United States
Environmental Protection
Agency

Science Advisory
Board
Washington, DC 20460

EPA-SAB-EPEC-95-003
March 1995

EPA

An SAB Report: Ecosystem Management

Imperative for a Dynamic World

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

March 31, 1995

EPA-SAB-EPEC-95-003

OFFICE OF THE ADMINISTRATOR
SCIENCE ADVISORY BOARD

Honorable Carol M. Browner
Administrator
U.S. Environmental Protection Agency
401 M Street, SW
Washington, DC 20460

Subject: SAB Environmental Futures Project--EPEC Futures Report "Ecosystem Management: Imperative for a Dynamic World"

Dear Ms. Browner:

The Ecological Processes and Effects Committee (EPEC) of the Science Advisory Board (SAB) has completed its report on Environmental Futures that discusses ways to use foresight in managing risks to ecosystems. This report is one of seven prepared by the SAB in response to your request that we look at Environmental Futures methodologies and evaluate a few future developments in detail.

In response to your request, the Executive Committee formed an Environmental Futures Committee to direct the activities of the Board. EPEC, which has primary interest in assessing the ecological consequences of human activities, focused on three elements of the overall charge:

a) developing a procedure for conducting in-depth examination of key future developments;

b) demonstrating the procedure using example scenarios; and

c) drawing implications and recommending actions to address future ecological risks.

In addition, the Committee was most concerned with longer time horizons (30 years or more) since ecosystems impacts and responses are best considered on decadal time scales. The time lag between imposition of stresses and ecosystem response creates unique challenges for managers and policy makers, making futures analysis particularly important for managing ecological risks.

The Committee based its approach on the principles developed in *Reducing Risk: Setting Priorities and Strategies for Environmental Protection* (EPA-SAB-EC-90-021) and the Agency's *Framework for Ecological Risk Assessment* (EPA/630/R-92/001). In our report, we describe a conceptual model for futures analysis that combines the use of future scenarios and the ecological risk assessment framework to provide a formalized approach to assess future ecological risks. EPEC was the only Committee that used both a conceptual model and scenarios in its futures assessment. The specific scenarios chosen are less important than the intellectual process of making assumptions about critical drivers of change, exploring the possible impact of such changes on stressors and ecosystems at risk, and evaluating risk management options to avoid or mitigate ecological risks. This methodology can add value and broader perspective to a wide range of planning, budget, and rulemaking activities.

The Committee demonstrated the approach for futures analysis by applying it to two scenarios of energy development and consumption in the U.S. As a result of this exercise, we offer the following broad observations and recommendations:

a) *The conceptual model for futures analysis can and should be used routinely and systematically by the Agency to establish a broad, comprehensive perspective on future ecological risks.*

The intellectual exercise of developing and evaluating scenarios using the conceptual model led us to consider ecological consequences that would probably not have arisen during an unstructured brainstorming. For example, we concluded that a future with abundant, very low cost energy may bring greater, rather than fewer, ecological risks. Such an effort would greatly enhance the Agency's ability to identify and evaluate emerging issues that pose the greatest ecological risks (and, by extension, risks to humans) and determine those issues for which the greatest risk reduction could be obtained per unit of funding or research effort.

b) *Futures analysis underscores the importance of focusing the national environmental agenda on protecting the integrity of ecosystems and landscapes.*

The ecosystem management paradigm, while still evolving, embodies the need to consider ecosystem products and services, the chemical and energy linkages within and between ecosystems, the importance to ecosystem health of human actions and policies, and the integration of ecological and societal goals and constraints.

c) *Effective risk management requires information on societal goals and values, improved monitoring of resource status and trends, and the greater emphasis on transfer of environmentally friendly technologies to developing nations.*

d) *The Committee reaffirms the conclusions in Reducing Risk that national ecological risks are dominated by larger-scale and longer-time issues, including global climate change, habitat alteration, ozone depletion, and introduction of exotic species.*

EPEC appreciates the opportunity to participate in the Environmental Futures Project, and we would like to assist the Agency in developing and applying the conceptual model and the ecosystem management paradigm described in this report. We look forward to your response to our recommendations.

Sincerely,

Dr. Genevieve M. Matanoski, Chair
Executive Committee

Dr. Raymond C. Loehr, Chair
Environmental Futures Committee

Dr. Mark A. Harwell, Chair
Ecological Processes and
Effects Committee

Dr. Kenneth L. Dickson, Chair
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Ecological Processes and
Effects Committee

EPA-SAB-EPEC-95-003
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An SAB Report: Ecosystem Management - Imperative for a Dynamic World

Prepared
by the
Ecological Processes and Effects Committee

Science Advisory Board
U.S. Environmental Protection Agency
Washington, DC 20460

Notice

This report has been written as part of the activities of the SAB, a public advisory group providing extramural scientific information and advice to the Administrator and other officials of the U.S. Environmental Protection Agency (EPA). The SAB is structured to provide balanced, expert assessment of scientific matters related to problems facing the Agency. This report has not been reviewed for approval by the Agency and, hence, the contents of this report do not necessarily represent the views and policies of the EPA, nor of other agencies in the Executive Branch of the federal government, nor does mention of trade names or commercial products constitute recommendation for use.

Seven reports were produced from the Environmental Futures Project of the SAB. The titles are listed below:

(1) Environmental Futures Committee EPA-SAB-EC-95-007

[Title: "Beyond the Horizon: Protecting the Future with Foresight," prepared by the Environmental Futures Committee of the Science Advisory Board's Executive Committee.]

(2) Environmental Futures Committee EPA-SAB-EC-95-007A

[Title: Futures Methods and Issues, Technical Annex to the Report entitled "Beyond the Horizon: Protecting the Future with Foresight," prepared by the Environmental Futures Committee of the Science Advisory Board's Executive Committee.]

(3) Drinking Water Committee EPA-SAB-DWC-95-002

[Title: " Safe Drinking Water: Future Trends and Challenges," prepared by the Drinking Water Committee, Science Advisory Board.]

(4) Ecological Processes and Effects Committee EPA-SAB-EPEC-95-003

[Title: "Ecosystem Management: Imperative for a Dynamic World," prepared by the Ecological Processes and Effects Committee, Science Advisory Board.]

(5) Environmental Engineering Committee EPA-SAB-EEC-95-004

[Title: "Review of Environmental Engineering Futures Issues," prepared by the Environmental Engineering Committee, Science Advisory Board.]

(6) Indoor Air Quality and Total Human Exposure Committee EPA-SAB-IAQC-95-005

[Title: "Human Exposure Assessment: A Guide to Risk Ranking, Risk Reduction and Research Planning," prepared by the Indoor Air Quality and Total Human Exposure Committee, Science Advisory Board.]

(7) Radiation Advisory Committee EPA-SAB-RAC-95-006

[Title: "Report on Future Issues and Challenges in the Study of Environmental Radiation, with a Focus Toward Future Institutional Readiness by the Environmental Protection Agency," prepared by the Radiation Environmental Futures Subcommittee of the Radiation Advisory Committee, Science Advisory Board.]

Single copies of these reports may be requested and obtained from the SAB, Committee Evaluation and Support Staff (1400), 401 M Street, SW, Washington, DC 20460 or by FAX (202) 260-1889.

Abstract

This report by the Ecological Processes and Effects Committee (EPEC) of the SAB was part of an Environmental Futures Project that the Board conducted during FY 1994. EPEC developed a conceptual model showing the relationship between the assessment of future environmental problems and the process of environmental risk assessment. The model was evaluated by developing two scenarios, descriptions of assumed possible future conditions, to reveal possible ecological consequences. EPEC concluded that the model was valid and appropriate for use by the Agency in developing guidance for the analysis of future environmental problems. They also noted that the process of considering possible future conditions and the driving forces and societal decisions today that would lead to those problems was more critical than the analysis. In addition, ecosystem management requires evaluations of very long-term trends, well beyond human generation times. The results of this analysis contribute favorably to the conceptual model and to an evolving ecosystem management paradigm that the Committee recommends the Agency develop. Specific possible future problems and a glossary are also appended.

KEY WORDS: Futures Analysis, Scenarios, Ecological Risk Assessment, Ecosystem Management

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Contents

1. Executive Summary

The Ecological Processes and Effects Committee (EPEC) of the EPA Science Advisory Board (SAB) developed a methodology and then applied it to examine the ecological consequences of future human activities. The Committee based its approach on the principles developed in *Reducing Risk: Setting Priorities and Strategies for Environmental Protection* (EPA-SAB-EC-90-021) and the *Framework for Ecological Risk Assessment* (EPA/630/R-92/001).

The conceptual model for futures analysis provides a methodology for developing and evaluating future scenarios by 1) making assumptions about driving forces and resource use (the ultimate causes of change); 2) identifying the interactions among drivers, stressors, and ecological endpoints; 3) delineating the causes and effects of environmental changes; and 4) exploring ways in which management actions can avoid, influence, or mitigate environmental risks. Comparing a series of scenarios can help to define "no regrets" actions that provide benefits under a wide range of scenarios, encourage the development of a strategic vision, and promote timely responses to unforeseen events.

The Committee evaluated the approach for futures analysis by applying it to two scenarios of energy development and consumption in the U.S. These scenarios (Low-Cost Energy Scenario and Oil Depletion Scenario) illustrate how the approach can be applied to identify the key components of environmental problems and consider how risks can be managed. Development and analysis of future scenarios are also recommended in the Technical Annex for the Environmental Futures Project (EPA-SAB-EC-95-007A).

Based on its futures exercise, the Committee developed the following conclusions and recommendations:

a) The conceptual model for futures analysis, which combines the use of scenarios and the analytical framework for ecological risk assessment (ecorisk framework), provides a formalized approach to assess future environmental risks.

b) This approach, when applied to two scenarios making assumptions about the cost and availability of energy, revealed possible ecological consequences that probably would not have been determined through an unstructured brainstorming.

   For example, in the Low-Cost Energy Scenario, the availability of abundant, low-cost energy was considered to result in expansion of human populations into previously minimally disturbed areas and increased per capita consumption, causing an increase in habitat fragmentation, biological depletion, and polluting by-products. In addition, light and noise pollution were predicted to become significant sources of ecological stress. Thus, a very low-cost energy future is not necessarily a "green" one.

c) Futures analysis reaffirms the importance of focusing the national environmental agenda on protecting the integrity of ecosystems and landscapes. The ecosystem management paradigm, while continuing to evolve, embodies the need to consider ecosystem products and services, the chemical and energy linkages within and between ecosystems, the importance to ecosystem health of human actions and policies, and the integration of ecological and societal goals and constraints.

d) Ecosystem management requires a larger-scale and longer-term perspective than typical human planning scales. However, management goals formulated on a regional or landscape scale must be implemented on a "local" scale by numerous public and private sector entities.

e) Effective risk management using futures analysis requires information on societal goals and values, improved monitoring of resource status and trends, and greater emphasis on transfer of environmentally friendly technologies to developing nations.

f) The Committee reaffirmed the conclusions in *Reducing Risk* that national ecological risks are dominated by larger-scale and longer-time issues, including global climate change, habitat alteration, ozone depletion, and introduction of exotic species.

2. Introduction

In July 1993, EPA Administrator Carol Browner requested that the SAB undertake an initiative, termed the Environmental Futures Project, to advise the Agency on ways to identify future environmental problems and provide the SAB's perspective on emerging environmental issues. The SAB Executive Committee consequently formed the Environmental Futures Committee (EFC) to direct the effort. The EFC requested the standing committees of the SAB to address the charge for areas of their particular expertise and interest and to produce separate reports that would supplement the overall report on Environmental Futures to be written by the EFC.

The charge to the EFC consisted of the following components:

a) develop a procedure for conducting a short- and long-term scan of future developments that will affect environmental quality and the nation's ability to protect the environment;

b) conduct as comprehensive a scan as practical to identify such important future developments;

c) choose a limited number of short- and long-term future developments for in-depth examination;

d) develop a procedure for conducting in-depth examination of key future developments;

e) apply the procedure; and

f) draw implications for the Agency from the in-depth examination of future developments and recommend actions for addressing them.

The EPEC held three public meetings, in January, February, and June of 1994, to discuss the Environmental Futures Project. EPEC has primary interest and expertise in assessing the ecological consequences of human activities. The Committee's contribution to the Environmental Futures Project focuses primarily on the last three components of the charge, although a discussion of ecological issues for the future is also included (Appendix B). In addition, the Committee was most concerned with longer term horizons, since ecosystem impacts and responses are best considered on decadal time scales (20 to 30 years, or more). Because of the time lags between imposition of stresses and ecosystem response, protection and management of natural systems raise issues of intergenerational equity; the policies and practices of one generation have strong impacts on future ecosystem values for succeeding generations.

3. Conceptual Model for Futures Analysis

The Committee adopted an approach for futures analysis based on the principles developed in *Reducing Risk: Setting Priorities and Strategies for Environmental Protection* (EPA-SAB-EC-90-021) and the *Framework for Ecological Risk Assessment* (EPA/630/R-92/001). In Appendix A of *Reducing Risk*, a matrix approach was used to evaluate the intensity of potential ecological effects, the uncertainties of these estimates, the type of ecological responses, and the time scales for ecosystem recovery following removal of the stressors. This approach provides a rational basis for evaluating ecological problems at various spatial scales (e.g., local, regional, and global) and temporal scales (e.g., 20 years, 100 years, and 1000 years). Similarly, the *Framework for Ecological Risk Assessment*, or ecorisk framework, provides a process for analyzing stressors and effects, characterizing risks, and examining consequences of risk management decisions. The premise of the ecorisk approach is that adverse ecological effects occur as a result of exposure to one or more stressors.

The conceptual model for futures analysis posed by the Committee (Figure 1) provides a methodology for evaluating future scenarios (developed using assumptions about driving forces) by 1) identifying the interactions among drivers (ultimate causes of change), stressors, and ecological endpoints; 2) delineating the causes and effects of environmental changes; and 3) exploring ways in which management actions can avoid, influence, or mitigate environmental risks. Comparing a series of scenarios can help to define "no regrets" actions that provide benefits under a wide range of scenarios, as well encouraging the development of a strategic vision, and promoting timely responses to unforeseen events.

Subsequent sections of this report describe the components of the conceptual model for futures analysis and its application in two example scenarios of energy development and consumption in the U.S. These scenarios illustrate how the approach can be applied to identify the key components of environmental problems and how risks can be managed. This exercise is the basis for recommendations in Section 8 for research and monitoring that would improve the Agency's ability to address future environmental problems.

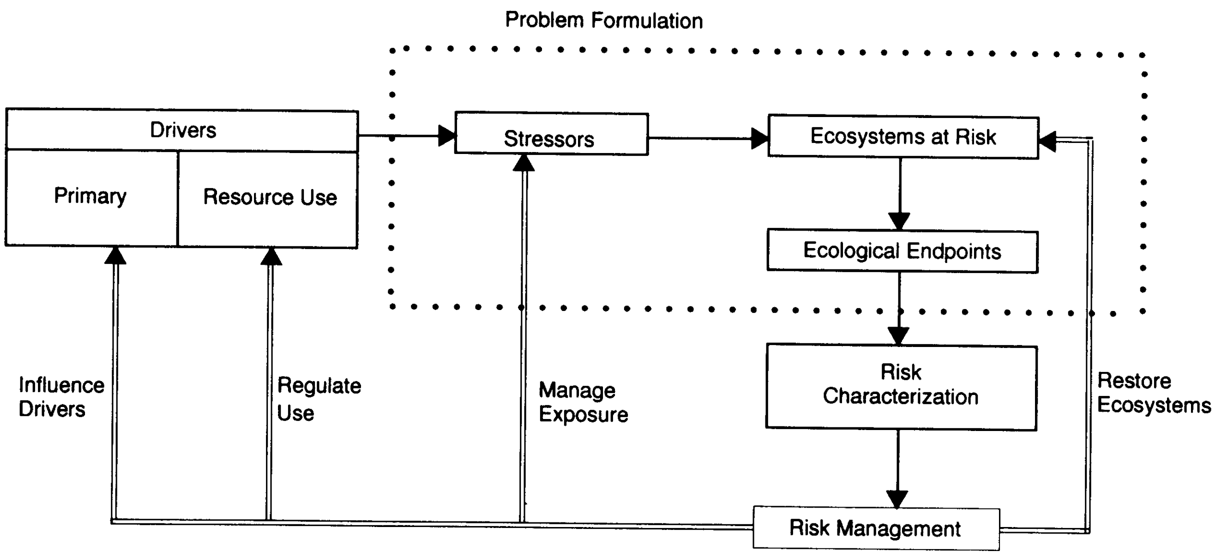

Figure 1. Conceptual Model for Futures Analysis.

4. Problem Formulation

4.1 Drivers

The first step of the scenario-building process is to define the "drivers"-- i.e., the major variables that determine trends in resource use and disturbance. Like the drivers that are commonly used to formulate societal, economic, and political scenarios, the primary drivers of ecological change are anthropogenic factors that affect ecological stressors. These drivers include human population characteristics, consumption per capita, globalization of the economy, technology, education, and environmental laws and policies. Of course, the primary drivers may differ depending on the issue and the temporal and spatial scales of interest.

While it is useful to begin with broadly defined categories of drivers, the Committee found it helpful to consider more detailed subcategories of these primary drivers in order to create a more focused scenario. For example, assumptions about human population growth and distribution might include increasing proportions of urban, as opposed to rural, populations worldwide. Similarly, assumptions about technology development and use might include broader use of existing industrial technologies in the developing world or development of more environmentally benign technologies distributed globally.

The Committee also recognized that each of the primary drivers affects patterns of resource use and availability. The latter, termed "secondary drivers" to acknowledge that they are dependent variables, may also be used to develop scenarios and determine linkages between the drivers and stressors. Relevant primary and secondary drivers for a global-scale, 30-year scenario are given in Table 1. For example, rapid human population growth might cause competition for water resources, both for agricultural and domestic use. Similarly, broader use of existing industrial technologies in less-developed nations may cause increased use and depletion of oil resources.

When developing a future scenario, it is important to identify the broad categories of primary and secondary drivers that are relevant to the chosen temporal and spatial scales, then to make focused assumptions about each of the drivers. The benefit of considering the effects of the primary drivers on each of the categories of secondary drivers is to develop scenarios that encompass situations outside of the universe of standard predictions. Recording these assumptions helps assure internally consistent scenarios.

4.2 Stressors

After the initial scenario is developed, the implications of the scenario for ecological systems can be evaluated using the ecorisk framework, i.e., identifying the causes of ecological change or damage, termed "stressors," and evaluating the effects of these stressors on relevant ecosystems and ecosystem components. The Committee examined the stressors identified in *Reducing Risk* as being most significant in

Table 1. Drivers of Ecological Change for a Global-Scale, 30-Year Scenario

Primary Drivers	Secondary Drivers
--human population growth, distribution, and age structure	--patterns of resource use and availability
agricultural expansion	land
urbanization	water
--resource utilization per capita	air
--economic structure	biomass
globalization of the economy	minerals
--technology	energy
development of more benign technologies	
broader use of existing industrial technologies	
--education	
increasing environmental ethics and stewardship	
--government laws and policies	
public/private resource ownership	
Third-world environmental institution development	

influencing future environmental problems and concluded that they pose the greatest risks to the integrity and sustainability of ecosystems. Thus, the Committee used the list of stressors in *Reducing Risk*, with a few modifications, as the starting point for translating future scenarios into predicted ecological effects (Table 2).

Refinement of the stressor list for specific temporal and spatial scales, as well as for particular scenarios, may be useful. For example, in evaluating the "Low Cost Energy" Scenario, described in Section 7.1, the Committee identified light pollution, electromagnetic fields (EMF), and noise pollution as significant potential future stressors.

4.3 Linkages Between Drivers and Stressors

Each of the drivers (primary and secondary) may influence ecological stressors. In order to determine the relationships between the anthropogenic drivers and the ecological stressors and to determine which effects are the most significant, the Committee found it useful to develop a matrix showing both the strength and direction of each linkage.

A sample matrix for the global, 30-year time scale is shown in Table 3. For each driver and stressor, the strength of the linkage or association was classified as high, medium, or low, and the direction of the linkage was characterized as positive, negative, or positive/negative (scenario-dependent). For example, an increase in the rate of human population growth would likely be strongly related to an increase in habitat loss, while stabilization of population growth would be strongly related to a decrease in the rate of habitat loss. For this reason, the linkage is characterized as high/positive. In contrast, increasing education levels would be expected to have little effect on climate change, but the small effect might be to decrease it (a low/negative association). In cases where the effect might be either to increase or decrease the stressor, depending upon the particular assumptions of a scenario, the indeterminate positive/negative designation was used.

In this example, the matrix displays the linkage with primary drivers, and assumptions regarding the secondary drivers are implicit; a similar matrix developed using secondary drivers would be equally informative. Similarly, although only the major categories of stressors were used in the current example, particular scenarios might suggest the use of the longer, disaggregated list of stressors (Table 2).

4.4 Ecological Endpoints

The concept of ecological endpoints (also termed assessment endpoints) is to identify particular attributes of ecological systems that can be used to characterize the health of an ecosystem. A suite of ecological endpoints is necessary, explicitly cutting across organizational hierarchy; i.e., at population, community, ecosystem, and landscape levels (Table 4). These endpoints are ecological characteristics, but they are selected to include both ecologically important features (e.g., biodiversity, primary productivity, critical species) and those that are important to humans (e.g., endangered, aesthetic, nuisance, or economic species). However, not all endpoints are necessary for every system and stress situation. Ideally, a set of ecological endpoints should be identified such that a significant change in one or more ecological endpoints indicates a change in the health of the ecosystem. Conversely, changes in ecological health should change one or more endpoints. Changes in ecological endpoints may be measured directly or assessed indirectly using ecological indicators (also termed measurement endpoints).

Table 2. Initial List of Drivers, Stressors, and Ecological Endpoints

Drivers	Environmental Stressors[1]	Ecological Endpoints
1. Government policies	1. Global climate change	1. Ecological condition
2. Population growth/distrib	2. Habitat alteration	–species
3. Globalization of economy	3. Stratospheric ozone/UV_b levels	–population
4. Distribution of wealth	4. Herbicide/pesticide use	–community
5. Consumption per capita	5. Toxics in surface water	–ecosystem
6. Education	6. Acid deposition	–landscape/region
7. Energy	7. Airborne toxics	2. Habitat quality/quantity
8. Urbanization	8. Nutrients	3. Biodiversity
9. Water availability	9. Biochemical oxygen demand	4. Productivity
10. Environmental ethics	10. Turbidity	5. Products and services
11. Resource ownership	11. Oil	6. Welfare/vista/aesthetics
12. Resource depletion	12. Groundwater contamination	
13. Agriculture	13. Radionuclides	
14. Technology	14. Acid inputs to surface water	
15. War	15. Thermal pollution	
	16. Exotic species introduction	

[1]Modified from *Reducing Risk: Setting Priorities and Strategies for Environmental Protection* (EPA-SAB-EC-90-021).

While the structure and criteria for selecting ecological endpoints can be specified in generic terms, particular ecological endpoints for any environmental problem are ecosystem- and often stress-specific. For example, the endangered species of concern differ with the ecosystem at risk and the stress the ecosystem experiences. Thus, the problem formulation stage of ecorisk assessment includes identifying the specific ecosystems at risk and ecological endpoints to be used for evaluating the status and trends of the health of the ecosystem.

Table 3. Strength of Linkages Between Drivers and Ecological Stressors (Global Scale, 30 Years)

	Stressors						
Drivers	Climate Change	Habitat Loss	UV_b Levels	Pesticide Use	Pollution	Nutrient Enrichment	Introduction of Exotic Species
Population	H +	H +	L +	H +	H +	H +	L +
Consumption per capita	H +	H +	L +	L +	H +	H +	M +
Globalization of economy	M +/-	H +/-	L -	H +/-	M +/-	L +/-	H +
Technology	M +/-	M/H +/-	L -	H +/-	M +/-	M +/-	H +
Education	L -	M/H -	L -	M -	M -	L -	M -
Environmental laws and policies	H +/-	H +/-	H -	H +/-	H +/-	H +/-	L +/-

Key: H, M, L = high, medium, or low degree of association; +/- means the driver increases or decreases the stressor.

Table 4. Categories of Ecological Endpoints[1]

Human Health and Welfare Concerns
- vectors for exposure to humans of diseases or toxics (e.g., distribution of disease-bearing insects)

Species-Level Endpoints
- species of concern selected based on having one or more of the following characteristics:

  Direct Interest
  –economic, aesthetic, recreational, nuisance, or endangered species

  Indirect Interest
  –interactions between species (e.g., predation, competition, or parasitism)
  –habitat role (e.g., physically dominant species such as mangrove tree species)
  –ecological role
  –trophic relationships
  –functional relationships
  –critical species (e.g., keystone species that affect overall trophic structure or control important ecological processes)

Community-Level Endpoints
–food-web structure
–species diversity of ecosystems
–biotic diversity of ecosystems

Ecosystem-Level Endpoints
–ecologically important processes (e.g., decomposition, nutrient recycling)
–economically important processes (e.g., wastewater treatment)
–water quality
–habitat quality

Landscape-Level Endpoints
–mosaic of ecosystem types (e.g., relative coverage of plant communities)
–corridors for migration (e.g., habitat for endangered species)
–spatial and temporal patterns of habitat (e.g., timing of and location of wetland areas necessary for bird nesting)
–feedbacks to regional- and global-scale physical systems (e.g., albedo, evapotranspiration, or sources of biogenic gases)

[1]Modified from Harwell et al., 1990.

5. Risk Characterization

After determining the relevant drivers and stressors, and evaluating the linkages between them, the next step in the conceptual model is to evaluate how the set of stressors translates into ecological responses and effects. As described in the previous section, ecological endpoints should be selected collectively to describe an ecosystem across a hierarchy of spatial, temporal, and organizational scales appropriate to the particular scenario under consideration. Since species-level endpoints will be ecosystem-specific and ecological endpoints are generally not stressor specific (i.e., endpoints are characteristics to describe ecological condition, not specific indicators of the presence or effects of a specific stressor), a matrix of stressors and ecological endpoints would likely have all cells filled in, as the effects of a stressor are likely to transcend ecological hierarchy.

The methodology proposed in the conceptual model (Figure 1), therefore, is to make the stressor-endpoint linkage by first identifying ecosystems at risk. For a given scenario, the ecosystems at risk can be identified by determining the spatial extent and co-location of a stressor and the environment. Based on the specific ecosystems at risk, appropriate ecological endpoints can then be selected to evaluate the condition and anticipated change of condition under the scenario, and specific measurements or indicators can be identified that need to be monitored. Monitoring changes in ecological condition of the ecosystems at risk then provides a basis for adjusting the management of drivers and/or stressors to achieve environmental goals.

6. Risk Management

A logical outcome of using the conceptual model for futures analysis to evaluate a particular scenario is identification of the risks associated with the specific problems defined and possible risk management strategies. In the conceptual model (Figure 1), we have identified four types of risk management options:

a) *Influence Drivers*: the risk may be managed by impacting the primary drivers of environmental change. Examples of this approach include changes in regulatory policy, incentives for technology development, and international agreements to enhance globalization of the economy (e.g., North American Free Trade Agreement, General Agreement on Tariffs and Trade).

b) *Regulate Resource Use*: risks can be reduced at the level of resource utilization through controls on resource use, e.g., land-use planning, energy utilization controls, water allocation, and timing of resource use.

c) *Manage Exposure*: this type of control impacts the stressors by limiting exposure of specific ecosystem components to stress. This can be accomplished, for example, by a variety of innovative technologies that either prevent pollution (via process modification or material substitution) or control the release of materials that can impact the ecosystem (e.g., seasonal wastewater releases to minimize exposure to critical life stages, changes to aircraft flight patterns).

d) *Restore Ecosystems*: this type of management applies to the specific ecosystems at risk, as identified by the targeting of where the stressors will impact. Restoration includes a variety of remediation technologies, as well as reintroduction of endangered species, revegetation, etc.

The selection of risk management options using the conceptual model must also incorporate information on societal values and goals, environmental research and monitoring, and environmental education:

a) *Societal Values and Goals*: public perceptions of values and goals for an ecosystem will impact how the risks are characterized, what ecological endpoints are identified as important, and which risk management strategies are likely to be most effective. Most often these goals will be implied since a clear statement is rarely available.

b) *Research*: in many cases the necessary information will not be available to characterize a risk or define what portions of an ecosystem will be impacted by a particular stressor. In these cases, research will be required to generate the information.

c) *Monitoring*: to assess changes in drivers and/or stressors realistically, as well as to evaluate the impact of risk management strategies, it will be necessary to have data on the status and trends of specific ecological parameters. The conceptual model for futures analysis assumes that the status of the resource is known. It may be necessary, therefore, to obtain additional data in order to construct and evaluate various futures scenarios.

d) *Education*: an important component of risk management is technology transfer, education, and training for the public and private sector on environmental issues. Education and risk communication play an important role at all points in the conceptual model as a mechanism for changing public values and behavior.

7. Example Scenarios

In order to demonstrate the application of the conceptual model for futures analysis, the Committee formulated two scenarios focusing on alternative assumptions regarding energy development. More surprising, and therefore more useful, results would probably be generated from a set of scenarios with varying assumptions about multiple drivers. Nonetheless, even the two example scenarios yielded unpredicted and useful conclusions.

7.1 Low-Cost Energy Scenario

7.1.1 Primary and Secondary Drivers

In the Low-Cost Energy Scenario, the Committee adopted the 30-year, regional scale (North America) for assessing effects and assumed that a major energy technology breakthrough in unexpected fields such as fusion power, plasma energy generation, or renewable energy would result in energy costs significantly lower than those of today. Minimal changes in current trends were assumed for the other primary drivers:

a) *human population*: population increases would continue at current rates, although distributions might change;

b) *consumption per capita*: resource consumption per capita would increase;

c) *globalization of the economy*: fundamental changes in economic structure and processes would not occur, aside from continuation of the current trend towards removal of trade barriers; and

d) *education*: education levels, including perceptions of environmental ethics, and government laws and policies would remain similarly unchanged.

The effects of the primary drivers on resource use and availability (the secondary drivers) are dramatic. Limits on water resources in arid regions would be largely removed because very low-cost energy would allow both desalination and widespread transport of water. Similarly, patterns of land use would change dramatically with the advent of low-cost transportation. As a result, human populations would spread to areas, particularly in the west, which are currently sparsely inhabited; most privately owned (but currently undeveloped) lands would be developed for business or recreational purposes; and increasing leisure time would result in greater human intrusion on publicly owned lands. Competition for and use of both biomass and mineral resources would increase, as a result of the "ruralization" of the population and concomitant construction, as well as a general increase in the standard of living. In other words, eliminating the current constraints to consumption, transportation, water use (and so forth) currently imposed by energy availability and price would cause North Americans to expand and consume more.

7.1.2 Driver/Stressor Linkages

To evaluate the effects of the Low-Cost Energy Scenario on ecological stressors, the Committee developed a driver/stressor matrix that summarizes the predominant effect of the scenario on each of the stressors (Table 5). The development of a new energy technology was predicted to reduce air emissions associated with the use of fossil fuels (e.g., carbon dioxide, SO_x, and NO_x) thus decreasing climate change and air quality stressors. On the other hand, increased availability of energy and potable water was predicted to promote expansion of human populations into areas that are currently minimally disturbed. The spread of human development, in combination with increased per capita consumption, would increase habitat fragmentation, noise and light pollution, introduction of exotic species, and water pollution. In addition, electric and magnetic fields associated with electric devices, power lines, and wiring would be more prevalent and more widely distributed in the environment. Although the human health and ecological effects of exposure to EMF are not yet clear, the exposure would be greatly increased under this scenario.

7.1.3 Ecological Endpoints

The Committee then considered ecosystems at risk under the Low-Cost Energy Scenario and selected ecological endpoints of concern. Under this scenario, cheap energy would increase water availability and reduce transportation costs so that people could live in areas currently considered inhospitable. Thus, desert and high mountainous systems would be at risk to intense habitat degradation. In general, any non-urban, terrestrial system would be at risk. In contrast, there would be fewer atmospheric impacts (e.g., air pollution from burning of fossil fuels) and coastal impacts (e.g., sea level rise associated with global warming, habitat destruction associated with oil spills or terminal construction, and discharges from coastal population centers).

Species that would be negatively affected under this scenario include those that live in xeric or high elevation environments, species with large home ranges (because of fragmentation of the natural landscape), nocturnal species (because of increased light pollution), and species highly

Table 5. Linkages Between Drivers and Ecological Stressors: Low-Cost Energy Scenario

Drivers	Climate Change	Habitat Alteration	Toxics in Surface Waters	Acid Deposition	Airborne Toxics	Nutrient Enrichment	Oil	Acid Inputs to Surface Waters	Thermal Pollution	Exotic Species	EMF
	Stressors										
Technology development	H-	H+/-	H+	H-	H-	M+/-	H-	H-	H+	H+	H+

Key: H, M, L = high/medium/low degree of association; +/- means the driver increases or decreases the stressor.

Assumptions

climate change:	greatly reduced use of fossil fuels, so reduced carbon dioxide emissions from that source
habitat alteration:	reduce stress from energy extraction, but increase stress from expansion of human populations
toxics in surface waters:	abundant, low-cost energy increases production by other polluting industries, speeds cycling of chemicals
acid deposition:	greatly reduced use of fossil fuels, so reduced SO_x/NO_x from that source
airborne toxics:	greatly reduced use of fossil fuels
nutrient enrichment	changes in population distribution will expand areas experiencing anthropogenic nutrient enrichment
oil:	reduced extraction and transport of fossil fuels
acid inputs to surface water:	greatly reduced use of fossil fuels
thermal pollution:	greater energy use
exotic species introduction:	more travel would increase opportunities for exotic species transport/introduction
EMF:	expect more power generation and wider distribution systems

sensitive to noise pollution. Some beneficial impacts on natural productivity would occur as a direct result of plastics being used more commonly. For example, plastics would replace some use of wood products that would lessen harvesting pressure on old-growth timber stands. In general, however, terrestrial ecosystems would be relatively more impacted than aquatic/coastal ecosystems.

7.1.4 Risk Management

The greater terrestrial impacts of the Low-Cost Energy Scenario would require more information on how terrestrial systems interact. In particular, more information would be needed on landscape processes (e.g., how large do preserved areas need to be? how can buffers and corridors be effectively designed to preserve species at risk from habitat loss?) Possible risk management options in the four categories discussed in Section 6 include the following:

a) *Influence Drivers*: Important drivers in this scenario would be technology development and government policies. Therefore, incentives to produce environmentally friendly technologies would mitigate negative ecological effects. Government policies to protect land areas at risk would also be beneficial.

b) *Regulate Resource Use*: Improved ecosystem management, for example via land use regulations, could protect habitats at risk. Regulation of water redistribution would also be important. In addition, increased taxation might be used to raise the cost of energy.

c) *Manage Exposure*: Control toxics in surface waters, nutrients, thermal pollution, EMF, light pollution, and noise pollution.

d) *Restore Ecosystems*: Clean up/restore areas impacted by prior oil transport and extraction activities (e.g., coastal wetlands).

7.1.5 Insights Gained

Perhaps the most significant outcome under the Low-Cost Energy Scenario was the predicted dramatic increase in the rate of habitat loss and biological depletion resulting from human intrusion into areas previously protected indirectly by resource limitations. In other words, the decrease in ecological stress related to extraction and use of fossil fuels would be more than offset by stresses resulting from the spread of human activities into previously undisturbed or minimally disturbed areas. Extensive fragmentation of terrestrial ecosystems was predicted, which would put particular pressure on species with large home ranges. Nocturnal animals would be stressed by continuous nighttime light pollution from ubiquitous human settlements.

Similarly, the future appeared increasingly polluted. Energy and water limits would no longer constrain the extraction or harvest of resources, nor constrain industrial processes. As a result, consumption of most products would increase, thereby increasing polluting by-products.

In short, a future with abundant, low-cost energy is not necessarily a "green" one.

7.2 Oil Depletion Scenario

7.2.1 Primary and Secondary Drivers

In order to place bounds on the effects of energy development as a driver, the Committee developed a second scenario, the Oil Depletion Scenario, which considers the ecological impacts of a high-cost energy future. In the Oil Depletion Scenario, the Committee assumed that global crude oil resources would be seriously depleted in a 30+ year timeframe and that new sources of energy or technology other than that currently available would not be developed. The use of nonrenewable resources ultimately leads to depletion of those resources and a shift to alternative materials or processes in order to satisfy needs or demand. Such is the case with natural liquid petroleum hydrocarbons (crude oil), which is being extracted at rates that will result in severe resource depletion over the next 30 to 50 years. With increasing world population and concurrent developing economies, it is likely that demand for petroleum products will increase and that the rate of crude oil depletion will accelerate.

The effects of oil depletion on resource use/availability (secondary drivers) will be several. As crude oil resources diminish, prices will increase and marginal oil fields will become profitable and will be brought on line. The pressure to exploit fields in areas that are now protected because of sensitive or fragile environments will also increase (e.g., areas along the Mid-Atlantic continental shelf or in Alaska). In addition, increasing volumes of surface waters will be injected underground in order to raise oil yields. Rising oil prices will also result in alternate sources of energy becoming profitable, necessary, and implemented. These will probably include an increase in nuclear power generation, greater use of coal, and the extraction of hydrocarbons from oil shale, all of which have associated environmental problems.

As alternative sources of energy come into greater use, the economic benefits and environmental risks will shift regionally and institutionally, reflecting resource ownership patterns (e.g., use of coal deposits in China and India, oil shale deposits in Siberia, and oil and gas resources in the China Sea). While rising energy costs could result in a decline in per capita consumption, which in turn would have positive ecological effects by reducing polluting and resource extraction, the scenario assumes that the effect of this driver would be slight because of the relatively inelastic consumer demand for energy.

7.2.2 *Driver/Stressor Linkages*

The expected effects of the Oil Depletion Scenario drivers on the dominant ecological stressors were evaluated by constructing a driver/stressor matrix (Table 6). The key stressors under this scenario are contamination of air, ground and surface waters, and habitat alteration. Sources of pollution include radioactive nuclear waste, formation water from oil extraction, and wastes and emissions associated with use of coal and oil shale. The composition of the wastes is largely unknown but will surely include polynuclear aromatic hydrocarbons (PAH), some of which are know mammalian carcinogens, in addition to trace metals (e.g., mercury) and natural radioactivity.

7.2.3 *Ecological Endpoints*

Under the Oil Depletion Scenario, oil field development activities would disrupt large marine ecosystems associated with the Mid-Atlantic continental shelf, the China Sea, and wilderness areas of Alaska. Mining of oil shale deposits in Wyoming and Siberia, lignite in the southwestern U.S., and coal in China and India would threaten the integrity of relatively pristine and protected areas because of strip mining and deforestation. Transportation of crude and refined hydrocarbons will place at risk those coastal ecosystems near loading/unloading terminals, thus threatening a diverse group of species ranging from commercially important fish to caribou.

7.2.4 *Risk Management*

Research should be conducted to determine the ecological risks from developing alternative energy sources such as coal, oil shale, and lignite in anticipation of their greater use as oil prices rise. Possible risk management options to minimize the ecological impacts under this scenario include:

a) *Influence Drivers*: although resource depletion is identified as the primary driver in the scenario, there are opportunities to manage risks by influencing related drivers such as technology development (e.g., technologies to minimize risks from extraction of alternative sources of hydrocarbons fuels) and government policies (e.g., revise water and land use laws and policies to improve water management and allocation among competing needs).

b) *Manage Exposure*: site loading/unloading terminals for hydrocarbons away from sensitive coastal resources such as wetlands and productive estuaries.

c) *Restore Ecosystems*: develop land restoration techniques to reclaim surface-mined lands.

7.2.5 *Insights Gained*

The plausibility of the Oil Depletion Scenario rests in its long-time scale; the question is not whether crude oil resources, or other nonrenewable resources, will be depleted, but rather when. Placing the scenario well into the future allows policy makers to consider more effectively the implications of such depletion. For example, the scenario argues for a thoughtful discussion of the best uses for remaining crude oil supplies, anticipation of geographic areas where public goals of preservation and oil extraction/use will come into conflict, and needed research and technology development for using alternative sources of energy. In addition, the scenario highlights the truly global nature of the issue, since environmental effects from depletion of finite resources such as crude oil are often not in the same geographic location as the demand (i.e., risks and benefits fall to different populations). Thus, our choices will be greatly influenced by international markets, multilateral negotiations, and information and technology transfer.

Table 6. Linkages Between Drivers and Ecological Stressors: Oil Depletion Scenario

Drivers	Stressors: Climate Change	Habitat Alteration	Toxics in Surface Waters	Acid Deposition	Airborne Toxics	Turbidity	Oil	Ground Water Contamination	Radionuclides	Acid Inputs to Surface Waters
Resource depletion	L+	H+	H+	H+	H+	H+	H+	H+	H+	H+

Key: H, M, L = high/medium/low degree of association; +/- means the driver increases or decreases the stressor.

Assumptions

climate change:	switching to other fossil fuels, so carbon dioxide emissions not greatly affected
habitat alteration:	increased exploration/extraction, use of biomass for energy
toxics in surface waters:	increased exploration/extraction
acid deposition:	greater coal use
airborne toxics:	greater coal use
oil:	generally not available
ground water contamination:	increased exploration/extraction
radionuclides:	increased exploration/extraction, greater use of nuclear power
acid inputs to surface waters:	increased exploration/extraction (e.g., acid mine wastes), greater coal use

8. Conclusions and Recommendations

8.1 Benefits of Using the Conceptual Model for Futures Analysis

The conceptual model for futures analysis described in this report combines the commonly used techniques for developing future scenarios with the analytical framework that has been developed by the Agency to analyze ecological risks (the ecorisk framework). As a result, the technique can be used to explore the ecological impacts of future human activities. The benefits of routinely using a formalized approach to assess future environmental risks are evident from the results of the two scenarios explored by the Committee. For example, unstructured brainstorming about a future characterized by unlimited energy resources would probably not have resulted in the Committee's strong conclusions regarding the importance of light and noise pollution on ecosystems currently far from human development. Second, the process clearly identified "no regrets" actions, outlined in Sections 8.2 and 8.3, which could be pursued in light of either energy extreme (very low-cost or high-cost energy futures). Finally, the conceptual model includes explicit consideration of a variety of management actions that could be undertaken to prevent or mitigate predicted future risks.

As part of the Environmental Futures Project, the Committee did not attempt individual ecological risk assessments for each identified stress and each ecosystem at risk for each scenario, as that would be well beyond the scope of the present activity. Rather, we have developed an approach that should be used in such a comprehensive exercise, and we strongly recommend that the Agency complete this exercise systematically to establish a broader and more comprehensive perspective on future ecological risks. Such an effort would greatly enhance the Agency's ability to identify emerging issues that pose the greatest ecological risks (and, by extension, risks to humans) and determine those issues for which the greatest risk reduction could be obtained per unit of funding or effort.

8.2 Management of Future Ecological Risks

The scenario/futures analysis exercise reaffirms the conclusions in *Reducing Risk* that national environmental risks are dominated by larger-scale and longer-time issues, including global climate change and habitat alteration. Moreover, these risks may already in large part be foreordained by current trends. Therefore, the national environmental agenda needs a dramatic shift in emphasis toward protecting the integrity of ecosystems and landscapes to supplement the historical focus on single-chemical, human-health risks; an ecosystem management regime should be developed that incorporates ecorisk principles as contained in the Agency's ecorisk framework.

The ecosystem management paradigm, while still evolving, embodies numerous elements based on our current understanding of ecosystem structure and function, including the need to consider ecosystem products and services, the chemical and energy linkages within and between ecosystems, the importance to ecosystem health of human actions and policies, the integration of ecosystems into landscapes and landscapes into regions, and the need better to understand ecosystem resilience and sustainability.

Ecosystem management to avoid or mitigate future harm also requires a larger-scale and longer-term perspective, in which ecological time frames (e.g., generation times of forest trees) rather than human-perception times (e.g., time between elections) are followed. Moreover, landscape- and regional-scale issues are necessary to specify what mix of ecological systems are to be located where and what environmental health levels are to be attained for each ecosystem in this management mosaic. This may require, for example, identification of certain locations or certain ecological systems to be selected for greater environmental alterations (e.g., agricultural areas, urban areas) in order for other areas to be afforded higher levels of protection from human stresses (e.g., national parks, wildlife refuges). This process occurs throughout the nation at present but is often the inadvertent result of policies or individual activities; in contrast, the ecosystem management approach is to do this in a systematic, risk-based, holistic framework that brings together into one picture both the ecological and the societal constraints and relationships.

Although ecosystem management goals should be formulated with a regional/landscape perspective, implementation of these goals must occur at the "local" scale, with management units of relatively small size (e.g., watershed units) by numerous public and private sector entities. In many cases, this will require the development of new management tools that incorporate key ecosystem and habitat management principles.

In summary, components of a futures-oriented ecosystem management system include:

a) identification of ecosystems for various levels of protection (e.g., core/unmanaged and intermediate/ buffer areas of protection, and areas with greater human use); this requires development of a shared vision of the regional landscape and is not always compatible with the concept of "multiple use";

b) management of the environment at regional spatial scales and intergenerational time scales, recognizing the characteristic heterogeneity in space and time of both ecological and societal systems;

c) establishment of ecological endpoints for each ecosystem type in each area to evaluate the health and change of health of the systems;

d) selection of goals for environmental condition for each ecosystem type and for each protection area based on both ecological considerations and societal values (i.e., explicit incorporation of humans as part of ecosystems, recognizing that ecological and societal sustainability are mutually dependent);

e) identification and development of the human institutions, policies, and activities, relying on adaptive management and risk-based approaches based on the best science available, that need to be implemented in order to attain those ecological goals; and

f) institution of long-term environmental monitoring/ characterization studies to measure progress in attaining the ecological goals, and continued research to reduce uncertainties.

8.3 Information Inputs to Risk Management

Effective risk management using the conceptual model for futures analysis requires information on societal goals and values, improved monitoring of resource status and trends (including recurrent, high quality assessment of key indicators of ecosystem health), and greater emphasis on transfer of environmentally friendly technologies to developing nations. New technologies must be systematically evaluated with regard to risks and positive and negative impacts on ecosystem values (both monetized and non-monetized). The conceptual model for futures analysis is a suitable approach for conducting this analysis. The Agency should also make a strong commitment to provide education on the environmental risks and benefits of emerging technologies.

8.4 Use of Computer Simulation Games

As part of the Environmental Futures Project, the Committee also explored the use of computer simulation games as an aid to understanding the impacts of future environmental problems. *SimEarth: The Living Planet*, software by MAXIS, is a computer game that projects maps and data on vegetation types, dominant sentient beings, air and sea temperatures for the Earth under varying scenarios using simple models for the geosphere, atmosphere, biosphere, and human civilization. While the Committee was frustrated by the technical limitations of the *SimEarth* game (e.g., the unrealistic initial conditions of the models, unrealistic rates of change, and difficulty in identifying modeling assumptions from the game documentation), it did recognize the utility for such a game in helping decision-makers explore the ecological ramifications of future events.

The Committee encourages the Agency to pursue the use of computer games in futures analysis, particular those games that operate on ecosystem or regional scales. The gaming exercise is not intended to replace the development of scientifically rigorous models but to provide managers with an easily accessible tool for considering the implications of future developments. Careful consideration should be given to the assumptions, spatial scale, time step, grid size, and initial conditions of selected games. It may be useful to develop simulation games focusing on a select set of issues in order to refine the intuition of scientists and policy-makers about potential outcomes of particular future scenarios.

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Appendix A. Glossary

Biological diversity: a measure of the variety and relative abundance of plants, animals, and microbes present in an ecosystem in terms of number of species and genetic diversity

Community: an assemblage of populations of different species within a specified location in space and time

Driver: a natural or anthropogenic force or agent of change that affects ecological stressors

Ecological endpoint: an explicit expression of the ecological characteristic that is to be protected, also known as an assessment endpoint

Ecological risk assessment: the process that evaluates the likelihood that adverse ecological effects may occur or are occurring as a result of exposure to one or more stressors

Ecosystem: the biotic community and abiotic environment within a specified location in space and time

Ecosystem management: integrated management of resources within the geographical boundaries of an ecosystem based on a knowledge of ecosystem function and explicit attention to human linkages to the ecosystem

Exposure: co-occurrence of or contact between a stressor and an ecological component

Landscape: the pattern and distribution of natural and human land uses in an area

Risk characterization: a phase of ecological risk assessment that integrates the results of the exposure and ecological effects analyses to evaluate the likelihood of adverse ecological effects associated with exposure to a stressor

Scenario: a story about the future that is used as a tool for ordering one's perceptions about alternative future environments in which one's decisions might be played out

Stressor: any physical, chemical, or biological entity that can induce an adverse response

Appendix B. Ecological Issues for the Future

The EPEC focused its efforts primarily on developing a conceptual model/process for futures analysis. However, during the development of the conceptual model and its application to a range of energy scenarios, the Committee identified a number of ecological issues that may be very significant in the future. These issues can be organized into five categories: Issues from *Reducing Risk*, Stressors Causing Effects in the Near Term (0-30 years), Stressors Causing Effects in the Longer Term (30+ years), Other Possible Future Concerns/Stressors, Effects Caused by Cumulative Stresses (Syndromes).

1. High Risk Problems Identified in *Reducing Risk*

The Committee reaffirms the importance, significance, and relative ranking of the risks to ecological resources (i.e., stressors) identified in Appendix A of *Reducing Risk*. Risks that received high rankings included:

a) global climate change

b) habitat alteration and destruction

c) stressors that cause loss of biological diversity

d) stratospheric ozone depletion

These four environmental problems continue to present high risks to ecological systems and human welfare because the geographical scale of all four is very large (regional to global), the time that could be required to mitigate all four is very long, and some effects are irreversible.

2. Stressors Causing Effects in the Near Term (0-30 years)

a) Habitat Alteration and Destruction - The greatest stressor to the world's biological resources is alteration and loss of habitat. Loss, degradation, and fragmentation of habitat associated with urbanization, land use changes associated with agricultural and silviculture activities, and transportation stress terrestrial biota. Flow modifications, channel alterations, damming, siltation, and nutrient enrichment eliminate and degrade aquatic habitats, thus impacting aquatic biota.

b) Exotic Species - Accidental or misguided introduction of exotic species (both plant and animal, terrestrial and aquatic) poses a significant threat to endemic species and overall biodiversity. Introduced species often out-compete native species because of a lack of natural predators and disrupt the structure and functioning of ecosystems. Examples include zebra mussels in Lake Erie, Asiatic clam, kudzu, chestnut blight, Dutch Elm disease, water milfoil, hydrilla, mesquite, Japanese beetle, and sea lamprey. With globalization of the economy, a significant risk exists for an increase in the transport and introduction of exotic species. Development of transgenic species may pose a similar threat if not carefully evaluated and managed.

c) Pollution - Persistent bioaccumulative chemicals, metals, some pesticides, and nutrients (phosphorous and nitrogen) continue to have adverse impacts on terrestrial, freshwater, and near-coastal ecosystems in many parts of the world. Bioaccumulative chemicals such as dioxin and polychlorinated biphenyls (PCBs) concentrate in top predators and can adversely affect growth, development, and reproduction of terrestrial and aquatic consumers. Metals in soil, sediments, and water can exert acute and chronic toxic effects on plants and animals. Continued use of highly toxic and persistent pesticides, particularly in developing countries, threatens ecological resources. Excessive use of fertilizers in urban and agricultural applications is causing eutrophication of freshwater and near-coastal ecosystems that smothers habitats, encourages growth of nuisance organisms (e.g., "red tide"), and depletes dissolved oxygen.

d) Over-Exploitation of Natural Resources - Adverse impacts on ecological systems from over-exploitation of natural resources are significant. Excessive withdrawals of ground water and surface water for irrigation, industrial use, and drinking water supply are contributing to the spread of deserts in many parts of the world. Poor agricultural practices contribute to erosion and subsequent loss of soils. Over-exploitation of near-coastal and marine fisheries have decimated many stocks of fish. Nonsustainable harvesting of timber, particularly in the tropics, is causing unprecedented losses of biodiversity. Surface mining of minerals destroys terrestrial habitats and contaminates aquatic ecosystems.

3. Stressors Causing Effects in the Longer Term (30+ years)

The Committee continues to be concerned about the ecological consequences of global climate change caused by build up of greenhouse gases and increases in ultraviolet light (UV_b) reaching the Earth because of depletion of stratospheric ozone. Adverse ecological effects from these stressors (e.g., inundation of coastal wetlands and marshes from thermal expansion of the oceans, and UV_b impacts on phytoplankton photosynthesis in the oceans) may not be realized until many years in the future. However, because of long lag-times in realizing the benefits of mitigation activities, efforts should begin immediately to address these issues.

4. Other Possible Future Concerns/Stressors

Using the conceptual model for futures analysis to evaluate two energy scenarios, the Committee identified light pollution, noise pollution, and EMF as having possible adverse ecological effects in the future.

a) *Light pollution*: If energy becomes inexpensive and widely available globally associated with advances in fusion and/or hydrogen technologies, it is likely that this energy will be used to light up the planet. Many animals and plants use light cues to initiate their reproductive activities. Nocturnal animals have evolved life strategies that partition niches based on nighttime activities. Excessive light could significantly disrupt plant and animal physiology and behavior, potentially causing significant effects.

b) *Noise pollution*: A more populated Earth with increased dependency on technology (machines) will also be a noisier place. This noise has the potential to disrupt communication critical for reproductive behavior and territorial defense for many species. For example, many birds use calls to mark and defend their territories, and whales, whose population numbers are small, communicate with sound over long distances. As noise pollution increases, interference with essential communication activities will increase. Aircraft flying in remote areas (e.g., parts of Alaska) has already been implicated in noise stress for animals.

c) *EMF*: With inexpensive, widely available energy, it is likely that EMF will increase and with it the potential for impacts on terrestrial plants and animals.

5. Effects Caused By Cumulative Stresses (Syndromes)

Individual organisms, populations, communities of organisms, and ecosystems respond to the cumulative impacts of stressors. Examples of significant ecological problems that appear to be caused by cumulative stresses are marine mammal die-off, forest decline, and coral reef bleaching. These phenomena appear to be increasing in frequency and extent. Protecting ecological resources from cumulative stresses will require an integrated and long-term commitment to pollution prevention and resource protection.

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