Handbook of Ecological Restoration

Volume 2
Restoration in Practice

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INTRODUCTION

The burgeoning impacts of human activity on the local, regional and global environments have created a lot of public concern and debate, especially since the latter part of the last century. Environmental protection, conservation of natural resources and restoration of the affected ecosystems have become pressing issues of national and international significance. Scientists and policy-makers around the globe are currently grappling with these issues. In the Americas, and particularly in the United States of America, this call has become quite urgent because of the fast-paced, large-scale exploitation of natural resources, which often leaves behind a trail of environmental and ecological disturbance and degradation. Consequently, such terms as restoration, rehabilitation and reclamation are now commonly used in the scientific and non-scientific literature to describe those practices that help re-establish the structural and functional characteristics of a disturbed ecosystem to its natural or near-natural state.

Transformation of the natural ecosystems of the North and South American continents began with native Americans and has increased considerably since the days of European settlement. As the population of the Americas grew, housing and road construction followed; industrial and agricultural activities expanded and multiplied; mining for minerals, coal and other materials became essential; and the disposal of waste products became an equally inevitable necessity. The ecological impacts of such activities vary widely in their scope and significance. For example, large-scale deforestation, extensive sod breaking for cultivation of monoculture crops, and intensive grazing may result in unsustainable conversion of land use, extirpation of some plant and animal species, soil erosion, and weather modification. Mining scars the earth rendering it temporarily or permanently unproductive, and may cause serious surface and/or groundwater problems. Likewise, enormous networks of highways and urban sprawl take away land irreversibly from other natural uses and capabilities. In most case the impacts of such activities manifest themselves locally or regionally, but in some cases the impacts may be global in their significance, such as ozone depletion and global warming.

In the past three decades, especially since the 1972 United Nations Conference on Human Environment held in Stockholm, numerous scientific studies have focused on a wide array of problems and practices related to ecological restoration. These studies have produced a vast body of information on issues such as: loss of topsoil and organic matter; overgrazing of grasslands; deforestation; desertification; endangerment and loss of plant and animal species; and impacts of intensive agronomic practices, mining and other industrial activities on land and water resources. Most of these investigations employ a multidisciplinary approach in analysing as well as solving the problems. However, restoration of ecosystems disturbed by massive earth-moving operations, such as surface mining, calls for a high level of integration among a number of basic/applied sciences, engineering and economics. Also, because large-scale disturbances occur in a wide variety of ecosystems, ranging from forest to desert, the ecological and engineering challenges posed and the kind of technical expertise required are far greater than those required in most other cases of

Table 1.1. *Human population (actual and projected) in the Americas ($\times 10^3$)*

Region	1998	2025	2050	Annual growth rate 1995–2000 (%)	Population density per km^2 mid-1998
Northern America[a]	304,716	363,612	391,781	0.8	14
Central America[b]	130,457	188,504	222,502	1.9	53
Caribbean[c]	37,351	47,287	52,026	1.1	159
South America[d]	335,715	460,866	534,382	1.5	19
World	5,901,054	7,823,703	8,909,095	1.3	44

[a] Northern America includes Bermuda, Canada, Greenland, Saint Pierre and Miquelon, and United States of America.
[b] Central America includes Belize, Costa Rica, El Salvador, Guatemala, Honduras, Mexico, Nicaragua and Panama.
[c] Caribbean includes Anguilla, Antigua and Barbuda, Aruba, Bahamas, Barbados, British Virgin Islands, Cayman Islands, Cuba, Dominica, Dominican Republic, Grenada, Guadeloupe, Haiti, Jamaica, Martinique, Montserrat, Netherlands Antilles, Puerto Rico, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and Grenadines, Trinidad and Tobago, Turks and Caicos Islands, and United States Virgin Islands.
[d] South America includes Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, Falkland Islands (Malvinas), French Guinea, Guyana, Paraguay, Peru, Suriname, Uruguay and Venezuela.
Source: United Nations (1998).

restoration. Indeed, an impressive body of knowledge has been accumulated for the restoration of drastically disturbed ecosystems.

The need to convey the results of restoration investigations to the law- and policy-makers has never been so paramount as it is now. For, while finding solutions to problems lies within the purview of scientists, mandating the applications of the findings of science lies with the policy-makers and legislators; in the latter context, science becomes a social enterprise. Active participation of the scientific community is crucial in making public policy. This has been occurring in many countries, and a new discipline, environmental law, has emerged with its roots in both ecological/environmental sciences and law. Some of the American nations have a strong infrastructure of laws, rules and policies that mandate or encourage protection of ecosystems from abuse. To appreciate fully the legal requirements and scientific procedures in the Americas that address the issues of ecosystem restoration, it is first necessary briefly to acquaint the reader with the types of natural ecological regions (biomes) that exist in these two continents, and the type and extent of disturbances to which they are subject.

DIVERSITY OF BIOMES IN THE AMERICAS

For both ecological and economic systems, national boundaries have little meaning when one considers the interactions of regional and global interdependencies. Human populations depend on these systems and their linkages for survival. Consistent with the global trend, the human population of the Americas has been increasing (Table 1.1). Population growth, import and export linkages, and economic and ecological limits determine what is mined, grown and produced in a given region. Restoration and rehabilitation of degraded and destroyed ecosystems in the Americas, therefore, have significant implications for the well-being of communities and economies at both local and global scales. Ecological restoration strategies must be examined at a combination of different spatiotemporal scales: species, community, ecosystem and landscape (seascape). In order to succeed, these

Table 1.2. *Current land cover (km²) of the Americas as depicted by DISCover*[a]

Land cover classes	Current vegetation	Potential vegetation[b]	Human-induced change[b]
Evergreen forest	10 036 268	14 200 623	−4 164 355
Deciduous forest	957 683	2 748 511	−1 790 828
Mixed forest	3 333 949	4 427 083	−1 093 134
Woody savanna	2 578 185	638 819	+1 939 366
Savanna	1 350 552	4 772 712	+3 422 160
Shrubland	6 724 171	6 286 924	−437 247
Grassland	2 795 509	2 968 184	−172 675
Desert	2 711 947	2 008 580	+703 367
Cropland	2 970 387	0	+2 970 387
Croplands mosaic	4 488 301	0	+4 488 301
Urban and built-up	104 484	0	+104 484
Wetlands	314 998	314 998	NA
Snow and ice	3 918 725	3 918 725	NA
Region total	42 285 159	42 285 159	42 285 159

[a]The Data and Information System data set (DISCover) was initiated by the International Geosphere Biosphere Programme and implemented through collaboration of many agencies (in particular, US Geological Survey Earth Resources Observation System Data Center) because of the need for global land cover data with known classification accuracy (Loveland & Belward, 1997). The 1-km resolution of DISCover captures the heterogeneity missed by the coarser resolution of past remote sensing estimates and is the first to utilize this resolution on a global scale (Loveland *et al.*, 2000). Greenness classes were defined by monthly AVHRR NDVI composites from images taken between April 1992 and March 1993 (Loveland & Belward, 1997, slightly modified by H. Gibbs).
[b]Data on potential vegetation (Mathews, 1983) and human-induced change synthesized by H. Gibbs (pers. comm.).

plans must come from policies that account for socio-economic realities of the regions in which they are implemented.

North and South America are the third and fourth largest continents, together comprising an area of 42 million square kilometres. Extending from the Arctic to the sub-Antarctic latitudes, the Americas support every biome from the rainforests of the Amazon Basin to the arid steppes of Patagonia, with tremendous diversity within each system. Current land use patterns reveal the relative significance of croplands and urban systems in relation to natural systems (see Fig. 1.1, colour plate; Table 1.2). The United States alone supports a tremendous diversity within its ecosystems, with more than 200 000 native plant and animal species (Stein *et al.*, 2000). South America supports about 800 species of terrestrial mammals (19% of the world total) and an estimated 90 000 known species of flowering plants (more than one-third of the world total), even though it only comprises 12% of the world's land area (Mares, 1986). The Caribbean supports the second richest region of marine biota in the world (Reid, 1992).

Tundra

The tundra is circumpolar, the northernmost biome, and typically receives less than 60 cm of annual precipitation. At its northern limits, it is a region of cold, lifeless desert, while at its southern limits, it is characterized by small-stature vegetation adapted to constant soil disturbance, strong abrasive winds, infertile soils, and a short growing season (usually not more than 60 days). Permafrost, a zone of subsurface soil that is continuously frozen, controls soil moisture. Low-lying, wet sites support grasses, sedges, dwarf shrubs and sphagnum moss; better-drained sites support dwarf trees. The dominant vertebrates are caribou (*Rangifer tarandus*), lemmings (species of *Lemmus*, *Dicrostonyx*, *Synaptomys*), arctic hares (*Lepus arcticus*) and musk oxen (*Ovibos moschatus*). Alpine tundra, the vegetated area above the tree lines of mountains, has similar features, with the exception of permafrost. One threat to this fragile ecosystem is the major oil development involving the 600 000 ha coastal plain of the 7.7 million ha Arctic National Wildlife Refuge in Alaska, characterized by some as the 'Serengeti of North America'.

Taiga

The taiga, or boreal forest, lies south of the arctic tundra, covering 11% of the earth's terrestrial surface. Winters are cold, but milder than polar regions; the average annual temperature is below 5 °C; rainfall is between 40 and 100 cm annually; soils are poor in nutrients. Boreal forests are dominated by relatively few tree genera, including the conifers species of pine (*Pinus*), spruce (*Picea*), larch (*Larix*) and fir (*Abies*), and the deciduous aspen (*Populus*) and birch (*Betula*). Droughts are frequent and the forests are adapted to fire. Caribou and moose (*Alces alces*) inhabit the taiga, often consuming as much as 50% of young plant growth. Humans, through logging, can also have a significant impact on this biome. Major logging operations are going on in the boreal forests of Canada, and Acharya (1995) reported that these were being 'destroyed' at a rate of more than 2 ha per minute. Schindler (1998) lamented that the North American and European ecologists have been preoccupied with the impacts of disturbance effects in South America while equal or greater impacts on the boreal ecosystems in North America and Europe were ignored.

Temperate rainforest

Large evergreen forests dominate the coastal areas of the Pacific Ocean, where abundant precipitation (200–380 cm per year) and ocean mists allow massive trees to develop. These forests are stratified and support abundant epiphytes, although the soils are often leached of nutrients.

Temperate deciduous forest

The biome lies south of both the boreal forest and in many cases the subalpine areas. In this region the annual precipitation, in the form of rain or snow, exceeds evaporation. Once dominated by deciduous trees that are leafless during periods of frequent freezing temperatures, these forests have experienced major human disturbance. Depending on the latitude, the growing season ranges from three to nine months. The vertical structure of the forest is relatively simple compared to tropical rainforests, often with just one subcanopy of trees, shrubs and herbs. The forest floor is often covered with small, herbaceous plants, mosses and lichens. This biome has been heavily logged over the past 100 years, and has undergone numerous transformations as human habitation has increased. In addition to major urban development and construction of roadways, significant areas have been subjected to drastic disturbance. Many investigations on restoration have provided a rich body of knowledge on steps necessary for substrate stability and the establishment of a vegetation cover (see for example, Hutnik & Davis, 1973; Cairns *et al*., 1977; Schaller & Sutton, 1978; Leopold & Wali, 1992; Keddy & Drummond, 1996). The cooperation of industry, private and government agencies and academic scientists is now apparent in a number of projects in this biome (see, for example, Boxes 1.1 and 1.2).

Temperate grasslands

South and west of the temperate deciduous forest biome are the temperate grasslands. Regions where rainfall is too low to support forest, but too high to allow deserts to form (25–80 cm per year) were historically covered by grasslands. Grasslands covered the centre of North America, and the southern tip of South America. In most years, evaporation exceeds precipitation, resulting in cycles of drought and fire. These systems are known in various parts of the world as prairies, steppes, pampas and velds. Large and small grazing animals such as

Box 1.1 Restoration of mined lands in the temperate deciduous forest biome

THE WILDS, OHIO

Over 3700 ha of abandoned surface mine land in southeastern Ohio was donated by American Electric Power company in the early 1970s for wildlife conservation, scientific studies and education programmes. The abandoned mine site had a rugged terrain with steep ravines and extensive erosion. Initially, seeding/planting was done directly into the spoil material, but later the area was recontoured and topsoil that could be salvaged was respread at the site. The reshaped site was seeded with a mixture of grasses, forbs and legumes. Currently, the vegetation at the site consists of alien species of European alder (*Alnus glutinosa*), black locust (*Robinia pseudoacacia*), autumn olive (*Elaeagnus angustifolia*), ailanthus (*Ailanthus altissima*), some species – probably invading and/or planted – of ailanthus, eastern cottonwood (*Populus deltoides*) and sycamore (*Platanus occidentalis*), and major species found in remnant stands are sugar maple (*Acer saccharum*), northern red oak (*Quercus rubra*), yellow (tulip) poplar (*Liriodendron tulipifera*), American elm (*Ulmus americana*), white ash (*Fraxinus americana*), big-tooth aspen (*Populus grandidentata*), red maple (*Acer rubrum*) and a dense understorey of grasses and other herbaceous species. Although the vegetation for the most part is indigenous or cultivated varieties of the temperate regions, a number of tropical animals (such as giraffes, elephants, rhinoceros and zebras) have been introduced in the area as a zoological park. Over 350 000 persons had visited The Wilds by 1998. Although the efforts in the 1970s and 1980s were on ensuring surface stability and rehabilitation, The Wilds now maintains an active programme of research in conservation biology, and in ecosystem restoration and management.

CARBON SEQUESTRATION, OHIO

Given the present concern about fossil fuel emissions and global climate change, attention is now being focused on the potential role of restoration in carbon sequestration. The total land area impacted in Ohio by mining in 1997 was 0.13 million ha of which 0.1 million ha has been reclaimed since the early 1970s. Native and introduced grass species are the predominant plants that have been used for reclamation, but some areas have been reclaimed using mixed and monoculture hardwood forest species. A chronosequence of 0, 5, 10, 15, 20 and 25-year-old reclaimed mine spoils in Ohio was studied to assess the rate of carbon sequestration by pasture and forest establishment in comparison with undisturbed pasture and forest (Akala & Lal, 2000). Over a period of 25 years, the soil organic carbon (SOC) pool of reclaimed pasture and undisturbed sites for 0–15 cm very nearly approximated each other but was lower in the reclaimed sites at 15–30 cm depth. For the reclaimed forest and undisturbed sites, SOC pool was approximately the same for both depths. The SOC pool of the 15–30 cm depth of the pasture site stabilised sooner than the forest site. Dynamic simulation modeling studies on carbon efflux rates that take into account soil erosion, plant production and biogeochemical cycles reveal the phenomenal potential of rehabilitation in sequestering carbon and lessening the impact of climate change (Wali *et al*., 1999; West & Wali, in press).

bison (buffalo) (*Bison bison*), and burrowing mammals such as gophers (species of *Geomys*, *Pappogeomys*, *Orthogeomys*, *Thomomys*, *Zygogeomys*) and prairie dogs (*Cynomys* spp.) dominate the areas. Much of the productivity in grasslands is due to massive root growth; rainfall (ranging from 25 to 75 cm per year) and available soil water are major determinants of grass growth. Fire is an important ecological factor in grasslands, indeed, it maintains them. In North America, as the gradient of decreasing precipitation occurs from east to west and south, it also causes an ecological gradient from the tall grass prairie (wetter), followed by mixed grass to short grass prairie (drier), and finally the desert grasslands. The prairies have historically been dominated by large herbivores. Because of rich soils that make farmlands productive, most grasslands have been converted to cropland or pastures for grazing. For

Box 1.2 Restoration of the longleaf pine (*Pinus palustris*) ecosystem

At one time, the longleaf pine ecosystem covered an estimated 36 million ha in the southeastern United States. Today, that area has been reduced to about 1 million ha, representing a 97% reduction; the exclusion of fires, preferred management given to commercial species, and urban development has caused this change. As a result, over 30 plant and animal species of these ecosystems are endangered or threatened, including the red-cockaded woodpecker (*Picoides borealis*) and gopher tortoise (*Gopherus polyphemus*). Through partnerships of private, government and academic agencies, the disturbance to longleaf pine ecosystem has abated, and now demonstrates a trend of areal increase. These partnerships have initiated longleaf pine habitat restoration projects on 20 different sites, totaling 525 ha, across the southeast. Several thousand additional hectares of potential restoration projects, involving over 20 private landowner partners, have been identified. The restoration plans include the reintroduction of fire and management techniques that favor longleaf pine. Widespread efforts are under way to produce large numbers of longleaf pine seedlings for plantings on sites once occupied by the pine. The Longleaf Alliance, an organisation of researchers, academicians, private groups and individuals, and public agencies, is devoted solely to the restoration of longleaf pine, and co-ordinates restoration and research activities.

example, Iverson (1988) notes that only 0.01% of the original unploughed prairie remains in Illinois. With a widespread conversion of prairies to agricultural land uses, and with increasing deforestation rates, numerous plant and animal species are being extirpated. Specific long-term studies on the restoration of both abandoned mine lands and those under the stipulations of new laws have provided good measures of ecosystem recovery in relation to time (Wali & Freeman, 1973; Iverson & Wali, 1992; Wali, 1999). There are several successful examples of rehabilitation and conservation from the American prairies and some are presented here (Boxes 1.3 and 1.4).

Tropical forest

Latitudes between 10° N and 10° S support tropical rainforest. There is little annual variation in rainfall (200–400 cm per year) and temperature (25 °C), although these features can vary widely on a daily basis. They do not form a continuous belt around the equator because of the influence of mountains, winds and oceans on precipitation patterns. This biome has the greatest diversity of flora and fauna in the world. Constant warm and wet conditions allow for evergreen nature of vegetation and high rates of primary productivity. Animal distributions are also stratified by height in the forest. Large herbivores include the tapir (*Tapirus* spp.); predators include jaguars (*Panthera onca*). The soils are highly leached. The rate of nutrient cycling is high because of rapid litter decomposition. A recent report (D'Aleo, 2000) provides some staggering data on deforestation. Originally in Brazil, forest cover constituted nearly one-third (7.3 million km^2) of Brazil's total area of 21.8 million km^2. The present extent of the forest cover is 4.61 million km^2. At the current 2.3% annual rate of deforestation, about 128 000 km^2 are disturbed each year. The rehabilitation processes after deforestation are ecologically documented in some examples from Brazil (see Box 1.5).

Tropical dry forests

These forests are found between 10° and 20° latitude, where the Intertropical Convergence Zone migrates seasonally. This produces a long dry season (three to six months) and distinct periods of productivity and dormancy. Soils in these forests are richer and not highly leached.

Tropical grasslands and savanna

Savannas are a mixture of grasses and scattered trees that occur where rainfall is between 50 and 200 cm per year. They are most extensive in tropical climates including South America. Variation in rainfall is usually extreme and ranges from 85 to

Box 1.3 Restoration of abandoned mine lands

THE UNITED STATES

From 1978, when Surface Mining Control and Reclamation Act (SMCRA)-based Abandoned Mine Lands (AML) programme was initiated, to the year 2000, 26 states and the native American tribes have restored about 13 521 ha of abandoned spoil and haul roads, 4737 ha of exposed pits, 230 453 km of highwalls, and 3102 ha of land degraded by gob piles, slurry and industrial and residential waste. Also under this programme, among many other hazardous conditions left by past mining, 734 km of clogged streams, 8601 ha of clogged stream lands and 2312 ha of subsidence features have been restored. (Based on data provided by Chuck Meyers, Office of Surface Mining, Washington, DC.)

NORTH DAKOTA

Since 1981, over 80 primary reclamation projects at abandoned underground and surface mine sites at a cost of $22 million have been completed by the Abandoned Mine Lands (AML) Division of the North Dakota Public Service Commission. In 1998, three reclaimed sites (Hazen-West, Noonan and Fritz) were evaluated for hazard abatement, soil development, erosion control, revegetation success, wildlife use, wetland and stockpond water quality, and improvements in land use capability. The Hazen-West site had been mined from 1952 to 1974, and covered over 388 ha, of which about 75 ha were reclaimed in 1991. The reclamation plan consisted of eliminating the hazardous pit and constructing two ponds and two wetlands for wildlife enhancement. Good quality spoil salvaged from the site and mixed with coal fines was used to cover the backfilled and regraded pit area. The site was fertilised, seeded and mulched. The Noonan site had been mined from 1930 to 1963 and covered 566 ha of which 202 ha were reclaimed in 1994–5. A 3.2-km long, dangerous highwall was eliminated, and several large wetlands, diversions and a concrete weir were constructed for water management and wildlife use. A portion of water-filled pit was preserved as a fishing pond. A mixture of tall grasses and forbs was seeded to provide cover for nesting waterfowl and other wildlife. The Fritz site had been mined from late 1950s to 1967 for extraction of uraniferous lignite. The exposed lignite was burnt in the pit or in nearby kilns for concentrating uranium in its ash, which was sold to the Atomic Energy Commission. The 63-ha wasteland thus created contained acidic material and water and was contaminated with uranium, cadmium and molybdenum. Restoration of this site began in 1992. The contaminated material was identified and buried under 1 m of uncontaminated spoil, and the area was graded to a gently rolling topography. One stockpond, five wetland sumps and two terraces were constructed for surface water management, and to return the land to native grassland and grazing use. Within four to seven years of reclamation, all three sites established permanent vegetation of diverse grass and forb species. The soil quality, vegetative cover and productivity, and the quality of water in the constructed wetlands and ponds at all the three sites have improved significantly (Dodd & Ogaard, 1998).

150 cm per year but is seasonal and scattered. The vegetation is adapted to frequent fires.

Chaparral

These regions fall mostly between 32° and 40° N and S in western North America (California), and central Chile. They are characterised by Mediterranean climates that have hot, dry summers and cool, moist winters. About 65% of the annual precipitation falls during winter and there is at least one month when the temperature remains below 15 °C. The vegetation is adapted to drought, fire and infertile soils. These systems are often considered to be shrublands rather than deserts with thickets of evergreen shrubs and small trees, often with sclerophyllous leaves. Fire is common in the chaparral region and the plants are adapted to it.

Desert

Deserts form where evaporation exceeds precipitation, often by a factor of 7 to 50, in every year. They cover 26% of Earth's land in two distinct belts centred on 20° N and S latitude (the Tropics of Cancer and Capricorn). Deserts form where dry air masses

Box 1.4 Conservation and reclamation in the grasslands biome under the SMCRA requirements

A case of well-planned and highly successful achievement of combining proactive reclamation with conservation was presented by Bellaire Corporation's Indian Head Mine in North Dakota. This is one of the oldest surface mines in the country, operated since 1922 under different ownerships. The pre-mine area was characterised by diverse topography, land uses and wildlife habitats. In the early 1980s, the then North American Coal Corporation began conducting extensive studies in preparation of mining a 1012-ha area that contained several wooded draws surrounded by native rangeland. The goal was to conserve the wooded draws, and mine around these precious wildlife habitats. Appropriate design plans for pit layout and surface water management, and creation of permanent ponds were adopted to achieve the goal. The wooded draws that were thus saved from destruction contained green ash (*Fraxinus pennsylvanica*), American elm (*Ulmus americana*), box elder (*Acer negundo*), silver buffaloberry (*Shepherdia argentea*), june berry (*Amelanchier alnifolia*), round-leaved hawthorn (*Crataegus rotundifolia*) and chokecherry (*Prunus virginiana*). The ground cover consisted of bluegrasses (*Poa* spp.), sedges (*Carex* spp.), dwarf wild indigo (*Amorpha nana*), buckbrush (*Symphoricarpos occidentalis*) and poison ivy (*Toxicodendron radicans*). Breeding bird censuses indicated 10 species in 1979, before mining around the wooded draws was started, 13 species in 1984 when mining was fully operational, and 15 species in 1992 when final reclamation and vegetation establishment was completed. Mourning dove (*Zenaida macroura*), least flycatcher (*Empidonax minimus*) and yellow warbler (*Dendroica petechia*) represented 64% of the breeding pairs. The wooded areas and the surrounding rangeland provided excellent habitat for mule deer (*Odocoileus hemionus*), white-tailed deer (*Odocoileus virginianus*), coyote (*Canis latrans*), sharp-tailed grouse (*Pedioecetes phasianellus*), ring-necked pheasant (*Phasianus colchicus*), great horned owl (*Bubo virginianus*) and over 40 species of other non-game birds. By skillfully avoiding deleterious impacts on the wooded draws, Bellaire was able to preserve the habitat. For this restoration project, Bellaire Corporation received the 1992 National Hall of Fame award from the US Department of the Interior Office of Surface Mining.

The agricultural land adjacent to the wooded areas that was actually mined and reclaimed under the full requirements of SMCRA covered 884 ha. The pre-mine land uses included cropland, hayland and native grassland. Most of the reclamation activities were completed by autumn 1993, and all temporary sedimentation ponds were reclaimed by spring 1995. The land was returned to all the pre-mining land uses, and the Bellaire Corporation started receiving partial bond releases as early as 1985. Monitoring of revegetation progress has been carried out for several years following the initial seeding/planting. Cropland yields on the reclaimed areas, including those of prime farmland, have exceeded the required yield standards on average by 26% in each year. The yields of reclaimed hayland and tame pastureland have been, on average, 37% higher than the required standard. The vegetative cover and productivity of the reclaimed native grasslands have also exceeded the required standards. On average, the reclaimed grasslands produced about 34% more than undisturbed grasslands of similar type. Many tracts of cropland, hayland/pasture and native grasslands have received final bond release. Grazing by livestock on reclaimed native grasslands has been ongoing without any adverse effects. Wildlife monitoring and assessment of groundwater resources have revealed no harmful effects either. For the project, Bellaire received the US Department of the Interior Office of Surface Mining's 'Best of Best' award for 1997's example of surface mine reclamation. (Source: the written records of Bellaire and North Dakota Public Service Commission.)

are produced by Hadley cell circulation, the rain shadow effect of mountains, or the presence of high-pressure systems. Drought resistant plants and animals inhabit all deserts. The density of plant cover varies from sparse to moderate, and the species composition can be grasses or shrubs. Cold deserts occur at high elevations where relatively low evaporation improves water availability. Such areas are

Box 1.5 Wetland Restoration and Conservation

THE UNITED STATES

The North American Waterfowl Management Plan (NAWMP) was initiated in 1986 by the United States and Canada, in recognition of the need for international co-operation to restore wetlands and associated grassland habitats for declining migratory bird populations. The plan became continent-wide with the addition of Mexico as a signatory in 1994. The three governments, with co-operation from non-federal partners, are implementing a strategy to restore waterfowl populations to levels of the 1970s by protecting, restoring and enhancing wetland and adjoining habitats. The plan focuses on regional 'joint venture' areas that are designed to conserve those wetland habitat complexes identified as critical to sustaining populations of breeding, migrating and wintering waterfowl. The 1998 update to the Plan calls for restoration and enhancement of 6.2 million ha and protection of an additional 4.9 million ha of wetlands. The North American Wetlands Conservation Act (NAWCA) has become an important mechanism for wetland conservation under NAWMP. Since 1991, NAWCA has provided $343 million for habitat restoration with an additional $782 million provided by over 1300 non-federal partners. Private conservation organisations like The Nature Conservancy, Ducks Unlimited, the Delta Waterfowl Association and the California Waterfowl Association play a major role in wetland restoration and conservation. To date, over 1.9 million ha of wetlands and surrounding uplands have been acquired, restored or enhanced in the United States and Canada. Nearly 4 million ha have been affected in biosphere reserves by education and management plan projects in Mexico. Waterfowl hunters also support wetland conservation from the sale of duck stamps that contributed an additional $43 million to habitat conservation in 1999. In addition to the ecological values that accrue from hydrological, biogeochemical and trophic processes within wetlands, the values of North American wetlands accrue to the United States economy. Waterfowl hunting and viewing generated $13.4 billion that supported an estimated 135 000 jobs in 1991. The NAWMP has proven effective in large-scale habitat conservation and ecological restoration, serving as a model for integration of similar continental migratory bird conservation programmes.

THE CACHE RIVER ECOSYSTEM

A partnership of federal, state and private interest groups formed the joint venture to establish the Cypress Creek National Wildlife Refuge in southern Illinois. A watershed management plan was developed to improve water quality by reducing erosion and sedimentation, and to preserve and restore the natural resources over 194 253 ha of the Cache River watershed in a manner that is compatible with a healthy economy and high quality of life. Situated in an abandoned channel of the Ohio River, the Cache River has been adversely impacted by channelisation and sedimentation associated with forest clearing, flood control and agricultural development over the last century. The Cache River gained international recognition in 1996 when the Cache River and associated Cypress Creek wetlands were added to UNESCO's list of 15 'Wetlands of International Importance'. Located at the crossroads of mid-continental climate zones, the Cache River basin's 20 natural community sites include the most notable cypress–tupelo swamps, southern flatwoods and bottomland forests, and upland forests and limestone/sandstone glades. The area supports 104 state and seven federally threatened or endangered species. Wetland restoration efforts in the region include revegetating forested bottomlands, establishment of riparian corridors and filter strips, and restoration of natural flow regimes to the Cache river and its tributaries.

THE TENSAS RIVER BASIN

The Tensas River Basin area is part of the Lower Mississippi Valley Joint Venture of NAWMP and includes 290 570 ha in northeastern Louisiana. Of the 92% of once-forested watershed, 85% of the area has been cleared for row-crop production since the 1950s. About 26 305 ha of bottomland swamp remain in the

Tensas River National Wildlife Refuge and Big Lake Wildlife Management Area. Loss of wetlands and riparian areas has degraded water quality, increased sedimentation and flooding, and caused loss of wildlife habitat and biodiversity. Federal, state and non-governmental agencies and local citizens formed collaborative partnerships to develop a Watershed Restoration Action Strategy. Best management practices, erosion control structures and reforestation measures have been implemented through the US Department of Agriculture's Environmental Quality Incentives and Wetland Reserves Programs (WRP). The US Department of the Interior Fish and Wildlife Service and state and federal partners work with private landowners to voluntarily protect and restore bottomland forests in the region. To date, an estimated 22 663 ha of farmland and 1619 ha and over 9 km of riparian area have been reforested, with another 19 425 ha enrolled in WRP.

dominated by shrubs as in the Great Basin of southwestern United States. Low annual rainfall (30 or less cm per year) and sparse plant cover characterise deserts. Perennial plants have a variety of adaptations to minimise water loss. Annual plants have adapted their life cycles to infrequent precipitation patterns: when rain comes, they develop quickly, flower, and die.

Wetlands and aquatic systems

The Americas support a tremendous diversity of lakes, rivers, estuaries and marine systems. In North America, Canada has over 750 000 km^2 of water bodies, the United States has over 470 000 km^2 and Mexico has about 50 000 km^2. In South America, Brazil contains over 55 000 km^2, and Colombia supports over 100 000 km^2 of water bodies. Wetlands, in particular, are vital as repositories of incredible biodiversity, critical for fish, bird and mammal species, and as sources of groundwater recharge. These systems are threatened, however, by agricultural and urban expansion. For example, the Everglades ecosystem in the southern coastal plain of Florida has been transformed by both draining and impounding water for agriculture and urban development since the early nineteenth century. 'Of the three traits that characterized the pre-drainage system in the Everglades: (i) habitat heterogeneity; (ii) large spatial extent; and (iii) a distinct hydrologic regime—the new water control works most directly affected the last, but the destruction of the system's hydrologic regime led, inevitably, to a reduction in the size and biotic diversity of the wetlands' (McCally, 1999). US President Bill Clinton signed into law the Comprehensive Everglades Restoration Plan, a 30-year, $7.8 billion project designed to eliminate dams and restore the original drainage patterns of the Everglades ecosystem. The implementation and effectiveness of this programme remains to be seen. It is worthwhile to record that of all habitat types, wetland restoration finds much support and financial subsidy from, besides the government, waterfowl hunters, sports fishery enthusiasts and other private agencies and supports jobs and generates revenue (Box 1.6).

NATURE AND EXTENT OF THE PROBLEM

Ecosystem disturbance may be defined as an event or a series of events that changes the relationship between organisms and their natural habitats/niches, both spatially and temporally (Wali, 1987). The changes may be small or large, temporary or permanent, with little to severe consequences. 'The most pervasive incidents of environmental degredation result from recurring and incremental impairments," notes Robinson (1992). Bazzaz (1983) has listed seven major activities as the causative agents of ecosystem disturbance: extensive clearing of natural vegetation for agriculture; selective harvesting of desirable species and introduction of alien ones; mining; draining of wetlands; introduction of chemicals in the environment; and the impact of war. Synthesising data from earlier studies, Houghton (1994) notes that deforestation rates in the tropics since the 1970s, and so in South America, have increased sharply. Ramakutty & Foley (1999) have specifically calculated the conversion of

Box 1.6 Restoration of deforested areas in tropical rainforest in Brazil

With 6 million ha of the Amazon Basin converted to pasture in 20 years, there is an urgent need to determine the potential for abandoned pastures to revert to forest. Near Paragominas, Para, Brazil, Buschbacher *et al.* (1992) examined succession on 15 different abandoned pastures of varying use intensities and ages since abandonment. They found significant potential for re-establishment on light-use areas that had been cleared and only lightly grazed. These areas developed closed canopies within 10 years and had high species diversity. Moderate-use areas, which had been repeatedly burned and heavily grazed before abandonment, recovered more slowly with a significant loss of diversity. Heavy-use areas, characterised by the use of machinery in the clearing process, showed very slow recovery. Pioneer species were slow to become established and species diversity was quite low. Their analysis led the authors to estimate a 500-year recovery period for heavy-use areas to return to mature forest. Clearly, lighter-use sites have much greater potential for rehabilitation to productive ecosystems, and use intensity should be minimised on current pastures to allow for reasonable recovery times.
Loss of on-site regeneration capacity, slow seed dispersal, seedling predation and unfavorable microclimates all contributed to slow recovery of pasture areas.

After forest clearing, the use of forest plantations to re-establish forest cover can catalyse the recovery of secondary forest. These plantations should be contiguous with an undisturbed forest area as a seed source. Seed dispersers such as birds and bats were found to utilise plantations, accelerating the regeneration of small-seeded species. Large-seed dispersers, however, did not utilise plantations as extensively, creating a bias in regeneration. Even on abandoned strip mines, plantations can accelerate the recovery of forest diversity. Changes in physical and biological site conditions within the plantations facilitate succession by making soil surface conditions (light, temperature and moisture) favourable for seed germination. However, seed dispersal vectors are required to bring seeds to these favourable sites. Therefore, the plantation areas require an ecological connection to existing habitat for seed dispersers and seed sources. Plantations on a former bauxite mine showed significant recovery 10 years after planting, although seed dispersal vectors were found to be limiting recovery. Greater distance from undisturbed forest had a negative correlation with species diversity. Creating favourable habitat conditions for seed dispersers within forest plantations could further accelerate the rate of recovery (Parrota *et al.*, 1997*a*, *b*).

land to, and abandonment of, croplands between 1700 and 1992, noting the extent of accompanying land degradation in the Americas. The overall extent and magnitude of soil degradation in the Americas has been significant resulting from the combined activities of deforestation, resource exploitation, overgrazing and agricultural activities (Table 1.3).

Obviously, any restoration work needed will depend on the type of ecosystem disturbance encountered or expected. Also, like proactive or mitigative restoration, preventing ecosystems from getting damaged in the first place requires implementation of conservation policies and management plans. Many countries in the Americas have set aside some wilderness areas, which, because of their fragile ecosystems or aesthetic or scientific value, are left untouched in their pristine quality. Even such areas require constant management and care. However, the challenges involved in proactive and mitigative restoration vary widely depending upon the intensity and extent of the disturbance. For example, in the forest systems where logging operations are carried out, concomitant replanting of seedlings of same species, with appropriate management for minimising soil erosion and maximising survival rate of the planted seedlings, may suffice. Likewise, the impacts of agricultural practices on soil degradation may be minimised by using appropriate soil conservation practices, including minimum tillage, plant residue management, and crop species/cultivars that are genetically disease-pest-resistant and nutrient-uptake efficient. Overgrazing, which destroys native grasslands and exposes the

Table 1.3. *Soil degradation (area in Mha) of the Americas*

	South America	Central America	North America
Extent			
Water erosion	123	46	60
Wind erosion	42	5	35
Chemical	70	7	+
Physical	8	5	1
Total	243	63	96
Causative Factors			
Deforestation	100	14	4
Overexploitation	12	11	–
Overgrazing	68	9	29
Agricultural activities	64	28	63

Source: Based on Oldeman (1994).

land to erosion, is essentially a result of mismanagement and lack of proper scientific information. The restoration challenge posed by overgrazing includes dealing with the socio-economic reality of that region, in addition to applying proper scientific remedies.

Appropriate strategies for restoring drastically disturbed ecosystems can be developed based on a 'systems approach' (Wali, 1975). Revegetation of disturbed ecosystems is primarily a substrate/soil-driven process, and its success is dependent on the germ plasm (seeds, propagules) that can arrive naturally (or are seeded), and survive at these sites (e.g. Wali & Freeman, 1973; Bradshaw, 1983, 1997; Tilman, 1988; Gleeson & Tilman, 1990). Topography of the affected site may need to be modified to restore the area to a desired land use, to eliminate any potential hazards to the public, to re-establish proper surface drainage pattern, or a combination thereof. The presence or absence of organic matter (hence topsoil) is also a critical factor as it determines the rate at which the disturbed ecosystems recover toward long-term biological productivity (Stevenson, 1986; Logan, 1989, 1992). A schematic view shows factors and standards that must be considered in restoring/reclaiming a disturbed area (Fig. 1.2); it also shows how science and law work together in developing the appropriate standards and procedures for ecological restoration.

Cairns (1988*a*) calls restoration ecology the 'new frontier in both theoretical and applied ecology', no less in significance than biotechnology. For ecological restoration to be meaningful, understanding of ecological succession in a regional context is necessary (Whittaker, 1974). To comprehend the relative differences in stability of successional and self-maintaining communities, due recognition of regional climaxes is stressed. The successional aspects of restoration ecology have been discussed in many publications (e.g. Wali & Freeman, 1973; Woodwell, 1992; Marrs & Bradshaw, 1993; Wali, 1980, 1999; Keddy & Drummond, 1996; Walker, 1999), which provide ample guidance in these aspects.

Finally, consideration must also be given to the fact that revegetation of a site by the same type of species, genotypes or ecotypes that existed before disturbance may not be possible because of some edaphic stress factor that may have been unleashed as a result of the disturbance itself. The edaphic stress may be due to physical or chemical characteristics of the substrate material. Poor infiltration and/or water storage capacity resulting in droughty conditions; trace metal toxicities; nutrient deficiencies; saline, sodic or acidic soil conditions; low soil biological activity due to paucity of microflora, etc. constitute edaphic factors that can make revegetation of disturbed sites very difficult. In such situations, dependence on soil amelioration only may not prove as successful as the use of those plant species, cultivars or ecotypes that are naturally tolerant (adapted) to such edaphic stresses. This approach has worked well in production agricuture as well as in restoration ecology (Bradshaw *et al.*, 1965; Bradshaw, 1970; Brown *et al.*, 1972; Epstein & Norlyn, 1977; Safaya, 1979; Asay, 1979).

In this chapter, we have purposefully chosen to concentrate on restoration of drastically disturbed ecosystems (by mining) for several reasons. Mining of metals, minerals, aggregates and fossil fuels is widespread in the Americas (see Doan *et al.*, 1999), and will greatly expand in the future, given the current emphasis on economic development. The disturbances to ecosystems will increase not only by mining *per se*, but also because of the enormous

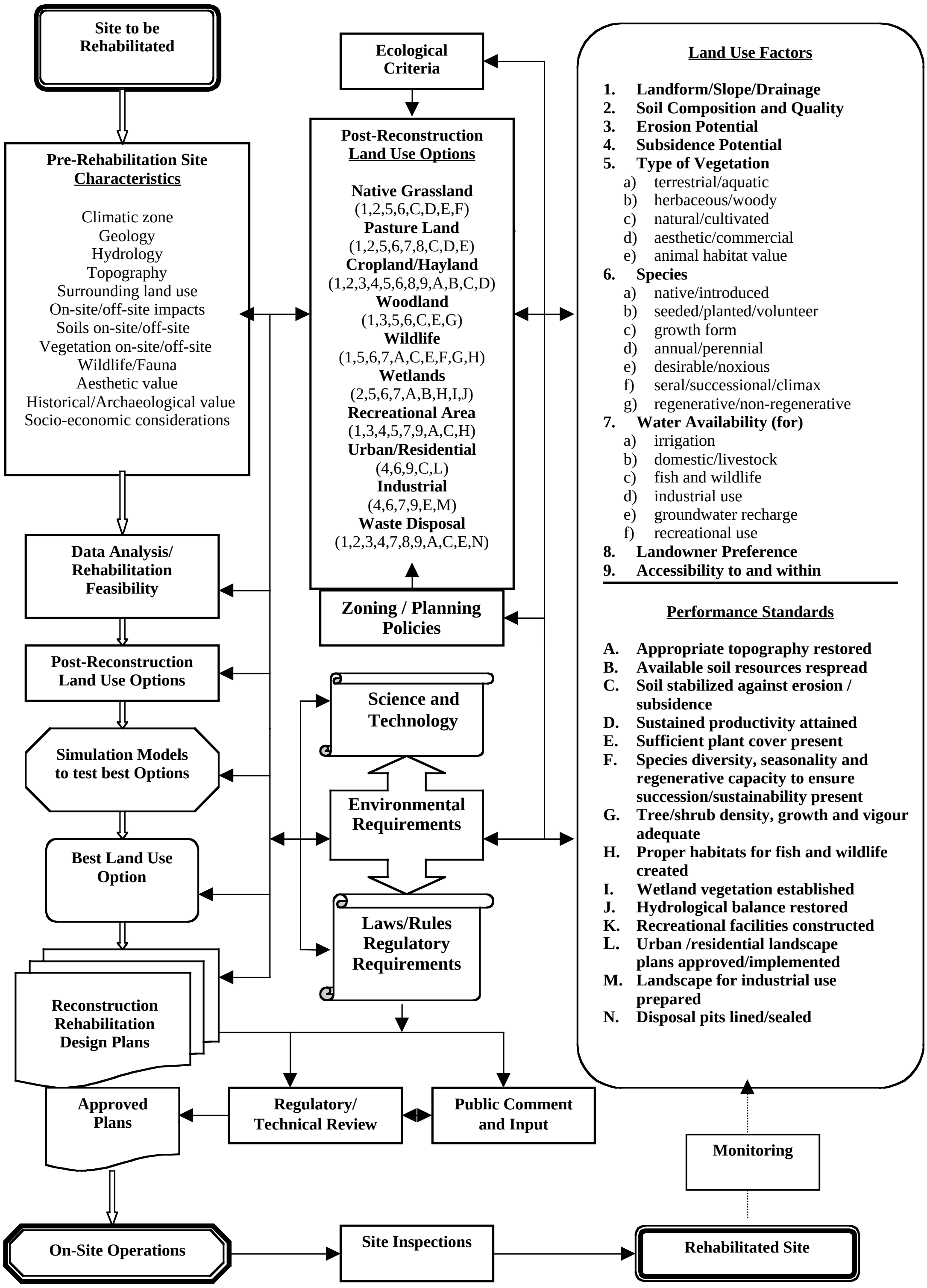

Fig. 1.2. A flow diagram showing the centrality of ecological knowledge base and the planning-and-decision process for the rehabilitation and management of degraded ecosystems. When fully implemented, the Surface Mining Control and Reclamation Act of the United States should closely match the expectations of restoration for multiple land use sustainability.

generation of waste materials from processing of ores (see Gardner & Sampat, 1998) and coal. The waste and gob piles will also need to be properly stabilized and reclaimed. Moreover, a number of American countries have legal requirements in place that mandate reclamation of mine lands and wastes. In the United States the legal requirements and the scientific technology developed for restoration of mined lands is in a fairly advanced stage of implementation, and these concepts and practices can also be used elsewhere. Finally, restoration of mined lands provides opportunities to plan for multiple land use and integrated resource management (Wali, 1975; Cairns, 1988*b*).

ECOLOGICAL RESTORATION OF DAMAGED ECOSYSTEMS: EXISTING POLICIES AND LEGAL FRAMEWORK

The United States of America

A large number of environmental laws have been passed in the United States of America over the years, with about 90 of them in force since 1950 (Wali & Burgess, 1985; Wali, 1987). It was the great depression and dust-bowl experience in the last century that led the United States to enact its first soil conservation law (Public Law 46) in 1933 that created the Soil Erosion Service (SES) in the Department of Agriculture (USDA). The agency was later named Soil Conservation Service (SCS), and renamed again in 1994 as the Natural Resources Conservation Service (NRCS). Over the years, working closely with the agricultural land grant universities, this agency, responsible for private agricultural lands, developed comprehensive information on soil and water management techniques; surveyed, mapped and classified soils; and collected data on soil and crop productivity. Its role in developing and implementing policies aimed at preventing highly erodeable lands (HEL) from excessive cultivation cannot be overemphasised.

The management of public lands in the United States is carried out by US Department of Agriculture Forest Service and Department of Interior's Bureau of Land Management. The US Fish and Wildlife Service is responsible for habitat preservation, management, and enhancement, and is also the lead agency for implementing the provisions of the Endangered Species Act of 1973. The US Army Corps of Engineers oversees issues related to wetlands. But a recent decision rendered by the US Supreme Court with regard to wetlands may increase the responsibility of states in this matter. All these agencies have a direct and vital role in the protection, rehabilitation and maintenance of various ecosystems in the United States. Private organizations such as Ducks Unlimited and Nature Conservancy also continue to contribute actively in the preservation and restoration of some of the natural ecosystems in the United States and Canada.

National Environmental Protection Act

A new era of environmental protection policy and regulation emerged in 1969 when the National Environmental Policy Act (NEPA) was passed by the US Congress. NEPA (Public Law 91-190) established a national charter for environmental protection and created the US Environmental Protection Agency (US-EPA), giving it a broad jurisdiction over research and regulation for land, water and air pollution control. NEPA also provided the citizens a voice in ecosystem rehabilitation (Holmberg *et al*., 1978).

The US-EPA has developed comprehensive rules, policies and performance standards to implement the Clean Water Act, Clean Air Act, and the laws related to the handling and disposal of hazardous and non-hazardous waste materials. The overall objective of these laws and rules is to protect human health and the environment. The US-EPA carries out this mandate in collaboration with the state agencies that are charged with a similar mission at the state level. The relevance of NEPA to the restoration of disturbed ecosystems lies in the fact that it does not focus only on prevention but also on the reduction and elimination of the existing harm to the environment. For example, the primary objective of the Clean Water Act is to restore and maintain the chemical, physical and biological integrity of the nation's fresh water and oceanic ecosystems. Another example of NEPA's overriding role in restorative ecology is given below.

NEPA requires that all federal agencies prepare a concise public document, called an Environmental

Assessment (EA), prior to undertaking any action or project that may have a significant adverse effect on the human environment or an ecosystem. If the EA shows that adverse effect(s) is/are likely to occur, an Environmental Impact Statement (EIS) must be prepared. The EIS is a detailed written statement that provides a thorough analysis of the possible adverse effects of a proposed action or project. It is also required to include alternative plans that may have less adverse side-effects. EPA also recognises a category of actions called Categorical Exclusion, which are exempted from EIS preparation because individually or cumulatively they have no significant effect on the human environment. So, even before an EA is prepared the agency proposing an action has to make the categorical exclusion determination. If an EA shows that no significant impacts are likely to occur, the agency may prepare a Finding of No Significant Impacts (FONSI), instead of an EIS. But if an EIS is necessary, then a Notice of Intent (NOI) is published in the Federal Register of the US Government to inform the public that the agency intends to prepare an EIS for the proposed project. Thus, EIS procedure guarantees integration of scientific facts with the government decision-making process, and tries to ensure that only such actions are undertaken that have very little adverse effect on the environment. The EA/EIS procedures are required to be followed in the reclamation of abandoned coal-mined lands as well as the lands that are currently mined for federally leased coal.

Surface Mining Control and Reclamation Act

The legal and scientific framework for the restoration of drastically disturbed ecosystems is perhaps best exemplified by Public Law 95-87, Surface Mining Control and Reclamation Act of 1977 (SMCRA). Its historic importance was clear since its very inception (Imes & Wali, 1977, 1979). Although the mandates of SMCRA apply only to the coal-mined lands in the United States, the principles and technology developed to meet these mandates would be equally effective for restoration of ecosystems disturbed by most other means.

Prior to SMCRA, many coal-producing states in the United States had passed some form of legislation to minimise the adverse effects of surface coal-mining (Beck, 1973; Bowling, 1978): West Virginia in 1939, Indiana in 1941, Illinois in 1943, Pennsylvania in 1945, Ohio in 1947 and North Dakota in 1969. Indeed the North Dakota law (Beck, 1973) provided the title for federal legislation. But two events triggered the need for a national policy on mining and reclamation. First was the publication of *Surface Mining and Our Environment: A Special Report to the Nation* from the US Department of the Interior (1967), in which the extent and magnitude of surface mining was recorded. Second, shortly after the 1973 energy crisis in the United States, it became clear that more domestic coal would have to be mined both to reduce the oil imports and meet the energy needs of the nation.

In its statement of findings, the SMCRA recognised the importance of mining for coal by both surface and underground methods for meeting the nation's energy needs. However, it also recognised that many surface mining operations result in disturbances of surface areas that destroy or diminish the utility of land for commercial, industrial, residential, recreational, agricultural and forestry purposes; cause erosion and landslides; contribute to floods and water pollution; destroy fish and wildlife habitats; impair natural beauty; and undermine efforts to conserve soil, water and other natural resources (SMCRA, Title I, Section 101). Thus, a nationwide programme to allow coal-mining under strict application of reclamation rules and standards was established to prevent the adverse effects of coal mining on the environment and restore the former uses and productivity of the lands disturbed by mining. The SMCRA created the Office of Surface Mining Reclamation and Enforcement (OSM) in the Department of the Interior, with powers to implement and enforce the provisions of this Act.

However, the SMCRA recognised that 'because of the diversity of terrain, climate, biological, chemical, and other physical conditions in areas subject to mining operations, the primary governmental responsibility for developing, authorizing, issuing, and enforcing regulations for surface mining and reclamation operations subject to this Act should rest with the States.' Thus, any state wishing to retain its primacy over coal-mining and reclamation within its borders was able to do so by developing a

State Regulatory Program (laws, rules, policies, etc.) that met the approval of the US Department of the Interior if the rules and standards contained therein were no less stringent than the federal counterparts. The states would receive federal funding to develop and implement their state programs to achieve the objectives of this Act.

The SMCRA also provided for the development and implementation of the Abandoned Mine Land (AML) programme that is totally dedicated to reclamation of lands that were degraded by mining operations prior to the enactment of this Act and were abandoned without any reclamation or restoration. The primacy states run the AML programme, which is funded by the Department of the Interior from a trust fund derived from reclamation fees (10 to 35 cents per ton of coal) levied on currently active and regulated coal-mining operations.

Prior to the SMCRA, mining for coal, metal ore, uranium, bentonite, sand, gravel, hard rock, etc., had left numerous sites throughout the United States in a state of utter degradation. The size and severity of disturbance varied according to the type of mining, the biogeoclimatic characteristics of the area, and the degree to which they may have been revegetated naturally or by human effort (Merrill & Safaya, 1984). The AML program required that all such sites be inventoried and classified into various categories, mainly (1) those that posed a direct threat to public health, safety and welfare (i.e. highwalls, surface instability, toxic radioactive substances), and (2) those that reflected environmental degradation due to increased potential for erosion, reduced biological productivity, chemical contamination, or any other condition. Priority for reclaiming the abandoned mine sites was also given in the same order as the categories listed above. Reclamation of the sites involved highwall reduction, landscape restoration, surface manipulation, use of ameliorative additives and fertilisers, and seeding/planting of adapted grasses, forbs, shrubs and trees. These efforts have paid off very well, as a large number of previously degraded ecosystems have been restored to a better level of stability and productivity (Boxes 1.3 and 1.4).

The SMCRA and its implementing regulations are very clear and specific about requirements and standards for post-1977 mining and reclamation procedures. First of all, no one can engage in surface coal-mining without a valid permit from the surface mining regulatory agency. Permits or authorisations from several other federal, state and local agencies are also required. Furthermore, mining cannot begin without the mining company posting a bond as an assurance for the successful completion of all reclamation requirements. The SMCRA also provides for public and landowner participation and comment in the process. The permit application must contain accurate information about: (1) the company and its legal rights to mine a proposed area; (2) a detailed inventory of premining environmental conditions (geology, hydrology, land use, soils, vegetation, wildlife, threatened and endangered species, historical and archaeological resources, etc); (3) how the area will be mined and reclaimed; and (4) the methods that will be used to prove that successful reclamation has been achieved. The permit must also contain specific design plans for the construction of surface water management structures (sedimentation ponds, diversion channels, etc.), and plans for monitoring surface and groundwater, wildlife, etc.

All this information, which may require thousands of pages, is critically reviewed by the regulatory agency. After a mining permit is issued, the regulatory agency inspects and monitors all mining and reclamation activities at the mine regularly, and if there are any violations of law, rules or the permit condition noted, an enforcement action is taken that may result in a fine, cessation of mining, or revocation of the permit.

The core environmental requirements established by the SMCRA are as follows:

- Restore mined lands to former or better use
- Backfill and grade the mined areas to their approximate original contour
- Control erosion and attendant air and water pollution
- Minimise disturbance to the hydrological balance – surface and groundwater
- Remove, segregate and respread topsoil (plus subsoil in case of prime farmlands)
- Establish adequate vegetation on the mined lands.

In revegetating mined lands, the SMCRA, Section 515(b)(19), mandates that an operator shall:

establish on the regarded areas, and all other lands affected, a diverse, effective, and permanent vegetative cover of same seasonal variety native to the area of land to be affected and capable of self-regeneration and plant succession at least equal in extent of cover to the natural vegetation of the area; except, that introduced species may be used in the revegetation process where desirable and necessary to achieve the approved postmining landuse plan.

The reclaimed area must be seeded within three years of coal removal. After the last year of augmented seeding/planting, the permittee is required to assume responsibility for successful reclamation and revegetation for a period of five years in areas where average annual precipitation exceeds 65 cm, and for ten years in areas of 65 cm or less precipitation.

Obviously, the SMCRA expects that land disturbed by mining can and must be restored to the same landform and land use, with the same kind and amount of vegetation, as existed before mining. The surface drainage system and the underground resources of water, in both amount and quality, must also be restored to support the former uses of that land. The simple but sanguine mandate regarding revegetation of mined lands has spawned a comprehensive set of rules and standards for assessing its success.

Each land use category must meet its own set of standards; failing which, a final bond release cannot be granted. For a reclaimed native grassland to qualify for final bond release, its productivity, ground cover, diversity, seasonality and permanence must equal or exceed that of similar agricultural lands in the surrounding area under equivalent management, in the last two years of the responsibility period. Demonstration of equivalence for both productivity and cover must be made with 90% statistical confidence. For tame pasture lands only productivity and cover are required to meet the standard. For croplands and haylands, meeting the productivity standard is the only criterion, but for prime farmlands success must be evaluated over a period of three years. Vegetation data of the reclaimed areas are compared with those obtained from reference areas, or with an appropriately calculated technical standard, to determine the success of reclamation.

The success of post-mine woodlands, including the wooded riparian zones or floodplains alongside streams as wildlife and fish habitats is determined on the basis of tree and shrub numbers, vegetative ground cover, and an evaluation of species diversity, season variety and regenerative capacity of the vegetation so established. In the first place, the woody and herbaceous species required to be planted on the reclaimed lands must be approved by the regulatory agency in consultation with state counterparts of Fish and Wildlife, Forestry, and NRCS.

Any wetlands destroyed in the mining process must be replaced, and the total post-mine wetland area must equal the pre-mine area. For the initial inventory and identification of wetlands, consultation with NRCS is required to ensure compliance with the Wetland Conservation Provisions of the 1985 Food Security Act and the 1990 Food, Agricultural, Conservation, and Trade Act. The Army Corps of Engineers must also be notified. The seasonal, semi-permanent and permanent wetlands are reconstructed using appropriate engineering designs, suitably respread with previously saved wetland topsoil, and seeded with appropriate hydrophytic vegetation. The successful establishment of the wetlands is assessed on the basis of vegetation zones/communities, species composition, and the quality of water.

SMCRA's clarity of purpose, comprehensiveness, and on-the-ground achievements are unmatched. Once the SMCRA's legal stipulations are fully implemented, we believe, it should prove to be a model legislation bringing together effectively scientific research in the restoration plans for multiple land use as depicted (Fig. 1.2). A number of success stories as well as some that pose problems are displayed in the web site of US Department of the Interior's Office of Surface Mining (www.osm.gov). There are, however, some shortcomings in SMCRA and other areas that are discussed later.

Canada

Problems associated with drastic disturbance and ecosystem restoration in Canada are discussed by Thirgood (1978), Gunn (1995) and Ripley *et al.* (1978, 1996); the latter approach the problems in an ecosystematic perspective. In eastern Canada specifically, Watkin (1979) identified three major problems that required reclamation urgently: sulphide-containing mines wastes which can produce acid tailings, highly alkaline asbestos tailings, and shoreline erosion on the Great Lakes.

One of the examples that caught national attention was the case of Sudbury, Ontario. Degradation, beginning with the logging of spruce, fir and pine forests in the late 1800s, intensified when the area became a major copper and nickel producing area. In extracting and processing ores, it polluted both the air and water in the region rendering thousands of hectares of land and water barren of life. Casting the story of the region in both a historical and ecological perspective *sans* effective governmental regulation, Gunn (1995) provides a comprehensive account of the restoration of Sudbury. Three lessons are clear from this story. First, had there been an effective government policy, many productive ecosystems would have been spared extreme degradation. Second, the tallest smokestacks of Sudbury were not only a hazard to the immediate area but also to a much larger area that received the emissions. Third, the dedication of many professionals, industry, and citizens can indeed be effective. Recent work from Canada on the restoration of alpine and subalpine areas (Macyk, 2000), western surface-mined coal lands (Fedkenheuer & Macyk, 2000), and oil shale mined lands reviews the successes and shortcomings of these efforts. However, lack of enforcement, scaled-down financial resources of governmental agencies responsible for environmental protection, and undue reliance on voluntary enforcement makes a strong case, according to the Environmental Law Institute (2000*a*), for a national framework.

Canada is a major producer of metals and minerals and exports nearly 80% of them. At the federal level, Canada now has a Minerals and Metals Policy which specifically addresses the current state of the natural environment, mine reclamation, and establishment of protected areas, and links restoration strongly to sustainable development (Government of Canada, 1996; Shinya, 1998). These pronouncements are further strengthened by the recent passage of the Canadian Environmental Protection Act (CEPA) (Government of Canada, 2000). CEPA 2000 includes some impressive fact sheets but none addresses ecosystem restoration directly. Hence, unlike in the United States, there is no federal agency that regulates or oversees the restoration or reclamation of lands disturbed by mining or other large-scale activities. This responsibility lies with the provincial governments of Canada. The provinces may differ in their legislative or administrative procedures for the restoration of disturbed ecosystems, but the overall goal is to minimise land degradation and air and water pollution. The concept of sustainability of the environment is underscored in all such efforts. Examples of two Canadian coal-producing provinces, Alberta and Saskatchewan, are given below.

In Alberta, reclamation of coal-mine lands is regulated under the Land Surface Conservation and Reclamation Act of 1973, which replaced the Act of 1963. The Act is implemented through a set of guidelines rather than rules. The guidelines are adjusted periodically as the technology evolves. There is a close co-ordination between the government and the industry in the area of reclamation research. Coal-mining is allowed through a stepwise process of approvals granted by the Energy Resources Conservation Board (which approves mining plans and issues mining licenses) and by the Department of Environment (which approves reclamation plans).

The permitting process involves sequentially: (1) preliminary disclosure; (2) environmental impact assessment; and (3) detailed review of licensing. Mined lands must be returned to the level of soil capability equivalent to that which existed before mining. There is no requirement for returning mined land to its approximate original contour or productivity *per se*. Topsoil and subsoil have to be salvaged for respreading only to the extent needed to return the land to its pre-mining level of soil capability. Erosion control is a major concern in the hilly areas, and considerable emphasis is placed on sediment control measures. The success of reclamation is assessed by ensuring that the desired soil capability has been attained, and there is no waiting or responsibility period for proving that fact.

In Saskatchewan, coal-mining is regulated under the provisions of the Environmental Management and Protection Act of 1983/4 and amendments thereto, and by the Mineral Industry Environmental Protection Regulations that went into effect in 1991. Neither the Act nor the regulations focus exclusively on coal-mining. The underlying philosophy of the Saskatchewan law and rules is to control pollution and return the land disturbed by mining or mineral exploration to a sustainable productive use. The Industrial Branch of Saskatchewan Environment and Resources Management is the primary regulatory agency for coal and all other mining operations.

Applications for reclamation approval require relatively very little information (legal land description, land use, topsoil/subsoil/overburden data, soil classification, schedule for various mining and reclamation activities, proposed cover soil depth, and the proposed land use). Plans for water and air pollution control and waste disposal are also included. Reclamation plans are submitted on an annual basis. Guidelines and mutually agreed-upon performance standards are the basic mechanisms for regulation. Reclamation should be concurrent with mining, and the disturbed lands should be returned to 'acceptable, predetermined land use' (preferably the pre-mining use, or that which is achievable) and 'ensure physical stabilization'. Regrading must be done within two years of mining disturbance, appropriate for the intended post-mining land use. Revegetation is required using 'good agricultural practices', but assessment of revegetation success *per se* is not required. Land is released, parcel by parcel, from the burden of reclamation, when the regulatory authority is satisfied, based on expert judgment.

Latin America

Since Mexico shares much more in common with South and Central American countries, many authors treat them together as Latin America. Most countries in this region now have overencompassing environmental legislation that addresses many issues of air and water pollution, and the protection of many newly established nature reserve or protected areas.

Latin America has been experiencing a major boom in mining investment since the early 1990s. We explored specific areas of legislation that would relate to ecosystem restoration. The environmental impact assessment process appears to be gaining ground. While such assessments are the 'linchpin' for preventing adverse environmental impacts in such countries as Bolivia and Chile, these seldom include specific measures that should be taken to prevent adverse effects (Environmental Law Institute, 2000*b*). Ecosystem rehabilitation or restoration do not seem to be a high priority.

Part of this is due to improved economic conditions and structural reforms that have opened up the economies of the region and made them more hospitable to foreign direct investment. In addition, several countries, such as Chile, Argentina, Bolivia and Peru, have introduced sectoral mining reforms and adjusted their legal, fiscal and environmental policies. This has led to a significant expansion of the mining sector in Latin America. Mining investment is new in several countries of the region, as in Argentina, and even for traditional mining countries, the magnitude of the projected investment has no precedent.

That companies developing resources all over the world have had an 'unprecedented access to a large portion of the earth's surface than ever before' during the 1990s (Otto, 1998) is especially true for South America. Almost three-quarters of these exploration activities were concentrated in five countries in 1996: Chile (18.2%), Mexico (16.6%), Peru (16%), Brazil (14.5%) and Argentina (8.8%). Productive investments in mining in Latin America over the next five years are projected to be the largest of any region in the world, accounting for 44% of the total world investment in the mining sector, or about US$17 billion. A compilation by the Economic Commission for Latin America and the Caribbean arrives at a forecast of $24 billion in mining investment by the year 2000 in only five countries (Argentina, Chile, Mexico, Peru and Venezuela). Much of this is for copper mining, which accounts for 66% of projected investments.

Mexico

Mexico's General Ecology Law on Ecological Balance and Environmental Balance, passed in 1988 and substantially amended in 1996, sets out principles for ecological planning and management, and the respective roles of state and municipal governments and the general public (Environmental Law Institute, 1998). With a total area of over 1 972 550 km^2, Mexico is the 14th largest country in the world but ranks fourth in its biological diversity because of a