Educating Engineers on International Environmental Security

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Introduction

The engineering profession wields the power of science and technology with the intent of building a better world. However, evidence exists suggesting that we may have become so good at the job of building new technological marvels that we fail in the mission of making a better world. In engineering terms, the life cycle costs of the engineered systems in the world may be an expense this earth can't afford, at least as technology is being implemented today. Admittedly, this represents a worst-case view of the environmental future. Technology has the capacity to do great harm or immense good. All engineers must learn to address the issues of a sustainable environment, and not just environmental engineers. Further, and more difficult, engineers must bridge the gap between the social science and the hard sciences to develop workable solutions within the social/political construct that governments employs to make public policy decisions.

This paper addresses two themes, one concerning engineering education and the second concerning the importance of sustaining the environment as a national security interest. The discussion of environmental security will be used to emphasize the first theme of broader approaches to engineering education.

Consider an illustration, working engineers recognize the importance of conducting design integration pulling together the individual pieces of a design into one coherent package. They have learned that bringing the mechanical, electrical, civil, etc., together to assemble the individual pieces into an efficient and workable design is an essential part of any complete engineering project. There is, however, a level above the engineering design integration step. This is where the social, political, economic, and technological components are integrated. The hypothesis here is that if these components are to be part of the engineer's job, they should be part of their education. At West Point we have developed this concept into the overarching educational goal of the Academy, stating[1];

> ***Graduates anticipate and respond effectively to the uncertainties of a changing technological, social, political, and economic world.***

Continuing with the example of design integration, how many engineers received educational preparation on this part of the engineering process? Nearly all senior engineers did not, while younger engineers may have some course work in this component of the design process.

Hopefully, this example highlights the need for the educational theme for this paper – Engineers must consider the complete implications of their projects and these must be in the broader terms of political, social, and economic impacts. Scientists and engineers are well known for their general disinterest in these kind of issues. How many of us have snickered at a television report or a news article where some political figure has done a really bad job of discussing the science of an issue. It isn't quite as funny when considering who is going to be responsible for making important public policy decisions about these issues, which will impact all of us.

The second message in this paper is built around this author's belief that the environmental burden of technological development exacerbated by a burgeoning population, represents the next generation of engineering challenges, and therefore, one that must become a goal for our engineering education. This is a view that global environmental issues must be addressed, not only for environmental engineers, but by all areas of engineering. The age of end of pipe environmental protection measures is being replaced by green engineering concepts; characterize it as environmental life cycle analysis.

Engineering for a sustainable environment is not a new concept, but the approach taken here is different because it considers these environmental issues in a national security context. This paper will describe the impacts of human activity in terms of environmental security, a term which will be defined shortly. As the cataclysmic actions of September 11th have shown us, nations are motivated to action driven by the actual or perceived threat to their safety and security. Unless environmental issues such as deforestation, global warming or ozone depletion are related directly to national interests, governmental action cannot be expected. Further, environmental security puts these issues into the same context as other security interests so that they can be analyzed as public policy issues, not simply esoteric issues for tree huggers to grasp onto.

To accomplish its goals, this paper begins by defining environmental security and introducing some of the major global environmental security issues. From this basis, it will then examine approaches to preparing engineers and other scientists to consider the broader challenges of developing solutions that meet the social, economic, and political needs of society, and not just the technological requirements.

Environmental Security Defined

This paper uses the term "environmental security" in a much more restrictive manner than found in many existing definitions for environmental security[2]. A cursory review of recent literature found over twenty distinct definitions for the term applied across a range of issues, from military protection of critical ecological resources to applying the term to collectively encompass the U.S. Department of Defense environmental compliance programs. The definition presented here is intended to describe the application of the term to the context of this paper and is not purported to be a final, inclusive definition of "environmental security."

> *Environmental security is a process for effectively responding to changing environmental conditions that have the potential to reduce peace and stability in the world and thus affect U.S. national security. U.S. environmental security involves accomplishment of the environmentally related actions specified in the National Security Strategy. Accomplishing U.S. national environmental security goals requires planning and execution of programs to prevent and/or mitigate anthropogenically induced adverse changes in the environment and minimize the impacts of the range of environmental disasters that could occur*[3].

Also important in defining environmental security is setting the limits as to what is not included in this working definition. This definition excludes issues of protecting deployed military forces from environmental hazards, issues related to war damage and restoration, and military unique environmental protection issues. Glenn[2], King[3], and others have found these issues discussed under the umbrella of environmental security, but they will not be applied here.

Environmental Security Issues

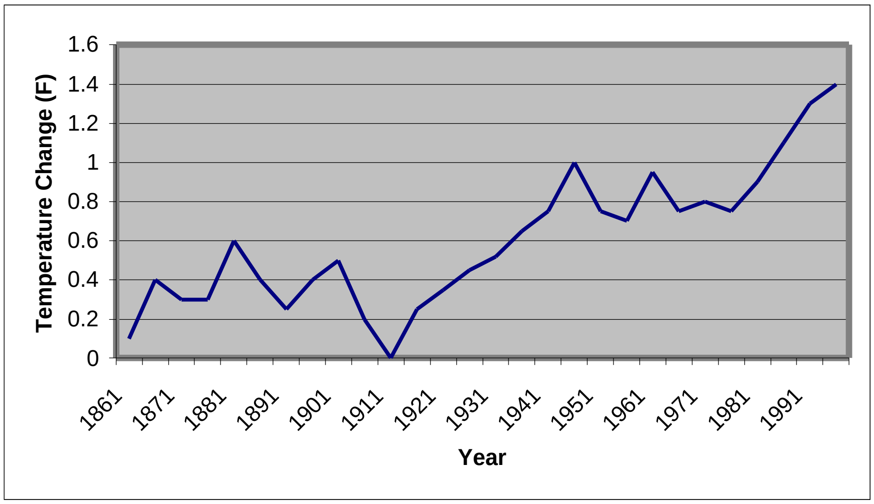
The environmental issues highlighted here are global climate change, deforestation, and water as a scarce resource. These are selected issues, intended to illustrate the concepts of environmental security, chosen from a compilation of environmental concerns identified in works published by the U.S. Environmental Protection Agency[4]. This environmental analysis begins with the issue of global climate change. Climate change is critical because it poses a significant risk based on its high probability of occurrence and the potential for severe consequences. Deforestation issues follow because, as the discussion will reveal, they are linked in both cause and effect to climate change and have a major impact potential, particularly in the developing world. The last general environmental security issue will be water as a scarce resource. The linkage between water and conflict is already well established by Lee[5], Schwartz[6], and many others, with the concerns for the future being more fraught with danger than any time in history.

Global Climate Change

Understanding global climate change is technically complex because of the many dependent variables associated with the carbon cycle, the enhanced greenhouse effect, and natural variability of weather and climate, even before factoring in anthropogenically induced change. Breaking the impasse on the science of global climate change has required considerable international cooperation, and in a sense can be considered as progress in security because of the many fruitful and cooperative relationships that have evolved. In 1988, the Intergovernmental Panel on Climate Change (IPCC) was formed. Over time the IPCC has produced several significant studies on this subject and has contributed to building consensus and reducing uncertainty[7]. The IPCC results will be the basis for discussion at several points in this review and analysis, particularly in areas where a wide diversity of opinion exists.

Many scientists now believe that global climate change in the form of global warming caused by anthropogenic activity is occurring. Driving global climate change is a series of interwoven phenomena including, but not limited to, deforestation, burning of fossil fuels, and industrial pollution. Each activity occurs independently at different rates, and concurrently with the natural variability in climate. Figure 1 depicts the change in world temperature over the past 140 years, the period for which accurate measured data are available.

FIGURE 1
Global Temperature Changes (1861–1996)



Source: IPCC (1995), updated.

Many look at these data and conclude that global warming is an acute problem brought on by human abuse of the environment[8]. Others, however, point out that this change over such a minute period in the history of the Earth is well within the statistical bounds of natural fluctuations[9]. Logically, the change illustrated in Figure 1 must be the result of both, i.e., the forced changes caused by human inputs imbedded in the natural variability for that period. Unfortunately, there is insufficient scientific understanding to precisely separate the two components at this time.

The consensus of scientists today is that the increase in carbon dioxide (CO_2) has a direct impact on temperature. Specifically, the increase in CO_2 is producing the increase in global temperatures. Data have confirmed the increase in atmospheric CO_2 by about 50 parts per million by volume over the last 40 years[10]. There is little argument that this increase is directly related to carbon emissions from burning of fossil fuels. Rate of temperature change within the

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dynamics of greenhouse gas behavior and natural climate processes is a key area of uncertainty in the global warming debate. The Intergovernmental Panel on Climate Change, predicts a 1.4 to 5.8 ^{o}C temperature increase (relative to 1900) by the year 2100[11].

This leads an area of debate in the global climate change discussion, and arguably the one of greatest contention in the scientific community. Complex interactions between systems, actions and counteractions of the carbon cycle, and other processes make it difficult to determine exactly how atmospheric warming will affect the Earth's ecosystem. Based on our current understanding of climate and weather, a rise in temperatures worldwide and changes in temperature distribution, spatially and temporally, will change weather and climate over large areas of the Earth. Weather is primarily driven by the sun's energy being unequally distributed over space and time. Higher temperatures will produce more evaporation from the oceans and this will increase rains, somewhere. Higher temperatures over land will increase evaporation of soil moisture, raise dry soil temperatures, and melt ice. All of these factors will combine to change the weather patterns of a particular region, in both frequency and intensity of events. These can, over time, sum to changes in regional climates in many parts of the world. Grasslands, forests, and deserts may shift in response to evolving climates.

Sea level rise as a direct response to global warming is an issue that has captured considerable public attention, although there are many other equally important issues, particularly in considering environmental security. Using the 1992 IPCC estimate as a basis for temperature rise, Houghton[10] predicted a 50-centimeter (1.65 feet) sea level rise by the year 2100. The most detailed statistical analysis of sea rise predicted a 35 cm rise by 2100 as the most likely result, with a 10 percent chance of sea rise reaching 65 centimeters, and a 1 percent chance of a 1 meter rise[12]. This rise, coupled with natural land subsidence in some lowland regions, could have large impacts in several critical areas of the world, such as Bangladesh and Egypt[11].

Deforestation

Deforestation, throughout time, has been the most fundamental and ongoing action of human modification of the environment. Trees are removed to clear land for agriculture, to provide lumber for building, to burn for heating and cooking, and for many economic activities. However, deforestation is not a completely anthropogenic process. Natural changes in climate and weather, forest fires and forest disease all occur at natural rates, producing changes in the types and locations of the world's forests. In a sense, a primary difference between developed and developing countries is that developed countries have reached equilibrium with respect to their renewable forest resources, while developing countries continue to reduce forest areas.

Tropical forests, located in the wet, always warm mid-latitude belt centered around the equator, occupied 1.8 billion hectares in 1990[13]. Nearly all tropical forests in the world today exist in the developing countries. These forests include both the rainforests with constant leaf cover and monsoon forests that lose their leaves in a dry season. Rainforests, which have literally thousands of species per hectare, are the most biologically diverse biome on Earth. Because of the thickness of the vegetation and the perennial biological activity, tropical forests are the world's most efficient regions for removing carbon dioxide from the atmosphere. The United Nations Food and Agriculture Organization (FAO) estimated deforestation in the tropics as 0.8 percent per year or 15.4 million hectares lost per year from 1980 to 1990[13] (that equates to denuding an area about the size of the state of Georgia each year). Population pressure is a direct and acute factor affecting the rate of deforestation. The need for more land for food production is the obvious driving force, but with 35 percent of the world's population relying on wood for cooking and heating—and most of these people in areas without good options to replace wood fuels—the population pressure is doubly intense[13].

Temperate forests contain a much wider variety of both deciduous and evergreen forest types and cover a much larger area of the world, 2.4 million hectares in 1990 as reported in the FAO study[13]. Temperate forests contain both deciduous and evergreen species of trees capable of survival in all but the coldest and/or highest altitudes in the world. Though not as productive in carbon cycling or as diverse in species as tropical forests, temperate forests have the ability to propagate over larger areas of the world, thus making them a critically important worldwide resource. Over the period 1990–1995, developed countries showed a net growth in temperate forest area of 0.12 percent per year. Some caution must be taken when considering this number, because it hides any losses in natural forest. In the FAO data calculations, losses in natural forest can be compensated for by increases in plantation acreage.

In many parts of the world, forests are the only appropriate use for the land because of shallow soils and high rainfall rates. Removing trees destroys the root structure that holds soil, thus increasing the intensity of runoff and allowing the soil to be more quickly eroded and washed away. In addition to affecting rates of storage of rainfall, deforestation has other detrimental effects on regional hydrologic cycles, with a net effect of less available water over time. Thus, the clearing of former forestlands for grazing and farming can have effects opposite to those intended. Clearing of the Amazon forests for pastures is a classic example of this issue as described by Serrao and Toledo[14]. These pasture lands quickly degraded into unproductive lands, which has caused people to cut more forest to replace the lost grazing capacity.

There is a strong relationship between the reduction in the amount of forest area in the world and environmental security. On a global scale, forests are important for the uptake of carbon dioxide as part of the global carbon cycle, which then serves to regulate the greenhouse effect. This alone would be sufficient reason to consider the security implications of deforestation, but there are further issues that result from the widespread loss of forest areas in a region. In relation to environmental security, the most critical concerns are:

- Reduced carrying capacity of the land,
- Loss of biodiversity with all of its known and unknown implications,
- Increased flooding and loss of soils, with resultant mudslides and waterway siltation, and
- Reduced economic benefits from loss of forests as a renewable resource.

Water as a Scarce Resource

Water is a resource critical for life and essential for economic success in a modern developed society. Water is required for domestic consumption, sanitary use, industrial use, electric power generating cooling water, hydroelectric generation, and agricultural irrigation. Water quantity can be measured in terms of total demand, but for this discussion is better represented in terms of the quantity per person over some period of time (daily or yearly). Over the past century, there was an eight-fold increase in total water demand driven primarily by population increases, while demand per person has generally doubled[15].

In terms of environmental security, an important question is -- what is the basic water requirement for a person to sustain a healthy life? This value must include water for drinking, cooking, and basic sanitation requirements such as personal hygiene and cleaning. One widely accepted estimate is the 50 liters per day per person purposed by Gleick[15]; his analysis for the mid-1990s estimated that 55 counties were unable to meet this requirement.

Quality is an under considered issue that must be addressed in any discussion relating water supplies to security. The World Health Organization (WHO) estimated that 1 billion people a year contract a water-borne diarrheal disease and that 3.3 million of these people die, every year[16]! This does not account for many other water-borne diseases that inflict pain and suffering pandemically throughout the world. A primary quality concern in the developing world is human waste being disposed of in surface waters. This contaminates drinking water supplies, and this water then being consumed without adequate treatment. Clean water is a critical issue for parts of South and Central America, most of Africa, and much of Asia. The human and economic impacts of disease are major destabilizing influences in many countries world-wide.

Salinity in water is another major quality issue of concern in agriculture and industry. Salts present in irrigation water are retained and concentrated in the soil as water naturally evaporates from the upper soil layers. Over time and without adequate rain to dissolve these salts back into the water for transport away, salt levels in irrigated soil build up to concentrations toxic to many plants. These lands are then lost to production or can only be used for crops more tolerant of salt. Such crop choices are quite limited. Salination is reducing food production rates in many parts of the world today, mostly in arid regions where lack of rainfall makes soil recovery times very long. As an example, the U.S. is experiencing this problem in isolated parts of the arid West and Southwest.

Many contend the economic development is a long-term solution to many of the water related problems. The impact that development has on water use can be seen by comparing water use in the U.S. with world water use. In 1900, world demand was approximately 300 cubic meters per person per year (M^3/p/yr), while in the same units U.S. demand was 700. In 1980, world consumption had grown to 700 M^3/p/yr, while in the U.S. demand had reached 2700 M^3/p/yr. In terms of these units which factor population growth out of the equation, water demand in the U.S. had grown by a factor of four while world demand had increased by a factor of only two [15]. The important point here is that transforming from a developing to a developed society has greatly increased the requirement for water.

The water problem evolves to one of trying to reconcile supply with the spatial distribution of demand based on population. Supplies are fixed, while demand continues to grow rapidly, and not always in the best locations. There has been progress in improving management practices, but these have reduced the rate of growth in demand per person, not total consumption. In this context, the U.S. can be considered a recent good news story. By 1995, demand in the U.S. had dropped from 2,700 to 2,200 cubic meters per person per year, resulting in a flattening of total demand over the past 20 years. This was achievable only in concert with a small population growth rate over the same period.

The bottom-line for water as a scarce resource is:

- Demand will continue to increase steadily and in direct proportion to population growth,
- Modernization (development) will increase demand, not reduce it, and
- It can be expected that, in areas experiencing water shortages now, conditions will worsen, while many more areas of the world will reach their limits of available water resources.

Overall, water is a problem affecting basic survival in at least one third of the world and a limiting factor in development for most of the world. As an anonymous American sage once said, “People argue over politics; they fight over water.”

In summary, just three examples highlight how the environment can produce the security and stability concerns in a region. By studying Table 1 one can see the range of major environmental concerns by region of the world. This summary clearly demonstrates the breadth and depth of the issues, while recognizing the threats to world stability they pose. These data strongly support the need for action on many of these problems and the imperative of continued study to better define the impacts for many others.

Educating Engineers on Environmental Security

The sciences underlying the environmental security issues are straightforward for most engineers, while answers to what should be done are generally much more elusive. Analysis to develop answers must begin by examining the fundamental concepts essential to defining the social, economic, and political impacts. Educationally, engineers study only the technical component., For this reason, it is helpful to examine in the context of environmental security the social, economic and political components in just a little more detail.

The economics of security issues have been succinctly portrayed within the old civics debate of whether a government should invest in 'guns or butter' — defense or domestic spending. Engineers are well trained in the economics of calculating the time value of money and life cycle costs. They spend far less time in studying macro-economics or the international economic system, yet these are the systems that must be employed to find solutions to global scale problems such as environmental security.

The social/political sciences that are most relevant to the engineer and scientist working in public policy decision-making are those that help define the operating governmental structure. This concept is absolutely true for studies of environmental security. The *U.S. National Security Strategy (NSS) for a New Century* is the blueprint for all governmental actions associated with national defense and thus is the basis for strategic planning[17]. The NSS is the guide for all segments of national government as they map out their activities in pursuit of peace and security for the U.S. Environmental security is one of several issues raised in the NSS requiring coordinated actions from many agencies and departments, including but not limited to the Department of Defense (DOD).

The use of military power is only one way of protecting national security. The U.S. *National Military Strategy states*[18], "The military is a complementary element of national power that stands with the other instruments wielded by our government." Diplomacy through the Department of State and economic leverage are just two examples of how other government activities can be brought to bear on security issues. These are complex systems that operate well outside the normal perspective of the engineer or scientist. Here political law, regulation, and policy are controlling.

Educating Engineers– Some Thoughts

The obvious primary finding of this work is – more attention must be paid to educating engineers on social, political, and economic aspects of policy decision-making. How this is accomplished is the difficult issue. Certain basic knowledge must be addressed in a core curriculum for all students, a set of courses imbedded in all majors focused at achieving a set of overarching academic goals. Secondly, engineering curricula need to encourage opportunities for students to pursue interests outside the technology in their disciplines. The ugly and many headed beast, ABET (Accreditation Board of Engineering and Technology), has long been viewed as the major encumbrance to a broader education for engineers, but this impediment seems to be lessening with new criteria of ABET 2000[19].

Focusing on the ideas of environmental security presented in this paper, environmental education that discusses green engineering concepts more than treatment technologies must be developed and implemented in engineering education. These topics should become part of every engineering course of study. One shouldn't think about new courses as much as the need to look at opportunities for incorporating these topics into teaching the design process. Environmental protection topics may be the best opportunities available for all types of engineers to consider the social, political, and economic considerations of design. They also yield a robust set of courses of action, which produce challenging multi-disciplinary team projects and lead to developing better problem solving skills.

Consider, one example to illustrate this idea – A project to develop a small hydroelectric dam on a river separating two developing countries. Civil, electrical, mechanical, and environmental engineers will be heavily involved in the technical aspects of developing a concept design for the project. But, as practicing engineers well know, there is much to this project that involves the economic, social, and political ramifications. Typically, it will be these issues that will control the fate of this project, not the technical aspects. Where to build the dam has social, economic, political, and technical constraints. Water as a scarce resource for the region has the same suite of concerns across the four areas of interest. The environmental setting before and after the dam must be analyzed. The region security implications of the project become a primary political concern. Done well the project could enhance security of all parties. A poorly designed project could disadvantage one group creating more instability than existed before. Courses of action that address and mitigate different concerns must be conceptually designed and analyzed. Problem solving becomes complex and open-ended. Overall, the benefits of this type of project and this approach to education are clear. A cost is that more preparation of students in non-technical subjects is needed. Additionally, these types of projects, particularly if conducted in an interdisciplinary framework, generally require more administrative work for the faculty.

The West Point environmental science and engineering program has developed three approaches to addressing a broader education base and environmental security analysis. There is a capstone course, which focuses on environmental security issues. Second, there is a water resources course that deals with primarily water as a scarce resource, while applying rational decision making tools to evaluate courses of action for design. Third, there is an increased emphasis on developing inter-disciplinary senior design teams to conduct undergraduate special studies. The West Point model is not directly transferable to all schools because there are unique aspects to the curriculum that allows employment of these three approaches. Primarily, there is a core curriculum for all cadets that establishes a foundation to leverage in considering social, economic and political dimensions of a problem. All cadets take courses in economics, social science, and political science. However, this allows us to work at a higher level of detail, but does not mean that others could not introduce and discuss ideas related to social, political, and economic principles. As educators, this represents a challenge to many faculty members, taking us out of our comfort zone of science, while requiring us to prepare to teach in different ways.

Summary

Environmental security is an issue of growing importance in the world, one that shakes at the foundations of world peace. The best example that can be offered is Afghanistan. Following the methods of analysis developed in ***Understanding Environmental Security***[3]. Afghanistan is one of the world's 'TOP 10' worst countries, from an environment security perspective. It is heavily deforested, cannot provide even minimal potable water, has almost no public sanitation, and continues to have high birth rates in the population. The Taliban and the foreign terrorists were the visible security threats, but the true story is the hopeless human condition that underlies the country. History shows that these conditions are requisite for fomenting anarchy in a population and as catalyst to terrorism[8].

Engineers are going to be required to address the root problems just described in Afghanistan and rebuilding the infrastructure; there will always be a technical component. However, engineers must also be prepared to do more than just technical design, at least some of them. Teams will need to answer all the questions, not just the technical issues. The educational goal should be engineers that are capable of dealing with social, economic, and political components of complex interdisciplinary problems based in science. Otherwise, we may have to teach engineering and science to the politicians and that would be really hard.

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TABLE 3

Impacts of Environmental Change[3]

	Global Environmental Concerns				Regional Environmental Concerns			
Environmental Issue	Farmland	Forest	Water / Fish	Human	Farmland	Forest	Water / Fish	Human
Global Climate								
- Warming	Inundation of arable lands, drier soils in summer	Change in shape of temperate and tropical forests	Weather changes impact the hydrologic cycle	Natural hazards, property loss, heating & cooling costs	Wetter wet seasons, drier soils in dry season	Shifts in size and location of temperate and tropical forests	Changes in rain patterns, change in temporal and spatial distribution	Increased disease in developing countries
- El Niño	---	----	---	---	Increased erosion	Change in water distribution	Increased winter rains, loss of fish in Pacific	Flooding and other natural hazards
- Ozone depletion	UV damage to many species of plants & animals	UV damage to many species of plants & animals	---	Cancer	UV damage to many species of plants & animals	UV damage to many species of plants & animals		Cancer in Southern Hemisphere
Land Issues								
- Deforestation	---	Greenhouse gases produced, less CO_2 recycled, loss of biodiversity	Reduction of groundwater recharge, siltation of streams	Indigenous tribes endangered, biodiversity lost	Temporary increase in cropland	Net loss, particularly in tropical forests, Biodiversity loss	Decreased groundwater recharge, increased runoff rates	Loss of Indian habitat in rainforest, loss of beneficial species
- Desertification	---	---	---	Displacement herding populace	Loss of productive lands	Encroachment on fragile forests	Reduced soil moisture, can increase runoff & reduce recharge	Migration of African nomads
- Waste disposal	---	---	Contamination of surface & ground water and fish	Toxic exposure	---	---	Poisoning of water supplies & fish	Toxic exposures; contamination of water resources and food chain
Water								
- Quantity	---	---	Freshwater fish lost, reduced productivity in estuaries	Increased migration	Reduced irrigation and grazing	Highly variable impacts by regions	Freshwater fish lost, reduced productivity in estuaries	Increased migration
- Quality	---	---	Toxicity and bioaccumulation of toxics	Increased rates of disease	Salinity reduces productivity	Acid rain damage	Toxicity and bioaccumulation of toxins	Disease increases in developing countries
- Oceans	---	---	Overfishing is endangering stocks	Loss of fish, disease exposure	---	---	Overfishing is endangering stocks	Loss of fish protein; disease