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CHAPTER 23

RESTORATION, RECLAMATION, AND REGENERATION OF DEGRADED OR DESTROYED ECOSYSTEMS

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Ecosystems are exposed to a wide range of disturbances that range from the fall of a single large tree in a forest that opens to sunlight a patch that had previously been shaded, to disturbances covering a substantial portion or possibly all of the globe as described in the "nuclear winter" article by Ehrlich et al. (1983). Small disturbances caused by natural phenomena are often followed by a very rapid recovery process. The disturbances covered in this chapter, however, are entirely the result of human activity and are not so quickly healed. The nature of the disturbance, its duration, scale, and, frequently, selectivity may ensure that recovery to original condition is highly improbable. Since the nature of the disturbance plays a pivotal role in ecosystem recovery, a different management strategy usually must be developed for each type of disturbance. An illustrative list follows that the reader will almost certainly be able to expand.

1. *Sudden and unexpected disturbances.* Examples are derailments of railway cars carrying hazardous chemicals, oil drilling blowouts, ship accidents, or manufacturing facility failures such as Three

Mile Island in the United States or the Seveso accident in Italy. As a result of the unexpectedness of the accident, the preaccident condition of the ecosystem will most likely be unknown. In addition, confusion following the accident results in data not gathered, data gathering handled improperly, or data gathering of the wrong kind or in the wrong place. In many instances, spill control teams may contain the deleterious material, immobilize it, or destroy it in situ. In other cases, such as the tetraalkyl lead spill described by Tiravanti and Passino (in press), the material may spread over a substantial area and be difficult or impossible to control.

2. *Disturbances that have been occurring for a substantial period of time but were only recently detected.* Examples of this are industrial discharges that were thought to be harmless to the indigenous biota but were actually more harmful than anticipated. In the absence of careful environmental monitoring, including chemical, physical, and biological information, such predictive errors may go undetected until the disturbance reaches gross levels identifiable by laymen. Such evidence may include fish kills, noxious growths, or direct harmful effects on humans. In these cases it is also quite likely that no substantive ecological background information has been gathered, so the predisturbance condition of the ecosystem is known in only the most general and cursory fashion. If the material being discharged or leaching from a burial site is a persistent chemical at toxic concentrations, reduction to tolerable concentrations in the ecosystem may be difficult. Thus, even if the discharge ceases or is reduced to appropriate levels, recovery of the ecosystem to any significant degree is not likely until the hazardous material is either removed or immobilized. Allowing the waste to move and become less harmful through dilution is a common but unsatisfactory solution to the problem. Decontamination in situ may be both expensive and difficult with present technology as attempts to cope with improperly designed hazardous waste storage sites have shown.
3. *Situations where the disturbance is planned.* If the disturbance is anticipated, a thorough ecological evaluation of the predisturbance characteristics can be undertaken. Examples of this situation are surface mining, discharge of sewage or chemical wastes, construction of a manufacturing plant, or construction of a dam or a highway.

Three major determinations must be made following ecological disturbance before appropriate corrective action can be taken: the degree of change; the area in which change has occurred; and the ecological significance of the change, including the probability that it will adversely affect adjacent ecosystems. Some questions will assist in these determinations; for example: What is (or was) the ecosystem like (including variability)? At what rate does normal change occur? How does one determine a deviation from the nominative (as defined in Odum et al., 1979) state? What parameters provide an early warning of recovery malfunction?

DESIGNATED USE CATEGORIES

Regulatory criteria for judging recovery of damaged ecosystems may be dramatically different from criteria based on ecological principles. Illustrations of this point are based entirely on water, since I know this area best. The Clean Water Act defines acceptable uses for water and mandates continuation of specified uses. These include propagation of fish and wildlife, public water supply, recreation, agricultural, industrial, and navigation (Sec. 303, C, 2 Clean Water Act). The U.S. Environmental Protection Agency (1980), in reviewing the regulations enacted by the 50 states, indicates that the states have at least 15 general use categories for streams. However, only one of these categories—propagation of fish and wildlife—was common to all. This is most fortunate, because it is a category entirely compatible with sound ecological principles, whereas navigation is not. However, the regulatory requirements for a significant number of use categories may be satisfied by water quality most ecologists would not consider ideal for aquatic life. It is important to recognize that both the types and number of specific use categories developed by each state are often driven by the needs of its commerce.

DECIDING ON RECOVERY GOALS

Magnuson et al. (1980) have noted that one might *restore* a displaced ecosystem to its original condition, *rehabilitate* it by restoring some of the most desirable original features, or choose some alternative ecosystem that has been designated *enhanced* (Figure 1). Other alternatives are to let the degradation proceed if the stress has not been removed, or to let it remain in its present condition if the stress has been removed but there are no signs of recovery. There are some instances, such as the use of dispersants in oil spill cleanup, where the management practices proved more harmful to the ecosystem than doing nothing. As a consequence, situations exist where knowledge of the system itself and the recovery process, or of the effects of the

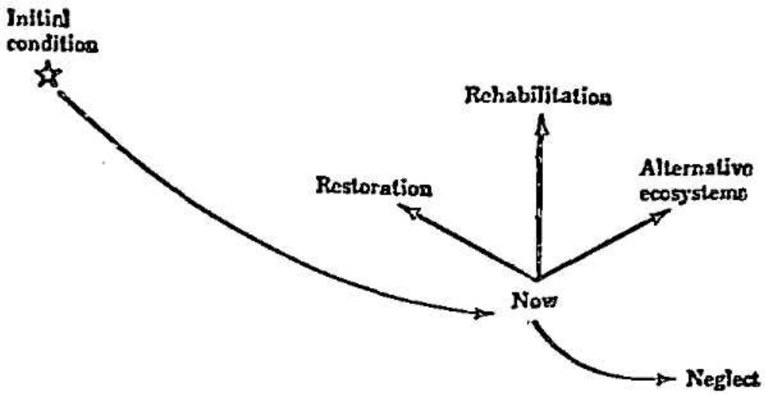


FIGURE 1. Management options for surface-mined lands. (Modified from Magnuson et al., 1980.)

cleanup processes, are so poorly understood that doing something might prove more harmful to the ecosystem than doing nothing. This is repugnant, particularly to Americans who tend to feel that immediate positive action should be taken in almost every situation. (Readers wishing to study some case histories for Europe and North America can find them in some of the books listed under suggested reading.)

When there is insufficient data to decide among alternative recovery goals or actions, one positive course of action is research. If properly designed, such research into alternative recovery projects can proceed in such a way that mistakes can be quickly rectified, and the information generated can be more generally applied to a number of other sites. This will require enormous flexibility and mutual trust on the part of the regulatory agencies, the industry causing the damage, and the academic community or consulting firms carrying out the study. Flexibility of the regulatory agency will be essential because whatever course of action is taken will probably not comply with existing laws and regulations. Flexibility is essential on the part of the industry (or other group causing the damage) because it will be faced with what it will probably regard as unjustifiable research expenses. This group may prefer a court fight to a study that will further understanding of the recovery process if it thinks the fight will be less expensive. The academic community will have to be flexible because, although it is naturally interested in the research aspects of the study, it must also realize that the information generated must be useful in the decision making process and must be, in so far as possible, cost effective. All of this must be communicated effectively to the general public before the study begins.

RECOVERY OF ECOSYSTEMS FOLLOWING DISTURBANCE

Criteria for determining degree of recovery

Criteria selected to characterize ecosystem recovery must not only be scientifically sound but must, of necessity, encompass a broad range of attributes related to the expectations of and intended uses by the general public. Ecologists must recognize that industry is unlikely to take any action not required by law unless there are compelling economic reasons to do so. In the United States, the Environmental Protection Agency and the individual states, in continuing to meet their responsibilities, must promulgate regulations using the best information available to establish degrees of recovery. They are not likely to embrace joyfully the latest research finding, even if published in the most prestigious scholarly journal, until it is widely accepted and used. A number of other factors also influence acceptance.

1. *Reliability of extrapolations from one system to another.* Since ecologists regularly emphasize the uniqueness of each ecosystem, regulators and industry may be wary of claims of general applicability of results and/or methods. As a consequence, the reliability of extrapolations must be adequately documented.
2. *Interpretation.* What does the parameter or characteristic mean in terms of environmental recovery? Do ecologists agree on this interpretation? Will laymen, including courts of law, accept this interpretation and the level of significance assigned to it? In short, the interpretation must have the endorsement of a substantial majority of professionals and, if possible, its significance should be understood and accepted by the public.
3. *Sensitivity.* From a regulatory standpoint, each response or end point should be sufficiently sensitive to avoid excessive false positives (that is, no one should think that the ecosystem has recovered when it has not).[1] At the same time, industry will want an end point that does not produce excessive false negatives (that the system has not recovered when it has). The precise level of sensitivity finally accepted will be a function of an array of factors, including the number and kinds of alternative methods that provide confirming or alternative evidence, the objectives of the study, the correspondence of the end point to ecosystem stability, and the consequences of error in estimating the degree of recovery.

[1] For those unaccustomed to these word usages, Cairns (1985) might be helpful.

4. *Variability*. If the response being measured is a discrete variable (such as diversity), the precision of the measurements being made can be more easily documented than is possible for nondiscrete variables (for example, nutrient spiraling). Nevertheless, a rough positive correlation appears to exist between the relative sensitivity of the tests and the degree of variability encountered. It is possible that variability of functional parameters is itself an indicator of ecosystem condition. Both J. Harte (personal communication) and I have noted increased variability of functional attributes in microcosms under stress. However, even if this hypothesis is correct, simultaneous attempts to optimize sensitivity and reduce variability will almost certainly not succeed. Since both are desirable, a compromise between the acceptable degree of sensitivity and reduced variability is the probable outcome. Considerable professional judgment will be required for these decisions because a fixed formula for reaching a decision seems unlikely.
5. *Replicability*. From a regulatory standpoint, methods used for determining degrees of recovery should be sufficiently simple and standardized so that they can be routinely used by a variety of laboratories (consulting firms, state and federal agencies, industry, and academia) that have widely varying capabilities. Since our knowledge of the recovery process in damaged ecosystems is not extensive, it is unlikely that methodology meeting these criteria will be available soon. An interim alternative would be a group of "ombudsmen" or a "science court," composed of respected professionals with experience in these matters, to determine the adequacy of the proposed methods (and staff competency to use them and interpret the results) on a site-specific basis. This approach presents a number of disadvantages (such as finding qualified people willing to serve), but, given the complexity of the problem and our present state of knowledge, there are no other good solutions or alternatives.

Selection of end points to demonstrate a desired state has been achieved

At the population level, end points are relatively well known and fairly generally accepted. Examples include reproductive success, recruitment rate, and age and sex structure. End points for higher levels of biological organization include productivity, diversity, trophic balance, and nutrient spiraling, among others. The probability of achieving anything approaching a professional consensus on the relative importance, reliability, replicability, measurement, interpretation, and a variety of other issues regarding end points at the community and ecosystem level is small. During this period, ecological end points might easily be discarded and replaced with horticultural ones (for example, easily established vegetation) if the discussion is so contentious that laymen lose confidence in ecological end points.

The first step in establishing criteria for ecosystem recovery or achievement of alternative goals (such as rehabilitation) is an investigation into the organization, nature, and function of a number of types of systems needed for the decision making just described. There must also be recognition that changes in ecosystem characteristics are more often step functions than trends, and that ecosystems are highly variable. Recent evidence suggests that species aggregates may be one of the criteria for the recovery of ecosystems. In this case, "modules of species" means interacting subsets of the larger natural community that can be maintained in a natural state in the laboratory. Where various interactions occur, the use of modules of species to predict ecosystem condition has promise. The use of "guilds" (species that exploit the same class of environmental resources in a similar way) for estimating ecosystem condition is another alternative worth investigating.

The "performance" of a system is anything the system does as a whole, including its state and structure. End points should not be based on transitory system performance because these are likely to generate false positives or negatives with regard to condition. However, if one can determine the capacity or potential of the system to perform,[2] this would allow the selection of end points that are most invariant and presumably most fundamental.

Whatever end points are chosen to document ecosystem condition, their relevance must be communicated to the general public and to decision makers in regulatory agencies, industry, and various levels of government. An illustrative checklist follows.

1. *Technical relevance.* Does the end point represent a realistic measure of population, community, or ecosystem condition? Using this information, can one determine the degree of ecosystem change following disturbances based on objective criteria?
2. *Social relevance.* Is the end point meaningful to the public? If not, an effort must be made to communicate the information and reasoning. Our present economic situation requires that any activity requiring substantial investment be understood and supported.
3. *Legal relevance.* One must establish that each end point is useful for establishing that ecosystem condition following disturbance is

[2] "Capacity to perform" means processing nutrients, cycling energy, and other functions characteristic of ecosystems (Cairns, 1985).

satisfactory. The information has no legal relevance unless it influences the decision being made.

4. *Cost and timing.* Well-publicized increases in energy and labor costs coupled with tough foreign competition have made industries extremely cost conscious in recent years. Federal deficits and pressures on state tax funds have produced comparable pressures in regulatory agencies. In industry, these pressures are manifested by a reluctance to do anything not required by law. In regulatory agencies, one important manifestation is an attempt to standardize the actions necessary to demonstrate compliance with legislation. In addition, persuasive information must be provided that the cost is reasonable in terms of the objectives. Cost is, as usual, largely a function of the time necessary to carry out the tests, space and facilities required, and the level of professional competence necessary to generate data and interpret them. The decisions regarding acceptable costs are driven primarily by the degree of certainty required about ecosystem condition.

REGULATORY CONDITIONS FOR TERMINATING MANAGEMENT RESPONSIBILITIES

Phase I

The organization responsible for damaging an ecosystem can be identified in a majority of cases. If damage was caused by normal operations, as in strip mining, all necessary information should be part of the permitting process. Where ecosystem damage is the result of an episodic event, such as a catastrophic spill of hazardous chemicals, defining the damaged area and the extent of the damage precisely may be extraordinarily difficult and is often impossible. This is particularly true of spills into the atmosphere. The highest priority should then be given to defining the fate of the material spilled, including touchdown points for atmospheric movement and transformations in water and soil. Simultaneously, biological evidence should be gathered, including estimates of damage through acute toxicity, estimates of bioconcentration and accumulation, and estimates of long-term toxicity, using laboratory and microcosm tests for materials that are persistent or bioconcentrating. In cases where delayed effects are anticipated for any reason, biological monitoring programs should be designed and implemented to document these and predictive models should be developed to aid in this process. In addition, the following institutional and administrative steps should be taken:

1. The organizational structure and responsibilities of various components should be immediately and crisply defined.
2. A means of pooling and sharing information should be immediately developed, preferably utilizing a system already prepared for this purpose.
3. The credentials and qualifications of the organizations and personnel employed in the tasks just described should be carefully examined to eliminate at least the grossly incompetent and to reduce conflict over the quality and interpretation of the data when they are finally analyzed.
4. A quality assurance program, preferably along the lines of a standard practice recommended by the American Society for Testing and Materials or some other standard-setting agency, should be followed.

Phase II

Once the extent of the damage has been defined as precisely as possible, a management decision should be made on which of four options should be used (Cairns, 1983). These are:

1. Restoration to original condition.
2. Rehabilitation of some of the original conditions and possibly some that were not there originally.
3. Development of an alternative ecosystem (e.g., a pond or lake where there was a terrestrial ecosystem previously).
4. Neglect or natural reclamation (doing nothing either because of inadequate information, or because the courses of action available might incur additional damage).

Although ecologists instinctively want to choose restoration to original condition, this is not always possible, either for physical reasons or because the knowledge or funds are not adequate to ensure success. For example, strip mining in the western part of Virginia and most of the state of West Virginia, as well as parts of Kentucky, is carried out in areas where the slope may well be in excess of 20 degrees (Figure 2). Under these conditions, restoring to original contours is often impossible for two reasons. First, even after coal or minerals have been removed, the broken up rock and other material will often not fit in the space from which it was removed. Replacement on the original site most commonly results in a bulge of material that does not closely resemble the original contour. Second, even if the original contours are restored in areas where the slope is steep, it is unlikely

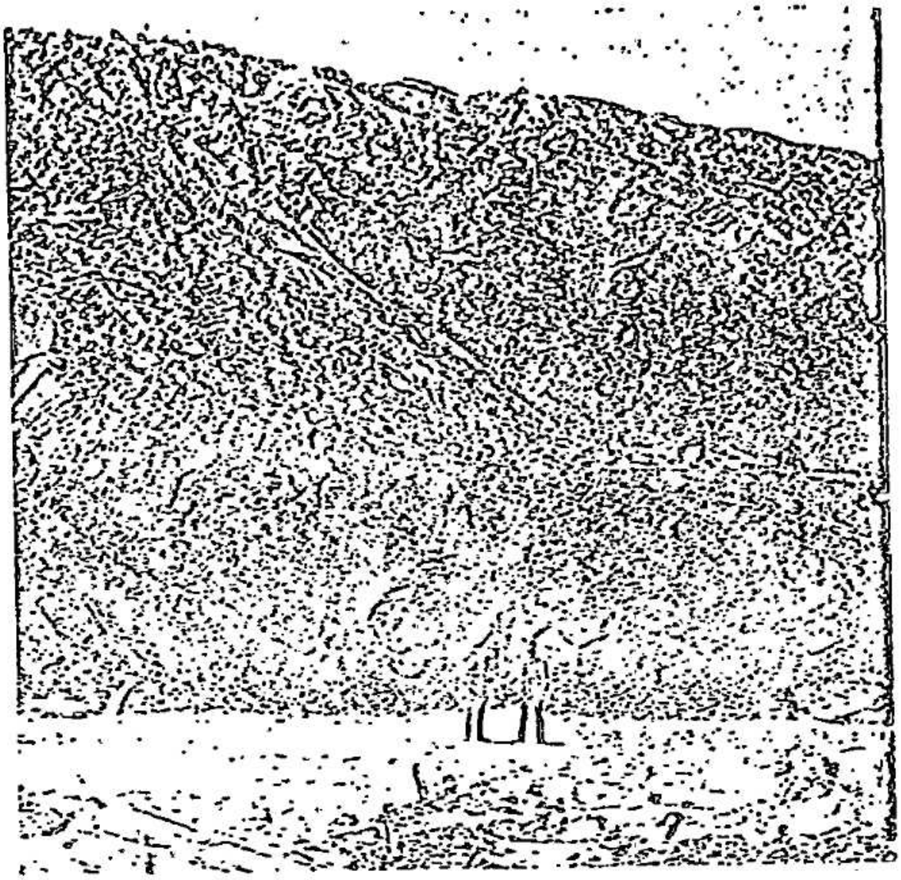


FIGURE 2. Devastated landscape generated by unregulated coal surface mining in the southern Appalachians of Virginia. Ecosystem recovery on such sites is hampered by acid spoil materials, excessive spoil compaction, low water holding capacity, and low levels of nitrogen and phosphorus available for plants. (Courtesy of W.L. Daniels, Powell River Project.)

that they will be maintained long enough for the indigenous vegetation to become fully established.

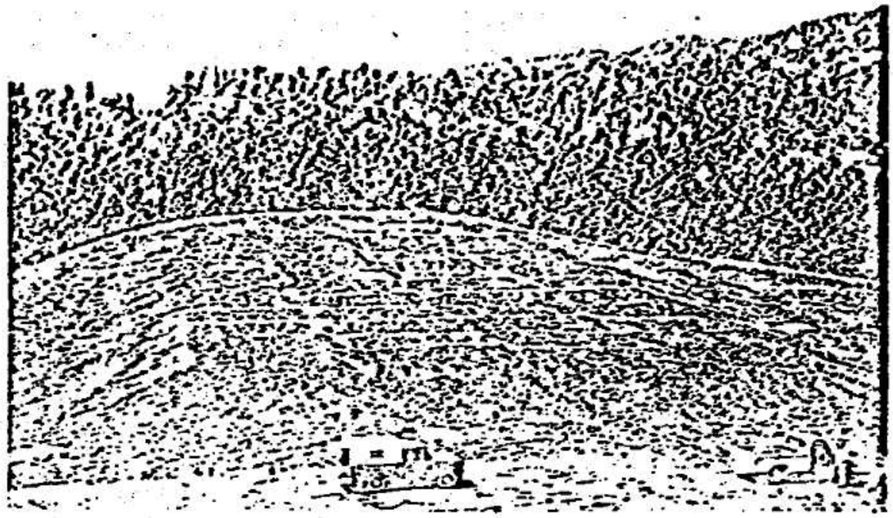
In the phosphate mining areas of Florida, where large quantities of material are removed from the surface of a relatively flat landscape, a majority of the citizens may prefer lakes to the original condition of the land. If any option other than restoration to original condition is selected, a determination must be made as to whether the level of importance of the ecosystem is national, state, or local. It is important that the citizens (or their representatives) at the level selected be fully informed in lay terms of the reasoning behind the selection of the alternative options, the course of action proposed, the time frame within which it will occur, and that they be given a fairly explicit description of the final product. One or two open public meetings would be the best course of action at the local level. For larger systems, a consensus reached by representatives of various organizations, environmental and commercial as well as public, will probably furnish the most detailed and important commentaries. At any rate, some considerable attention to these matters will be essential.

Phase III

The proposed course of action decided upon in Phase II should be immediately undertaken because there is good evidence that postponement often increases the cost of whatever option is finally chosen. Additionally, the ecosystem will presumably serve a wider variety of public needs after whatever course of action is undertaken than it will in its damaged condition. If the damage was caused by a persistent hazardous chemical, there are public health reasons for expeditious action. The work of the organization(s) chosen to implement the course of action selected should be monitored by a scientific advisory group representing the various interests involved. The advisory board should make periodic reports in lay terms to the representatives of interested organizations and the general public. Detailed evidence should be made available to them on the progress being made as well as any reasons for deciding the performance has been satisfactory or unsatisfactory.

Phase IV

Determining when management responsibilities for implementing the option chosen have been fully met is particularly difficult because of lack of evidence on the reasonableness of the various courses of action. For example, for Virginia strip mine reclamation, all of the practices are implemented immediately (grading, seeding, planting, fertilizing, etc; Figure 3). Then at the end of five years, the results are examined and determined satisfactory or unsatisfactory by a state agency. Since the five-year period has not yet elapsed for any of the sites known to me, it is difficult to determine how successful this particular policy will be. I have chosen it because it illustrates some of the problems involved. The intent is clearly sound—namely, to have vegetation that will survive the climatic conditions of that region without management intervention for a moderate number of years. Since the organization doing the strip mining is bonded and a significant amount of money is tied up while the bond is in effect, the five years represent



(A)

(B)

FIGURE 3. Thick, uncompacted, productive minesoils produced by controlled placement, grading, fertilization, and seeding of nontoxic overburden in southwest Virginia. (A) Approximately two months after seeding; the vigorous growth in the foreground plots is due to sewage sludge applications. (B) Photograph taken after the end of the second growing season, usually the critical period for the establishment of permanent vegetation. In order for this plant–soil system to become fully self-sustaining, however, considerable amounts of atmospheric nitrogen and mineral phosphorus must be fixed into organic form by the vegetative and microbial communities, then decomposers must become established to release the nutrients back to the plant community. To achieve this, a diversity of nitrogen-fixing legumes, grasses, and woody species must be established on the site with appropriate microbial populations. (Courtesy of W.L. Daniels, Powell River Project.)

a compromise between ecologists, who might feel that it is not enough time, and those paying for the bond, who almost certainly feel it is too long. During the five years, no additional seeding, fertilizing, watering, or other management practices are permitted. One might make a good case on ecological grounds for permitting two years of management of any kind and requiring that the system be acceptable after three years of no-management intervention. It seems at least possible that the quality of the ecosystems might be better and that more of them might meet the specifications required if the management period were longer. It might also reduce the cost even if only by spreading it over a greater number of years. More important, the number of total failures should be reduced as should the number of fresh starts required.

To my knowledge, an explicit statement of ecosystem qualities that will be required to determine when management is no longer needed in the rehabilitation process (whether the initial disturbance was strip mining, hazardous chemicals, or anything else) is not available. Furthermore, it seems improbable even if a list were available that qualities such as stability or diversity would be uniformly interpreted by a majority of ecologists (Pimm, Chapter 14). Ecologists should give considerable attention to these matters, not only because they are of considerable national and international importance but because they are an ideal means of testing our understanding of ecosystems and a number of theoretical models. We should also keep in mind that perfection in these activities will probably not be achieved in our lifetimes, but improvement over the present situation is almost guaranteed. Therefore, flexibility in our attitudes, as well as the regulatory and industrial attitudes, should be fostered.

ECOSYSTEMS RISK MATRIX

Every ecosystem in the world is theoretically at risk from an accidental spill of hazardous material or from such widespread problems as acid rain. However, certain types of ecosystems undoubtedly are disturbed more frequently than others, and vulnerability to disturbance is clearly not uniform. A simple association matrix (Table 1) can be used to identify the categories where information should be obtained. Ecologists will undoubtedly have a difficult time determining degrees of vulnerability, but even the crudest estimate will enhance efforts to develop better precision.

Another correlation that will help with decision making relates the severity of disturbance to the time of recovery or the degree of ecosystem displacement. Possibly the latter should be used initially

TABLE 1. Simple association matrix to determine categories of information needed on recovery of ecosystems with different frequencies of disturbance and varying vulnerability.

Frequency of disturbance	Vulnerability to disturbance: Extremely vulnerable [1]	Highly vulnerable [2]	Moderately vulnerable [3]	Minor vulnerability [4]
[1] Once a year or more	1	2	3	4
[2] 1–3 years	2	4	6	8
[3] 3–10 years	3	6	9	12
[4] 10–100 years	4	8	12	16
[5] >100 years	5	10	15	20

since there is a toxicological data base for making the displacement estimate but little information for estimating recovery time.

HAZARDOUS WASTE SITE CLOSURE

Although hazardous waste sites are small in total area, their closure will be one of the most difficult problems we face in rehabilitating disturbed ecosystems. These sites were developed for chemicals so hazardous to human health and the environment that immobilization and storage were considered preferable to release into the environment. Although there are some exceptions, most of the material is difficult to transform into less harmful material. Unfortunately, many of these sites were poorly designed—as most of the public now knows. Monitoring of their performance has ranged from nonexistent to exemplary. Because containment of the hazardous wastes has not been as effective as originally predicted, or because new methods for improved containment or transformation of the hazardous materials are now available, closure of many of these sites is now being considered. In many cases, hazardous materials will have seeped into the surrounding area and may be difficult to isolate and immobilize. In such cases, rehabilitation of the disturbed ecosystem will have to be carried out in such a way as to minimize risk to human health and the environment in the surrounding area rather than selecting characteristics matching those of the original ecosystem.

The most important criterion for selecting colonizing species will be reducing transport of hazardous chemicals into the surrounding area. Transport might occur because species from the surrounding area feed in the disturbed site or when the hazardous material is transported as detritus. In addition, the probable effect of any introduced organisms on the geohydrology must be given serious attention. If they alter soil characteristics (such as density, porosity, or permeability), the hydrostatic conductivity or gradient, the infiltrating rainwater rate, or the groundwater or surface water flow rates, the transport of the residual hazardous waste will almost certainly be altered, possibly in an undesirable way. Fortunately, if the preceding information is known, then equations using contamination as a function of depth, soil adhesion properties, distribution coefficients, solubility, and the like will permit relatively accurate predictions of transport potential. These provide estimates of contamination as a function of distance and time, unsaturated and saturated zone transport rates, hydrological flux, surface and subsurface water contamination potential, and material balance. For example, a pathway analysis for metals transport would show the transport rate to be affected markedly by soil adhesion properties. These would in turn be affected by such things as pH and alkali and organic content of the soil. One could then use regulatory standards for the hazardous materials to determine whether or not the measures taken to implement ecosystem recovery from disturbance would keep the concentration of the hazardous substances within acceptable limits.

ARE ECOSYSTEM SERVICES MORE EASILY RESTORED THAN ECOSYSTEM FORM?

An important but essentially unaddressed question is whether ecosystem "services" (functions beneficial to society) are more easily restored than ecosystem form (species diversity, trophic structure, and the like). There are three possible scenarios:

1. Ecosystem form and services are so intimately related that one cannot be restored without inadvertently restoring the other.
2. There is so much functional redundancy in natural systems that services can be restored much more easily than form.
3. Ecosystem form must be restored completely in order that the services be delivered under all seasonal and other changing conditions, as well as to reduce the management costs that are incurred when functional redundancy is minimal.

Magnuson et al. (1980) differentiate between ecosystem *recovery* (a return to original condition following displacement) and *rehabilitation* (restoration of certain desirable attributes that have been altered, but not all of the original attributes). They believe that under certain circumstances certain portions of the original form as well as certain of the original services can be restored independently of some of the other attributes. There seems to be some empirical evidence that this can indeed be accomplished (examples include the restoration of the Thames River in the United Kingdom and Lake Washington in the United States). Additionally, they make a case for the creation of alternative ecosystems in which both form and services (these words were not used but implied) could be totally different from the original condition but designed to meet societal needs using ecological management principles.

I have discussed elsewhere (Cairns, 1983) the difficulties of having an adequate information base, as well as the scientific capability for restoring disturbed ecosystems to their original condition. Environmental impact statements often have exhaustive inventories of indigenous species, but I think even the most charitable ecologist would not accept an inventory alone as an adequate description of ecosystem form. Spatial relationships, recruitment rates, population and community dynamics, predator/prey relationships, trophic interrelationships, and a variety of other attributes would be necessary to describe ecosystem form adequately. As a consequence, even when a complete species inventory is available, restoring to original form will not be easily accomplished.

Most environmental impact statements pay little or no attention to ecosystem services, at least in so far as they are related to ecosystem function. The functional attributes of ecosystems upon which services presumably would depend heavily either are not described at all or are given only cursory attention. In cases of accidental spills where no predevelopment information was gathered (as opposed to surface mining and other types of planned disturbance), one would be forced to use presumably comparable ecosystems as models for restoring either form or services.

Ironically, both form and services are more easily described for alternative ecosystems than for most original ecosystems. This is because the alternative ecosystems in relatively common use are based on well-tried aquacultural or horticultural practices to achieve comparatively limited objectives. For example, a lake or pond that replaces a terrestrial ecosystem consisting of pine, shrubs, etc. would have an ecosystem form designed to optimize recreational fishing services. If an array of restoration options, all attractive to the public and achievable, are to be available, the scientific information base on restoration of ecosystem form and services must be markedly improved.

USING DAMAGED ECOSYSTEMS TO PRESERVE RARE, ENDANGERED, AND THREATENED SPECIES

The number of rare, endangered, and threatened species is probably increasing exponentially (Myers, Chapter 19). A large number of these will probably be lost forever if protective measures are not implemented soon. Another major problem is the increasing number of damaged ecosystems, many of which cannot be restored to their original condition either because the original condition is unknown or because the science and technology to do so are not presently available (Pimm, Chapter 14).

There is a marvelous opportunity to address both these problems simultaneously when the ecosystem cannot be restored to original condition. In some of these cases, the ecosystem could be restored in such a way as to enhance the chances of survival for one or more rare, endangered, or threatened species. Since a large number of species are in difficulty because of habitat loss, possibly some favorable habitat might be restored on the sites of surface-mined lands or where other types of damage have occurred. Surface-mined lands can be rejuvenated in the ecological sense to either aquatic or terrestrial ecosystems. Since restoration is now mandated by law, the alternative form of rehabilitation just espoused can be implemented through increasing the flexibility of both state and federal regulatory authorities (Cairns, in press).

In this age of computer data sorting and information display, a list could easily be compiled of rare, endangered, and threatened species by region, together with a list of habitat requirements for each one. A printout would be available of the damaged ecosystem sites where rehabilitation is contemplated along with a list of their habitat conditions at present and how well they match those of the rare, endangered, and threatened species. Considerable scientific judgment would be necessary to determine how many of the missing habitat characteristics could be supplemented in an ecologically justifiable way to meet the requirements of one or more species. This idea should be tested in three stages.

1. Stage 1 involves making a damaged ecosystem acceptable to a relatively common species indigenous to the region. The advantage of doing this is that it enables one to work out the ecological prerequisites and to test predictive models without risking a species

already in danger. This design offers a higher probability of success because the habitat requirements are being checked against a large number of existing habitats within the region. In the case of an endangered species, the current habitat is probably very restricted. Such a species, therefore, is not a good candidate for a research program of this magnitude. It is worth noting that Stage 1 should pose no serious regulatory problems because a damaged ecosystem is being restored to provide habitat for a component of the indigenous biota. However, some regulatory flexibility will be required because that species may not have lived on this particular site before it was destroyed.

2. When a sufficient number of successful demonstration projects have materialized and the habitat modeling has become more precise and scientifically sound, Stage 2 can begin. In this stage, a threatened species from the same region will be used, but the species should not be threatened everywhere. This will enable a further check on the rehabilitation model's capabilities and species habitat requirement estimates and, at the same time, introduce another important component: moving a species that is not doing well elsewhere in the same region to a site where ecological conditions are thought to be better as a consequence of the rehabilitation effort. The importance of this exercise is to determine whether a strain or race can be established on a site other than the one it inhabits. No doubt many variations will occur among plants and animals that are on one of the three lists; part of this exercise is to accumulate information on the types of variablity and adaptability that exist. Presumably, most threatened species are in danger because of their limited adaptability, but this may not necessarily be true.
3. For the final and crucial Stage 3, an endangered species likely to become extinct soon will be considered, and regenerated habitat on a damaged ecosystem site will be used for continuing its existence. In a sense, the site would be similar to an outdoor "zoo" or a botanical garden, but with a habitat that would permit natural recruitment of replacements for the species.

Organizational requirements

Perhaps an organization such as the Nature Conservancy could accept the organizational requirements of this new mission. If not, perhaps a new organization, the "Species Conservancy, could be formed. Alternatively, various wildlife organizations already devoted to the preservation of species might form a consortium for this purpose. Among the responsibilities of the organization would be:

1. Identifying species that need help and matching their needs with potential sites.
2. Gathering experts with the appropriate experience to carry out each specific project.
3. Accepting the management responsibilities and stewardship of those sites where the effort is successful. Presumably, a few people in the vicinity of each site might form an organization for this purpose.

Financial support

Since industries and organizations that have damaged ecosystems are now legally responsible for their rehabilitation, in some instances this proposed process could be paid for entirely within these requirements. In others, more than the normal cost of rehabilitation may be necessary; this might be provided by special tax incentives to the industry or other organization responsible for the rehabilitation. In other cases, additional funding will undoubtedly be necessary. A particularly troubling problem will be those instances where the attempt to turn a damaged ecosystem into an acceptable habitat for a particular species has failed and the site must be rehabilitated for other purposes. Presumably, since an ecologically viable system was produced, it could be left alone without any further effort. In some instances, the continuing management requirements for ecological stability might be greater than they would have been with "normal rehabilitation." In such instances, the industry or other organization willing to experiment should not be penalized for doing so, and additional funds should be available for such experimentation. Since the National Science Foundation and other government funded agencies have been instructed to consider some of the practical benefits of research, perhaps some of the funding could be through these traditional sources.

Derelict or abandoned ecosystems, where the people and institutions who should bear the burden of the rehabilitation costs are no longer alive or accessible, pose a particular problem. The cost of such rehabilitation will clearly have to be borne by either state or federal governments. These sites are the ones in which particularly risky experimentation should be carried out, leaving the more straightforward rehabilitation for sites where funding sources other than tax dollars are more clearly available. The opportunities for ecological research on such sites are enormous (Cairns, in press), and perhaps directing some of the purely theoretical projects to sites of this sort might furnish additional evidence that will help in habitat rehabilitation and, at the same time, furnish data that will be useful to theoretical ecologists.

SUGGESTED READINGS

Bradshaw, A.D. and M.J. Chadwick. 1980. *The Restoration of Land.* University of California Press, Berkeley.

Cairns, J. Jr. (ed.). 1980. *The Recovery Process in Damaged Ecosystems.* Ann Arbor Science Publishers, Ann Arbor, MI.

Cairns, J. Jr., K.L. Dickson and E.E. Herricks (eds.). 1977. *Recovery and Restoration of Damaged Ecosystems.* University Press of Virginia, Charlottesville.

Dubos, R. 1980. *The Wooing of Earth.* Charles Scribner's Sons, New York.

Hardin, G. and J. Baden (eds.). 1977. *Managing the Commons.* Freeman, San Francisco.

Holdgate, M.W. and M.J. Woodman (eds.). 1978. *The Breakdown and Restoration of Ecosystems.* Plenum, New York.

Janick, J. 1963. *Horticultural Science.* Freeman, San Francisco.

Lewis, R.R. III (ed.). 1981. *Creation and Restoration of Coastal Plant Communities.* CRC Press, Boca Raton, FL.

Loehr, R.C. (ed.). 1977. *Land as a Waste Management Alternative.* Ann Arbor Science Publishers, Ann Arbor, MI.

Swanson, G.A. (coordinator). 1979. *The Mitigation Symposium.* General Technical Report RM-65, U.S. Government Printing Office, Washington, DC.