Task Group Summary 8

Ecological robustness: Is the biosphere sustainable?

Challenge Summary

Ecological systems provide services to humanity that support life as we know it. These “ecosystem services” include obvious and direct products such as food, fiber, fuel, and other goods that we extract from living beings; indirect benefits such as the mediation of climate and the sequestration of toxic substances; and, most subtly, aesthetic pleasure such as the provision of wilderness. There are those who believe that ecosystems have evolved regulatory mechanisms that will maintain resilience and robustness in the face of disturbances, or that technological advances will be able to compensate; yet, from an evolutionary point of view, such confidence cannot be justified. Ecosystems and the biosphere are complex adaptive systems, in which the selfish agendas of individual agents threaten the robustness of the whole. What is the adaptive potential of the biosphere to deal with climate change and other global and regional stressors, and how can we relate the robustness of macroscopic features to the microscopic dynamics of species? Can the modeling of coupled ecological and social systems provide the necessary feedbacks to prevent catastrophic shifts? Do we have an ethical obligation to preserve the regulatory and adaptive mechanisms of the world’s ecosystems?

Key Questions

• Are there quantifiable and universal emergent properties of populations, communities, and ecosystems? • Do scaling laws apply to ecological systems? Could the data ever be adequate to test hypotheses?

• Can we model the biosphere and its coupled processes with predictive capability? Can we prove that we cannot?

• Do food webs have common architectures? Signatures of self-organization?

• Co-evolution of biosphere and geosphere: How does life shape the non-living components of the planet?

• The biosphere and climate: Can the trajectory of this complex system be understood?

• How does the information encoded in genomes manifest itself in the biogeochemical properties of ecosystems (e.g., the ratios of elements in living matter)?

• How does cooperation among organisms emerge over the course of evolution?

• Are there common features of biochemical networks within the cell (systems biology), and networks of the ecosystems that are built from them?

Required Reading

Kirchner JW. The Gaia hypothesis: can it be tested?. *Reviews of Geophysics* 1989;27:223-235.

Levin SA. Ecosystems and the biosphere as complex adaptive systems. *Ecosystems* 1998;1:431436.

Levin SA, Barrett S, Aniyar S, Baumol W, Bliss C, Bolin B, Dasgupta P, Ehrlich P, Folke C, Gren IM, Holling CS, Jansson A, Jansson BO, Mäler KG, Martin D, Perrings C, Sheshinski E. Policy Forum: Resilience in natural and socioeconomic systems. Environment and Development Economics (1998), 3:221-262. Cambridge University Press. [Accessed online

June 2, 2008: http://journals.cambridge.org/download.php?file=%2FEDE%2FEDE3_02%2FS1355770X98000126a.pdf&code=9c2b0dcbaeacab587fc0936b8a4b398c.]

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TASK GROUP SUMMARY

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The drowning polar bear of the Arctic is a vivid symbol of climate change's impact in shaping the life or death of a species. The threat facing the polar bear is representative of what happens when the footprint of human activities becomes so vast that if affects the quality of water, land, and air, and even the temperature of our planet. Today, climate change is just one of many causes pushing ecosystems into decline, but the polar bears are merely the most visible symbol of a deeper problem. At the 2008 National Academies Keck *Futures Initiative* Conference on Complex Systems, a group of scientists from interdisciplinary fields tackled the following question: is the biosphere sustainable? To answer the question, which includes concepts of ecological robustness, requires expertise on all the inner workings of an ecosystem, from microbes and plants to nutrient cycling and atmospheric chemistry.

At the moment, what is known about the ecosystem is vastly overshadowed by what is still unknown. Biosphere 2, the largest *in vivo* recreation of Earth's ecosystems, was built in the Arizona desert in the late 1980's. Eight humans spent two years within its walls during 1991-1993, but the experiment failed spectacularly when swarming ants took over the land and the residents required supplemental oxygen for survival. If we are to create a habitable Earth on Mars, or sustain the ecosystems we already have on Earth, we must first know where we stand today, and what is needed to create a sustainable biosphere.

The Group's Approach

The group began with the consensus that our current patterns of resource consumption and habitat destruction are not sustainable. As fisheries collapse, savannas turn to desert, and thousands of species hurtle towards extinction, we are degrading and, in some cases, irreversibly destroying the world's ecosystems. The human population is expected to reach around 9 billion by 2050, so the scope of our impact is likely to increase with time.

The group defined sustainability as the ability to use the resources of the biosphere without depletion in the long-term. To use a financial analogy, if the biosphere is an investment, how can we limit ourselves to using the interest rather than the principal? A major limitation to formulating solutions is the severe lack of understanding of many, if not most, ecosystem functions. Moreover, a lack of long-term observational data makes it difficult to discern trends from variation. Nonetheless, the depletion of resources and significant shifts in long-term and large-scale patterns in the biosphere is evident and undoubtedly caused by human intervention. Due to the urgency of the problem, solutions need to address the problems, without further exasperating them through unknown interactions and feedbacks.

Solutions

The group split its solution into five sections: modeling, data, experiments, interventions, and resources. The first three are aimed at understanding processes to guide human actions and policy. Interventions will flow from these results; resources will be needed to turn these plans into reality.

Modeling

In the documentary *An Inconvenient Truth,* Al Gore makes repeated use of the hockey-stick graph showing global temperature increases over time. Developed by scientists, models are powerful tools for policy-makers. The best models will present likely scenarios for the future and offer pragmatic paths that characterize different possible outcomes.

In order to understand the biosphere as a whole, it is necessary to develop models that can integrate processes across vast spatial and temporal scales. Currently, there is a lack of consistency across data sets. Different models use measurements and units that are incompatible with one another, and the general lack of connectivity limits the use of these models. The group proposed the creation of a World Biosphere Organization (WBO) to integrate and coordinate ecosystem research and sustainability efforts. The WBO would also promote the accessibility of data by requesting that ecology journals only publish articles from scientists who will share their research for free (either online or through print).

Modeling is an iterative process that changes with time, but it can be improved through competition and review. A good example is CASP (Critical Assessment of Techniques for Protein Structure Prediction), an online forum through which protein structures are proposed, tested, and validated or refuted. The WBO could use CASP as an example to promote the testing of ecological models against one another, in order to increase quality and to keep the models up-to-date.

Data

Ecologists are awash in streams of data that capture moments in time. Buoys in the ocean can monitor temperature, salinity, and pH; biologists can manually count the number of monarch butterflies in one area of the world, but integrated, time-series data on processes such as nutrient cycling, photosynthesis, and biogeochemical cycles are largely missing. Without information about rates, fluxes, and flows, it’s impossible to gauge the connections in an ecosystem. We need a concerted, worldwide effort to create devices that monitor ecological processes.

In addition, data collection is unevenly distributed around the world. Detailed satellite data are often concentrated in developed countries, but ecosystems do not respect international boundaries. To extend the network of data-gathering, it would be helpful to promote the participation of citizen scientists, using cell phones as a vehicle for communicating data. Many developing countries are "leapfrogging" over traditional barriers to development by promoting cell phone use instead of landlines. The phones have computational power, so cell phone users who sign onto the program would receive a small compensation for their help in monitoring local ecosystems. The data would be stored in their cell phones and transferred through the Internet. Development of the data-transfer systems would be done through the WBO.

Having millions of citizen scientists around the world would allow for fast on-the-ground monitoring. If something unusual happens, ecologists can immediately focus their efforts on the issue in much the same way that the CDC rushes to the site of an epidemic *Experiments.*

Halfway between the extravagance of Biosphere 2 and the simplicity of glass-blown EcoSpheres (miniature marine ecosystems sold as paperweights), mesocosms are ideal for ecosystem experimentation. A series of mesocosms, collectively called Biosphere Exploratory Experiments, could bridge the gap between lab work and *in vivo* experimentation. The mesocosms would cover a range of ecosystems scales; some would contain just dirt, microbes, and water, while others will have more complexity. Like mini experimental stations, the mesocosms would be used to discover connections, feedback loops, and connectivity within ecosystems.

It's important to note that most life forms are microbial, unknown, and, at present, unculturable. We have a lot to learn about microbial life, but by experimenting on multiple scales, we can track and model the influence of microbes in ecosystems.

Intervention

While the proposed WBO will coordinate research worldwide, a similar organization for the United States could operate productively on a national level. Unlike the EPA which is focused on regulations, the new group (which could be called the National Institute of the Environment) would concentrate on research alone.

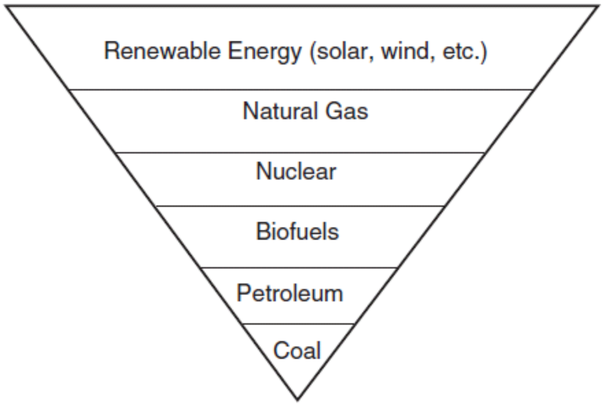
Public outreach and education are essential for spreading the word about ecological threats. The food pyramid is an ideal example of outreach, and its design is simple, attractive, and easy to understand. More important, the pyramid offers consumers a way to visualize changes in their personal lives. The group proposed creating similar pyramids for energy, water, policy, economics, etc. based on a sustainability gradient.

The energy pyramid could look like this the one on the following page.

It's important to emphasize how different pyramids could interact. Meat is an essential part of the food pyramid, but cows produce large quantities of methane that contribute to global warming. The pyramids would allow the public to map the connections between ecosystems, human actions, and sustainability.

Ultimately, the group's goal is to promote a preventionist approach. Instead of cleaning up the mess after we destroy an ecosystem, the models and experiments will reveal projections of ecosystem futures, and what we can do to steer the biosphere towards a path that will sustain humans for generations to come.

Energy Pyramid



Resources

And finally, none of the plans would be possible without adequate funding. The annual US budget spent on environmental and ecological research is about $2 billion. A 1987 study estimated that the Global Biosphere Product was US $33 trillion, nearly double the 1987 Gross World Product of US $18 trillion. The numbers show a clear discrepancy between the funds allocated to R&D and the high cost of damaging the ecosystem. A mechanistic understanding of ecosystems functions is the first step towards sustainability; more funds must be appropriated in order to understand how the biosphere works, where it is headed, and what we can do to maintain its continued prosperity.