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THE ECONOMICS OF ENVIRONMENTAL SECURITY: INTRODUCTION

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FOREWORD

Among the expected consequences of economic globalisation are several environment-related issues, each of which could involve some potential for international disagreement:

- more competition for some environmental resources (e.g. water, ocean fisheries);
- more places at which pollution originating in one country might affect people living in another country (e.g. transborder air and water pollution);
- increased international traffic, and therefore new opportunities for international transport-related environmental disasters (e.g. oil spills), or for pests/health hazards to enter into the environments of other countries (e.g. alien species);
- increased ability of citizens in one country to be aware of environmental problems in other countries, and the way in which these problems might affect them.
- differing valuations being placed by different countries on environmental degradation. Different valuations may, in turn, lead to different views about how serious the environmental problems are, and what should be done about them.

Failure to adequately deal with each of these issues could contribute to a problem of "environmental security" in some OECD countries. This possibility has therefore gained some degree of predominance in recent years. For example, the final Communiqué from the June 1998 G-8 meeting in Denver did not address environmental security issues *per se*, but did state that:

"... Together, we are pursuing a strategy of global integration to create a more *secure and stable* international community. Already, we have used our political co-operation to broaden and deepen the community of open markets and open societies, and in the next year we will work together to build on these efforts. Our Partnership for Development is designed explicitly to support the economic and political development of nations which run the risk of being marginalised from the process of integration. We will focus our energies on strengthening adherence to the norms and principles of international co-operation, and will work together to take effective measures against those who threaten those objectives. We recognise our common interest and responsibility in helping *bring an end to conflicts* that threaten to *disturb international peace* and to undermine our deepened co-operation." (Emphasis added).

This report is a first attempt at scoping some of the *economic dimensions* of the environmental security problem. It was originally drafted by Robert C. Anderson, Resource Consulting Associates, USA. It has since been revised, based on comments received from OECD Member countries.

The report is published under the responsibility of the Secretary-General.

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Introduction/context

Although the term "environmental security" has appeared regularly over the past decade in the foreign policy literature, there is no clear consensus on a definition. The term is used most often to address national security issues and threats of military action that are caused entirely or partly by environmental problems. For example, Gorrissen (1993) identified several avenues through which national security interests could be adversely affected by environmental issues.

- transboundary environmental issues as problems for external relations;
- environmental degradation as a cause of regional conflict;
- destruction of global ecosystems that precipitate interstate conflict;
- environmental issues in international law;
- environmental degradation caused by military activity;
- ecological consequences of conflict; and
- destruction of the environment as an instrument of war.

As early as 1983, Ullman argued that a nation's security would be threatened by events that could drastically degrade the quality of life for inhabitants over a relatively brief period of time, or that could significantly narrow the range of policy alternatives available to governments (Ullman, 1983). In this perspective, the threat of military action or open conflict is not necessary for there to be a threat to national security. Environmental or resource problems that could greatly diminish incomes or employment, cause health problems, or constrain policy responses of the government would also be threats to national security.

Former US Secretary of State Warren Christopher and his successor Madeline Albright have both argued that environmental and natural resource problems in other nations are security concerns for the US, to the extent they affect the health or prosperity of US citizens. In this view, dealing constructively with natural resource and environmental issues in other countries is essential if US foreign policy objectives of political and economic stability throughout the world are to be achieved. A recent initiative of the US State Department set up six regional environmental "hubs", with six more scheduled for 1998 (Table 1).

Table 1. US Environmental "Hubs" and their Principal Concerns

San Jose, Costa Rica	Biodiversity, deforestation, and coral reef management
Addis Ababa, Ethiopia	Nile River sharing and desertification
Amman, Jordan	Water sharing and environmental issues related to Middle East Peace process
Kathmandu, Nepal	Water sharing, deforestation and energy
Bangkok, Thailand	Deforestation and marine resources
Tashkent, Uzbekistan	Aral Sea

Politicians and scientists in Germany, Norway and other European nations have also made public statements on environmental security that recognise both the "conflict-based" perspective and the "economic well-being" perspective (e.g. Stubb, 1996; Bachler *et al.*, 1993). Many international organisations also have active research programs on conflict-based risks created by environmental problems and potential responses that could be taken (Table 4).

The various descriptions of environmental security that are offered in the literature converge around four broad issues. One is *environmental* (or resource) degradation. Environmental degradation may then result in *economic* losses and/or increased international economic competition. Environmental and economic problems can escalate into *political* conflict within and among nations. If these political conflicts become severe enough, *military* conflict may ensue. Each of the issues described in this paper touches on different elements of this classification. For example, biodiversity is still largely an environmental issue, water pollution is mainly an economic question, climate change is now a political problem. Whether any current environmental security issue poses real threats of military action is debatable.

Other ways of classifying environmental security issues include their geographic scope (global, regional, or local), or whether they are "environment-based" (climate change, stratospheric ozone depletion, air and water quality, biodiversity, oil spills, micro-organisms) or "resource-based" (water quantity, minerals, land degradation and fisheries).

This report reviews evidence that a number of OECD countries are already experiencing a loss of economic well-being from mismanagement of resources partially or totally outside their immediate control. It begins by reviewing a number of prominent environmental security issues. It then summarises what is known regarding the economic dimensions of these issues. These economic dimensions include: (i) the size of the problem; (ii) where the problem is most severe; and (iii) the costs and benefits of potential policy responses to these problems. The paper then concludes with a discussion of several options for future OECD work in this area

Principal environmental security issues facing OECD nations

This section provides an overview of several prominent issues in environmental security. However, it does not claim to provide an exhaustive list of all the issues, nor of all countries in which these problems actually occur. In addition, all of the historical material cited here for each example is already on the public record. The objective of the section is merely to give an indication of the breadth of the issues involved, not to focus attention on the specific situation in any particular country.

The section begins with an examination of environmental security issues that are primarily *global* in scope: climate change, stratospheric ozone depletion, and loss of biodiversity. It then turns to issues that are largely *regional* in scope: transboundary air and water pollution, land degradation and desertification, water scarcity, mineral rights, nuclear power plants, fisheries management, and viruses. Finally, it examines issues that are mainly of *local* interest: introduction of alien species, hazardous waste disposal, and oil spills. These classifications may be debated, and should not be viewed as being fixed. For example, fisheries management problems could have global, regional, or local elements, depending on the particular species being assessed.

Climate change (global)

Scientists are now in basic agreement that anthropogenic emissions of carbon dioxide, methane and other gases will intensify the "greenhouse effect" in the earth's atmosphere (Houghton *et al*., 1996). While the timing and location of these effects are still being debated, there is potential for a warming of several degrees Centigrade, melting of parts of the polar ice caps, and more violent storms.

Some threats to national security are likely to be very direct. Small island nations could actually disappear as the oceans rise. Low-lying coastal areas that are presently home to hundreds of millions of people could become inundated, or swept by storm surges. Other threats are more indirect. For example, changes in rainfall and temperature could increase crop yields in some areas, and reduce yields elsewhere. Reduced crop yields could precipitate population migrations toward urban areas, or from country to country. Population movements could create unrest and political difficulties among nations (Bruce *et al*., 1996).

Stratospheric ozone depletion (global)

Until recently, chlorofluorocarbons (CFCs) and hydrofluorocarbons (HCFCs) were widely used as refrigerants to produce styrofoam, and as propellants for hair spray and other consumer products. Scientific evidence now shows that CFCs and HCFCs emitted into the atmosphere can migrate to the stratosphere and attack ozone molecules that otherwise provide a shield against ultraviolet radiation (Service, 1995). Resultant increases in ultraviolet radiation are likely to increase human skin cancers, damage eyesight and adversely affect plant and animal life. CFCs and HCFCs also are potent greenhouse gases (USEPA, 1996). A world-wide response to these concerns led to the ratification of the Montreal Protocol, whose aim is to phase-out production and use of CFCs and HCFCs. The main potential national security issue here is related to a world-wide threat to health and economics (well-being).

Biodiversity (global)

A recent UNEP report concluded that 5-15 per cent of some groups of plants and animals could face extinction in the near future (UNEP, 1995). One of the principal economic arguments for preserving species is that many useful drugs have been derived from "wild" organisms. Quinine, aspirin, and taxol are among many other drugs with natural origins. One might take these discoveries as justification for preserving the rain forests of South America and Southeast Asia, as well as the jungles of Africa and other locales, as potential sources of new medicines. Preservationists might also argue that humans do not have a moral right to harvest higher-order organisms, such as whales, seals, elephants, tigers, etc.

Rare or exotic species may also have a commercial value in game parks or for "ecotourism." There may be ecological values derivable from protecting ecosystems, and from maintaining a balance among naturally-occurring species. In addition, individuals may wish to preserve biodiversity and natural habitats for aesthetic, ethical or spiritual reasons. Thus, threats to environmental security related to a loss of biodiversity arise largely from decrements in human well-being caused by impacts on aesthetic values, a loss of economic opportunities, increased health risks, and reduced recreational opportunities.

Viruses, micro-organisms (global)

Despite improved medical technologies, new and improved drugs, and better scientific understanding of their processes, bacteria, viruses and other tiny organisms continue to exact a toll on human life, a toll that may be increasing over time.

Pirages (1996) identifies several reasons why micro-organisms continue to adversely affect human welfare: population growth; increasing urbanisation (especially in poorer areas in developing nations); the immunity that several pathogens have developed to modern drugs and treatments; and increased opportunities for the transmission of disease through tourism and air transport. Animal-to-human transmission of disease is also increasingly being recognised as a source of health risks.

Threats to national security from micro-organisms are largely health- and welfare-related. Recent experiences with "mad cow disease" and the "bird flu" in Hong Kong illustrate that micro-organisms can cause political tensions, in addition to generating significant economic losses.

Fisheries (global, regional, and local)

According to the UN Food and Agriculture Organisation (FAO), world ocean fish catches have increased five-fold since World War II. These catches have increased steadily since 1991, after a modest decline in the three preceding years. They stood at 87.1 million tonnes in 1996. A not insignificant amount of the 1991-96 increase appears to have been in the categories of "miscellaneous fishes" or "miscellaneous marine crustaceans", suggesting that at least some of this increase has come from the exploitation of new and under-used species.(FAO, 1996). Fishing effort (measured both in terms of vessels and catch capacity) grew even faster than catches, with the consequence that yields per unit of effort has fallen significantly since the early 1980s. FAO data also indicate that 11 of the 15 major fishing regions of the world are already seriously depleted, or being fished near their regenerative limits.

Security issues related to world fisheries arise in at least two contexts. First, there is the immediate risk of conflict over access. Second, there are often conflicting views among countries about the optimum long-term management of international fish stocks.

With nearly one-fifth of the world's population dependent on fish as its primary source of protein, it is not surprising that there would be occasional conflict between nations over access to ocean fisheries. While physical conflicts over fisheries access are uncommon, heated political disputes are still occasionally observed throughout the world.

FAO statistics reveal well over 100 international disagreements in this area (Wigan, 1997). Before 200-mile territorial limits were accepted, fishers participated in a number of serious confrontations. For example, conflict erupted between the UK and Iceland on three separate occasions (1958, 1972-73, and 1975-76), when Iceland extended its fisheries exclusion zone from 4 to 12 miles, then from 12 to 50 miles, and finally from 50 to 200 miles (Trolldalen, 1992).

Canada and the United States have also argued over which country has rights to the salmon that migrate across the BC-Alaska boundary. In 1997, the British Columbia government brought a lawsuit in a Seattle court seeking compensation of up to $350 million for alleged US over-fishing (Morrison, 1997).

Canada and EU nations (especially Spain) have argued for years about the impacts of European fleets operating on the outer edges of Canada's eastern continental shelf. Iceland and Norway have argued

over rights to the cod fishery in the Barents Sea; Japan and Russia have had recurring fisheries disputes, as have China and the Philippines. Chile, Peru and Argentina each have on-going disputes over access to their coastal fisheries with the US and Spain (Trolldalen, 1992). In addition, Japan has on-going disputes with Australia and Indonesia; France with Morocco; and the UK with Spain (Wigan, 1997). At least as far as OECD countries are concerned, regional fisheries management organisations (RFMOs) are contributing to the defusion of some of these disputes.

Long-run management of the fisheries is another source of international tension -- a source which is becoming increasingly visible as world fishing fleets continue to expand. Over-capitalisation (too many boats and too many fishermen) relative to available stocks wastes valuable economic resources. Depletion of fisheries stocks due to over-fishing and pollution ultimately reduce food supplies in some situations. With better management, FAO estimates that the fisheries catch on the high seas could be increased by at least 30 per cent, and that this higher catch could be attained with about half of the present level of investment (FAO, 1995).

Transboundary air pollution (regional)

Transboundary air pollution is a contentious issue in many parts of the world. For example, soft coal burned in a large electric power station in Mexico has been reported to impair visibility in Texas' Big Bend National Park -- an area that once had a 200-mile (320 km) visible range on most days (National Park Service, 1997). Factories and automobiles in Juarez pollute the air in nearby El Paso. Sometimes, financial arrangements can be made to share the burden of costs associated with pollution control activities. In the Juarez-El Paso case, Mexico and the US have agreed to a regional program to trade emission reduction credits in an effort to reduce pollution control costs (Anderson and Lohof, 1997).

Sulphur dioxide emissions from coal-fired power plants in the UK are transported via northerly winds to the Scandinavian countries, where they are thought to damage forests and ecosystems (Spratley, 1996). The US and Canada argued for years about damage to their respective forests and lakes from sulphur dioxide emissions from electric power plants in their respective jurisdictions, before agreeing to reductions in emissions in both nations (USEPA, 1998). Japan and Korea have complained about the impact on their forests and lakes from sulphur dioxide emissions produced by coal-fired power plants located in China. Japan currently is paying China to install scrubbers, in an effort to reduce this problem (Hadfield, 1997).

During the months of August and September each year, loggers on the islands of Sumatra and Borneo set fire to brush to clear lands for palm oil plantations. While the fires often spread to nearby brush and forest areas, they are usually soon contained by monsoon rains. Because of very dry conditions in 1997, burning brush and forests ignited peat and soft coals below the surface. A severe regional haze spread across Indonesia to the neighbouring nations of Singapore, Brunei, Malaysia, southern Thailand, and as far as Manila in the Philippines. Visibility of as little as 1 meter in Kuching, capital of the Malaysian state of Sarawak, disrupted land, sea, and air traffic (*Straits Times*, 1997*)*. Sarawak declared a state of emergency, and all schools and government office buildings closed in Kuching. In Indonesia and Malaysia, over 50 000 people were treated by their doctors or admitted to hospitals for respiratory problems. The result was considerable tension among the various nations involved.

Transboundary air pollution affects both health and economic welfare. Pollution sources in one nation have little or no incentive to incur costs to control pollution that inflicts most of its harm on inhabitants of down-wind nations. With sufficient complaints from the victims, transboundary air pollution can often escalate to become an important political issue. For a variety of reasons, this problem

is unlikely to be completely remedied by the victims offering cash payments to the polluters to stop their activity. This remedy will work reasonably well in some circumstances (and several international side payments based on the "Beneficiary Pays Principle" are already in existence). However, this approach will not work well in all situations (high transactions costs of aggregating payments by "beneficiaries" and "free-rider" problems make side payments problematic; perhaps the "polluter" is unwilling to alter its behaviour at any price).

Several international agreements exists to cope with problems caused by transboundary air pollution. Among these are the (1979) Convention on Long-Range Transboundary Air Pollution, and its various Protocols (especially the Protocol of 1985, which called for a 30 per cent reduction in SO_2 emissions; the (1988) Protocol Concerning the Control of Emissions of Nitrogen Oxides or Their Transboundary Fluxes; and the (1991) Protocol Concerning the Control of Emissions of Volatile Organic Compounds). By 1993, all Parties to the Sulphur Protocol had reached their reduction targets, and overall emissions were down 48 per cent from the 1980 baseline (UNECE, 1995). A new Protocol on Further Reduction of Sulphur Emissions (known as the "Second Sulphur Protocol") was then adopted in 1994 by a wider range of countries than had signed the original Protocol nine years earlier. This Protocol called on signatories to limit their emissions of SO_2 according to percentages defined in a specific schedule. It also set emission requirements for certain stationary sources, and for the sulphur content of some fuels. New Protocols on Persistent Organic Pollutants (both pesticides and heavy metals) are also currently under development.

Transboundary water pollution (regional)

Pollution of rivers that cross (or form) national boundaries is a significant problem in many countries. Consider the Rhine River in Europe, where water quality is much improved today, largely due to an agreement among several nations to control effluents (International Commission for the Protection of the Rhine, 1994). Reducing industrial, municipal and agricultural discharges into the Danube has been much more difficult (Murphy, 1997). The discharge of municipal sewage and industrial waste into rivers flowing from Mexico into the United States is a long-standing problem that has proven very difficult to resolve, despite pollution control laws in both nations (Pauw, 1996). In Central Asia, pollution of the Syr Darya from mining wastes and agricultural runoff in the upstream Kyrgyz Republic, has created significant problems at downstream settlements in Kzyl-Orda and other parts of Kazakstan (Corzine, 1997).

Transboundary water pollution is primarily an issue of health and agricultural productivity, although it also affects fisheries and other wildlife resources. Pollution sources in one nation typically have little incentive to control pollution that inflicts most of its harm on down-river nations. With sufficient complaints from "victim" nations, transboundary water pollution can sometimes become an important political issue -- one that can only be resolved through negotiations involving the governments of the countries involved.

Land degradation and desertification (regional)

According to von Kalbermatten (1996), in the next 20 years, as many as 100 million people may be displaced due to land degradation in dryland areas and tens of millions more where tropical forests have been replaced by agricultural activity. Degradation of drylands is termed "desertification", and is the subject of the 1992 Desertification Convention.

Land degradation is attributed largely to unsound agricultural practices. Forests and brush are cut and crops are planted in thin soils on sloping lands. The land is subject to erosion, polluting water supplies and reducing the potential of the land to grow anything of value. Declining productivity of the land adversely affects food supplies and incomes, creating pressures for migration, as well as the potential for conflict.

This problem is especially apparent in Nepal, India, the Philippines and large parts of the African continent. In the Americas, Haiti has lost 98 per cent of its forest cover and nearly one-half of its lands are no longer productive. Argentina, north-east Brazil, the Peruvian coast and much of Mexico have also experienced major losses of this type (Schwartz and Hanson, 1997).

Losses of productive land may exacerbate population migrations towards already-overpopulated urban areas, as well as adding to migration-related tensions among some countries. In this context, the environment may suffer a "double setback". Land degradation is the source of the problem, and can lead to population migration. These populations then settle in new areas (or new countries), where new environmental pressures are then generated.

Water scarcity (regional)

Water scarcity has resulted in economic and/or political tensions among many nations of the world. Looming water scarcities are a threat to global peace over the next several decades, since several countries are already reported to be withdrawing considerably more water than natural renewal rates (World Resources Institute, 1996).

For example, the Jordan River has no binding water-sharing agreement, and water-related conflicts between Israel and its neighbours have simmered for decades. Water is also an issue among Turkey, Syria, and Iraq in the Tigris-Euphrates Basin (World Bank, 1995).

The Nile Waters Agreement of 1959 between Egypt and the Sudan allocates water between the two countries in proportion to populations at that date, with Egypt receiving 75 per cent and the Sudan 25 per cent of the average flow at Aswan. However, about 85 per cent of Nile flows originate in countries that did not participate in the 1959 accord. Until now, there has not been much of a problem, since flows have generally exceeded demands. However, new agricultural and industrial development throughout the basin may increase demand to the point where allocation issues become more acute (Marcus, 1997).

Following the break-up of the Soviet Union, five nations formed in Central Asia: Turkmenistan, Tajikistan, Uzbekistan, Kazakstan, and Kyrgyzstan. Two major rivers (Amu Darya and Syr Darya) originate in the high mountains of the Kyrgyzstan, Afghanistan, and Tajikistan, and flow to the Aral Sea. Water resources in the region are very scarce. When control of the dams and irrigation systems of the region rested with Moscow, the over-riding objective was to maximise cotton output. The challenge now for these nations is to agree on an overall strategy of water allocation to maximise collective welfare (Keith, 1997).

The operation of the Toktogul reservoir on the Syr Darya provides another example. Having few fossil fuel resources, Kyrgyzstan would like to maximise its electric power output during the winter months. However, the downstream republics of Uzbekistan and Kazakstan need the same water for irrigation during the summer months. This situation is complicated by the fact that the channel of the Syr Darya cannot carry all of the flows released from the Toktogul Reservoir during the winter months, with the result that the excess water must be diverted to the Aral Sea. For the past three years, Uzbekistan and

Kazakstan have agreed to send coal and natural gas to Kyrgyzstan during the winter months, in exchange for greater water allocations during the summer growing season. These barter arrangements, however, are fragile. Pressure is therefore growing to forge a permanent arrangement (Keith and McKinney, 1997).

Europe has also witnessed its share of water allocation disputes. In 1976, for example, the governments of Czechoslovakia and Hungary signed an agreement to construct the Gabcikovo-Nagymoros Barrage System on the Danube. The objective of this agreement was to produce electric power, to provide a new route for inland navigation, and to stimulate economic development in the region. Citing environmental reasons, Hungary stopped work on the project in 1989, but the Slovak Republic decided to build a similar structure further upstream. This action upset Hungary, because it altered the natural border between the two countries, and changed the navigational route for Hungarian trade, so that it passed through Slovak territory. The EU entered the discussions in 1992, and attempted to broker a compromise. The case was finally referred to the International Court of Justice, which ruled in September 1997 that both countries were at fault -- Hungary for backing out of the original agreement, and Slovakia for unilaterally constructing the dam. The Court ordered both countries to resume good faith negotiations to resolve outstanding issues (Eckstein, 1995).

Several other ongoing disputes over the management of transboundary rivers and/or international lakes are identified in Table 2.

Table 2. Selected Water Management Disputes

River System(s)	Countries Involved	Main Sources of Dispute(s)
Elbe	Czech Republic, Germany	Industrial pollution
Ganges	Bangladesh, India	Siltation, flooding
Great Lakes	Canada, US	Water diversion, industrial pollution, agricultural runoff
Indus, Sutlei	India, Pakistan	Irrigation
Jordan, Litany	Israel, Lebanon	Water flow
Lauca	Bolivia, Chile	Dam, siltation
Mekong	Kampuchea, Laos, Thailand, Viet Nam	Water flow
Parana	Argentina, Brazil	Dam, flooding
Rhine	France, Germany, Netherlands, Switzerland	Industrial pollution
Rio Grande, Colorado, Tijuana	Mexico, US	Salination, water flow, agricultural runoff
Szamos	Hungary, Romania	Industrial pollution
Yarmouk	Jordan, Syria	Water flow

Source: Adapted from Trolldalen, 1992.

Nuclear power plants (regional)

In Central and Eastern Europe, there are more than 30 nuclear power stations, with 70 operable reactors. At least 30 more are under construction, and approximately 40 are in the planning stage. Despite having a smaller proportionate number of reactors, the CEE region is thought to have a much higher risk of accident than the rest of Europe. Many of the reactors are of Soviet design and lack the outer containment shell that is found on western installations. The explosion at Chernobyl, with associated loss of life and contamination of the environment, illustrates the risks inherent in these reactors (Nuclear Energy Agency, 1995).

Bulgaria, Lithuania and Slovakia have received notification from the EU that their membership in that Union may be deferred indefinitely unlss they honour promises to close Soviet-designed nuclear power stations at Kozloduy, Ignalina, and Bohunice, respectively (European Union, 1997).

Oil, natural gas, and mineral deposits (regional)

Disputes over who owns rights to valuable mineral deposits have led to armed conflict in the past, and may do so again. A number of ongoing disagreements also have biological, economic and political overtones. That there was a military response to Iraq's invasion of Kuwait in 1990 has been widely attributed to US and other western nations' energy security concerns, although political and other factors undoubtedly also played a role in that decision (Trolldalen, 1992).

The existence of 200-mile exclusive economic zones offshore from coastal nations have also led to conflict in the past, and may do so again in the future. Offshore islands become particularly contentious in this context, since they can be used as a base for projecting these 200-mile limits. For example, the 1982 Falkland Islands conflict, involving the UK and Argentina, was at least partially over which nation would gain from the discovery of any oil or natural gas deposits (Trolldalen, 1992). Following this conflict, both nations reached agreement on terms for petroleum exploration and development in a "Co-operation Zone" lying between the Falklands and Argentina, providing a useful example of how environmental and resource concerns can be resolved through negotiations for mutual gain.

The South China Sea is another region experiencing tensions of this type. Five nations claim rights to certain "islands," several of which appear only at low tide. While access to fisheries resources constitute part of the motivation behind these claims, access to hydrocarbons could be much more economically-important over the longer-term A 1992 Russian study indicated that 6 billion barrels of oil equivalents might be found in the area (US Institute of Peace, 1998).

The right to extract minerals located near deep sea vents is another potential source of tension emerging on the planning horizon. Although an international agreement for sharing the mineral resources of the seabed was reached several years ago, this agreement was premised on the mining of manganese "nodules" that presently are not economic to extract. Recently discovered accretions of gold and other valuable minerals near deep sea vents have attracted new mining interests throughout the world, and plans are underway to begin mining in selected areas. These activities would not be covered by the existing agreement. Some scientists also object to these plans, arguing that the rich biological resources of the vents must be preserved for study, since they are likely to hold clues as to the very origins of life on earth (Gulliver, 1997; Carr, 1998).

Introduction of alien species (regional and local)

Non-native species can have significant adverse effects on natural communities. These effects are neither predictable nor easily quantifiable in economic terms. Some of the most dramatic examples of these adverse impact can be found on remote islands. For instance, feral goats introduced to Santa Catalina Island off the California coast heavily damaged native plants (Catalina Island Conservancy, 1998). The brown snake has upset the ecosystem on the Island of Guam, and caused the extinction of several bird species. Mosquitoes brought to the Hawaiian Islands provided a vector for the transmission of disease, resulting in the loss of several bird species. In these cases, losses go beyond the simple extinction of native species, since the loss of biodiversity is often accompanied by deleterious impacts on island ecosystems (Stein and Flack, 1996).

Alien species have had well-documented (Stein and Flack, 1996) adverse impacts on continental ecosystems as well. Some examples include the (intentional) introduction of rabbits in Australia and Japanese Kudzu in the south-east US as a ground cover; and the (unintentional) introductions of the Mediterranean fruit fly to the New World, and the zebra mussel in the US Great Lakes (Florida Caribbean Science Center, 1998).

The primary threats to security from alien species are health and biological, although significant economic losses can also result in some cases. Alien species introductions have not yet been an important source of political conflict.

Natural disasters (regional and local)

Floods, droughts, earthquakes, typhoons, and volcanic eruptions are examples of environmental security threats posed by nature itself.. According to the UN (http://www.un.org/p/web-cgi/iopcode2.pl), damages inflicted by natural disasters kill one million people each decade, and leave millions more homeless. Economic damages from natural disasters have tripled in the last thirty years. In the 1960s, disasters cost the world an estimated USD40 billion; in the 1970s, the cost was USD70 billion; by the 1980s, it had risen to USD 120 billion.

Before 1987, there was only one disaster whose cost had exceeded USD 1 billion in insured losses. Since 1987, thirteen additional such disasters have occurred. In January 1995, the city of Kobe, Japan, suffered a heavy death toll, as well as economic damages estimated to be in the order of USD 50 billion.

Table 3. Losses from Natural Disasters (1983-1994)

Event	Economic losses in billion USD
Hurricane Alicia (USA, 1983)	1.65
Winter storm Herta (Europe, 1990)	1.90
Forest Fire (USA, 1991)	2.00
Winter storm Wiebke (Europe, 1990)	2.25
Hurricane Iniki (Hawaii, 1992)	3.00
Winter storm Vivian (Europe, 1990)	3.25
Winter storm (Western Europe, 1987)	3.70
Blizzard (USA, 1993)	5.00
Typhoon Mireille (Japan, 1991)	6.00
Winter storm Daria (Europe, 1990)	6.80
Hurricane Hugo (Caribbean, USA, 1989)	9.00
Floods (USA, 1993)	12.00
Earthquake (USA, 1994)	30.00
Hurricane Andrew (USA, 1991)	30.00

Source: As cited in WHO, 1994.

While industrialized countries suffer greater economic damage in absolute terms, poor countries are impacted more severely in relative terms. For example, GNP lost due to natural disasters has been estimated to be 20 times greater in developing countries than in developed ones.

Disposal of hazardous wastes (local)

A number of high-profile incidents which occurred during the 1970s and 1980s highlight an issue that makes many individuals uncomfortable: wealthy nations paying to dispose of hazardous wastes

in poorer nations. Controversy over such practices led to an international agreement on the control of the trans-boundary shipment and disposal of hazardous wastes. In March 1994, the 65 signatories of the Basel Convention agreed to ban the export of toxic wastes.

That this issue could be successfully resolved at the international level probably rests on two factors. One is that the cost advantage to firms engaging in the practice disappears if all industrialised nations agree to ban hazardous waste exports. "Clean" firms do not want their "dirty" competitors to have a cost advantage, resulting in broad support for any ban that affects all participants in the market-place. Second, adverse publicity and its potential impact on product sales make most firms reluctant to engage in the practice in the first place.

Oil and other spills (local, regional)

Spills of oil and other substances into marine waters pose risks to wildlife and to economically-important fisheries, beaches, and recreational areas. Very large oil spills, such as the grounding of the *Amoco Cadiz* off the coast of Brittany in 1978, as well as recent chemical spills in Switzerland, Italy, and India have generated similar political tensions.

The quantities of oil spilled on the high seas have declined considerably in the past two decades, despite increases in the volumes shipped. Technological improvements and much improved instrumentation are often cited as reasons for this improved performance, but the key underlying reason seems to be tightened liability laws and the related financial consequences for those who spill the oil. Few companies can afford the consequences of the multi-billion dollar liability that Exxon incurred when the *Exxon Valdez* ran aground off Alaska. Overall, oil spills might be cited as an example of an environmental security issue that seems to be on the way toward a satisfactory resolution, although some problems clearly remain -- such as lack of full accountability for minor incidents.

Large chemical spills are fairly rare events, so it is difficult to discern any particular trends in their occurrence. However, it seems that liability laws and the potential for adverse publicity both provide strong incentives to avoid such disasters here as well.

Table 4. Conflicts grouped by hierarchy and geographic scope

Hierarchy of Conflict	Geographic Scope of Problem		
	Global	**Regional**	**Local**
Biological, human health	• biodiversity • viruses	• transboundary air and water pollution • desertification • viruses	• alien species • oil spills • fisheries
Economic	• fisheries	• fisheries • water scarcity • mineral rights	• alien species • oil spills • fisheries
Political	• climate change • ozone depletion	• fisheries • water scarcity • mineral rights	• hazardous waste • fisheries
Armed Conflict		• water scarcity • mineral resources	

Summary

Each of the environmental security issues discussed above have been characterised in Table 4 in terms of the types of tensions that could be generated.

Organisations working on environmental security issues

Many organisations have active research, monitoring, and information-sharing programs dealing with environmental security topics. A partial listing of these organisations, their principal fields of activity, their outputs, and how access to their materials can be obtained (primarily via the Internet), are provided in Table 5.

Economic dimension of environmental security problems

Based on this brief literature review, it seems that the economic dimensions of environmental security problems have been the least-studied to date. An economic framework for analysing these questions has not yet appeared in the literature, perhaps because it is more complicated to develop such a framework than might seem at first glance. One problem is that, for some issues, economic gains and losses are symmetric (one party's gain is another party's loss), but for others, they are not symmetric at all (gains can exceed losses, or *vice versa*). A second problem is that most of the issues have components or impacts that are felt beyond economic markets, making valuation of these effects difficult (e.g. loss of ancestral lands, loss of biodiversity, polluted drinking water, invasions by alien species, etc.). Furthermore, identifying the least-cost policy response to achieve a given objective is never easy. Finally, there may be no reliable mechanism for making economic transfers from those who stand to gain to those who stand to lose from a particular policy change aimed at enhancing environmental security. Thus, even if all gains and losses can be calculated, the parties involved may not be able to find a mutually-agreeable solution.

As a first step toward a better understanding of the economic dimensions of each of the environmental security issues discussed earlier, a brief overview is provided below of what is currently known about the potential economic gains and losses associated with each. Are these gains/losses symmetric? What are relevant management options (e.g. *status quo*, direct regulation, change in property rights, liability, economic instruments)? For each option, how large would the costs be of altering present management strategies, and what are the anticipated benefits? Do we know to whom the costs and benefits would accrue?

Climate change

From an economic perspective, the two key economic questions associated with climate change are: (i) Will there be sufficient benefits associated with avoiding climate change to justify the costs of mitigation? (ii) What are the most cost-effective mitigation strategies? There are also several "non-economic" dimensions to the policy question -- especially the apparent desire by some countries to abate greenhouse gas emissions now, rather than risk an uncertain environmental future ("Precautionary Principle").

Several economists have analysed the potential economic costs of controlling CO_2 emissions (e.g. Cline, 1992; Nordhaus, 1994). These studies tend to forecast relatively large costs of abatement -- as much as 3-5 per cent of GNP for many nations. Cline has also provided preliminary estimates of the benefits (to the US) of preventing global warming: at least 1 per cent of GDP annually to prevent a 2.5^0C increase in temperature, and perhaps 6 per cent annually to prevent a 10^0C increase. Conversely, Nordhaus and others offer the view that the net damage to the world economy from global warming is likely to be

quite small. For example, many agricultural regions would actually be expected to experience *gains* in productivity if climate change were to occur, due to the "fertilising" effect of an atmosphere which is richer in CO_2.

Table 5. Selected Institutions Active in Environmental Security Research

• Bellona Foundation, Norway http://www.bellona.no	• Activist organisation which monitors, evaluates and reports on the state of environment in northwest Russia. Also takes action against "environmental culprits".
• Cambridge University, Global Security Program (http://www.gsp.cam.ac.uk)	• Environmental, development and international relations perspectives combined in their analyses. Project was completed Sept. 1997, but web site is maintained as an archive.
• Consortium for International Earth Science Information Network (CIESIN) http://www.ciesin.org	• Focus on human dimensions of global environmental change and sustainable development. Worked on several security-related issues, including VP Gore's Task Force on State Failure.
• Global Environmental Facility http://www.gefweb.com	• Funds projects on stratospheric ozone depletion, climate change, biological diversity, and international waters. Seeks to promote sustainable development, especially with respect to land degradation, deforestation and desertification.
• Intergovernmental Panel on Climate Change (UN) (http://www.unep.ch)	• Established by WMO and UNEP to assess scientific, technical, and socio-economic information on climate change.
• International Security Network Center for Security Studies http://www.isn.ethz.ch	• Maintains a web site with a large number of links to other organis'ns specialising in the environment, including security.
• North Atlantic Treaty Organization, Scientific and Environmental Affairs http://www.nato.int/science/scope/es.htm	• Views regional problems in water resources and transboundary air pollution as being particularly important. Also interested in man-made disasters, marine pollution, the consequences of climate change for environmental security, industrial air pollution, nuclear and chemical decontamination, and agricultural management issues.
• Pacific Northwest National Laboratory, Center for Environmental Security http://www.pnl.gov:2080/science.html	• Focus on environmental restoration, cleanup, and clean energy technologies as affecting environmental security.
• United Nations Environment Program http://www.unep.ch	• Large and active research program on topics related to environmental security: trade and the environment; financial services and the environment. Implements international Conventions on desertification, stratospheric ozone depletion, biodiversity, CITES; migratory species, and climate change.
• US Central Intelligence Agency http://www.odci.gov/cia/ciahome.html	• Research and monitoring activities on linkages between the environment and national security. "…depletion of forest areas and wetlands, the extinction of animal and plant species, and the deterioration in air and water quality (especially in Eastern Europe and the former Soviet Union) pose serious long-term problems that governments and peoples are only beginning to address." From CIA World Factbook, 1996.
• US Department of Defense http://www.acq.osd.mil/ens	• Research and monitoring of defence-related threats caused by environmental issues.
• US Department of State, Bureau of Oceans and International and Scientific Affairs http://www.state.gov/www/global/oes/index.html	• Foreign policy development and its implementation concerning global issues in environment, resources, science and technology. Priority issues include marine pollution, fisheries, global climate change, toxic substances, infectious diseases, forests and biodiversity.

Table 5 (cont'd).
Selected Institutions Active in Environmental Security Research

• United Nations Economic Commission for Europe (http://www.unece.org)	• Studies related to the implementation of ECE Conventions on Long Range Transboundary Air Polution (and its Protocols); Environmental Impact Assessment in a Transboundary Context; Protection and Uses of Transboundary Waterways and International Lakes; and Transboundary Impacts of Industrial Accidents.
• University of Toronto, Project on Peace and Conflict Studies http://www.libraby.utoronto.ca/www/pcs/pcs.htm	• Active research program on all aspects of environmental security. Identified and reported on violent conflict in Chiapas, Pakistan, India, Indonesia, China, Rwanda, South Africa and Gaza that have environmental conditions as important contributing factors.
• Woodrow Wilson Center, Environmental Change and Security Project http:/wwics.si.edu/PROGRAMS/DIS/	• Gathers information, organises meetings and public seminars, and publishes an annual report and other papers related to environmental security.
• World Resources Institute Washington D.C. http://www.wri.org	• Engages in policy research and provides technical assistance on global environmental and development issues. Publishes *World Resources: A Guide to the Global Environment*.
• Worldwatch Institute Washington D.C. http://www.worldwatch.org	• Focus on environmental sustainability; researches issues such as climate change, degradation of the oceans, loss of biodiversity, stratospheric ozone depletion, and linkages between environmental degradation and social conflict.

The gains and losses associated with climate change are unlikely to be symmetric. While some nations would seem to benefit from warmer temperatures (at least in the short-term), others would appear to lose. For example, low-lying island nations may actually disappear. Up to one-half of Bangladesh may be submerged. Violent storms may ravage other areas. But there will be clear gains to areas such as northern Canada and Russia, which could experience lengthened growing seasons and milder winters. Nor will the time scales be identical for both costs and benefits.

Most nations would also incur substantial costs to control greenhouse gas emissions, but economists generally agree that market-based instruments should be an integral feature of any large-scale program to control greenhouse gas emissions, due to their cost-minimisation characteristics.

With the Framework Convention on Climate Change and its associated (Kyoto) Protocol, industrialised nations have implicitly accepted the proposition that the net benefits to the world from reducing emissions will be positive. The Kyoto Protocol also envisions an ambitious international program for trading greenhouse gas emission permits as a cost-minimising strategy; however, the details of how such a program would actually be implemented in practice have not yet been fully worked out.

Stratospheric ozone depletion

In accordance with the terms of the 1987 Montreal Protocol on Substances that Deplete the Ozone Layer and subsequent amendments, the production of ozone-depleting chemicals such as chloro-fluorocarbons (CFCs) for most uses in OECD countries was phased out by January 1, 1996. The Montreal Protocol was a rapid and decisive world-wide response to scientific warnings that CFCs were destroying

ozone in the stratosphere that blocks harmful ultraviolet radiation. While stratospheric ozone destruction centred on a seasonal hole above Antarctica, the concern was that the hole would spread, and that increasing ultraviolet radiation would cause millions of cases of skin cancer and disrupt plant life on land and in the oceans.

At least two problems currently exist with this Protocol. First, it allows production in the US and Europe of two classes of ozone-depleting substances: methyl bromide (a pesticide used by strawberry and tomato growers), and hydro-chlorofluorocarbons (HCFHs), widely used as interim replacements for CFCs. Second, developing countries have been given until 2010 to phase out their production of CFCs. Because of this, and because it is legal to use recycled CFCs and CFCs acquired by vendors before the deadline, an active black market in illegally imported CFCs has been observed in several of the signatory countries (Warrick, 1997).

In September 1997, representatives of more than 100 governments met in Montreal and agreed to phase out methyl bromide in the developed world by 2005, and in developing nations by 2015. They also adopted an international trade registration system that gives police and customs officials greater power to detect illegal imports. However, participants failed to accelerate the previously-agreed deadline for phasing out HCFCs. In sum, while progress is being made to reduce emissions of ozone-depleting substances, there remain fundamental differences about precisely how to control illegal imports, and whether or not the phase-out of HCFCs should be accelerated. These differences rest largely on perceived economic advantages to individual countries from the continuing production and use of these ozone-depleting substances.

A recent comprehensive review of the economic dimensions of stratospheric ozone protection (Environment Canada, 1997) concluded that the economic damages avoided by the Montreal Protocol have been huge, in comparison with the costs of implementing the Protocol. A discounted net benefit stream of CAD 225 billion was estimated in that study, consisting of both health benefits (approximately 30 per cent) and benefits to agriculture, fisheries, and materials (approximately 70 per cent).

Biodiversity

Biodiversity issues often seem to divide developing and developed country interests. Although many developed nations would probably emphasise the preservation of tropical rain forests, wetlands, and other natural habitats, developing nations often feel pressure to respond to policy objectives which may seem damaging to biodiversity (e.g. job creation and food supply). The principal beneficiaries of protecting biodiversity are therefore often perceived to be the developed nations, while the developing nations are viewed as likely to bear most of the costs of preservation. Given such differences, it is unlikely that international treaties or conventions will be able to resolve all biodiversity tensions without some form of burden-sharing arrangement between these two groups. One important (and perhaps growing) exception to this may be noted: developing nations may find it advantageous to preserve certain "charismatic" species as tourist attractions, even in the absence of financial support from the developed countries.

How much compensation might developed nations be prepared to offer for potential new drugs, or for the protection of exotic species? One recent study (Simpson *et al.*, 1996) suggests that the genetic information contained in individual species is not likely to be valued very highly at all. For example, these authors calculate that the expected value of a single species for pharmaceutical uses is quite low (probably less than $10 000), making it improbable that drug firms would have much of an incentive to protect individual species. The reason for the low value is that sources of genetically-useful materials are

typically so common as to be redundant, since the same compound normally can be derived from many species. If a potentially-useful compound is unique to one species or very uncommon in nature (thereby increasing its value), the authors conclude that this compound is unlikely to be found at all. Following this logic, the authors calculate that drug companies would be willing to pay only about $2 per hectare to protect habitat in western Ecuador, the region which has the highest concentration of pharmacologically-interesting species in the world. Similarly, the most promising areas of Asia would be worth only between $1-$2 per hectare in terms of their expected value for yielding new drugs, and no other part of the world would be worth as much as $1 per hectare for this purpose.

Other estimates are far higher. Peters *et al.* (1984) claim that protecting rain forests for sustainable harvests of forest products in Peru is nearly $7 000 per hectare. Protecting Africa's oldest tropical rain forest in the Korup National Park, Cameroon could be worth as much as $41 300 per hectare in terms of tourist visitation (Ruitenbeek, 1992), although the author himself indicated that this estimate involved considerable "guesswork."

Few studies have attempted to quantify either aesthetic or existence values for exotic species. One memorable study of the whooping crane (Stoll and Johnson) placed a total value of $5 billion on the some 150 cranes still living -- over $30 million each! Since the whooping crane is a particularly "charismatic" bird living in a relatively wealthy country (the US), this probably represents an upper limit on the willingness of society to pay to preserve a rare species.

How do estimates of the value of saving exotic species and habitat compare with the value of converting tropical forests and other areas to agricultural use? Several studies conducted in China suggest that conversion to agricultural purposes was valued more highly than wildlife habitat by the Chinese, but these studies did not take into account possible values to other nations (Yu-Shi, 1997).

Viruses and other micro-organisms

While many organisations have active programs to monitor disease, to control its spread, and to treat the victims of diseases caused by micro-organisms, there appear to have been only limited efforts made to understand the economic consequences of these diseases. For example, the economic consequences of the recent "mad cow" and "bird flu" scares in Europe and Hong Kong have not yet been assessed.

Fisheries

In 1982, the United Nations Conference on the Law of the Sea appeared to take an important step toward reducing over-fishing, giving approval to the 200-mile exclusive economic zone that most nations had by then claimed. This act effectively reduced the proportion of global fishery resources that were being treated as part of the "global commons". However, most national fisheries continued to be managed under "open access" regimes, and the new 200-mile limits simply encouraged more rapid expansion of national fleets. The international operators who were now excluded from access to near-shore resources turned their attention to fisheries outside the 200 mile zones, using new gear technology to harvest fish more efficiently. In some case, this resulted in more than just the over-fishing of fish stocks -- it also generated new environmental problems, as well as new environmental solutions. For example, driftnet fishing was banned by the UN General Assembly banned driftnets in 1992.

Fishing subsidies are part of the problem. Milazzo (1998) estimates that annual fishing subsidies worth about 14.0-20.5 billion USD exist world-wide. These subsidies have stimulated over-fishing and caused significant depletion of fisheries stocks (see also Williams, 1997).

In the short-run, fisheries harvests have the characteristics of a "zero sum" game: what one party gains, another loses. But over the longer-run, fisheries can be managed in such a way that total harvests are increased, resulting in a net gain for *all* participants. This potential for mutual gain is well understood by fisheries biologists and economists, but to date, has had very little impact on either fisheries policies or fisheries management practices. The reason appears to be that few nations have yet reached the stage where they can manage their fisheries in such a way as to maximize long-term profitability or sustainable yields. Rather, most are at best able (or willing) to protect their fisheries from severe depletion, and tend to focus more on keeping people employed in fishing communities, even if it means keeping fishers idle, while supporting them through social welfare payments. Alternative management strategies, such as those which reduce access (e.g. licensing, total allowable catch), or tradable quota arrangements, can increase incomes from the fisheries, and reduce pressures on existing stocks (assuming, of course, that any action to reduce capacity is not counterbalanced by new capacity re-emerging from other countries in unregulated or high seas fisheries).

In some regions, access to fisheries has been closed, via limits on the number of vessel licenses. Notable examples include the salmon fishery of British Columbia and other fisheries in Canada, Norway, and the United States. However, this approach sometimes fails to protect fish stocks because fishers feel competitive pressures to invest in ever more sophisticated boats and gear. This usually leads to shorter seasons, and to other restrictions ultimately aimed at protecting fish stocks. This achieves an environmental objective (stock protection), but is inefficient in economic terms, in that it encourages excessive investment in fishing capacity. Each fisher wants to beat competitors to the limited stocks that may be available. In extreme situations, fishing seasons come to be measured in hours, even though the fleet is capable of harvesting the total allowed catch many times over.

A relatively recent management innovation is the Individual Transferable Quota (ITQ) approach, currently used for one or more fishery in at least eight nations (Australia, Canada, Iceland, Netherlands, New Zealand, Portugal, UK, and US) (OECD, 1997). Although Norway does not have ITQs *per se*, it does utilise individual vessel quotas. Denmark's quotas are not transferable. The ITQ approach limits incentives for investments in a fishery, since fishers are allocated a fixed share of the catch. Nations that currently do not use ITQs might achieve gains in the economic returns from their fisheries through such an approach, and many of these nations are now actively considering this idea for at least some of their fisheries. Although the ITQ approach may offer considerable opportunities for improving management, it is not completely without problems. For example, it may encourage fishers to "high-grade" by throwing less valuable species overboard, generating new environmental concerns. ITQs are rarely used in isolation; typically, other management instruments (e.g. input controls; gear; area or seasonal restrictions) are also applied at the same time.

Transboundary air pollution

Many studies have examined the economic impacts of different air pollutants on cities, on parts of countries, and on entire nations (for example, see Asian Development Bank, 1996; Dixon *et al.*, 1994; Freeman, 1982). In one of the most comprehensive assessments of this type, the USEPA estimated that total benefits of existing control measures were $6.8 trillion (best central estimate), and total costs were $436 billion over the period 1970-1990 (USEPA, 1996*b*). Another study suggested that West Berliners

would be willing to pay about 7 per cent of GDP, in order to improve air quality in that city from "smoggy" to "clean" (Schultz, as cited in OECD, 1989).

Cross-border economic effects from air pollution are well-known to exist, but have not often been studied from an economic perspective. This may be due to the difficulty of obtaining necessary data for modelling sources, and to other science-based technical difficulties (e.g. the specific location of pollution sources and destinations often matters to the estimation of total costs). A noteworthy exception to this is the UNECE Convention on Long-range Transboundary Air Pollution, which has effectively examined the cross-border economic aspects of both SO_2 and NO_X emissions (i.e. damages to buildings; health impacts; etc.) (see, for example, UNECE, 1995; Amann, 1993).

Transboundary water pollution

The 1944 Treaty for Utilization of Waters of the Colorado and Tijuana Rivers, and of the Rio Grande between Mexico and the US guarantees Mexico an annual quantity of water in these rivers. The Treaty does not speak to the issue of water quality, which became an issue in the Colorado River in the 1950s, following rapid agricultural development in the US Southwest. Drainage water from farms that was heavily polluted with salts was finding its way back into the Colorado River, and was making its use for agricultural or drinking purposes in Mexico problematic. A subsequent agreement guarantees Mexico water suitable for irrigation. To satisfy its obligations under this agreement, the US installed a desalting plant ($256 million construction cost) at the US-Mexico border near Yuma, Arizona that it is obliged to run if the salt content of the river becomes too high. The US has since spent significant amounts of money on other upstream salinity control measures, to satisfy its treaty obligations to Mexico (Van Der Werf, 1994). Freeman (1982) has estimated yearly benefits of $6-$28 billion (1984 dollars) for water pollution controls imposed by law in the US.

Mantymaa (1991) has estimated that protecting water quality in Lake Oulujarvi, Finland was worth $269 per person for users, and $221 per year for the general public (non-users in Finland). Construction of a wastewater treatment facility near Lake Timsah (Ismalia, Egypt) would also produce estimated benefits of $24 million from increased recreational use of the lake, and $2.5-$22.5 million in increased housing values (Luken, 1987).

Transboundary water quality improvements will generally benefit downstream nations and impose costs on upstream nations. In such a situation, the "Beneficiary Pays Principle" might be invoked for any improvements beyond internationally-agreed water quality standards.

Land degradation and desertification

Few studies have looked at the economic consequences of land degradation and desertification. One of those which *has* addressed this issue is Repetto (1989), who calculated that the annual losses in agricultural productivity in Java (Indonesia) due to soil erosion amounted to $367 million (4-7 per cent of agricultural production). Estimates of annual losses due to silt deposits in irrigation systems, channels and reservoirs ranged from $29-$106 million. Peters *et al.* (1989) have estimated that preserving the quality of cattle pastures in Brazil was worth nearly $3 000 per hectare. Estimates of economic damages due to land degradation and desertification in Zimbabwe and the Philippines have also appeared in the literature (Winpenny, 1991; Finney and Western, 1996).

Resolving problems of land degradation and desertification would offer potential gains for all parties. The United Nations Convention to Combat Desertification recognises this fact, making both funds and technical assistance available for that purpose.

Nuclear power plants

The damage caused by the catastrophic failure of a nuclear power station at Chernobyl in 1985 was both large in magnitude and widespread in its effects. Radioactivity transported from the several plumes at Chernobyl affected not only the Ukraine but also Europe, Canada, the United States and Japan. Thirty-one people died during the incident, while more than 100,000 people were evacuated from the 30 km radius around the site (OECD, 1995). Up to 800,000 people worked on emergency actions on the site, eventually enclosing the damaged reactor core in a concrete "sarcophagus."

The predicted longer-term effects on health are a slight elevation in cancer incidence (0.004 per cent) in the Northern Hemisphere, or about 300 people per year for several decades. The impact on agricultural practices, food production and use, and on other aspects of the environment are more visible than direct health effects. Large parts of the Ukraine remain closed or restricted in terms of agricultural activity (OECD, 1995).

Oil, gas and minerals

Access to mineral deposits has the characteristic that one nation's (or person's) gain is another's loss. Further, the valuation of minerals is generally not difficult; market prices are reliable indicators of social value in this case. However, there are two main issues to consider here: are there publicly-available estimates of mineral resource values for contested areas (e.g. South China Sea), and would the availability of such estimates help in negotiating a compromise among contesting nations?

Alien species

Nations regularly spend considerable sums to protect their agricultural interests from exotic species. Agricultural inspectors at international borders attempt to stop the importation of fruit, vegetables and plants that have not been inspected. Several nations also regulate the discharge of ballast water from ships, in order to prevent such problems as the zebra mussel.

The damage caused by alien species introductions can be huge. In the Great Lakes Region alone, damage and control costs attributable to the zebra mussel are expected to be 2-5 billion USD by the year 2000 (Florida Caribbean Science Center, 1988).

Hazardous waste disposal in developing countries

Apparently, there are no studies on the economic damages to developing countries caused by their acceptance of hazardous wastes for disposal.

Oil spills

The principal economic issue related to oil spills is that of the need to internalise external costs. Most international conventions limit the maximum liability per barrel for spilling oil, and generally restrict recoveries to tangible economic losses such as damage to fishing gear and cleanup costs. While this is convenient for ship and cargo owners (e.g. by making it easier to insure their activities), it probably leads to less than an optimal amount of environmental protection.

However, not all maximum liability provisions are as restrictive as this. For example, recoveries for damages from oil spills in US waters are subject to the provisions of the Oil Pollution Act of 1990. This Statute makes ship and cargo owners potentially liable not only for tangible losses, but also for such intangibles as lost recreational use of beaches, and the existence value of wildlife.

Strategies for minimising costs

There are several market-based approaches that offer promise for resolving some environmental security issues. One can point to existing successes with local or regional programs in tradable fisheries quotas, effluent and emission taxes, tradable pollution permits, and debt-for-nature swaps (Anderson and Lohof, 1997). There also are situations where market-based approaches will be inappropriate for one reason or another (e.g. the administration or transaction costs associated with these instruments might be prohibitive). Efforts should therefore be made to ensure that any strategies adopted to enhance environmental security are as efficient as possible. This goes for market-based approaches, as well as for other alternatives. In general, the economic implications of not using the least-cost approach should be systematically assessed.

Table 6. Strategies for Minimising Costs

Hierarchy of Conflict	Geographic Scope of Problem		
	Global	Regional	Local
Biological, human health *Least-cost solutions likely to involve political agreements on spending and priorities.*	Biodiversity, viruses *Global treaties and conventions*	Transboundary air and water pollution, desertification, viruses *Regional treaties, public disclosure, eliminate subsidies*	Alien species, oil spills, fisheries *Direct regulation; eliminate fisheries subsidies*
Economic *Least cost solutions often rely heavily on use of economic instruments*	Fisheries *International agreements, coupled with economic instruments: tradable permits, and eliminate subsidies*	Fisheries, water scarcity, mineral rights *Regional agreements with tradable rights, eliminate subsidies*	Alien species, oil spills, fisheries *For alien species: use rules and regulations. For oil spills: use liability rules. For fisheries, use tradable quotas*
Political *Least cost solutions often rely heavily on use of economic instruments*	Climate change, ozone depletion *International agree-ments, coupled with economic instruments*	Fisheries, water scarcity, mineral rights *Regional agreements with tradable rights*	Hazardous waste, fisheries *For hazardous wastes, use direct regulations. For fisheries: use tradable quotas*
Armed Conflict *Least cost solution is to avoid the conflict in the first place*.		Mineral resources *Royalties, payments*	

In situations where they are deemed appropriate, well-designed market-based approaches should produce least-cost outcomes. But how does one decide on the outcome to be pursued? Those decisions *could* be based on a deliberate economic calculation (e.g. total benefits less total costs), but are more often are the result of a political process.

Table 6 suggests which types of least-cost solutions are most likely to be associated with each of the elements of the taxonomy that was presented in Table 4.

Future efforts

This section examines a range of initiatives which need to be taken on environmental security issues. Both short- and long-term elements of a potential research agenda are identified. This agenda reflects the general views that:

- Although *fisheries* are very important in terms of the potential economic losses from their mismanagement, they are extremely contentious politically, and are already the focus of active research programs at the FAO and elsewhere.

- *Transboundary water quantity and water quality* disputes are another important environmental security priority. Although active research and diplomatic efforts are underway on these issues, study of their economic dimensions is largely missing.

- Conflicts over *access to mineral resources* do not seem to pose the rich array of economic problems present in some of the other issues, and are therefore not recommended here for priority effort.

- *Transboundary air pollution* issues have also already received considerable attention in several existing fora (e.g. UNECE), so they need not be the subject of special priority in the future.

- Finally, the economic dimensions of *land degradation, desertification and deforestation* problems should also receive higher priority in the future than they have in the past.

A short-term agenda

1. Initiate an active research program on the *environmental and economic significance of transboundary water quantity and water quality* issues. Consider appropriate policy responses, including market-based policies (such as eliminating environmentally-harmful subsidies to agricultural and other users, as well as the possibility of creating systems of tradable water rights). Some issues here also need to be addressed outside of traditional welfare economics. For example, should access to water in transboundary rivers be determined by “willingness to pay” criteria? Should polluters and users be asked to pay for water services, or should there be some allowance made for “public good” elements of these services? If so, how should these proportions be determined?

2. Initiate an active research program on the *environmental and economic causes/consequences of land degradation*. Consider appropriate policy responses, including market-based policies (e.g.

eliminating environmentally-harmful subsidies), altered legal arrangements of land tenure, and subsidising environmentally-friendly technologies.

A longer-term agenda

3. Additional items might also be added to Table 4 (i.e. extend the list of environmental security threats). For each of the new threats identify the geographic areas where the problem is most pronounced and the type of threat being posed (environmental, economic, or political).

4. For each of the environmental security threats described in this paper (and augmented in task 3 above), seek better quantification of economic effects, as well as better understanding the potential "gainers" and "losers." For some of the potentially important issues whose impact is highly uncertain at present (e.g. spread of viruses and introduction of alien species), conduct original work to estimate benefits. Decide which threats have the largest economic consequences. Which particular nations face the greatest risks?

5. Evaluate the potential for solving each of the identified problems. Most of these problems are not new. There already are more than 900 international agreements concerning environmental issues (Jacobsen and Weiss, forthcoming). Almost certainly, more than one agreement already is in place for each of the issues described in this paper. Except in rare circumstances, forging new agreements is unlikely to be very helpful. However, better implementation of existing agreements may have some potential. In addition, the scope for greater use of "side payments" to encourage desired behaviour should be investigated. Which existing agreements affect each of the issues? How are these agreements working?

6. Assess the most cost-effective means of dealing with each of these issues. One very effective form of enforcement for many environmental problems is to make reporting mandatory. After determining where reporting requirements are likely to be most effective (e.g. review literature, review existing applications, etc.), countries could be encouraged to report salient environmental statistics at the country or firm levels.

7. There are a number of examples world-wide where several nations have already reached agreement over the management of common resources (e.g. Rhine River, Colorado River, El Paso airshed), or where environmental quality played a large role in the deliberations. A better understanding of the mutual benefits obtained in these arrangements (including how costs and benefits were eventually shared) could help in the design of regional approaches to other security-related problems affecting countries or regions (e.g. ground-level ozone pollution across Western Europe).

8. On a selective basis, the establishment of regional markets in resources should be facilitated, such as fisheries, air emissions, and water (both quantity and quality). Proposals for "joint implementation" under the Framework Convention on Climate Change, for example, hold promise not only as a way of improving the cost-effectiveness of reducing greenhouse gas emissions, but also for facilitating the preservation of valuable habitat, such as tropical rain forests.

9. A number of international agreements contain mechanisms for subsidising desired behaviour on the part of LDCs. For example, the Global Environment Facility finances projects dealing with climate change, international waters, protection of biodiversity, and the phase-out of CFCs. Most OECD nations are also active in financing environmental improvements in LDCs. Opportunities to use these programmes to achieve environmental security objectives should be fully exploited.

10. Opportunities to strengthen institutional co-operation on issues related to environmental security should be investigated, both within countries (e.g. national environmental agencies), and in international economic arrangements. Various multi-country agreements such as NATO, ASEAN, NAFTA, GATT, and the WTO could become more involved in these questions.

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