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Group Report
Does Bioscience Threaten Ecological Integrity?

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INTRODUCTION

The condensed question in the title requires interpretation if it is to serve as the goal for a meaningful discussion. The first unclear term is "ecological integrity". Here the group addresses the question of how human action influences "nature" (1) and what we consider desirable (2). Before discussing possible threats posed by bioscience (4), the group attempted to sketch a perspective by describing the demands presently placed on our environment and how bioscience might reduce these (3).

ECOSYSTEMS AND HUMAN HABITAT: HOW CAN WE ASSESS HUMAN INFLUENCES?

Seen over a longer time scale, almost no part of the globe has escaped transformation by human influence. The only examples of comparatively undisturbed areas which readily come to mind are the deep sea and the Antarctic. Our question was meant to address relatively recent influence or relatively fast changes.

Assessment first requires tracing causal chains of effects back to human actions. For large parts of our immediate surroundings this is no problem, since they are so profoundly transformed by our purposeful actions as to be virtually artificial. Examples are our urban surroundings, highway systems, and most agricultural fields. For areas only partially transformed, like canalized river valleys or forests regrown after logging, influences are sometimes not so clear, but often identifiable (see box: ASWAN). In those areas not transformed by recent human actions (e.g., unlogged tropical forests and some tundras) subtle or distant changes may still have considerable, even irreversible effects.

ASWAN:

Since the High Aswan Dam became functional in 1965, the freshwater outflow to the Mediterranean with its usual load of nutrients has been reduced to some 6%. Egyptian marine fish landings dropped to about 25% of the predam level, and the Sardinella fisheries were even more drastically affected. The silt load is entirely trapped behind the dam. Shore erosion has become a problem, since it is no longer compensated for by the flood deposition of sand and silt. The loss in soil fertility in the Nile valley and delta is compensated for by intensified chemical fertilization.

However, any balance sheet of the positive and negative effects of the High Aswan Dam must include at least four major benefits: the magnitude of the hydropower generated; the doubling of the farmland area; the creation of a new fishery in Lake Nassar with catches similar to the last marine catches; and, no less crucial, the regulation of water supply to the country despite a decade of severe drought in the Sahel-Sudan-Ethiopian belt. Life in the Nile valley and delta is entirely dependent on the river as a water artery, rainfall being insignificant. The deficiency in the flood water supply necessitated a continuous emergency withdrawal of large volumes of water from the reservoir to protect the country from the catastrophic effects of drought. From 1978/79 to 1984/85, the total deficit compensated from the reservoir reached 73.5 km^3 (Halim 1990).

Three general approaches are often utilized to determine if a given ecosystem has been adversely influenced. One approach is aesthetic or visual and, while qualitative, is sufficient to discern large-scale changes or dramatic short-term effects. A second approach is quantitative determination of structural and functional changes in an ecosystem. This would be considered a professional ecological approach and is exemplified by measurement of species abundance, system robustness, quantified primary productivity, etc. The third approach could be called analytical and is best exemplified by chemical measurements of toxins, pollutants, or other environmental perturbants.

In ecosystems from which we harvest, a decrease in productivity (the ratio of harvest to input) is an indicator of stress. Even more sensitive may be an increase in the yearly fluctuation in harvest size. There are many cases (e.g., coral reefs and tropical forests) where systems will not return to their previous state when stress is relaxed (Goodland 1975).

In many cases, the influence is easy to assess but hard to convey to the public. Bioscientists understand the danger in destroying tropical forests well, yet Amazon voters have elected a public official who campaigned against conservation.

The problems with assessment which occur most often are that:

- we lack baseline information for recognizing a change (there are very few long-term data sets upon which to draw baseline conclusions, and these are often of obscure origin);
- the change is so subtle as to escape attention (e.g., despite very good records, there is still some debate as to whether we are observing a global increase in temperature);
- we do not know how to measure the phenomenon (e.g., "patchiness" in plankton density or in soil microbes);
- we do not know how to distinguish human from "natural" influences;
- the cause of change is multifactorial;
- we simply do not have enough data.

Although this last is a chronic complaint of scientists, our capacity to record experimental data in fact far exceeds our capacity to interpret it. Reinterpreting existing, published data can be scientifically quite rewarding. For example, the correlation between global warming (if it is occurring) and CO_2 concentration could not have been detected had the latter not been carefully recorded over years for entirely different reasons. This illustrates the potential value in monitoring systems and publishing the data, even when no apparent problem focuses our attention.

A suggested principle for assessing human influence is: if we observe in an ecosystem a change which we have never seen before and for which we have no alternative explanation, we should assume it is due to human influence (e.g., coral reef bleaching and red tides). This appears to be a conceivable strategy for dramatic changes, although it tacitly assumes that science has seen everything "old", so what is now discovered must be "new" phenomena. There was spontaneous disagreement as to whether we already follow this strategy, and whether we should.

Possibly, biotechnological tools could help in assessing ecological changes. DNA analysis as a tool to count microbes in soil is presently possible, and even species specifically engineered as indicators are feasible.

WHAT ARE THE ATTRIBUTES OF THE ENVIRONMENT WHICH WE WANT AND NEED?

We want and need environmental integrity, that is, a balanced environment. Although the notion of a "balance of nature" is useful (almost necessary) as an image around which we can organize our relationship with the environment, it is exceedingly elusive when we attempt to give it scientific meaning. Certainly, if we are to live within the "balance of nature", we must establish a sustainable interaction with our environment.

There are many attributes which we expect of our environment, ranging from the obviously essential to desiderata. There was general consensus that we expect our environment to provide the following:

a) ecosystem services;
b) production;
c) beauty;
d) preferred species;
e) biological diversity.

a) A balanced environment provides a host of ecosystem services: our sewage and innumerable other pollutants are degraded by organisms in our environment, the plant growth around us regulates the water cycle, breaks the wind, and filters dust from the air.

We tend to take many such ecosystem services for granted, and the majority of them cost us nothing. They can generally be substituted on a local scale, either by other system components or by artificial means. Artificial substitution, however, usually takes conscious effort and is sometimes quite expensive.

An example of an ecosystem service which probably cannot easily be substituted is the regulation of atmospheric CO_2. The concentration of CO_2 in the atmosphere is increasing at only one third the rate which would be expected from the amount of fossil fuel burned, and even less when the additional output from forest burning is considered. This probably reflects the absorption of CO_2 by the oceans and their phytoplankton and by terrestrial plants (Post 1990).

b) We depend on the material productivity of our environment for food, fiber, fuel and timber. Although habitual food preferences and material culture can offer strong resistance to change, there is still widespread substitutability of these products. For example, in the developed world, fuel and many other ecosystem products are at present derived largely from fossil sources. But production remains the most massive demand we place on our environment.

c) A sizable part of the tourist industry is based on the perceived beauty of landscapes. In most societies, people will pay quite a high premium to live in what is considered a beautiful environment. Substitutability depends here heavily upon cultural traditions, but is also limited by other factors, e.g., problems of transport.

d) We expect our environment to harbor certain preferred species. For example, the Great Lakes of North America produce roughly the same amount of fish today as in the early part of this century. However, the fisheries of commercially valuable species such as lake herring and lake trout have collapsed, and much less valuable species like alewife and rainbow smelt are fished today (Loftus 1987). Another example of a preferred species is the Madagascar periwinkle (*Vinca cataranthus*), a source of raw materials for the production of valuable drugs (Ehrlich 1987).

There is relatively little substitutability here, since specialized properties of the species are crucial. When preferred species are lost from an ecosystem and cannot be restored, the quality of the ecosystem is clearly degraded.

e) Biological diversity is meant here to include both diversity between species and within a given species. Its function in ecosystems is not well understood, but the loss of biological diversity may have many consequences for the functioning of natural systems, among which may be a loss of stability (Pimm, this volume). It seems plausible that biological diversity should increase the potential for a system to change in reaction to changing requirements.

Wild species provide not only gènes for conventional breeding but also for transgenic work, making genetic diversity within a species desirable as a source of new varieties of crop plants and domesticated animals. A loss of biological diversity as the result of extinction must be considered irreversible, and there appears to be no substitutability here.

Some indications of a nonsustainabile interaction, and thus attributes we obviously do not want, are:

- soil erosion;
- loss of diversity (within species and extinction of species);
- harmful plankton blooms;
- epidemics/pest outbreaks;
- declining or more erratic harvests;
- chemical pollution.

Other possibly desirable attributes, such as continuity and self-management, were discussed but either defied clear definition or remained debatable.

In many situations, the attributes in the above list will overlap or will be in conflict with one another, as when gardening locally reduces biological diversity in favor of beauty. In particular, increased total demand for products is often met by trading more area away from the attributes a), c), and e) (although some will find endless cornfields beautiful). Economic priorities regularly conflict with the preservation (or achievement) of these attributes. The conflicts cannot be solved at a scientific level, but bioscience can make them visible, so that other social institutions can mitigate them.

Lacking a scientifically viable notion of the "balance of nature", a suggested guide is the "principle of precaution": do not change more than you must. But the term "must" is ambiguous at best, so that an alternative version appears both more rigorous and more practical. This is the "principle of environmental reciprocity": avoid any activity likely to bring about irreversible changes in ecosystems.

Natural processes can lead to recovery of a system; active effort can lead to its restoration. In either case, reversibility denotes not only the possibility of recovery or restoration, but also its feasibility or practicality. The time it will take, the likely cost in money, labor, and other resources, and the quality or authenticity of the resulting system are further important aspects (see box: FIRES).

HOW CAN BIOSCIENCE HELP TO ACHIEVE A SUSTAINABLE INTERACTION WITH OUR ENVIRONMENT?

In this section we will concentrate on sustainable interactions as a catch-all for desirable interactions. None of the group members questioned the fact that this (rather static) goal was desirable. Again, no rigorous definition of sustainability was presented, because this must include the question of population size and average consumption per capita.

FIRES:

The identification and assessment of human influences on ecosystems may seem deceptively simple in retrospect. A good example is the difficulty of determining how humans have influenced various ecosystems through the use or the suppression of fire. For example, the tallgrass prairies and savannas of central North America were probably burned more or less annually by fires set by Indians or by lightning, usually in the spring or fall. Various observers, including Thomas Jefferson, speculated that fire accounted for the scarcity of mature trees in these ecological communities, but the actual nature of the relationship between fire and vegetation was not clear. These speculations were supported by observation when the frequency of fires declined dramatically following settlement by Europeans in the 19th century. Fire was suppressed deliberately as a safety measure and inadvertently by plowed areas which served as fire breaks. Following this development, many Midwestern grasslands were rapidly invaded by trees and converted to the oak forest common in the landscape today.

Nevertheless, the relationship between fire and vegetation remained controversial among ecologists, and first attempts at prairie restoration, undertaken at the University of Wisconsin-Madison in 1935, did not employ fire. Only when these initial efforts were unsuccessful did ecologists begin experimenting with fire on prairies. This line of research has gradually worked out the relationship between humans, fire, and the vegetation of the area (Jordan, this volume).

Similar experiences have produced comparable insights in other North American ecosystems, including forest ecosystems of the West and the Southeast. This work teaches us the value of restoration attempts as a way of identifying causal factors influencing the condition of a landscape. Without understanding these causal relationships, we can often change a system easily enough – by burning it, for example, or by altering a historic pattern of fires –, but we are less likely to be able to restore it.

Maintenance of natural or historical ecosystems may also depend critically on this understanding. Thus, the prairies, and even more dramatically, the oak savannas of the Midwest, were almost entirely lost as a result of initial failure to appreciate their dependence on fires of human origin (Packard 1988).

Note that growth can only be sustainable if it is asymptotic, tending toward an absolute upper limit. Any given system of exploitation will eventually be outstripped if growth in consumption or population is not limited.

The image of the "noble savage" projects a sustainable interaction, but it is scientifically debatable whether this has ever been achieved. In particular, along with alleged examples of sustainability (Mayan society, Javanese society), there are many examples of societies which visibly did not achieve this goal (Greek and Roman societies together deforested the Mediterranean countries). The North American Indian cultures, sometimes cited as examples of sustainability, may have massively changed their habitat, driving to extinction many of the large game animals of North America (Martin 1984).

Alleged examples of sustainable societies tend to have been sedentary and relatively undisturbed by major wars, which suggests that cultural accumulation of knowledge about the environment may play an important role. Also, very little is known about the per capita consumption they had. Sustainability virtually assumes local production of food, fiber, and fuel. If at all, the "noble savage" probably existed at a much lower population-consumption level than we have today.

Humans directly or indirectly divert ca. 40% of terrestrial primary production to satisfy their demands (see box: NET PRIMARY PRODUCTION). Although other systems exhibit diversion rates between 5% (tundra) and 90%, those with a high diversion rate generally have a low-standing crop or cover only small areas.

There was consensus that the present human population-consumption level is not sustainable using presently known techniques. This was extensively debated, and there were many suggestions for increasing primary production, all relatively marginal. Some examples:

- Increasing the integration of agricultural systems may increase yields by a factor of 2–3, but this will apply to only a few areas.
- The potential of mariculture is generally overestimated (see box: FOOD FROM THE SEA). Only the integrated use by farmers of irrigation water for raising herbivorous fish promises a marked increase in local net productivity.
- Indirect consumption could be reduced if we chose to eat less meat. But most of the world is largely vegetarian already, and, far from exporting their present grain surplus, the meat-eating countries now import part of their animal feed.
- Despite mineral fertilizers and pesticides, primary production, e.g., in Great Britain, has been virtually constant during this century, although there has been a shift toward species which humans can better utilize.

These considerations all turned on the possibilities of providing consumption needs. During this discussion there was no reference to the effect this might have on the other attributes of a sustainable environment mentioned above in the section "What Are the Attributes of the Environment Which We Want and Need?" From the point of view of the ecologist, evolutionist, or geneticist, however, the preservation of biological diversity is by no means a luxury.

NET PRIMARY PRODUCTION:

Net primary production (NPP) is the amount of energy left after subtracting the respiration of plants from the total amount of solar energy that is fixed biologically. NPP provides the basis for maintenance and growth of all animal consumers, and so is a limit to the total food resource available to us.

The estimates of NPP differ widely across different kinds of ecosystems. Deserts and arctic and alpine regions represent a substantial part of the planet's terrestrial surface (37%), but contribute only a small fraction of the terrestrial production (<4%).

Similarly, the oceans constitute about 70% of the total surface, but are very unproductive with the exception of areas of coastal upwelling. In total, the oceans may produce only about 40% of the global NPP.

Vitousek and collegues provide three estimates of the degree to which NPP is used by humans:

- A low estimate as simply the amount of NPP used directly for food, fibre, fuel, or timber. Direct human consumption represents about 5% of terrestrial NPP, or 3% of global NPP.
- An intermediate estimate, adding to this the productivity of all lands devoted entirely to human activities. For example, although only a small amount of the biomass in a grain field is actually consumed, yet the entire area of the crop is devoted to our food production. With this in mind, the percentage of terrestrial NPP in one way or another co-opted by humans rises to about 30% (20% of global NPP).
- A high estimate, adding to this the production lost, for example, as a result of converting land to cities and highways, forests to pasture lands, or desertification and over-use leading to soil erosion. This estimate raises the figure to nearly 40% of terrestrial NPP, or about 25% of global NPP (Vitousek et al 1986).

Consensus is difficult to reach on what a sustainable population level is. An example is Europe, for which the group consensus was:

- in no way is the present European population-consumption combination sustainable;
- if consumption as measured by energy could be reduced to ca. 20% of its present level, then sustainability may be conceivable.

Some experiments in developed countries have shown only a marginal drop in agricultural productivity when use of artificial fertilizers and pesticides is discontinued. (However, some pesticides may have been used in adjoining crops, and the material export was compensated by organic fertilizers.) Consensus could not be reached on whether this implies the capability of the developed countries to feed themselves without fossil energy. (At present,

FOOD FROM THE SEA:
Confronted with potential food shortage, owing to growing human demand, many officialsd, managers and large segments of the lay public see the oceans as a major new source of food. This view is problematic for three reasons:

- The oceans are already exploited, and provided in the late 1980s about 80 million tons per year of high quality protein (FAO 1990).
- Sustaining this harvest under present fishing practices and lack of efficient management will be difficult, and increasing it to match a decade or more of predicted population increase appears downright unfeasible.
- Mariculture, like any farming enterprise, requires secure sites and inputs (feeds, fertilizers) which are in limited supply. It must compete with capture fisheries for sites and with agriculture for inputs. Also, most mariculture operations use soy-based pellets or cheap fish like anchovies to feed high-priced species such as salmon, seebass, or grouper, generally with losses of about 90% of the protein fed.

About 90% of the world's marine fish harvest stem from the shallow "shelves" with high primary production which gird the continents down to 200 m (Gulland 1970). All of the world's major shelves are now exploited, with serious overfishing problems reported from most of them, such as the North Sea (Gulland 1982) and the Sunda Shelf (Pauly 1988). Exceptions are possibly parts of the Patagonian, Antarctic, and Sahul shelves.

Attempts to identify "unconventional" marine resources have involved among others:

- lantern fish (fam. Myctophidae), of which billions of tons may occur in the bathypelagical zone of the world's oceans, but generally at very low concentrations (in the order of 1 gram per ton of water), precluding their commercial exploitation (Gjoesaeter 1980);
- oceanic squid, whose biomass and production appear to be very high (based on sperm whale stomach contents), but which are extremely difficult to catch and to market;
- Antarctic krill (*Euphausia superba*), the key trophic link in the Antarctic ecosystem. Krill feeds the antarctic fish, penguins, seals, and whales, now considered for protection. In any case, krill could not be exploited by (protein-)poor countries;
- fish or invertebrates in OTEC (Ocean Thermal Energy Conversion) plants, driven by artificially upwelled, nutrient-rich deep waters. This would require investments beyond the reach of countries now unable to secure sufficient protein (Linsky 1981).

Overall, no major marine resource appears to exist which would be capable of sustaining a new, economically viable fishery and whose landings would be cheap enough for consumption in developing countries, where most of the need will be.

no developed country does so.) Nor could consensus be reached on how this question could be resolved.

Advanced conventional biotechnology and new genetic engineering methods can play an important role in sustaining the interaction of human population with the environment at an acceptable level of ecological integrity. There is considerable literature on biotechnological approaches to agriculture which can be pursued to make developing countries relatively self-sufficient in the production of food, fiber, and fuel. While much of this biotechnology is conventional, recent advances in genetic engineering and plant cell culture technology will permit a more rapid pace of development. The goal is customizing crop species to increase productivity and reduce environmental impact. In this regard, engineered plants are likely to see widespread field demonstration within the next few years. If this technology proves safe and effective, applications for bioengineered animal products, feed additives, probiotics, and disease-resistant breeds may follow.

Turning away from plants, a host of biotechnological developments using both native and genetically engineered microbes is underway:

- for restoring damaged ecological and depleted agricultural systems;
- for reducing toxic and hazardous waste discharges and existing environmental contamination or for remote sensing of pollutant degradation;
- for cost effective, low impact resource recovery and recycling;
- for mixed organic waste treatment systems.

Already, synthetic plastics from bacterial biopolymers are a reality on a pilot scale. Realistic projections for the coming decade envision the combination of these with developments in composite material science and bioelectronic polymers lessening the demand for petrochemical processes. Plant and microbe-based systems are in development to improve soil fertility, composition, and texture, e.g., using nitrogen-fixing microbes or mycorrhizal plants.

A compilation of potential environmental biotechnology is beyond the scope of this report, but could also include bioconversion and biocatalysis systems, composting technology for wastes, solvent and biogas production, artificial photosynthesis, and CO_2 fixation systems.

Finally, strategies exist for development of gene storage banks as a last resort for conserving some of the biodiversity presently in jeopardy and for environmental health assessment using molecular detection and cataloging systems. The former cannot, however, realistically replace physical preservation of species, e.g., in reserves.

There is a major need to integrate these technologies with research on the dynamics and control of natural ecological systems for safe and effective applications. There is also a pressing need for evaluation of the indirect effects of these technologies, for example through the displacement of existing social and economic systems. Clearly the development costs are significant, but there is a likelihood of low cost application in an environmentally safe manner.

The ecology of developing countries is threatened most by the demands resulting from rising population, which can outstrip any increase in productivity we can create. There are two ways biotechnology can affect this problem: first, by contributing culturally more acceptable ways to control population growth; and second, by increasing primary productivity enough to bridge the time span until population has been stabilized. The techniques used must be robust and independent of sophisticated or expensive infrastructure.

The ecology of developed countries is threatened most by the demands resulting from rising consumption, which again can outstrip any increase in productivity we can create. Biotechnology can only affect this problem by giving us techniques to mitigate the environmental effects until consumption has been reduced to the sustainable.

One source of ecological problems is that external costs are often not included when actions are evaluated. In particular, simple economic models of exploitation tend to assume that any resource can be substituted and, by discounting future values, to overemphasize the present. However, shifts in exploitation mechanisms may prove less of an economic burden than first appearences would suggest, as illustrated by the ban on whale hunting (see box: WHALES). Bioscience can help make external costs visible which would otherwise go unnoticed.

HOW DO WE ASSESS THE ECOLOGICAL RISKS OF NEW BIOLOGICAL TECHNOLOGIES?

We mention first two indirect risks which are not peculiar to new biotechniques, though these may increase them:

- As new agricultural strains with better performance replace older strains, the latter may disappear, reducing future options.
- Breeding for resistance to adverse conditions can lead to a negative feedback cycle. For example, the breeding of salt-resistant plants may lead to irrigation with saltier water, thus, over time, creating demand for increasingly salt-resistant strains.

WHALES:

A number of natural living resources are presently under serious threat from an increasing world population; these include tropical forests, coral reefs, numerous species of large terrestrial mammals and birds, rare varieties of our major crop plants, etc. For most of these, prospects are generally bleak. However, the longterm prospect of one major group has radically improved in the last two decades: the great whales.

About these, Day wrote that the "rapid shift of attitude toward the killer whale from antipathy in the early 1960s to total sympathy by 1970 coincided with the same period of radical change in attitude toward all great whales. Opinion moved from indifference during what was the most wanton destruction of the whale in history (some 60.000 a year in the 1960s) to shock and alarm by the early 1970s, when some nations continued to hunt despite the obvious collapse of all whale populations" (Day 1987).

Changed public perception of the whales from mountains of lard (Gulland 1988) to sensible beings has gradually made their exploitation morally repugnant, thus changing the parameters of the very science investigating them, and rendering even "scientific whaling" inacceptable (Pauly 1987).

Quite aside from the tactics used by opponents of whaling, as detailed in Day's book, we feel there is a lesson to be learned about the conservation of other living resources. This applies particularly to the general public, which understands that the key issue was not one of conservationists fighting to "stop development" or to destroy jobs. The danger was one of irrevocably losing options, including that of watching whales, now a major industry.

More direct are the risks involved in the planned release of transgenic organisms which reproduce. Lacking direct observational data, we must depend on analogies, e.g., the introduction of alien species or genotypes. Many introductions have a negative effect on the ecosystem as defined by the criteria above in the section "What Are the Attributes of the Environment Which We Want and Need?" The risks which we might expect from this analogy are that the new organism will be a crop pest or invade the natural habitat.

For this analogy, we have many examples to draw from, such as the introduction of goats to islands lacking large predators, or the effects of introduced diseases like the chestnut blight. Note that Europe is a poor basis for intuition in this field, as almost no crop has become a pest there. This is in contrast to other areas (e.g., sorghum in the continental U.S.A., guava in Hawaii, carrot in several subtropical areas).

Theoretically, a simple invasion model would predict population growth from the intrinsic growth rate modified by such effects as competition, predation, parasitic diseases, and the like. Whether or not an invasion results depends on the values of the parameters, which are too numerous to be individually estimated. It is more realistic to determine the growth rate experimentally under controlled conditions. First results appear promising (Crawley, this volume).

It is debatable how good this analogy is for small transgenic changes in current crop plants. It may tend to overstate the risks, since transgenic introductions are derived from one individual and hence lack genetic variability. Self-destructing mechanisms may also be built into the genes of transgenic organisms, but these mechanisms might fail, e.g., the organism might mutate or find an unsuspected niche. It is thus safest to assume that release is irreversible.

A good way of freeing the analysis from emotion is to judge the product, not the process by which it has arisen. However, the ways in which techniques of genetic manipulation differ from "natural" evolutionary or breeding processes carry the potential for risks and for benefits:

- the rate at which viable mutants are created is higher than the natural mutation rate;
- the selection process is accelerated, at least with repect to the desired traits;
- recombined genetic material might later move to different sites on the DNA (newer technology might solve this problem);
- by combining genetic material which could otherwise not come together, adaptive peaks could be jumped.

It is also conceivable that natural processes might transmit genetic material from the introduction to other species.

Taken all together, the immediate risks to our environment arising from new biotechnology do not appear major when compared with those posed by present growth in human consumption and human population.

PRIORITIES AND CONTRIBUTIONS TOWARD THE COVENANT

Science is probably driven as much by funds as by curiosity. Funding policy can thus be used to direct effort toward projects which include analyses of potential environmental effects beyond those which are immediately obvious. The environmental impact assessments presently required by law in many countries are generally too narrow in scope, although they are a step in the right direction.

Societal fear of biotechnology is neither all unfounded nor all too justified. The discourse between bioscience and the lay public can be intensified to increase agreement on the significance of potential risks and benefits in research and in development projects. In particular, only sound, defensible arguments should be used when working in the political arena. A counterexample was the fight against the Tellico dam, centered around alleged impending extinction of the snaildarter (Disilvestro 1989).

Both at the level of teaching and of research there is need of a more integrated environmental science. Elementary textbooks generally contain only "consensus science", and debates on curriculum reform seem endless. Effort spent creating incentives for outstanding scientists to write interdisciplinary textbooks and participate more strongly in teaching would be well spent. Another way of improving the quality of ecology professionals and teaching could be through professional organizations. Present orientation in research is primarily toward pushing biotechnology to new frontiers. More emphasis should be placed on assessing what has been achieved and on developing an integrated, interdisciplinary approach. Funds are not the primary problem here, and rapid progress is improbable.

Aside from research directed toward increasing the options for controlling population, the most pressing research problems from the standpoint of ecological integrity are:

- To find ways of defining sustainable population-consumption levels in various settings.
- To make biotechnological results cheaply available, independent of sophisticated infrastructure. Particularly emphasize those which increase production of locally desirable food, fiber or fuel without drastic effects on the environment.
- To monitor apparently stable systems to gain baseline data. Top priority goes to systems with monitoring programs in progress which are in jeopardy. Also monitor variability within indicator species and the loss and gain of species.
- To systematically investigate theoretical and analogical ways of estimating the risk of transgenic and "conventional" introductions.
- To find ways of determining what levels of stress are reversible, depending on measurable system parameters.
- To find more ways of restoring systems after overstress or deliberate partial destruction (healing art).

Two points deserve mention which remained debated:

- What changes constitute damage to an ecosystem? Here opinions ranged from "potentially almost all changes" to "irreversible functional changes".

- Should the burden of proof be transferred to the party proposing an active change in an ecosystem? Here opinions ranged from "this would improve public acceptance without unduly hampering research" to "this would bring bioscience to a screeching halt".

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Standing, left to right: Daniel Pauly, Michael Bernhard, Kenneth Hsü, Wolfgang Van den Daele, Peter Kafka, Horst Nöthel, William Jordan III
Seated, left to right: Robin Gordon, Stuart Pimm, Michael Crawley, Gary Sayler, Youssef Halim