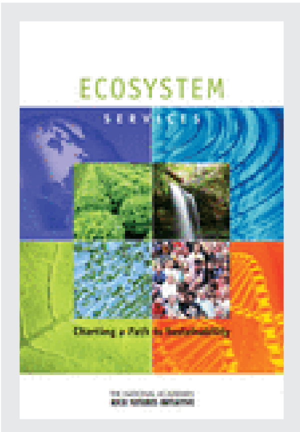

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ECOSYSTEM SERVICES: CHARTING A PATH TO SUSTAINABILITY

INTERDISCIPLINARY RESEARCH TEAM SUMMARIES

Conference
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THE NATIONAL ACADEMIES KECK *FUTURES INITIATIVE*

The National Academies Keck *Futures Initiative* was launched in 2003 to stimulate new modes of scientific inquiry and break down the conceptual and institutional barriers to interdisciplinary research. The National Academies and the W. M. Keck Foundation believe that considerable scientific progress will be achieved by providing a counterbalance to the tendency to isolate research within academic fields. The *Futures Initiative* is designed to enable scientists from different disciplines to focus on new questions, upon which they can base entirely new research, and to encourage and reward outstanding communication between scientists as well as between the scientific enterprise and the public.

The *Futures Initiative* includes three main components:

Futures Conferences

The *Futures* Conferences bring together some of the nation's best and brightest researchers from academic, industrial, and government laboratories to explore and discover interdisciplinary connections in important areas of cutting-edge research. Each year, some 150 outstanding researchers are invited to discuss ideas related to a single cross-disciplinary theme. Participants gain not only a wider perspective but also, in many instances, new insights and techniques that might be applied in their own work. Additional pre- or post-conference meetings build on each theme to foster further communication of ideas.

Selection of each year's theme is based on assessments of where the intersection of science, engineering, and medical research has the greatest potential to spark discovery. The first conference explored *Signals, Decisions, and Meaning in Biology, Chemistry, Physics, and Engineering*. The 2004 conference focused on *Designing Nanostructures at the Interface between Biomedical and Physical Systems*. The theme of the 2005 conference was *The Genomic Revolution: Implications for Treatment and Control of Infectious Disease*. In 2006 the conference focused on *Smart Prosthetics: Exploring Assistive Devices for the Body and Mind*. In 2007 the conference explored *The Future of Human Healthspan: Demography, Evolution, Medicine and Bioengineering*. In 2008 the conference focused on *Complex Systems*. The 2009 conference explored *Synthetic Biology: Building on Nature's Inspiration*. The 2010 conference focused on *Seeing the Future with Imaging Science*. The 2011 conference focused on *Ecosystem Services* and the 2012 conference will focus on *The Informed Brain in a Digital World*.

***Futures* Grants**

The *Futures* Grants provide seed funding to *Futures* Conference participants, on a competitive basis, to enable them to pursue important new ideas and connections stimulated by the conferences. These grants fill a critical missing link between bold new ideas and major federal funding programs, which do not currently offer seed grants in new areas that are considered risky or exotic. These grants enable researchers to start developing a line of inquiry by supporting the recruitment of students and postdoctoral fellows, the purchase of equipment, and the acquisition of preliminary data—which in turn can position the researchers to compete for larger awards from other public and private sources.

NAKFI Communications

The Communication Awards are designed to recognize, promote, and encourage effective communication of science, engineering, medicine, and/or interdisciplinary work within and beyond the scientific community. Each year the *Futures Initiative* awards $20,000 prizes to those who have advanced the public's understanding and appreciation of science, engineering, and/or medicine. The awards are given in four categories: books, film/radio/TV, magazine/newspaper, and online. The winners are honored during a ceremony in the fall in Washington, DC.

NAKFI cultivates science writers of the future by inviting graduate students from science writing programs across the country to attend the conference and develop IDR team discussion summaries and a conference overview for publication in this book. Students are selected by the department director or designee, and prepare for the conference by reviewing the webcast tutorials and suggested reading, and selecting an IDR team in which they would like to participate. Students then work with NAKFI's science writing student mentor to finalize their reports following the conferences.

Facilitating Interdisciplinary Research Study

During the first 18 months of the Keck *Futures Initiative*, the Academies undertook a study on facilitating interdisciplinary research. The study examined the current scope of interdisciplinary efforts and provided recommendations as to how such research can be facilitated by funding organizations and academic institutions. *Facilitating Interdisciplinary Research* (2005) is available from the National Academies Press (www.nap.edu) in print and free PDF versions.

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Preface

At the National Academies Keck *Futures Initiative* Conference on Ecosystem Services, participants were divided into fourteen interdisciplinary research teams. The teams spent nine hours over two days exploring diverse challenges at the interface of science, engineering, and medicine. The composition of the teams was intentionally diverse, to encourage the generation of new approaches by combining a range of different types of contributions. The teams included researchers from science, engineering, and medicine, as well as representatives from private and public funding agencies, universities, businesses, journals, and the science media. Researchers represented a wide range of experience—from postdoc to those well established in their careers—from a variety of disciplines that included science and engineering, medicine, physics, biology, economics and behavioral science.

The teams needed to address the challenge of communicating and working together from a diversity of expertise and perspectives as they attempted to solve a complicated, interdisciplinary problem in a relatively short time. Each team decided on its own structure and approach to tackle the problem. Some teams decided to refine or redefine their problems based on their experience.

Each team presented two brief reports to all participants: (1) an interim report on Saturday to debrief on how things were going, along with any special requests; and (2) a final briefing on Sunday, when each team

- provided a concise statement of the problem;
- outlined a structure for its solution;
- identified the most important gaps in science and technology and recommended research areas needed to attack the problem; and
- indicated the benefits to society if the problem could be solved.

Each IDR team included a graduate student in a university science writing program. Based on the team interaction and the final briefings, the students wrote the following summaries, which were reviewed by the team members. These summaries describe the problem and outline the approach taken, including what research needs to be done to understand the fundamental science behind the challenge, the proposed plan for engineering the application, the reasoning that went into it, and the benefits to society of the problem solution. Due to the popularity of some topics, two or three teams were assigned to explore the subjects.

Nine podcasts were launched throughout the summer to help bridge the gaps in terminology used by the various disciplines. Participants were encouraged to listen to all of the podcasts prior to the November conference.

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APPENDIXES

To listen to the podcasts or view the conference presentations, please visit our website at www.keckfutures.org.

Conference Summary

Keith Rozendal, NAKFI Science Writing Scholar
University of British Columbia, Vancouver

Natural environments provide enormously valuable, but largely unappreciated, services that aid humans and other earthlings. Civilizations rely on these intangible life-supports just as much as they rely on the resources and produce extracted from wild and cultivated land and seascapes. Agriculture—the cornerstone of large, complex human societies—would collapse but for the reservoirs of clean freshwater, soil laced with essential nutrients and microbes, and stable climates generated by natural systems. It's becoming clear that those life-support systems are faltering and failing worldwide due to human actions that disrupt nature's ability to do its beneficial work.

Ecosystem services scientists work to document the direct and indirect links between humanity's well-being and the many benefits provided by the natural systems we occupy. The knowledge they produce can structure the way humanity, now surging past seven billion individuals, provides for its exploding needs. It can shape decisions on land use, resource extraction, manufacturing, and trade so that the widespread declines in the ecosystem-rooted life-support systems can be arrested or reversed.

It seems that Spaceship Earth faces an "all hands on deck" emergency. A boatswain's distress call has been issued by the organizers of the 2011 National Academies Keck *Futures Initiative* (NAKFI) Conference on Ecosystem Services. A broad community of academic researchers, industrial and agricultural professionals, and policy experts responded. In 14 Interdisciplinary Research (IDR) Teams, biologists and earth scientists collaborated with physicians, engineers, economists and a wide range of social scientists—all were needed. As the chair of the conference steering committee put it, "The only prerequisite was brilliance."

IDR Team 1 explored the many ways in which human health requires healthy ecosystems and the services they provide. In response to their challenge, "How do ecosystem services affect infectious and chronic diseases?," the team boldly stated that all diseases have links to the health of ecosystems. Though in general, infectious diseases have stronger links than chronic diseases. Seeking the physical and biological processes that connect ecosystem changes to health-related outcomes would be the critical first task, once any relationship is uncovered. Team 1 was one of many to recognize the huge numbers of interconnections between human and ecological systems, coining the phrase "webs of causation" to best reflect their dazzling complexity. The team observed that some diseases, like malaria, had already been well-mapped by other interdisciplinary scientists, who may not realize that their research fits into an ecosystem services framework. This led the team to devise a "call to arms" bringing together researchers from specific fields, such as epidemiology, urban planning, and atmospheric sciences to work on this challenge under a common framework of health-supportive ecosystem services.

Three teams under the IDR 6 banner explored ways to estimate the overall value of the inventory of human dependencies on natural capital. These teams recognized that the price currently paid for products, such as food, does not include the values to society of the services provided by nature. A "shadow price" would incorporate a full accounting of the social costs and benefits of products and policies, and would most likely inflate prices. However, this would require that economists grapple with a fundamentally different framework for pricing, one that can precisely reflect the worth of hard-to-pin-down social, cultural, and ecological values. One team memorably called the difficult-to-value end of the spectrum, "squishy." Economists do have well-developed methods to value things that don't fit into a traditional market framework. Two teams recommended applying revealed preference analysis measurements to the task of comprehensively valuing ecosystem services. Another said interactive social games could expose the way any person values intangible ecosystem services by tracking their choices among actions that create tradeoffs between different competing values.

Food demand will double this century, and agriculture already has the biggest impact on the environment, by far. Three IDR 4 Teams tackled this problem. One team set out several achievements that together could meet future food demand without further depleting soils, water, nutrients, or biodiversity—but only if all these goals can be met simultaneously. They include putting a halt to deforestation, helping farmers achieve the full potential yields of their lands, abandoning meat-centered diets, and reducing food waste. Another team proposed a few further goals for an ecosystem-maintaining food system and suggested a design competition to identify key experiments to undertake. The third of these teams extensively developed one such project, mass-scale urban-based agriculture.

IDR Team 5 was challenged to imagine how humanity might aim even higher than simply meeting future food demand. The lofty state of food security isn't merely concerned with food *quantity*. Food secure families eat food of adequate *quality* to support an active life that promotes peak development and healthy aging. This requires a shift in global farming priorities, according to this team. Currently, food producers receive incentives and supports to grow staple crops such as rice, maize, and potatoes. Such foods can meet basic caloric needs, but true food security is built on diverse diets of non-staple crops like fruits and vegetables.

Oil and natural gas, once extracted and burned, can never be replaced. The Earth's supply of phosphorous, an element critical to agriculture, is also being mined to exhaustion. IDR Team 2 confronted the challenge of developing new means of recovering such nonrenewable resources currently going to waste. The team created a general purpose analytical tool called an eco-interactome map, using it to track phosphorous from its birth in mines to its end fate deposited in watersheds, soil, landfills, and human and animal feces. Putting numbers to the map showed where the greatest losses occurred with the biggest opportunities to recover phosphorous. The team evaluated a long list of potential technologies to do the job and suggested a pilot project: Using anaerobic digestion to treat animal manure produced in concentrated animal feeding operations. Phosphorous could be recovered from the treated waste with several add-on benefits.

Two IDR 7 Teams sought ways to consolidate and expand approaches to ecosystem services so every federal decision might one day weigh these concerns. One team said an interagency training center would harmonize and improve the ecosystem services work already being done across the federal system. Extending these practices into new decision-making areas could start by modifying policies already in place. For instance, one team recommended recruiting the Securities and Exchange Commission to require ecosystem services accounting within publicly traded businesses. One team began to write a potentially historic bill, the Valuing Natural Capital Act—a short and simple, but far-reaching law. But even this idealistic team suggested practical first steps—starting with a measure that values natural capital at the city or state level to build momentum for broader regulations on its success.

In an age of globalization, national policies will never be enough to fully account for the values humanity derives from nature. IDR Team 8 imagined ways in which the global trade system could begin to monitor and reduce its impacts on ecosystems. The team used the term 'policy' elastically. Certainly, the actions of governments and international bodies matter, but actions by private parties and market-based mechanisms targeting corporations, producers and consumers can also dramatically shape international trade. Take, for example, private sector roundtables, voluntary changes in producer practices, certification schemes, and shareholder activism. Existing import risk assessment policies could easily incorporate the value of ecosystems. In such decisions, a given commodity might be banned for import or levied with additional taxes on the basis of social, environmental, and economic criteria.

IDR Team 3 looked at how human societies adapt to the abrupt changes in ecosystem services following natural or technological disasters. The team observed that proactive adaptation plans have only developed where an urgent and widespread perception of vulnerability exists. Thus, the team made a specific call for research psychologists to join the work on this challenge. They identified factors that encourage or discourage societal preparation and resiliency: Is the crisis caused by human actions, and over what time scale and spatial extent does the event occur? Finally, the team recommended developing a case study library and a game-based tool to help people explore the range of options available for adapting large populations to abrupt change.

For many of the proposals emerging from this year's NAKFI to succeed, it seems essential that broad audiences understand the full value of ecosystem services to human well-being. IDR Team 9 began to develop the call for a National Academy of Sciences "PlanetWorks" conference. They aim to bring government figures from the federal down to municipal levels together with leaders of high-tech companies (especially the top Internet firms), other big businesses, foundations, and the news and entertainment industries. The conference would plant the seeds for a massive social network dedicated to communicating worldwide the importance of incorporating ecosystem services and natural capital concerns into the way business, government, and our daily lives operate. The team imagined interactive instructional games based on solid science and projects that engage big crowds to gather data on ecosystem functioning. Because an ecosystem services framework highlights nature's impact on human health, values, and wealth, there are natural "hooks" for engaging the common concerns of a huge audience.

A theme threaded through the entire NAKFI Conference on Ecosystem Services. Taking ecosystems services seriously reveals how fragmented and self-defeating policies emerge from fragmented and competitive decision-making bodies entrusted with social and economic planning. Perhaps, just as the melded efforts of scientists speaking across wide disciplinary boundaries can best meet the challenges posed at this conference, new comprehensive political bodies might better put ecosystem services goals into practice locally and globally. Incorporating the value of ecosystem services in planning for the future will foster fully informed, and one hopes, wiser choices. This approach can make explicit the ecological sacrifices humanity has been making without knowing. It can lead the globe to account for previously hidden benefits and losses, to think on geologic time scales, and to respect the true complexity of the planet's massively interdependent natural systems.

IDR Team Summary 1

How do ecosystem services affect infectious and chronic diseases?

CHALLENGE SUMMARY

Many attributes of ecosystems directly affect human health (Millennium Assessment 2005). For example, biodiversity may have implications for infectious disease transmission and for the availability of biopharmaceuticals; air quality affects mortality and morbidity from respiratory and cardiovascular diseases; wetlands affect the availability and quality of drinking water; wildlands can provide environments for disease vectors; climate can affect food production, the transmission of infectious diseases as well as mortality and morbidity from chronic diseases; and natural disasters can affect both physical and mental health in profound way. Substantial health and health ecology work documents these and other linkages between human health and ecosystems broadly defined (e.g., McMichael et al. 2003; Tzoulas et al. 2007).

In some cases, the same ecosystem may contribute differentially to more than one health issue. Wetlands filter water but may also provide habitat for mosquitoes transmitting malaria. Historically, society has weighed the tradeoffs of these services and disservices, opting to manipulate the ecosystem to get rid of the disservice. For instance, the development of Washington, D.C. was enhanced by the draining of malaria infested wetlands (Foggy Bottom) along the Potomac. Such decisions were relatively easy to make at the time because overall stress on ecosystems were sufficiently small so that the tradeoffs in question, in this case water filtration, did not affect the supply of quality water to the capital.

The situation today has changed in at least three ways. First, the combined stressors on all ecosystems—resulting in human modified ecosystems and landscapes—is such that multiple, interacting ecosystem services are stressed simultaneously. Second, the worldwide cumulative effect of these stressors promises to alter the earth system with human health consequences (e.g., climate change and movement toward the poles and high elevation for tropical diseases). Third, the features of ecosystems that are believed to be relevant to health are much broader than previously thought and are likely to affect not only infectious diseases but also the most common chronic diseases. For example, ecosystem services that are directly related to human health include food production, water supply and quality, air quality, as well as other aspects of the human-environment interface related to the ways in which human settlements are built, organized, and linked to their natural environments.

The challenge is to understand the overall impact of ecosystems on infectious and chronic diseases broadly defined, as well as the consequences of changes in ecosystems—not only on overall rates of morbidity, but also on health inequalities by place and person.

Key Questions

- What are the relevant aspects of human health that would be important to measure?
- What kinds of features of ecosystems are likely to be most important to human health over the next few decades?
- What are the key outstanding questions in understanding the links between ecosystems and chronic and infectious diseases?
- What kinds of methodologic approaches (measures, studies, and analytical approaches) are necessary to understand and predict ecosystems effects on chronic and infectious diseases?
- Can measure be developed to capture the overall human health consequences of changes in multiple ecosystem services?

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IDR TEAM SUMMARY

Laura Smith, NAKFI Science Writing Scholar
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IDR Team 1 was asked to determine how ecosystem services affect the transmission of infectious and chronic diseases. While the services that ecosystems provide are thought of primarily in relation to the sustainability of the food supply or the effects of climate change, they also play an important role in the regulation of disease. Human interference in the environment—intentional or not—can change patterns of disease. It is generally accepted, for example, that the degradation of ecosystems facilitates the emergence of infectious diseases. If we can better understand how ecosystem services are linked to specific diseases, then we can also predict how human alteration of the environment might affect human health.

IDR Team 1 tackled the challenge by considering what knowledge exists on the subject, then pinpointing areas that would benefit from future research. What the team discovered is that the key to a better understanding of the relationship between ecosystem services and disease may be a fusion of existing knowledge from disciplines such as epidemiology, ecology, and microbiology to form a common research framework. To establish this framework, the team proposed a conceptual article to review existing literature, identify gaps in knowledge, and outline how to demonstrate direct links between ecosystem services and human health.

Finding the Link

The majority of the group's time was spent exploring examples of diseases thought to be linked to ecosystem services. The team thought about everything from changes in land use, its effects on water resources and possible connections to water-borne diseases like cholera, but also considered the effects of green space and recreation on important indices as mental health and obesity.

The "aha" moment

The struggle to explain linkages among diseases and ecosystem services resulted in two major conclusions. One is that, though many diseases have potential links to the environment, some are more directly linked than others. The diseases more strongly correlated with ecosystem services should be easier to control through improvements to the ecosystem or by monitoring the way humans alter the environment. The team decided that these diseases would prove the most beneficial to study further. For example, it may be more productive to focus improvement efforts on air quality to reduce asthma rather than spending time and money on a disease with a more tenuous connection to ecosystem services that may be better addressed in other ways.

The other conclusion was that infectious diseases are more obviously linked to ecosystem services than chronic diseases. While the team did come up with some examples of chronic diseases that could be related to certain ecosystem services—like some cancers caused by toxins—the relationships were less defined and spurred more debate than those involving vectors, for example.

Establishing a test

Given the large number of diseases that could be understood to have links to ecosystem services, the team developed a "test" to determine if a disease is directly or indirectly linked to a specific ecosystem service. The test asks two questions:

1. Does a change in an ecosystem lead to a change in a health-related outcome?
2. Can this relationship be linked to a specific function that the ecosystem provides?

If the answer to both questions is yes, then the disease in question is considered to be directly related to ecosystem services. The team used the example of trees next to a roadway capturing particulate matter from vehicles in sufficient quantity to reduce the incidence of asthma in nearby communities.

If the answer to one or both questions is no, then the disease is more likely to be indirectly linked to ecosystem services. For example, polio has re-emerged because of a decrease in vaccinations, related to both social and political reasons; although polio likely has some links to the environment—it is transmitted via food or water and outbreaks are common in overcrowded urban areas—improvements in ecosystem services are unlikely to affect future polio infection rates.

A spectrum of diseases

After some debate, it was decided that the diseases would be divided into infectious and non-infectious disease categories, and that they would fall along a gradient in terms of how directly they are related to ecosystem services.

Infectious diseases that have very clear, direct relationships with ecosystem services include zoonoses with the potential to become pandemic (i.e.; influenza), vector-borne diseases (i.e.; Lyme disease), and water-borne diseases (i.e.; cholera). Those that are less clearly related to ecosystems include food-borne, airborne, and sexually transmitted diseases.

Within the chronic disease category, respiratory illness related to particulates are considered more strongly linked to ecosystem services, followed by nutritional illnesses, mental health, immune disorders, cardiovascular disease, cancers and reproductive disorders.

Meshing models

At first, the team attempted to create its own basic model for assessing the relationships between human-led change in the environment, ecosystem services and disease-related outcomes. However, a quick Google search revealed that existing ecological approaches used for diseases like Lyme disease already seemed to contain some of the same elements team members were trying to fit into a new model.

The team concluded that adapting existing modeling approaches from disease ecology and epidemiology, as well as other related fields, to make them more relevant to ecosystem services research is a sound approach. These models may help in understanding the webs of causation that occur among ecosystem services, human use of the environment, and disease.

In fact, as the team pointed out, several biomedical disciplines (microbiology, epidemiology, immunology, etc.) already conduct research relevant to ecosystem services, but don't necessarily make the connection between specific ecosystem services and health outcomes. Bringing experts from these disciplines together may be the key to launching future research geared specifically toward understanding the links between ecosystem services and disease.

Next Steps

To work toward the establishment of an ecosystem services model, or a common framework, the team proposed a conceptual review article looking back at previous research and outlining how to identify and define linkages among certain diseases and ecosystem services. A review of the existing literature should reveal specific diseases that can be used as cases demonstrating strong links to ecosystem services. A basic research question that would need to be answered using the resulting framework is "how do changes in the ecosystem affect ecosystems services, and subsequently human health?"

The answer to that research question is crucial for affecting substantive change in ecosystem management practices on a policy level. The research article is an important step toward understanding how ecosystem services, and our own actions, can affect human health outcomes. Not only would such an article help create a framework from which to study such relationships, but it would also serve as a tool for policy change. If specific diseases can be shown to have direct linkages to ecosystem services, then it will be easier to show policy-makers the benefits of ecosystem management by providing them with concrete evidence and even financial incentives for maintaining the relevant ecosystems. A last element of the team's plan was to begin a "call to arms" for researchers in all of the fields that deal with ecosystem services, whether it's ecology or urban planning, to work together to improve human health through ecosystem management. Through advertisements, podcasts, journals and other avenues, experts in every related discipline need to be made aware of the health component of ecosystem services and the possibility of working together to improve human health worldwide.

IDR Team Summary 2

Identify what resources can be produced renewably or recovered by developing intense technologies that can be applied on a massive scale.

CHALLENGE SUMMARY

Modern society depends on harvesting dense, but nonrenewable resources. While fossil fuels are the most obvious examples, mining of phosphate rock and metals also falls into the nonrenewable category. In general, the nonrenewable sources will be depleted, which will cause major cost increases and severe disruption to social/economic patterns. In many cases, the use of the nonrenewable resources also causes serious environmental disruptions, such as global climate change for fossil fuels, eutrophication, and the pollution impacts of mining operations.

It is possible in some cases to develop processes that can create renewable substitutes for nonrenewable resources or that can capture the nonrenewable resources so that they can be reused. In the energy arena, photosynthetic biomass can be grown using sunlight as the energy source, which (at least in principle) generates renewable, C-neutral energy feedstock. Likewise, phosphorus can be captured from agricultural and food waste streams, while metals can be captured from used products.

The challenge is that the scale of these renewable technologies must be massive to have an impact. For example, about 84% of the energy use from human society today comes from fossil fuels; this is about 11 terawatts (TW) of fossil energy (or the equivalent of 160 million barrels of oil per day). Replacing fossil energy with renewable energy directly from photosynthesis at the TW level will demand that large expanses of the earth's surface be devoted to photosynthesis targeted to bioenergy production, and production systems will need to be managed so that they are highly intensive.

Phosphorus is now mined at a rate of about 17.5 metric tonnes per year, with about 80% being applied to crops. Since the supply of minable phosphorus ore will last only for a few more decades, technologies will need to be developed to recover most of the P being lost to runoff, animal waste, and human waste. Likewise, the so-called "green minor metals" have finite supplies and will need to be recycled. The most critical are tellurium, indium, and gallium, which are key to photovoltaic technology.

Key Questions

- What resources can be produced renewably or recovered by developing intense technologies that can be applied on a massive scale?
- What resource do we need to produce/recovery this way?
- What is the likelihood that we can develop intense, massive technology to do it?
- What are the impacts that need to be evaluated before we implement the technologies?
- Economic—how much will it cost to develop, implement, and operate? How can we afford to make the investments?
- Ecological—how will ecosystems be altered by massive implementation of renewable technologies that necessarily take up a large surface area?
- Environmental/climate—how will the massive implementation of renewable technologies alter climate or other environmental conditions? What other environmental conditions?
- Social—how will the organization of societies be altered by the massive implementation of renewable production/recovery technologies?
- Social/Economic—who will benefit or be hurt by the shift to renewable sources on a massive level?
- What are the foreseeable successes?
- Are catastrophic failures foreseeable?

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IDR TEAM SUMMARY

Kristina Twigg, NAKFI Science Writing Scholar
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IDR Team 2 was asked to identify what resources can be produced renewably or recovered by developing intense technologies applied on a massive scale.

Ecosystem Services and Renewability of Resources

The 2011 National Academies Keck *Futures Initiative (*NAKFI) focused on ecosystem services—those benefits provided to people by nature. Some ecosystem services are difficult to value, like a wetland's ability to filter water. Others provide marketable goods, such as oil or lumber. However, because of increasing demand, growing population and many other factors, humans are straining ecosystem services and using resources at an unsustainable rate. Many resources formed over hundreds of years, and at current rates of use, some of these nonrenewable resources will diminish within decades. Oil and phosphorus are two examples.

Sustainable Solutions: An Issue of Scale

Without viable alternatives, running out of nonrenewable resources will cause widespread social and economic disruption. In addition, the current use of nonrenewable resources is often unsustainable for social and environmental reasons. Phosphorus, for example, is a key component of fertilizers used in high-yield agriculture. Early agriculturalists used bat guano and other animal manure. However, fertilizer use spiked after the green revolution, which greatly increased the yield of previously marginal lands through irrigation and nutrient inputs. To supply the necessary fertilizer, mining of phosphate rock became the primary source of phosphorus. While the green revolution allowed for much greater food production, there were environmental trade-offs. The mining of phosphorus, as with many other materials, causes widespread soil and water degradation. Furthermore, the overuse of nutrients—primarily nitrogen and phosphorus—has led to algal blooms and dead zones in inland and coastal water bodies.

In addition to finding renewable replacements for nonrenewable resources, pursuing a sustainable course also requires conserving, recycling and recovering resources. Phosphorus is currently used at an unsustainable rate of 17.5 metric tons per year with scientists projecting that supplies will last only a few more decades. Phosphorus can be recovered from waste streams. However, while technology currently exists to recover resources and harvest renewables, it cannot yet be applied at the massive scale required to meet demand. In addition, developing these intense technologies must be done with social and environmental costs in mind.

IDR Team 2: The Discovery Process

IDR Team 2 created a list of resources that will likely need to be produced renewably on a massive scale in the coming decades. The list included

- Rare earth elements
- Other metals (iron, potassium, copper, etc.)
- Phosphorus
- Energy
- Water
- Plant-based products (e.g., palm oil and rubber)
- Environmental buffers (ecosystem services)

The EcoInteractome Map

The team decided that a generalized process map, which the group termed an EcoInteractome Map, could be applied to each resource on the list and would be a helpful output from this meeting. Starting with rare earth elements, the group examined resource extraction and processing all the way to products and waste streams. Mapping allowed the group to investigate points throughout the process for improving efficiencies, substituting renewables, and recovering resources. The map also provided an aid for understanding externalities such as social, economic, and environmental impacts and drivers along spatial and temporal scales. Figure 1 is an example of a generalized EcoInteractome Map.

Rare earth elements are actually not rare, but rather, they are difficult to mine due to high dispersion throughout the earth's crust. Examples include neodymium, cerium, and gadolinium. Rare earth elements are important in an increasing number of technologies, particularly those with magnets and lasers. However, because they are in the early stages of use, the amount of rare earth elements in the environment may not allow for effective recovery or recycling. Since the amount still available is quite large, the issue is not as time sensitive as phosphorus, for which resource depletion projections are rapidly approaching.

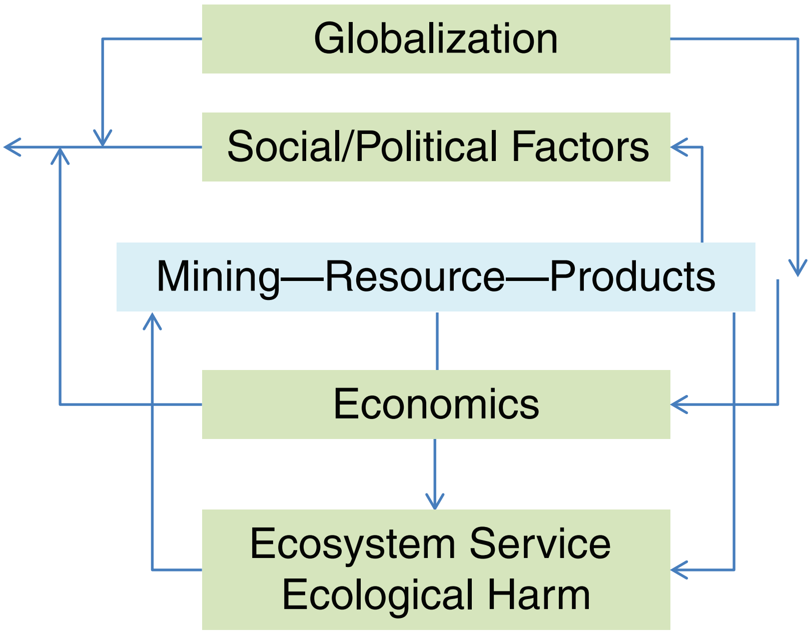

FIGURE 1: A generalized EcoInteractome Map used for assessing the process of resource recovery or large-scale production of renewables within a social, ecological, and economic framework.

Therefore, the group applied the EcoInteractome Map framework to phosphorus, as shown in Figure 2. The map follows the global movement of phosphorus, going from mined phosphorus ore to fertilizer production to application on arable lands. As a fertilizer, phosphorus adsorbs to soil particles, which are subject to wind and water erosion. During heavy rain events, runoff transports phosphorus into nearby waterbodies and is the greatest source of phosphorus loss globally. Phosphorus is a main component of fertilizer because it is a very important element biologically. It is a major component of bones and is imperative for DNA formation and cell respiration. Therefore, phosphorus is also released as a waste product in animal manure. The disposal, erosion and other removal of animal waste represents the second greatest loss of phosphorus from the system.

Phosphorus recovery pilot study

After completing the phosphorus EcoInteractome Map and identifying points of major phosphorus loss, IDR Team 2 brainstormed ways to recover phosphorus from the environment. "We need to close the loop," said one IDR Team member. Ideas ranged from proven technologies, such as struvite extraction, to a seemingly outrageous robot army—designed to collect phosphorus in sediments and aquatic systems. The group then arranged these ideas based on where they fit within the map (see Figure 3).

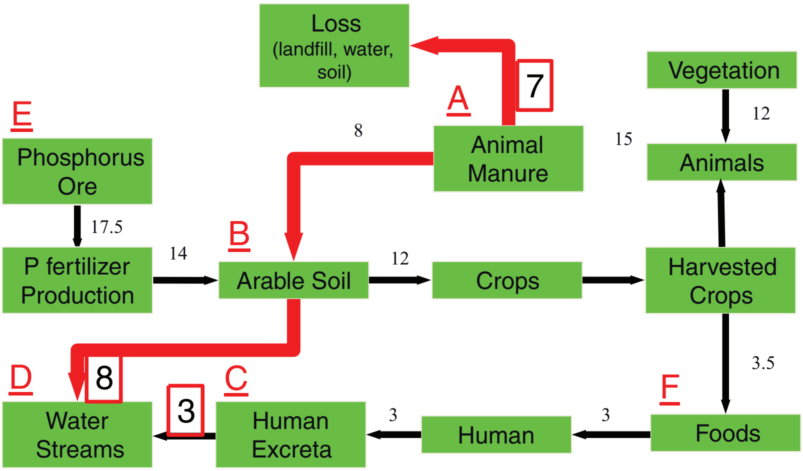

FIGURE 2: A simplified EcoInteractome Map of global phosphorus mass flow. The numbers express phosphorus in million tons and are derived from Cordell et al., 2009.

Biologic treatment	Engineered systems
• With Aerobic and anaerobic bacteria (A) • With plants (B) • Algae cultivation (A, D) • Algae harvesting (D)	• Robot armies (B, D) • Redesigned fertilizer (B) • Modified plants (B) • Bioactive biochar (B)
Thermochemical processes	**Mining new and existing phosphorus sources (E)** **Biomimickry**
• Pyrolysis and gasification (A) • Struvite extraction (A, C) • Phosphorus sorption (B, D)	• Bone formation (E) • Bird digestion (E) • Producing biosynthetic food (F)
Group A—Capturing phosphorus from animal waste streams *Group B—Capturing phosphorus in sediments (includes erosion prevention)* *Group C—Capturing phosphorus from human waste streams* *Group D—Capturing phosphorus from water* *Group E—New sources of phosphorus* *Group F—Changes in food production*	

FIGURE 3: A list of innovations or technologies to generate or recover phosphorus on a massive scale. The letters correspond with points along the EcoInteractome map shown in figure 2.

Some solutions focused on phosphorus recovery from sediments, manure, and municipal wastewater while others proposed entirely new sources, such as mimicking bone formation. In the end, the group decided the technology most amenable to massive scale up would be a process for extracting phosphorus from animal manure (see Figure 4).

While concentrated animal feeding operations (CAFOs) come with their own set of environmental issues, they are now used to meet the world's demand for cheap meat. According to the U.S. Environmental Protection Agency, there were approximately 20,000 CAFOs in the U.S. in 2006. This number is only a subset of the 450,000 U.S. animal feeding operations. The U.S. Department of Agriculture estimates that the amount of manure produced annually at all animal feeding operations in the U.S. exceeds 335 million tons of dry manure.

IDR Team 2 developed the framework for a pilot study to test a manure-based phosphorus recovery strategy at two percent (400) of CAFO facilities. While starting small, the project goal would be a massive scale-up of the technology that could provide a large portion of phosphorus used within the U.S. Another project goal would be to quantify ecosystem benefits and impacts of the technology, such as water quality improvements, a decrease in antibiotic resistant genes, and lower greenhouse gas emissions.

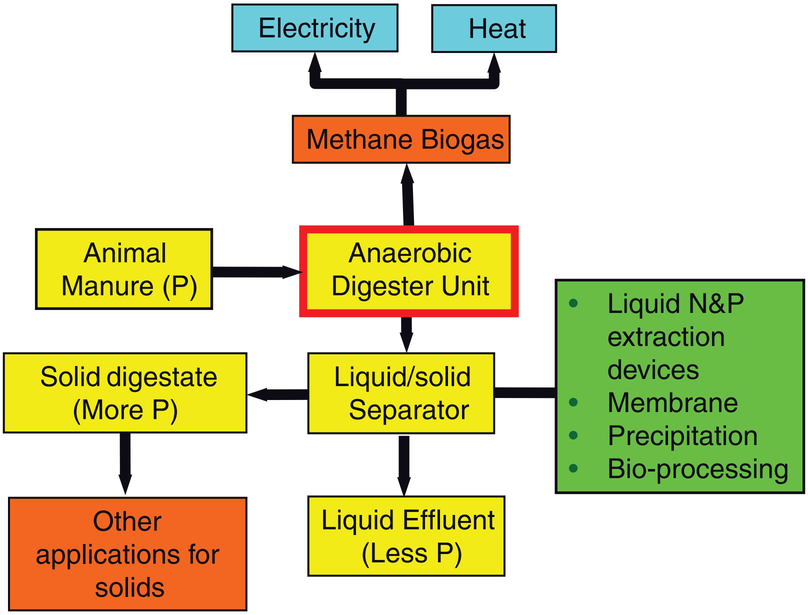

FIGURE 4: Shows how phosphorus could be recovered from animal waste on a massive scale.

The pilot would also allow researchers to anticipate social, economic, and political barriers to the scale up. For example, the program might explore incentives for CAFOs to use this technology and evaluate the willingness of fertilizer production facilities to accept phosphorus from the pilot farms.

Moving Forward

Progress toward recovering resources and producing renewables on a massive scale has been slow due to opposition from industries that rely on nonrenewable resources and because renewables are still more expensive to produce—a cost passed on to the consumer. Research and development, such as the suggested pilot study, are necessary to move forward sustainably. Acceptance by the public and decision makers is also a major component. Along with education, the ability to produce affordable renewable alternatives will help garner this acceptance. Society needs to accept that nonrenewable resources are finite and move forward with sustainable solutions now in order to successfully develop the capacity to meet the demand of a growing population.

IDR Team Summary 3

Develop social and technical capabilities to respond to abrupt changes in ecosystem services.

CHALLENGE SUMMARY

Abrupt changes to ecosystem services imply rapid changes in the structure and function of ecosystems such that thresholds or tipping points are reached that affect the quantity or quality of the expected services from the ecosystem. Much attention has been given to abrupt climate change (e.g., Alley et al. 2003; Lenton et al. 2008), and various studies point to past abrupt changes, such as the flushing of Lake Agassiz into the North Atlantic shutting down the thermohaline circulation and generating global cooling. Owing to the sharp loss or change in services, the presumption is that the affected human population will experience a disservice, perhaps registered as disaster.

A substantial research tradition examines societal risk and hazards to environmental events. Much attention has also been given to human responses to environmental events (e.g., tornadoes, tsunamis, floods), which may be viewed as abrupt disservices. More recently, attention has focused on the vulnerability and resilience of social-ecological systems under stress, illuminating the interactions among the two subsystems and the synergies and tradeoffs in their respective responses. This work, perhaps more often than not, suggests abrupt changes in ecosystem services involve the emergent properties of complex social-ecological systems, such as the Dust Bowl on Great Plains of the U.S. generated by climate and land management interactions (Cook et al. 2009); and the human responses to these properties are far more complex and nuanced than is captured in popular societal collapse interpretations.

Much of the work on abrupt emergent properties is hypothetical and that on human responses captured in (pre)historical interpretations, before the human-environment conditions of the Anthropocene. The challenge is gleaning the lessons about societal responses to projected and "surprise" abrupt changes in the Anthropocene.

Key Questions

- What are the types of projected abrupt change for which society has demonstrated a willingness to prepare?
- What characteristics of changes in ecosystem services and societal coping mechanisms make human populations more robust and resilient, and less vulnerable to abrupt change?

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- Gregory M. Masters, University of Maryland
- Katrina Mullan, University of California, Berkeley
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IDR TEAM SUMMARY

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IDR Team 3 was asked to design social and technical capabilities to respond to abrupt changes in ecosystem services. An abrupt change can be truly sudden—a sharp shock to the system such as a tsunami, asteroid impact, volcanic eruption, or earthquake—or years in the making. The farmers who first populated the Great Plains of the United States, for example, engaged over a number of years in agricultural practices that were ill-suited to the environment. When the wet cycle gave way to sudden drought in 1931, wind carried the over-plowed topsoil into great dust clouds that blackened skies and destroyed crops. Another example of a "slow-onset" yet abrupt change is the sudden collapse of the Northern Cod fishery in 1992, which followed decades of overfishing.

Team 3 considered these kinds of changes in the context of ecosystem services: the range of benefits that humans derive from the natural world. Changes in the environment are distinct from changes in ecosystem services, but the former generally cause or trigger the latter. The Dust Bowl, a rapid change in the physical environment, affected food supply. Deforestation affects timber supply, flood prevention, carbon sequestration, and nutrient cycling. And many abrupt changes in the environment have the potential to affect recreation, ecotourism, and the spiritual enrichment that nature can provide. An abrupt change might affect few, several or all types of services.

The team recognized that some perturbations may actually increase certain ecosystem services while causing a decline in others. Slash-and-burn deforestation in tropical areas, for example, increases that land's ability to provide food while reducing its capacity to absorb carbon. It is important to consider the possibility of trade-offs in ecosystem services following abrupt changes.

Organizing and Classifying Abrupt Changes

To begin, the team found it useful to organize the range of environmental changes that trigger abrupt changes in ecosystem services. While these involve multiple variables, the two the team thinks most essential are spatial scale and rate of onset. A large asteroid impact, for example, may have an intermediate- or large-scale impact, but the onset is always fast. Slash-and-burn deforestation also has a fast onset but a more local impact. The collapse of a fishery often has a slow onset and an intermediate impact. To show these kinds of relationships, the team developed the diagram shown in Figure 1. The abrupt changes in the diagram are color-coded to represent the number of ecosystem services affected.

Some kinds of abrupt changes display complex interrelationships among variables. The impact of the loss of biodiversity, for example, varies according to spatial scale; local biodiversity loss affects only a few ecosystem services, while global biodiversity loss may affect all of the services in the system. Drought has a fast start (one day it stops raining) but a slow onset because it takes days before dramatic changes occur. Also, spatial scale and rate of onset seem to be coupled in the case of drought; the wider the impact, the slower the rate of onset.

The team focused on three basic classes of change: outliers, state changes, and tipping points. An ecosystem may bounce back to its original state following a dramatic change (such as a 100-year flood) or it may persist in a different state; these two scenarios are outliers and state changes,

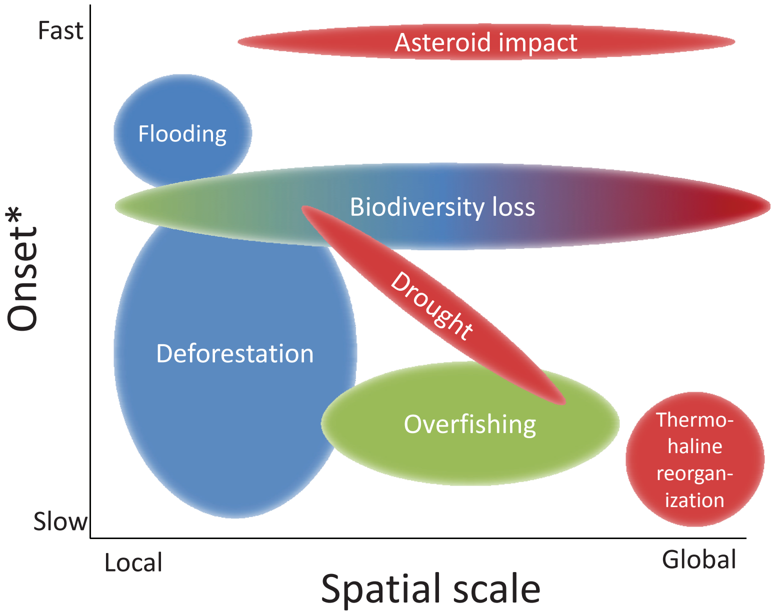

FIGURE 1: Potential abrupt changes in the environment are organized according to their expected rate of onset, spatial scale, and number of affected ecosystem services.

respectively. The third type of abrupt change occurs when the ecosystem passes a "tipping point" or threshold after a period of chronic stress and repeated perturbations. After passing a tipping point, the system often persists in the altered state. Easter Island's civilization collapsed suddenly when a species of palm went extinct following centuries of overharvesting. According to climate scientists, a potential tipping point in the world's climate may soon be reached if enough fresh meltwater enters the North Atlantic to shut down the thermohaline circulation, the density-dependent ocean conveyor that provides heat to northern latitudes.

Willingness to Prepare: A Matter of Perception

The team considered the kinds of changes for which society has demonstrated a willingness to prepare. Whether people have direct experience with a certain change, whether the change can be predicted and whether it can be managed are all factors the team thought to be important in influencing willingness to prepare. Also, society sometimes shows a disproportionately strong response to ecosystem disruption that causes a direct threat to public health. The spread of novel diseases such as West Nile virus, for example, usually inspires a significant response even when the number of people affected is small. Another example is E. coli-contaminated spinach; when an outbreak occurred in California's Salinas Valley in 2006, only three people were killed yet one of the consequences was a drastic change in food safety policy in California.

Examples like these highlight the importance of perception in influencing responses to abrupt changes in ecosystem services. The team discussed the need for more human behavioral research into people's perceived sense of risk. One interesting question is whether abrupt changes inspire overreaction while chronic changes lead to complacency. For example, does sudden raiding of crops by elephants in Africa or Asia inspire a stronger reaction than consumption of exposed grain stores in the Midwestern United States by rats, even though the latter (chronic) situation ends up costing farmers more in terms of loss of grain?

Anticipating response

The team considered several categories of preparation for an abrupt change in an ecosystem service. Of course, one common response is to simply accept life's inherent risks (the "fateful" response). Putting aside this untroubled approach, actual preparations can broadly be labeled either mitigation or adaptation; mitigation is working to prevent the change, while adaptation is planning some kind of response in the event the change occurs. Adaptive responses might be reactive—a rush of activity that addresses only the most immediate vulnerability and the associated ecosystem service—or active, addressing multiple ecosystem services through continuous refinement of strategies based on lessons learned.

How vulnerable people perceive themselves to be strongly influences the number and type of strategies they will embrace and pay for. Where the perception of vulnerability is high, there likely will be more mitigation strategies and more active adaptive responses. Where the perception of vulnerability is low, one would expect to find fewer mitigation activities and more reactive adaptive responses. If the abrupt change in question occurs, the people who perceived their risk to be low may begin to change their perception and shift their portfolio of strategies. The team represented these hypothesized behavioral patterns in a flow chart, shown in Figure 2.

What Makes Societies More Robust and Resilient?

Robustness and resilience are often conflated; robustness refers to a system's ability to withstand change, while resilience refers to the time it takes for the system to return to its previous state. The team considered

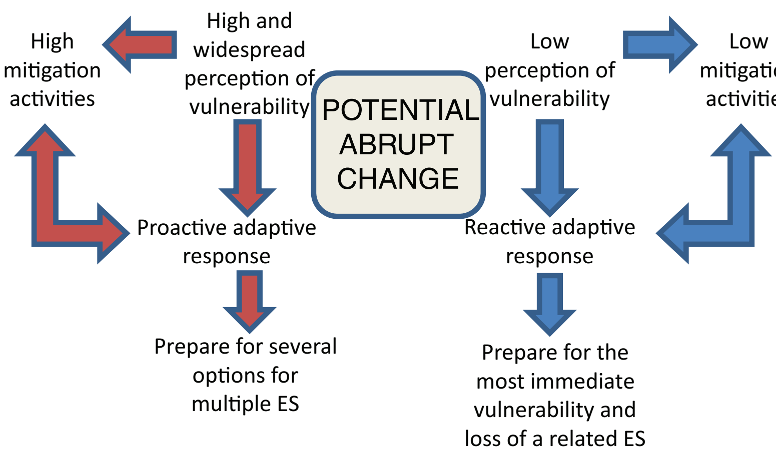

FIGURE 2: How perception of vulnerability to a potential abrupt change might affect mitigation activities and adaptive responses.

factors that make societies more robust and resilient in the face of abrupt changes, including characteristics of the abrupt changes themselves as well as societal coping mechanisms.

Societies are more likely to prepare well for (and be less vulnerable to) slow-onset abrupt changes (as opposed to sharp, unexpected shocks), changes that are predictable, reversible and local-scale, changes that increase rather than decrease ecosystem services, and changes in which technology can replace the lost ecosystem service.

To improve robustness and resilience, societies should provide multiple options for people to cope and adapt, and institutions should be flexible. Societal coping mechanisms should include access to insurance, technology for mitigation and adaptation, and the ability to diversify livelihoods so as to decrease dependence on a single ecosystem service. Also important are social networks, which can be considered a kind of insurance. As one person in the team observed, many people in Japan who live in high-risk areas decided not to move after the tsunami because they did not want to accept the risk associated with losing their network of family and friends.

Future Research

Given the important role of perception in governing responses to abrupt ecosystem change, future research should focus on understanding the reasons behind human behavioral responses to abrupt changes. The team suggests a project to build a library of case studies of past abrupt changes and information about how people prepared or coped. Information should be gathered on the abrupt changes themselves, including specific ecological functions and services that underwent change, as well as the social dimensions of the societal responses. Of interest would be the role played by social networks, information systems and governmental institutions, as well as the livelihood practices of people affected—whether, for example, farmers used multicropping or other means of biological insurance to reduce risk. The team also noted the need for research concerning the relationships between specific ecological *functions* and ecosystem services they provide; this knowledge can help in the monitoring of service changes.

Lastly, the team suggests the development of specific early warning systems—including ecological indicators of tipping points—and tools that allow people to explore the mitigation and adaptation options available to them. A computer simulation game, for example, could serve this purpose while also informing research on risk perception.

IDR Team Summary 4

Design agricultural and aquacultural systems that provide food security while maintaining the full set of ecosystem services needed from landscapes and seascapes.

CHALLENGE SUMMARY

Humanity needs to provide food security to 9 billion or more people through the second half of this century. This presents a major challenge on several fronts: agroecology and crop production; maintenance of adequate flows and quality of freshwater, retention of nutrients, maintenance of soil quality, and conservation of living resources; and social distribution of benefits and costs. Food security is commonly interpreted as access at all times to enough food for an active, healthy life. This definition encompasses not only access to sufficient quantities of food (i.e., calories), but also access to foods of sufficient quality (i.e., macro and micronutrients needed for growth and health).

Crop and cultivation advances yield sufficient quantities of food for our species, although provision of food is not synonymous with meeting nutritional needs to maintain optimal health. Furthermore, the institutions governing access deliver highly uneven distributions of food. An irony today is that while food-based indicators of global-average human well-being are increasing, as well as basic health indicators, the total numbers of those malnourished and in hunger are increasing as well. Much attention has been given to the production advances needed to feed a world >9 billion and to the means by which the distribution of food access could become more equitable. Much less attention has been given to environmental/ecosystem consequence of achieving either.

The growth of agricultural yield since about 1960 has been driven mainly by increased use of irrigation, fertilizer, and new crop varieties. As a result, agriculture is the largest consumer of fresh water withdrawal globally and the largest polluter of that water. Among human activities, agriculture (including pasture) is the largest contributor to climate change. It also consumes more land area than any other activity and in the process is the largest driver of biodiversity loss. While the rate of growth in irrigated land and fertilizer applications is tailing off, in part because technology is facilitating more efficient use, agricultural production is increasingly devoted to biofuels, animal feed, or human 'junk foods' that are of low nutritional value. In addition, most of the prime agricultural land of the world is in use, and some of it is being lost to urbanization or degradation processes. Importantly, food production increases have not had to pay for a large number of "externalities," precisely those that draw down non-provisioning ecosystem services such as regulation of natural hazards, erosion, carbon storage, or freshwater flows and quality. It is expected that these externalities will increase in the future, demanding more attention relative to food security questions.

In these conditions, it will be a challenge to provide food security to 9 billion people while reducing pressures on land, freshwater or fertilizer, decreasing net emissions of greenhouse gases from agriculture and freshwater pollution, increasing recharge of critical aquifers, moderating runoff and large floods, and building and conserving soil to sustain future food production.

Key Questions

- What matrix of farming systems are needed to meet dietary needs (both amount and nutrition) of 9 billion people?
- How can provisioning of food and related ecosystem services be made resilient to massive environmental changes such as climate change or shocks such as emergence of new crop diseases?
- What ecosystem services will be needed to support these systems?
- How can these systems provision without drawing down other ecosystem services?
- How do these systems affect entitlements (food access institutions)?
- How can tradeoffs between further agricultural expansion and greater intensification on existing land be evaluated?

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Because of the popularity of this topic, three groups explored this subject. Please be sure to review each write-up, which immediately follow this one.

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IDR TEAM SUMMARY—GROUP 4A

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IDR Team 4A took on the challenge of developing an approach to feed nine billion people—the estimated global population in 2050—while maintaining ecosystem services.

Designing agricultural systems for food security is a many-faceted problem. Agriculture must meet the current demand for food while also preparing to meet future demands, in anticipation of population growth and shifts in diet. It must do so sustainably, without destroying the ecosystem's ability to provide food or other ecosystem services. In addressing each of these requirements, agriculture must fight a staggering array of conflicting economical and sociopolitical forces.

Five Steps to Achieving Food Security

The world is home to seven billion people, a billion of whom are currently not getting enough to eat. By 2050 there will be an estimated nine billion people on the planet. Meanwhile, people around the globe are shifting their diets, eating more meat and other environmentally expensive foods.

As a result, experts estimate that by 2050 the world's food production will have to at least double in order to keep up with demand. At the same time, society will have to reduce its negative impact on the environment—otherwise, food security will be short-lived and other ecosystem services will be compromised. Agriculture is the most damaging of all human activities, in terms of land use, water use, water pollution, and greenhouse gases.

Is it even mathematically possible to double food production while cutting environmental costs? One team member, who had recently published a major paper addressing that question, reported that the answer is yes: it is physically and biologically possible to achieve sustainable agriculture and food security—provided that we make some major changes in the way we farm and eat. The paper had identified five tasks that must be accomplished simultaneously:

1. *We have to stop deforestation.* When we expand agriculture to take over new land, the loss of ecosystem services far outweighs the gain in food.
2. *We have to close yield gaps.* Many regions around the world are not yielding as much food as they are capable of producing.
3. *We have to use resources more efficiently.* Through less-than-optimal use of water, fertilizers, and other resources, we are both polluting the environment and failing to make the most of limited resources.
4. *We have to shift our diets and reduce biofuels.* By devoting agricultural resources to livestock feed and nonfood crops, we are producing fewer calories for human consumption than we could be.
5. *We have to waste less food.* We make food security less attainable by throwing away unused and past-expiration food, particularly meat.

To avoid reinventing the wheel, IDR Team 4A reached a consensus to base further discussion on this set of five steps for achieving food security. The team agreed to (a) assess whether accomplishing those five steps would have a net positive impact on other ecosystem services, (b) identify mechanisms for accomplishing each step, and (c) identify what to do next, outside of the NAKFI conference.

How Will the Five Steps Affect Other Ecosystem Services?

IDR Team 4A assessed whether accomplishing the five steps would have a positive or negative impact on other ecosystem services, in addition to food availability.

The team selected a handful of important ecosystem services and developed a table (Figure 1), listing some of the impacts that each food security step would have upon each ecosystem service; impacts are simplified as positive, negative, or neutral symbols.

Some of the food security steps were estimated to have an especially strong positive impact. The team had access to data showing that the strong positive effects in the "Improve Resource Use Efficiency" category more than compensated for the negative effects in the "Close Yield Gaps" category.

This table gave the team a rough indication that the five food security steps would cause more positive than negative impacts on ecosystem

Ecosystem Services:	The Five Steps to Achieving Food Security				
	(1) Stop Deforestation	(2) Close Yield Gaps	(3) Use Resources More Efficiently	(4) Shift Diets & Reduce Biofuels	(5) Reduce Food Waste
Carbon Sequestration	++	+, –	+	+	
Improved Water Quality	+	–	++		
Soil Fertility	+	+/0 –	++	+	
Emission Reductions	++	–	+	+, –	+
Water Provisioning	+, –	–	++	+	
Biodiversity	++	–	+		
Food Availability	0	+	0	+	+

FIGURE 1: Hypothetical impacts of the "five steps to achieving food security" upon selected ecosystem services. Impacts are strongly positive (++), positive (+), neutral (0), or negative (–).

services. It furthermore identified areas in which care must be taken to minimize environmental harm.

Actions and Agents for Accomplishing the Five Steps

Satisfied that the five-step plan would benefit other ecosystem services along with immediate food needs, IDR Team 4A tackled the question of how to begin accomplishing the plan. Since each step is an enormous task fraught with difficulties, the team members looked for ways to break it down into more manageable pieces.

For each step they considered four sub-categories in which actions must be taken:

- Research and development; technology
- Economics

- Institutions and governance
- Culture and norms; politics

Actions: Thinking in terms of the four sub-categories, the team identified some of the individual actions that would bring us closer to achieving each of the five food security steps. For example, one of the steps for food security is "use resources more efficiently." When the team members considered that problem through the lens of research and development, the actions they came up with included "improve irrigation technology" and "develop perennial crops." When they considered the same problem through the lens of culture and norms, they thought of actions such as "discourage farmers from applying extra fertilizer for insurance."

Agents: Then, the team members identified some agents who would need to be involved in carrying out each action. For the research and development example above, they identified agribusinesses, universities, government agencies, and funding groups as the agents that would play a role in improving resource efficiency. For the culture and norms example, they identified farmers and the media as relevant agents.

For each of the five steps, the team members constructed a table that listed actions and agents, broken into the four sub-categories. They noticed that many of the same types of agents recurred across the different steps and subcategories.

Moving Closer to Real-World Application

The members of IDR Team 4A had established that the five-step plan could achieve food security while benefiting other ecosystem services. They had identified some of the actions and agents necessary to accomplish each step of the plan. Finally, they sketched out strategies to move toward real-world application.

The team proposed further research to determine the minimum extent to which each of the five steps must be met. Such knowledge would allow activists to best allocate efforts in the face of economic, social, and political opposition.

Another strategy that the team suggested is convening a workshop to evaluate the United States government's current priorities in agriculture, food, the environment, and health. The team proposed looking for alignments and efficiencies among these different concerns, to find opportunities for harmonizing efforts and funds.

IDR Team 4A lastly proposed collaborating with existing groups to fine-tune the lists of actions and agents they identified, by collecting and conducting more research. The team suggested contacting and engaging those agents, to set the wheels in motion for achieving food security through sustainable agriculture.

IDR TEAM MEMBERS—GROUP 4B

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IDR SUMMARY —GROUP 4B

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Statement of the Problem

IDR Team 4B was asked to design agricultural and aquacultural systems that provide food security while maintaining the full set of ecosystem services needed from landscapes and seascapes. Instead, based on the group's unique specialties, it narrowed the challenge to studying ecosystem services in agricultural landscapes only, specifically designing solutions that cross the traditional urban-rural divide.

The group drew inspiration from Joel Cohen's keynote speech about the potential challenges that come because of increases in human population. According to Cohen, who is a professor and head of the lab of populations at Rockefeller University and Columbia University, urban expansion is growing at a super-exponential rate; a new city is in the process of being built somewhere in the world every few hours. The group found this trend to be highly threatening in regard to maintaining food security in the coming decades. It pointed out that rapid urban expansion may not be a big deal in places with plenty of land, like North America, but in developing countries such as India, food production would diminish due to the conversion of agricultural land for urban use.

Goals

The group decided that its primary goal should be to think about how to equitably distribute healthful foods by increasing food production in urban, suburban, and exurban areas where the majority of people live. That is, agricultural systems should be integrated into existing and developing urban infrastructure in order to adequately feed future city populations.

Constructing vertical farms in every newly built city is one way to support this unique merging of uses between agricultural and residential landscapes. The group agreed that vertical farms, which are essentially high rises with floors of fields that produce crops all year round, would also help them achieve a second goal: to prevent new conversion of forests, grasslands, and wetlands into prime agricultural land to sustain urban areas.

The group also suggested provisions to reuse waste normally filtered out into urban fringe areas in order to power the new urban-agricultural food production systems. For example, food towers require artificial light to operate, and hydrologic power from recycled wastewater would provide the energy needed to sustain agricultural operations. And because it's estimated that by 2050 most of the world's population will be living in urban areas, agricultural infrastructure in urban areas would incidentally slash transportation costs and carbon-dioxide emissions associated with importing and exporting foods long distances. By the same token, group members surmised that by moving farms closer to where people live, some communities could maintain themselves entirely with the food produced within their own city limits.

Approaches/Gaps in Technology

In order to bring this new agricultural infrastructure into being, the group came up with three different strategies. One: educate consumers and producers about the amount of resources it takes to produce and transport food, and thereby adjust cultural norms for waste expenditure. One idea was to put sticker barcodes on each individual food item. Ideally then, consumers and producers would be able to use their smart phones to scan the barcode and see the amount of energy it took to produce that single food item. Because putting a barcode on every piece of produce may be overreaching, the group also suggested putting devices on delivering trucks to track the miles and the amount of carbon emissions released to transport food. Using this new information about the history of produce, group members hoped that stakeholders, consumers, and producers would challenge current systems and vie for more sustainable urban-agricultural practices.

The group's second strategy suggests using government regulations to enact new production systems and provide incentives for agricultural businesses to adopt environmentally sustainable practices. Unlike other groups, this group emphasized the importance of rooting research in community decision-making processes. In order to help local government officials make informed decisions about food systems and land use, the group thought that a suite of metrics that integrate the resources used to produce food should be developed. Examples of these metrics are as follows: carbon and water footprints, food source and location, energy type, land use and biodiversity.

As such, the group's third and final strategy was to design and build the technology using the new set of metrics that explains the link between land use management, food production, hydrology, biogeochemical cycles, and socioeconomic systems.

Above all, each group member agreed that it was necessary to identify the thresholds and "safe operating spaces" of agricultural ecosystem services as it pertains to climate change before new systems are put into place. With climate change, changes in ecosystem services are imminent, and as such, areas where agricultural lands thrive are subject to change as well. The group predicted that recognizing these thresholds would influence policy maker decisions about how and where food is produced, thus perhaps providing a bigger incentive to adopt urban-agricultural farming techniques like vertical farming.

Integrating Land Use and Food Systems

Before building a new city, policy makers should consider a variety of factors in order to integrate urban land use and food production and delivery. Most obviously, cities should designate certain areas of the city for food production only, and incorporate enough room for food production systems like vertical farms. Moreover, policy makers and architects should design systems that harness hydrologic power from wastewater facilities. Lastly, government regulations to banish mono-crop industries should be implemented in order to put power back into the hands of the individual farmer, increase agricultural diversity and provide incentives to adopt sustainable, urban-agricultural farming practices.

Conclusion/Benefits

The group sees vast benefits in adopting integrated urban and agricultural infrastructure. For one, due to an increasing dependency on local agriculture, and consequently, a sharp reduction in carbon emissions for transportation, the group thinks that air quality will dramatically improve. Likewise, implementing local agriculture systems in poor, urban areas will inevitably improve access to healthful foods for vulnerable populations.

Moreover, the group expects that recycling wastewater to power urban-agricultural food systems will cut down on water pollution. Instead of grey water and storm water from urban areas trickling out and polluting hinterlands and fringe areas, the water would be continuously cycled back to power the food production system.

Government regulations of mono-cropping industries would encourage biological and agricultural diversity, thereby also enhancing overall ecosystem resilience and the retention of nutrients in soil. Finally, the group agreed that one of the most overlooked but beneficial outcomes would be the improvement of the aesthetic, recreational, and cultural quality of life. The reduction of air and water pollution, combined with less land conversion for agricultural use, would result in cleaner outdoor spaces, ideal for leisurely activities like biking, hiking, walking, and even eating.

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IDR TEAM SUMMARY—GROUP 4C

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IDR Team 4C was asked to design agricultural and aquacultural systems that provide food security, while maintaining the full set of ecosystem services needed from landscapes and seascapes. The team listed priority traits of a desirable system across diverse landscapes and geographical regions that could produce high food yields while maintaining ecosystem services, and envisioned an international design competition that could help fill crucial gaps in our knowledge of production systems.

The advent of agriculture has, slowly but surely, changed the size and nature of human populations as advances have occurred during the past thousands of years. As people became able to control food production, the world's population increased, as did human beings' ability to live in culturally and economically productive societies.

There is no doubt that Earth's already large population of some seven billion people will continue to grow at a rate that will create serious new demands on food production, as well as natural ecosystems. There will be significant challenges to feeding the growing population of the world, challenges made even more difficult because of the need to protect the natural systems important to humans and animals, often known as ecosystem services. Simply put, the worlds' ecosystems provide vital services to human populations and to the natural world itself. Historically, agriculture has caused major deforestation, depleted topsoil, and decreased water quality and biodiversity throughout the word. Other forms of human activity have also caused soil, water, and air pollution, hatibat loss, desertification, disease dissemination, climate change, etc. In addition, current food production and the systems through which food is distributed still leave two billion people in the world without adequate nutrition.

Natural ecosystems provide all of the nutrients and life cycles needed to ensure regeneration, but they also provide services that are imperative for human survival, such as food, clean water, clean air, minerals, energy, nutrients, seeds, and carbon sequestration. Without the combination of all necessary ecosystem services, living conditions could become very difficult, and eventually impossible with the addition of two billion more people on Earth, which is projected to occur by 2050.

The Creative Challenge

There is no one solution to the challenge of balancing massive food production and protection of ecosystems on a global level. Agricultural, financial, geographical, and cultural standards are diverse. For that reason, IDR Team 4C decided that the best way to tackle the problem of designing agricultural and aquaculture systems that provide food security while maintaining a full set of ecosystem services was to first, describe the current system and its benefits and failings, second, to determine what a desirable system would look like, and third, come up with tactics for potentially improved food production systems. The goal is a long way off, but assembling a base of knowledge and data is a practical start to the huge problem humans face. If a desired set of outcomes were agreed upon, farmers, scientists, and citizens from varied cultures and geographies across the world could work to solve the food crisis with a system of best practices based on a global agricultural design competition.

Mapping the Road Between Unsustainable Food-Production Systems and a World of Adequate, Sustainable, and Nutritious Food

If our present methods of agriculture continue while we have to feed another two billion people by 2050, it is hard not to imagine a dramatic impact on ecosystem services globally. To design a better future, it is imperative to know where we are, and how we got here. Because agriculture is a large producer of greenhouse gases and the biggest polluter of fresh water, change in agricultural practice is imperative. Twentieth century agriculture was very successful in using fertilizers, irrigation, and crop technology to meet the growing food needs of billions of people around the world. However, those methods have created a situation in which many ecosystems have become depleted of important resources and may not be able to support agriculture in the future. As climate changes, further threats to agriculture and ecosystems will occur, creating new challenges for solving the problem of food security—a term used to mean that people can count on sufficient nutrition day by day to be healthy.

Meeting demands for a broad, local-to-global effort to feed nine billion people will require policies, institutions, and markets that will lead to reduced demand, improved efficiency of food systems, intensification of agriculture in some places, and more equitable access to food that provides sufficient calories and nutrients in places in the world where people are now undernourished. Because the team chose to focus on the actual elements of the food production system, distribution of wealth and political feasibility were considered outside the scope of the IDR challenge.

Traits of a Desirable Food Production System

In order to feed nine billion people, humans will have to eat less meat and eat more grains, because farm animals consume large amounts of grain themselves and take up valuable agricultural space, which could be devoted to feeding humans. Ideally, diets emphasizing grains, vegetables, and fish would also provide necessary nutrients in addition to necessary calories. Ideal agricultural systems would also be designed to be resilient to changes in the environment, such as drought and climate change, so that negative environmental events would not wipe out entire crops and put people at risk of famine. This could possibly be achieved through innovative farming methods and advances in crop science. On a social and political level, education about food systems is extremely important so that producers and consumers can make more informed choices to help protect food production and understand the value of ecosystem services.

Knowledge Gaps and Research Needed

Acknowledging that human food production systems are a long way from a path to a sustainable production system to feed nine billion people, and that there is no current comprehensive plan to deal with the problem, IDR Team 4C took the approach of identifying important impediments to learning how to create a balance between food systems on multiple scales and natural ecosystems, and how those barriers could be incorporated into a design competition challenge with the hope of inspiring innovative solutions.

1. Important and necessary elements of a multi-scale food production system

The team agreed that, first there is a need for research on improved strategies for food production, in addition to strategies for valuation and protection of ecosystem services. These strategies could include growing more food on current agricultural lands where appropriate, rehabilitation of degraded agricultural land, and research on new production methods that produce high yields while not compromising the ecosystem. This system would include multi-scale ‘foodsheds’, or the idea that food security extends from the groceries you put on the family table to large-scale global agriculture.

2. Linkages between production methods and ecosystem services

A fundamental aspect of the team challenge was to understand how production methods affect ecosystem services. There is not enough information in this area because technologies that produce data on ecosystem service losses are expensive and unavailable to people in many parts of the world. While feeding nine billion people, it will be important to measure and model the cumulative effects of agriculture and identify tradeoffs between food production and ecosystem services.

A system of identifying tradeoffs and synergies would combine what the team called an agro-ecosystem, where any food production system would take into account the effect on ecosystem services, such as soil quality, carbon storage in soils and forests, pollination of crops and wild plants, biodiversity and water quality.

3. Ability to quantify and document ecosystem services at multiple scales

A major barrier to establishing the value of ecosystem services and the effect that agricultural production has on natural systems is the lack of readily available and cost-effective technologies to measure trends in ecosystem services. In order to be able to judge the effect of agriculture on the environment, the team acknowledged that it is imperative to be able to measure the effect on ecosystems from thousand-acre cornfields to intensive small-farming operations. Cost effective technologies to measure ecosystem services can enable performance-based policy.

IDR Team 4C outlined important examples of how developing technologies could enhance knowledge of ecosystem and agricultural tradeoffs. The team argued that traceability, meaning the ability to track calorie efficiency in a food system, especially with meat and grains fed to animals, water usage, and oil for transport, would be integral to knowing how much energy humans put into agriculture and what the effects are. Tracking nitrogen in food systems is also important because when it is overused in fertilizers and enters the environment, it can cause harm to the ecosystem. The team also acknowledged the need for better remote sensing techniques for carbon sequestration because of its important role in climate change.

4. Human choices of food production systems

In order to fully grasp the global problem of producing food while maintaining a sustainable production system, it is important to understand the cultural norms and institutions of diverse societies, and what the economic and cultural tradeoffs of different agricultural systems are.

Place-Based Sustainable Landscape Configurations: An International Design Competition

To fill in the important gaps of knowledge, and to begin to create a system that could work in diverse environments on a global scale, IDR Team 4C proposed the creation of an international design competition to explore and apply the gaps in research so that there can be a large pool of resources and recommendations to draw upon in the creation of locally led, but globally relevant food production systems that value the preservation of ecosystem services. The first step in this process would be to identify and characterize informative landscapes throughout the world to provide the diversity of broad and applicable models.

Once key stakeholders were engaged, participants would be given a set of design principles to use as a template for the concepts of model food production systems. Stakeholders, including governments, small farmers, agro-business personnel, and other producers and consumers would be encouraged to use real landscape data and local knowledge to evaluate sustainability, with the goal of proposing more resilient landscape designs that incorporate the valuation of ecosystem services.

Comprehensive plans for diverse geographical regions would be submitted to an international design competition committee to engage fundraisers and key stakeholders. The program would be a long-term process, and results would be continually repeated to synthesize lessons learned. The team acknowledged that this would be a costly, ambitious, and long-term endeavor, but one that could potentially provide a template as a global model for locally led and globally inspired sustainability, ultimately which would lead to a balance between food production and ecosystem services.

The World and Food Ahead

Although 21st century food production challenges will persist, especially in the face of climate change and population growth, IDR Team 4C believes that bringing together the best technology and collaborative agricultural research, global and local, will produce results that can be used around the world to promote sustainable food production and consumption from the kitchen table to the largest agro-industrial operations.

IDR Team Summary 5

Design production systems for ecosystem services that improve human outcomes related to food and nutrition.

CHALLENGE SUMMARY

Human health and well-being cannot be achieved without food security. This security involves more than the production of food. It includes secure and sufficient access (or entitlements) to a sufficient quantity and quality of food to support the growth of children and permit an active, healthy life at all ages. Together, food production and access constitute food systems. Insufficient or unpredictable food supplies commonly result in malnutrition, illness, poor cognition, and both acute and chronic diseases. Poor food security tends to link with economic impoverishment to create conditions that lower agricultural productivity, and in turn, lead to poorer management of multiple land uses, potentially affecting a variety of related ecosystem services. In contrast, poor food security has been associated with another type of poor health in populations with intermittent food access: periodic overconsumption of calories relative to energy expenditure, leading to overweight/obesity and related chronic diseases. It is an open question whether the dominant forms of agriculture and aquaculture contribute to these problems by way of the variety and quality of foods produced. Regardless, the character of food systems holds systemic outcomes for people and environment.

The challenge is to better understand how to improve the two sides of food security by changing agricultural and aquacultural systems and the environmental consequences of these changes. Possibilities include increased food productivity, more food diversity, biofortification, and improved food distribution systems.

Key Questions

- How can food security best be measured in order to examine associations with human outcomes?
- How can the performance of food systems be measured in regard to the health and well-being of both the human and environmental subsystems?
- How do agriculture and aquaculture affect food security, and how does a lack of food security affect human health, and in turn, agricultural/aquacultural systems?
- How can food security be made resilient to sudden shocks such as natural or man-made disaster?"

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IDR TEAM MEMBERS

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IDR TEAM SUMMARY

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IDR Team 5 was asked to design production systems for ecosystem services that improve human outcomes related to food and nutrition. Currently, the global food system fails approximately two billion people, ~1 billion of whom are undernourished, while another ~1 billion are obese. With the global population growing at a super-exponential rate, the problem of meeting nutritional needs will only grow. Food production and distribution systems are not sustainable nor do they enhance the services upon which the systems depend.

There was much debate throughout the first day of discussion about the meaning of the team's challenge and how to create viable solutions without a clear understanding of the task. While the team struggled, initially, to find focus and clarity, the first breakthrough came when the team members agreed that "human outcomes related to food and nutrition"—such as malnourishment—is encompassed by the phrase "food security," which has been defined at the FAO, World Food Summit as: *"Food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious foods to meet their dietary needs and food preferences for an active and healthy life."*

With a clear definition of food security, the team began to consider whether or not the assigned challenge encompassed the reality of the food security problem. After lengthy discussion, the team members crafted what they believed to be the most concise statement of the problem:

"Current food systems do not match the energy and nutrient needs of an expanding population and are not sustainable."

"Food systems," in the problem statement, is meant to encompass all elements of the "field to fork" system, which includes production, processing, distribution and consumption. The team agreed that major infrastructural issues exist that threaten human outcomes for food and nutrition, primarily inadequate integration across cultures, environments, populations, economics, science, and technology.

This concise, two-part problem statement laid the framework within which the team could characterize human outcome failures, identify and address major threats to food security, and craft possible solutions, all within the context of ecosystem services.

Threats to Food Security

The team members created a lengthy list of threats to food security and opportunities for mitigating those threats. Some of the basic threats to food security include questions of ability, access, and utilization. Threats were identified within every stage of the "field-to-fork" system. While extensive, the list is by no means complete.

Threats to production and distribution include the emergence of major diseases, such as cassava mosaic and wheat rust, an underestimation of diseases, lack of crop diversity, inefficient production contingent upon market forces (e.g., cattle production based solely on grass when the price of corn is high). A major threat to distribution is reliance on petroleum. There are also political threats, including government instability, inadequate, and too few, public dollars going toward agricultural research. Economic threats include speculation on food prices and ever-changing market forces.

Other threats to food security include the psychology of the consumer; that is, their taste preferences, their unwillingness to purchase more expensive foods, resistance to Genetically Modified Organisms, and an overall dissociation from food production. The psychology of the farmer is also involved. The team raised this question: how do you convince the farmer of ecosystem services benefits? For example, how do you persuade a farmer to invest money to begin growing a more sustainable crop when there are no financial incentives to change his current operations?

Each of these threats is compounded by rapid population growth—global food demand is expected to double by 2050—and climate change, which results in various problems such as too little or too much rain. In an effort to mitigate climate change, biofuel development is an emerging industry. But biofuel production often results in competition for land and resources that can negatively impact food security because biofuel often comes from grain.

The team outlined opportunities for mitigating threats and improving food security. These opportunities included halting the transmission of disease, moving agriculture closer to urban populations, encouraging Community Supported Agriculture (CSAs), biofortification, and diversification.

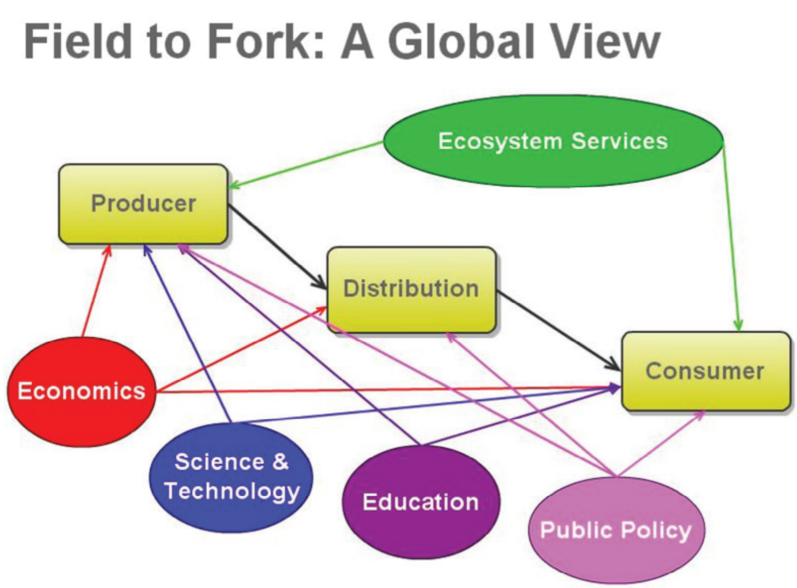
Each of these opportunities represents the beginning of solutions to the food security problem.

For example, moving greenbelt diversity closer to urban populations would reduce the distance between food production and the consumer. This would improve ecosystem services of land that may be blighted in urban areas, reduce the carbon footprint of that food system, improve water infiltration and storm water control, produce nutritious food, and potentially improve soil quality.

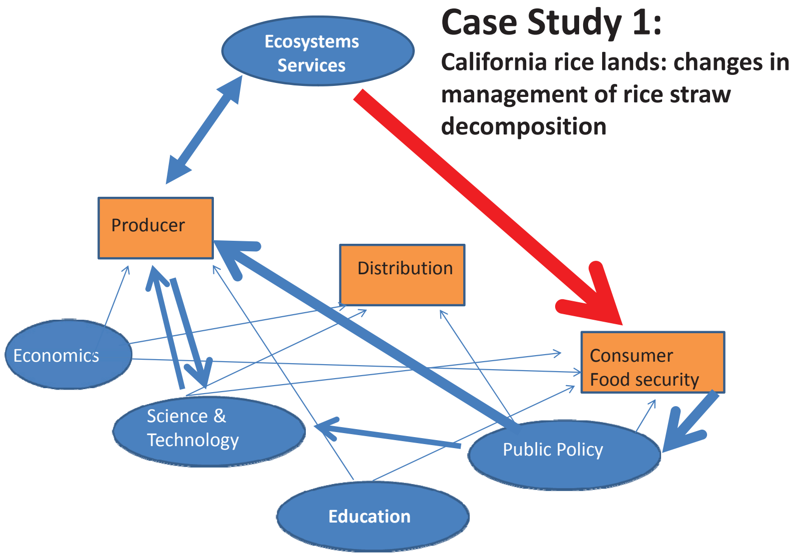
But the team readily agreed that these opportunities must be place-specific. Broad solutions would not suffice because food security needs and agricultural goals differ geographically.

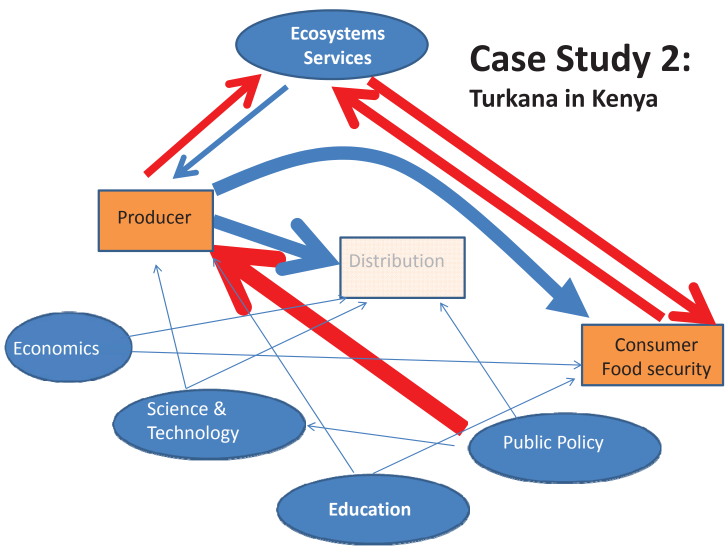
Eliminating Threats: Finding Place-Based Solutions

In lieu of broad solutions the team began to create a graph that illustrates the connections between the food system (e.g., producer, distribution, and consumer) and entities that directly impact the system; that is, economics, science and technology, education, public policy, and ecosystem services. This gave the team the framework required to conceptualize linkages and develop solutions.



Once a base food system illustration was created, the team then sought to illustrate the same processes within two different case studies. With case study-specific illustrations, the team was able to isolate the strongest connections in specific locations, thereby identifying which changes might have the greatest impact.





After brainstorming food system improvements for each case study, the team was able to isolate three solutions that encompass major issues across food systems. First, make agriculture production more multifunctional and resilient, which includes farm level services, off-farm services (e.g., distribution), and integration of production practices as a system. Second, develop missing indices of environmental factors. For example, develop an ecosystems services footprint, much like the current carbon footprint, to measure impact on ecosystem services. Finally, change the nature of the incentive system. The team suggested changing subsidies to encompass ecosystem services and nutrient density through taxes, tax exemptions, and penalties.

Future Research and Improvements

With almost every solution offered, the team was able to identify a knowledge gap that impedes progress, requiring further research and policymaking. Some of the important gaps in science and technology identified by the group include a way to quantify ecosystem services in the context of food security, an understanding of how to influence the incentive structure through policy changes, the development of new technologies to meet projected food and nutrition needs in a changing global climate, place-based adaptation of technologies, an understanding and incorporation of local knowledge on agrobiodiversity to increase food security, and other transformational technologies.

The team concluded that with further research, solutions to improve long-term food security could be developed and the subsequent benefits to society would include enhanced human potential and quality of life, environmental conservation, and human conflict reduction. These benefits represent a large step toward enhanced ecosystem services and ecological sustainability.

IDR Team Summary 6

Develop appropriate methods to accurately value natural capital and ecosystem services.

CHALLENGE SUMMARY

Ecosystems provide a wide array of goods and services of value to people ("ecosystem services"). Some ecosystem services lead to the provision of marketed commodities (e.g., fish, timber) but most ecosystem services do not flow through markets (e.g., provision of clean water, habitat for species). There is little direct signal of the importance of these nonmarketed ecosystem services and little incentive to manage ecosystems to maintain natural capital necessary for the sustained provision of ecosystem services. One way to give incentives for sustained provision is to assess the value of ecosystem services in a common monetary metric and provide payments for provision. Valuing ecosystem services requires both the ability to quantify the amount of a service produced and methods of nonmarket valuation. Economists have developed a range of methods of nonmarket valuation that can be applied to value ecosystem services. Critics of the economic approach raise questions about the incompatibility with the economic approach to value services that are centered on human well-being and the intrinsic value of nature. Critics also question whether the aesthetic beauty of a landscape or the continued existence of a species can or should be measured in monetary terms. These debates raise fundamental questions about our understanding of the contribution of ecosystem processes to human well-being and whether we can accurately gauge, in either a quantitative or qualitative manner, the relative importance of various ecosystem services.

Key Questions

- Should we attempt to express ecosystem processes in terms of ecosystem services? Can we accurately assess the provision of ecosystem services?
- At the global and regional level how can ecosystem service delivery be assessed through time utilizing remote sensing technology?
- Should we attempt to estimate monetary values for ecosystem services and natural capital? Can or should all values of nature be measured in monetary terms? Is it possible to accurately measure such values as aesthetic beauty and the existence of species in monetary terms that can be compared to the value of crop or timber production?
- What is the relationship between the value of natural capital and the value of ecosystem services?
- What are the main difficulties involved in estimating monetary values for ecosystem services and natural capital?
- What are the main methods used by economists to value ecosystem services and natural capital? What are the strengths and limitations of these methods?
- What are the main methods used by other social scientists besides economists to value ecosystem services and natural capital? Are the methodological approaches of economists and other social scientists consistent, conflicting, or nonoverlapping?
- Because of the difficulty of valuing some ecosystem services, the U.S. Office of Management and Budget recommends quantifying benefits that can be quantified, monetizing benefits that can be monetized, and giving a qualitative description of benefits than can be neither monetized nor quantified. Do you think that doing so will mean that ecosystem services that are only qualitatively described will be taken less seriously than those that are given monetary or quantitative values? In other words, is there a bias against evidence that is not based on "hard" numbers?
- How should we weight benefits from ecosystem services to different groups? If harm from loss of services accrues to poor or disadvantages groups should that be weighed differently than loss of services to wealthy groups?
- How can we design a reporting system for natural capital that is equivalent to measures of manufactured capital and other forms of assets to derive a measure of inclusive wealth? How can we design a reporting system for ecosystem services and incorporate these values into national income accounting? Can these reports be updated annually and reported at the country, state, and national levels, analogous to and supportive of the FAOstat on agricultural commodities.

- Can markets for regulating services (erosion control, local climate control, disease control, etc.) be developed?

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Because of the popularity of this topic, three groups explored this subject. Please be sure to review each write-up, which immediately follow this one.

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IDR TEAM SUMMARY—GROUP 6A

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IDR Team 6A was asked to develop appropriate methods to accurately value natural capital and ecosystem services. Human population growth and the expanding material appetites of many societies are straining the world's natural resources and ecosystems. Taking a full account of the services we derive from those systems could help reveal nature's unappreciated benefits to humanity and inform choices that will secure the long-term viability of ecosystems.

While many ecosystems provide us with tangible benefits, such as timber and seafood, the pricing of these benefits—or ecosystem services—may not reflect the total value of the ecosystems that produced them. Other ecosystem services, such as seed dispersal, nutrient cycling, and water purification are typically not reflected in markets at all.

The team faced well-trod ground. There have been many attempts to incorporate the qualitative or quantitative values of ecosystem services into decision-making. Additionally, debates about whether or not it is appropriate to assign dollar values to ecosystem services have been waged for decades.

With economists, ecologists, an urban planner, and two industry representatives in the group, IDR Team 6A was well-equipped to address the problem of valuing ecosystem services. Then the question became, with so many existing frameworks for valuing ecosystem services, what could IDR Team 6A contribute?

The Ecosystem of Valuation Methods

The team developed a thought exercise that exposed the diversity and specificity of possible pathways to arrive at the "how" of valuing ecosystem services.

What is the structure and function of systems being valued?

The team agreed that this is the foundation for valuing ecosystem services. Gaps in spatial and temporal understanding of a system could begin as small uncertainties, but become magnified as ecosystem data are combined with uncertainties in valuations. Also, ecological studies are generally not tailored to meet the needs of the valuation methods that economists use.

An important ecosystem consideration is that some ecosystem services are derived from disturbance of ecosystems by human activities, and that sometimes the most altered and exploited ecosystems provide a great deal of service in the short term. An example is pastoral land compared to pristine forest. How can we compare the carbon sequestration and erosion control benefits of the forest with the food production and aesthetic benefits that people receive from mixed woodland and agricultural areas?

Why they are being valued?

Is a business trying to weigh tradeoffs in locations for building a new plant, is the government trying to determine how wetlands should be remediated, or is a nonprofit trying to calculate a global value of a service to make a statement? The purpose of the valuation will help determine which methods to apply.

Who is interested in the information?

The valuation may be dependent on the stakeholder group. A beachfront landowner will value the services from his or her property differently than the rest of the community will value the property's flood protection services.

These considerations create context for how ecosystems services should be valued and demonstrate that IDR Team 6A's challenge went beyond methodological concerns. To eliminate some of the dizzying array of options, the team focused on quantitative valuation of ecosystem services and elected not to tackle qualitative valuation problems.

Within the world of quantitative valuation, there are still a number of methods to consider, including the market price method, productivity method, hedonic pricing method, travel cost method, substitute cost method, contingent value method, contingent choice method, and benefit transfer method.

Improving Benefit Transfer

IDR Team 6A elected to focus on benefit transfer based on the method's familiarity to the group and its ongoing application by government. Given the specificity and diversity of ecosystem services and applications, it would be ideal to quantify and value services for each situation, but this is not practical. So, benefit transfer is used to generalize valuation estimates and apply them across locations and time. For example, agencies such as the U.S. Environmental Protection Agency use it to assess the benefits and costs of federal environmental regulation when time and money limit site-specific measurements.

The team then identified ways in which benefits transfer could be improved. According to team members, benefits transfer is subject to large inaccuracies and validity concerns. The economists in the room also noted that effort going into valuation studies has been declining over time and new technologies and models should be considered to improve value transfers.

An Alliance Between Social Science and Natural Science

The team set out to answer the question: "How can natural scientists and social scientists improve the validity and accuracy of benefits transfer?" Specifically, they wanted to address the following challenges to the accuracy of benefit transfers:

- Ecosystem knowledge is incomplete.
- Temporal and spatial scales vary.
- Valuation of ecosystem services is context dependent.
- Source studies establishing ecosystem services values may be inadequate.
- What matters to the affected population is site specific.
- There is a vast number and variety of ecosystem services.

The group considered the possibility of standardized methods for valuing ecosystem services but decided that would be intractable. They settled on a framework that centers on ecosystem service indicators to improve benefits transfers. Indicators would translate what ecologists know is important for ecosystem services into what stakeholders care about. For example, the public may not care about lake sediment levels, but they may value the ability to see their feet when they walk into the lake to swim. They may be willing to drive farther to use a lake where they can see their feet, versus one where they cannot.

The team identified a number of approaches to address the problem of valuing ecosystem services and decided that the approaches should be implemented simultaneously to produce more reliable ecosystem valuations. First, primary valuation estimates at the source should continue, because they are integral to improving benefit transfers. Ecological models should continue to be integrated into economic valuations. Nonmonetary measures of value such as tradeoffs and thresholds should also be considered as options when monetary valuation is not appropriate for the decision-making context.

Developing and Applying Ecosystem Service Indicators

IDR Team 6A's final product was a conceptual, iterative framework for developing ecosystem service indicators that could be used for more reliable benefit transfers between sites (Figure 1). The general framework relies on the natural sciences to apply ecological models that ingest site-specific data to generate indicators of ecosystem services. Those indicators will act as proxies to inform economic valuations of ecosystem services which account for the values and specificity of interests of the affected populations.

The team used ecosystem services in a generalized forest to think through the application of an ecosystem service indictor derived from one system (Figure 2). Forests provide services of carbon sequestration, water quality regulation, aesthetics, cultural value, temperature regulation, recre-

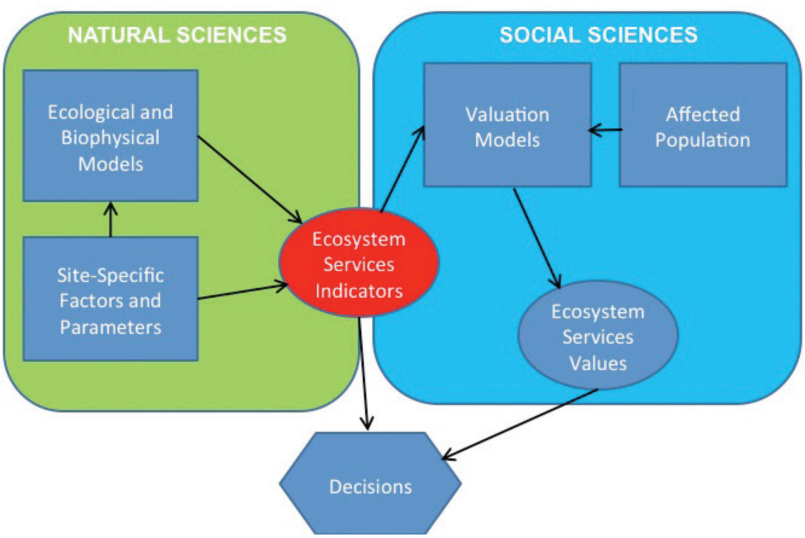

FIGURE 1

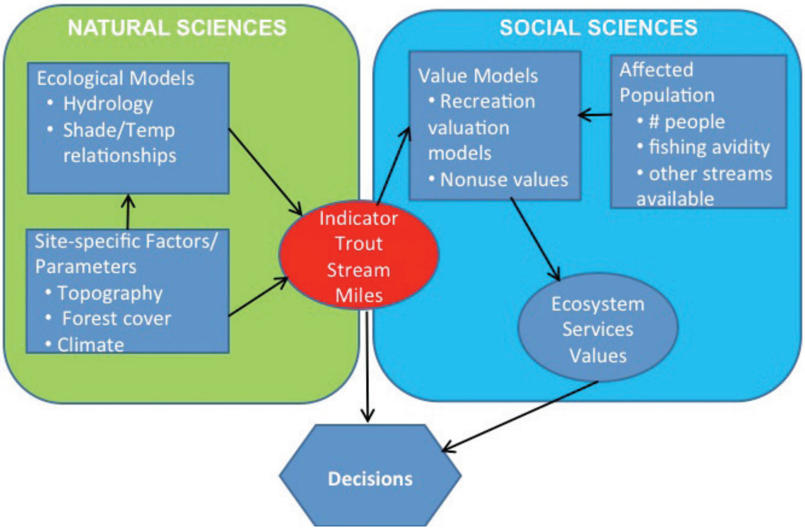

FIGURE 2

ational value, and habitat, among others. There are many ways to measure these services but it is generally not practical when performing a benefit transfer. Therefore, could one measure represent many ecosystem services?

The group selected the indicator "trout stream miles" as a known forest indicator that could be applied in ecosystems that are relevant as trout habitat. Trout habitat requirements could become a proxy for other ecosystem services. Trout depend on the temperature regulation afforded by forest cover over streams; they depend on aquatic invertebrates, which are intolerant of polluted water and they depend on clear water that is not contaminated with sediment from runoff. If you buy the ecosystem service indicator of trout stream miles, you get at least three or four more indicators free.

The group concluded with two main science questions that need to be answered to implement their framework. First, how will we know if indicators are working in different contexts such as varied scales of space and time or at different levels of governance? For example, could indicators developed in one country be applied in another? The team's discussion ended with the open question of how natural and physical scientists can develop ecosystem service indicators that will be transferrable, accurate and useful.

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IDR TEAM SUMMARY—GROUP 6B

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IDR Team 6B was asked to create a quantitative valuation system for ecosystem services. The team framed its challenge as a way of arriving at a larger, more consumer-oriented goal: Correcting the prices shoppers see in the grocery store.

The cheapest shrimp shoppers can find in the seafood section may well extract a high cost on the environment where it was harvested. If trees were cleared from a mangrove swamp to make way for the farm where the shrimp were grown, then people living near the mangroves would have lost an important tool for fighting erosion—hence, lost the mangroves as a source of ecosystem services. If the shrimp farm put antibiotics or high-nutrient feed into its water, then local populations would suffer a reduction in water quality. Yet those costs, which are real but difficult to quantify in dollars, do not show up in the final store price of the shrimp that most consumers see. At the 2011 National Academies Keck *Futures Initiative* Conference on Ecosystem Services, IDR Team 6B was especially interested in putting quantitative values on ecosystem services such as erosion protection and water quality, in the hope that such values might translate into fuller, truer prices on shrimp or any other consumable item.

The team was composed of ecologists, economists, and a computer scientist. The group reviewed what is being done now to give values to ecosystem services, then discussed what additional components ecologists wished valuations could include, such as the value of biodiversity or the social cost of environmental degradation to the people who live near exploited ecosystems. Ultimately, it outlined what is needed for a next-generation mathematical model that would put quantitative values on ecosystem services. Because of the state of current research, such a model is not yet possible, but IDR Team 6B's outline points to what research is needed.

If IDR Team 6B's model were implemented, one of its greatest benefits would be to inform everyday shoppers. More accurate ecosystem values might get incorporated into the global market. Therefore, more environmentally damaging goods would cost more, while more environmentally friendly goods would cost less. Right now, people often choose to buy less expensive, more environmentally damaging goods but have no idea that they are doing so. Only if goods are consistently priced to reflect full environmental costs, will the public know the connection between price and its relation to ecosystems.

How Ecosystems Are Valued Now

One way that economists put price tags on ecosystems now is by conducting primary surveys, in which a large sample of people are asked how much they would pay for the protection of ecosystem services such as water filtration through a forest or storm protection from wetlands. The researchers estimate the value of each service through the aggregated answers from everyone they survey.

These valuations have several weaknesses. Most people are not exactly practiced at trying to buy anything as large and valuable as an ecosystem service. Also, people's decisions about their money don't always follow rational economic models, and valuing ecosystem services is no exception.

Primary surveys are a static snapshot of an ecosystem service's worth at a moment in time. Such surveys are poor at predicting what would happen to a service's value if its ecosystem were to suffer further degradation or to improve under protection or restoration efforts. This approach also has a hard time accounting for how changes in one ecosystem service affect other ecosystem services, an important facet in an ecosystem's overall functioning.

Beyond primary surveys, different research groups and consulting companies have created different computer programs and surveying methods to put quantitative values on ecosystem services. Each group's program may give a different value for the same ecosystem service, however, which industry groups and policymakers find frustrating.

Benefit transfer approaches involve taking valuation estimates derived for one ecosystem and extrapolating to apply those estimates to another area. For instance, if a valuation study finds that a forest in Washington State is worth $100 per acre for carbon sequestration, watershed, and habitat services, then valuing a similar forest in Oregon using benefit transfer methodology would use the same parameter of $100 per acre. This saves time and money since primary research is not necessary, but a potential weakness is that the ecosystem to be valued using benefit transfer methods is not similar enough to any ecosystems for which we already have values.

A Better Model

IDR Team 6B's imagined model would amend many of primary surveys' weaknesses. It would be easy to tweak the model whenever conditions in the ecosystem changed. The model would include equations to represent the relationships between people and environmental services, and the relationships between environmental services.

Team members decided to use shrimp farming in mangrove habitats to demonstrate their idea. If someone wanted to clear some mangroves to make a shrimp farm now, the price of doing so would just be the price of the land, equipment, and labor required to build the farm. The farmer would not pay for the native fish habitat, storm protection, water filtering, and carbon sequestering abilities that would vanish with the cleared trees.

A better model of the price of the shrimp farm would allow the modeler to set constraints. The constraints would be ecosystem services that local residents want to maintain at a certain level: A certain native fish population dynamic, for example, or certain degree of storm protection. Within those constraints, the model would maximize the shrimp harvest for the farmer. As another example, a tourist company could use the model to maximize the number and hours of tours they gave, while keeping within constraints set by local residents to protect ecosystems.

The idea of creating a fuller, truer price for goods, including the ecosystem damage their production causes, is not new. What IDR Team 6B's model adds, team members say, is the inclusion of constraints. Team members also hope to apply their model to ecosystems all over the world and hope the outputs from the model would be in the same units, so that people could compare what is happening in different ecosystems.

Right now, it is not possible to create the model IDR Team 6B envisions because there is not enough research to write all the equations needed.

Team members identified research questions in various fields that would fill the gaps. Researchers need more ecological data to better characterize how individual constraints affect the overall system and how ecosystem services affect one another. Researchers who work on valuing services in similar ecosystems, such as mangroves in Central America, Asia, and Africa, should share their results. More computer scientists are needed to work on ecosystem services, to create new, better models.

Better Pricing from a Better Model

Even if researchers did create a better model for valuing ecosystems, there is still a leap between accurate modeling and seeing prices in stores that reflect ecosystem damage or protection. Prices from the ideal model could inform regulators who could require companies, such as a shrimp farming business or a tourism outfit, to absorb more of the price of the environmental damage they cause. "Correct" or more accurate prices could go into the Environmental Impact Assessments that construction companies need to file before they build. Risk rating agencies and insurance companies could look at a database of more accurate pricing and levy higher premiums on environmentally pricier projects.

If these adjustments still don't bring prices in stores close enough to the theoretical model price, stores could still post model price information, so consumers know the true price of what they're shopping for. That information may help some shoppers change their habits, though more behavioral studies are needed to find how people will really react to seeing valuations of ecosystem services.

Beyond Valuation

Valuation is one of many ways of encouraging the protection of ecosystem services, and all ways are useful in different situations because different people respond to different strategies.

If IDR Team 6B's model successfully made the leap to actually influence prices in stores, it would target consumers looking for the best bargains they can find. If not, having accurately modeled valuations would be useful with business people and some policymakers, who might respond best to monetary values.

With other people, appealing to their emotions or environmental interests might play a role. Cultural changes that make environmentally friendly decisions, such as buying local produce or fair trade products, socially valuable would be necessary.

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- Maria Pellegrini, W.M. Keck Foundation
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IDR TEAM SUMMARY—GROUP 6C

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The problem IDR Team 6C set out to solve was creating a functional and accurate valuation system for ecosystem services. The team focused most of its discussion around one reason that valuation can be hard: some services are easier to quantify than others.

For example, there is a park in Northern Ontario that hardly anybody visits. It's remote, beautiful, and isolated. But, is it valuable?

Valuing the ecosystems services of that park in Northern Ontario is hard. The park keeps a watershed clean, but since no one lives nearby the immediate economic value is minimal. The global service it provides—carbon sequestration—is small in comparison with the planet, and yet it does have some value. The ecosystem services that the park really confers are, as group 6C put it, somewhat squishy. They are cultural and aesthetic. People value simply knowing that there are pristine ecosystems out there in the world, even if they never visit them. People have spiritual connections to land that are hard to quantify.

This divide between the easily quantifiable components of ecosystem services, and those that are more qualitative—or squishier—is the problem that group 6C debated. How do economists and ecologists construct a system of ecosystem valuation that takes into account and properly weights, both easily quantifiable variables like food output or carbon sequestration and the more qualitative variables like the value of leaving some places on Earth uncompromised by human use?

Here's another example that caught Team 6C's attention: Recently, a photograph of a Brazilian chief crying whipped through a number of online news outlets and blogs. The caption on the picture explains that Chief Raoni was crying because the Brazilian government had just approved a dam that would flood 400,000 hectares of land and displace 40,000 indigenous people. It has since come out that Chief Raoni was not actually crying over the dam, but rather crying over seeing someone he had not seen in a very long time, as is custom for his tribe. (He did say, however, that he was extremely angry and distraught about the dam).

The Problem

The tradeoffs that the Brazilian government considered to make the decision to build the dam are a perfect example of the challenge of integrating quantitative and qualitative ecosystem services. On the one hand, the government can calculate how much power the dam would produce, and how much it would cost. It can measure the amount of land lost, and the amount of food that would not be produced. It has a much harder time measuring the value of something like Chief Raoni's tribe, or the value to someone of just knowing that the there are pristine ecosystems in the world.

The basic distinction between squishy and non-squishy variables seemed to be Quantification. The absence of quantification leaves a set of characteristics that affect the ways economists characterize services that ecosystems provide, how they might make decisions about them, how easily those services are traded, and so on. The squishier a service gets, the more necessary it is to have stakeholder participation and good communication in order to give it a value.

Take, for example, two very different cases of flood plain management: The Charles River in Boston and Napa Valley in California. In the case of the Charles River, the Army Corps of Engineers, looking for a way to manage flooding did a very straightforward cost-benefit analysis, and figured out that restoring the flood plain and river system was the most cost effective way to go. From their expert knowledge and valuation they went ahead and restored the area. In Napa Valley, the restoration of floodplains came about from a grassroots movement that dealt more with regional pride and aesthetics. The community organized to restore the flood plain. While the benefits certainly included flood protection, that was not the primary driving force for the project's approval.

In these two cases we see a similar outcome—the restoration of a floodplain—but with very different histories. The Charles River case was very quantitative, expert driven and top down. The situation in Napa Valley was based on local consensus, and came from the ground up. One was, as the chart says, less squishy, and the other was more squishy. That's the kind of valuation that IDR Team 6C really focused on.

Challenges to Participation

So how does a government or agency measure those squishy values when making decisions about ecosystems? There are some traditional economic tools—like surveying people and asking them a set of questions about what they think is important and what is less so. And with more subjective things like cultural value and spiritual importance—the importance that an indigenous community places on the ecosystem as part of the local belief system—getting stakeholders involved is often the only way to get a real sense for that value.

But getting large-scale stakeholder participation isn't easy. Identifying which stakeholders should participate can take time, as can designing a valid questionnaire. On the other side, the cost of participation by stakeholders can be higher than they might be willing to incur—while it might seem easy to get people to take a simple questionnaire, the response rates for many surveys is very low. And to get valuable information, you often have to take more than a few minutes of people's time, and ask them to think about several situations they have never encountered before. And often those stakeholders aren't given a process for conferring with one another about their decisions.

Therein lies the true problem that IDR Team 6C tackled: to achieve a valuation based on more qualitative ecosystem services requires more citizen participation and that participation can be difficult to effectively and efficiently facilitate.

Gaming for the Greater Good

What the IDR Team settled on was a gaming approach. The basic premise was to harness the power of interactive games to learn more about what people really think about ecosystem services, and what value they place on services that cannot be readily quantified.

Within the gaming structure, IDR Team 6C saw several advantages. First, researchers could present gamers with multiple scenarios that are easy to understand. Unlike standard surveys, in which people are asked to imagine a scenario they've never encountered, the game could actually present players with various scenarios in a way they could move around in and explore. This would make their responses to those scenarios far more accurate. This use of game-playing would also allow economists to perform conjoint analysis on the various aspects of those ecosystem services tradeoffs to figure out which individual characteristics are most valuable to people playing the game. The approach lends itself to valuation of ecosystem services using both monetary and nonmonetary metrics. Monetary values for services might be associated with ecosystem goods and services by requiring players to make tradeoffs among alternative outcomes that have monetary consequences in terms of taxes, job opportunities, or economic outputs. Further, the gaming could shortcut the process of identifying ways to characterize ecosystem services that are meaningful to people to improve results from contingent valuation surveys that are used to monetize squishy outcomes.

Second, one could design the game that would require players to communicate with one another to come to a decision about the ecosystem they are interested in protecting or changing. Those interactions could be useful for economists to mine information about the way people think things should be, and how they justify their choices. When players have to discuss their decisions, economists no longer have to guess why players are acting in one way or another.

Third, games can greatly reduce the cost of participation. Often, the most vocal citizens on a subject are those who can afford the time and money to attend meetings and calling into their representatives. Sometimes, entire segments of the community are completely overlooked because they don't have access or don't know how to participate in the conversation about their ecosystems. Games could allow these overlooked stakeholders to participate more than they normally might. Rather than having to come to a town hall meeting, or call up a representative, stakeholders could play from their homes. Parents could put their children to bed and log on. People who don't have the time, or don't feel strongly enough to attend public meetings could suddenly be provided a voice in the decision making process.

Of course, gaming has its own issues, both logistic and conceptual. However, it is clear from present day experience that there are already a number of online games that can be used to obtain data about human behavior and values, so it is a reasonable approach to explore.

IDR Team Summary 7

Design a federal policy to maintain or improve natural capital and ecosystem services within the United States, including measuring and documenting the effectiveness of the policy.

CHALLENGE SUMMARY

The renewable wealth of the United States resides in its people, land, and waters. The capacity to generate ecosystem services is a component of natural capital, which is in turn a component of renewable wealth. Natural capital is related to the capacity of a region to provide food, fiber, pharmaceuticals, potable water and other goods; maintain water and air quality, soil fertility, and other characteristics of a healthful environment; and present people with educational, recreational, and spiritual values of nature. A given area of landscape or seascape yields many ecosystem services, and the aggregate yield of ecosystem services depends on management by people.

Yet natural capital is not monitored, unlike indices of financial and social capital (stock markets, inflation, T-bill yields, unemployment, educational status, etc.). Regulatory ecosystem services (which maintain water and air quality, soil fertility, and other characteristics of a healthful environment) and a number of provisioning and cultural ecosystem services are not marketed and rarely measured. However some ecosystem services such as food production and recreational use are marketed and measured.

"In the beginning, the world was one." Now, however, the responsibility for natural capital, or the ecosystem services it generates, is balkanized among federal agencies, as well as among federal, state, and local jurisdictions. For example at the federal level, one agency deals with agricultural and forestry yields and soil conservation; another deals with water infiltration and runoff; another with fish and wildlife; another with water and air quality in relation to human health. And many ecosystem services and important elements of natural capital fall between the cracks in U.S. legislation and policy—there is no mandate, for example, to monitor and maintain ecosystem services such as pollination, natural hazard regulation, pest regulation, or aesthetic values.

Just as the nation developed policy and legislative frameworks for environmental issues such as water and air quality and endangered species in response to growing scientific and public understanding of the importance of these issues, it may now be time to develop a policy and legislative framework for the more comprehensive management of natural capital and ecosystem services.

Key Questions

- What would be the goal of a U.S. policy for natural capital and ecosystem services? (In considering this and the following questions, be sure to include regulating ecosystem services as aspects of natural capital that are essential for sustained flows of all relevant ecosystem services.)
- How should a new U.S. policy or legislative framework integrate, replace, or be integrated into the many existing laws and policies that guide various aspects of ecosystem service management?
- What would key elements of a U.S. policy (considering both actions that federal agencies could take within their existing mandates and needs for new legislation) consist of, particularly with respect to (a) assessment of the status of ecosystem services; (b) management; (c) monitoring; (d) accounting; and, (e) public communication and education? With respect to the assessment needs, no federal policy provides for assessment of ecosystem services or natural capital. How can this be done?
- How can the effectiveness of policy for ecosystem services be measured? How can we improve policy based on iterative assessments of ecosystem services?

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Because of the popularity of this topic, two groups explored this subject. Please be sure to review the other write-up, which immediately follows this one.

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IDR TEAM SUMMARY—GROUP 7A

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IDR Team 7A was asked to develop an effective federal policy aimed at maintaining or improving the legacy of the nation's ecosystems for future generations. Earth's ecosystems—from rainforests to deserts, from marshes to mountaintops—have been formed over millions of years of geological changes and biological evolution. The diverse ecosystems provide shelter to their plant and animal inhabitants while providing us with resources and services that sustain and enrich our lives. Some resources like food, water, and minerals can be priced in dollars; others, including the value of a forest for its beauty, the aesthetics of a waterfall, or the preservation of pristine places on Earth are intangible. Ecosystem services refer to the entire gamut of benefits that ecosystems provide, both tangible and intangible.

Task at Hand

As the world population continues its super-exponential growth, a greater need for human use of physical space is coupled to an ever-increasing demand for basic necessities like food and water, in addition to the goods that have come to define the comforts of modern human life. As society encroaches upon ecosystems to satisfy these needs, the cost-benefit analysis that underlies such actions is so heavily skewed toward tangible factors, that intangible services meted out by the ecosystems are unspoken for.

This limited system of valuation is flawed. Given the long-term contributions of ecosystems to human experience, it is important to not only consider the immediate impacts of our actions, but also their legacy for the future. Federal regulation of the environment through the Clean Air Act, Clean Water Act, Endangered Species Act to name a few, are geared to promote human health and biodiversity but not necessarily the health of our ecosystems. As such, there is a need to revamp our federal policies to protect our natural capital.

Redefining the Task

Just as the fiscal policy of the government is designed to increase the GDP and expand the economy, the team recommended that environmental policies ensure an overall net increase of natural capital within the national balance sheets. In other words, it should be the objective of the federal government to identify and rehabilitate strained ecosystems, strategize to maintain or enhance the ones currently in use and prevent the degradation of others.

With near 10% unemployment, two wars, and the possibility of a double-dip recession preoccupying an acrimoniously partisan Congress, shepherding a new piece of environmental legislation through the Congress would be a herculean task. Therefore, the team focused its efforts on designing a conceptual framework to guide a federal policy over a long term, while also recommending immediate measures within the purview of existing mandates of federal regulatory agencies, sidestepping the need for immediate legislative action.

Federal Policy

Given the great number of unknowns concerning ecosystem characterization and valuation, the team chose to lay out a logical framework for infrastructure building central to an effective policy. The best strategy for a visionary federal policy would involve identification and measurement of key variables, training of personnel, and effective implementation of the policy.

Building the infrastructure

For successful management, it is essential to keep a regular tab on the assets. Thus, in agreement with the 2011 President's Council of Advisors on Science and Technology (PCAST) report, the IDR team recommended instituting a quadrennial assessment of the state of the nation's ecosystems. This would entail the characterization of ecosystem health in terms of measurable parameters. A scholarly identification of such parameters forms the backbone of any such evaluation. If such parameters have not yet been identified, it is essential to fund academic research to do so.

National ecosystem data portal

Once these parameters have been identified, it is essential to develop tools for efficient data collection and analysis. Currently, data regarding various aspects of any ecosystem are being collected by different agencies. For instance, the Environmental Protection Agency (EPA) collects data on air and water quality while the Department of Agriculture (DOA) collects data on soil composition. However, these data are not shared across agencies, and the analytical tools to link data and extract information regarding the health of our ecosystems are lacking. Thus, the team recommended creation of a national repository, where all information pertaining to an ecosystem, whether gathered by a local or a national agency, can be entered. There is a need for the development of an analysis system to interchangeably compare the costs of various components of an ecosystem in terms of their benefits and incorporating this information with accounting decisions for any projects. The interoperability of this interagency data portal would be a key requirement for adoption of sound practices that analyze complex data and include it in the rubric of federal decision-making.

Interagency training center

The team strongly felt the need to break down the governmental stove piping and require regulatory agencies to share responsibility and make management decision collectively. Given the lack of incentives for agencies to engage in a dialogue, the team recommended creation of an interagency training center to cultivate knowledgeable, skilled, and capable managers from multiple agencies as a vehicle for ensuring better understanding of ecosystems as a whole. With a goal to promote synergy, cooperation, and efficiency as these agencies work together, the best practices would be shared across agencies for the implementation of cost-effective actions.

Customize targets

Data collection is not the goal, ecosystem preservation is. The team concluded that the need to set identifiable environmental goals is crucial for ensuring sustainable ecosystem services. Academic research including modeling studies need to be commissioned to identify clear endpoints for the various ecosystems. Rather than rigid strategies like total maximum daily loads (TMDL) for water pollution, the team realized that endpoints would require adaptive management strategies, which would need to be determined for each ecosystem on a case-by-case basis. It is not expected that the ecosystems will be untouched, rather, that the final action would be taken to maximize ecosystem service.

Were a new infrastructure for analysis and management to be put in place, it would be the responsibility for the government to pass legislation aimed at codifying updated practices at the regulatory agencies and employing adaptive management strategies to ensure timely response to human actions. Evaluation of current tax subsidies while accounting for the benefits from ecosystems is essential in order to ascertain whether existing tax policy is hurting ecosystems. Adoption of ecosystem centric practices within governmental bodies like Securities Exchange Commission would set the tone for businesses to adopt similar practices.

Recommendations for Immediate Action

In addition to the long-term goals of federal infrastructure development and Congressional action, the team made recommendations for immediate implementation by federal agencies like National Oceanic and Atmospheric Administration (NOAA), the EPA, and the DOA that already recognize the concept of ecosystem preservation and restoration. The Army Corps of Engineers, whose mandate is "*to restore significant ecosystem function,*" also plays a role here. Schemes such as mitigation and species banking, watershed management projects, as well as farmbill payment programs, currently at work at local, state, and national levels highlight regulatory agency efforts for maintaining ecosystem health.

What hinders the effectiveness of these efforts in achieving optimal solutions is the lack of proper targeting of resources. Absence of a framework to reward projects with best practices and of incentives to replicate these on a larger scale is another problem.

A clear example of ineffective resource management is the Conservation Reserve Program with an annual budget of $6 billion for payments to farmers as incentives to adopt environmentally friendly practices. Rather than recruiting farmers with land that can provide greatest net ecosystem service, CRP recruits the lowest bidder. Incentives are provided for adoption of practices irrespective of the final measurable benefits. Rather than ensuring healthy practices on land currently in use, CRP focuses on retired land.

CRP needs to identify ecosystems that would generate the most services and link payments to measurable outcomes. For example, it makes greater economic sense to ensure maintenance of wetlands in the Mississippi delta than paying a farmer in the desert to not use a tractor on a Wednesday.

Other immediate recommendations include

a. assigning engineers at NASA to design satellites with enhanced remote sensing abilities that can provide a real time account of the state of an ecosystem's health;

b. directing part of Federal Emergency Management Agency (FEMA) budget on disaster relief to preventive pilot projects including wetland preservation, as a buffer against flooding;

c. developing an interagency training center and data portal as outlined above;

d. implementing the findings of the PCAST 2011 report.

Summary

Given the academic consensus on the importance of the ecosystems as a critical part of our nation's present and future infrastructure, it was the recommendation of the IDR Team 7A to enable better environmental practices following a three step approach:

1. Lay the groundwork for comprehensive legislation to generate momentum within the civil service to make informed decisions.

2. Outline a national policy that would focus on adaptive management strategies.

3. Guide immediate actions by regulatory agencies to optimize decision-making based on tradeoffs between the benefits and consequences of human actions to ensure long-term benefits from ecosystems.

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IDR TEAM SUMMARY—GROUP 7B

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IDR Team 7B was asked to design a federal policy to maintain or improve natural capital and the benefits humankind receives from ecosystems within the United States, including measuring and documenting the effectiveness of this policy. The first action the team took was to analyze the group's strengths. The team, mostly composed of ecologists and biologists, decided that its purpose was to look for inspiration for protecting natural capital, develop a "do no harm" policy, and illustrate where ecosystems could make or have already made a difference in environmental quality.

These analyses led to a slight adjustment in the wording of the team challenge: Design federal policy to maintain or improve natural capital and ecosystem services within the United States, including that ecosystem services be integrated into decision making and that policy effectiveness be documented and measured.

Even with the revised wording, the team thought there are several challenges in this general task. The first challenge is defining natural capital, and then how would anyone determine the value of an ecosystem service or an improvement. Although there has been debate over the definition of ecosystem services and what the term entails, the group decided to accept the meaning that ecosystem services are the benefits humans receive from the natural processes that make up an ecosystem. These benefits include purified drinking water, food, climate regulation, pollination, and even spiritual or recreational benefits.

The second challenge centered around the policy aspect of the task and whether a new federal policy is needed and what the exact goal of the policy would be. The third, and probably most delicate challenge, was in how to handle tradeoffs among ecosystem services. Often an improvement in one area will result in a detriment to another, or refocusing improvement efforts from one area to another will result in harm.

What's the Problem?

To help the team tackle the task, the group first tried to define the problem. The issues surrounding the value of ecosystems are multifaceted, and each of the sides must be taken into account before a successful policy can be put into place. First and foremost, team members believed that it is necessary to know the current state of ecosystems. After that, one can address the knowledge problem. Among the general public, there is a lack of understanding of what ecosystems are and why they are so valuable. In order to effect change, the public, including legislators at all levels of government, need to understand the role ecosystems play in providing benefits that are important to human life and health.

The team also saw translation, institutional application, and communication as problems surrounding ecosystem services. Translation involves monitoring the ecosystems themselves and analyzing the accumulated data to determine the ecosystems' status. Using this information, scientists can better make informed tradeoffs to get the best overall value out of the ecosystems. Combining the knowledge of ecosystem services and the translation of data into useable decision making tools makes up the institutional application problem. Here, the knowledge and translation come together for use in policy development, implementation, and management on the appropriate scales. This is a tricky balancing act, requiring that the knowledge and data are firmly and clearly in place. The last problem, communication, refers to the communication to the public and to policy-makers. The team decided to put this issue aside for IDR Team 9 to handle.

All of these issues form a feedback loop that should be maintained for optimal understanding. One issue to consider independently, however, is that the relationship between these issues changes depending on which frame is taken, either by the scientists providing the information or the politicians acting on the data. The issue of ecosystem services maintenance can be viewed through a human-centric lens, one in which human benefit and well-being are focused on above all else. The other frame looks more at protecting resources and ecosystems because it's the morally right thing for humans to do. One team member pointed out that the relationship between human benefit and resource benefit is complex, since history has shown human well-being to continue to increase even as resources or ecosystem availability decreases.

How Will Policy Help?

At first, the team was skeptical new policies to regulate ecosystems would even be accepted, considering the current political climate which is averse to more regulatory policies and the introduction of a new policy would be a long term goal. This view led the team to look at current policies, analyzing whether or not they are helpful or if they could be adjusted to meet the ecosystem needs. Policies of other countries were also discussed, because ecosystems often cross borders and to truly protect all of the ecosystems that the United States enjoys, we will still need a global approach to ecosystem maintenance. Of all of the different avenues available for legal change in the United States, the team decided changes on multiple levels need to be made.

New federal and state policies, such as implementing a set of minimum standards to maintain the integrity of ecosystems, will help, but lower level incentives need to be in place to really bring about a change to current ecosystem management. For example, municipal bonds or tax codes could offer incentives to those doing their part to better local ecosystems. State-level incentives for other green infrastructure could be suggested. The federal government could encourage lower-level improvements in environmental policy by enforcing current laws, by encouraging comprehensive planning, and by offering subsidies and other incentives.

Passing a federal policy seems like a lofty goal, especially with so many unknowns to account for. One of the major aspects to be considered is the assessment of current ecosystems, though there is no policy currently in place for this. Because little is known about the current state of ecosystems, one of the only ways to create a policy in this area would be to create a broad yet ambitious plan. The hesitation is that perhaps the policy would have no effect because the lack of information available would mean little could be done to enforce the policy. One thing that scientists could do to help in this dilemma is to switch focus in research to look at the current states of ecosystems. The team thought that could help tremendously in what they called the "we don't know" battle.

Policy Recommendations

Even with the pessimism about a regulatory bill passing now, the team came up with a list of things to include in an ideal political world. The team's policy would contain sections addressing the following aspects: Assessment, management, monitoring, accounting, communication, and funding.

Under the assessment section, the policy should define the services and natural capital for a given social-ecological context, be realistic about what people can do and know, take a precautionary practice-based approach, be explicit about the range of actors involved, do not limit to native species, and set ecosystem services targets for restoration and improvement. These targets would set standards that everyone using a particular area would need to be aware of in order to maintain or improve the area and would include things like limits on hunting or fishing, water pollution, crop fertilization, or other human processes that can negatively impact an area. This section also gives scientists the green light to study more, addressing the "we don't know" battle.

The management clause would identify policy and other strategies to achieve the goals listed in the assessment clause. It could take into account private versus public land as well as freshwater, marine, and terrestrial systems. The main purpose of this clause is to say who exactly is responsible for which aspect of maintaining a specific part of an ecosystem or an area. It would require interagency cooperation, such as between the Environmental Protection Agency and the U.S. Corps of Engineers.

The third clause, monitoring, will measure the effectiveness of the policy and related actions by building in explicit targets. This is primarily a balance between the scientists and the government; scientists will look at the changes in monitored areas over time and compare those values with the values obtained before the policy started. If the values are better, showing that the different aspects of the ecosystem are healthier, then the policy succeeded in that case. The final three clauses, which were not fleshed out completely, deal with accounting, public education and communication, and funding to monitor and manage adaptively.

Based on these ideas, the team recommended that we actually implement a policy meeting these criteria. The team thinks that passing this law will integrate ecosystem services into current laws, create a demand for ecosystem services approaches and information, generate policy-relevant research, and lead to longer term institutional change at multiple scales of governance. We as a society will be more adaptive, handle uncertainty, and ensure provision of services if we do these things.

The team also recommended that a test site, like a case study, be done in managing an ecosystem service. This test might include changing the tax code or other benefits to those doing as suggested. A test site may provide more incentive to a larger policy implementation if all goes well. And if that policy is enacted, resulting in healthy ecosystems, that will lead to healthy communities and healthy economies, greatly benefiting society.

IDR Team Summary 8

Design a system for international trade that accounts for impacts on ecosystem services.

CHALLENGE SUMMARY

The goods moved from country to country in global trade are associated with changes in ecosystem services in both the selling and buying nations. For example, the United States exports a very large fraction of the soybeans and corn grain that it produces to other countries. The funds derived from this exchange helps the farmers and the national economy. However, there are disservices left behind that are uncompensated. A certain fraction of the fertilizers that went to produce the corn and soybeans end up in the Mississippi River and are related to the dead zone in the Gulf of Mexico. The country that buys the corn and soybeans can reduce the land they use for food, the water that is needed to produce it as well as the fertilizers and pesticides used that end up reducing the value of ecosystem services that could have been provided. A number of other cases of "virtual" or "embodied" ecosystem services have been analyzed. Nations with limited water supplies can purchase water-intensive commodities such as rice or cotton, and thereby shift the impact on freshwater ecosystem services to the seller. Studies of the carbon costs of crops generally show that mechanisms that shift food production from temperate to tropical farms decrease carbon storage. Countries that establish policies to protect forests do not save forest ecosystem services globally, because the supply of forest products merely shifts deforestation to other nations. In many cases, markets for ecosystem services are blind to the side effects of virtual or embodied ecosystem services.

The literature on trade in virtual or embodied ecosystem services is growing, and could be extended to a wider range of types of ecosystem services. However, there has not been comparable progress on policies and regulations to address the hidden costs of environmental damage associated with trade in ecosystem services. How can this complex, emerging and serious problem be addressed by policy makers and trade regulation organizations?

Key Questions

- How can we transparently monitor the full effects on ecosystem services of international trade?
- What policy instruments are available for accounting for virtual or embodied ecosystem services in international trade?
- What should be the goal of an international policy for managing virtual or embodied ecosystem services?
- How could a policy for virtual or embodied ecosystem services be integrated with existing structures that regulate international trade?
- If policies were established to address virtual or embodied ecosystem services in global trade, how could the effectiveness of those policies be assessed? How should such assessments feed back into the evolution of policies for global trade?

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IDR TEAM SUMMARY

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IDR Team 8 was asked to design a system for international trade that accounts for the economic impacts on ecosystem services. To address this challenge and identify areas for future work, they used palm oil production as a practical framework because it is particularly damaging to ecosystems rich in biodiversity and often spans multiple countries. Palm oil represents one of the few global commodities responsible for a large share of negative effects on ecosystems, thus a useful example for new policy.

The palm oil in a store-bought birthday cake in the United States, for example, is often farmed in a foreign, relatively poor, country on a large-scale palm plantation where a rainforest previously stood. Raw pulp is harvested from the palm tree fruit and shipped off to a second, often moderately wealthy, country where it is refined and processed in a smoke-spewing factory. On the last leg of its journey, the finished product is sent to the United States where it is added to cake mix and sold. The same international trade transactions also occur for palm oil that ends up in other foods, such as granola bars, ice cream, frozen pizzas, and candy, as well as other products such as in beauty products, biofuel.

Each time palm oil changes hands, the hidden costs of production are being traded as well. That palm plantation in the first country is replacing a biodiverse, functional ecosystem that once had pollinators, native plants and animals, carbon storage, and nutrient cycles. Now, in its place is a plantation with fertilizers, pesticides, topsoil run-off, and no place for a backwoods hike. When the second country receives the raw palm oil, it is importing a product while, perhaps unthinkingly, exporting the loss of ecosystem services. But the second country, which processes the oil, has also cleared an ecosystem to make way for a factory that puts out industrial waste. By the time the palm oil gets to the United States, the process has damaged a series of ecosystem services that are not factored into the transaction costs or the price of the birthday cake purchased at the supermarket.

Accounting for the Ecosystem Services that Count

In order to account for those lost ecosystem services, the team first grappled with the definition of 'services'. Generally, ecosystem services span the range of benefits that ecosystems can and do provide society. These include, but are not limited to, services such as cleaning water, easing floods, cycling nutrients, providing places for recreation and homes for pollinators that ensure that crops bear fruit.

Scientists have so far tried to account for the negative effects on ecosystem services by focusing on individual resources—proxies for overall ecosystem services. These include the amount of clean water, carbon sequestration, and nutrients such as phosphorus and nitrogen that are cycled or accumulated. But these resources are difficult to value since they're dependent upon each other. For instance, without nutrient cycling, there might not be successful vegetation that can store carbon. Thus, accounting for multiple services may involve counting proxies multiple times.

While considering the possibility of redundancy in placing a dollar value on ecosystem service proxies, the team also acknowledged the need to consider trade-offs. Disrupting some ecosystem services may be worthwhile in order to produce crops or meat, provide jobs for local communities, and establish an industry that will bolster the overall local economy.

These issues, which account for the importance of ecosystems on local and global scales, are new questions that will need to be addressed on a case-by-case basis. A policy of ecosystem service valuation will greatly increase the nature of policy regarding international trade of ecosystem services.

So, what are those possible policies?

With the uncertainty of how trade-offs could be assessed, the team interpreted "policy" loosely to include policies by governments, campaigns by nonprofits and other organizations, and mechanisms instituted in the private sector that would help account for or mitigate ecosystem service losses. In addition, with the compounding factors of different priorities from different governments, ecosystems, and social impacts, policies would likely not be a one-size-fits-all matter where win-win situations are always possible.

There is already a variety of mechanisms available that could start accounting for ecosystem services tied to traded goods. These include

- Taxes and subsidies: The government of a country importing palm oil could tax that transaction if the oil was coming from a country/company that isn't sustainably producing the oil. Likewise, the same government could provide subsidies for imports that are coming from responsibly produced oil.
- Market based instruments: Countries where palm oil is being made could allow quotas of individual ecosystem service proxies, such as carbon, and provide tradable credits for companies that don't reach their limits.
- Private sector activities: Companies producing palm oil can willingly institute their own policy to reduce ecosystem service loss.
- Financial pressures: International-banking agencies can alter a palm oil company's access to loans and credit in return for responsible environmental policy.
- Outreach programs: By having companies put labels on their products that boast that their palm oil came from a sustainable plantation, public awareness and purchasing trends could persuade companies to reduce their damage to ecosystems.

While these approaches provide a framework to start accounting for impacts on ecosystem services attached to goods that cross the globe, they still don't comprehensively account for individual ecosystem service costs and trade-offs. Moreover, some ecosystem service effects are felt at different time and space scales. For instance, palm oil plantations that provide work for local community members tomorrow, may contribute to greenhouse gas emissions that will affect generations years to come and reduce the biodiversity of a regional ecosystem.

A new mechanism to address valuing trade-offs in ecosystem services is to bundle them by valuing multiple proxies. In countries with palm plantations, the ecosystem services of the original rainforest could bundle the attraction of tourists to rainforests and a diversity of tropical wildlife.

Bundled ecosystem services can then be balanced or compared with contrasting aspects of ecosystem service impacts, such as the production of a commodity, in this case, palm oil.

Policies in Practice

How will regulators know that these policies account for or reduce the impacts on ecosystem services in the production of internationally traded palm oil? Governments, companies, or other international agencies will have to accurately measure and monitor the ecosystem service impacts on local and global scales. This requires some measuring tools that aren't developed yet. While scientists can continue to monitor proxies for local ecosystem services, as of yet there is no mechanism for measuring some ecosystem services on a global scale. IDR Team 8 suggested that part of this problem could be dealt with by setting up a system to monitor the effect on ecosystems throughout the supply chain, which can reassess cumulative ecosystem service effects of palm oil as it travels through the three countries.

Possible watchdogs and judges

While many institutions and structures, including the World Trade Organization, already exist to monitor trade, IDR Team 8 was uncertain whether current regulatory bodies could take on the new role of ecosystem service impact monitoring or if new entities need to be established. However, the team acknowledged that current national policy bodies could provide a starting point for monitoring impacts linked to trade.

When developed countries import any goods, they usually perform a risk assessment to determine if it's worth importing, rather than making the goods within its own borders. The risk assessment takes into account threats such as the likelihood that the trade will also import hitchhiking invasive species. The risk model could be expanded to include ecosystem damage and social impacts of production.

If, upon review of preexisting structures, no current institutions seem appropriate for coordinating and monitoring new policy, the team suggested the creation of an international institution to step in and launch global ecosystem service impact policies. One means by which to sustain a new institution would be for it to have authority of taxing global traders that were determined—using ecosystem service impact monitoring—to be "worst offenders." A worst offender classification would apply to companies that create particularly harmful effects on the ecosystem services. An example would be companies that clear out rainforests to make way for large-scale oil palm plantations, versus a company that repurposes land. The funds provided by this tax could also be invested, through international banking institutions, into companies that provide positive ecosystem service impacts.

Although many questions and unknowns remain about how exactly to monitor ecosystem service impacts that accrue during international trade, the IDR Team 8 agreed that the more countries committed to addressing the challenge, the better.

IDR Team Summary 9

Develop a program that increases the American public's appreciation of the basic principles of ecosystem services.

CHALLENGE SUMMARY

Political Scientist Jon Miller's research on scientific literacy suggests that less than one third of Americans know that DNA is a basic genetic building block of life (rather than the Drug and Narcotics Agency as suggested by some who were surveyed), and that about half know that the earth orbits around the sun (and not vice versa). If this is true, what is their level of appreciation about the importance of pollination to human nutrition and food supply, or the value of other ecosystem services to human well-being?

Many people understand that degradation of nature can have negative impacts on human well-being. However, the true value of ecosystem services to human well-being—and the features and functions of these services that are substitutable versus irreplaceable by technology or engineering—are not well understood. This uncertainty can come between the research findings and public perception or understanding of these findings; resulting in a public that is not prepared to implement policy and practical changes that will reverse the decline in ecosystem services, or protect their future.

The research areas of measurement, modeling, remote sensing, mapping, scale-free networking, and complex adaptive systems have improved the public's understanding of a wide-range of issues from human brain activity and biological processes to social networks and weather prediction. What tools could be used to improve the public's understanding of the interaction between ecosystem services and human well-being? How can they be used across different time and space scales to provide real-time understanding of these interactions, and to better elucidate the benefits of ecosystem services to a public audience? Exploring the application of these research areas in the context of ecosystem services could help to advance the public's appreciation of ecosystem services, so that they are able to engage in the practical and policy decisions that will be required to chart a path toward sustainability in the next 50 years.

Key Questions

- What do we know about the American public's appreciation of ecosystem services? What is the difference between the aspects of ecosystem services that are appreciated by the public versus those that are less appreciated?
- What marketed or nonmarketed ecosystem service can be valued, either qualitatively or quantitatively, in a tangible way—providing "today's" value and the value for future generations? What is the appropriate scale and timeline for such valuation?
- What ecosystem services are most ripe (i.e., we "know what we know" and "we know what we don't know") for developing methods to measure, map, and model, so that the public can better understand the effects of human behavior and policy on the services, and the resulting effects on these services to human well-being? How can these methods be used to develop interactive applications to engage the general public and improve their understanding of ecosystem services?
- How can remote sensing technology be used to develop applications that provide synchronous understanding of the effects of human behavior and policy on ecosystem services to engage the general public and improve their understanding of ecosystem services?
- The "general public" consists of a diverse group of constituents with varying levels of appreciation for ecosystem services, and there are many strategies to address each of these audiences. Which "audience(s)" (e.g., k-12 students, parents, the voting public, policy makers, iPod users, others?) would provide the greatest cost-benefit for an initial program to increase their appreciation of the basic principles of ecosystem services? Do we start with people who already have an appreciation for nature, or is there a better starting audience?
- What are the most cost-effective strategies to increase the selected audience(s) appreciation of the basic principles of ecosystem services?

—Citizen science led to the creation of the National Weather Service and has been defined as "projects or ongoing scientific work in which individual volunteers or networks of volunteers, many of whom may have no specific scientific training, perform or manage research-related tasks such as observation, measurement, or computation." How can citizen science be used to engage the general public and improve their understanding of ecosystem services?

—The NAKFI conference will focus on nine aspects of ecosystem services, plus a host of other ideas that are generated during the poster sessions and other conversations among participants. Summaries of these think-tank discussions will be published by the National Academies Press, and grants will be awarded on a competitive basis for new ideas that are generated by the conference. How can these tools be utilized to support a public awareness program?

—What are the roles scientists, engineers, and institutions in strategies to increase the public's appreciation of ecosystem services?

—How can the interactive, end-user applications identified above be transformed into mass-scale tools such as iPhone applications, video or board games (Game of Life concept), museum exhibits, online tools, etc., to increase the selected audience(s) appreciation of ecosystem services?

—Other strategies?

- Or, is it even worth the effort to try to "increase the selected audience(s) appreciation of the basic principles of ecosystem services?" given recent statistics about the American public's scientific literacy of general topics (see first paragraph of the challenge summary). For example, will we make more progress in conserving a watershed by educating people and decision-makers about the ecosystem services that it provides for water quantity and quality, or simply by building on the known popularity of protecting open space and maintaining recreational opportunities? Or, are behaviors that maintain ecosystem services best achieved by direct incentives or regulations, such as payments for ecosystem system services, taxes on activities that diminish ecosystem services, zoning and so forth?

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IDR TEAM SUMMARY

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IDR Team 9 was asked to develop a program that increases the American public's appreciation of the basic principles of ecosystem services. The team began by deciding to define ecosystem services as the ones listed in *The Economics of Ecosystems and Biodiversity (TEEB) Manual for Cities.* This guide lists seventeen services divided into four categories: provisioning, regulating, habitat or supporting, and cultural services. The IDR Team also concluded that ecosystem services—conceived here as processes and connected cycles—are distinct from natural resources, which are discrete objects that nature provides. In this way, its definition is somewhat different from that of other IDR teams.

Do We Even Need to Improve the Public's Appreciation?

According to research, at some level, a fair number of people (90% by some measures) already value ecosystem services. However, most Americans don't connect with the term itself. When asked, many think it means some sort of cleanup—or servicing—of the ecosystem. Is this a problem?

Terminology

One of the members of the team, in reference to ecosystem services, said, "the term is soul destroying." However, everyone agreed that the public doesn't need to respond to or even understand the meaning of "ecosystem services." The important thing is getting people to engage with the principles behind the term. Thus, there needs to be a rebranding of the concept, perhaps with the phrase "nature's benefits," which people surveyed seemed to like better.

Action

The group decided that just appreciating ecosystem services and their benefits to human and environmental health is not enough if the public does not behave accordingly. Therefore, the real problem is how to create a systematic change in people's behavior to preserve or augment ecosystem services (or at least not undermine them). People have a general sense of what they could or should be doing—conserving, recycling, etc.—and many have the desire to act. However, there needs to be a unified push to give them specific tools and to show them what individuals can do to participate and where their principles can be applied. This is important in a political system such as ours, because educating the voting public can help give politicians the will to make certain difficult choices.

Communications Principles

IDR Team 9 thinks an understanding of the basics of communication is essential to developing any sort of program designed to reach the public. One of the first steps, everyone agreed, should involve listening. Understanding people's current thoughts, attitudes, and beliefs would help frame the subsequent communication in a much more relevant way. Some team members advocated for a three-step communications strategy: get the attention of the public, pique their interest, and then deliver the message after they are more responsive to it. Others suggested a more formal, pyramid-style approach, with goals, specific audiences, framing, and messages. One thing everyone agreed is vitally important, regardless of the specific plan, is making hidden connections visible. Many people think we no longer depend on nature, now that we live in such a technology-laden world. To convince people to the contrary, it will be important to keep repeating that message and to refine it over time.

The team debated potential communication tactics. For example, games can be an excellent way to keep the message alive and deepen understanding of the importance of ecosystem services, perhaps without the audience even noticing a communications objective. More explicit messages could also work: someone suggested that an effective ad would state that the ecosystem is working for us and we're not paying it. Others suggested using tangible guides for progress in preserving ecosystem services. For example, one group member noted that Stockholm has a sculpture by its train station that shows visually, through lights, how healthy the city is.

Timing can also be important. People can be most open to behavioral change after a disaster, and if the message is that ecosystem services might help prevent the next flood or hurricane, there could probably be no better time to tell people.

Audiences: what do they value?

The American public is a heterogeneous group of audiences, including both groups and individuals. The groups include major institutions, such as governments (local, state, and national), schools (primary, secondary, and university-level), corporations, foundations, and the media. Smaller groups, such as religious, or artistic, or athletic communities should have targeted messages as well. For example, faith-based leaders are increasingly interested in conservation as a way to honor God's creation. Finally, there is the general public, which can itself be split up into infinite numbers of other audiences (by age, gender, geography, etc.), who all have different interests.

What are the motives for people to engage this issue?

The group suggested that people's motivations for preserving ecosystem services fall into two categories: self-interest (usually in the form of money or health) and principles (romantic ideals about preserving nature). Of these, it is probably safe to say that self-interest is the more powerful; in fact, the ecosystem services model was designed to explicitly tap into people's understanding of a good cost/benefit ratio. People listen when the message is that ecosystems save them money. Nearly as strong, though, is the desire to be safe and healthy, which means having food, clean water, medicine—all of which are linked to ecosystem services. Other self-interested motives, such as preserving a forest because it offers good camping or wanting clean water supporting lots of fish for fishing also come into play.

Drinking Water: An Example

To illustrate some of what they would like to accomplish, IDR Team 9 decided to use clean drinking water as an example. The reasoning was simple: people understand the importance of having clean water to drink. At the time of the meeting, 2,230,714 people were fans of a Facebook page for "Drinking" (and no, the page refers specifically to water, not alcohol!) Some would say that sanitary water is the greatest public health contribution of the twentieth century. Corporations have begun to recognize water's importance as well; one of the group members pointed out a recent article in the *New York Times* describing Levi Strauss' efforts to make (and sell) jeans that use less water in the manufacturing process.

Using the *TEEB Manual for Cities* as a guide, the team noted that ecosystems provide drinking water through precipitation (and other parts of the flow of the water cycle, such as evaporation), storage (in groundwater and fresh bodies of water), and purification (primarily through soil filtration). Humans can affect these processes through agriculture (which uses water that might otherwise be available for drinking), industrialization (which causes pollution), and energy production (which can sometimes have an effect on water storage systems, such as rivers used for hydroelectricity).

Although much of this information seems like the subject of an elementary school science lesson, the group brainstormed ways to give people a more intuitive understanding of how they can affect their own clean water supply. A few of the ideas:

- Geolocation apps, in which messages pop up on a mobile device when the user enters a particular watershed, for example
- Incorporating water use into Farmville and other popular online games
- Technology that lets individuals measure their own water use

- Illustrations of water quality in one's community
- Rainwater cisterns at schools to give children a tangible example of water storage

Plan: The NAS PlanetWorks Conference

IDR Team 9 decided that it did not have the necessary skills and connections to create an effective public awareness campaign. However, they—together with NAS—might be able to get a group of influential people together to do so. These individuals would ideally be those with power, contacts, and skills in a variety of fields—people who wouldn't normally work together, coming together to create new, large concepts for action. Such groups might include professional communicators and media consultants; Hollywood producers and directors; foundations, funders, and other philanthropists; behavioral psychologists; economists; government representatives; bloggers; game and app designers; and even celebrities (who could help turn the meeting into an event worthy of press coverage).

The group proposed (pending the approval of the National Academies) the name NAS Planetworks Conference for this gathering, which might also include smaller subsequent meetings for particular groups. These smaller groups might take the form of partnerships—the pairing of one group or individual doing something well with another individual group who would like to learn from their successes. Other partnerships could be between those with different skills but similar goals.

The team imagined the participants each going back to their communities armed with a replicable, scalable toolkit—including contacts, core concepts, and media tools—that could be distributed across different contexts, hopefully leading to a viral network effect of continuing action.

Appendixes

List of Ecosystem Services Podcast Tutorials

Ecosystem Services: An Overview
Podcast Released: September 1, 2011
Stephen R. Carpenter (NAS)
Director of the Center for Limnology
S. A. Forbes Professor of Zoology
University of Wisconsin-Madison

Valuing Natural Capital and Ecosystem Services
Podcast Released: September 8, 2011
Peter M. Kareiva (NAS)
Chief Scientist
The Nature Conservancy

The Effects of Ecosystem Services on Chronic and Infectious Diseases
Podcast Released: September 15, 2011
Peter Daszak (IOM)
President
EcoHealth Alliance

Processes to Create Renewable Resources, or to Recover Resources
Podcast Released: September 22, 2011
Bruce E. Rittmann (NAE)
Regents' Professor of Environmental Engineering
Director, Center for Environmental Biotechnology, Biodesign Institute
Arizona State University

Federal Policy to Maintain or Improve Natural Capital and Ecosystem Services in the United States
Podcast Released: September 29, 2011
Walter Reid
Director, Conservation and Science Program
The David and Lucile Packard Foundation

The Relationship Between Food Production Systems and Ecosystem Services
Podcast Released: October 6, 2011
Per Pinstrup-Andersen
H.E. Babcock Professor of Food, Nutrition and Public Policy
J. Thomas Clark Professor of Entrepreneurship
Professor of Applied Economics
Cornell University

A Comprehensive Ecosystem Services Approach; Global Perspective on Agricultural Connection to Natural Capital
Podcast Released: October 13, 2011
Jonathan Foley
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Systems for International Trade That Account for Impacts on Ecosystem Services
Podcast Released: October 20, 2011
Elena M. Bennett
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McGill University

Scientific Literacy of the Ecosystem Services Challenge
Podcast Released: October 27, 2011
Randy Olson
Scientist-Turned-Filmmaker
Randy Olson Productions

All tutorials are available at www.keckfutures.org.

Agenda

Friday, November 11, 2011

7:00 a.m. and 7:15 a.m.	Bus Pickup: Attendees are asked to allow ample time for breakfast at the Beckman Center; no food or drinks are allowed in the auditorium, which is where the welcome and opening remarks take place at 8:30.
7:30 a.m.	Registration (not necessary for individuals who attended Welcome Reception)
7:30 – 8:30 a.m.	Breakfast
8:30 – 8:45 a.m.	**Welcome and Opening Remarks** Harvey V. Fineberg, President, Institute of Medicine Stephen R. Carpenter, Chair, NAKFI Steering Committee on Ecosystem Services
8:45 – 9:45 a.m.	**Keynote Address** Joel E. Cohen, Abby Rockefeller Mauzé Professor of Population at The Rockefeller University

9:45 – 10:00 a.m.	**Interdisciplinary Research (IDR) Team Challenge and Grant Program Overview** Stephen R. Carpenter, Chair, NAKFI Steering Committee on Ecosystem Services
10:00 – 10:30 a.m.	Break
	Poster Session A Setup
10:30 a.m. – Noon	Poster Session A
Noon – 1:00 p.m.	Lunch
1:00 – 5:00 p.m.	IDR Team Challenge Session 1
3:00 – 3:30 p.m.	Break
	Poster Session B Setup
5:00 – 7:00 p.m.	Reception/Poster Session B
5:30 p.m.	NAKFI Science Writing Scholars Meet with Barbara Culliton
7:00 p.m.	Bus Pickup: Attendees brought back to hotel.

Saturday, November 12, 2011

7:00 and 7:15 a.m.	Bus Pickup
7:15 – 8:00 a.m.	Breakfast
8:00 – 10:00 a.m.	IDR Team Challenge Session 2
10:00 – 10:30 a.m.	Break

10:30 a.m. – Noon	IDR Team Challenge Preliminary Reports (5 to 6 minutes per group)
Noon – 1:30 p.m.	Lunch
1:30 – 5:00 p.m.	IDR Team Challenge Session 3
3:00 – 3:30 p.m.	Break
	Poster Session C Setup
5:00 p.m.	IDR Team Challenge Final Presentation Drop-Off: IDR Teams to drop off presentations at information/registration desk, or upload to FTP site prior to 7:00 a.m. Sunday morning.
5:00 – 7:00 p.m.	Poster Session C and Reception
7:00 p.m.	Bus Pickup: Attendees brought back to hotel.

Sunday, November 13, 2011

7:00 and 7:15 a.m.	Bus Pickup: Attendees who are departing for the airport directly from the Beckman Center are asked to bring their luggage to the Beckman Center. Storage space is available.
7:15 – 8:00 a.m.	Breakfast
7:15 a.m.	Taxi Reservations: Attendees are asked to stop by the information/registration desk to confirm their transportation to the airport or hotel.
8:00 – 9:30 a.m.	IDR Team Challenge Final Reports (eight to 10 minutes per group)
9:30 – 10:00 a.m.	Break

10:00 – 11:00 a.m.	IDR Team Challenge Final Reports (continued) (eight to 10 minutes per group)
11:00 a.m. – noon	Q&A Across All IDR Teams
Noon – 1:30 p.m.	Lunch (optional)

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