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Habitat Assessments

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Overview

Articles in this section address the development, interpretation, and analysis of ecological information over very large geographic regions and are characterized by the huge undertaking to assemble and manipulate the data required. These articles illuminate the imperative need for information at multiple levels of both geographic scale (site, small watershed, state, regional, national) and biotic organization (population, species, natural community, landscape, and biome).

A systematic approach toward the development of science-based ecological information at multiple scales and across large areas has been lacking from our management of natural resources. Significant gains in achieving an environmentally sustainable society with an acceptable standard of living can be had by addressing this issue, and the articles in this section point the way.

Edwards and Stoms and Davis present some early results of the National Gap Analysis Project (see box by Scott et al., this section). Edwards shows that less than 10% of the vegetation cover types in Utah are represented within conservation lands. There is no assurance that the 90% of vegetation types (or habitat types) not represented in conservation lands will not be eliminated by changes in land use. In a world where the demand for raw materials is increasing and the rate of land-use change is rapid, adequate representation of habitat types in conservation lands is important if we are to prevent extinctions. The lack of adequate representation of habitat types in conservation lands is also the situation described by Stoms and Davis in the next article. They show that while almost 10% of the total surface area of southwestern California is managed to protect native biological diversity, most of this land is at high elevations. Natural communities at low elevations, such as coastal sage scrub and California walnut woodlands, are in considerable danger of extinction.

Shaw and Jennings describe the Multi-Resolution Land Characteristics Database, which is the first effort to provide consistent, direct, and integrated observations of large-area ecosystems, producing basic as well as interpreted information for a range of purposes. This effort includes the land-cover types of agricultural and urban areas as well as natural areas. With access to these data sets, policy decisions as well as daily management choices may, for the first time, be regularly examined in a biogeographic context covering the entire distribution of a natural feature of concern (such as a particular habitat type). Some of these data are already available in digital format over the Internet.

Loveland and Hutcheson compare the most current picture of general vegetation patterns (taken from the weather satellite, which is at an altitude of 833 km, or 517 mi, above Earth) with a map of what the vegetation may have been like before European settlement. In addition to providing some idea of the difference between the land cover of today and, hypothetically, presettlement land cover, they show conceptually the value of being able to make these kinds of comparisons. The authors carefully point out the limitations of each of the maps they use, then they walk the reader through how such a comparison is made. Because of the coarse geographic scale used, only general patterns can be shown and the results of this comparison are more meaningful when used to estimate large-area carbon flux, for example, than for calculating changes in biological diversity. The importance of this article is not in the results of the comparison but in the concepts of using large-area land-cover data to assess the past and present trends of landscape-level ecological conditions and processes.

Wilen's article cites studies showing that half of the nation's wetlands have been converted to uplands since colonial times. He demonstrates that the apparent slowing trend in overall wetland loss is deceptive because qualitative changes that do not show up as a net loss of wetlands are occurring in different types of wetlands. For example, in recent times, vast tracts of forested wetlands have been converted to other wetland forms, such as wet meadows. This is especially important because of their complex functions, such as flood control and pollution abatement, as well as their providing critical wildlife habitat. By using data from the National Wetlands Inventory, Wilen shows that overall, wetlands are losing their diversity. Without systematic science-based efforts like the NWI to map our natural resources, there can be no meaningfully coherent information for making decisions about how to manage them.

Because the dynamics of larger systems (e.g., landscapes) constrain the behavior and occurrence of the smaller systems that they encompass (e.g., populations or species), by means that are independent of the smaller systems, conservation efforts implemented at the levels of populations or species cannot be effective when systemwide changes are occurring at the landscape level. Environmental changes that were formerly limited to affecting populations and species are now manifest at scales by which natural community and landscape systems function. Therefore, if we are to make significant progress in slowing the loss of our biological heritage, the basis for solving problems and implementing decisions must be predicated on information derived from multiple scales of geographic resolution as well as of biotic organization.

Gap Analysis: A Geographic Approach to Planning for Biological Diversity

by
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The Gap Analysis Program (GAP) is an approach to protecting the nation's biological diversity based on a collaborative effort among citizens, businesses, nonprofit groups, universities, and local, state, and federal agencies. More than anything, GAP is a method of developing information about biological diversity that will enable individuals, planners, managers, and policy makers to make informed decisions. Species and habitats not adequately represented within conservation areas constitute gaps in programs meant to prevent species from becoming extinct. By providing information before extinction crises, GAP seeks proactive rather than reactive solutions.

The questions that GAP asks are: How can we prevent the components of biological diversity from becoming endangered with extinction before they reach social and economic crises? What is the present conservation status of all species and their habitats, not just those currently endangered?

To answer these questions on a state-by-state basis, people with expertise in geography, sociology, economics, zoology, botany, statistics, and ecology cooperate in mapping the distributions of dominant natural vegetation (as habitat types), and the distributions of each vertebrate species. Nationwide standards are used so that the maps of one state will fit with the maps of adjacent states. Because these maps are standardized across the United States, yet based on state and local information, they provide a critical framework for ecosystem management that is integrated across the private and public sectors. For example, these maps help define areas with the highest species diversity as well as how these areas match up with present conservation areas.

In the process of mapping land cover, GAP provides most states not only with computerized maps of existing conditions throughout the state (most for the first time ever), but also with maps of these same conditions across contiguous states, thereby providing context for what occurs within the state. The GAP is not a substitute for detailed studies of any particular site; instead it provides information, focus, and direction for management decisions at the ecosystem level. GAP is now under way in 33 states and consists of more than 200 cooperating organizations nationwide. It is coordinated by the National Biological Service.

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Furthermore, the mechanisms, or the "emergent properties," by which an ecological system operates cannot be identified by a simple aggregation of its smaller components nor by a reduction of its larger components (Allen and Starr 1982; O'Neill et al. 1986). To adequately characterize an ecosystem, it must be observed as a functioning whole rather than only inferred by reducing it to its component parts and then re-aggregating the information discovered about the components. For ecosystems that cover large areas, observation is difficult, perhaps impossible, without using aerial photography and satellite imagery along with computerized systems that can handle the large amounts of information for analysis.

There are four requisites to the effective management of biological diversity, soil, water, and natural processes across large landscapes: standardized definitions of the resources; replicative scientific methods for inventories that must go beyond lists of species to include natural communities and their processes; a high-quality environmental information system with easy access for all; and the expertise to usefully synthesize the information (Jennings and Reganold 1991). The National Wetlands Inventory, Gap Analysis, and the Multi-Resolution Land Characteristics Database are achieving these requisites.

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Protection Status of Vegetation Cover Types in Utah

by
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Maintaining biological diversity must be done at all levels of an ecosystem, not just for endangered species (Noss 1991; Scott et al. 1991). The Gap Analysis Program is one proactive approach for assessing the current status of biodiversity at all levels. By using computerized mapping techniques called geographic information systems (GIS) to identify "gaps" in biodiversity protection, gap analysis provides a systematic approach for evaluating how biological diversity can be protected in given areas. If problems are identified through gap analysis, appropriate management action can be taken, including establishing new preserves or changing land-use practices (Edwards et al. 1993; Scott et. al 1993; Edwards and Scott 1994).

Our gap analysis includes three primary GIS layers: distribution of actual vegetation cover types; land ownership; and distributions of terrestrial vertebrates as predicted from the distribution of vegetation and from observations. By using the GIS, map overlays of animal distribution and land ownership are compared to estimate the relative extent of protection afforded each vertebrate species. Gap analysis functions organize biological information by using the data base to provide the context for other, more detailed studies.

In this article, we apply gap analysis to assess the protection status of mapped vegetation cover types in Utah. We briefly describe the process used to model and map vegetation cover types and how this process was linked with land ownership to provide an estimate of the level of protection afforded each vegetation cover type in Utah. A central tenet of gap analysis is that the degree of conservation protection afforded a given area can be determined by ownership and management. To assess protection, we used land ownership maps; each ownership was assigned one of four management status codes (Table 1). For Utah, 38 vegetation cover types and land-cover classes were modeled by using Landsat Thematic Mapper satellite data (Table 2). How much land is necessary to protect biodiversity or certain species is problematic. We arbitrarily define adequate protection as requiring at least 10% of a vegetation cover type in status category 1 or 2.

Table 1. Management status codes applied to Utah land ownership (Scott et al. 1993).

Code	Description
1	An area having an active management plan in operation to maintain a natural state and within which natural disturbances (e.g., fire, floods) are allowed to proceed without interference or are mimicked through management.
2	An area generally managed for natural values, but which may receive use that degrades the quality of existing natural communities.
3	Most nondesignated public lands. Legal mandates prevent the permanent conversion of natural habitat types to anthropogenic habitat types and confer protection to federally listed endangered and threatened species.
4	Private or public lands without an existing easement or irrevocable management agreement to maintain native species and natural communities and which are managed for intensive human use.

Status of Lands

State and federal public lands make up roughly 71% of the 21,979,000 ha (54,288,130 acres) of Utah (Table 3). Land protection status reflects this public control over lands (Table 3). Only 1,554 ha (3,833 acres) of the state's land are considered status 1 lands; these are owned exclusively by The Nature Conservancy. The area in status code 2 is 874,736 ha (3.98%; 2,160,605 acres); the area considered status code 3 is 15,464,474 ha (70.36%; 38,197,251

Table 2. Protection status of mapped vegetation cover types in Utah.

Cover type	Status code								Total
	Status 1		Status 2		Status 3		Status 4		
	ha	(%)	ha	(%)	ha	(%)	ha	(%)	ha
Open water	61	(<0.1)	23,447	(2.7)	737,835	(86.3)	93,652	(11.0)	854,995
Spruce-fir	0	(0)	95,733	(19.3)	374,611	(75.4)	26,738	(5.4)	497,082
Ponderosa pine	0	(0)	2,281	(4.8)	39,677	(83.5)	5,577	(11.7)	47,535
Lodgepole pine	0	(0)	28,901	(12.6)	191,103	(83.3)	9,330	(4.1)	229,334
Mountain fir	0	(0)	17,376	(6.7)	198,893	(76.2)	44,862	(17.2)	261,131
Juniper	11	(<0.1)	83,467	(5.3)	1,248,615	(79.1)	246,778	(15.6)	1,578,871
Pinyon pine	66	(<0.1)	22,320	(3.4)	528,572	(81.4)	97,996	(15.1)	648,954
Pinyon-juniper	641	(<0.1)	78,067	(3.9)	1,619,168	(80.4)	316,571	(15.7)	2,014,447
Mountain mahogany	0	(0)	0	(0)	167	(62.1)	102	(37.9)	269
Aspen	0	(0)	20,660	(2.8)	475,551	(64.7)	238,769	(32.5)	734,980
Oak	88	(<0.1)	43,158	(5.4)	460,617	(58.1)	289,542	(36.5)	793,405
Maple	0	(0)	8,588	(11.4)	30,155	(40.1)	36,488	(48.5)	75,231
Mountain shrub	0	(0)	17,812	(8.6)	139,128	(67.3)	49,786	(24.1)	206,726
Sagebrush	43	(<0.1)	32,334	(1.5)	1 ,579,658	(73.5)	536,498	(25.0)	2,148,533
Sagebrush/perennial grass	0	(0)	50,818	(3.0)	863,295	(50.9)	781,212	(46.1)	1,695,325
Grassland	0	(0)	20,580	(2.4)	539,027	(62.8)	298,461	(34.8)	858,068
Alpine	0	(0)	33,542	(41.4)	46,270	(57.2)	1,123	(1.4)	80,935
Dry meadow	0	(0)	3,019	(1.4)	122,521	(56.6)	91,118	(42.1)	216,658
Wet meadow	0	(0)	40	(0.7)	3,956	(68.3)	1,793	(31.0)	5,789
Barren	0	(0)	67,922	(11.8)	451,191	(78.4)	56,378	(9.8)	575,491
Lodgepole pine/aspen	0	(0)	24	(0.4)	5,408	(92.2)	435	(7.4)	5,867
Ponderosa pine/mountain shrub	0	(0)	7,694	(3.4)	196,052	(86.0)	24,145	(10.6)	227,891
Spruce-fir/mountain shrub	0	(0)	104	(2.5)	3,320	(79.4)	756	(18.1)	4,180
Mountain fir/mountain shrub	0	(0)	117	(1.3)	6,271	(67.2)	2,943	(31.5)	9,331
Aspen/conifer	0	(0)	57	(0.4)	9,766	(71.9)	3,767	(27.7)	13,590
Mountain riparian	0	(0)	1,612	(4.2)	17,895	(46.2)	19,205	(49.6)	38,712
Lowland riparian	149	(0.3)	908	(1.8)	12,605	(24.7)	37,445	(73.3)	51,107
Lava	0	(0)	0	(0)	259	(100)	0	(0)	259
Agriculture	494	(0.1)	6,208	(0.7)	19,647	(2.1)	908,905	(97.2)	935,254
Urban	0	(0)	88	(0.1)	5,233	(3.6)	139,338	(96.3)	144,659
Salt desert scrub	0	(0)	98,802	(2.2)	3,660,972	(80.6)	779,929	(17.2)	4,539,703
Desert grassland	0	(0)	9,307	(1.0)	662,639	(73.8)	225,936	(25.2)	897,882
Blackbrush	2	(<0.1)	84,091	(8.8)	708,021	(74.1)	162,854	(17.1)	954,968
Creosote-bursage	0	(0)	308	(0.8)	36,084	(76.1)	10,925	(23.1)	47,317
Greasewood	0	(0)	1,316	(1.3)	73,890	(75.4)	22,840	(23.3)	98,046
Pickleweed barrens	0	(0)	3,990	(0.9)	385,163	(89.3)	42,401	(9.8)	431,554
Wetland	0	(0)	9,967	(18.5)	10,470	(19.5)	33,390	(62.0)	53,827

Table 3. Land ownership and protection status in Utah by major category.

Ownership	Total area		Status 1		Status 2		Status 3		Status 4	
	ha	(%)	ha	(%)	ha	(%)	ha	(%)	ha	(%)
Federal	14,006,997	(63.7)	0	(0)	699,692	(5.0)	13,307,095	(95.0)	210	(<0.1)
Native American	942,363	(4.3)	0	(0)	0	(0)	0	(0)	942,363	(100.0)
Private	4,699,145	(21.4)	1,554	(<0.1)	1,935	(<0.1)	0	(0)	4,695,656	(99.9)
State	1,666,700	(7.6)	0	(0)	173,109	(10.4)	1,493,591	(89.6)	0	(0)
Water	663,792	(3.0)	0	(0)	0	(0)	663,792	(100.0)	0	(0)

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acres). The remaining 5,638,229 ha (25.65%; 13,926,440 acres) are status 4 lands. By far, most lands in Utah are nondesignated public lands subject to multiple-use guidelines (i.e., status 3). Based on the 10% rule, only 6 of the 37 mapped vegetation cover types are protected as status 1 or status 2 lands (Table 1). Four of these six cover types are timber or other high-elevation cover types. The remaining two cover types are wetlands and barrens areas with less than 5% vegetation.

A common perception is that there currently exist sufficient protected lands that preserve and maintain biological diversity. Our analyses indicate that while some cover types are protected, most of the mapped cover types in Utah have less than 10% of their area protected. Our analyses also indicate that the Utah lands that are protected are more of a random product than a systematic approach to protecting the diversity of vegetation cover types. A more reasoned approach to the management of lands for the conservation of biological resources should include a systematic evaluation of the geographic distribution of resources.

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Biodiversity in the Southwestern California Region

by
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The Gap Analysis Program (GAP), coordinated by the National Biological Service, provides a regional screening of elements of biodiversity (plant communities and wildlife species) to identify elements most at risk and to identify general areas of highest concentrations of the at-risk elements. Data collection and analysis have been completed for southwestern California, the first of 10 regions to be analyzed in the state. This region covers roughly 8% of the land area of California, spanning the southern coast from Point Conception to the U.S.-Mexico border and from the western edge of the Sonoran and Mojave deserts to the Pacific Ocean. Urban growth has been exceptionally rapid in this region at the expense of species and habitats, particularly in the Coastal Plain. This article summarizes the gap analysis of this region and identifies plant communities and wildlife species considered at risk. Further details can be found in Davis et al. (1994).

Land Management Status

In this analysis we defined three levels of management to determine the protection status of elements of biodiversity. Level 1 represents areas managed for the long-term protection of biodiversity, such as wilderness areas, research natural areas, state parks, and some private preserves. Level 2 includes publicly owned lands not specifically designated for Level 1 management, and Level 3 contains lands with no formal management for biodiversity.

The amount of Level 1 areas managed to preserve biodiversity is 9.6% of the region, mostly in national forest wilderness areas. Other public lands managed at Level 2 account for another 30%, while the remaining 60% is private land. Lower elevations, where most urban and agricultural development occurs, are predominately private land. Government agencies manage most higher elevation lands, that is, lands at 1,500-2,500 m (4,920-8,200 ft), 25% of which is managed at Level 1.

Vegetation Status

A team from the University of California, Santa Barbara (UCSB) produced a map of actual vegetation. The California Natural Diversity Data Base staff has identified some plant communities of special concern; they generally have less than 10% of their distribution in Level 1 areas or over 70% of the mapped distribution in privately owned Level 3 areas. We used these criteria to identify other plant communities that are at risk.

Communities restricted largely to the lower elevations, like coastal sage scrub (Figure) and non-native annual grasslands, are at considerable risk (Table 1). Although grasslands are dominated by non-native species, they can be rich in native plant species and are habitat to many animal species. Roughly 88% of areas below 500 m (1,640 ft) have no formal protection status; most low-elevation land has already been converted to agricultural or urban uses, and most remaining low-elevation land is zoned for future urbanization.

Especially alarming is the condition of the California black walnut woodlands. The southern variety of this species is endemic to this region and its current distribution is highly fragmented and reduced compared with its original distribution. Sagebrush steppe shrubland, although widespread elsewhere in California, appears vulnerable in this region. A significant proportion of the sagebrush steppe habitat is on Level 2 lands, and conservation concern for these communities can probably be adequately

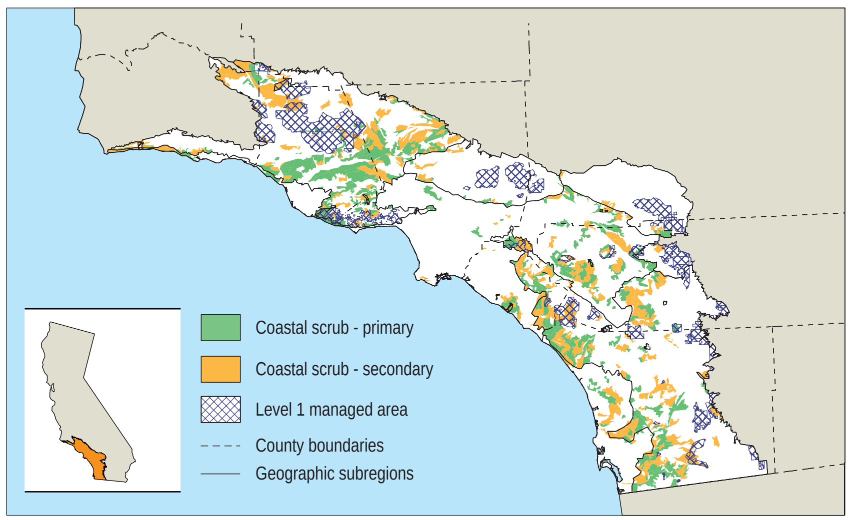

Figure. Gap analysis of coastal sage scrub in the southwestern region of California. Highlighted are landscapes where coastal sage scrub is the primary and secondary upland vegetation type.

Table 1. Natural communities identified as at risk by using Gap Analysis Program criteria. The list is ordered from highest to lowest percentage of the community that occurs on Level 3 private lands.

Natural community	Private lands %
Valley oak woodland *	94
Valley needlegrass grassland *	93
California walnut woodland	89
Coastal sage-chaparral scrub	82
Digger pine-oak woodland *	76
Non-native grassland	73
Coastal sage scrub	71
Coast live oak woodland	71
Coast live oak forest	70
Engelmann oak woodland	66
Southern mixed chaparral	62
Redshanks chaparral	42
Big sagebrush scrub	38
Upper Sonoran manzanita chaparral	24
Southern interior cypress forest *	22
Mojavean pinon woodland *	6
Northern juniper woodland	4

*Mapped distribution totals less than 50 km^2 (19.3 mi^2).

addressed by the public land managing agencies. Many oak woodlands appear to be at risk now or will be within the next one or two decades. Most of the chaparral communities seem reasonably secure; they are generally found on steeper slopes, largely on public lands, and in areas with 10%-20% Level 1 status.

Wildlife Status

Detailed field-based maps of the distribution of wildlife do not exist for all species and would be too difficult to compile in the time available. Biologists do know, however, what habitats most wildlife species prefer. We combined this knowledge, contained in the California Wildlife-Habitat Relationships (WHR) data base (Airola 1988), with the vegetation map to identify suitable habitat for all native wildlife species in the region. These predictions do not guarantee that a species occurs at a given location, only that suitable habitat exists. Threatened and endangered species usually had less than 15% of their distribution in Level 1 areas. We used this proportion as our criterion for identifying what other species breeding in the region are at highest risk.

Forty-two wildlife species are at highest risk from inadequate habitat protection (Table 2). Basically, the number of at-risk species is relatively uniform throughout San Bernardino, western Riverside, San Diego, and eastern Orange counties. The western half of the region in Los Angeles, Ventura, and Santa Barbara counties has fewer species that are at risk although some of these species may only occur in the western half; thus, this area should not be dismissed as less critical to preserving biodiversity until a comprehensive nature reserve network is designed.

Table 2. Wildlife species considered at risk based on Gap Analysis Program criteria.

Scientific name	Common name
Amphibians	
Batrachoseps pacificus	Pacific slender salamander
B. stebbinsi	Tehachapi slender salamander
Bufo microscaphus	Southwestern toad
Rana muscosa	Mountain yellow-legged frog
Reptiles	
Clemmys marmorata	Western pond turtle
Sceloporus orcutti	Granite spiny lizard
Phrynosoma coronatum	Coast horned lizard
Xantusia henshawi	Granite night lizard
Cnemidophorus hyperythrus	Orange-throated whiptail
Anniella pulchra	California legless lizard
Lichanura trivirgata	Rosy boa
Crotalus ruber	Red diamond rattlesnake
Birds	
Elanus caeruleus	Black-shouldered kite
Haliaeetus leucocephalus	Bald eagle
Aquila chrysaetos	Golden eagle
Coccyzus americanus	Yellow-billed cuckoo
Asio otus	Long-eared owl
Archilochus alexandri	Black-chinned hummingbird
Calypte costae	Costa's hummingbird
Empidonax difficilis	Western flycatcher
Tachycineta thalassina	Violet-green swallow
Polioptila caerulea	Blue-gray gnatcatcher
P. californica	California gnatcatcher
Sialia mexicana	Western bluebird
Lanius ludovicianus	Loggerhead shrike
Vireo bellii	Bell's vireo
V. vicinior	Gray's vireo
Dendroica petechia	Yellow warbler
Icteria virens	Yellow-breasted chat
Guiraca caerulea	Blue grosbeak
Aimophila ruficeps	Rufous-crowned sparrow
Amphispiza belli	Sage sparrow
Passerculus sandwichensis	Savannah sparrow
Ammodramus savannarum	Grasshopper sparrow
Agelaius tricolor	Tricolored blackbird
Mammals	
Tamias obscurus	California chipmunk
Perognathus longimembris	Little pocket mouse
P. alticola	White-eared pocket mouse
P. fallax	San Diego pocket mouse
Dipodomys agilis	Pacific or agile kangaroo rat
D. stephensi	Stephens' kangaroo rat
D. merriami	Merriam's kangaroo rat

Future Plans and Concerns

Implementation of protective measures should occur soon. Land-management agencies are the appropriate parties to set land acquisition priorities and to change existing management practices. The Southern California Association of Governments, for example, has used the GAP data base to identify natural communities of greatest concern throughout its six-county planning area as part of its Regional Comprehensive Plan Open Space Element. Multi-species conservation plans are also using biodiversity and land-management data to select and design a network of nature reserves to protect adequate habitat over large regions.

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Federal Data Bases of Land Characteristics

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At the federal level of government, there is a clear need for developing comprehensive and consistent land-cover and land-characteristics information for the United States. Increased attention to environmental research and planning that addresses spatial context and relationships requires baseline land characteristics across a range of spatial and temporal scales. The demand for this information parallels advances in computer and other technologies, such as geographic information systems (GIS) and remote sensing, which permit the processing, analysis, and management of this type and volume of data.

To initiate this effort for the federal government, four ecological and environmental research and monitoring programs have formed a partnership with the U.S. Geological Survey's (USGS) Earth Resources Observation System (EROS) Data Center to design, develop, and test a Multi-Resolution Land Characteristics (MRLC) monitoring program. The overall objective of MRLC is to develop a land-characteristics monitoring system that provides a baseline of multi-scale environmental characteristics and mechanisms for monitoring, identifying, and assessing environmental change. In addition, the MRLC program is developing a national land-cover data set based on Landsat Thematic Mapper satellite imagery. Partners of the MRLC program are described below.

EPA: EMAP

The Environmental Monitoring and Assessment Program (EMAP), managed by the U.S. Environmental Protection Agency (EPA) Office of Research and Development, is a research, monitoring, and assessment effort to report on the condition of our nation's ecosystems. The EMAP is developing and using ecological indicators for wetlands, surface waters, the Great Lakes, agroecosystems, arid ecosystems, forests, and estuaries. For the EMAP, land-cover information is critical to determine sample locations, resource extent, and potential human-caused stress. When fully implemented, the EMAP will provide comparable, high-quality data on the condition of our nation's ecological resources at regional and national scales.

NBS: GAP

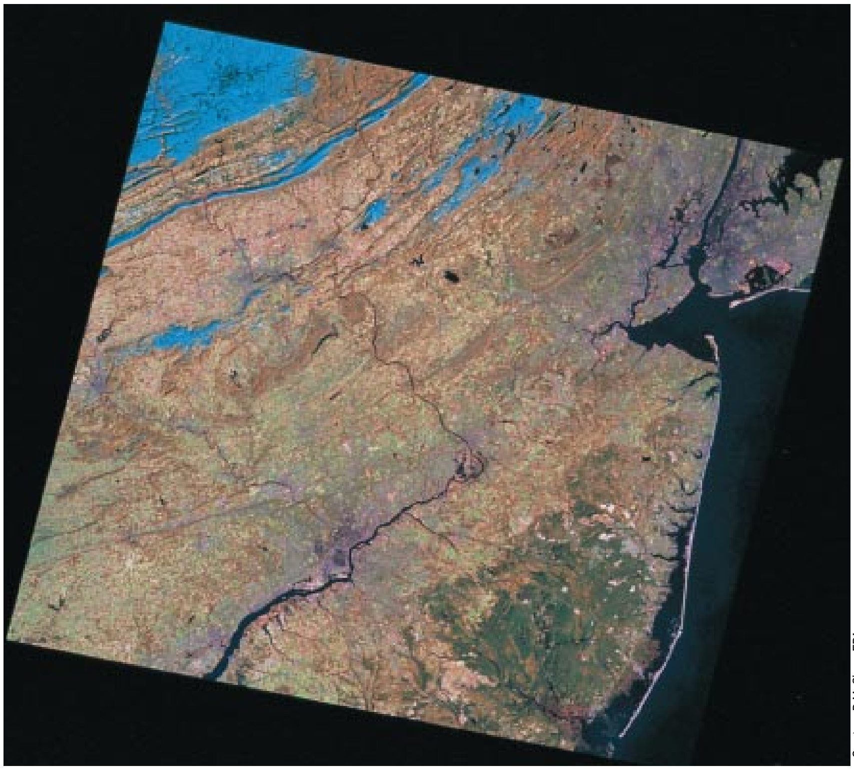
The National Biological Service's (NBS's) Gap Analysis Program (GAP) provides a regional and national overview of the distribution and protection status of biological diversity by producing comprehensive and synoptic biogeographic data. Analysis involves using GIS technology to compare the distributions of vegetation and native vertebrate species with land ownership and management. One of the central questions GAP addresses is how well native species are represented in areas managed for their long-term sustainability.

USGS: NAWQA

The National Water Quality Assessment (NAWQA) program of the USGS is designed to describe the status and trends in the quality of the nation's groundwater and surface-water resources and to link these status and trends with an understanding of the natural and human factors that affect water quality. The program integrates information about water quality at a wide range of spatial scales, from local to national, and focuses on water-quality conditions that affect large areas of the nation or that occur frequently within small areas.

USGS: EROS Data Center

The EROS Data Center is a data-management, systems-development, and research center of the USGS. Established in the early 1970's to receive, process, and distribute data from the National Aeronautics and Space Administration's experimental Landsat satellites (Fig. 1), it houses the world's largest collection of space and aircraft imagery of the Earth. It manages



Courtesy D.M. Shaw, EPA

Fig. 1. Landsat Thematic Mapper image of Philadelphia and New York City, taken May 20, 1991.

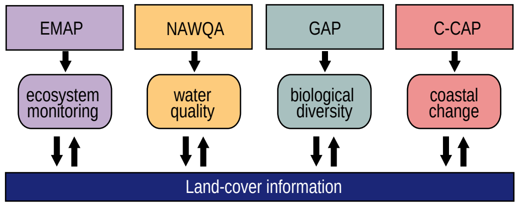


Fig. 2. Land-cover requirements of the Multi-Resolution Land Characteristics consortium land.

global Earth observational data, including the development and operation of advanced systems for receiving, processing, distributing, and applying land-related earth science, mapping, and other geographic data and information.

NOAA: C-CAP

The National Oceanographic and Atmospheric Administration's (NOAA's) Coastal Change Analysis Program (C-CAP) develops a comprehensive, nationally standardized information system to assess changes in wetlands and adjacent uplands in U.S. coastal regions. It uses satellite sensors to detect change in coastal emergent wetlands (mainly tidal marshes) and adjacent uplands and uses aerial photography to detect change in submerged aquatic vegetation. The ultimate goal of the program is to monitor coastal areas every 1 to 5 years, depending on the rate and magnitude of change in each region.

Approach

Collaboration among these programs is the most efficient approach (Fig. 2). Thus, the MRLC generates these data according to common standards for content, format, accuracy, and management; traditionally, environmental data collected for federal ecological studies have not been gathered according to standard or common methods, resulting in data that are not easily shared and in work that is duplicative. The MRLC provides partner programs and others with a data base that is collected according to consistent methods where possible.

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Monitoring Changes in Landscapes from Satellite Imagery

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It has been said that "a model without data has no predictive power" (Rasool 1992). The need to model the extent, condition, and trends in biological resources is a central element for most environmental assessments. Whether the issues involve biological diversity or the effects of changing biogeochemical cycles, accurate baseline data are essential to the environmental monitoring and modeling of future environmental conditions.

Methods and tools for monitoring natural vegetation at the level of plots to small sites-from a single square meter to millions of square meters are well developed and widely used (Küchler and Zonneveld 1988), but at the national level there is a lack of comprehensive environmental data from which we can assess national patterns of environmental diversity. The early western explorers conducted extensive surveys of regional geological, topographic, and ethnographical resources but did not collect enough detailed biological data that could provide us with a starting point for understanding the environmental transformations that have taken place since the nation was founded. More recently, Klopatek et al. (1979) tried to assess the modification of natural vegetation in the United States but concluded that the exercise was difficult because recent land-use changes were typically undocumented. As a result, assessments of current environmental conditions are too frequently based on decades-old data.

Current Estimates of Vegetation Patterns

Perhaps the best estimate of vegetation patterns of the conterminous United States before European settlement is from Küchler's potential natural vegetation (Küchler 1964). His map of the potential natural vegetation divides the country into 116 potential vegetation types. He defines potential natural vegetation as the vegetation that would exist today if humans were removed from the scene and if the resulting plant succession were telescoped into a single moment.

There are, however, limitations in using potential natural vegetation as an indicator of pre-European settlement vegetation patterns, including problems related to the coarse scale of the Küchler map (1:3,168,000), the processes of succession, and the determination of climax vegetation types (Klopatek et al. 1979). Küchler, for example, attempted to show the potential climax stage of vegetation, although some ecosystems never reached climax because of natural controls such as fire. Küchler also pointed out the difficulties and the assumptions in using the terms "natural" and "original" vegetation. His map, however, probably represents the best approximation available today of the continent's vegetation before European settlement.

The most current picture of national land-cover vegetation patterns is from a 1990 data set produced by the U.S. Geological Survey (USGS; Loveland et al. 1991). The USGS land-cover data were interpreted from 1990 satellite imagery from the Advanced Very High Resolution Radiometer (AVHRR) sensor aboard the National Oceanic and Atmospheric Administration's polar-orbiting meteorological satellites. The USGS map of land cover is limited in its use for local applications because of the coarse ground resolution of AVHRR data and its subsequent inability to distinguish vegetation structure, seral stages, and exotic versus natural vegetation. It does, though, provide a picture of vegetation and land-cover patterns at the national level. For example, in the lower 48 states, about 38% of the land is forested, 29% is rangeland or grassland, and 23% is agricultural land. While the USGS land-cover study did not identify urban lands, information from the Defense Mapping Agency's Digital Chart of the World shows that at least 14,500 km^2 (5,655 mi^2) or 1.0% of the conterminous United States is urbanized (Danko 1992).

It must be noted that a comprehensive assessment of accuracy of the 1990 land-cover map has not been completed, although an independent study shows that the classification of forest lands is within 4% of the estimate of the U.S. Forest Service (Turner et al. 1993). Comparisons with selected state land-cover maps and U.S. Department of Agriculture crop area statistics have also shown general correspondence between land-cover estimates at the national level (Merchant et al. 1995).

Change in Natural Vegetation

The estimated extent of change in the natural vegetation since European settlement is derived by comparing Küchler's potential natural vegetation (Küchler 1964) with the 1990 land-cover data set produced by the USGS (Loveland et al. 1991). Both potential natural vegetation (Fig. 1) and 1990 land cover (Fig. 2) have been generalized to show six vegetation groups: needleleaf forest, broadleaf forest, mixed forest, grassland, shrubland, and grassland-shrubland. Note that the 1990 land-cover classification does not distinguish between natural and altered vegetation (e.g., an even-age tree plantation is mapped as forest even though it does not have the ecological value or function of a natural forest). The 1990 land-cover map (Fig. 2) also includes four additional categories: urban areas, cropland, cropland-woodland mosaics, and cropland-grassland mosaics.

A representation of the percentage of land modified from its natural state by either cultivation or urban development was produced by calculating the percentage of 1990 agriculture and urban lands found within each Küchler

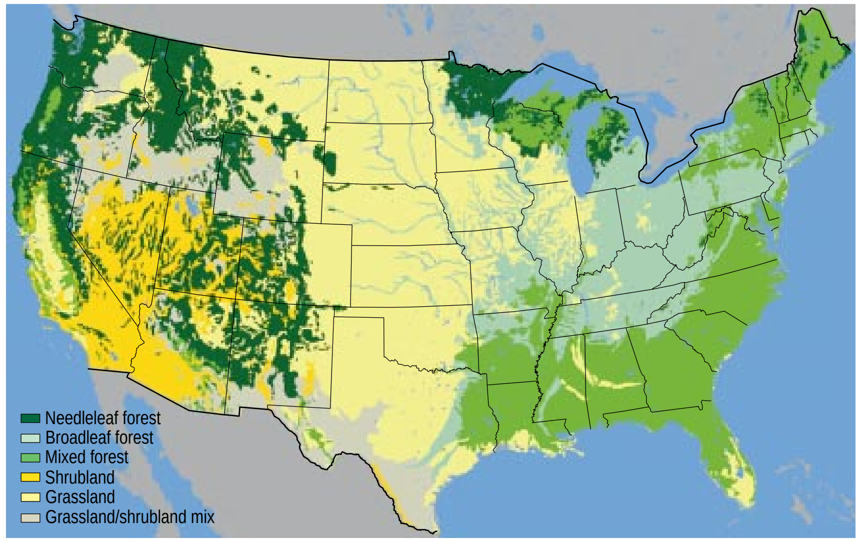

Fig. 1. Grouped categories of potential natural vegetation aggregated from Küchler (1964).

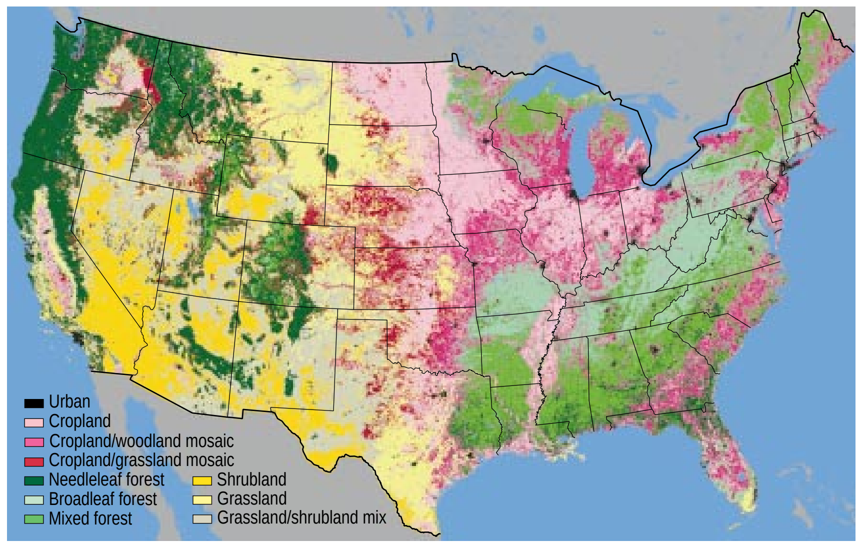

Fig. 2. Grouped categories of 1990 land cover depicting 1990 conterminous U.S. land cover that was developed from 1990 AVHRR imagery.

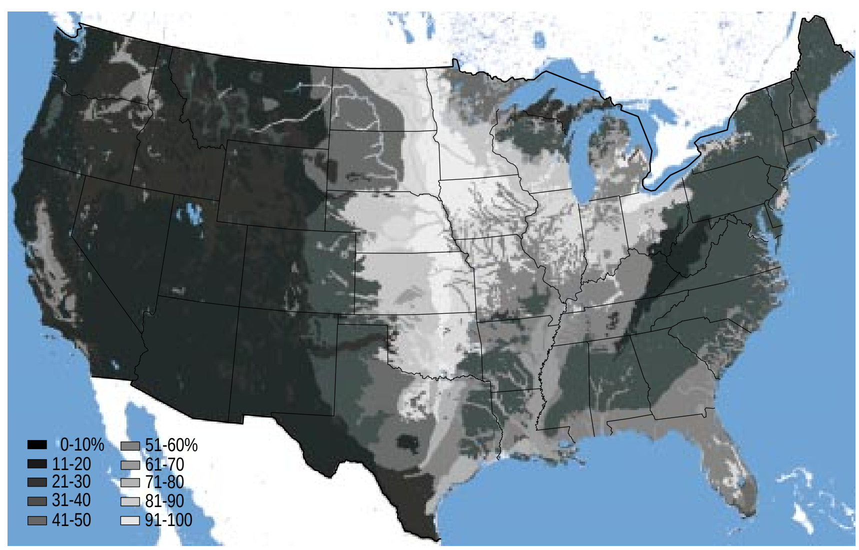

Fig. 3. Percentage of Küchler's potential natural vegetation types (Küchler 1964) that have been converted to agricultural and urban land cover. The lighter tones represent the higher levels of human modification. Percentages of modification are displayed as deca-percentiles.

Landsat MSS Images

Landsat Multispectral Scanner (MSS) images of the Dallas-Fort Worth area in 1974 and 1989 indicate that in this region urbanization has been the cause of land-cover change (Fig. 1). The population of the metropolitan area grew by an estimated 1.25 million during this 15-year period. The substantial conversion of cropland, woodlands, and grasslands to urban land uses resulted from the trend toward migration to sun belt cities and increased job opportunities.

Landsat MSS images can also display landscape transformations resulting from natural events such as the eruption of Mount Saint Helens in southern Washington and the subsequent recovery of vegetation (Fig. 2). The 1973 image represents the region in its "original state." The 1983 image displays the large denuded landscape north of the

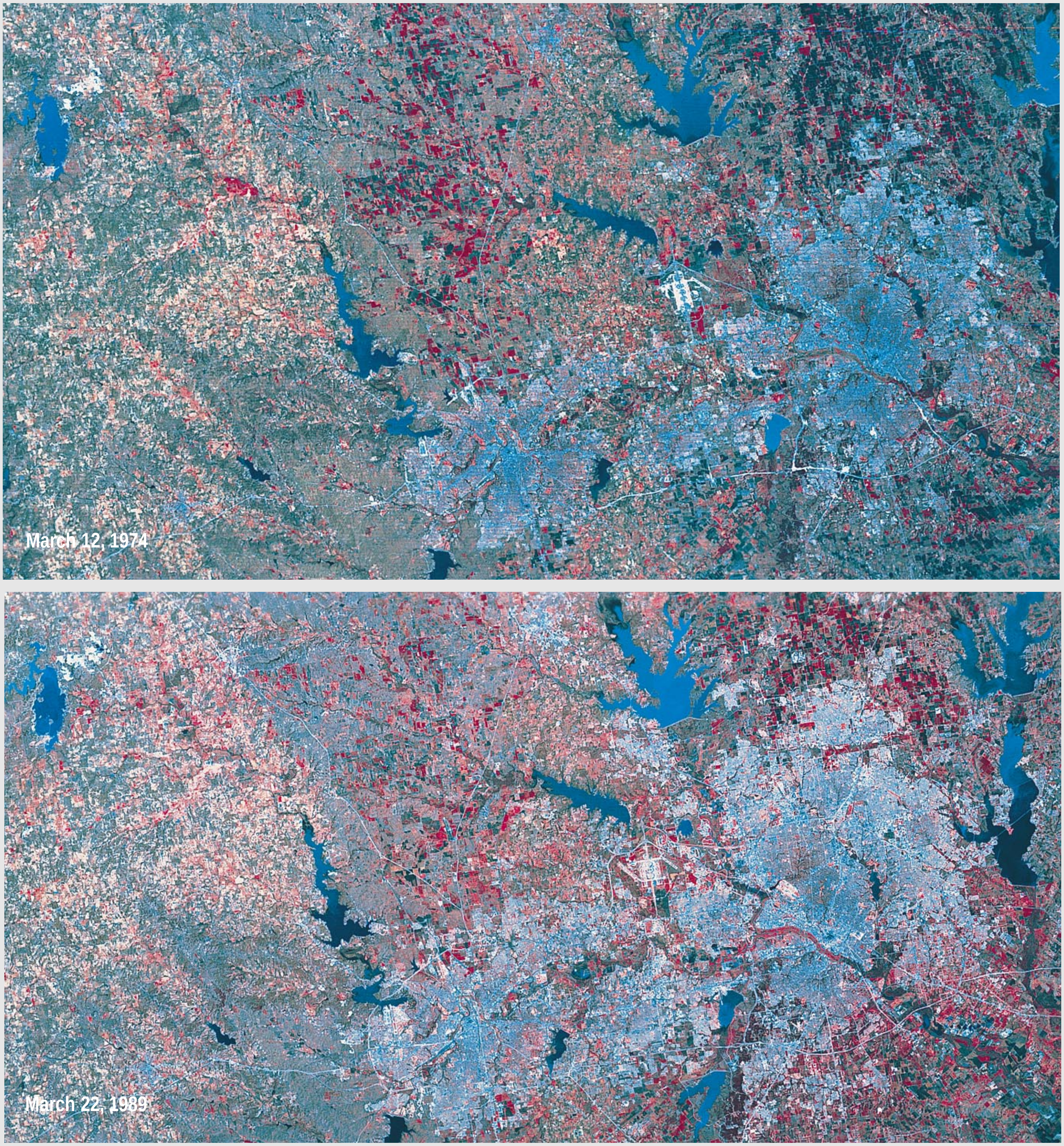

Fig. 1. The 1974 and 1989 Landsat MSS images of Dallas-Fort Worth, Texas. Expanded urban areas are clearly identifiable in the 1989 image and are particularly evident around Dallas-Fort Worth International Airport in the center of the image.

volcano shortly after its eruption May 18, 1980. The 1988 image shows revegetation of the northern slopes, and a landscape gradually recovering to a new "natural" state. A feature of this set of images is the small bluish rectangular patches surrounding Mount Saint Helens, representing areas that have been logged by clear-cutting.

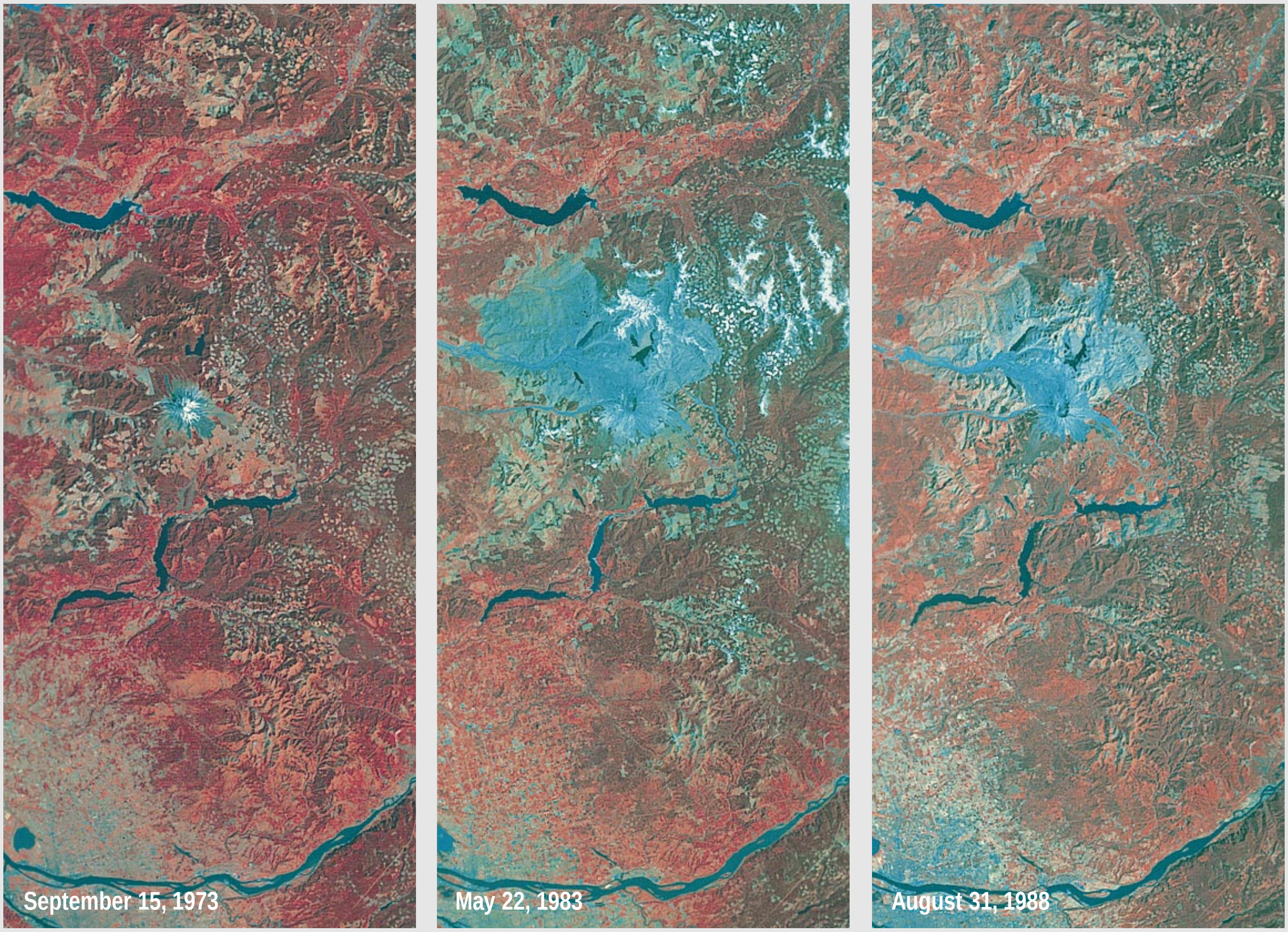

Fig. 2. Landsat MSS images of the Mount Saint Helens area in southern Washington in 1973, 1983, and 1988. The 1973 image shows the area before eruption. The area north of the crater in the image with the bluish color was most devastated by the 1980 eruption. In the 1988 image the light pink color in the blow-out area shows vegetation regrowth.

vegetation type (Fig. 3). Although more than 61% of the conterminous United States is covered with the same dominant vegetation as Küchler suggests, the percentage varies considerably by region. Almost 92% of the western forests region remains covered with tree species, while only 29% of the central and eastern grasslands region remains as grasslands.

It must be understood that a low percentage of agricultural or urban lands in a region does not imply that the landscape exists in a pristine, natural state. In some cases, the "natural" vegetation may be altered substantially by local land-use practices such as grazing and logging or changed by the introduction or invasion of non-native vegetation. Küchler (1964) recognized overgrazing as having long altered the central grassland. He also mentioned Kentucky bluegrass (*Poa pratensis*) as an exotic that has become the dominant grassland in regions including the Black Hills of South Dakota. As a result, many areas that are not affected by agriculture or urbanization are far from their natural state and do not perform the same ecological role as did the original ecosystem. The coarse nature of the AVHRR data and the lack of detailed baseline data on original vegetation conditions do not allow for the detection of these important landscape qualities. While these assessments have limitations, the comparisons represent the type of analysis and monitoring that can be done with a properly designed operational vegetation monitoring system.

The areas with the highest percentage of land modified from its natural condition are in the central United States. With one exception, the most intensively cultivated areas coincide with Küchler's grassland or mixed grassland-

Table 1. Küchler vegetation types least modified by urbanization and agricultural developments.

Type and location	Unaltered %
Grama-tobosa prairie (Arizona, New Mexico)	99.80
Trans-pecos shrub savanna (Texas, New Mexico)	98.82
Oak-juniper woodland (Arizona, New Mexico, Texas)	98.67
Southeastern spruce-fir forest (southern Appalachia)	98.18
Silver fir-Douglas fir (Oregon, Washington)	97.08
Cedar-hemlock pine forest (northern Rocky Mountains)	97.30
Grama-tobosa shrub-steppe (Arizona, New Mexico)	97.14
Creosote bush-tarbush (Arizona, New Mexico)	96.04
Chaparral (California)	96.03
Blackbrush (Utah, Arizona)	95.67
Montane chaparral (California)	95.36
Redwood forest (California, Oregon)	94.70
Mixed mesophytic forest (Pennsylvania, West Virginia, Ohio, Kentucky, Tennessee)	94.57

Table 2. Küchler vegetation types most affected by urbanization, their locales, and associated urban areas.

Type and location	Urbanized %
Fescue oatgrass (western slopes of northern coast ranges, California, San Francisco)	24.00
Subtropical pine forest (southern Florida, Miami)	21.07
Coastal sagebrush (coastal regions of southern California, Los Angeles)	15.87
Pine-cypress forest (coastal California)	6.10
Northeastern oak-pine forest (coastal New England to New Jersey, New York, Newark, Philadelphia)	5.86

Table 3. Selected grassland types arranged by percentage cultivation.

Grassland type and location	Cultivation %
Bluestem prairie (North Dakota and Minnesota southward to Oklahoma)	90.28
Wheatgrass-bluestem-needlegrass (North Dakota, South Dakota, Nebraska)	82.43
Bluestem-grama prairie (Kansas, Nebraska, Colorado, Oklahoma)	76.24
Nebraska sandhills prairie (Nebraska, South Dakota)	73.32
Wheatgrass-needlegrass (North Dakota, South Dakota, Montana, Wyoming, Colorado)	32.71
Grama-buffalograss (New Mexico, Colorado, Wyoming, Nebraska, Kansas, Oklahoma, Texas)	25.75
Wheatgrass-grama-buffalograss (South Dakota)	10.21
Grama-needlegrass-wheatgrass (Wyoming, Montana)	7.39

forest types. The exception is the elm-ash forest south and west of Lake Erie (91.03% cropland). This vegetation type covers a relatively small area (23,103 km^2; 9,010 mi^2). The principal vegetation type that is now more than 90% cropland or mixed cropland is Küchler's bluestem prairie, which covers 271,990 km^2 (106, 076 mi^2), 3.5% of the conterminous United States. The 1990 land-cover data indicate that 90.28% is predominately cropland.

The least cultivated of Küchler's types are grama-tobosa prairie (0.18%), trans-pecos shrub savanna (0.28%), creosote bush (0.60%), and blackbrush (0.66%). These four types are all part of the western shrub and woodland group. In the eastern United States, the most "uncultivated" of Küchler's types is the mixed-mesophytic forest (5.07%), which covers an area of 496,790 km^2 (193,748 mi^2) and has been noted as having the highest species diversity of all the eastern broadleaf forests (Braun 1950).

There are several other ways to evaluate the differences in the 1990 landscape versus the potential natural state. For example, certain Küchler types retain the highest percentages of areas not covered by agriculture or urban land cover (Table 1), although these areas may be presently highly disturbed by logging, road building, strip mining, grazing, or other activities. With the exception of the mixed-mesophytic forest and the relatively small southeastern spruce-fir forest, these are all in the western part of the country. Vegetation types from the Küchler map that have the highest percentage of urbanization on the USGS map (Table 2) are relatively small and are all coastal. Some, like coastal sagebrush, are types that are considered threatened (*see* Stoms and Davis, this section). For selected grassland types of the Great Plains and central lowlands, there is a decrease in percentage of cultivation from east to west (Table 3), reflecting the role of annual precipitation in conversion of grassland areas to cultivation.

Comparing forested areas from the USGS map with the Küchler map would indicate that about 57% of the potential forested area is currently covered by tree species (Turner et al. 1993). The potential impacts of these changes are significant. For example, the loss of forest cover since before European settlement (43%) has increased both albedo and carbon dioxide levels. A rise in albedo has been shown to cause a decrease in mesoscale rainfall (Charney et al. 1975). Increases in irrigated agriculture can result in a decrease in albedo, which can cause an increase in mesoscale rainfall (Barnston and Shickedanz 1984). Also, a shift from forest to grasses results in a decrease in primary productivity by a factor of two, thus reducing the rate of atmospheric carbon fixation.

Continuing Transformations

The comparison of 1990 land cover with potential natural vegetation illustrates the magnitude of change that has possibly occurred in the past 250 years. Changes in the landscape are not exclusive to that period, however; in fact, the 1990 view of United States land cover is already becoming outdated in some regions as natural and human forces continue to transform the landscape. For example, a comparison of 1970's and 1980's satellite images from the Landsat Multispectral Scanner (MSS; *see* box) shows that significant changes in some areas selected for examination are taking place. Landsat MSS images have been acquired over most of the United States since July 1972. With approximately 80 m x 80 m (260 ft x 260 ft) resolution, they provide a means to map in more detail the changes that have occurred in the past 22 years.

Future Possibilities

The vignettes presented here illustrate both the potential and the limitations associated with modeling and monitoring of environmental conditions and processes with satellite images. Clearly, baseline data are an essential starting point for these applications. Also needed is a sound framework from which baseline data can be collected, calibrated, and used in a monitoring system to target and assess environmental changes.

Remote-sensing images from orbiting satellites can play an important role in the collection of baseline vegetation data and in monitoring their status. Coarse-resolution data such as 1-km (0.62-mi) AVHRR imagery offer a means to view landscapes with daily frequency, thereby allowing the monitoring of vegetation condition both within a growing period and between years. Over a long period, AVHRR may provide a means for monitoring the subtle changes in the vegetation that may relate to such events as long-term drought. AVHRR data are not adequate for assessing the effects of more local changes. Landscape changes at the local level will be better understood with higher resolution imagery such as that provided by Landsat systems. Improved data from the sensors planned as part of the National Aeronautics and Space Administration's (NASA) Mission to Planet Earth's Earth Observing System will likely provide even better remote sensing systems for environmental monitoring.

Many components needed for a national environmental monitoring system already exist. A robust system that provides mechanisms for targeting and quantifying changes in the landscape will need to include both the synoptic overview capabilities from Earth-orbiting satellites and detailed site-specific observations of biological processes. The National Biological Service's Gap Analysis Program (GAP) provides an essential high-resolution inventory of habitat and natural vegetation for the United States by using Landsat Thematic Mapper imagery with 30 m x 30 m (98 ft x 98 ft) resolution along with substantial amounts of ancillary information such as field reconnaissance and air photos (Scott et al. 1993). Regional monitoring of the stressors to the natural systems is needed to improve the predictive capabilities of an operational monitoring system. Those systems, tied together with an integrated sampling and assessment framework, could provide a synergistic means for long-term environmental monitoring.

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The Nation's Wetlands

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The national interest in wetlands is set forth in the findings of the Emergency Wetlands Resources Act of 1986:

> The Congress finds that wetlands play an integral role in maintaining the quality of life through material contributions to our national economy, food supply, water supply and quality, flood control, and fish, wildlife, and plant resources, and thus to the health, safety, recreation, and economic well-being of all citizens of the Nation.

The act requires the Secretary of the Interior to map the nation's wetlands, develop a national digital wetlands data base, and report to Congress on the status and trends of wetlands within the conterminous United States. The U.S. Fish and Wildlife Service (USFWS) has delivered three reports to Congress (Frayer et al. 1983; Dahl 1990; Dahl and Johnson 1991). The reports show that half of the nation's wetlands have been converted to uplands since colonial times (Dahl 1990), and that although the rate of

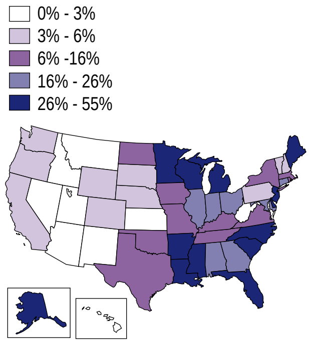

Fig. 1. Surface-area percentage of wetlands in each state: 1780's (Dahl 1990).

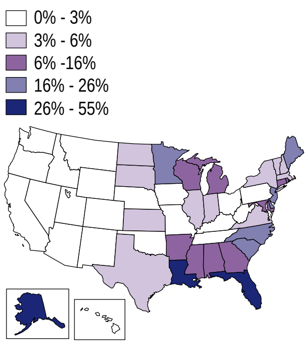

Fig. 2. Surface-area percentage of wetlands in each state: 1980's (Dahl 1990).

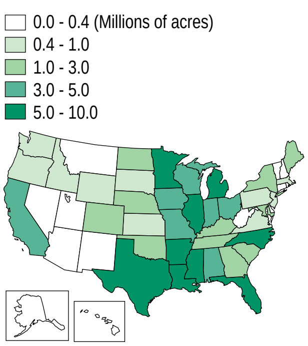

Fig. 3. Wetland acreage loss by state (Dahl 1990).

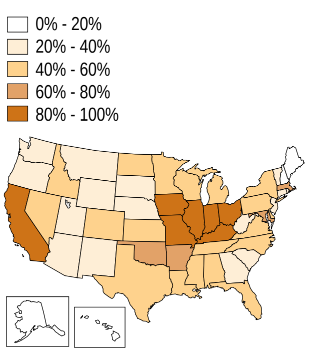

Fig. 4. Surface-area percentage of wetland base loss by state (Dahl 1990).

conversion has slowed, wetland losses continue to outdistance gains (Frayer et al. 1983; Dahl and Johnson 1991).

The quality of the remaining wetlands continues to be an unanswered question. Presidential candidate George Bush's 1988 No-Net-Loss campaign promise was adopted by the federal government as a policy goal. It was expanded by President Clinton in his August 25, 1993, policy statement, "Protecting America's Wetlands: A Fair, Flexible, and Effective Approach," to include a long-term goal of increasing the quality and quantity of the nation's wetlands resource base. Here we present a brief overview of wetlands, their definition, distribution and abundance, dynamics, functions, values, and future.

Wetland Descriptions and Definitions

The United States encompasses an area of about 931 million ha (2.3 billion acres) extending from above the Arctic Circle to the Virgin Islands and spanning the North American continent, and includes the Hawaiian Islands as well as Puerto Rico. Within this broad area, regional variations in climate, topography, hydrology, geology, soils, and vegetation create diverse wetland habitats ranging from the tundra in Alaska to the tropical rain forests of Hawaii to isolated wetlands in the arid Southwest.

Cowardin et al. (1979) defined wetlands as

> lands where saturation with water is the dominant factor determining the nature of soil development and the types of plant and animal communities living in the soil and on its surface. The single feature that most wetlands share is soil or substrate that is at least periodically saturated with or covered by water. The water creates severe physiological problems for all plants and animals except those that are adapted for life in water or in saturated soil. (p. 3)

There are three widely used definitions of wetlands. All use three parameters: hydrology, hydric soil (wetland soils), and hydrophytic vegetation (wetland plants). The USFWS's definition is ecological whereas the definitions used by the U.S. Environmental Protection Agency, the U.S. Army Corps of Engineers, and the Soil Conservation Service are regulatory. All three, however, endorse and use the same interagency wetland plant list, *National List of Plant Species That Occur in Wetlands* (Reed 1988), and wetland soils list, *Hydric Soils of the United States* (SCS 1991).

Regulators are concerned with establishing a definitive line to delineate wetlands from uplands and with placing the wetlands into administrative or regulatory categories. In contrast, the USFWS and the National Biological Service (NBS) are concerned with ecological characterization and mapping the biological extent of both vegetated and nonvegetated wetlands found on soils and substrates. The biological extent of wetlands should be established by scientists using biological criteria. Likewise, policy makers should establish regulations for the subset of wetlands that needs regulating. The subset of wetlands to be regulated and the degree of regulation have changed and will change over time based on our understanding of the functions and values of wetlands, wetlands scarcity, our ever-changing social values, and the political climate.

The USFWS classification system was developed to provide uniformity in concepts and terminology for wetlands. It is hierarchical, moving from systems at the broadest level through subsystems, classes and subclasses, to modifiers describing hydrology (water regime), soils, and water chemistry, and special modifiers relating to human activities.

These categories are used to form wetland types for mapping. More than 2,500 wetland types are commonly used on National Wetlands Inventory maps nationwide. Counties will have from 10 to 400 types, with an average of 100. These wetland types describe ecological units that have certain homogeneous natural attributes. The USFWS's National Wetlands Inventory maps are available for 84% of the conterminous United States, 28% of Alaska, and all of Hawaii.

Distribution and Abundance

The distribution of wetlands has changed dramatically since the 1780's (Figs. 1 and 2). In addition, the percentage of the landscape occupied by wetlands varies markedly from state to state (i.e., Alaska, where 43.3% of the landscape is covered by wetlands as compared with nine states where 1% or less of the landscape is covered by wetlands). The wetland areal loss by states tells one story (Fig. 3) and the percentage of the wetland base lost by states tells another (Fig. 4). Wetlands occupy 11.9% of the landscape of the United States, which is about 5% of the conterminous United States, 43% of Alaska, and 1% of Hawaii.

Wetland Dynamics

The three status and trends reports to Congress provide estimates of net wetland gains or losses; they do not examine wetland quality as a result of disturbance. Wetlands are constantly being disturbed. Even when a wetland is not converted to upland, its successional stage is often pushed back to an earlier stage. For example, between the mid-1970's and mid-1980's, forested wetlands suffered tremendous loss from agriculture and "other" uses. (The category of "other" includes all wetland areas converted to upland where the ultimate land use could not be determined.) Thousands of hectares of forested wetlands were converted to emergent, scrub-shrub, and nonvegetated wetlands. Likewise, thousands of hectares of scrub-shrub wetlands were converted to the "other" category and the agricultural land-use category. These losses were nearly offset by the conversion of forested wetlands to scrub-shrub wetlands. Despite these gains to the scrub-shrub category, however, there was an overall net loss of scrub-shrub wetlands during the study period.

The net gain of thousands of hectares of freshwater emergent wetlands is similarly deceptive. The thousands of hectares that were lost to agricultural, "other," and urban land uses were more than offset by the conversion of forested wetlands and scrub-shrub wetlands to freshwater emergent wetlands. The area of nonvegetated wetlands (primarily ponds) increased by several million hectares. Most of these gains, however, resulted from construction of ponds on uplands not used for agricultural production, but additional thousands of hectares were built on former agricultural lands. This category also experienced gains from converted forested wetlands and scrub-shrub wetlands.

Functions and Values

The functions and values of the nation's wetlands are nearly as diverse as the wetlands themselves (Table), but include flood protection and plant, fish, and wildlife habitat.

All wetlands do not perform all functions. Some functions tend to be compatible, such as flood control and water purification. Other functions tend to be incompatible, such as flood control and food chain support. In addition, wetlands of a given type do not have the same effectiveness in performing a given function. For example, the effectiveness of a given forested wetland for flood control depends on its size, shape, location in the watershed, and so forth. Because wetlands are constantly being affected by disturbance, their effectiveness in performing functions constantly changes. Thus, the effectiveness of a wetland area as wildlife habitat can be improved or degraded by the creation, maintenance, or destruction of vegetated corridors; the ratio of vegetated wetland to upland areas; buffer zones; and plants that provide for wildlife food and habitat. Uplands can and do perform some of the functions performed by wetlands, such as sediment trapping. But because wetlands are situated in the low points of the landscape or are adjacent to streams, rivers, lakes, and oceans, they are more able to perform these functions. In many cases, wetlands are the last line of defense for the protection of surface water quality.

Table. Major wetland functions and values documented in the National Wetlands Inventory "Wetlands Values Database."

Functions and values	Examples
Biogeochemical processes	Carbon cycling, sulfur cycling
Food chain	Detritus production, food source, nutrient cycling, nutrient export, primary production
Habitat	Amphibians, fish, furbearers, insects, mammals, nongame birds, reptiles, shellfish, shorebirds, waterfowl, endangered species
Hydrology	Erosion control, flood control, flow stabilization, groundwater discharge, groundwater recharge, saltwater intrusion prevention, storm dampening
Socioeconomic	Aesthetics, agricultural crops, aquaculture, archaeological, commercial harvest, cultural, educational, energy source (peat), food, forage, heritage, hunting and trapping, indicator species, medicinal, open space, natural products, recreation, research, timber, wastewater treatment, water supply
Water quality	Chemical and nutrient absorption, pollution filtering, oxygen production, sediment trapping

Some wetland functions and values can be replaced by artificial substitutes; for example, flood-control values of wetlands can be replaced by dams, ditches, levees, floodwalls, and reservoirs. Other wetland functions, however, cannot be performed by uplands or replaced by artificial substitutes. An especially important function of wetlands is supporting rich plant diversity. Although wetlands occupy only about 5% of the surface area of the conterminous United States, 6,728 plant species (31% of the U.S. flora) occur in wetlands (Reed 1988). Of these plants, half are restricted to, or usually occur in, wetlands. Thus, wetlands provide critical habitat for a high percentage of the U.S. flora.

Some argue that we cannot afford to maintain the remaining 40 million ha (99 million acres) of wetlands in the conterminous United States because of our increasing population, living standards, and competition for resources. Others argue that wetlands must occupy a greater percentage of the nation's landscape. In the conterminous United States, non-federal rural land occupies nearly 75% of the landscape and contains more than 75% of the nation's wetlands (USDA 1989). Wetlands comprise nearly 6% of the rural non-federal landscape. Specifically, wetlands occupy roughly 1% of cropland, 2% of rangeland, 5% of pastureland, 12% of forestland, and 31% of other rural land (USDA 1989).

Future

Although our understanding of wetlands is imperfect, it is clear we have more information upon which to make public policy decisions on wetlands than we have for many other ecosystems. The challenge for policy makers is to avoid ecologically irreversible choices that would diminish the wealth of future generations while promoting economic development and improving income distribution.

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