*** PRELIMINARY DRAFT ***

A Research Agenda to Sustain and Enhance Ecosystem Services

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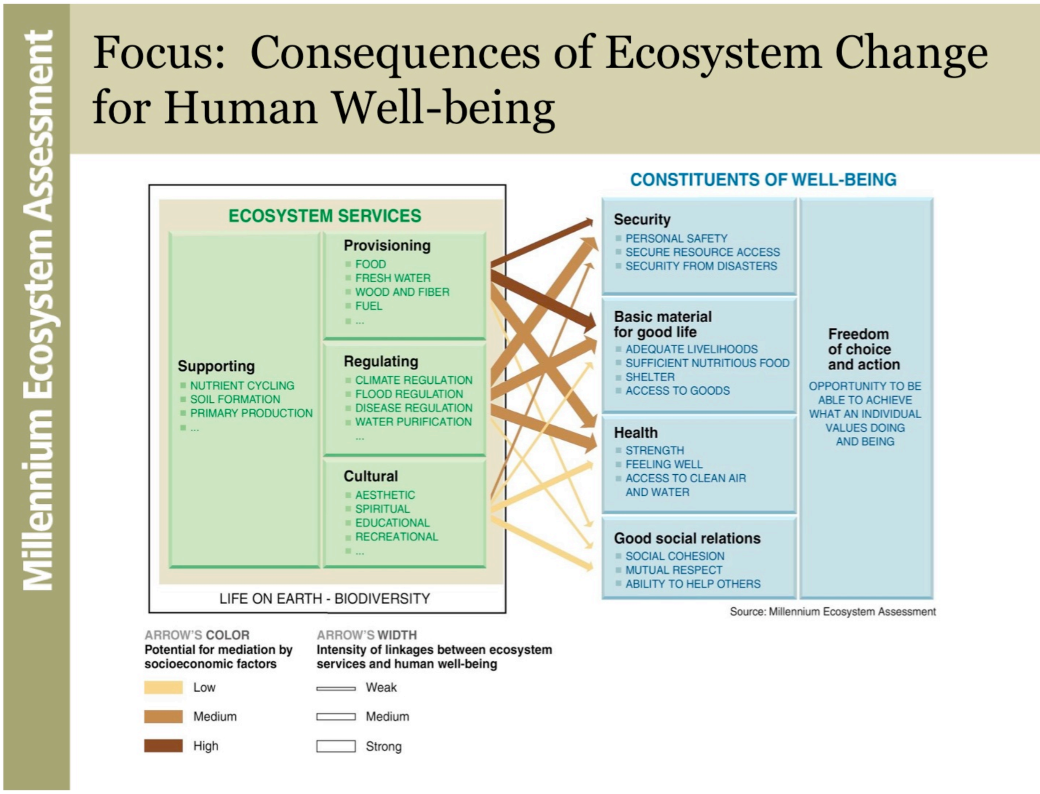
Introduction

While the buildup of greenhouse gases in the atmosphere will have catastrophic consequences if not reversed, an additional burden will be placed upon society if the continued degradation of ecosystem services-- the benefits that people obtain from ecosystems -- is not halted. When planning for future sustainability, it is imperative to better understand ecosystem services. A globally integrated system to measure, monitor, model, verify and communicate the current state of ecosystem services and how they respond to natural and anthropogenic changes is needed. In order to identify emergent patterns and processes, a wide range of data are needed across various spatial and temporal scales. Collecting and analyzing the flows of ecosystem services needs to be used as an input to a broad range of policies to ensure the future availability of these important services. This needs to be coupled to the appropriate distillation of data and trends for consumption by the general public. Systems that humans depend on for the continuous delivery of goods and services relating to food, water, climate and health are highlighted in the proposal to create a stimulus plan for future research relating to ecosystem services and human well-being.

Moving our global society toward a more sustainable enterprise is a grand challenge. While the buildup of greenhouse gasses in the atmosphere will have catastrophic consequences if not reversed, the goods and services that we rely on to maintain human well-being are also being threatened. Many of the decisions that are made in the context of consumption that have direct or indirect consequences on the biosphere are often neglected. At an abstract level, society either grows or mines all the resources for their sustenance, growth and prosperity. Current levels of population and resource demand are outstripping the rates at which these systems can sustainably replenish themselves, often with complex feedbacks that ultimately affect human well-being. The Millennium Ecosystem Assessment (MA) was the first major step in untangling the complex web of connections between humans and ecosystems. As the results of the assessment are revisited, and a future course of action is deliberated, the lack of data, models and policies to manage ecosystem services has become a focus for the near term.

A globally integrated system to measure, monitor, model and verify the current state of ecosystem services and how they respond to natural and anthropogenic changes is needed. This information can be used to assess trade-offs between ecosystem services and as an input to value ecosystem services. Adaptive policy frameworks are also required to manage feedbacks between new scientific understanding and the management decisions being made across scales.

In order to better understand and manage the interactions between humans and the environment, a more distributed, collaborative, and transparent system of data gathering, aggregation and processing needs to be established for social-ecological systems. While these data are important in a scientific context, it is also crucial to disseminate the lessons learned about human-environment interactions to the public and decision makers. These actors also should be urged to provide feedback to enhance the usefulness of future research. While many ecosystem monitoring systems currently in place are useful, there are emerging technologies that could be used across a broad range of ecosystems to better understand their interactions with humans.



The Ecosystem Services Toolbox: Measurement, Mapping & Modeling

Quantifying Ecosystem Sustainability

Ecosystem Sustainability can be defined simply as groups of organisms and the physical environment they inhabit. For ecosystem to be sustainable, the capacity of ecosystem to furnish its services as inputs must be maintained over time or the economy must find a substitute for the ecosystem to be capable of delivering an equivalent input. If both of these conditions are not met the current pattern of agricultural production and the ecosystem will not be sustainable.

A variety of methods can be used to measure, map, and model ecosystem services and therefore diagnose the sustainable use of those services. In this paper we take a stock and flow approach that in its essence is an accounting based approach, but when applied over time it may be used to represent dynamic systems. A stock, provides the total amount of ecosystem service asset stored and available for use. Measurement of the amount of stock over time provides information on the rate of depletion of the availability of ecosystem services. In some cases, an ecosystem stock may be used in multiple flows and therefore provide multiple services. Examples like forests that are used as a source of timber, carbon absorption, and erosion reduction. As natural resources, they provide direct use benefits, while as components of ecosystems they provide indirect services. It is necessary to recognize the services of forests and other biological resources if a complete picture of the benefits provided to humans by the environment is to be captured, deliberately introduced to enable different environmental aspects to be examined.

In contrast to the static quantitative measurements of stocks that provide ecosystem services are the rates at which those services are provided or used by human systems. Commonly referred to as a flow, flows demonstrate the rate of anthropogenic consumption of ecosystem services. The flow for the ecosystem services is based on the physical input-output table which is based on the identity of physical inputs and outputs for each industry. The flow is a simplified version of the physical input-output table and will be used in future versions of this paper.

The stock and flow approach to measuring, monitoring, and modeling ecosystem services requires addressing a large portfolio of possible services. Therefore, individuals or groups are often forced to prioritize services and allocate conservation efforts accordingly. Such efforts are necessary for the feasible collection of data at the global level and for its application to countries all over the world. The remainder of this paper uses the stock and flow approach to provide a framework for discussing the provision, support, and preservation of ecosystem services in a variety of contemporary fields of research.

Provision of Ecosystem Services

Background

While the process of industrialization has led people in the developed countries away from a direct connection to ecosystem services, many people around in the world still rely on direct resource extraction for their livelihoods, e.g. collecting firewood for home cooking or hunting for food within forests. As industrialized societies have moved away from this direct dependence on natural resources, the provision of ecosystem services is often "invisible". While all humans are ultimately dependent on nutritious food, clean water, breathable air and moderate climates in order to survive, it can be difficult for city-dwellers to sense how their activities have an impact on the ecosystems that support them. Therefore, this section provides a tour of the major ecosystems supporting human life on earth, what sorts of services are provided by these ecosystems and methods for monitoring changes in these services, and future research areas and solutions to help us address these challenges. It should be noted that the topics covered here are by no means an exhaustive list of all the ecosystem services that support life on earth

Ocean Food Production

Stock: Throughout history humans have been directly or indirectly influenced by the oceans. Ocean waters serve as a source of food and valuable minerals, as a vast highway for commerce, and provide a place for both recreation and waste disposal. Increasingly, people are turning to the oceans for their food supply either by direct consumption or indirectly by harvesting fish that is then processed for livestock feed. It has been estimated that as much as 30% of human protein intake comes from the oceans. Nevertheless, the food-producing potential of the oceans is only partly realized. For hundreds of years, fish from the ocean have provided the world with much of its protein. In the 1990's, after over 200 years of commercial fishing the collapse of the North Atlantic fishery and the listing of Atlantic salmon as an endangered species created an acute shortage of fish and a critical need for alternative sources of protein. More recently, our growing awareness of climate change and its effect on fisheries and aquaculture has added further concern as to the sustainability of commercial fisheries and sustainable development of aquaculture as a way to provide the world increasing demand of fish protein.

Flow: Sustainable fisheries and aquaculture are two separate challenges, because 70-95% of the world's fisheries are already threatened and therefore not commerically sustainable, but need to be conserved. This leaves only 5% to feed a growing world populations. And, because aquaculture is still a developing enterprise that can disrupt, by its practices, natural oceanic populations that maybe important to the commercial fishery. Further, the practice of aquaculture requires feeds to be derived from wild-based species, thereby further depleting the oceanic stocks. Significant research is need to develop non-wild-based feeds for aquaculture.

To appreciate the enormous degree to which we have extracted food from the ocean (both wild fish and cultured fish), the following facts are presented from the most recent FAO report (2008) on world fisheries and aquaculture. Capture fisheries and aquaculture supplied the world with about 110 million tonnes of food fish in 2006, providing an apparent per capita supply of 16.7 kg, which is among the highest on record. Of this total, aquaculture accounted for 47 percent. Outside China, per capita supply has shown a modest growth rate of about 0.5 percent per year since 1992, as growth in supply from aquaculture more than offset the effects of static capture fishery production and a rising population. In 2006, per capita food fish supply was estimated at 13.6 kg if data for China are excluded. Overall, fish provided more than 2.9 billion people with at least 15 percent of their average per capita animal protein intake. The share of fish proteins in total world animal protein supplies grew from 14.9 percent in 1992 to a peak of 18.5% in 2007. All this extraction has resulted in large scale exploitation of the world marine fishery. It is estimated that, in 2007, about one-fifth of the stock groups monitored by FAO were underexploited (2 percent) or moderately exploited (18 percent) and could perhaps produce more. Slightly more than half of the stocks (52 percent) were fully exploited and, therefore, producing catches at or close to their maximum sustainable limits, with no room for further expansion. The other 28 percent were either overexploited (19 percent), depleted (8 percent) or recovering from depletion (1 percent) and, thus, yielding less than their maximum potential owing to excess fishing pressure in the past, with no possibilities in the short or medium term of further expansion and with an increased risk of further declines and a need for rebuilding.

Future Research Areas: Fishers and fish farmers, in addition to oil rigs, sand miners, offshore wind projects, boaters and liquefied gas tankers that are not discussed in this paper, all compete for ocean access. In response to this usage a growing number groups say it is time to divide up space in the sea. A number if states; including Massachusetts, California and Rhode Island in the US have begun to zone the ocean and California is dividing its 1,100-mile coastline into five regions, brokering agreements with interest groups to establish marine protected areas. The federal government is considering a similar approach, which would require navigating 140 ocean-related laws split between 20 agencies. Dividing up the ocean presents mant scientific and political challenges, because very little of the ocean has been mapped in detail and there are many interest groups that are competing for sea space. Further, we lack specific data and knowledge to divide up the ocean for food production as only 20 percent of the exclusive economic zone (EEZ) that stretches out 200 nautical miles from the U.S. coast has been mapped. More important what has been mapped is only the geophysical bottom, not its habitats and species.

This lack of knowledge also impacted Marine Protected Areas (MPAs), a protected area of the ocean which includes some part of the ocean. While different types of MPAs contribute to conservation, the greatest benefits are associated with marine reserves. Marine reserves, also known as fully protected or no-take MPAs, prohibit all fishing, mineral extraction, and other habitat-altering activities. Marine reserves allow fish, mammals, and other marine life to breed, feed, and thrive free of human interference. In a scientific survey of more than one hundred reserves worldwide, scientists found that fish are larger, more abundant, and more diverse within these protected areas. Marine reserves are necessary and essential to restoring the health of the ocean. However, one of the problems that MPAs are likely to face are the shifting of species distribution with clmate change, the results of which are unforeseen. Thus one of the challenges of meeting the needs of ecosystem services is to comprehensive map both the biological and physical resources in order to assess value and provide information for economists and policy makers who will perhaps make the final decision how to divide up the sea.

Despite this impressive set of extraction and expoitation facts, both fisheries and aquaculture, however, require quantitative monitoring programs to be put into place to determine, the level of anthrogenetically derived stress that they are now encountering and to determine true extraction rates. Results from these programs will aid in determining how that stress levels are likely to change with increases in green house gases and temperature. The purpose of this monitoring program would be to serve as an early warning system for species in danger, in order for mitigating factors, such as reduction in quotas, and protection of habitat to be put into place in non-conventionally short time frames.

Freshwater

Stocks: Global freshwater stocks include wetlands, lakes, streams, rivers, glaciers, and aquifers. Many surface freshwater environments contain high biodiversity

Flows of Services: Humans value freshwater ecosystems for the provision of drinking water, irrigation, fish for consumption, water filtration, high biodiversity, and aesthetic beauty. At a fundamental level, freshwater is necessary for the functioning of the entire terrestrial biosphere, the provision of food, and the maintenance of biodiversity. Many of these ecosystem services are at risk due to human actions; specifically pollution (unsustainable inputs) and extraction (unsustainable use of freshwater).

While some gains in freshwater quality (specifically pathogen and organic pollution) have been made over the last 20 years in developed countries, most waterways globally have seen declines in water quality over the same time span. Toxics and endocrine disrupting chemicals persist and accumulate in freshwater ecosystems, creating hazards for ecological and human health. Nutrient pollution (primarily from agriculture) leads to eutrophication, hypoxia, and acidification - disrupting and potentially destroying downstream fisheries. Massive engineered watersheds are a major cause of this nutrient pollution, as drainage tiling in much of the developed world bypasses natural systems' abilities to filter runoff from agricultural lands.

Beyond contamination, the sheer amount of water used by humans and unnatural flow regimes compromise natural systems. Specifically, the quantity of freshwater used by humans globally doubled between 1960 and 2000, and now 5-25% of global freshwater use exceeds sustainable local supplies (and must be met by overdraft of groundwater or engineered water transfers). In dammed rivers, unnatural flow regimes alter river hydrology and morphology while devastating biodiversity.

Future Research Areas: Given the importance of freshwater ecosystems to human and ecological well-being, more work must be done to assess the services currently offered by freshwater ecosystems and to ensure the long-term protection of these services. Specifically, remote sensing tools can be utilized to assess the water purification benefits from natural vegetation in watersheds around the globe, enforce water quality protection policies, and predict the impact of climate change in regions dependent upon snow-fed or glacier-fed rivers. In regions where water purification services are impaired, we should research ecological engineering techniques to restore or create ecosystems. On managed rivers, we should work to quantify the ecosystem service benefits that can be accrued from mimicking natural flow regimes. On a broader level, more proactive, systems-based risk assessment of industrial and agricultural chemicals is necessary to prevent future contamination from novel pollutants.

Soils

Stocks: Global soil resources, with quality characterized by indicators including depth, soil moisture, biota, nutrients, and organic matter (Karlen et al 1997).

Flows of services: Humanity is crucially dependent on the thin film of topsoil on the land surface. Soil serves as a carbon storehouse, holds nutrients, filters water (along with the vegetation the soil supports), and – perhaps most critically – provides the growth medium for the food and fiber upon which humanity relies. Land use and agricultural management practices have led to soil erosion, decline of soil fertility, pollution, and compaction of soils throughout the much of the globe.

Neglecting the importance of soils' services to humans comes at a dire cost. Haiti, for example, has undergone a phase shift from lush tropical ecosystem providing many ecosystem services to a state characterized by desertification, extreme soil erosion, and susceptibility to natural disasters. Poverty, population growth, and perverse incentive structures (often encouraging deforestation for fuelwood) can "trap" poor nations into such unfortunate outcomes (Dasgupta 1995).

Research areas: Research should help us ensure sustainable use of our soil resources. We must understand how to break the cycle leading to "poverty traps" and soil degradation in poor countries, and account for the risks of catastrophic ecosystem shifts (e.g. desertification) in decision-making and economic accounting. In areas with degraded soils, we should utilize and further develop (bio-)remediation techniques for restoring contaminated soils. Expanded measurement, monitoring, and sharing of global soils data is critical; specifically, standardized, detailed, spatially-explicit gridded datasets of global soil statistics should be developed for the earth science field. More investigation is needed in how to "scale-up" agricultural management practices that promote soil health (e.g. perennials, polyculture, rotational grazing), thus shifting the balance from mitigation and restoration of degraded lands to prevention of degradation. Finally, economists should investigate structures linking the price of goods produced by the biosphere (food, fiber, and biofuel) to the way in which the soil was managed for societal benefit.

Terrestrial carbon sequestration

Carbon stocks

The terrestrial biosphere currently stores about 2,300 GtC in terrestrial vegetation, soils and detritus, while the oceans contain about 38,000 GtC (Denman et al., 2007). Therefore, these natural pools are large in comparison with the growing stock of about 750 GtC in the atmosphere, which is contributing to global climate change.

Carbon flows

Large exchanges of carbon occur all the time between the terrestrial biosphere, the oceans and the atmosphere, and in fact dwarf the relatively small signal from fossil fuels and deforestation. In pre-industrial times, these natural exchanges of carbon from photosynthesis, respiration and ocean gas transfer were roughly in balance, i.e. what was taken up during the growing season was primarily returned to the atmosphere during the dormant season. In addition, net uptake from vegetation growth was returned to the atmosphere by occasional events such as fires and ecosystem destruction from storms.

While these processes are still occurring today, terrestrial ecosystems have also increased their uptake capability and in the 1990's were estimated to have taken up a net amount of 2.6 GtC/ year from the atmosphere (Denman et al., 2007), or about 30% of the amount put in the atmosphere from fossil fuel emissions and land-use change. (Another 25% is taken up by the oceans.) Without this carbon sequestration function provided by the terrestrial biosphere and oceans, global warming would be worse than what we see today. The various mechanisms for terrestrial uptake include fertilization from excess CO2 in the atmosphere and additional nitrogen deposition, re-growth of previously harvested forests and fire suppression; however, the relative magnitude of these processes remains subject to debate and the future strength of terrestrial carbon uptake also remains uncertain. In addition to the saturation of current sinks, large releases of carbon to the atmosphere, e.g. from soil respiration in thawing permafrost, remain possibilities within the next century.

Research areas/ policy interventions

In terms of policy interventions to protect and grow non-atmospheric carbon stocks, one thing that is relatively certain is that maintaining existing forests prevents locked-up carbon from returning to the atmosphere through rot and decay, and that most intact forests have the capability to take up more carbon over time. This provides a strong incentive to reduce currently high rates of deforestation as one piece of mitigating climate change. In addition, given that most land surfaces on earth, apart from the polar ice caps, are populated by humans and are either directly or indirectly managed by humans, focusing on terrestrial carbon uptake provides the opportunity to design policies that preserve carbon stocks and promote sequestration.

In order to design such policies as well as monitor fossil fuel emission reductions, a sustained effort to monitor atmospheric CO_2 levels and surface sources and sinks of carbon is required at a global scale (Scholes et al., 2009). This could possibly be achieved by current efforts to create an atmospheric monitoring system of CO_2 concentrations from earth surface networks, as well as current and future satellites dedicated to this mission. Such a monitoring system will provide relevant information for two main objectives related to climate change modeling and mitigation.

A change in the net balance of natural carbon exchange can have a large impact on the relative amount of "anthropogenic" carbon that remains in the atmosphere. An atmospheric monitoring system could provide an early alert system for subtle, but catastrophic changes in the carbon cycle. In addition, uncertainty in the future of the carbon cycle remains one of the largest uncertainties in future projections of climate change. Therefore, refined estimates of regional (~100km x 100km) carbon sources and sinks from an atmospheric monitoring system would be useful for land surface and climate modelers, where the current inability to directly measure carbon exchange at the scale of model grid-cells hampers the ability of these models to provide predictions of future sources and sinks.

Second, information about carbon sources and sinks will be important within a climate change mitigation policy framework, especially if the annual net source or sink for a given region can be partitioned into relevant and "manageable" components. The most important partition would be between biospheric and fossil fuel emission fluxes, perhaps using the C^{14} isotope as a tracer. This would allow for a reliable, objective monitoring system to ensure that countries are meeting their stated fossil fuel emission reduction goals, from the point of view of the atmosphere, rather than relying on countries to report their emissions using a standard methodology based on fuel sales, imports/ exports, etc. Such methodologies are highly subject to different interpretations across countries, and can be implemented to varying degrees of quality given current data collection efforts and future capabilities within any given country. In addition, with a perception that the emission and carbon sink reporting methodology could be "gamed" for accruing carbon credits in the global marketplace, this will reduce the willingness of countries to sign onto a global mitigation framework, as well as reduce the efficiency of a global cap & trade system.

The biospheric carbon flux from such an atmospheric monitoring system could be partitioned even further to help inform land management policies. Such a partition would include the portions attributable to climate variability vs. direct human management impacts, e.g. from no-till agriculture or deforestation (Canadell et al., 2007). Further sub-divisions could include indirect human impacts, e.g. additional uptake due to excess nitrogen deposition in the environment or reduced growth due to ozone near urban areas. It should also be noted that many of these component carbon fluxes can also be calculated using bottom-up approaches, such as mechanistic models, remote sensing products and inventory data collection. However, different bottom-up models rarely agree on their estimates of net carbon exchange (Huntzinger et al., in review), let alone the magnitude of various component processes. Therefore, atmospheric methods have the potential to provide more objective estimates of net flux, and validate biospheric/ land-surface models and their estimates of component fluxes.

Finally, the land use, land use change and forestry component of the Kyoto Protocol was one of the most contentious issues in that agreement, and has been met with severe criticism since the late 1990's due to its arcane methodology and lack of incentives for reducing deforestation. A move to "full carbon accounting" at a global scale (Cowie et al., 2007) would help to value existing forest sinks and deforestation in an equal manner to fossil fuel emissions, providing full transparency for misguided mitigation strategies like forest clearing for biofuel production. A global monitoring system for both the biospheric and anthropogenic components of carbon sources to the atmosphere would help to advance the capabilities for a full global carbon accounting scheme.

Given all these needs for a global monitoring system for carbon sources and sinks, methodological challenges remain. The Global Greenhouse Gas Observing System (GoSAT) satellite was recently launched by the Japanese government, while the Orbiting

Carbon Observatory was also recently launched by the United States, but this latter satellite unfortunately failed to reach orbit. Such satellites will collect column-average CO2 concentrations, which can be translated into surface sources and sinks through inverse modeling and data assimilation techniques with relatively low uncertainties. Future satellites, e.g. the ASCENDS mission with a planned launch in 2016, will overcome limitations of previous satellites to sample around the clock and through clouds with the use of an active radar system. Given the current high cost associated with C^{14} measurements from space, it is not yet clear if these satellites will provide the necessary information to accurately partition total net flux into biospheric and fossil fuel emission portions. However, even without the use of C^{14} estimates from space, efforts are underway to expand high resolution (i.e. sub-daily, tens of kilometers) fossil fuel emission inventories across the globe through the Vulcan/ Hestia project led by Dr. Kevin Gurney at Purdue University (see http://www.purdue.edu/climate/hestia/index.shtml), although the quality of this dataset is subject to the quality and availability of the inputs, which may be lacking in certain regions of the globe. In addition, by synthesizing biospheric models and other remote sensing data products with atmospherically-derived estimates of carbon sources and sinks, it should be possible to arrive at consistent regional-scale estimates across the globe of emissions from both fossil fuels and deforestation and a coarse partitioning of biospheric sinks to inform land management strategies. All of these methods mentioned above remain active research areas.

Land-use and land-cover change

Stocks: How humans use the landscape inextricably couples them to the environment in which they live. While acting within this environment they utilize natural stocks in order to receive a variety of ecological services. In land-use systems, the EPA[1] describes the representation of land cover as a stock and land use as a flow. Additional stocks in the human system include population, available capital, labor, and knowledge.

Flow / Ecosystem Services: Anthropogenic land-use and land-cover change has altered over 30% of the Earth's surface. Second only to fossil fuel emissions, anthropogenic CO_2 emissions from land-use and land-cover change have also altered the Earth's climate. With global population expected to steadily increase up to 10 billion, from the current six billion, it is expected that these trends will continue and that further alteration of the Earth's land-surface and climate will significantly threaten the provision of ecosystem services that permit long-term sustainability.
How humans use the land can be equated to some of the services provided to humans by ecosystems. For example, preservation and maintenance of forest cover in a residential neighborhood provides several services including improved aesthetics, air filtration, and temperature moderation. In agricultural land use, services provided by the soil include fertilization storage and delivery, and water holding capacity and dissemination to crops.

Challenges to mapping and monitoring ecosystem services in land use systems

Perhaps the biggest challenge facing research in this field involves the translation of land-use to land-cover data to information on ecosystem functions and services. The ability to accomplish this task is partly impeded by the availability and resolution of land-use, and ecosystem function and services data. Despite the existence of global land-cover data, land-use data remain relatively rare and quantification of ecosystem services such as carbon storage, biodiversity, water purification, and others, at the global scale have yet to be done. Accomplishing such a task would require sampling a huge array of locations that have a huge spectrum of site conditions and ecosystem longevity and interpolating an average value of ecosystem services to other locations or use remote sensing techniques and translation algorithms to accomplish the task.

Remote sensing or aerial photograph data can be used to interpret land-use and land-cover and in some cases it can be used to estimate ecosystem function such as net primary productivity (NPP) or biomass. Without field-based auxiliary data it is difficult to directly estimate ecosystem function and therefore the services provided. In some cases we can infer the provision of ecosystem services by using proxy measurements attained from land-use and land-cover change data. For example, measurement of a land cover such as impervious surface in a watershed can be used to estimate the effects of built-up areas on ecosystem services such as water purification (e.g. proportion of surface water runoff and stream or river pollution), water availability (e.g. the reduction in natural ground-water recharge), local air temperature moderation (e.g. heat island affects without evapotransporation from vegetation), among other services.

Typically the measurements of land-use and land-cover change are based on the patterns of change (amount and location). Patterns can be measured using landscape metrics that provide insight into the degree of connectivity, cohesion, shape, size, and fragmentation of land cover. These metrics are often used as proxies for ecosystem functions such as biodiversity. In the case of biodiversity, studies have shown that a greater number of species locate in edge environments (i.e. the ecotone between two types of ecosystem, like forest and prairie), however, some species depend exclusively on core patch habitat. Therefore a landscape metric like edge-to-area ratio is sometimes used as a proxy to identify land-cover patterns that are more conducive to increased biodiversity.

Perhaps the best method for estimating the effects of land-use and land-cover change is to first identify what the optimal configuration of vegetation types in a region would be for a single ecosystem service like carbon storage, or host of ecosystem services. Then one could evaluate the current state of land use and land cover in a region and evaluate the ecosystem service potential that remains. Scenario analysis may then be used to identify the pathways and mechanisms that could be taken or altered in order to increase the provision of that service. Models could be used to perform this scenario analysis and identify how land policies, economic incentives or taxes, or public outreach may be used as tools by actors and decision makers to motivate the public and industry to help achieve the desired land-use and land-cover change outcome.

Alternatively, one could use participatory methods with stakeholders, local actors, and decision and policy makers to design future alternatives of land-use and land-cover change that regulate, preserve, and support the provision of ecosystem services. Using models, those alternative futures could be reverse engineered to identify the human behaviors, policies, and mechanisms that would be needed to direct land-use and land-cover change to produce landscape patterns that enhance or achieve a desired level of provision of ecosystem services.

Future Research Areas

What this leaves us with is a number of questions that could be used to guide future research on the provision, regulation, support, cultural significance, and preservation of ecosystem services under changing land uses and land covers in highly fragmented and human dominated environments. Specifically, how can we increase our ability to utilize land for multiple ecosystem services over time? For example, are there configurations of land-use and land-cover change that enhance carbon storage above that which would be naturally attained? How can we increase the efficiency of land-use and land-cover patterns to enhance ecosystem services and decrease negative externalities (e.g. roadway infrastructure costs and fuel consumption)? To what degree do we have to discount future rates and amounts of change in land use and land cover in order to ensure sustainable use of land resources. Under what conditions should one land use be substituted for another in order to improve the provision of ecosystem services and sustainable land-use behavior? What land-uses and land-covers can be collocated to produce non-linear cobenefits from interactions and feedbacks that are not attainable individually? And lastly, how do the efforts and outcomes of the questions postulated influence diversity and the vulnerability, resilience, and adaptability of local communities under a changing climate?

1 Web published information without authorship on this topic is available at this location. http://www.epa.ie/OurEnvironment/Land/CorineLandCover/AccountingforLandCoverChange/

Coupling Human and Environmental Systems

Humans have the ability to directly manipulate ecosystem stocks and structures to obtain desired benefits. One of the earliest forms of ecosystem manipulation was the development of agriculture. Humans discovered how to structure and ecosystem to derive benefits in the form of foods. We have continued to learn how to manipulate these systems for our benefit, and have amassed a general knowledge on how these systems can be structured to provide food, waste assimilation & treatment, water filtration, micro-climate regulation, amongst others.

The agricultural systems that supply food for most of the world's population have achieved high yields, but have relied on very large fossil energy inputs. These inputs have been used to power machinery and transportation systems, produce a variety of fertilizers, herbicides, insecticides, and provide irrigation. Climate disruption due to global warming, risk of catastrophic loss of stretches of uniform plants, depletion of topsoil by erosion and oxidation, exhaustion of mined freshwater, and undependable supplies of fossil fuels threaten this enterprise.

A number of alternative (and traditional) agricultural methods are being researched and developed to increase the resilience of the agricultural system in the face of changing climate and a carbon-constrained energy landscape. Many of these systems increase the numbers of ecosystem services provided through the agricultural practices, as compared to the traditional high-fossil input agriculture. Agro-forestry, agro-ecology, perennial agriculture and permacultural practices all offer alternative methods to now-dominant industrial agricultural practices which keep ecosystem services of an area intact, or offer the possibility of restoring ecosystem function (and its associated goods and services). These methods of agricultural production offer the possibility of maintaining or enhancing biodiversity, as they offer structures that resemble intact ecosystems. These methods also promote the sequestration of carbon into topsoil, providing a global-scale ecosystem service. Agronomy in recent decades has concentrated on optimizing industrial, fossil-fuel-intensive agriculture; now, much more research into both physical and social (including economic) aspects of alternative agriculture is urgently called for. This should lead to an incentive structure that rewards farmers who contribute to sustainability and thus increase local and global welfare.

At the same time, university and government agronomic research mostly seeks to refine and intensify industrial practices, while much less research funding is directed towards evaluating and improving methods aimed at sustainability. Specifically, theoretical analysis, observation, and experimental farming should immediately move to address: comparative yield (of calories and macro and micro nutrients) of industrial vs. ecological agriculture practices, and evaluation of methods of improving yield for the latter; comparative nutrient flows, soil ecology and long-term fertility, and carbon balances; impacts on local/regional climate for different plant configuration, watering practices, and soil water capacity; comparative economic consequences for farmers and for the foodshed; models for profitable farm operation and farmland retention; and impact on biodiversity, taking into account any change in the amount of land needed to grow food as a result of different yields and/or eating practices.

Cities are special cases in the context of ecosystem services. Around 50% of the global population currently lives in cities; this number is expected to increase to ~70% by mid-century. As currently structured, cities are often void of most ecosystem services, and place a disproportionate burden on ecosystems and services outside of the city boundaries. In general, it could be said that cities are sinks for ecosystem services, and produce little for themselves. For a sustainable future, we must reinvent the city, and reincorporate many of the ecosystems and services which have been lost. This is no easy feat, but can be achieved through careful ecological design and ecological engineering of systems and buildings in cities. There are a variety of new initiatives being undertaken in this vein, in which the research community should partner, along with community groups and various levels of local and regional government. For a sustainable human society, cities must limit their consumption and waste to what some region can provide and assimilate without damage to its biotic (and human) community. While the ideal of a city entirely self-sufficient in basic materials and energy is not possible for large crowded cities, moving to produce usable food and energy in-situ, and transforming waste products into useful (or at least benign) substances within and around cities can greatly contribute to sustainability. Much more research is needed on the feasible scope and ecological, economic, psychological, and cultural consequences (benefits) of this transition for cities of varying density and on how to implement it.

Specific interventions now being trialed and proven in many cities also tend to improve and restore ecosystem services. There are efforts to develop urban agriculture around, on (including green roofs), and in (vertical farming, Despommier 2008) buildings. There is also a move towards increasing storm and wastewater infiltration and purification (permeable paving, rain and stormwater gardens, increased plant cover, constructed/restored wetlands), which reduces treatment costs and pollution loads to nearby waterbodies. Local power generation (building-integrated photovoltaics, solar water heating, bi0digestion of organic wastes) and climate moderating (strategic planting, building design, reflective surfaces, trees and plants) are all being achieved in cities through ecological design and engineering. There are many ecosystem service benefits from these changes, including reduced greenhouse gas emissions (through reducing both energy demand and carbon intensity); lower air and water pollution (leading to healthier people and ecosystems); increased energy and food security; and strengthened social networks and community ties.

For those unable to produce sufficient ecosystem services locally to meet their needs or offset their emissions and wastes, a promising new economic scheme is being developed for protecting, enhancing or restoring ecosystems through financial agreements known as payments for ecosystem services (PES). In these agreements, an individual pays a landowner or government to keep or restore an ecosystem in a particular place, and in return the payer receives an ecosystem service based benefit. These benefits can be direct or local (clean water downstream from a protected area) or indirect and regional/global (climate regulation, carbon burial). As ecosystems are often more efficient at providing human well-being than technological alternatives, it is often financially profitable to protect ecosystems and reap the associated benefits. Well designed payment systems can promote the sequestration of carbon into soils along with the production of high quality food and forest crops. They also provide the opportunity for long-term funding of ecosystem conservation and restoration projects, as well as reliable income for local land-owners and labourers. Research projects, including experiments at various scales and evaluation of existing and new programs, can help determine what are good rules, institutional frameworks, and outreach efforts for the successful implementation of PES projects and programs. Formal markets and regulatory frameworks need to be developed to protect both the payer and payee in PES schemes. Research tools need to be proven for assessment of the services actually provided or restored through these schemes versus the stated objective (what was actually paid for). Monitoring of the impacts of the PES schemes on ecosystem, services, landuse and communities needs to also be implemented (using many of the same tools described early in the document for measurement, assessment and modelling of ecosystem services).

Conclusions and summary of research gaps

Over the past 50 years, changes to ecosystems by humans has resulted in a substantial loss of ecosystem services (except for the provision of food) and has had a major impact on biodiversity (MA, 2005). In order to manage the ecosystems and the goods they provide, a better understanding of how ecosystems function, and how they respond to change is needed. While there have been several studies completed on individual ecosystems or particular services, an integrated global campaign is needed to set a baseline of global ecosystem services.

An important first step to a global understanding of the flows of ecosystem services is an integrated framework that takes into account the temporal and spatial variations in the delivery of services. One methods that is being developed by the United Nations Food and Agriculture Organization (UN-FAO) uses flow and asset accounts for ecosystems to track ecosystem services. Currently these metrics are computed based on an analysis of land-use / land cover change, where the change of the service provided is proportional to the amount of disturbance. A more detailed, data-driven approach is needed to bolster our understanding of specific ecosystem function, and is explored in several examples.

While the oceans have been heavily fished over the last several millennia, there is still a very poor understanding of the spatial distribution of habitats that support marine life. New technologies are needed for data collection in coastal and deep-water fisheries, as well as at the ocean-land interface. While the biological assets of the ocean directly provide sustenance, it is equally important to increase the monitoring of ocean chemistry, currents, and other physical attributes that are likely to change in response to anthropogenic climate change.

Pollution and withdrawals have already threatened many freshwater sources around the world. Ecosystems that provide the service of water purification are also at risk, and need to be monitored to ensure future management decisions do not negatively impact fresh-water resources. Technologies such as remote sensing and wireless sensor networks can be used together to monitor changes in land-use and subsequent changes in freshwater systems. Tools are also needed to rehabilitate degraded systems.

Ecological measurements at the field scale have been hampered by a lack of consistency, high cost, limited repeatability and inability to capture data at varying temporal scales. An emerging technology that can be used to overcome these hurdles are wireless sensor networks. Previous generations of data loggers were bulky, expensive, and had to be regularly visited to retrieve data. New sensors are inexpensive, transmit data wirelessly to the internet and are significantly smaller. These sensor networks are also able to process data on the fly, providing in situ outlier analysis and ensuring data consistency. These data sensors could be used both in managed (agricultural) and natural ecosystems and provide data on both above and below-ground variables of interest.

While the use of monitoring technology is the crux to a better understanding of our planetary system, new visualization technology is also needed to effectively communicate how ecosystems respond to human pressures. This also needed to be coupled with a broad educational campaign to align the practices of ecosystem managers with new understanding about the dynamics of the system. Economic tools, like payments for ecosystem services, can be used to incentivize changes in behavior while political tools, such as global governance agreements, can be used to sustain global provisioning services. With the right information and the the sociopolitical will, ecosystem services can be maintained for many generations into the future.

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END OF OUR PAPER
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In a landmark 1997 paper, the average value of the world's ecosystem services was assessed at $33 trillion USD, as compared to the 1997 global GDP of $18 trillion USD

(Costanza et al, 1997). It was noted that many of the ecosystem services were non-market valued, and thus were not captured in standard economic metrics. When planning for sustainability, it is difficult if not impossible to account for, prioritize and manage those things that you do not measure nor assign value.

Ecosystem services flow from ecosystem functions. Ecosystem goods and services are the benefits that humans derive from the natural ecosystem functions. (Costanza et al, 1997)

Natural capital (represented by the ecosystem service product (Sutton & Costanza, 2002)) has been shown to contribute significantly to life satisfaction (Vemuri & Costanza, 2006).

The preservation of natural capital, and by extension its associated ecosystem goods and services, has been identified as a precondition for sustainability (Costanza & Daly, 1992).

Efforts for the global mapping of ecosystem services, which would allow for the identification of areas of priority, are in very early stages. Frameworks for doing so have been explored (Naidoo et al, 2008) [other models out there??? Mimes, Aries, Ideas???], but continued research funding and effort is necessary to bring this critically important information to light.

Ecological design and engineering practices have been under development since the 1970s (Odum, H.T., 1971; Todd & Todd, 1993) to provide for human well-being while at the same time protecting ecosystems and their related goods and services (Bergen et al, 2001).

Yadda, yadda, yadda...

Degraded landscapes can also be restored to varying levels of function. Restoration can be a slow process, or can be enhanced and accelerated through ecological design and engineering interventions. This restored function then allows for a restart in the flow of goods and services (Dodds, et al, 2008).

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Day one…

Ione: background in natural sciences, physiological and oceanographic tools
Anthony: algal biofuels, integrating ecology into urban settings
Greg: valuing ecosystem services???
Nir: climate and plant interactions as governed by water availability, and interested in

sust. Agriculture
Zaks: ag., climate change, ecosystem services,
Sharon: estimating carbon sources and sinks. Interested in valuing ecosystem services.
Derek Robinson: land use and land cover change, land use policy, patterns of CO_2 in land-cover patterns

Research questions:

Problem: current and future demand for food is increasing and leading to environmental impacts.
What do we have? How is it changing? What are alternative ways to account for what we care about? What policies or tools could help mitigate that?

How can global land use systems decrease their negative environmental impact and adapt to climate change while mitigating impacts?

Synopsis of first group discussion

Goals of our work/ challenges in this field:

- Understand how systems are changing
- Identify the drivers of harm
- Identify strategies to reduce those harms
- Develop quantitative measures of harm/ degradation for monitoring purposes (question of how to appropriately define baseline)
- Should aim to balance ecosystem degradation with human well-being in these measures

Overall, group has natural division, i.e. 1) How do we monitor/ model ecosystem services & degradation? And 2) What do you do with this information once you have it (technological solutions, policy interventions, etc.)?

Question over how much measurement/ modeling needs to be done to assess ecosystem degradation, perhaps a gap at the global scale?

In terms of solutions, technological fixes & policies have to work together to get to desired state.

Flow chart for our work:

What's wrong

How do we measure/ model this?

Solutions:

Technologies   Policy instruments

Day two…

Intro

How do we model/ measure/ develop quantitiative indicators for ecosystem services? (Why do we want to do this and how does it link to sustainability?)

Question: How do we incorporate biodiversity?

David: introduction

Measuring/ modeling/ quantifying ecosystem services

Sharon: strategies for monitoring carbon, also policies to make use of information, payments for ecosystem services (carbon offsets as an example)

Andy: LUCC & carbon stocks

Greg: how to measure ecosystem services within food & agriculture

Participatory citizen science…

Discussion section

Once we have this info, what do we do with it (i.e. technologies,adaptive policies, payments for ecosystem services)? For policies, given limited info, how to create adaptive policies? How do we develop a system that allows us to incorporate new information in a feedback loop?

Anthony: development of adaptive technologies given lack of all relevant information, avoid “lock-ins”

Nir: urban sustainability & relation to agriculture

Nate: water purification & topsoil

Derek: land use stuff

Tie this work into the material presented in course somehow!!! (complex systems, technological solutions vs. more holistic view including non-human systems?)

Everyone should write 1-2 paragraphs by tomorrow

Outline from Friday's discussion

- €€€€€€€€ Intro
- €€€€€€€€ Ecosystem services toolbox (quantifying ecosystem sustainability)
- €€€€€€€€ Provision of ecosystem services
    - Background with history of transition from resource-dependent societies to industrialized societies removed from provision of ecosystem services; many societies are still resource dependent!
    - Ocean food production
    - Freshwater
    - Agricultural systems – topsoil
    - Carbon absorption capacity
    - Air pollution (??)
    - Land use/ land cover change (ties together other ecosystem services)
- €€€€€€€€ Coupling human-environment systems (i.e. discussion)
    - Integrating human built capital into ecosystems
    - Protecting livelihoods of resource-dependent societies!
    - Payments for ecosystem services
- €€€€€€€€ Conclusions and summary of research gaps

Structure for each of the case studies:

Stock - description of the resource

Flow - extraction of services from resource & how its being degraded (is it sustainable?)

Future research areas/ solutions

[support for alternative agriculture research: as now on a small scale under USDA's Sustainable Agriculture Research and Education grant program, http://sare.org/]