spatially explicit information about grazing (intensity and animal density) through permits on public lands and stocking rates on private lands. Extraction of natural resources in the form of quarries and mines that cause significant land surface modification can be readily identified. However, activities with extensive but more diffuse disturbance (e.g., oil and gas wells or selective harvesting/thinning of forest products) are more difficult to identify and generate metrics from typical satellite imagery, though increasingly specialized databases (e.g., well locations) are being developed.

Recreation and Tourism—
This factor characterizes the intensity of human activities associated with use or visitation of an area. This is best represented by recreation and tourism activities, but can also include work-related activities. It includes the amount and type (mode) of recreational use (i.e., pedestrian only, passive, motorized, etc.). There are a large number of important data gaps here—particularly whether areas are publicly accessible, motorized vs. nonmotorized use, visitor use levels, etc. (Table 4).

Spatially explicit data on this aspect of human modification are particularly underdeveloped. Although general visitor use levels may be available for whole parks or national forests, more detailed data to map the visitation levels (and the timing) are particularly poor. Use has been estimated based on trail density (Schumacher and others 2000), though this suffers from the same limitation as road density methods—namely the assumption that areas close to trail heads receive the same amount of use as those more distant. Methods to estimate visitor use via spatial models of accessibility are increasingly common (Geertman and van Eck 1995).

Assessing Landscape Context—
To characterize risks within the landscape, we assign each factor a value along a 0 to 1.0 axis based on explicit criteria (Table 5). We use a fuzzy average approach to combine our individual surrogate layers (in GIS) into a composite value layer for each factor. This is calculated simply as

Table 3—Possible surrogate spatial data for production/extraction factor

Data	Source	Scale (extent/grain)	Notes
Grazing	U.S. Forest service; BLM; private	National/1:100K	Characterize by animal unit months, permit locations—but these data are mostly unavailable in electronic, spatial format
Oil & gas well density	Colorado Oil & Gas Conservation Commission	Statewide/1:100K	Point locations of wells, need to define "footprint"
Cropland, grazing	USGS National Land Cover Data set	National/0.09 ha	Cropland (NLCD classes 81-85) Grazing estimated from grassland, shrubland, and forested land
Mining (gravel, hard-rock, etc.)	Colorado Division of Minerals and Geology	Statewide/1:100k	-
Groundwater wells	State water engineer	Statewide/1:100K	Poor availability of data on recharge rate, spatial location often tied to center of Public Land Survey Section

Each row provides an example of a possible spatial datum that is commonly used as a surrogate for this factor.

Table 4—Possible surrogate spatial data for recreation/visitation factor

Data	Source	Scale (extent/grain)	Notes
Parks and protected areas	World Protected Areas Database Protected Areas Database; COMaP	Nationwide/block Nationwide/1 ha	Inconsistent; poor data for State, local (city and county), private (reserves, conservation easements)
Visitor use levels	National Forest Service survey?	Nationwide/?	Very coarse (State/forest) data, need data to be tied to trailheads
Recreational facilities (golf courses, ski areas, etc.)	Census TIGER; GDT; NavTec	Nationwide/1:100K	Use levels (visitor days per year) would be useful
Accessibility from urban populations	Cost distance weighting	Nationwide/1:100K	-

Each row provides an example of a possible spatial datum that is commonly used as a surrogate for this factor.

the maximum value (at every cell) of any single input. These ratio values are then spatially averaged over different neighborhood sizes and shapes to establish a measure of landscape context. A challenging part of developing estimates along the three factors is to be explicit about the spatial characterization. That is, for example, when a value for wilderness is prescribed, does this apply to an entire wilderness area (as a political designation), or within some defined neighborhood (e.g., within a 1-km circular window)? The spatial grain needs to be considered before one provides or computes estimates of any given factor. Here we summarize the spatial context using circular moving windows with radii of 1 and 5 km. These distance values are arbitrary, but attempt to capture the relatively local and midscale spatial context pattern. Again, our goal here is to provide an illustration of the broader method, and users will likely want to employ different values that reflect the species, process, or patterning that they are concerned about, which likely varies across ecoregions.

Table 5—Surrogate variables used for human modification framework factors for Colorado

	Factor		
Surrogate variable	**Convert urban/built-up**	**Extract Production/extraction**	**Visit Recreation/work**
Land cover (NLCD)[1]	Comm/ind (23) = 1.0 High dens. res. (22) = 0.9 Low dens. res. (21) = 0.8 Barren (33) = 0.6 Grass/parks (85) = 0.5	Orchards (61) = 0.6 Pasture (81) = 0.5 Row crops (82) = 1.0 Nonrow crops (83) = 0.7 Other ag (84) = 0.8 Quarries/mines (32) = 0.9	-
2000 housing density[2]	Urban (13-15) = 0.9 Suburban (12) = 0.8 Exurban (7-11) = 0.6 Rural (4-6) = 0.4	-	-
Roadedness[3]	Interstates (CFC A1x) = 1.0, 60-m buffer Highways (CFCC A2x) = 1.0, 30-m buffer Secondary (CFCC A3x) = 1.0, no buffer Local (CFCC 4x) = 0.5, no buffer 4WD (CFCC 5x) = 0.2, no buffer	-	-
Accessibility (only public lands)[4]	-	-	<0.5 hrs = 1.0 0.5-1 hr = 0.8 1-2 hrs = 0.5 2-4 hrs = 0.3 4-8 hrs = 0.1 >8 hrs = 0.0
Oil & gas wells[5]	-	W/in 60-m radius = 1.0, w/in 100 m = 0.7, w/in 200 m = 0.3, w/in 300 m = 0.1	-
Mining operations[6]	-	Coal exploration and unknown = 0.3 m, underground = 0.5, heap leach = 0.8, in-situ = 0.8, surface and underground = 0.9	-
COMaP (NF management types)	-	-	Ski resorts = 0.8 Motorized = 0.6 Multiuse = 0.4 Backcountry = 0.3 Wilderness = 0.2

[1] USGS National Land Cover Dataset, 0.09-ha resolution, ~1992-94.
[2] U.S. Census Bureau 2000 http://www.census.gov, Theobald 2005 www.asri.com/data, 1-ha resolution.
[3] Created from ESRI Streetmap 2006 data.
[4] Created from travel time along major roads, weighted by population size to nearest urban area, for urban areas with population > 100k and < = 100k, data from ESRI Streetmap 2006.
[5] Colorado Oil and Gas Conservation Commission, Well and facility shapefiles, downloaded 16 July 2006 from http://www.oil-gas.state.co.us.
[6] Mining data converted points to circles with area equal to permitted area (sqr([Permit_acr] * 4048 / 3.1415)).
Note: CFCC = census feature class code; 4WD = four-wheel drive.

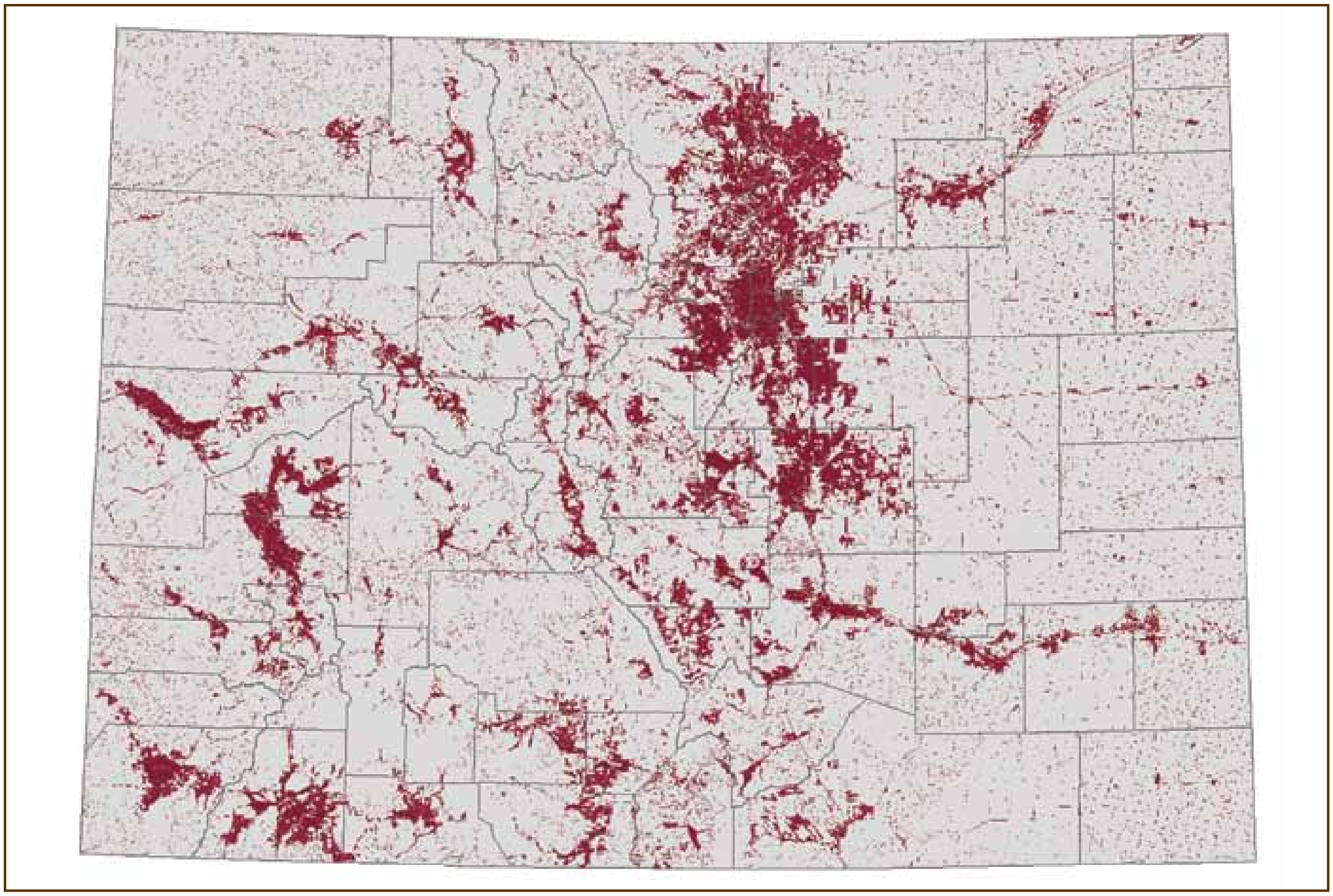

Figure 1—This composite map for urban/built-up areas in Colorado shows the degree to which locations have been converted, or built-up. This is a composite of commercial, industrial, and residential development (from National Land Cover Data Set); a "roadedness" layer that depicts the footprint of interstates, highways, and roads; and housing density (including exurban and rural densities) from SERGoM v2 (Theobald 2005). Darker shades show a higher level of built-up, grey shows absence, and grey lines show county boundaries. Note that the Front Range (Fort Collins, Denver, Colorado Springs) is clearly visible, as are many of the mountain valleys.

Results

The composite map of the degree to which an area is urban/built-up shows a relatively familiar pattern of urban areas, particularly the cities along the Colorado Front Range (Figure 1). Including information on slightly lower density of houses provides a fairly large expansion of locations that are developed beyond those locations identified in NLCD, particularly along mountain valleys.

The composite map of production and extraction-oriented land use provides a fairly different picture of Colorado (Figure 2). Extensive lands have been converted to cropland agriculture in the eastern plains and San Luis Valley. Another factor included is the extensive distribution of oil and gas wells, particularly in the northern Front Range area and western slope.

Perhaps the most unique contribution of this map is to portray the distribution of the extent and types of recreational uses found in Colorado (Figure 3). Compared with the typical map of public land ownership, portraying national forests, grasslands, and parks as being largely the same, this map clearly differentiates the heavy influence that accessibility to large populations (like the Front Range) can have. Accessibility here is computed as the one-way travel time (along roads) from urban areas. Also differentiated are the types of land management activities on public lands, distinguishing the heavily-recreated resort areas such as Aspen, Vail, and Breckenridge. This map also reflects

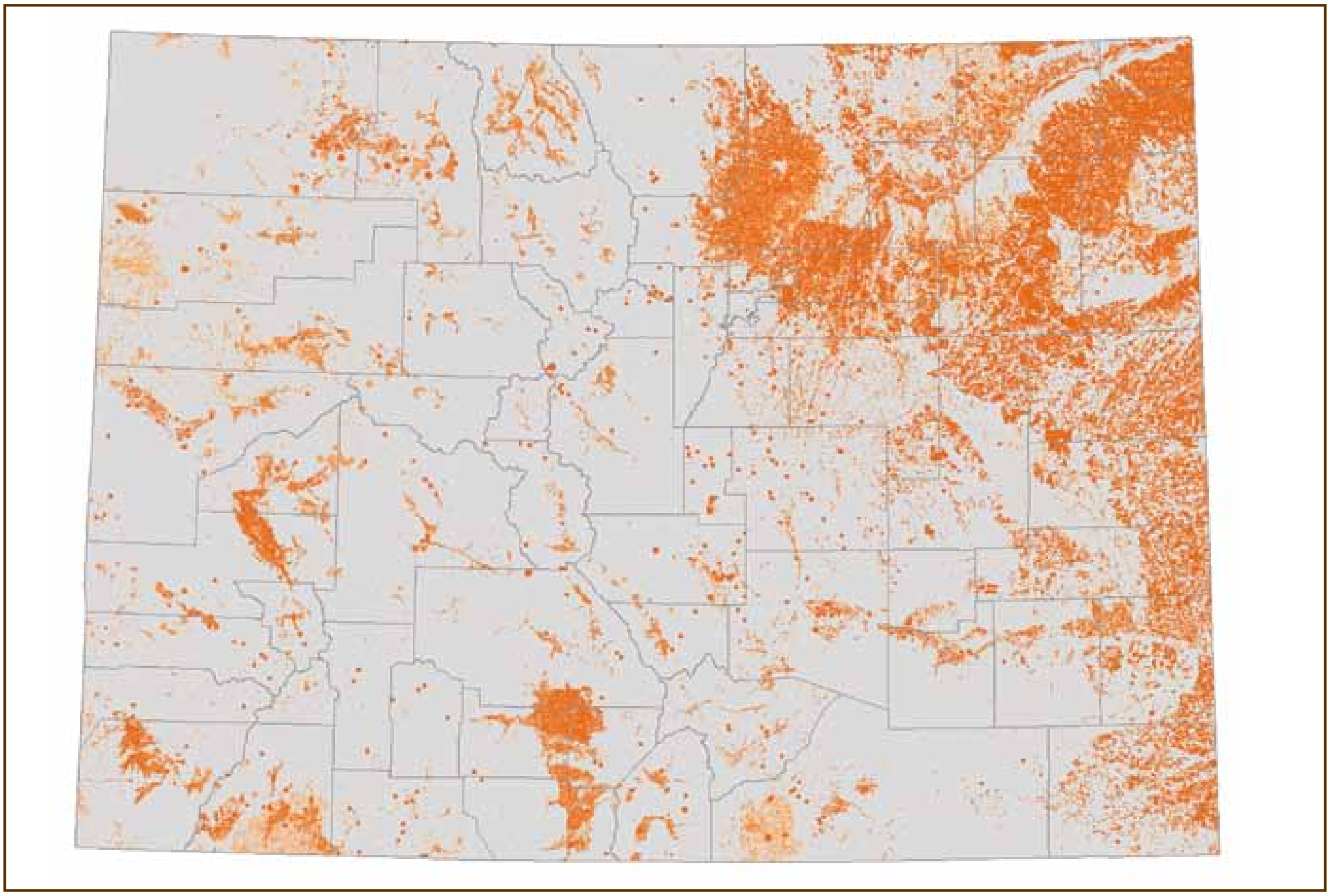

Figure 2—This map of Colorado shows the degree to which locations have some production or extraction-oriented land use. This is a composite of agricultural lands (from National Land Cover Data Set); mining activities; and oil and gas wells. Darker shades of orange show a higher level of activity, grey shows absence, and grey lines show county boundaries. Note that the productive agricultural lands of Weld and Adams County are clearly visible, as are the northeastern plains counties, whereas the San Luis Valley is visible in the south-central part of Colorado.

locations that are dominated by motorized vs. non-motorized recreation (future improvements should incorporate specific travel management plans).

The degree of human modification values vary across the State, with fine-grained differences particularly noticeable in riparian zones (Figure 4). The average HMF value is 0.392 (SD = 0.231). The range and distribution of HMF values can also be summarized by various ecological system types, such as lower montane, mixed, and upper montane zone (Table 6). Our results show that the midmontane zone has the largest average HMF score (0.428), indicating the highest degree of human activities that may modify or affect ecological systems in this zone. The upper montane zone (0.329) is the lowest of the conifer-dominated zones (lower montane = 0.405), but aspen forests have the overall lowest degree of human modification (0.313). In addition to summarizing by counties, different analytical units such as watersheds, ecoregions, ecosystems, etc., can be supported. It is important to note that although one can summarize values over fairly large areas, as we have done by major ecological system type, the fine-grained data will allow differentiation of more localized areas that are particularly impacted or have particularly low HMF values.

Commonly, population density is used as a surrogate indicator of the degree of impact on ecological systems. Although we found a loose relationship between population density and HMF score (Figure 5), there is a fair amount of variation as well, showing the additional information that

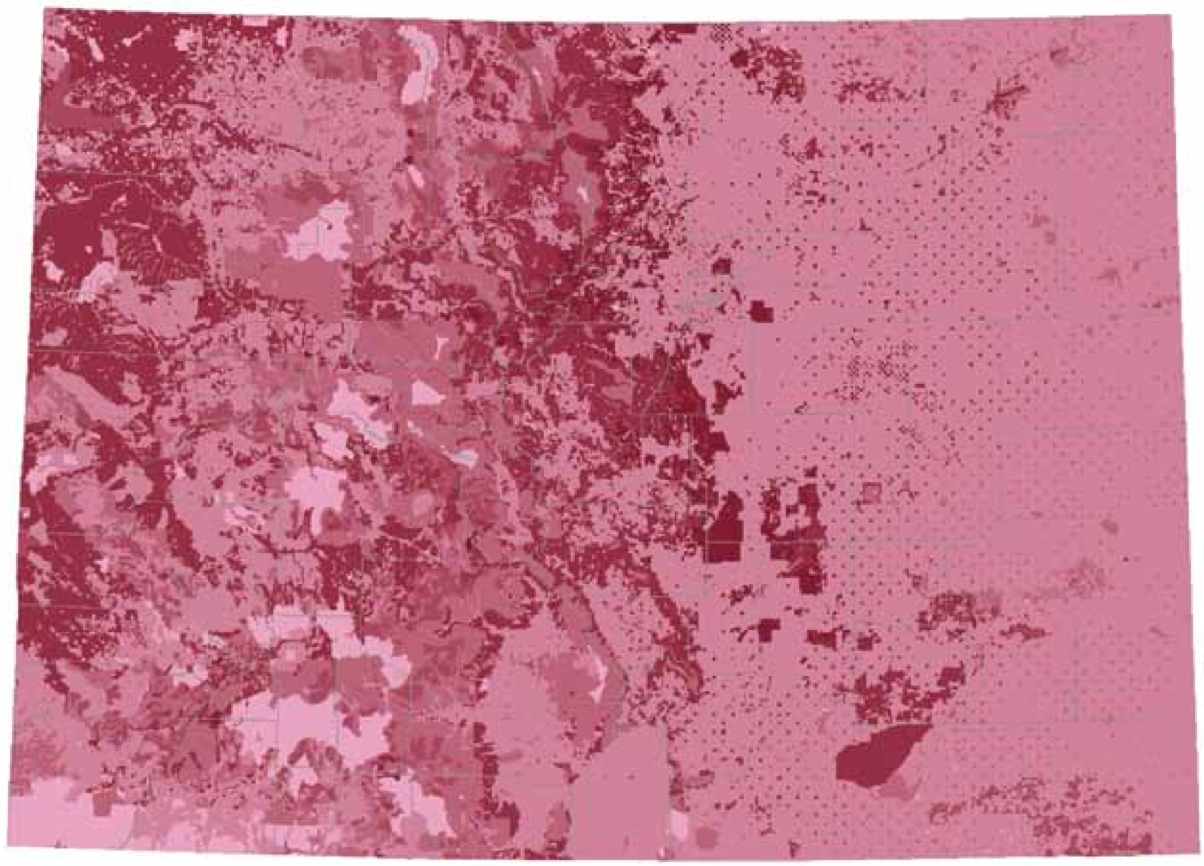

Figure 3—This composite map of Colorado for recreation/visitation shows the degree to which locations are likely to have recreation or tourism-oriented land use. This is a composite of an accessibility map that depicts the one-way travel time (along roads) from urban areas, and the type of public recreation and visitation targeted for different land management categories (especially for national parks and forests—data from the Colorado Ownership Management & Protection project). Darker shades of maroon show a higher level of activity and grey lines show county boundaries. Note that the public lands directly adjacent (mostly west of) the Front Range are highly affected, as are downhill ski resorts, and motorized recreation areas.

Table 6—Summary statistics for forested ecosystems in Colorado

Ecological systems[a]	Mean HMF (SD)
Upper montane (spruce-fir; 24, 26, 28)	0.329 (0.159)
Midmontane (Douglas-fir, lodgepole pine; 29, 30, 32)	0.428 (0.192)
Lower montane (ponderosa pine, pinyon-juniper; 34, 35, 36)	0.405 (0.203)
Aspen (22, 38)	0.313 (0.135)

[a] Data from the Southwest ReGap program.

The mean and standard deviation (SD) of the final human modification (HMF) score for upper, mid, and lower montane, and aspen forests.

Table 7—Summary statistics of human modification framework (HMF) scores as summarized by GAP status level in Colorado

GAP status[a]	Mean HMF (SD)	Minimum and maximum HMF
1	0.244 (0.149)	0.1, 0.893
2	0.295 (0.166)	0.098, 1.0
3	0.421 (0.133)	0.1, 1.0
4	0.397 (0.192)	0.1, 1.0

[a] Data from the Southwest ReGap program.

The mean, standard deviation (SD), minimum, and maximum of the final human modification score summarized for GAP status levels.

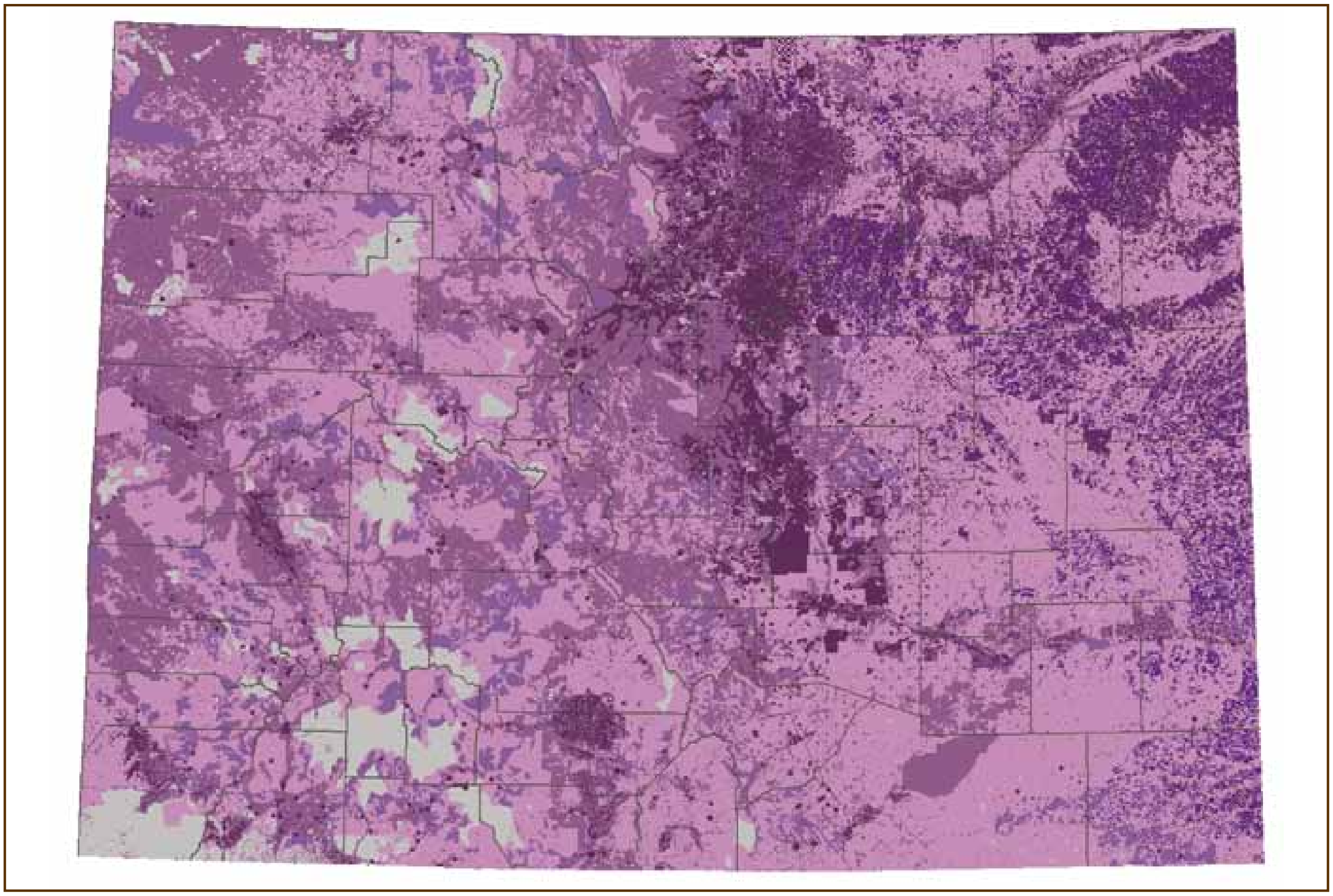

Figure 4—This map of Colorado shows the final map of degree of human modification (darker shade depicts higher degree of modification). This is a composite map of the urban/built-up, production/extraction, and recreation factor maps.

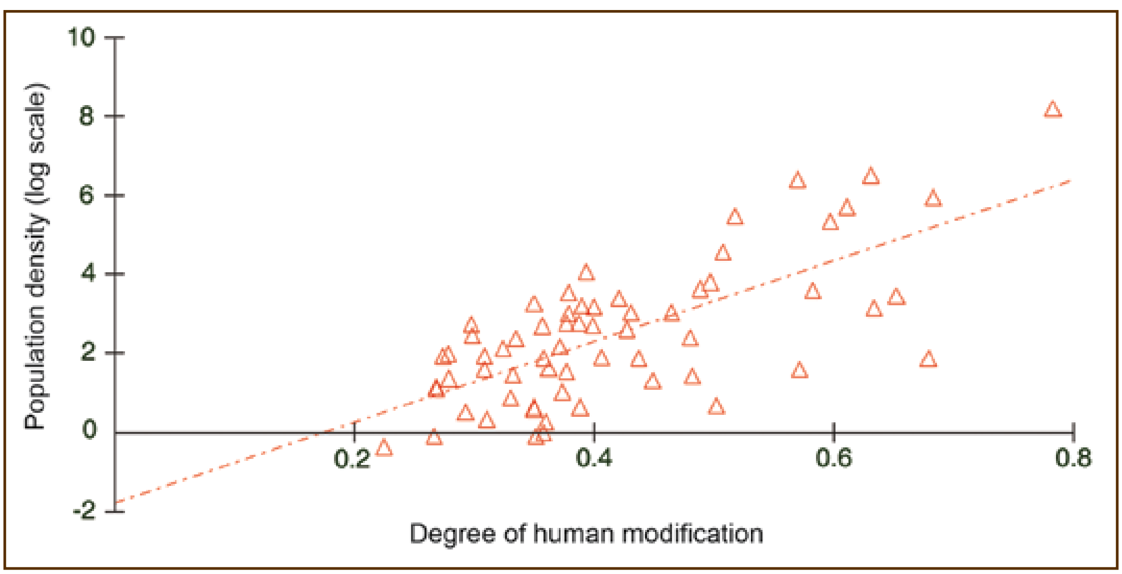

Figure 5—Population and degree of modification are compared in this graph of the county population for 2000 against the mean degree of human modification score. Although some counties fall along the linear relationship line, supporting the notion that larger populations lead to larger effects, there is a fair amount of variation as well.

this approach provides. By the same token, HMF provides a finer degree of detail than housing density—although housing density had a strong relationship.

We also compared HMF to GAP stewardship categories from the Southwest Regional GAP study (Table 7). We found that status 1 lands had lower average HMF values than status 2 (0.244 vs. 0.295), which were less than status 3 and 4. Interestingly, we found that status 4 had a lower mean HMF value than level 3 (0.397 vs. 0.421). Also, all status levels had very large maximum values (0.89 for level 1 and 1.0 for 2, 3, and 4).

Conclusion

In summary, we offer the human modification framework as an explicit approach to better quantify the spatial patterning and degree to which locations have been altered by human activities. We found that in our case study area, HMF showed markedly different results, particularly in the spatial patterns and distribution of disturbed areas, as compared to GAP status levels. An important, nonintuitive result is that we found that level 4 had less evidence of alteration than did level 3. This can occur because the HMF relies on surrogate variables that characterize current land use activities that have been shown to have effects on biodiversity. In contrast, GAP status levels characterize the legal protection from land use conversion (or management plans)—not the current condition per se. It is important to note that the HMF, as employed in this paper, shows existing (or at least currently known) modifications to the landscape, whereas the GAP and IUCN approach estimate long-term protection (in perpetuity). Although we did not document these trends here, the HMF methods could be easily applied to future growth or potential land use scenarios to examine the differences between their effects. The fine-grained approach and spatial context analysis in particular would be sensitive to differences in patterns of potential future land uses.

We believe that current approaches to estimating the degree of human modification can be improved in three ways. First, as understanding and elicitation of threats to protected areas matures, we believe that approaches will need to move from using general surrogates to factors that are more closely linked to the threats, ideally in a mechanistic way. In addition, we believe that finer-grained data are increasingly required to address concerns about fragmentation and other pattern issues. Finally, the spatial (or perhaps landscape) context is critical to incorporate. Further work is needed to develop methods for generating landscape context that more directly reflect ecological processes. For example, neighborhoods for freshwater should use a series of flow-connected watersheds. Similarly, the flow or movement of processes through other transport vectors such as air, soil transport, animal movement, seed dispersal, etc., should be explicitly represented as well.

There are a number of data gaps that need to be filled. Some of these gaps could be filled by collecting data from field offices, standardizing the data and entering them into an electronic database (with spatial coordinates recorded). For example, grazing permit data have been collected for many decades, but much of it remains in an unstandardized, unmapped, and nonelectronic format. The location of timber harvests (year, harvest method) data are available, but not in a consistent, easy-to-use format. Another type of data gap would simply require acquisition and compilation of existing spatial databases (e.g., highway structures such as fencing, culverts, bridges, etc., or hiking trails that would include structures, tread type, width, use, etc.). Spatial data about water infrastructure, in addition to large dams, would be useful as well for structures such as ditches, levees, rip-rap, and channelized segments.

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