Current Trends and Environmental Research Needs

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Seven trends are identified that may call for reorientation in environmental research and policies. These are

- **An increasingly 'total' concept of environment, tracing risks to more and more destinations with greater concern about fairness to different populations**
- **Rising spatial concentration of industry, with the possibility that manufacturing will take place largely in only a few regions, especially in Japan and the Pacific Rim**
- **Emergence of a new manufacturing style with unmanned factories and closed materials flows**
- **Expanding importance of electronics and biotechnology for the environment**
- **Waning of the radical vision of a return to a rustic, more 'natural' life**
- **Growth of giant cities**
- **Intensification of competition among nations for industrial leadership**

In turn, directions for environmental research are identified:

- **Complexes of causes and effects, and cumulative impacts**
- **Long-term technological change and its relation to environmental history**
- **Paradigms or theories of environmental evolution**
- **Applications of ecological theory**
- **Setting standards for the environment *per se*, in contrast to setting standards to achieve objectives primarily relevant to human health**
- **Chemistry of the atmosphere**
- **Inherently safer and cleaner technologies**

One conclusion is that technological trajectories may mean that some problems that have peaked in Western industrialised countries seem likely to reach new peaks in other areas.

For a decade, or perhaps two, environmental researchers and policy analysts have been comfortable with a world segmented neatly into domains of atmosphere and ocean, forests and rivers, city and wilderness, industrialised and developing countries. Environmental problems have been identified primarily in terms of energy and agriculture, and indicators such as birth rates and per capita energy use have become familiar in prefiguring imminent crises. Major environmental assessments have taken on a consistent, even routine, appearance.[1-3]

This stability could reflect mature science and accurate diagnosis. It could also indicate that we are nearing a transition from a phase of easy synthesis to a period when paradigms begin to weaken, points of reference shift and notions of purity and danger become less clear.[4] This review is intended to suggest that the frameworks and measurements that we have used so effectively in the past may be in need of adjustment or, at least, critical evaluation. Changing industrial practices and social moods and expectations may call for reorientation, a new search for meaningful indicators, and different expectations.

Environmental trends

First, let us consider seven trends. Some are impressionistic, and others are more readily quantifiable and less contestable.

- An increasingly 'total' concept of environment
- Rising spatial concentration of industry
- Emergence of a new manufacturing style
- Expanding importance of high technologies for the environment
- Waning of the soft-path vision
- Growth of giant cities
- Intensification of the competitive mood

These trends have ramifications across the spectrum, from locality, to region or nation, to the planet. The spatial scales at which they will intersect in the most troubling ways are a critical question.

An increasingly 'total' concept of environment

From rather piecemeal origins, there has been an extension of concern from the industrial and traditional common public environments to additional locations, including the office and home. We have moved from grosser, more obvious problems to subtler ones.[5] Whereas domains of early environmental attention included lakes and rivers, city sanitation and air, concern is increasingly spreading from, for example, problems of power plants or smog to more distributed and less direct issues, such as safe disposal of hazardous waste and effects of tobacco smoke on non-smokers. In a sense, the rather diffuse personal health movement of recent years is a forerunner and manifestation of this trend.

We have also moved toward what Friedman identifies for all aspects of US life as a 'general expectation of recompense for injuries and loss'.[6] Partly this is a reflection of past success in dealing with such salient problems as water supply, urban air quality, and noise. Partly it reflects the changing allocation of our time budgets - to the modern office building or airplane cabin, for example, where cigarette smoke or infectious agents or non-ionising electromagnetic radiation are more likely to present hazards than vinyl chloride or coal dust. A corollary of tracing risk structures to more and more destinations, especially white-collar and domestic ones, is greater concern with distributive effects and fairness in evaluating hazards to different populations.[7,8] Hazards in schools with young children, in offices with pregnant women, and in neighbourhoods of high-income groups are weighted differently from those to which blue-collar workers are exposed.

Rising spatial concentration of industry

The inverse of concern about increasingly dispersed environments where hazardous exposures take place is the apparently growing spatial concentration of primary industry. Data on world market shares and trade balances suggest an implosion of manufacturing to a few countries, led by Japan.[9] And within countries, 'economies of agglomeration'[10] also appear to be working strongly for concentration. With the productivity gains that are occurring in the industrial sector, fewer factories produce more goods, and fewer employees are needed to run the plants (Figure 1).

Perhaps economies of scale push the number of production facilities in the world toward a constant; Marchetti and Nakicenovic have suggested that fleets of commercial airplanes and seagoing vessels are roughly constant over long periods of time.[11,12] Maybe there are globally constant 'fleets' of factories. Or perhaps there are cycles: In the 19th century, Marx documented an implosion of production in such sectors as steel and textiles into a few intensely industrial regions in Europe, as capital, labour, and trade drained from the rest of the continent.

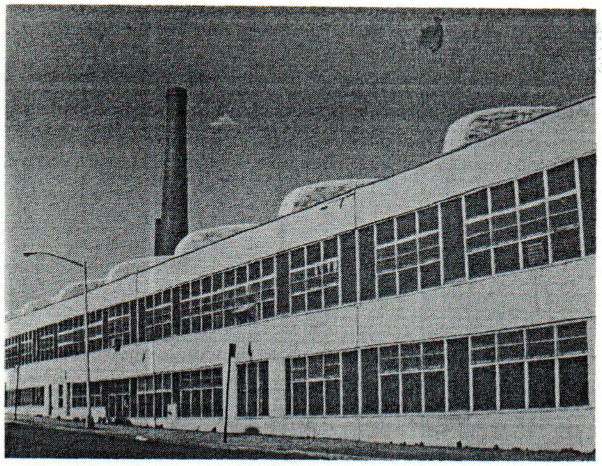
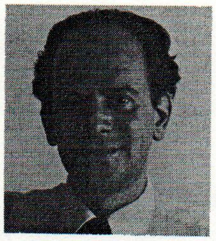


Figure 1. Factory in New York City on a Sunday. Will there be any factories left in New York in a few decades? Will operating factories have more than a handful of workers? Will material flows be entirely contained?

Environmental analysts have tended to proceed on the logic that, for purposes of illustration, with a doubling of world population and per capita income, and hence a quadrupling of world product, we would see roughly a fourfold increase in industrial emissions from steel mills, aluminium smelters, chemical plants, and so forth. Moreover, the location of emissions would be closely correlated with location of population and income. Such projections, as in Perry and Landsberg,[13] are not being tracked by reality. The difference results from both the shift towards a service economy and its companion, improvements in manufacturing productivity and process technologies.

We may be entering a world of high-volume, globally integrated industries - motor vehicles, for example - but these industries may be concentrated in a few locations. To draw an analogy with the parks or 'islands' for energy generation proposed in the 1970s,[14] the world may have only a few islands of manufacturing. We need to think through the environmental implications of this concentration, including the question of mobility of production and its new freedom from natural resource endowment as a primary determinant of location.



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The emergence of a new manufacturing style

Key factors for the environmental prognosis are new manufacturing technologies themselves. Safety, quality, reliability, and cost all seem to favour movement toward unmanned factories.[15] Materials employed are increasingly synthetics based on abundant elements where supply and access are not significant concerns in the classical fashion of exhaustible natural resources.[16] The potentials for engineering design are fantastic - and necessary. Closed-cycle processing will be a requirement because of the scale and hazardousness, or perceived hazardousness, of operations. Along with sheer inventiveness in process technologies,[17] robotics can make possible a great deal of the closed-cycle processing, including waste treatment.[18]

Tremendous pressure for closed-cycle processing is emerging. In the energy sector, we have concerns about inorganic combustion products, such as sulphur dioxide emissions from power plants. In the United States, there is also rapidly escalating concern about so-called toxic emissions. The House of Representatives' Subcommittee on Health and the Environment[19] especially noted four types of toxic emissions: synthetic organic chemicals, such as benzene, made from oil and natural gas; synthetic nonorganic chemicals, such as chlorine and ammonia, that also occur naturally; fibres, such as some forms of asbestos; and heavy metals, such as mercury, cadmium, and nickel. Many of these substances are carcinogenic, sometimes allegedly at very low exposures, and the question is the extent to which toxic emissions increase the risks to our health.

The Bhopal tragedy has set off an unprecedented review of the chemical industry, with re-examination of virtually every process and plant in all major companies. The House Subcommittee survey showed that most US chemical plant emissions come from a few large plants, less than 10% of all facilities, and that old plants with more primitive emission controls and process technologies emit far more toxic chemicals than new plants. In manufacturing, the potential is there for us simultaneously to isolate the risks and take the people away from the risks. Issues of transport, use, and disposal of goods may come to exceed by far issues of their production.

The expanding importance of high technologies for the environment

A key trend that may not yet be fully appreciated from an environmental point of view is the extension of the dominance of electronics, especially advanced electronics, in all sectors of human activity. Advanced electronics include electronic applications equipment, such as computers and automated machine tools, as well as the main components, semiconductors and integrated circuits, used in this equipment and in many other products. Advanced electronics offer opportunities for control of processes to improve purities, minimise below-quality batches that are discarded, monitor and optimise reactants, and so forth. The new biotechnologies offer parallel promise in the longer run as sensors, diagnostic tools, and sources of innovation in health care and agriculture.

These benefits come with a set of problems, however, both at the front end and at the back end, as usual. At the front end, some hazardous substances, such as the arsenic used to dope semiconductor materials and solvents for etching, are used in electronics manufacturing. There are already concerns about risks to water quality from leaking underground waste storage tanks at firms in Silicon Valley. Experimental release of genetically engineered organisms is stretching the capabilities of monitoring and regulatory systems with each appearance of a new product idea. Such concerns seem certain to become more widespread, although evidence of adverse effects on health or the environment remains unsubstantiated. Electronics and biotechnology are young industries, and we have surely failed to anticipate all of the risks they create. We should be alert for them.

At the back end, too, we should be alert. For example, disposal of several kinds of batteries has become a serious environmental issue in Japan. In fact, it is logical that, as production and consumption intensify in Japan and other nations of the Pacific Rim, we will look increasingly to these regions not only for manufacturing leadership but also as the area where many of the environmental issues of the 21st century will surface first.

The waning of the soft-path vision

Accompanying the surge of youthful technologies is the waning, already evident in the United States, of the soft-path vision - the vision of the radical, but also influential, sects of the broader environmental movement.[20] These sects have prodded and tempted and sometimes led the environmental movement for the past 15–20 years with a vision of a rustic, 'natural' life. As with so many utopian groups, the soft-path is failing to reproduce itself, to recruit new cohorts of young people (Figure 2).

In the United States, people through university age are again largely well integrated and pleased with new technology, especially electronics. Computers may be an issue for old people, but they are accepted tools and toys for children. It is true that the United States is notoriously trendy and that the pendulum of social fashion swings far and fast every decade or so, but for the present there is no significant back-to-nature movement among the young. Young people are developing software rather than crafting wood-burning stoves and are more at home in valleys of silicon than on an organic farm. What will be the effect of this shift on the environmental movement?

It may again be an important factor that the young are often out of phase with the generation holding power. While the adult world was landing on the Moon in July 1969, the youth were caravanning toward Woodstock. Now many youth are fantasising

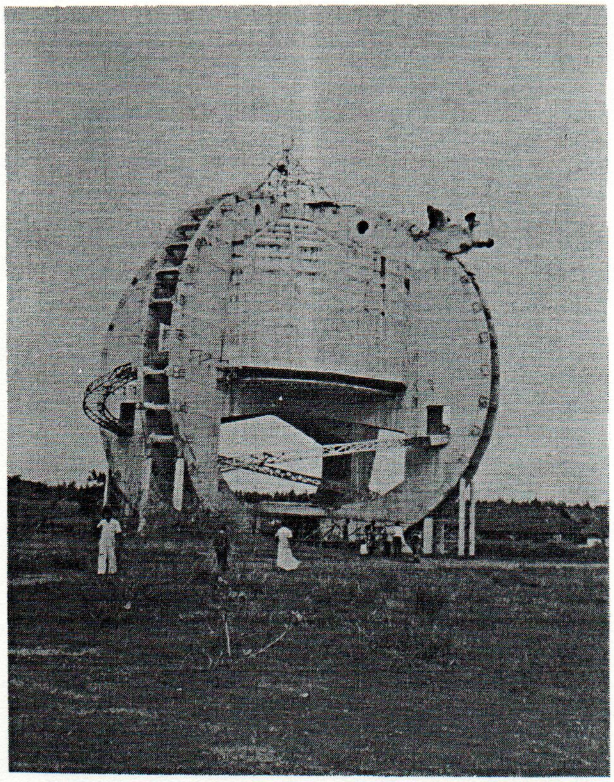

Figure 2. The Ashram of Auroville under construction near Pondicherry, India. Few soft-path communities have chosen or sustained the social organisation to build lasting infrastructure.

about the world of star wars, while their parents go to health clubs.

As Stinchcombe[21] pointed out, history shows great spurts in the foundation of organisations of a particular type or purpose, followed by periods of relatively slow growth, perhaps to be followed by new spurts, generally of a fundamentally different kind of organisation in the same field. For example, there was a rash of savings bank formations in the 1830s. Railroads and, concomitantly, steel companies had their great periods of organisation in the 1850s and 1870s. Organised socialist parties spread throughout Western Europe after the establishment of the Second International in 1889. In the United States, universities were founded mainly from 1870 to 1900. Streetcar companies and electricity-producing companies were all the rage from 1887 to 1910, and, other than printing and publishing, the mass communications industries were mostly organised in the 1920s. About 100 new biotechnology firms started up in the period 1977 to 1982.

Is the growth spurt of environmental organisations in the early 1970s,[22] shown in Figure 3, sustainable? Will the environmental movement as a whole face serious problems of aging? US environmental groups may have saturated, or even overshot, their niche. If resources for current operations of organisations come from endowments, the organisations may last well past the time when their structures are truly 'competitive' in meeting needs. For organisations facing 'market tests' of dues, philanthropic giving, sales, and appropriations, a period of mergers and consolidation may be in store. Institutional substructures of industry and government established to meet environmental objectives may also face reorganisation and redefinition of mission.

The growth of giant cities

A sixth trend affecting environmental issues is the growth of giant cities. The decentralisation of population so appealing to the agrarian environmental vision is not occurring. Instead, the megalopolitan areas are growing steadily in developed countries and very rapidly in developing countries. Cities that will soon have 20 million or more people include Mexico City and Shanghai, and complexes of 50–100 million people, like São Paulo–Rio, the Northeast Corridor in the United States, and the Shinkansen route in Japan, are connecting more and more uninterruptedly. Densities once familiar to only a few areas such as Manhattan or Calcutta will become widespread. We seem to be packing our centre cities with architecture minimising distances almost as closely as the central processing unit of a supercomputer.

What sociotechnical structures are necessary to sustain such tremendous population concentrations without environmental catastrophe? An essential condition may be a move to energy systems based on natural gas, which is cleaner-burning and can be stored and transported more efficiently than its competitors, and nuclear-generated electricity. Are there serious alternatives?

Intensification of the competitive mood

With the global overcapacity and saturation of markets in mature industries, virtually all regions, nations, and large firms find themselves in an unrelievedly competitive situation. There is little basis for revival of a more cooperative regime based on the current structure of the world economy until avenues for growth are found. Appropriately, many nations appear to be in a phase of entrepreneurial frenzy, well characterised by Schumpeter[23] in his 1939 discussion of long cycles of development. If we accept that history repeats itself, it will be a decade or so before this intensely aggressive period subsides.

From the point of view of environmental quality, the critical point is that national support for multilateral international institutions will continue to be threatened, dependent as such institutions are on a cooperative disposition in relevant countries (Figure 4). Joint efforts for international research, monitoring, and management will tend to run against the tide. There is even danger that acceptance of destruction of the environment will be an element in some competitive strategies for industrial leadership.

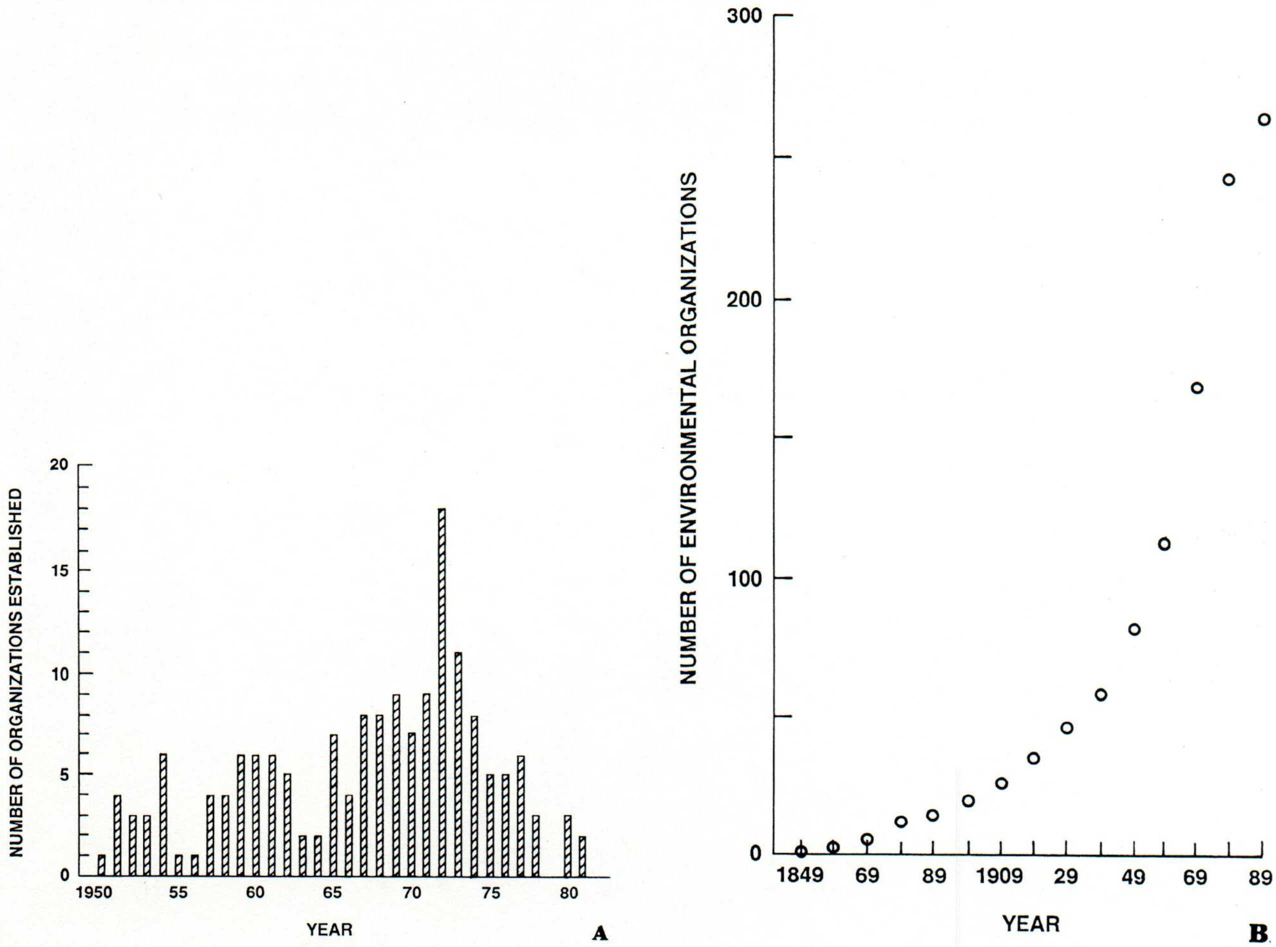

Figure 3. The birthdates and age profile of a sample of environmental organisations listed in the National Wildlife Federation Conservation Directory (1982) on the basis of stated objectives in relation to conservation of natural resources. The sample consists of a subset (about 80%) that publish a 'year of birth' of the organisation. *A*, Number of organisations in sample established each year between 1950 and 1981. *B*, Age profile of the sample. The points show the cumulative number of current 'living' environmental organisations established before the year indicated.

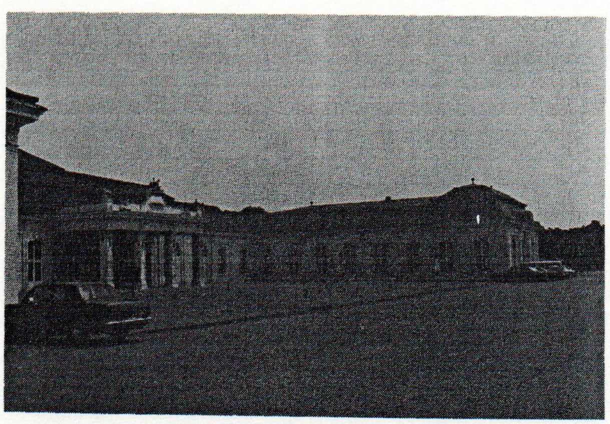

Figure 4. The Conference Center of Schloss Laxenburg, Austria. The International Institute for Applied Systems Analysis, housed in the Schloss, has led a troubled existence in recent years as the cooperative global 'problematique' defined by the Club of Rome in the 1970s has given way to global competition.

Environmental research needs

Let us now turn from these seven trends to seven directions for environmental research. These are

- Syndromes and cumulative impacts
- Technological change and environmental history
- Paradigms for environmental evolution
- Applications of ecological theory
- Setting standards for the environment
- Chemistry of the atmosphere
- Inherently cleaner and safer technologies

Syndromes and cumulative impacts

Syndromes refer to complexes of causes and effects. These may involve multiple causes for a single effect or vice versa and combinations of multiple causes with multiple effects. There are also several types of cumulative environmental effects.[24] Effects can be so crowded together in time that the ecosystem cannot dissipate the effects as fast as they accumulate. Effects can also be so crowded together in space that they overlap. The conjunction in space and time may be merely additive, or they may be more synergistic, as when pollutants interact to create a new toxic mixture. What will be the case for enhancement of plant growth caused by atmospheric CO_2 increase and diminution associated with ozone increase? How might acidification of the environment interact with climate change - in particular, warming and new distributions of rainfall?

The challenge is to move beyond single-issue examinations of the environment, which are essential and helpful simplifications at times but which ultimately can mislead both research and management. The World Commission on Environment and Development has presented a persuasive statement of the challenge.[25] Environmental policies defined for a single cause, effect, or episode may often be ineffective.

Attention to 'syndromes' can lead to more potent and quite different policy recommendations.[26] For example, considering as a whole the multiple effects of coal combustion (health, acid rain, CO_2) may favour elimination of coal as an energy source, whereas examination of a single effect in isolation might lead to a narrower recommendation for cleaner coal technologies. Thinking about links among environmental problems must be a central feature of future environmental research and policy.[27]

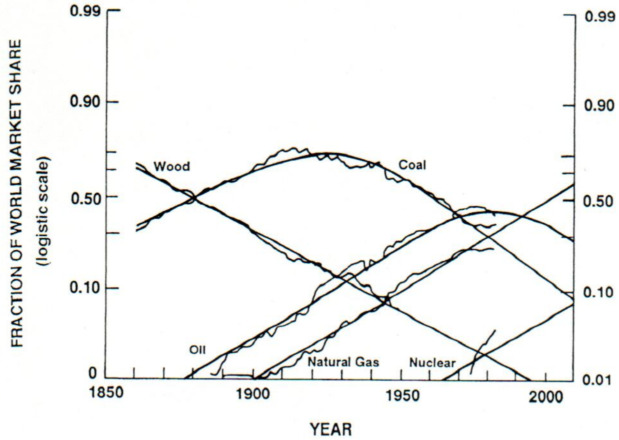

Figure 5. Substitution of primary energy sources for the world as a whole. The uneven lines show historic data, while the smooth lines show the estimated best fit and extrapolation to the year 2010. The history of world energy use has far fewer surprises and discontinuities than newspapers might make us think. If coal continues its decline and oil has peaked, one implication is that at a global level sulphur-related environmental problems will be appreciably less intense within a few decades, unless absolute rates of growth dominate changing shares. (Source: N. Nakicenovic, *Growth to Limits: Long Waves and the Dynamics of Technology,* International Institute for Applied Systems Analysis, Laxenburg, Austria, 1984. By permission of the author.)

Technological change and environmental history

This is essentially a suggestion to take time seriously, especially the connection between technological and environmental change. It is easy to recommend taking a dynamic view and usually difficult to follow through on it. But in environmental studies there remains a tendency to perform analyses in a static way or with linear extrapolation, when in fact the lesson of history is that there is characteristic growth, maturing, and fading of problems and orderly societal learning.[28]

A weakness of many environmental studies has been neglect of gradual technological change. Processes of technological substitution are often extraordinarily regular,[29] so we can do a much better job of anticipating shifting sources and solutions of environmental problems than we have done (Figure 5). In the 19th century it was no accident to be 'mad as a hatter' (chemicals employed in treatment of the felt used in making hats caused the condition), and there are intriguing conjectures about how trace materials in the pipes and pots of ancient Rome affected the health of the Romans. At the height of the coal era, around 1920, sulphur emissions in the United States may have reached a peak as high as in the 1970s.[30,31] There are many other important and interesting chapters in the history of the relation between environment and technology that have not been fully documented or appreciated, for example, the interaction of forests with the development of railroads and mining (Figure 6). Documenting environmental history may have surprising effects on future policy debates, strategies, and expectations.

Paradigms for environmental evolution

The search for a 'theory of the environment' could usefully be more active. Lovelock's Gaia hypothesis[32] is one good attempt at a paradigm for environmental evolution, but the debate over paradigms ought to be much livelier than it is. There are challenging questions: What is the extent of homeostatic mechanisms in the environment? Are there truly key ecosystems with great leverage over the global system? There ought to be more such fundamental hypotheses about environmental systems and research programmes to test them, as the Global Atmospheric Research Program in the 1970s explored 'the limits of predictability' of weather and climate.

Developing a theory of long-run environmental change, including human activity, is obviously an open-ended project. The concomitant to it is the need for more good attempts at a theory of human history. How and why has the locus of the world's industrial activity moved over long periods of time? A research programme under Douglas Johnson at Clark University is looking at related questions. For instance, what is the spectrum of long-term fluctuations of human

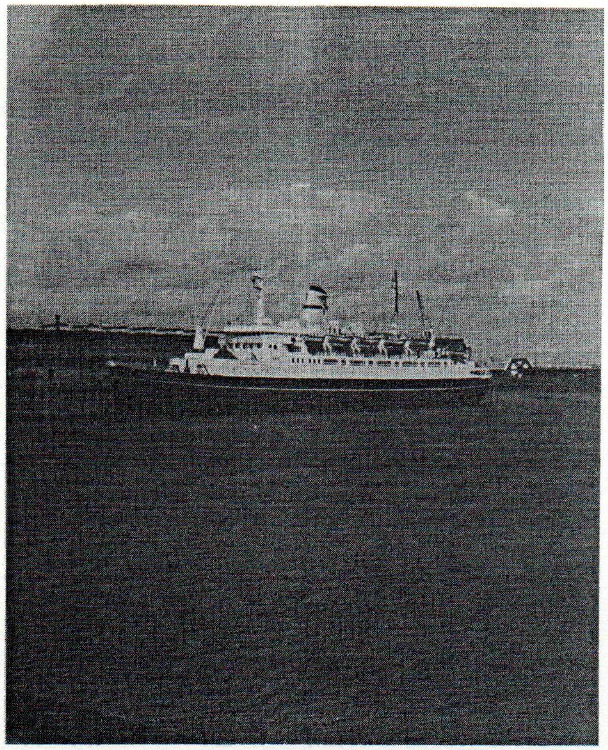 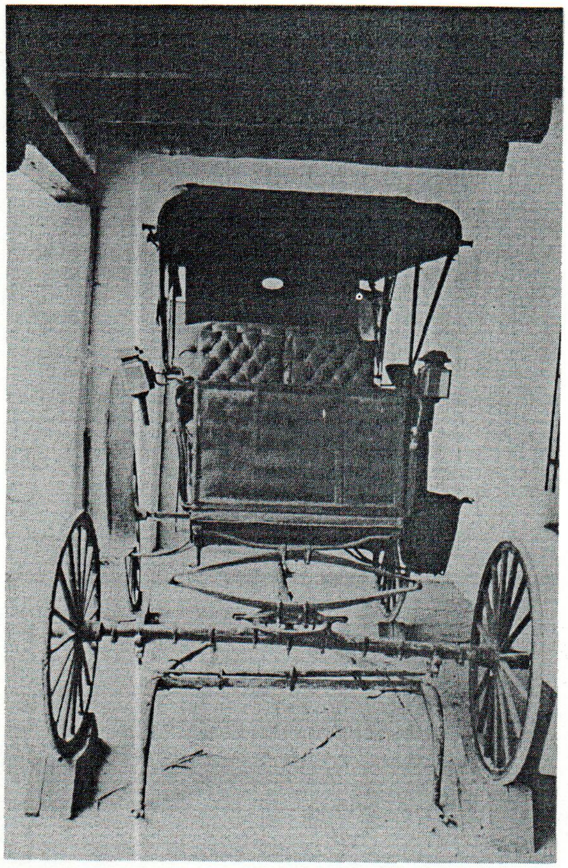

Figure 6. Two relics of once aggressive transportation systems.

(*Left*) The *Stefan Batory*, the last true passenger liner regularly scheduled on the North Atlantic route, before sailing from Montreal to Europe. It made its last Atlantic crossing in August 1987. The process of substitution between ships and airplanes for passenger and freight travel has been remarkably steady. On the North Atlantic air passengers first exceeded ship passengers only 30 years ago, in 1957.

(*Right*) A late-19th-century carriage with a convertible sunroof in Sante Fe, New Mexico. Annual manufacture of horse-drawn carriages was surpassed in 1914 by that of automobiles, substituting one set of environmental problems for another.

populations? What are the interconnections of population, resources, and environment over many centuries and millennia? It is important to note that deficiencies in theory of environment may be at the root of our puzzlement about design of environmental monitoring systems.

Applications of ecological theory

Though there is a need to develop better long-term conceptions of life as a planetary phenomenon, on more modest scales we need to consider the applicability of existing ecological theory. From a recent National Research Council study[33] (Table 1), it is evident that much environmental management is associated with no theory at all or with inappropriate theory. Blending ecological theory with environmental management, especially in a serious, experimental way, is not an easy charge.[34] As we move toward examination of cumulative impacts, it may become yet more difficult to employ theory, but without some rigorously developing theory the technical community certainly has no special authority with regard to prediction.

Table 1. List of case studies reviewed by the US National Research Council's Committee on Applications of Ecological Theory to Environmental Needs.[a]

Halibut Fishery Management
Vampire Bat Control in Central America
Biological Control of the California Red Scale
Experimental Study of Malaria Control in Africa
Protecting Caribou during Hydro Development
Conserving a Regional Spotted Owl Population
Restoring Derelict Lands in Great Britain
Optimising Timber Yields in New Brunswick Forests
Control of Eutrophication in Lake Washington
Raising the Level of Southern Indian Lake
General Studies of the Ecological Effects of Nuclear Radiation
Review of Studies on the Effects of Forest Clear-cutting
Historical Review of the Environmental Effects of DDT

[a] Underlying responses to some of these problems was a reasonably explicit theory, for example, with regard to predator–prey relations or competition among plant communities, while in other cases management was based largely on unsystematic trial and error.

Source: National Research Council, *Ecological Knowledge and Environmental Problem-Solving: Concepts and Case Studies*, National Academy Press, Washngton, DC (1986).

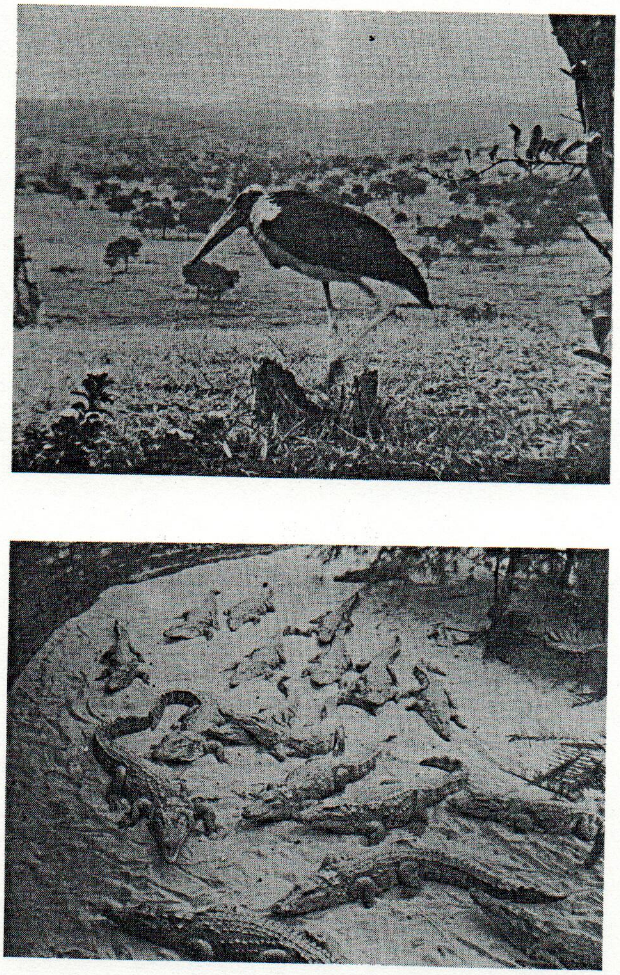

Figure 7. (*Upper*) Maribou stork in central Tanzania. How can we determine the 'value' of such an endangered species?

(*Lower*) The Crocodile Bank in Madras, India. Long one of nature's fittest species for survival, crocodiles now must rely on mankind's environmental ethic for survival.

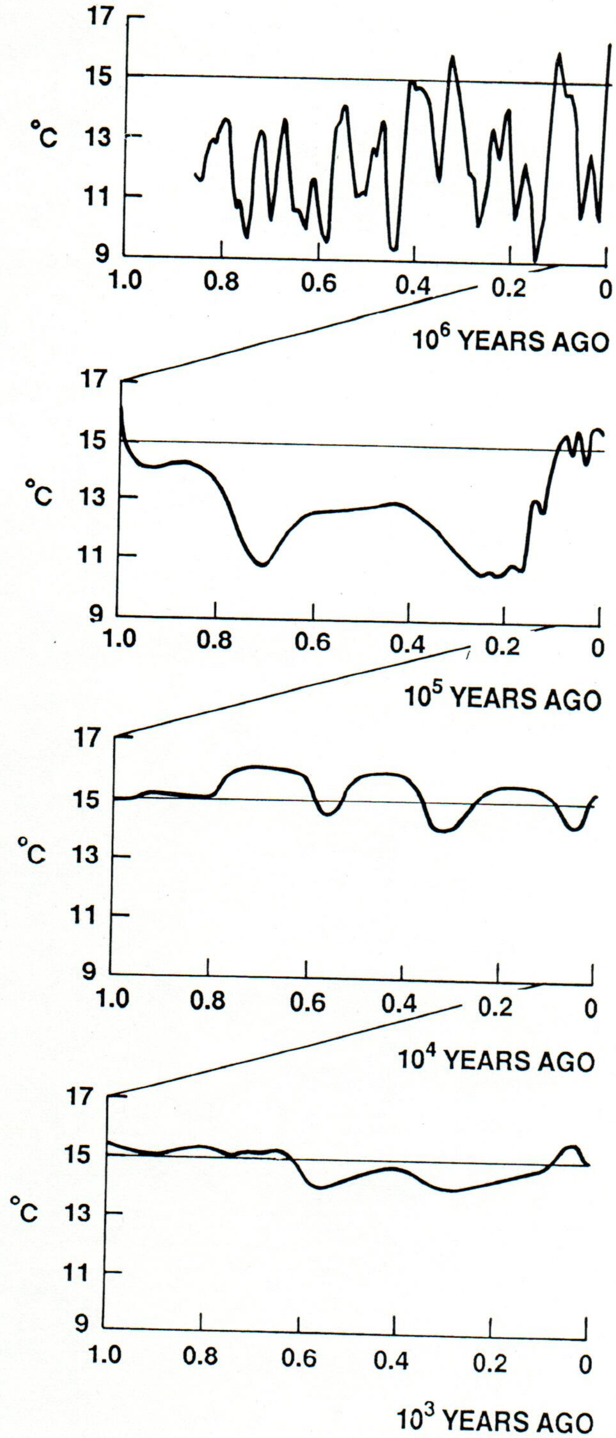

Figure 8. An approximate temperature history of the Northern Hemisphere for the last 850 000 years. The panels are at the same vertical scale. The top panel shows the past million years, the second panel amplifies the past 100 000 years, the third panel the past 10 000 years, and the bottom panel the past 1000 years. The horizontal line at 15 °C is included simply for reference. A warming from all greenhouse gases might average 2–3 °C globally over the next 100 years. Is there any 'natural' basis on which to set limits for rates or levels of acceptable temperature change? (Source: W. C. Clark, ed., *Carbon Dioxide Review: 1982*, Oxford University Press, New York 1982. By permission of the author.)

Setting standards for the environment

An example of an area where lack of theory specifically hampers us is in the setting of standards for the environment *per se*, in contrast to setting standards to achieve certain objectives with regard to human health. For example, how do we set standards for the loss of a species? What is 'rarity'? (See Figure 7.) Should concern begin at a certain trophic level? Are there truly key species for which a change in population will bring about large or destabilising reactions? How can stress to the environment be characterised? Can terms such as resiliency, diversity, and stability be translated into indices useful for environmental management? What do we mean by an adverse environmental response? One example is to consider how we think about acceptable ranges of temperature for global climate (Figures 8 and 9).

It has been suggested that a *de minimis* principle may have broad applicability in environmental standard setting.[35] This principle states that for risky phenomena that occur or fluctuate naturally in the

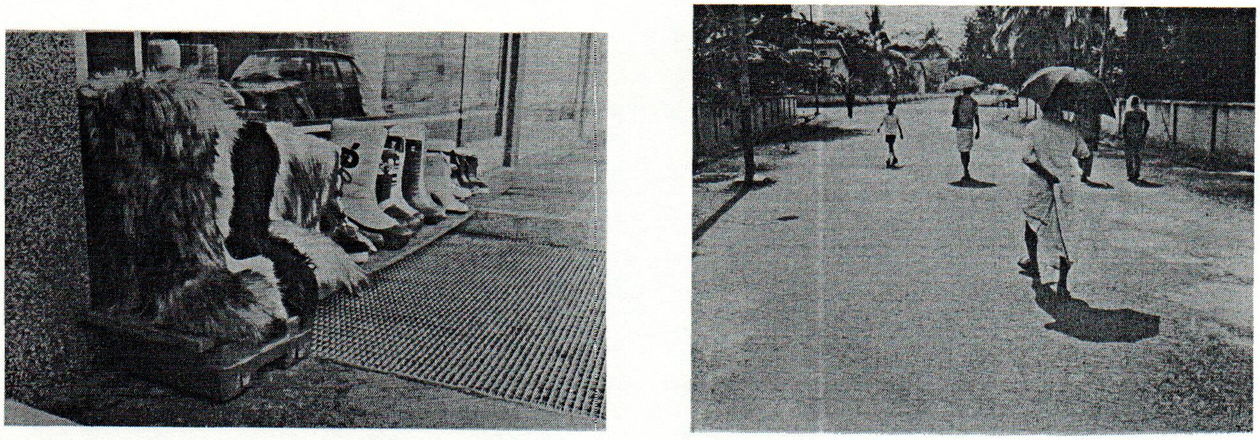

Figure 9. (*Left*) Boots for sale in Vienna, Austria; (*right*) street scene in Cochin, India. People can adapt well to both cold and heat, and our capabilities may be called upon with increasing urgency, in light of forecasts of a global greenhouse warming for the next century brought about primarily by burning of fossil fuels.

environment, regulation should be concerned with human activity only when it provokes exposures or comparable indices beyond natural background levels. A *de minimis* standard may be sensible in comparing background and anthropogenic radiation levels. How far can it be extended in other realms? Thoughtful consideration of standard setting and measurable indicators of adverse responses with regard to the environment are much needed.

Chemistry of the atmosphere

Understanding the chemistry of the atmosphere will be central to understanding and addressing many urgent environmental problems of the next decade or so (Figure 10). These include not only ozone, CO_2, other greenhouse gases, and acid deposition, but also toxic emissions and indoor air quality. As indicated by an ambitious research program outlined by the National Research Council,[36] interdisciplinary individuals or groups skilled in combinations of chemistry, meteorology, and other intersecting fields should be intensely employed for some time.

Inherently cleaner and safer technologies

For engineers and technologists, the job of developing technologies that are inherently superior from the point of view of their effects on the environment has rarely been more pressing. This is true not only for energy production and use and chemical and other materials processing but also for many manufacturing and service industries as well. The work involves facilitating substitution of technologies, such as gas for coal and oil, as well as improving particular maturing technologies. Although the system may evolve globally at a pace we can influence but little, there may be enormous local differences in efficiency and quality of technologies. These gaps may be the difference between a healthy, acceptable environment and a hostile, unacceptable one.

What then are examples of environmental issues that could be characteristic of the next decade or so? One issue that may become prominent is indoor air quality. A recent US Environmental Protection Agency report confirms that there could be serious human health concerns here.[37] A study of 11 toxic

Figure 10. Wrapped statue in Villach, Austria. Acid rain and other changes in the chemistry of the atmosphere will accelerate the erosion of many buildings and monuments.

air pollutants associated with household products such as cleaning agents, building materials, gasoline, and cigarette smoke revealed indoor exposures many times typical outdoor exposures, even for people living close to chemical factories.

There is an irony in that we may have exacerbated the problem of indoor air quality through improved energy conservation over the last 15 years. With the widespread adoption of energy-efficient building ventilation systems and tightly sealed office buildings, the incidence of health problems reportedly related to office air has risen.[38] Though new systems can save resources and money, they may also produce possibly dangerous buildups in toxic substances and bacteria. Indoor air pollution is a problem where technical fixes, such as air exchangers, can be a big part of the solution, just as new chimney designs made life safer and more pleasant in the Middle Ages.

Cumulative impacts and chemistry may be critical to this issue and also to a resurgence of concern about the stratosphere. Early theoretical work and enhanced ability to measure chemical changes in the stratosphere were closely followed by concern about the consequences of operating a fleet of supersonic transport aircraft. The current wave of concern about the 'hole' in the ozone layer over Antarctica is focusing on emissions of chlorofluorocarbons, used as refrigerants and propellants. But both civil and military air traffic has expanded enormously, and as we monitor the chemistry of the atmosphere more closely, we can reasonably speculate that disquieting trends may be again associated with aviation and space transport. Within the foreseeable future, the air and space industries will become one of our largest energy users and they will have to face the consequences of this situation.

More generally, we should be alert to environmental problems that may be associated with massive quantities of transport between giant cities. Within cities, the very tall and large-volume structures now being erected are likely to reveal hazards as they age, whether inside or outside, as a result of objects loosening and falling from their exteriors. Other problems in the operation of giant cities could well appear.

On the brighter side, the few regions that may manufacture so many of the world's goods could be surprisingly clean and safe. And living conditions for people and trees in cities and forests could improve significantly if important moves, such as a shift to natural gas, proceed.

To return to the early question of spatial scales of environmental problems, the important point may be to recognise that the traditional master social processes of differentiation and integration are at work simultaneously.[39] We must not be too quick to assume that everyone will have the same problems at the same time or that many more truly 'global' problems will rapidly appear. Consistent with the view of technological change suggested earlier, some problems that may have peaked in the Western industrialised countries, such as sulphur emission, seem likely to reach new peaks in areas such as Eastern Europe and China before fading.[40]

Conclusions

The green world may need, as much as anything, to be protected from our too often misguided interventions. As Woodwell has noted, 'The solution, if there is one, must recognise that detailed management of the biosphere is beyond human capacity at the moment, since the biosphere is dominated by natural communities whose function is poorly known.'[41]

Should we believe that science will 'narrow the uncertainties' and provide society with more confident and decisive guidance? It is quite possible that we face a period of increased confusion. There is more widespread appreciation of the inherent dynamism of the systems with which we are dealing and the complexity of the syndromes. And our ability to measure continues to spurt ahead of our theory, chemistry, and ethics. Fortunately, the system of evolution of the environment and technology appears not infrequently to have an intelligence that overrides, and makes use of, many human errors.

The views expressed are those of the author and do not necessarily reflect the views of the National Academy of Engineering.

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