2002

Blue Planet Prize

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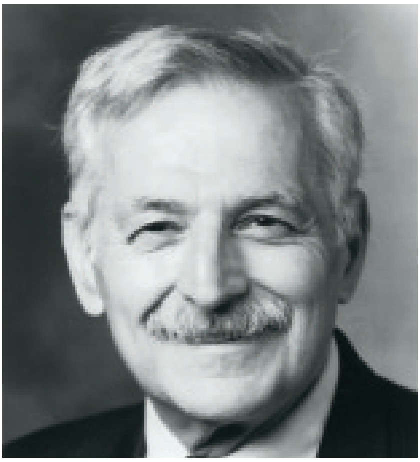

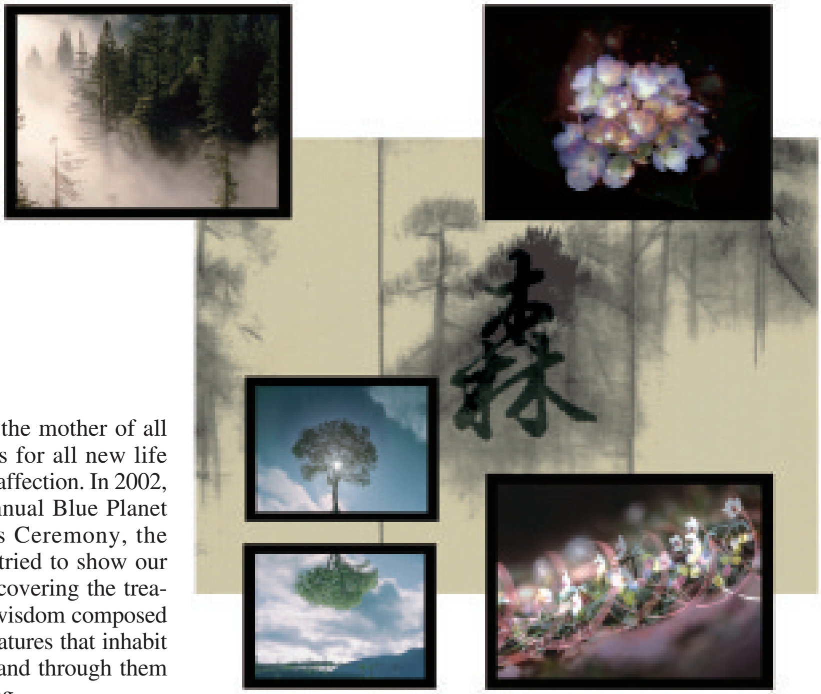

The Forest:
Our planet is the mother of all life. She cares for all new life with love and affection. In 2002, at the 11th annual Blue Planet Prize Awards Ceremony, the opening film tried to show our effort at rediscovering the treasure trove of wisdom composed by myriad creatures that inhabit it; the forest, and through them the joy of living.

His Imperial Highness Prince Akishino congratulates the laureates

Their Imperial Highnesses Prince and Princess Akishino at the Congratulatory Party

Hiromichi Seya, chairman of the Foundation delivers the opening address

Blue Planet Prize Commemorative Lectures

Dr. Jiro Kondo, chairman of the Selection Committee explains the rationale for the determination of the year's winners

Howard H. Baker Jr., Ambassador of the United States of America to Japan, congratulates the laureates

The prizewinners receive their trophies from Chairman Seya

Prof. Harold A. Mooney

Prof. James Gustave Speth

Profile

Professor Harold A. Mooney

Professor, Department of Biological Sciences, Stanford University

Education and Academic and Professional Activities

1932	Born on June 1 in California, USA
1957	Graduates from the University of California at Santa Barbara
1960	Obtains doctorate at Duke University
1960	Associate Professor, University of California at Los Angeles
1961	Ecological Society of America, Mercer Award
1968-1975	Associate Professor, Stanford University
1975-present	Professor, Stanford University
1976-	Paul S. Achilles Professor of Environmental Biology
1983	Merit Award, Botanical Society of America
1990	Ecology Institute Prize for Terrestrial Ecology
1992	Max Plank Research Award
1996	Eminent Ecologist Award, Ecological Society of America
2000	Nevada Medal of Science Award
2000-2003	Senior Fellow, by courtesy, Institute for International Studies, Stanford University

Professor Mooney entered the University of California at Berkley as a political science major, but dropped out of school for economic reasons and got a job on a freighter traveling down the west coast of the Americas. While transiting the Panama Canal, he read in a magazine about a "Plant Hunter for the United States Department of Agriculture," which led to a major change in his career path. Professor Mooney, who had a strong interest in plant life through his activities in the mountains of California, was extremely attracted to an occupation in which both plant exploration and adventurous travel would be possible. So he returned to the University of California at Santa Barbara in order to study botany.

In 1957, he researched the physiological processes of Arctic-Alpine plants over a vast natural range extending from Alaska to the Rocky Mountains. He studied photosynthesis and respiration of the plants using an infrared gas analyzer and equipment that he helped to design and was able to demonstrate the physiological basis for ecotypic differentiation. He showed that plants adapted their physiological processes to their local environments.

After he obtained his doctorate in 1960, he embarked on research into convergent evolution that showed that different plant species develop the same physiological characteristics in response to the same severe environments. He earned acclaim for demonstrating that similarities between different species were not limited to form, which had already been demonstrated, but also extended to function. He accomplished this by comparing the ecology and physiological characteristics of plants in the drought-limited Mediterranean climates in the geographically disparate California and Chilean coastal regions and Mediterranean Basin.

In the 1970s, he took a broader approach to examine not only carbon gain but carbon use by plants in an area of California ranging from the desert to the White Mountains and applied a cost-benefit approach to clarify how carbon resources are allocated to different sites in plants. He had a significant impact on later studies into plant physiological ecology and advanced research into carbon gain and use in plants by showing in a detailed cost analysis how plants obtain carbohydrates and nitrogen, and how they distribute and store them to obtain the greatest effect with the lowest expenditure of energy. To date, he has authored over 400 scientific books, papers and articles.

In the latter half of the 1980s, he pursued research into the effect of the invasion of different plant species on naturally occurring species under the auspices of the Scientific Committee on Problems of the Environment (SCOPE), setting up the first global evaluation of invasive plant species. He regarded the acceleration of problems related to invasive species due to increased international commerce with grave concern, recognized the need for joint research between naturalists and social scientists, and launched the "Global Invasive Species Program" with many international institutions as partners.

Professor Mooney has been active in building up worldwide communities and networks of ecologists and scientists in recent years, especially with problems related to biodiversity and global warming. He played a central role in the International Geosphere-Biosphere Program (IGBP), having an influential part in setting the guidelines for the formulation of environmental policies. He has advanced numerous international research programs as Secretary General and Vice-President of the International Council for Science (ICSU). Furthermore, he is working to solicit the interest of the general public in many scientific topics through the media and other channels. He continues to work toward the development of new environmental sciences that will be required for the continued existence of humankind.

Essay

Ecologists, their Science and Careers, and their Role in Society

Professor Harold A. Mooney

July 2006

Gareth Edwards-Jones (2006) recently wrote an essay on "Sustainable development: What's ecology got to do with it?" He tells a very interesting story of his own career experience relating how he attended a meeting of the British Ecological Society Easter Symposium some 20 years ago when the very distinguished ecologist, John Harper asked this question in a speech, "What if a bomb went off in this auditorium right now and killed 250 of the world's best population biologists? Would it have any impact on the future of the planet and the development of the human race?" Harper answered his own question by saying, "Not one jot!" That was a dramatic statement, and as an ecological practitioner at that time I probably would have made a similar remark in a speech in my own country. I thought times had changed though, and that the ecological community was much more engaged in societal issues so I was saddened to read further in Edwards-Jones' essay that he had planned to attend a symposium on "Ecological Limits to Sustainable Development" at this year's British Ecological Society Easter meeting but learned that the symposium had been cancelled for lack of interest.

Gareth Edwards-Jones speculates as to why there was such a lack of interest in this recent symposium proposal, and he proposes that career development seems to take such a large role in our time allocation that little is left for venturing to the big questions relating to the relevance of what ecologists know, and learn, to societal development. There certainly is no escaping the fact that, in academia at least, the pressure for peer recognition and hence job security is intense. A number of years ago a large group of senior ecologists wrote a short piece on this dilemma (Bazzaz, et al. 1998). They contended that times had changed and that academic ecologists should now add a third task to their job description. The traditional tasks were 1) to conduct high quality research and 2) to make the results available to their peers by publishing it in the technical literature. To these they would add the additional task of 3) informing the general public (who in the end pay for the work performed) of the social relevance of their efforts. They addressed Edwards-Jones' concern for the lack of motivation, or more specifically reward, for doing so, other than personal satisfaction. The Bazzaz et al. paper called for more formal recognition, within academia, not only for the production of high quality research, but also for success in informing the public of the relevance of the research products to human well being. Making the latter case is not too difficult since the work of ecologists is central to understanding how community and ecosystem processes lead to the ecosystem services upon which society depends.

I do certainly see changes happening in the attitudes of individual scientists and this is a very hopeful sign. I will illustrate the changes that I see with two examples. In recent years there has been the development of a global scientific assessment process. Leading scientists from around the world donate their time and expertise to critically evaluate the literature, relating these finding to the crucial environmental issues of our time, and noting the certainty of our knowledge. One of these assessments is the Intergovernmental Panel on Climate Change, or IPCC. This group has made a series of assessments through time to determine what effect the emissions of greenhouse gases has on climate change. The resulting documents are very authoritative since so many international scientists are involved and the review process is very stringent. The change in attitude that I perceived was the recognition by the participants that they had been selected by their peers for involvement in an important task. Rather than hiding these activities from one's promotion papers it was actually highlighted. This is a real change in perception by the scientists on the importance of this "extracurricular" work for the benefit of society, as well as for their own career development.

Another recent global environmental assessment was the Millennium Ecosystem Assessment, or MA. The program used the IPCC template, to a large extent, and with similar results—a very large international group of leading scientists produced the first global assessment of the status of the Earth's ecosystems and their capacity to deliver ecosystems goods and services to society. An innovation of the assessment was the involvement of young scholars as fellows for this work, in addition to the established scientists. A wonderful group of young scholars, graduate students and recent graduates, became fully engaged in the work and were very excited and rewarded by doing so. The important point is that evidently they did not get negative feedback from their mentors that it was not appropriate at their stage in career development to become engaged in this work; quite to the contrary, it was a plus to their career as well as serving an important societal role.

The second example I use to illustrate the change in attitude about involvement of scientists in outreach to society is a training program in the United States called the Aldo Leopold Leadership Program. This program is designed specifically to give young scientists the tools they need in order to communicate their scientific findings to a larger audience through newspaper and magazine articles, and in interviews with journalists from radio, print or television, as well as how to engage with decision makers about the relevance of their work to society. Each year 20 fellows are chosen. The pool of applicants has been truly outstanding throughout the length of the program, which is now more than 5 years. Obviously, the desire to communicate the best of science findings to the general public is great, and the applicants again see their selection for the program as a plus for their career and their role in society. The pool was originally set for young scholars who had just attained tenure at their place of employment so that they would not have job security as a barrier to involvement. However, through time many exceptions have been made since some absolutely outstanding pre-tenure scientists have applied because they thought that the program was important to what they wanted to accomplish in their careers. Again, I see this as a very definite change from the perceptions that Edwards-Jones noted at his science meeting.

However, the issue of scientists at an annual professional society meeting being attracted to events that address societal problems directly is another matter. Although large changes in attitude have indeed occurred, I do not see the kinds of fundamental changes in attitude that I spell out above applying to these events. Scientists at these meetings gravitate to those sessions that are most relevant to their own personal research so they can keep up with the increasingly fast moving pace of virtually all science endeavors. They look to other venues for the science/society interface, such as in the United States, the annual meeting of the Association for the Advancement of Science, which often includes many policy relevant issues, and is well attended by communicators of science from the media.

Professional Societies

There has been a rather dramatic change in the activities of ecological societies in the past few decades which also speak to the changing vision of the role of ecologists with the general public. For years the membership of these professional groups resisted formal interaction with society at large but now some, like the Ecological Society of America, have very substantial and active public outreach and policy offices.

Universities

Universities are very slow to evolve however, although the increasing development of interdisciplinary programs and large research teams give an indication of some fundamental restructuring that is occurring and is a recognition of the complexities of the problems that society faces, which need new approaches. Nonetheless, it is still devilishly difficult to pursue and get funding for interdisciplinary work, and promotions are still, at most universities, generally decided by individual research output in prestigious journals with teaching performance and public service lower on the list. With funding harder to get for research support, it is easy to understand that the prime driving force for career development is likely to be: production of very good science with little time left for the extra step of outreach, hence a real basis for Edward-Jones' concern. Further, there is some disdain, in many academic quarters, for those who address relevant societal issues and who attempt to communicate to the general public. Thus, there is not only no reward but there is almost punishment for devoting time to communicating to others rather than immediate peers. These attitudes are disappearing though and the motivation of individuals and how they can best contribute to science and society are becoming more predominant.

Professional Society Role

In summary, I think the community of scholars working on environmental issues is beginning to accept the challenge of communicating their work to society at large and that there are large changes occurring in scientist involvement in efforts to do so. Still though, there is not a universal agreement that such outreach is an appropriate role for scientists, many of whom still seem to think that placing their results in a good scientific journal fulfills their contract with society and that somehow society will find these results without further help. These attitudes though seem to be fading somewhat, however it is true that academic institutions have been slow in recognizing and rewarding those who are conscientious and skillful in conveying their work to others outside of the literally handfuls (most commonly) of people that will read about it in a scientific journal.

As we continue to mine the Earth's resources, to an ever greater extent, it is vital that scientists who understand the consequences of the potential disruptions to ecosystem functioning and services, make these results widely available to society at large. Ecologists must assume the responsibility for not only increasing public awareness and understanding of these issues but also provide tools and approaches that will lead to a more sustainable future.

I think now we can be confident that the times have changed since John Harper's rather gloomy assessment of the relevance and engagement of the work of ecologists, including his target population biologists, to the welfare of society. If this is not the case it certainly needs to be so, and quickly.

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Lecture

The Sorcerer's Apprentice and the New Biological Order

Professor Harold A. Mooney

It is a privilege to have come to Japan and to address this audience on a few of the many issues that humanity is facing as we fundamentally alter the nature of the earth system and the resource base upon which we all depend. I, along with many others, extend an appreciation to the Asahi Glass Foundation for their dedication to the search for solutions to global environmental problems, by the establishment of the Blue Planet Prize, as well as by conducting their annual global surveys on opinions of environmental experts on the status and future of Planet Earth.

Before I embark upon the substance of my address I provide a little background on my own career, which provides the foundation for the work I will tell you about.

My early career centered on the study of the physiological adaptations of plants to their environments. This work brought me to embark on investigations in many of the world's major ecosystems from deserts to Polar Regions to the tropics. What my students and I learned was how closely ecologically tuned plants are to their local environmental conditions and of the many mechanisms that they have evolved to cope with local limitations of resources.

We also learned that a given environmental suite of conditions brought forth similar adaptive modes in organisms no matter what their evolutionary history might have been. Specifically, comparable climates in places distant in the world produced similar adaptations in the biota through convergent evolution.

These findings have shaped my own appreciation of the evolutionary constraints on how plants utilize their resources and hence on what the limitations are on the utilization of natural systems by humans in different parts of the world. We also found some universal mechanisms that plants employ to capture and utilize resources no matter what habitats they may reside. These findings enabled us to predict how plants deploy the resources they have captured to compete under differing conditions of environmental stress be it limiting water, nutrients or predator pressure.

Early involvement in international environmental science, through the International Biological Program (IBP), led me to appreciate the power of scientists from around the world working together to identify and help solve problems of universal importance to society. The IBP focused on the limitations to primary productivity in the earth's diverse ecosystems and in doing so laid the foundations for systems ecology. Subsequently, I participated in a number of programs coordinated by the Scientific Committee on Problems of the Environment (SCOPE)—a group of international scientists dedicated to assessing the status of the global environment and highlighting emerging issues.

Through SCOPE I became engaged in a number of global issues, including fire ecology, invasive species, on which I concentrate in this address, and the significance of biodiversity on the ecosystem functioning and the services that it provides to society, which I also touch on briefly. Through other venues (primarily ICSU-the International Council for Science) I also became involved in the design of global research programs on earth system functioning and the science of biodiversity. All of these activities have impressed upon me the rapidly growing extent of human activity on the functioning of the earth system and of the urgency of educating all of us on the consequences of these changes and the options that we have, and must pursue, for building a sustainable biosphere.

Introduction to the Sorcerer's Apprentice

We are witnessing a dramatic transformation in the nature and functioning of the biotic resources that sustain us all. These changes in biological diversity are occurring at all levels—from the very genetic structure of organisms to the configuration of organisms on the landscape. Many of these changes are to the benefit of humanity, and are intentionally driven, but others are detrimental and inadvertent. In this essay I examine what is happening, what is driving these changes, and what the potential consequences of these changes are to societies? I particularly examine how fast these changes are occurring and how the increased tempo of change leaves us with limited options for corrections of trajectories that we may find unfavorable. The complexities of the biological order challenge our current understanding of the underlying forces driving and sustaining them and thus we must proceed with caution as we rearrange biotic landscapes, and the individual organisms constituting them, to provide for the activities of human societies. I conclude with a description of how scientists, at last, have mounted a comprehensive global survey of the current status of biological systems, how they are being modified and the most likely consequences of these changes and the options that we have for influencing favorable outcomes.

The Sorcerer's Apprentice

One of the most compelling movie sequences ever filmed was an episode in Fantasia where Mickey Mouse plays the sorcerer's apprentice. In this sequence, based on the poem by Goethe, and set to music by Paul Dukas, Mickey, the apprentice, using the power of the hat of the absent sorcerer, commands a broom to do his menial task of fetching water from a fountain to fill a large vat. He then falls asleep and upon awakening he finds that the broom has been very efficient and has filled the vat to overflowing. Mickey, lacks the full knowledge of the sorcerer and cannot make the broom stop. He then, uses an axe to cut the broom into pieces. Then the nightmare occurs of the pieces replicating themselves into new full brooms and resuming the task of bringing in more water, creating a flooding disaster. The sorcerer returns, and with his knowledge of how to reverse magic spells, he turns to broom back to an inanimate object and thus no longer a threat.

What is frightening about this episode is the self-replication of a tool that has gone wrong. A mistake is made, but then it is compounded by replication of the mistake. The one making the mistake, based on his incomplete knowledge, is helpless to reverse this compounding error and disaster follows.

Unfortunately this exact same story is played out all over the world today, not by Mickey Mouse, but by real people, again seeking a simple solution for solving a task. The tool they invoke is an organism possessing some apparently useful property, which by its nature already has the power of self-replication. The potential for disaster is thus closer at hand than for Mickey, who only upon trying to correct his mistake compounds it by conveying self-replication upon an inanimate object.

How Organisms Used to Move Among Continents

I use this fable to introduce the topic of the movement of biological material across biogeographic borders and the consequences, both good and bad that can ensue. Before the Age of Exploration, the exchange of biotic material among continents was a rare event limited to cases of organisms floating, or rafting, in the seas and surviving journeys over great distances, or small seeds being carried, inadvertently, by migrating birds. Some microscopic organisms however are transported long distances by wind (Figure 1). The rarity of successful long distance journeys of organisms can be appreciated by the few numbers of species that were shared among continents prior to the age of exploration.

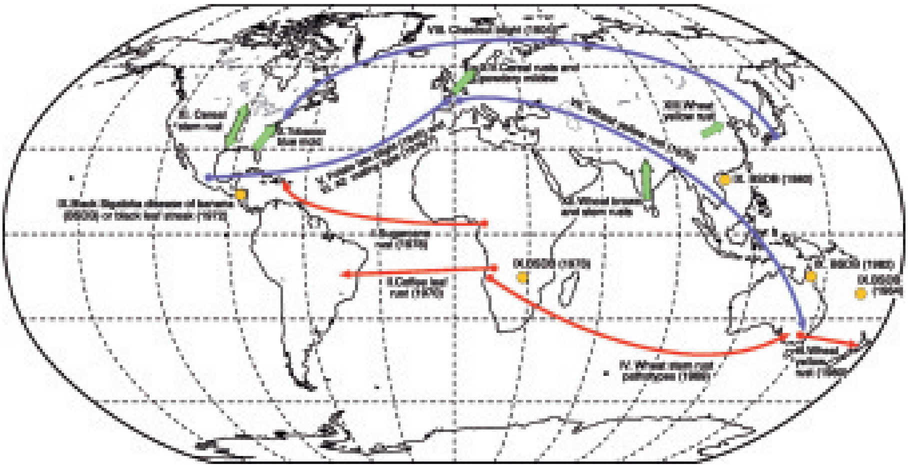


Figure 1. Long distance transport of pathogens. Purposeful and accidental human-mediated transport of organisms is the principal source of invasive species although some spores of pathogens can be transported long distances in the air stream [1]. Red arrows indicate most likely long-distance aerial transport of disease and blue arrows most likely human transport(figure content reprinted with permission from Brown and Hovmoller. 2002. Science 297:537. Copyright 2002. AAAS. Permission for the reproduction of the base map by C. Lukinbeal).

The Destruction of Global Biogeographic Barriers

The result of this lack of mixing meant that each continental area of the world developed a rich and unique biota. As evolution proceeded, complex interactions developed between predator and prey, herbs and herbivores, fungi and their hosts, and the other manifold two-way biological interactions that occur. Populations of a given species were held in check by competition with similar organisms as well as the action of predators and pathogens. Co-evolutionary forces resulted in the development of survival strategies against specific enemies as well as the unique means of defense against these enemies such as chemical toxins of all sorts.

All of this changed with the first explorers who traversed the oceans, generally seeking economic rewards, directly or indirectly, such as gold or natural resources such as spices and herbs. Even from the first, the issue of the very good, as well as the very bad inadvertent consequences accompanied these interchanges. As a result of the "Columbian Encounter," biotic riches of lasting value were transported to Europe, such as corn, beans, and tomatoes. At the same time this encounter inadvertently introduced diseases from Europe into the Americas that resulted in the death of millions of Amerindians resulting, in large part, in the subjugation of the survivors. Today the extent of biotic exchange is enormous across continents as shown in Table 1.

A world sampling of the numbers of naturalized species

Region	Plants	Fish	Birds
Europe	721	74	27
California	1023	42	19
Australia	1952	22	32
South Africa	824	20	14
Hawaii	902	19	38
New Zealand	1623	30	36
Japan	1196	13	4

From Vitousek, et al., 1997, Elredge and Miller, 1997, Hobbs and Mooney, 1998. Enomoto,1999

Table 1. The extent of the global exchange of plant species (from [1-4]).

The New Sorcerer's Apprentices—All of Us

Good Intent

Thus even in the early stages of humans breaching the age-old biographic barriers that separated the continents, good and bad results could be seen. In the case noted above the good was "purposeful introductions" and the bad was accidental introductions. However, later the cases of the bad became augmented and many of these detrimental examples were cases of purposeful introductions that did not work out as originally envisioned. These thus are examples of the work of the Sorcerer's Apprentice—the deeds of well-intentioned people with imperfect knowledge and control over the self-replicating agents that they employed to do their work. Examples abound—the introduction of the Nile Perch into Lake Victoria to augment the food supply of the local population, which entrained a series of events that actually resulted in less food from the lake for local people, promoted deforestation, eutrophied the lake, and drastically impacted local biodiversity. Other examples include the introduction of biocontrol agents such as the cane toad and the mongoose which have caused enormous damage either ecologically or economically, or the introduction of erosion control plants, such as the kudzu vine that did that job but unfortunately also has had a very large inadvertent impact on forest growth [5] [6].

Once established, these good deeds gone wrong are very difficult to correct because of the self-replication of the error. The sorcerer does not exist with the knowledge to right the wrong that has been inadvertently entrained. Thus brute force has to be applied and the tools at our disposal are primitive, costly and really not all that effective.

Our only hope in these cases is to use much greater caution in order to avoid such mistakes to begin with. However the pressures to repeat the mistakes are great and are getting greater as I discuss below.

Accidents Happen Once the Walls are Down

Of course it is not only cases of good deeds gone wrong that concern us but also the fact that opportunities for inadvertent accidents are increasing. No one purposefully brought the Zebra mussel into the Great Lakes (it came in released ballast water) (Figure 2) or the Formosan termite into the United States, yet both of these organisms are causing billions of dollars of damage. Again, no one purposefully introduced the ctenophore (*Mnemiopsis leidyi*) into the Black Sea, yet it arrived, again by ballast water, and successfully wiped out the commercial fishery of that region [7] (Figure 3).

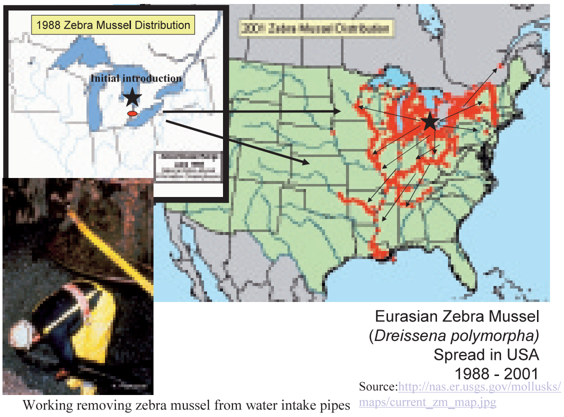
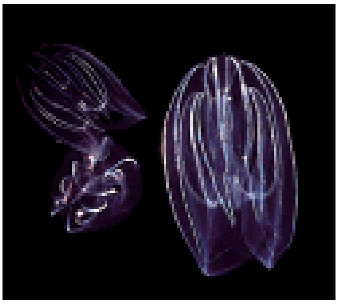


Figure 2. The explosive invasion of the zebra mussel into the United States (source-http://nas.er.usgs.gov/mollusks/maps/current_zm_map.jpg).

The Destruction of a Fishery



In 1982 *Mnemiopsis leidyi* (left) invaded the Black Sea evidently as a result of the discharge of ballast water from the United States. This invasion contributed to a sharp decrease in local fisheries. A subsequent inadvertent introduction and invasion by a predator of the Mnemiopsis is leading to a recovery of the fishery.

Figure 3. The dramatic impact of invasive species on fisheries (from [7, 8]). Photo of *Mnemiopsis leidyi* by E. Prosser Armstrong and used with permission.

We are still woefully inadequate in our capability to predict which organisms, of all that are crossing biogeographic barriers, will successfully establish, and spread, once they do arrive [9]. We do know that quite often those species that are successful are so in part because they have escaped their co-evolved pests and competitors.

Given the cases of introductions, both purposeful and inadvertent, that have gone on to create ecological and economic havoc in their new homes, there is the obvious need for considerable precaution in purposefully introducing new organism as well as protecting borders against inadvertent introductions.

The Forces Against Caution

The forces that work against caution include:

Ignorance

Many individuals of modern societies are becoming detached from understanding the natural base that sustains us all. They are unaware of the detrimental consequences of certain alteration of landscapes through human activities much less the potentially devastating effects of introducing new biotic material into a region. Thus the issue of invasive species is not high on the agenda of individuals much less of decision making-bodies that respond to public pressures.

Lack of capacity

Certain nations that have suffered the devastating effects of large numbers of invasive species have instituted elaborate systems for intercepting potentially invasive species. These systems are costly and require highly trained people to operate. They are however cost-effective in the long run since interception of even one potentially damaging invasive species can have large economic impacts. It has been demonstrated that interception is cheaper and more successful than eradication, which may not even be possible even if desired once an invasive species becomes established. Unfortunately not all nations have the economic means to establish surveillance systems at their borders, nor a pool of trained people to run them. Thus infection spots of invasive species are maintained in many nations that could have been avoided by more effective border control.

Increasing global connectivity

The job of border control is made extremely difficult by the increasing numbers of potential intercontinental transport vectors (ships and airplanes and the goods and humans that accompany them) that cross borders every day. Even with a highly developed inspection system the US agricultural border stations can only sample a small fraction of these shipments that arrive every day. There are now over 45,000 registered cargo-carrying vessels in the world and the ballast water that they carry inadvertently deposits organisms in places far distant from points of origin. It is estimated that as many as 7000 species of marine life are transported daily around the world in ballast water on any given day [10].

Global trade promotion

Trade without caution. In recent years there has been a large effort to decrease barriers to international trade as is embodied in the efforts of the World Trade Organization. The result of this aggressive policy is the agreement that if a nation has some concern about the potential detrimental impact of an import they must do the risk assessment analysis to demonstrate this danger. Thus the burden of proof is on the potential victim, not the potential perpetrator of environmental damage, or the one who will profit from the potential trade, leaving the costs of mediating any undesirable consequences to the general public. This runs counter to the concept of the precautionary principle that was developed to protect society against potential hazards embodied in poorly understood ecological interventions.

Even before aggressive promotion of international trade there have been dangers of the intercontinental exchange of first class mail containing seeds that are not subject to inspection or of the transport of potentially invasive horticultural material through traditional exchange routes.

Adding to the potential dangers of the institutionalized and routine promotion of global trade is the illicit illegal movement of potentially invasive organisms, through promotion on the internet.

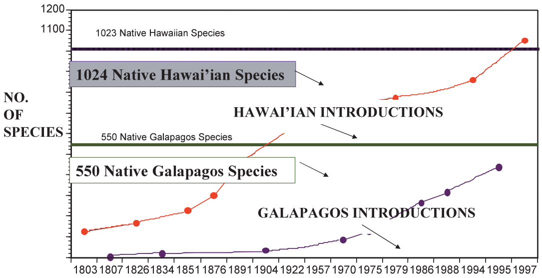
The Forces For Caution

What are the forces working to counter the movement of organisms across biogeographic borders? There are a number of treaties that address the movement of unwanted organisms away from points of origins. These include the IPPC, Intergovernmental Plant Protection Convention, which is directed principally at pests of agricultural plants and CITES, Convention for International Trade in Endangered Species of Wild Fauna and Flora, focused on trade of endangered species. The Convention of Biological Diversity had no directive toward trade restriction although it recently adopted a decision to "evaluate introduction pathways."

National Protection Plans

Various nations and regions have trade restrictions and border inspection of biological material to varying degrees. Some are very restrictive, such as New Zealand. Other areas, such as the Galapagos Islands, even though they have extraordinary biodiversity to protect, have until recently, had no restrictions on imported biological material with very sad consequences toward which millions of dollars are now being expended to correct (Figure 4).

The numbers of introductions now match the numbers of native species



From Eldredge and Miller, 1998, Tye, 2001, and Wester, 1992.

Figure 4. Time course of plant introductions into the Hawaiian and Galapagos Islands. There are now as many established plant species on these islands, as there are native species (Data from [11-13]).

The Consequences of the New Biology

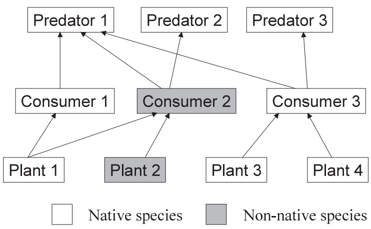
Sharing global resources

As noted earlier the benefits of the exchange of biotic materials across borders have been immense, particularly in agriculture, animal husbandry, horticulture, and fisheries. With more rapid and distant trade these benefits are increasing in terms of the availability of biological products year round, everywhere.

The changing course of evolution and ecological interactions

There is a cost to this convenience, a dark side to the movement of organisms, that is, the potential for the release of those that can cause undesired and continuing damage because of the Sorcerer's apprentice effect and its magnification as fundamental ecological and evolutionary processes are disrupted. There is wide documentation of how new organisms entering into new territory are not only evolving to fit the new conditions but are also changing the evolutionary trajectory of those impacted native species. New hybrids are being formed that are swamping out native distinctiveness. New complex food chains are being established that make it very difficult to manage these systems without undesired consequences (Figure 5). Ecosystems are always in a state of flux however these disruptions can totally alter their nature and bring them to a new functional status [14].

We are building new and complex ecosystems



Removal of feral sheep (Consumer2) from Santa Cruz island led to an explosion of invasive weeds (Plant2)

Zavaleta, Hobbs and Mooney, 2001

Figure 5. Invasive species are building new food webs in ecosystems adding to the complexity of control efforts. Removing one invasive species may lead to the explosive development of another (from [15]).

Enhancement and disruption of ecological services

Of course, purposeful introductions can enhance the ecosystem services, in addition to providing useful goods, which can aid human societies, such as erosion control, soil nitrogen enrichment, toxic cleanup, water clarification and so forth. Even accidental introductions, such as zebra mussels, can provide services such as water clarification, but unfortunately also many unwanted effects such as species extinctions and clogging water works. But even those introduced species that may provide useful services may escape and do great unintentional damage, as was the case with kudzu vine that originally was introduced for erosion control.

It is the disruption of ecological services provided by natural ecosystems that are of most concern and unfortunately examples abound around the world many of which are accompanied by very large economic consequences. These include the destruction of important forest trees by invasive diseases, the devastation of crops by invasive pests and pathogens, the clogging of water ways by pernicious water plants, the promotion of large and unseasonal fires by weedy grasses, the acceleration of the loss of water from watersheds, rendering rangelands less productive [16].

The Good, the Bad and the Ugly

What we have learned then from the movement of biological material around the world is that great benefits and riches have been gained at the same time great damages and economic losses have been incurred. This is actually part of the larger story of human modifications of natural ecosystems—great benefits have been gained in terms of food and fiber production, control of floods and fires to a certain degree, and so forth but at the same time fundamental changes have occurred to these systems that threaten their long term sustainability such as the losses and extinction of biodiversity and loss of topsoil. As in the classic movie, "The Good, the Bad and the Ugly" there are sometimes difficulties in distinguishing the good from the bad in these modification states in natural systems since in part these assessments depend somewhat on the beholder and their own particular interests, which are often based on very short term considerations. What may be of benefit to one segment of society is a detriment to another. However, the point that I would develop further below is that our analysis of good and bad, in terms of human well-being gained from natural resources, is often incomplete since it generally only considers a modification of a single resource in isolation from that occurring to other resources and hence the total net gains and losses, or goods and bads, are not perceived and hence are not a guiding force for resource management.

Dangerous Ignorance and Tinkering in the Dark

So, thus far what I have said is that we are fundamentally changing the very nature of biological systems that have evolved through the millennia by deleting species and parts of ecosystems as well as by adding new species where they have not previously occurred. In addition we are altering, in a major way, the many drivers of ecosystem functioning by modifications such as inadvertently adding nutrients [17]. We know that these changes are having dramatic impacts on the capacity of ecosystems to sustain human populations, both positively and negatively. At the same time we are relatively ignorant on how ecosystems, with their co-evolved members operate, much less how they will respond to the addition of new players introduced purposefully or accidentally. At the most fundamental level we haven't even described the myriad species that inhabit the earth or is there much possibility that will be able to do so using traditional methods because of the sheer size of the task but also because of the loss of technical capacity to do so. We have very little capacity to account for the numbers of critical organisms and how their abundances and ranges are changing, except for the largest of mammals and birds. We are generally ignorant of the role that species play in ecosystems except in the most general way. For example we often cannot predict a priori what the consequences will be of the removal of many species to the operation of ecosystems, or of additions, as noted earlier. We are often caught off guard by outbreaks of pests. In sum, being an ecologist is a life full of surprises because of our lack of basic knowledge added to the general complexity of ecosystems such as the non-linearity of their responses to perturbations induced, either naturally, or due to human activities. It is not that such knowledge is unobtainable; it is just that it is hard to come by, and gaining such knowledge has not been a high priority in many nations. This knowledge takes scientists, time and resources. As noted above we not only lack focus and resolve on these issues but we also are losing the capacity to attack the problems. As society shifts more attention to the promises of new technology, such as molecular engineering, it is losing capacity, not only in identifying the pieces of ecosystems but also in studying how these pieces function, since the field of physiology, both plant and animal, is being neglected.

We are putting substantial resources into human health but not into learning about the fundamental ecological foundation in which humans derive their livelihoods and well-being. In the U.S. for example, a nation which spends a great deal of money on science, 90% more is spent on human health research and development than on natural resources and the environment. This ratio is even more skewed when considering basic research alone [18].

It is small wonder that ecologists have embraced the precautionary principle so readily in dealing with proposed interventions in ecosystems. It is not that they are trying to stop change it is just that they still lack the capacity to offer knowledge on outcomes with a high degree of certainty and because of the nature of complex systems; such knowledge may never be fully obtainable. Why are they concerned with the proposition to fertilize the oceans in order to sequester more carbon? Why are they concerned with unrestricted free trade of live biological materials? The primary reason is that we cannot predict the full outcome of these interventions and hence cannot be confident of the proposed long-term benefits.

The Task Before Us—Lifting the Darkness

The job of getting the information we need to understand and better manage our natural world is daunting. However it is encouraging that there are the beginnings of a commitment to assess our current knowledge base on the operation of biotic systems and on their capacity to deliver the goods and services upon which societies depend. This effort is certainly overdue and as was noted recently, we have been 'flying blind' in making environmental decisions since our knowledge base is so poor. We have, however, made enormous strides in the past couple of decades in understanding the basic operation of the earth as a coupled system—how the atmosphere interacts with the earth and how the earth's climate system is regulated and interacts with biogeochemical cycles. This information was crucial in assessing the potential impacts of the activities of humans on global climate change. However we, as yet, do not have comparable capacity to understand fully the consequences of these climatic changes, much less the other global changes that are occurring, on the operation of ecological systems in time and space. In order to get this information we need a comprehensive evaluation of the pieces of ecosystems, how they interact as a functioning whole and how they respond to perturbations. This information is now becoming available. This last decade has seen a concerted effort to learn the role of biodiversity in the functioning of ecosystems and the development of an understanding the role of ecosystem functioning in providing the goods and services upon which societies depend [19]. The task thus is to bring this information together on functioning and services and to in turn relate these to how humans are altering the fundamental capacity of ecosystems to provide these services.

Recently, a global analysis, the Millennium Ecosystem Assessment was conducted on the status of the world's ecosystems and the services they provide [21]. The results were not encouraging in many ways since it was concluded that virtually all of the Earth's ecosystems have been transformed by human action and that the past 50 years has seen the most rapid rate of change in history. Accompanying these changes has been a great loss in the capacity of these systems to provide clean water, erosion control, disease regulation, pollinator services, to say nothing of the losses of biodiversity and cultural values. A consequence of many of these perturbations, accompanied by a globalized economy, is the fostering of invasive species, such as pests and emerging diseases, which in turn often degrade services even further.

Conclusion

We are engaged in massively disrupting and degrading those ecosystems upon which societies have been built and whose services we depend upon. An important element of these disruptions is the homogenization of the Earth's biota and the increasing occurrence of invasive species that cause great economic damage as well as ecological perturbations. These invasive species are not subject to "recall" once they become established. It is important that we fully appreciate and understand what we need to do in order to sustain those natural and managed ecosystems that sustain humans and the role that invasive species can cause in ecosystem functioning and service provision. The escalation of those elements fostering the transport and establishment of invasive species lend some urgency to our task.

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