Indicator Development for Landscape-Level Aquatic Ecological Vulnerability Assessment in Western United States

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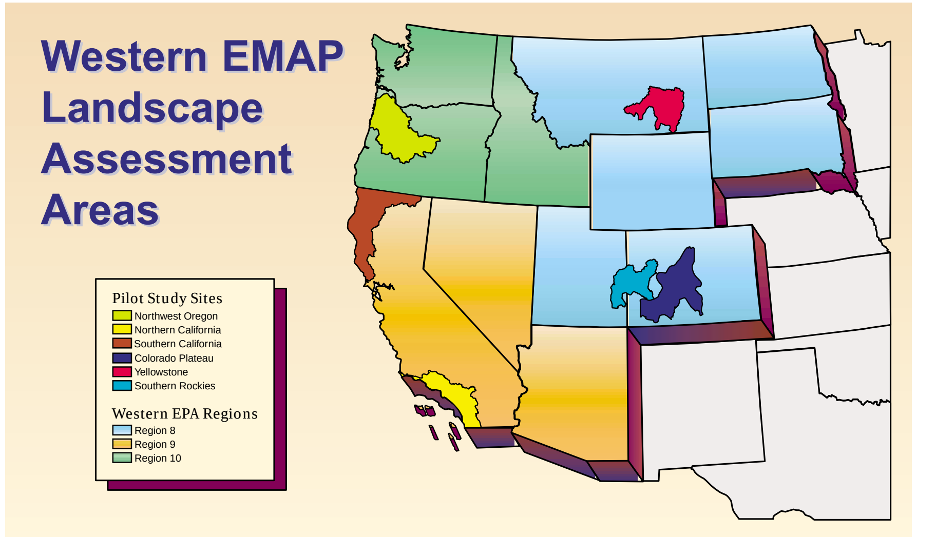

Western EMAP Landscape Assessment Areas

Abstract

Initial landscape assessment efforts for the USEPA Environmental Monitoring and Assessment Program's Western Pilot focused on improving and testing landscape indicators previously developed for the mid-Atlantic region of the United States.

Landscape indicators representing three general categories were developed for six study areas in the western United States. These categories represented indicators derived from (1) single spatial databases, (2) intersections of two or more spatial databases, and (3) models. Study areas were chosen to represent a variety of ecosystems distinct from those in the mid-Atlantic region and encompassed multiple watersheds. An intensive human use index was developed to assess the relative distribution of dramatic anthropogenic land cover change caused by urbanization and agricultural development. The presence of agriculture on steep slopes was used as an initial indicator of upland soil loss potential. Dasymetric mapping of population density was used to provide a more realistic representation of human occupancy of the landscape than simple mapping of census data. Indicator results were highly skewed with many values near zero. Several areas (Willamette Valley in northwestern Oregon, viticultural areas in northern California, and the coastal plains of southern California) had high scores for all indicators and were expected to have the most degraded aquatic resource conditions. Needed improvements in the indicators presented are also discussed.

Overview of Landscape Indicators

Landscape indicators are measures, indices of measures, or models describing the condition of an ecosystem or one of its critical components (Hunsaker et al., 1990).

An indicator may reflect biological, chemical or physical attributes of ecological condition. Indicators are used primarily to characterize status and to track or predict significant change. Landscape indicators may also be used to identify significant ecosystem stress.

Landscape indicators are generated in a geographic information system (GIS) from spatial data derived from satellite imagery and other data sources (e.g., elevation coverages generated from dense field measures and models). Three general categories of landscape indicators can be used in ecological assessments: (1) those generated from single spatial databases (e.g., percentage of watershed area that is forested generated from a digital land cover map); (2) those generated by intersecting two or more spatial databases (e.g., the percentage of watershed area with agriculture on slopes greater than 10% calculated by comparing a map of land cover to a map of slopes); and (3) those generated from relatively simple models (e.g., potential nitrogen loss from a watershed calculated by applying a nitrogen export model to a land cover map).

For the EMAP western pilot, we have created an initial list of landscape indicators, based primarily on previous work in the mid-Atlantic region of the United States (Jones et al., 1997), and will evaluate the ability of these indicators to explain variation in aquatic resource condition through a set of watershed studies. Our initial landscape assessment efforts have focused on testing landscape indicators developed for the mid-Atlantic region in six multiple watershed areas in the western U.S. These study areas represent a variety of ecosystems distinct from those occurring in the Mid-Atlantic region. We will also develop additional landscape indicators potentially related to aquatic resource conditions. These indicators will emphasize the effects of mining, logging, grazing and population growth. Conceptual models of watershed processes and functions will be used to establish hypotheses of those landscape indicators that might be most important in explaining aquatic resource conditions.

This poster presents results of representative landscape indictors from each of the three categories described above. Each landscape indicator was calculated for the six study areas in the western United States. Assessment units were 10-digit hydrologic unit code (HUC) basins for the Northwestern Oregon, Northern California, Southern California and Lower Yellowstone study areas; 8-digit HUC drainage areas were used for the Southern Rockies and Colorado Plateau study areas. The assessment units in Northern California do not meet the minimum size criteria for 10-digit HUC basins. The large number of small assessment units in this area skews the frequency distribution of indicator results and prevents the results to be meaningfully reported on a quantile basis. Indicator results are therefore reported using logical breaks in the data.

Data Sources

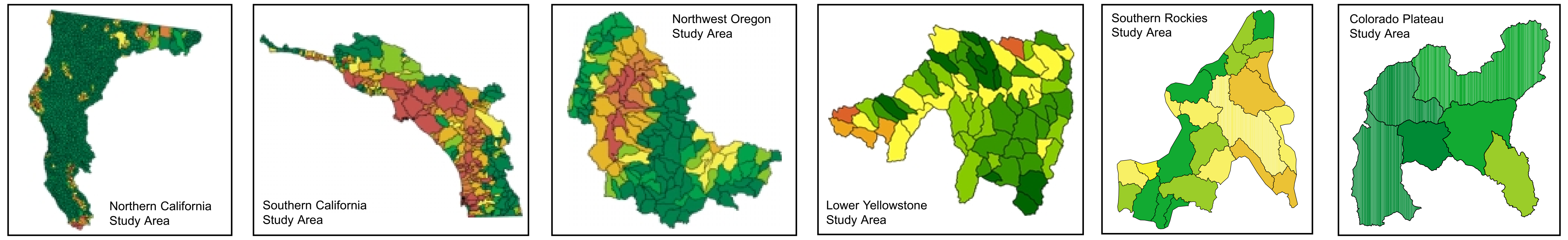
A variety of geospatial data was used to derive the indicators for the six study areas.

Comprehensive databases do not currently exist for many of the spatial data types used. Although this could potentially complicate the comparison of indicator results across the study areas, where possible, data were reclassified to facilitate comparability. As national data sets become available in the next few years, all affected indicators will be recalculated to improve comparability.

For the Northern California, Southern California, Lower Yellowstone, Southern Rockies and Colorado Plateau study areas, land cover data were obtained from State Gap Analysis Programs (GAP). The Northwestern Oregon study area utilized the Multi-Resolution Land Characteristics Interagency Consortium's (MRLC) National Land Cover Database. Because States did not always use the same criteria to classify higher level land cover categories, data were reclassified into broad land cover categories for indicator development. GAP data will be replaced by MRLC data as they become available.

U.S. Geological Survey (USGS) 30-m Digital Elevation Models (DEMs) were used for all study areas except the Southern Rocky Mountain and Colorado Plateau where 90-m DEMs were used. Population data (1990) were obtained from the U.S. Census Bureau.

Intensive Human Use Index



Percent Area
🟩 0 - 1 🟩 1 - 5 🟩 5 - 10 🟨 10 - 25 🟧 25 - 50 🟧 50 - 75 🟥 75 - 100

Perhaps the simplest indicator of potential environmental impact is the extent that humans have converted natural vegetation to urban or agriculture land cover. Such dramatic land cover conversion results in profound changes in terrestrial and aquatic ecosystem structure and function.

Methodology

The proportion of watershed area with land cover corresponding to intensive human use was employed as an initial indicator of potential anthropogenic impact on aquatic ecosystems. Land cover data were reclassified to nine land cover types (i.e., urban, cropland, pasture, rangeland, forest, wetland, barren, water and other). Only urban, cropland and pasture land cover were expected to unambiguously correspond to intensive human use. The proportion of area having each of these land cover types was summed and reported for each assessment unit. Grazing and forestry were explicitly excluded from this indicator because these land uses do not result in permanent conversion to intensive human use. Both of these land uses involve short-term disturbance of vegetative cover followed by recovery or replacement by a modified ecosystem. Furthermore, the land cover classes in the GAP and MRLC databases did not distinguish between grazed and ungrazed rangeland (a category including scrub-, shrub- and grassland), or logged and unlogged forests.

Results

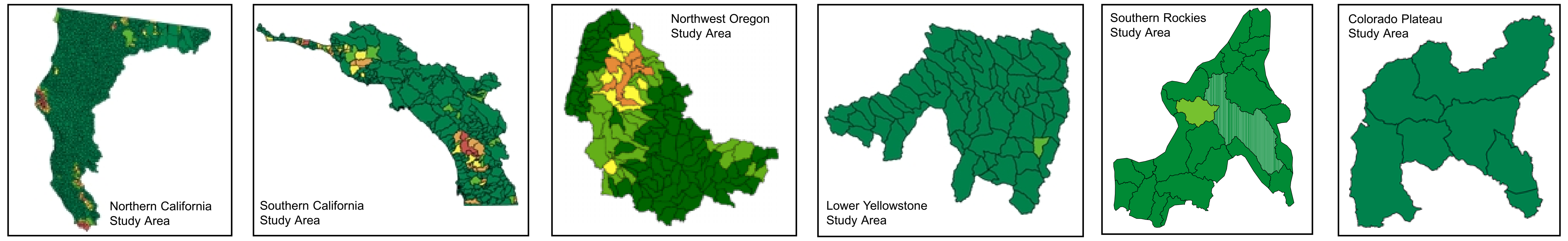
The intensive human use index shows the relative distribution of dramatic anthropogenic land cover change in the study areas. The table below summarizes the indicator results for the six study areas. Results are reported as the percentage of assessment units or area having the designated percent intensive land use. In the Northwestern Oregon study area, the intensive human use index was highest in the two regions dominated by agricultural and urban land uses, the Willamette Valley and Deschutes River basin. For Northern California, the highest values of the intensive use index occurred in viticultural areas of Sonoma and Mendocino counties, the Humbolt Bay area, and agricultural areas in the northeastern part of the study area. In Southern California, the high proportion of intensive human use was due to extensive urban and agricultural development on the coastal plains. Little intensive human use occurred in portions of the Transverse and Coastal ranges. The highest indicator values for the Lower Yellowstone study area occurred in agricultural areas in the west and north (52% and 55% percent of assessment unit area). The Colorado Plateau had generally low values of the intensive use index (less than 8%). In the Southern Rockies, the highest values for the index were in the eastern and southeastern portions of the study area. These regions correspond to agricultural areas and the city of Evergreen.

Intensive Human Use (%)	Percent of Assessment Units	Percent of Area
<1	72%	35%
1 - 4.9	6%	20%
5 - 9.9	4%	0%
10 - 24.9	6%	14%
25 - 49.9	5%	10%
50 - 74.9	4%	4%
75 - 100	3%	5%

Discussion

High index values correspond to areas that have experienced dramatic land cover conversion as a result of anthropogenic activity. The aquatic resources in drainage basins having high index values are hypothesized to be degraded by pollutant inputs and habitat alteration. This hypothesis will be tested in the indicator quantification phase of the project. Future indicator development efforts will focus on assessing the extent and severity of impacts from forestry and grazing. This may require the acquisition of imagery from more recently deployed sensors and the use of new image processing techniques.

Agriculture on Steep Slopes



Percent Area
🟩 0 - 1 🟩 1 - 5 🟨 5 - 10 🟧 10 - 25 🟥 25 - 75.3

In the absence of effective soil conservation, agricultural practices can result in increased rates of soil erosion, leading to increased sediment deposition in streams, lakes and estuaries. Potential soil loss from agricultural areas is related to surface cover, slope steepness, slope length, rainfall erosivity, soil erodibility and management practices (Hillel, 1998).

Methodology

As an initial indicator of upland soil erosion potential, the percentage of watershed area under intensive agricultural management on steep slopes was calculated. This indicator represents a modified version of an indicator developed in the mid-Atlantic region of the United States by Jones et al. (1997). Intensive agriculture was defined as land cover classified as row crop, vineyard, orchard, pasture, small grains or fallow in the land cover vegetation databases. Grazing and timber harvesting were not included in calculating the indicator. Percent slope was used as a measure of slope steepness, and slopes greater than 10% were considered to have increased erosion potential regardless of soil type. Slope was calculated from USGS 30-m DEMs. The percentage of watershed area having intensive agriculture on steep slopes was calculated by intersecting areas of intensive agriculture with areas having slopes greater than 10%. The output of this operation was then intersected with the assessment unit polygons.

Results

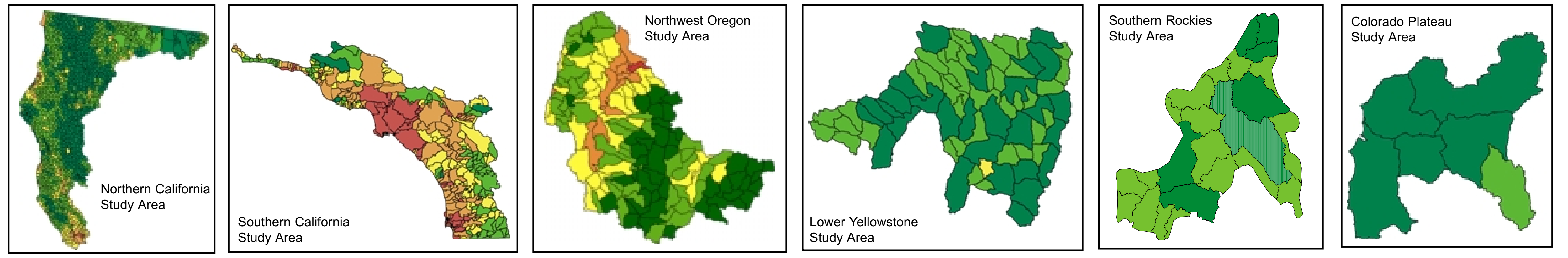
The percentage of assessment unit area with agriculture on slopes greater than 10% provides an indication of upland soil erosion potential. The results from this indicator are summarized in the table below. Few assessment units had agriculture on steep slopes over a large portion (> 25%) of their areas. Those that did were located primarily in viticultural areas of Northern and Southern California. The Willamette Valley also contained a number of assessment units with fairly high proportions (10-14%) of their area cultivated on slopes greater than 10%.

Agriculture on Steep Slopes (%)	Percent of Assessment Units	Percent of Area
<1	90%	87%
1 - 4.9	4%	8%
5 - 9.9	2%	2%
10 - 24.9	2%	2%
25 - 49.9	1%	0.3%
50 - 75.3	1%	0.3%

Discussion

This indicator provides an indication of some of the lands most vulnerable to soil loss. However, many lands vulnerable to soil erosion are not captured by this indicator. For example, depending on soil texture and structure, erosion may occur on slopes less than 10%. Similarly, rainfall intensity, slope length and land use practices (e.g., irrigation methods, mulching, cover crops) also affect soil erosion. The results of this indicator should therefore be viewed as minimum percentages of potentially erodible areas. The focus on erosion from agricultural lands also precludes consideration of soil loss from grazed and forested landscapes. The current indicator only considered sheet and rill erosion potential; channel erosion and mass wasting (e.g., slumping) are not addressed. Future efforts will focus on improving estimates of upland soil erosion potential by application of the Revised Universal Soil Loss Equation on a 10-digit HUC scale.

Dasymetric Population Density



Capita/Square Kilometer
🟩 0 - 1 🟩 1 - 10 🟨 10 - 100 🟧 100 - 1,000 🟥 1,000 - 10,000

Population density can serve as a measure of human use intensity. Current spatial databases of human population distribution (e.g., 1990 U.S. Census Bureau data) do not necessarily relate to human use intensity. Alternative approaches suggested in the literature often integrate remotely sensed imagery with data from the U.S. Census Bureau (Yuan et al., 1997).

Because census data locate human population primarily in residential areas, actual spatial patterns of human use are not accurately depicted when these data are used alone. For example, heavily used commercial and industrial areas may have much greater daytime population densities than suburban residential areas.

Methodology

A dasymetric mapping approach was used to apportion human population to specific land cover types within assessment units (Schumacher et al., 1999). This indicator incorporated human population from the 1990 U.S. Census Bureau data, land cover data reclassified into seven land cover types (i.e., urban, agriculture, forest, wetland, barren, water and other), land ownership, and USGS DEMs. Block-group level population counts were obtained from the 1990 U.S. Census Bureau. A sequence of filtering steps was applied to reassign the population counted within each block group to smaller map units (Schumacher et al., 1999). Three land cover types (i.e., water, wetland, barren) were assumed largely uninhabited and excluded from the block groups. Publicly owned lands with the exception of U.S. Forest Service, U.S. Fish and Wildlife, Bureau of Land Management, Bureau of Reclamation, and Agricultural Research Services lands were further excluded from block groups, as were lands with slopes exceeding 30%. Population counts for each block group were then redistributed into the four habitable land cover classes (i.e., urban, agriculture, forest, and other) weighted by area and proportions reported by Schumacher et al. (1999) using the following formula:

$$P_i = \frac{w_i A_i}{\sum w_i A_i} P_T$$

where, P_i is the population assigned to land cover i, P_T is the total population in the block group, w_i is the weight assigned to land cover i, A_i is the area of land cover i, and $i \leq n$, the maximum possible number of land cover types. Assuming all four land cover classes were present in equal proportions in a block group area, 80% of the population was allocated to urban areas, 5% to agricultural lands, 5% to forested lands and 10% to other. In reporting units lacking one or more of these land cover categories, these relative proportions would be maintained. For example, if one block group contained only agriculture, forest and other, both agriculture and forest received effective weights of 25%, while agriculture received an effective weight of 50%.

Results

The dasymetric population density results show the relative distribution of human population density across the six study areas. The table below summarizes these results.

For the Northwestern Oregon study area, population density was highest in the Willamette Valley and Deschutes River basin. Northern California was sparsely populated with the highest population densities (capita/km^2) occurring in Sonoma County. Population density in Southern California was concentrated in the metropolitan areas of Los Angeles and San Diego. The Lower Yellowstone, Colorado Plateau and Southern Rockies study areas were sparsely populated with the highest population density (10 capita/km^2) occurring in the vicinity of Lame Deer in the Lower Yellowstone study area.

Population Density (capita/km^2)	Percent of Assessment Units	Percent of Area
0 - 0.9	40%	46%
1.0 - 9.9	39%	35%
10 - 99	12%	10%
100 - 999	6%	7%
1,000 - 9,999	2%	2%

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Discussion

This indicator represents an improvement over the use of raw census data for displaying population distribution across the landscape. However, several modifications are required to improve the utility of this indicator. The weighting factors utilized in this indicator were derived for use in western Montana, and may not accurately reflect population distribution in other areas of the western U.S. (e.g., southern California). More regional population distribution information is required to improve the accuracy of this indicator. In some regions (e.g., highly urbanized southern California) block group areas were smaller than assessment units. The dasymetric mapping of population in these cases resulted in inefficient data processing and no improvement in the realism of population distribution. In such cases population distribution could be made more realistic by using larger census units (e.g., tracts) for dasymetric mapping. The algorithm employed also did not account for inter-block group population transfer. This may be important in regions with significant metropolitan areas.

Conclusions

- Indicator results were highly skewed with many values near zero.
- The Willamette Valley in northwestern Oregon, viticultural areas in northern California, and the coastal plains of southern California had high scores for all indicators. These areas are expected to have the most degraded aquatic resource conditions.
- The low indicator scores for most assessment units in the Lower Yellowstone, Colorado Plateau and Southern Rockies study areas appear to suggest few aquatic resource impacts. However, many potentially significant stressors (e.g., grazing, forestry and mining) were not addressed by the indicators presented.
- Assessing potential grazing and forestry impacts will require the use of additional remotely sensed imagery and/or more sophisticated image processing techniques.
- The indicator of upland erosion potential will benefit from a more sophisticated modeling approach.

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