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Vulnerability and the Environment

**Ecological, Socio-Economic and
Institutional Dimensions of Exposure,
Adaptation and Collapse**

ASEC Services & Vulnerability Project
Final Report prepared for The Geneva Association

September 2005

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VULNERABILITY AND THE ENVIRONMENT:
Ecological, Socio-Economic and Institutional Dimensions of Exposure, Adaptation and Collapse

Final Report prepared for The Geneva Association

September 2005

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Foreword – The ASEC Services & Vulnerability Project

The Applied Services Economic Centre is an affiliated organization of the Geneva Association whose continuing purpose is to investigate developments and trends within the global service economy which might be of broad interest to the insurance industry. To this end, ASEC identifies important cross-cutting themes and issues related to services and the modern service economy, conducts enquiries and studies on those themes, participates in and sometimes sponsors seminars and conferences, and attempts to contribute to a better understanding of the role and function of services and insurance in modern global services economies.

The ASEC Services and Vulnerability Project focuses on the concept of vulnerability, as distinct from related notions of risk, hazard and uncertainty, as a controlling concept for understanding our 21st century world. We understand vulnerability to refer to *inherent or circumstantial conditions which may result in an event/outcome occurring with causes or consequences unknown.* Since 2003, ASEC has been involved primarily in efforts to explore and understand this underlying concept of vulnerability as an essential feature of services economies/societies and to proceed towards the development of a metrics, diagnostics and coping strategies for dealing with multiple and different types of vulnerabilities affecting the modern global service economy. Research studies are being undertaken on four dimensions of vulnerability: technological, environmental, economic/ financial, and institutional/ organizational. We are now disseminating its findings as a set of Foundation Papers which explore key features of the concept of vulnerability as well as an open-ended series of Themes and Issues Papers which will treat either broad themes of vulnerability or specific issues and case studies.

In the November 2005 issue of The Geneva Association's Risk Management Newsletter, the Swiss author Max Frisch is quoted to the effect that "catastrophes are only known to the people who survive, nature does not know disasters". There is much to glean from this sage comment. Indeed, what we conventionally understand to be the environmental catastrophes and disasters of the day – the recent Asian tsunami or Hurricane Katrina in New Orleans or even the "human impact issues" posed by fisheries depletion or global warming – are self-identified by us as particular events or outcomes which somehow challenge the natural order of things. They represent seemingly abrupt changes that for the most part we do not choose to happen, that seem as unpredictable as to their incidence as they are uncertain in terms of their consequences, and which reveal uncomfortable vulnerabilities in the environmental systems and processes which constantly bear upon our lives. That such environmental vulnerabilities are presented as merely natural phenomena -- part of a set of systems and processes largely outside of human control though not of human impact – does not mean, however, that that they should be studied intensively for what they reveal about the pervasive vulnerabilities of our 21st century world.

The present study by Craig Johnson and Robert McLeman of the University of Guelph in Canada explores the "contentious" theme of vulnerability and the environment. The very concept of "environmental vulnerability" is found to be contentious precisely because it raises unsettling questions about human cognition and human agency as these relate to natural systems and processes. Is it really appropriate to understand the natural world as subject to vulnerabilities or are these phenomena matters of normal change and variation? How does our understanding – actually our often conflicting understandings -- of environmental problems affect our capacity to take deliberate action to deal with them? And to what extent can a "metrics of vulnerability" be developed and applied to better assess and compare different environmental problems? The authors treat these important themes in the course of examining three quite discrete and different environmental problems: natural disasters like storms, floods and earthquakes, the ongoing depletion of the world's fisheries resources, and global climate change. They find that one of the critical features of environmental vulnerabilities are their essential "irreversibility", both in terms of their underlying conditions which give rise to them and the set of human behaviors which underpin them. In addition, the authors pay particular attention to matters of scale in relation to the three issues treated, as well as the vexing question of what kinds of knowledge get factored in (or factored out) of decision-making under conditions of uncertainty. In their concluding comments, the authors find the concept of vulnerability to be a useful and promising approach to understanding the environmental problems which confront or 21st century world.

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Executive Summary

The Geneva Association is supporting a series of studies aimed at developing an understanding of the nature of vulnerability. This report develops an enhanced general framework to identify factors influencing vulnerability to environmental conditions and change. It does so using three case studies from areas in which human societies are particularly vulnerable to shocks and stresses commonly associated with environmental change:

- Natural hazards (using the example of flooding);
- Resource depletion (using the example of coastal fisheries); and
- Climate change.

In selecting these areas, our focus is on environmental problems that occur when ecological processes that are sensitive to change are substantively affected or disrupted by human activity. Human values and knowledge profoundly shape the ways in which societies create and respond to environmental processes, and receive recurrent treatment in this investigation of vulnerability.

Vulnerability can be understood as a function of exposure to environmental change and the capacity to adapt. Exposure and adaptive capacity, and therefore vulnerability, can be understood in terms of their ecological, socio-economic and institutional dimensions. This report compares ecological, socio-economic and institutional dimensions of vulnerability in three case studies: flood hazards in river valleys and coastal areas; the collapse of the northern cod fishery; and climate change.

Exposure to flooding, fishery collapse and the potential impacts of climate change are all products of socio-economic path-dependencies and institutional incentives which reflect and further exacerbate the exposure. Human settlement in flood plains and coastal areas, for instance, reflects long-standing patterns of consumption, irrigation, transportation and resource use. These dependencies have been further exacerbated by public and private forms of insurance, which compensate property-owners for losses incurred during cataclysmic events. Public policies support the development of infrastructure in areas that are prone to flooding. Government programs which encouraged the development of the Atlantic cod

fishery, and those which encourage the burning of fossil fuels have similar effects on exposure in those cases.

The ability to prepare for and respond to uncertain and potentially cataclysmic environmental events (i.e. adaptive capacity) is also constrained by dependencies and political interests. In the case of the northern cod, economic and political pressure undermined government assessment and action in a fishery in ecological decline. The interests of private property owners in areas prone to flooding take precedence over planning initiatives.

The case studies suggest that the ability to recognize signs of environmental hazards or ecological collapse and to take adaptive action is constrained by the limitations of management/science and by the strategic behaviour of individuals and groups whose interests, decisions and indecisions discourage mitigating actions. This is particularly the case in climate change, where despite evidence that human activity generates ever-increasing amounts of greenhouse gases to the atmosphere, there continues to be debate over whether this phenomenon poses any significant risks.

Vulnerability may stem from “contentious problems” (where something is believed to be possible but disagreement exists over whether something is actually occurring, such as sea level rise) or “consensus problems” (where disagreement exists over whether something is possible or likely in the first instance). Such problems complicate the ability to calculate probability and manage risk because they compromise the ability of scientists, managers, politicians, etc. to reach consensus about the nature of the problem and whether the problem has in fact occurred. They also complicate the task of establishing metrics for environmental vulnerability. In addition, systems of measurement, description, explanation and regulation are often so complex they render the management of the resource and the ability to adapt to unforeseen processes and events increasingly difficult.

The paper proceeds as follows. The introduction describes a number of possible metrics of vulnerability and questions to be addressed in the case studies. Section II describes the conceptual evolution of vulnerability from its origins in natural hazards science and introduces a framework for analyzing vulnerability in the case studies. Section III explores the vulnerabilities that arise from flood hazards and settlement patterns in river valleys and coastal areas. Section IV studies the collapse of the Northern Cod fishery on the Grand Banks of Newfoundland. This is followed by a case study of climate change in Section V. Section VI concludes the paper, re-visiting the metrics of vulnerability introduced in Section I.

1 Introduction

In March 2005, the United Nations released the *Millennium Ecosystem Assessment* (Reid et al. 2005), the single most comprehensive publication of knowledge and statistics concerning the state of the global environment. The assessment involved more than 2,000 authors and reviewers and required four years to complete. The approach taken in this assessment focused on the relationship between changing environmental conditions and human well-being, referred to as “ecosystem services”. Of the 24 ecosystem services identified by the assessment team, which include such things as food and fuel sources and climatic conditions suitable for human development, it was found 60% are being degraded or used unsustainably. The assessment warns that such changes appear to be behaving non-linearly; that is they are becoming abrupt, accelerated and/or irreversible, with increasingly harmful effects that are not shared equally among all members of society.

The publication of this assessment is reflective of a resurgent concern about the impact of human society on the environment, other examples of which include Jared Diamond’s deeply pessimistic study of *Collapse* (2005), Ronald Wright’s *Short History of Progress* (2004) and *the Ingenuity Gap*, by Thomas Homer-Dixon (2001). We also see a pronounced articulation of concern about the environment in the popular media of a scale not since the run-up to (and the fallout from) the 1992 Earth Summit.

The term *vulnerability* has become an increasingly common part of our lexicon when we contemplate the conditions of our existence and the human relationship with the natural environment (Weichselgartner 2001). The Geneva Association is supporting a series of studies aimed at developing an understanding of the nature of vulnerability. This paper explores three areas in which human societies are particularly vulnerable to shocks and stresses most commonly associated with environmental change:

- Natural hazards (using the example of flooding);
- Resource depletion (using the example of coastal fisheries); and
- Climate change

In the cases of climate change, resource depletion and many types of natural hazards (such as flooding), human agency is believed to have affected or influenced the bio-physical characteristics and processes of ecological systems, which in turn have a feedback effect on human well-being. In other words, vulnerability is not created simply by some event or change that originates solely from bio-physical processes, but by the outcomes of particular interactions of human and bio-physical processes.

Hazards, resource depletion and climate change differ from one another, however, in terms of scientific and popular knowledge about the extent and potential reversibility of their impacts, and in terms of the extent to which past and potential disturbances are accepted within society. In the case of resource depletion and climate-related shocks to food production, conventional understandings of causal relations, feedback mechanisms and human agency are *relatively* clear and not contested. We accept the notion that if people harvest too many fish (or trees, or game animals) at once, the ability of the stock to reproduce may be harmed. This is not to say that opinions are universally agreed about the relative impact of human agency on a resource versus non-human agents such as disease or natural predation, as will be discussed later. Rather, it implies that phenomena such as flooding, drought and over-fishing are conventionally understood as negative or costly environmental phenomena in which human agency plays an important contributing factor. In contrast, climate change is a case in which scientific uncertainty exists, especially about its likely future manifestations, and consensus about the normative value of stopping or curbing anthropomorphic influences on the environment is not universally shared (Essex and McKitrick 2002).

By contrasting cases which vary in terms of human understanding and moral consensus we may explore the ways in which ecological processes and social organization, including the organizational processes that produce knowledge and reduce uncertainty about future outcomes and events, combine to produce vulnerability. Insofar as they contribute to people's understanding of environmental issues, debates about the environment affect the extent to which people and societies in general are vulnerable to environmental change. What differs and what makes for interesting comparison, though, is the quality of knowledge people have about different environmental issues and how they value the perceived costs and benefits. For example, climate change is somewhat unique in the sense that the risks arising as a result of greenhouse gas emissions are not universally known and the value of reducing emissions of them is not universally shared. In contrast, the costs associated with flooding, drought and fisheries depletion are relatively well known and valued across wide segments of society.

1.1 Metrics of Vulnerability

Human societies are remarkably able to adapt to new and unusual circumstances, and to re-constitute their ecological surroundings to suit their needs and utility. In comparison to other species, humans are exceptional in their ability to transform the most fundamental ecological properties of their habitat at scales from the local to the global. Leaving aside the normative terms on which vulnerability and environmental change are used elsewhere, we can identify an initial set of criteria – or metrics – by which we may measure and understand the kinds of vulnerability which may underlie a particular system. To do so, we expand upon the following "metrics of vulnerability," developed by Woodrow and Liedtke (2004):

1) Measures of Source and Agency – whether individual human action or out of control forces are at work in explaining exposure to and impact of particular vulnerabilities, as exemplified by distinctions such as *deliberate/accidental, voluntary/involuntary*, *chance/skill*, etc;
2) Measures of Scale, Scope and Intensity – whether the range and impact of particular vulnerabilities can be characterized in terms of dichotomies such as *discrete/widespread*, *limited/extensive*, *intense/*weak, etc;
3) Measures of Explanation -- whether the origin and evolution of particular vulnerabilities are best explained by *causality/correlation, endogenous/exogenous*, *circumstantial/deductive*, etc;
4) Measures of Interconnectedness – whether the various elements and linkages involved in particular vulnerabilities, are *simple/complicated/complex, loosely/tightly coupled*, etc;
5) Measures of Criticality – whether the seriousness and acuteness of particular vulnerabilities can be treated as *non-critical/critical*, *stable/unstable, evolutionary/transformative*, etc.

From these metrics flow a number of questions that assist our investigation of vulnerability.

First, is the disturbance – that is, the condition or event that gives rise to vulnerability - one that affects human populations, non-human populations or both? Although ecosystems are by nature highly inter-related, human populations not only have the ability to modify environmental conditions but also the technological capacity to insulate themselves from many adverse impacts of environmental conditions, such as extreme cold, flooding and so on.

Second, how does the disturbance vary in terms of scale? The scale of environmental change can be measured in terms of intensity, duration and magnitude. Intensity is the relative weight, speed or size of the disturbance. Standardized measures of intensity may exist for some disturbances, such as the categorization of hurricanes. Duration simply refers to the time that elapses between the onset and termination of a particular disturbance.[1] Disturbances of short or long duration can be equally destructive. The 2004 Asian tsunami, for instance, lasted for only a matter of minutes, but killed as many as 200,000 people. In contrast, the accumulation of toxins or carcinogens in a given location may occur over extended periods of time before a level of danger is finally reached.. Magnitude may entail three basic elements. One is the total physical area affected by the disturbance. A second is the change in the actual quantity of resources (in the case of resource depletion) or the quantity of people or assets harmed (in the case of a hazard). A third element is a transformation in the quality of a resource, such as. its capacity to serve a particular human need (Blaikie and Brookfield 1987) .

Third, are the effects of the disturbance relatively discrete or widespread? Are there knock-on or domino effects, such as in SARS pandemic or the northeastern North American blackout of 2004, which expand the scale of the disturbance? How “tightly coupled” are natural and human-made systems, and to what extent do environmental disturbances lead to non-linear effects?

Fourth, are the changes in question characteristic of historical patterns and historically derived projections? In other words, is the disturbance “normal” or abnormal? And, by extension, to what extent are human populations able to draw upon past experience in recognizing and responding to the disturbance?

[1]Although, as Scoones (1999) argues, this is not to suggest that environmental conditions reach and maintain “optimal” equilibria.

Fifth, how critical are the assets and activities affected by the disturbance? An ice storm that disables the chairlifts at a ski resort may cause significant monetary loss to the resort operator and inconvenience guests, but be far less critical than if the same storm were to knock out an electrical pylon on the lines delivering power to the resort community. A following question is how we value the effects of the disturbance. For example, is a cyclonic storm worse if it causes significant property damage or if it takes a number of lives?

Sixth, on what basis is our understanding of vulnerability constructed, disseminated, perceived and acted upon (or not) within society? There are several elements to this set of questions. Modern environmental management is rooted in the idea that science can *and should* produce facts and knowledge on which environmental risks can be assessed and managed. However, science may provide only a partial understanding of the phenomena at play and the potential outcomes, as shown in our following review of northern cod fishery management and in international action on climate change. In many instances, such as the risks associated with nuclear accidents, the risks may be understood primarily through such things as historical accidents or computer models which provide only partial information. In such cases, some argue for a precautionary principle, to avoid or discontinue activities or technologies where the risk is uncertain and the potential impacts catastrophic. This in turn begs the question of what constitutes an *acceptable* risk.

Seventh, to what extent are the changes reversible or irreversible? How resilient is the system in question, and how well is it able to prepare for and adapt to sudden or catastrophic change or depletion? Natural resources are often characterized as being either renewable or non-renewable. Renewable resources, such as trees, fresh water and oxygen, are situated within ecological systems that perpetuate their reproduction. So long as critical thresholds are not exceeded, they may be resilient to sudden change or human depletion. Non-renewables, by comparison, are not so readily reproduced; the timescales needed for natural systems to create fossil fuels make them essentially finite by human reference points. Hence the depletion of renewable resources by human activity or damage to them resulting from natural hazards may be a temporary, reversible process, with the opposite being the case for non-renewables.

Eighth, to what extent are the behavior patterns which give rise to environmental changes or disturbances reversible or irreversible? Homer-Dixon (2001:119) argues that new means of production, processing, communication and transportation have extended the "agency horizon" of human populations, in turn expanding the pace, density and intensity of our interactions with one another and with the natural environment. The worldwide spread of technologies requiring the consumption of fossil fuels occurred over a relatively short period of time, creating very strong dependencies which mitigate the ability to move into cleaner and less destructive forms of technology. A complementary question asks to what extent may we be able to mediate the effects of environmental impacts through technology? Are there forms of environmental change that preclude adaptive strategies?

All but the last two of these sets of questions are largely compatible with the metrics of vulnerability laid out by Woodrow and Liedtke (2004). The final two, which address the reversibility of the underlying condition and the reversibility of the behavior that leads to the underlying condition, present additional challenges which this paper will explore.

1.1.1 Starting Assumptions

In this paper we focus on environmental problems that occur when ecological processes that are sensitive to change are substantively affected or disrupted by human activity. In doing so, we recognize that there are environmental changes that occur without any human stimulus, such as volcanic eruptions and the effects these can have on atmospheric processes. We also recognize that disagreement exists about the impact that human activities have on ecological processes, and is a defining feature of modern environmental politics. Because human values and knowledge profoundly shape the ways in which societies create and respond to environmental processes, we have chosen them for recurrent treatment in the following attempt at expanding understanding of human vulnerability.

By "vulnerability," we use Woodrow and Liedtke's definition in which vulnerability implies an underlying or circumstantial condition, which could result in an event occurring, with unspecified consequences. We also develop and expand upon a recent conceptualization from climate change literature in which vulnerability is understood as a function of exposure and adaptive capacity. By uncertainty we mean a condition under which the probability of any occurrence or event – as well as its specific consequences – is effectively unknown. Risk, on the other hand, we treat as implying an ability exists or potentially exists to calculate the probability of an undesirable outcome or event, in which the consequences are well specified. Earlier we suggested that vulnerability may encompass human and non-human systems and populations. Here we focus largely on the vulnerability of human populations and systems to environmental changes or conditions, while bearing in mind that human wellbeing may be indirectly influenced by the vulnerability of non-human systems. A classic example is that raised in biodiversity conservation, where it is recognized that plant species vulnerable to extinction in deforested tropical areas may have yet-untested pharmaceutical potential.

The paper proceeds as follows. In the following section we introduce how vulnerability has evolved from its origins in natural hazards science and introduce a framework for analyzing vulnerability in the case studies. In Section III we explore the vulnerabilities that arise as a result of natural hazards and settlement patterns in river valleys and coastal areas. Section IV studies the collapse of the Northern Cod fishery on the Grand Banks of Newfoundland. This is followed by a case study of climate change in Section V. Section VI concludes the paper, re-visiting the metrics of vulnerability introduced in Section I.

2 Vulnerability to Environmental Conditions and Change: Conceptual Evolution

2.1 Summary

In this section we review the development of the concept of vulnerability as it relates to the relationship between humans and the natural environment. We begin with its origins in natural hazards science and trace it through to its current encapsulation in the United Nations Framework Convention on Climate Change. The section concludes by introducing the generic framework with which we explore vulnerability in the case studies that follow.

The study of vulnerability to elements present in the natural environment has become of increasing interest among scientists in geography, environmental studies, epidemiology and other scholarly fields. In these fields there is a growing convergence of ideas that vulnerability refers in its most general terms to the potential for loss, and that it is a product of both biophysical and human socio-economic processes.

Much of the current understanding of vulnerability to environmental conditions can be traced to research on natural hazards. Phenomena now referred to as “natural hazards” were traditionally described as “Acts of God”, their origins beyond the comprehension and their effects beyond the control of human beings (Steinberg 2000). Gilbert White’s 1945 doctoral thesis at the University of Chicago, *Human Adjustment to Floods*, is often cited as an early example of the transition from thinking of hazards as acts of God to events whose impacts were often influenced by patterns of human behaviour. A popular quotation from that thesis states “"Floods are 'acts of God,'" he wrote, "but flood losses are largely acts of man." (White 1945).

With Ian Burton and Robert Kates, White would in 1978 make another landmark contribution to the natural hazards field, *The Environment as Hazard*, which also became highly influential in vulnerability research. Focusing on factors that limit rational behavior and pulling together much of the research on natural hazards that preceded it, the authors illustrated using a variety of examples how human activities transform features of the natural environment into either resources or hazards, depending on whether the feature is beneficial or detrimental to human well-being.

In one example from the book, Burton, Kates and White observed that the difference in storm impacts along American's Atlantic seaboard and in Bangladesh (high property damage, low loss of life in the former, the reverse in the latter) is influenced by the relative economic well-being of the two countries. Furthermore, within any given population, the relative vulnerability of individuals to hazards is influenced by economic conditions; the poorest people may be obliged to live in the most hazardous places simply because they have few other choices given their income. Vulnerability to natural hazards (or conversely, the degree to which people can benefit from potential resources) is therefore affected by human decision-making, and this is in turn constrained by a range of economic, social and individual factors. The authors use the term "bounded rationality" to capture this idea. Later work by Slovic, Kunreuther and White (2000) explored this concept further, suggesting that the risks posed by natural hazards are often misjudged because decision-makers rarely have a full range of alternatives or information about alternatives available to them. Moreover, most decisions are made in response to hazard events when they occur and not in contemplation of potential risks.

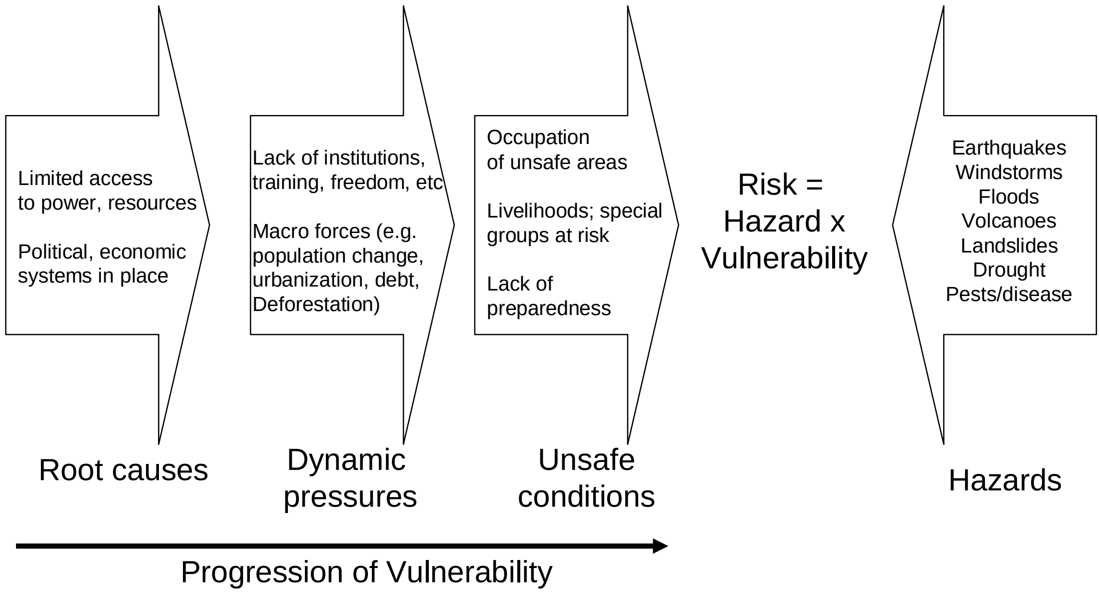
Shortly after the release of *The Environment as Hazard*, the first use of the concept of vulnerability to environmental conditions appeared in Timmerman's 1981 *Vulnerability, Resilience and the Collapse of Society* and Gabor and Griffith's (1985) research on community vulnerability to accidents involving hazardous materials (Clark et al. 1998; Weichselgartner 2001).

At about the same time, a trio of books brought a markedly different approach to the understanding of human-environment interactions, and had a considerable impact on the newly-developing conceptualization of vulnerability. A volume edited by Kenneth Hewitt, *Interpretations of Calamity from the Viewpoint of Human Ecology* (1983), featured research by several well-known authors who investigated how socio-economic processes and systems far beyond the control of individuals, communities or even individual states affect the vulnerability of people to natural hazards. Although natural hazards should not be seen as Acts of God, Hewitt suggested they should also not be treated as management problems where the outcome depends on the availability of information and resources (i.e. bounded rationality). He suggests that vulnerability to natural hazards is a characteristic of the place or society in which they occur, and not an accident. He and the other authors in the volume go on to illustrate how “disasters”, such as famine or catastrophic loss of life in storms, may be stimulated by environmental conditions or events, but become disasters because of prevailing social and political conditions.

In 1985, Piers Blaikie, (like Hewitt, a geomorphologist who sought to uncover the socio-economic factors driving physical changes to landscapes) released *The Political Economy of Soil Erosion in Developing Countries* and in 1987 *Land Degradation and Society* (with Harold Brookfield). In these, Blaikie explored how socio-economic processes can force people into destructive land use practices that decrease their own well-being. Although degradation of land resources typically occurs over long periods of time, it is not considered to be a problem so long as there are easy response options available. As easy response options run out, the subsequent responses reflect differential access to political power and reinforce existing class and socio-economic differences. Those at the bottom end of the socio-economic spectrum become most vulnerable to loss of livelihood; those on the socio-economic margins often literally end up occupying the most environmentally marginal areas.

With others, Blaikie (Blaikie et al. 1994; Wisner et al. 2004) would later extend this logic to the development of models to explain how natural disasters occur, with the “pressure and release” model (Figure 1) becoming a particular reference point for future vulnerability analyses (Turner et al. 2003; Neumann 2005). The pressure and release model argues that the risk of disasters triggered by environmental hazards is created through an accumulation of socio-economic processes operating at several scales which place pressure on local social and environmental conditions, thereby creating vulnerability. This pressure is manifested by such phenomena as particular social groups occupying physically unsafe areas, lack of institutional capacity to respond to emergencies, prevalence of endemic diseases and people relying on livelihoods that are easily shattered. When an environmental disruption occurs that is sufficiently strong to release this pressure, a disaster may occur explosively, as if opening a bottle of carbonated beverage that has been shaken.

Figure 1: Blaikie et al. “Pressure and Release” model



Modified from Wisner et al, 2004

These and subsequent studies of risks to human life and livelihood in particular locations to particular hazards, naturally occurring or otherwise, have given rise to a rapidly-growing field of vulnerability research that

- considers the potential for loss or harm resulting from events at scales from local (e.g. flooding) to global (e.g. ozone depletion);
- ranges from the tangible impacts of naturally occurring events to the psychological perceptions of risk
- explores temporal scales from momentary, instantaneous occurrences (e.g. tornadoes) to ongoing changes in processes over centuries (e.g. climate change)
- investigates risks to human well-being that have origins in bio-physical processes (e.g. hurricanes) to those with origins in human use or misuse of the natural environment (e.g. depletion of fish stocks)

This interest in vulnerability gained further prominence in the 1990s when, in a single decade from its appearance in Timmerman, the concept of vulnerability moved to centre stage in an international convention to respond to a long-term biophysical process that had not previously been treated as a pressing environmental problem. Human-induced climate change, and especially its potential manifestations in the forms of sea level rise and global warming has in the past two decades become a preoccupation of many in the scientific community, policy-makers, industry (especially the insurance industry) and people generally. Demeritt (2001) attributes the rapid growth in concern about climate change to events in the late 1980s, when large-scale droughts and heat waves in North America followed on the heels of the first wave of widely-publicized scientific synthesis reports on climate change research.

Whatever the origins of such concerns, vulnerability quickly became an extraordinarily influential concept in international climate policy. Indeed, the text of the United Nations Framework Convention on Climate Change, first adopted in 1992, makes specific reference to vulnerability in the description of its key principles:

> Article 3.2: The specific needs and special circumstances of developing country Parties, *especially those that are particularly vulnerable to the adverse effects of climate change*, and of those Parties, especially developing country Parties, that would have to bear a disproportionate or abnormal burden under the Convention, should be given full consideration. [italics added]

and in describing the commitments made by parties to the Convention:

> Article 4.4: The developed country Parties and other developed Parties included in Annex II *shall also assist the developing country Parties that are particularly vulnerable to the adverse effects of climate change* in meeting costs of adaptation to those adverse effects. [italics added]

The inclusion of the term vulnerability in the UNFCCC relates back to its usage by the Intergovernmental Panel of Climate Change (IPCC), a body created in 1988 to assess and report to UN members on scientific, technical and socio-economic information related to human-induced climate change. Many of the panel's members were influenced by vulnerability research developing in the natural hazards field. The IPCC Working Group that reports specifically on impacts, adaptation and vulnerability to climate change defines vulnerability as "the extent to which a natural or social system is susceptible to sustaining damage from climate change" (McCarthy et al. 2001, 89), a definition consistent with the concept as it was and is used in hazards literature by people like Ian Burton.

2.2 Conceptualizing Vulnerability

A recent conceptualization of vulnerability that captures the key elements of the discussion so far in this chapter is one based on the 2001 report of the Intergovernmental Panel on Climate Change (IPCC) on Impacts, Vulnerability and Adaptation (McCarthy et al. 2001). In it, the authors (Smit and Pilifosova 2003) present vulnerability as:

$V_{lit} = f(E_{sit}, A_{sit})$

where

V_{sit} = vulnerability
E_{sit} = exposure
A_{sit} = adaptive capacity
s = a given stimulus (in this case, a climatic stimulus)
i = a given system
t = a given period of time

This representation suggests that the two principal elements of vulnerability are exposure (E), which refers to the probability or actual occurrence of a condition that may disturb a system, and adaptive capacity (A), which refers to the ability of those exposed to cope with or respond to those conditions.[2] The subscripted elements emphasize that both elements of vulnerability are specific to the nature of the system in question, the given location and periods of time, and to specific manifestations of climate change. The form of the relationship between vulnerability, exposure and adaptive capacity is not specified, but it is implicit that vulnerability increases as exposure increases and decreases as adaptive capacity increases. Despite the presentation, it should not be inferred that exposure and adaptive capacity are independent variables; actions taken with the intent of increasing adaptive capacity can also affect the nature of exposure, and vice versa.

[2] Instead of adaptive capacity, other authors in the climate change field have used the term “resiliency”, which refers to the ability of a system to absorb shock or perturbation from an adverse event and return to its previous state (e.g. Adger 2000); still others have used the term “coping capacity”, again implying that that vulnerability in part reflects the ability of the exposed community to absorb impacts without being changed (e.g. Yohe and Toll 2002).

The Smit and Pilifosova representation of vulnerability makes no reference to scale. A distinction is often made in vulnerability literature between community and household vulnerability and adaptation (e.g. Kelly and Adger 2000), but such a distinction is made largely to facilitate analysis. Vulnerability can be considered at the scale of individuals in small villages to ongoing global scale environmental change (Roy and Venema 2002). to the scale of large communities or nations to the impacts of natural hazards that occur over short timeframes at local or regional scales (Dorland et al. 1999) to any permutation in between.

This model provides a useful, if essentially broad way of identifying factors which create vulnerabilities for different populations in different settings. However, the model, which is deliberately general to allow for replication in settings that vary in terms of ecological, socio-economic and institutional factors, hints generally at the factors that institutional and social would affect exposure and adaptive capacity in different locations and over different periods of time. It is particularly silent on the kinds of assets and lifestyles different kinds of adaptation would ideally sustain.

2.2.1 The Creation of Vulnerability: Framework Used in the Case Studies

To expand this model, we suggest an elaboration of the ecological, socio-economic and institutional factors which determine exposure and the capacity to adapt both before (*ex ante*) and after (*ex poste*) the onset of environmental disturbance and change. This is simplified through presentation as Table 1. We are not the first to suggest or attempt an approach along these lines (e.g. Handmer et al. 1999) and other authors have elsewhere developed typologies and categorized factors that influence vulnerability and adaptation in particular economic sectors or activities (e.g. vulnerability to climate (Smit and Skinner 2002). Our attempt here is to develop an enhanced general framework of the factors influencing vulnerability of human populations to environmental change and conditions that is applicable across stimuli, scales, regions, and socio-economic activities.

Table 1: Factors in Creation of Vulnerability

Vulnerability	Ecological	Socio-economic	Institutional
Exposure			
Adaptation *ex ante/ex post*			

“Exposure” here implies the extent to which human populations are affected by a particular disturbance, a description that is not a great departure from that employed elsewhere. “Adaptation” entails the efforts, practices, technologies and institutions on which societies can draw, either before the disturbance occurs (*ex ante*) or after (*ex poste*). The value of differentiating between *ex ante* and *ex poste* strategies is it highlights the extent to which officials, vulnerable populations and societies in general have prepared for possible or probable contingencies, and the extent to which vulnerabilities and complexities (Perrow, 1984) emerge in these instances. Examples of *ex ante* forms of adaptation would include breakwaters, vaccinations, etc. Examples of *ex poste* strategies would include evacuation, water purification (after flooding) and so on.

Ecological Dimensions

Ecological factors can affect the extent to which human populations are exposed to potential hazards, as well as their ability to anticipate and respond to these disturbances. Ecological dimensions of exposure may include the geology of a watershed, the meteorology of a particular region, the composition of species and so forth.. Ecological dimensions of adaptive capacity may include the nature of a terrain, which may prohibit evacuation and other forms of adaptation. They also refer to the relative complexity of the ecosystem in question, which may overwhelm the ability of scientists, managers and vulnerable populations to understand and respond to the disturbance.

Socio-economic Dimensions

Socio-economic dimensions of vulnerability may include such things as the historical factors that drive populations to settle in, work in and/or visit areas that are exposed to potentially hazardous situations. They also entail the socio-economic incentives which exacerbate the intensity and scale of resource depletion and environmental degradation (e.g. heavy reliance on fossil fuels; intensity of agricultural production; consumerism) and developments that affect the ability to respond to change (e.g. disparities in income between rich and poor). In relation to institutional capacity, socio-economic factors may compromise the ability of scientists and environmental managers to regulate (and therefore adapt to) the problem. Examples include such things as public transportation practices and infrastructure, the influence on of pressure and advocacy groups (e.g. fossil fuel lobby, environmental lobbies, trade unions) on government, political pressure on scientists and environmental managers, and so forth.

Institutional Dimensions

Institutional factors are the formal rules, regulations, practices and mechanisms that would reduce exposure and/or improve the capacity to adapt to environmental problems. Here we would include factors such as zoning, planning, the allocation of property rights and other laws and procedures governing industry and settlement in vulnerable areas. Examples here might include internationally negotiated settlements, like the Kyoto Protocol on climate change, national or sub-national statutes like the US Environmental Protection Act,, as well as professional and informal practices, such as science, experience, the limitations of science, excessive reliance on expertise, early warning systems, cyclone shelters, insurance (private, public and community), and disaster response mechanisms.

The differentiations between these three categories are not entirely water tight, as will be seen in the case studies that now follow. In the case of the northern cod, for instance, we document instances in which the historical dependence and the power of the commercial fish industry put enormous pressure on scientists and fisheries managers to expand rates of extraction on the Grand Banks of Newfoundland. Similar assertions could be also made about the historical dependence on fossil fuels and the impact of the fossil fuel lobby.

In the following sections we consider ecological, socio-economic and institutional dimensions of vulnerability through exposure and adaptive capacity in three issue areas: (1) natural hazards (particularly flooding in coastal zones and river valleys); (2) the collapse of the north Atlantic cod fishery and (3) climate change.

3 Natural Hazards and Vulnerability

3.1 Summary

In this section we apply the vulnerability framework introduced in Section II to the cases of coastal and river valley flooding, in order to illustrate the ecological, socio-economic and institutional contributions to the formation of vulnerability.

The concept of vulnerability has existed in the natural hazards literature for a considerable length of time, and there exist numerous papers that review the development of the concept (Cutter 1996; Liverman 2001; Weichselgartner 2001). Here we take the key functional elements of vulnerability, exposure and adaptive capacity, and categorize the physical, socio-economic and political-institutional processes that influence these elements and thereby shape vulnerability to natural hazards.

Table 2 begins this exercise by providing a simplified tabulation of elements of human systems that may be vulnerable to natural hazards and conditions to which those elements may be vulnerable (Table 2).

Table 2: Context of vulnerability to natural hazards

Vulnerable elements of human systems	Potential hazards to which human systems are vulnerability
- human health & well-being - human life - public infrastructure: roads, rails, utilities, health care - private property: residential, commercial - financial markets - law enforcement/public peace	- precipitation extremes (too much, too little) - high winds - extreme storms (monsoons, hurricanes) - earthquakes - flooding: riverine, coastal - extreme heat - extreme cold - tornados - avalanche, landslide - post-hazard events: disease outbreaks; breakdown in civil order

From this list of potential hazards, we select one in particular – flooding – to use in illustrating key elements in the formation of vulnerability.

Flooding can occur in coastal and continental areas, and is an outcome of a number of possible climatic or geological events. Flooding does not hold any potential for loss or harm for human systems unless human occupancy or activities occur in the place where flooding occurs; in other words, socio-economic and political-institutional systems are necessarily influential in the creation of vulnerability to floods. Moreover, the nature of loss or harm due to flooding is directly related to the nature of the human activities occurring in the exposed areas. Table 3 provides a starting point for interpreting the creation of vulnerability to flooding by identifying some of the processes that create exposure to flood risks. For ease of discussion we separate processes that create exposure to flooding in coastal areas from those that create exposure to flooding in continental areas, typically in river valleys.

Table 3: Elements in the Formation of Exposure to Flood Hazards

Exposure to:	**geological, biophysical processes**	**social, economic processes**	**institutional, political processes**
Coastal Flooding	- morphology of coastal zone (e.g. cliffed shoreline, beach shoreline, slope of underwater shelf, etc) - location of faults, nature & timing of tectonic activity - tidal conditions/tidal range - frequency, intensity of extreme storms and accompanying surges - agricultural potential of coastal area	- tourism - transportation - aquaculture - agriculture - urbanization	- coastal zone management - engineering (e.g. breakwaters) - emergency preparedness - seismic monitoring - sharing of information, strategizing across jurisdictions
	- quantity of snow cover, timing and speed of melt - extreme weather events - landscape modification in catchment	- transportation - recreation - industry - urbanization - historical processes (e.g. mills)	- zoning, land-use planning - flood control engineering - flood insurance - regulation of catchment area land use (e.g.

River Flooding	- post-drought conditions in catchment - intermittency of streamflow - precipitation: quantity, duration, intensity, spatial distribution - utility of catchment for human activities: agriculture, industry, settlement		forestry - post-flood compensation - emergency preparedness - meteorological systems - research and funding

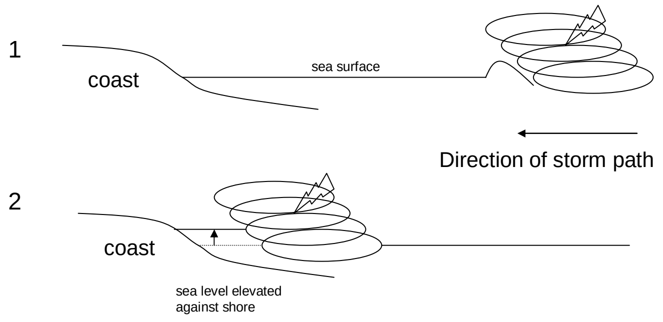
3.2 Flooding Exposure: Coastal Zone - Geological and Biophysical Factors

Coastal zones are often inherently desirable areas for human settlement for a number of reasons. The climate of a coastal region is typically far more moderate, with fewer extremes in temperature than neighbouring continental areas at the same latitude (consider the local climates of Vancouver versus Winnipeg or London versus Kiev). Fresh water is typically in plentiful supply year-round, particularly in places where river catchment areas drain into the coastal zone. Soil that has eroded off continental areas is often carried into coastal zones; combined with the plentiful fresh water supply, conditions are often favourable in coastal zones for agriculture. This complements the access to fish and shellfish to provide coastal zone populations with high quantities of accessible food. Water transportation has historically been, and continues to this day to be the least expensive means of transporting large quantities of goods, facilitating commerce in coastal zones. Coastal areas also hold an inherent recreational attraction for people, be it international resort destinations in tropical areas like Phuket or the Caribbean, but also Mediterranean climates like the French Riviera or southern California and cool temperate climates like Blackpool or Victoria BC.

Coastal zones are not homogeneous in their geomorphology, and vary significantly from one to another with respect to their latitude, geology, the nature of adjacent ocean conditions and climatology. Some are more conducive to human occupance than others. The point to be taken here is simply that there are very good reasons why large human populations are concentrated in coastal areas throughout the world.

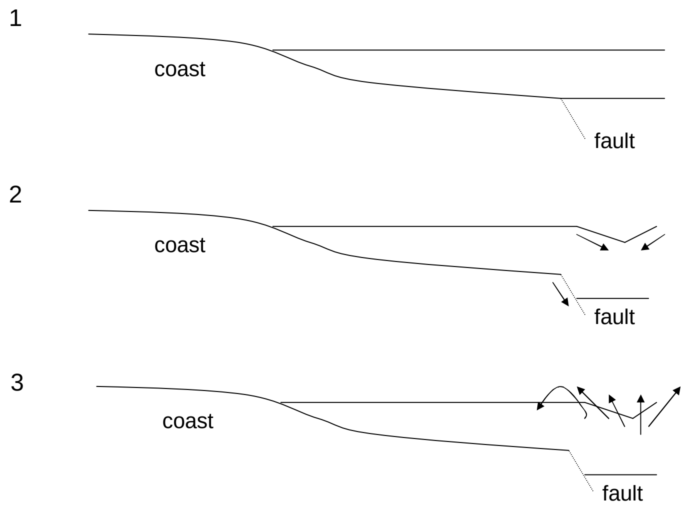
One physical cause of flooding in coastal zones is storm surges that accompany extreme weather events. As the name suggests, a storm surge develops as a storm moves across open water, elevating the sea surface before it (Figure 2). When the storm surge reaches shore, the elevated water becomes trapped and pressed against the shore. Other physical factors affect the spatial extent and magnitude of the flooding. For example, depending on whether the tide is in or not influences the height of the surge relative to the shore. A coral reef, barrier island or mangrove forest present off or along the coast may absorb much of the initial impact of the surge, mitigating the impact on the protected shore. A cliffed shoreline with an elevated coastal plain may be less likely to be inundated than a gradually-sloping, low-lying coastal plain.

Figure 2: Storm surges



Another cause of coastal zone flooding that occurs less frequently but can be particularly destructive, as witnessed in Southeast Asia in 2004, are tsunami that may occur as a result of seismic events. When movement occurs along a submerged fault, depending on the direction of shift of the adjoining plates relative to one another, the water above the fault may suddenly be displaced, spontaneously triggering a wave or waves on the surface that can be much larger than those generated by meteorological events. The relative impacts of tsunami on the coastal zone when they reach land are influenced by features similar to those that affect the impacts of storm surges. The proximity of an undersea fault to a coastal population reduces the time between the slip and the impact of the wave(s), but coastal populations distant from the fault may still be affected by the tsunami. Such was the case in 2004 when the Sri Lankan and Somali coasts were struck by tsunami as were the Indonesian and Thai coasts much closer to the fault.

Figure 3: Tsunami formation



3.2.1 Flooding Exposure: River Valleys - Geological and Biophysical Factors

We use here the term “river valleys” to refer to inland watercourses generically, regardless of their size, streamflow or morphology. As with coastal zones, river valleys tend to be inherently desirable places for human occupance. They provide reliable sources of freshwater, as well as an efficient means of removing waste and effluent from the occupied area. River valleys often contain deep deposits of soils suitable for cultivation, their productivity enhanced by the availability of water for irrigation. The quantity, velocity and seasonal reliability of water in a watercourse affect its suitability for transportation of goods by boat or for other industrial uses; navigable watercourses may have a particularly high economic value.

A variety of climatic, geologic and bio-physical processes influence the amount of water in a watercourse at a given point in time. Precipitation in a watershed is a key factor, and its rate of collection in watercourses is influenced by such factors as its timing, duration, variability, volume and spatial extent. For example, in semi-arid regions, precipitation events may occur only occasionally throughout the year, meaning that watercourses may contain water only intermittently or at low levels most of the time. Vegetation cover, which slows movements of water across surfaces, is typically of a low density in such landscapes. Consequently, when precipitation events occur, it may accumulate very rapidly in watercourses, potentially giving rise to flash floods. Conversely, in a temperate area with regular precipitation and little seasonal variation, the range of flow in a watercourse may vary considerably less. Vegetation cover tends to be naturally dense, moderating the rate at which precipitation accumulates in watercourses. In such environments, protracted heavy rainfall events that saturate the soils in the watershed, or extreme rainfall events that suddenly dump large quantities of precipitation on a small spatial area may be needed to cause a watercourse to exceed its usual flow range and flood its banks. When extreme rainfall events occur, the receiving watercourse may suddenly flood while another only a few kilometers away may be unaffected.

While in the tropics precipitation usually occurs only as rainfall, in higher latitudes it may occur as snow, meaning that it may accumulate on land and not immediately begin draining into watercourses. Its effects on streamflow therefore depend on the quantity of snow that accumulates in the watershed and the speed with which it melts. A sudden shift in air temperature, for example, from below freezing to many degrees above freezing, produces a much faster accumulation of snowmelt in watercourses than a gradual change, such as when daytime temperatures are above freezing and nighttime temperatures are below freezing over a period of weeks. In cases where snow melts especially quickly, it may enter watercourses before ice has had a chance to break up. In such cases the ice may form a dam, causing the watercourse behind it to rise suddenly and flood the surrounding area.

There are physical factors other than precipitation that affect stream flows. The topography of land in a watershed or area within a watershed, for example, may consist of frequently steep slopes that speed surface run-off into watercourses, or it may be relatively flat and feature wetlands where water accumulates and only gradually discharges into watercourses. Different soil types allow for different rates of infiltration. Densely packed clay soils may become saturated very quickly, causing precipitation to run off quickly and, where it is found on steep slopes, create the potential for sudden slope failures. Sandy soils, on the other hand, may allow large volumes of precipitation to infiltrate before becoming saturated.

The nature and extent of vegetation cover may have a significant effect on the rate at which precipitation accumulates in watercourses. In mature tropical rainforests, for example, little precipitation that falls reaches the ground directly; most of it is captured by the canopy and percolates its way to the forest floor through vegetation and flowing along stems. Most of the organic material in tropical forests resides in the vegetation and not in the soil, so when tropical forest cover is removed, the exposed soils in such areas tend to be thin and highly susceptible to erosion.

3.2.2 Flooding Exposure: Socio-economic Factors Affecting Exposure

The nature of how land in such areas is used, and the social behavior of populations that occupy such areas have a significant influence on the nature and degree of their exposure to flooding, be it in river valleys or coastal areas.

In coastal areas, human activities and infrastructure are rarely distributed uniformly or randomly along the shore; rather certain types of activities tend to occur in particular areas. For example, not all parts of a coastline make for safe harbours for shipping; features such as deep water close to shore, few offshore shipping hazards like sandbars or reefs, and shelter from wind and waves are highly desirable features for ports. Such features make ports typically less susceptible to storm surge flooding and wave damage than other coastal areas.

Once ports are established, large amounts of economic activity, capital and people tend to accumulate around them relative to other areas in the coastal zone. This includes the boats and ships, which may be for transportation, fishing, pleasure or other uses; the infrastructure that facilitates the loading and unloading of cargo; the myriad of goods that converge at such points; and the people who depend on such activities for their livelihoods. Consequently, in the rare instances when a storm surge overwhelms a port’s natural and human-engineered defenses, the ensuing property damage and loss of life can be immense, as was the case when a hurricane storm surge hit Galveston, Texas in 1900, killing 6,000 of a population of 37,000 (Lutz 2005). Although the city of New Orleans did not experience a direct hit from Hurricane Katrina in 2005, the city’s system of levees collapsed under the volume of precipitation that accompanied the storm.

Other coastal areas may be poorly suited for ports but may be valuable for other uses. Low lying coastal areas and deltaic environments may be highly suited for agriculture, aquaculture or both. The deltas of the Mekong, Ganges and Nile rivers support very large agricultural populations. Deltaic soils tend to be very fertile, and are frequently recharged by deposits from periodic flooding of the rivers. At the same time, such floods pose hazards for populations living in deltaic environments, as water channels migrate and housing once well above waterline may suddenly have the soil beneath it washed away. Low-lying coastal areas in many parts of sub-tropical Asia have been converted to aquaculture, where valuable species of shrimp and prawns are raised in ponds (Barbier and Cox 2003). The construction of such ponds often entails the removal of coastal mangrove forests, which would otherwise absorb and dissipate the force of incoming storm surges. Nutrients washing off the land may also cause algal blooms that harm protective offshore barrier reefs, further increasing the exposure to storm surges..

Land degradation, particularly the deforestation of steep slopes in coastal areas, can increase the destructiveness of storm-related flooding. In Honduras in 1999 and in Haiti in 2004, precipitation that accompanied hurricanes caused massive mudslides and flooding. In both instances, large areas of steeply-sloped hillsides had been denuded by impoverished people seeking fuelwood and/or places on which to build squatters' dwellings (Girot 2002). The fact that poor populations have been obliged to resort to such areas in an attempt to secure the means of survival is not unique to those countries, but is a familiar repetition of processes leading to land degradation in Africa reported a quarter century ago by Blaikie (1985) and Blaikie and Brookfield (1987). Moreover, there is no reason to believe that socially marginalized people who eke out a living on marginal lands, such as the poor hillslope residents of Honduras and Haiti, are unaware of the risks they take or of the possible environmental consequences of their activities. Forsyth (1996) for example, has shown that poor residents in rugged areas of Thailand do take steps to mitigate impacts of their activities on the landscape as far as their means will allow. The point to be taken here is that severe poverty may serve to magnify vulnerability to flood hazards.

Affluence, too, may affect vulnerability to flood hazards. Over the past half-century, air travel has become increasingly affordable for residents of more developed parts of the world, making even remote destinations increasingly accessible. Catering to tourists may be lucrative for a number of reasons, not least of which it can be a significant source of hard currency, an aspect that is attractive to many developing nations. Consequently, coastal areas in many developing countries have been converted to tourist accommodation and recreation. Common features that western tourists find attractive include sandy, gently sloping beaches, a coastal morphology that makes them highly susceptible to inundation. The infrastructure that accompanies tourist development in coastal zones – hotels, vacation homes, pleasure boat marinas and so forth – tends to have high monetary value, so that floods in such areas are often relatively costly in terms of property damage. The tourist-based economy of the Maldives was hit particularly hard by the 2004 Asian tsunami.

River valleys are natural features where human wealth is highly concentrated relative to other continental landscapes. Where used for agriculture, river valleys often host crops with high soil moisture requirements and/or specific micro-climatic demands, such as grapes and tree fruits. Because they are more challenging to grow in large quantities than crops like cereals, the crops found in valleys tend to have high commercial values. Even greater concentrations of wealth emerge when river valleys host large concentrations of industry and large population centres. There are strong historical reasons for urbanization to occur in river valleys. Up until the beginning of the last century, an available streamflow was necessary for many industrial activities based on milling, such as the production of lumber, flour, and woolens. Rivers that had sufficient flow for summer navigation had even greater economic value. It is no surprise that industrial production and the necessary populations of workers first became concentrated in large river valleys. Population concentrations in river valleys continue to remain high as societies throughout the world become increasingly urbanized, since urban centres require large amounts of water for industrial and household consumption and for treatment and discharge of waste water.

These concentrations of infrastructure, population and land uses with high economic value increase the potential for property damage and/or loss of life when river levels increase. This is in part due to the simple presence of such activities in the valley, but it is also due in part to the ways in which such activities tend to alter the geomorphic processes in a valley. For example, urban areas are less vegetated than non-urban areas; in many cases, large swaths of land in an urban area may be covered with pavement and drained with sewers. Rather than infiltrating gradually through vegetation and soil, precipitation falling on an urbanized watershed may be channeled quickly and directly into watercourses, causing rises in streamflow that are much more rapid than would naturally occur. The banks of watercourses in urban areas are also often altered, through removal of vegetation or construction of reinforced channels. This restricts the lateral expansion of watercourses, increases the rate of vertical rise in the watercourse, and increases the velocity of streamflow. In other words, the features of river valleys that make them so attractive for human occupance may in turn be made more hazardous by that very occupance, depending on its nature.

3.2.3 Flooding Exposure: Institutional and Political Factors

Development in coastal zones and in river valleys throughout much of the world has been loosely regulated or planned, if at all. What makes this a significant factor in exposure to the hazard of flooding is that the allocation of land use according to, for example, its economic value may not be consistent with minimizing the risk of inundation. The removal of coastal mangroves may increase the economic value of a land parcel as a hotel property, since greater beachfront and unobstructed water views increase the prices that may be charged per room. However, the act of doing so may increase not only the risk of storm surge inundation to the hotel property, but to other landward properties as well. Decisions on land use may be made by non-resident property owners, whose risks are purely monetary in nature, and who do not share in the physical risk of inundation. The absence of institutional preparedness may increase the destructiveness of floods when they occur. Given their sheer geographic expanse, river valleys and coastal areas may encompass or traverse multiple jurisdictions at multiple scales. The investment needed to undertake coordinated emergency planning, monitoring meteorological and seismic activity and similar actions to protect populations may only be possible at the state level. Decisions to undertake these investments as opposed to other, unrelated responsibilities that typically fall to states, may entail any number of actors and agencies, may be constrained by availability of resources or political will, and may depend on perception of the risks in comparison with other identified priorities requiring investment.

In the case of river valleys there is an added dimension that makes them vulnerable to flooding, in that it is not simply the use of land in the area at risk of inundation that is of concern, but land use throughout the watershed. For example, forestry practices in the upper reaches of a river's catchment area may affect the rate at which precipitation run-off and snowmelt enter the streamflow, thereby affecting the risk of downstream flooding.

Decisions to modify stream channels may affect downstream flows as well. Engineering controls put into place to protect urban centres from flooding may include channel enlargement, through excavation of channel bottom or elevation of banks, to speed large volumes of water past the city. Such measures may increase the potential for flooding and the destructiveness of floods for downstream areas. Other flood control measures may require deliberate decisions to permit flooding along one section of the watercourse to reduce flooding at another. This may be done to protect urban areas, where more resources, people and political power is concentrated, at the expense of others.

Another factor influencing exposure to flood risks is the very definition of flood risk itself that is used by regulating authorities. For example, in many jurisdictions, regulating authorities use terms such as ‘50-year flood’ or ‘100-year flood’ when formulating land-use planning guidelines. Such terms typically refer to measures taken of the highest water levels recorded in a given watercourse in a given area in the preceding period of years. Land use activities within such areas may be restricted to those which are least susceptible to flood damage, or may place restrictions on residential occupancy to reduce flood damage and loss of life. A by-product of this choice of guidelines may be the development of false perceptions, such as that areas higher than the 100-year flood line have a minimal potential to be inundated, that areas within the 100-year flood line have a 1 in 100 chance of being flooded in any given year, or that a flood of that magnitude will not re-occur for another century once it has occurred. There is, in fact, no geophysical reason why the highest water levels recorded in a given watercourse in the past century may not be exceeded the following year, and the year after that, and so forth. The city of Peterborough, Ontario, for example, experienced its worst recorded flooding in 2004 following an extreme thundershower event. The city previously recorded a ‘hundred-year’ flood in 2002. If the 2004 event were to be selected as the ‘100-year flood’ for that city, there is no reason to believe it could not be eclipsed as quickly as was the previous 100-year flood event that occurred two years prior.

Government programs to compensate and insure against hazards such as flood damage, which would at first seem to be logical means of reducing vulnerability, may actually serve to maintain or increase exposure to flooding, by removing incentives to reduce exposure or by reinforcing economic behaviour that places people and property at risk of flooding

(McLeman and Smit, forthcoming 2006). The case of flood insurance in the United States, which follows at the end of this section, illustrates this point.

3.3 Flooding and Adaptive Capacity

In the preceding section, factors that contribute to exposing populations to the risk of flooding were categorized according to their physical, socio-economic and institutional origins. Similar categorizations may be used to describe factors in the formation of the capacity to adapt to the risk of natural hazards such as flooding. In this section, however, rather than treating coastal flooding and river valley flooding as separate examples, we consider them together and instead separate out the elements that form adaptive capacity before and after the hazard event occurs (*i.e. ex ante and ex poste)*; what might be otherwise described as anticipatory adaptation and responsive adaptation (summarized in Table 4).

Table 4: Elements in the Formation of Adaptive Capacity

Adaptive capacity	**geological, biophysical processes**	**socio-economic processes**	**institutional, political processes**
before event	- timing, persistence, endurance of hazard risk - predictability of hazard risk - possibility of alternative land uses	- available financial resources - perception of risk - cultural norms and transfer of knowledge	- planning priorities and capabilities - perception of risk - capacity and will to regulate land use - technological capabilities
after event	- topography - ease of access to event site - post-event climatic conditions - soil conditions, ability of vegetation to regenerate	- available financial resources - distributions of wealth - alternative forms of capital	- available financial resources - organizational behaviour - management skills - institutional memory

3.3.1 Adaptive Capacity: Geological and Biophysical Factors

The capacity of populations to adapt to risks in their environment, such as flooding, may be moderated or influenced by local or regional physical conditions. In coastal zones, the risk of storm surge-related flooding may be present throughout the year, but in many coastal environments the occurrence of storms and extreme weather events follows seasonal patterns. In Bangladesh, the risk of flooding is especially high during the summer monsoon season; on the US Atlantic coast the risk is highest during hurricane season of June-November. Because the risk of storm surge-related flooding is not constant throughout the year, coastal areas may have some flexibility in their planning and allocation of resources for such things as emergency preparedness and forecasting, by increasing their readiness during higher-risk seasons (although climate change may make contingency planning Less certain in the future).

The risk of tsunami-related flooding is considerably different in nature from storm surge-related flooding in terms of options for adaptation. Tsunamis caused by geologic processes are infrequent events that may not affect a given coastal area for years, decades or even centuries, yet, the risk may be omnipresent. The relative infrequency of seismic events presents different monitoring and preparation challenges than storm monitoring.

Technologies to monitor atmospheric conditions for storms and faults and offshore sea conditions for seismic activity and tsunami exist, and either or both can be implemented assuming financial resources are available. However, the applications of meteorological technology and satellite imagery extend beyond storm monitoring, and for this reason may therefore present a more justifiable public investment than seismic monitoring.

Another set of physical factors that may influence adaptive capacity relate to the availability of land, topography and the range of alternative land uses. In the case of a small island state, there may be no land anywhere within that state's territory that is not at some degree of risk of inundation (as was the case of many islands in the Maldives archipelago during the 2004 Asian tsunami). Consequently, there may be no option of arranging land-use activities so that those least susceptible to flood damage are carried out in the most exposed locations and vice versa, or locating essential services in areas that are not exposed at all. There may also be few safe locations where people can take shelter during a storm. Conversely, in a large jurisdiction with coastal and non-coastal environments, activities that are particularly sensitive to flood damage may be kept away from exposed areas. Emergency evacuation routes can be established that quickly lead people to higher ground when an event occurs. The remoteness of exposed areas may also be a significant factor once a flood event occurs.

Should a population affected by flooding require relief assistance, the speed with which outside workers, equipment and supplies can reach the location is influenced by distance, speed of communication and availability of transportation routes.

3.3.2 Adaptive Capacity: Socio-economic Factors

An undeniable factor in the formation of adaptive capacity is the financial resources available to populations exposed to hazards. The classic and oft-cited example is the difference in impacts of cyclonic storms on Bangladesh and the US Atlantic coast (Burton et al. 1993). Storms in Bangladesh are often accompanied by enormous loss of life, while in the US enormous dollar values in property losses are common, but loss of life is rare.

Its relative wealth allows various levels of government in the US to make heavy investments in disaster preparedness, monitoring and warning systems, and to compensate victims of natural hazards. The relative affluence and recreational preferences of its citizens means that places that are most frequently hit by storms, such as the barrier islands off the Carolina coast and the Florida Keys, include many vacation homes, resorts and pleasure boat marinas – that is, properties of high financial value. Sufficient advance warning is often received so that residents can secure their property and retreat inland before a storm hits. Bangladesh's coastal islands, by contrast, are home to concentrations of subsistence farmers of limited financial means, who may receive minimal information about impending storms and have few places to seek shelter.

Not all people who live in coastal areas, even in the US, are homogeneously wealthy, and particular groups such as the elderly, infirm, and destitute may have less capacity to adapt to hazards such as coastal storms than do other groups (Clark et al. 1998). Hurricane Katrina produced unforgettable images of African Americans stranded for days awaiting evacuation from New Orleans – an ugly reminder of the social and economic divisions that too often fall along racial lines. People of limited financial means may, for example, live in dwellings that are less able to withstand storm damage, may be forced to occupy land that is more exposed to storm conditions, or may not have access to simple means of communications such as television, radio or telephone from which to receive warnings. In both Australia and the US, for example, trailer or caravan parks where large proportions of residents dwell permanently are often found in locations with a high physical risk of flooding (Meyer 2000; Yeo 2003).

Hurricane Mitch , which struck Honduras, Guatemala and El Salvador in 1998 and Hurricane Jeanne which struck Haiti and the Dominican Republic in 1994, were storms that struck hardest the poorest members of the population in Honduras and Haiti, many of whom had been obliged to live in makeshift dwellings on steep slopes that were washed away by heavy rains. This is an example of a widely held observation that people occupying the economic margins of society often occupy the physically most marginal land areas.

How people interpret and perceive risk may also influence their capacity to adapt to hazards, particularly in terms of preparedness. Even when repeatedly warned about a high impending danger of flooding, many residents of Grand Forks, North Dakota refused to purchase flood insurance in 1997, some simply not believing their property was at risk, others being overly confident in the robustness of the city's engineered flood defenses (Pynn and Ljung, 1999). Cultural norms and the transfer of knowledge from one generation to another have a role to play in adaptive capacity. Following the 2004 Asian tsunami, several media outlets reported of indigenous groups occupying small islands off the coast of Indonesia and in the Andaman Islands who experienced no casualties. These groups had passed down oral histories of past experiences with tsunamis, containing the information that whenever earth tremors are felt one should immediately seek out high ground.

3.3.3 Adaptive Capacity: Political and Institutional Factors

The case of government-subsidized flood insurance illustrates how political and institutional decisions can alter vulnerability to natural hazards in sometimes unintended ways. More than 10% of Americans live in areas that are subject to periodic flooding, over six million buildings exist in areas identified as '100-year' floodplains, and almost 90% of counties in the U.S. experienced at least one flood in the 20th century (Blanchard-Boehm et al. 2001; Burby 2001). Since the 1960s, the federally-funded National Flood Insurance Plan has provided subsidized flood insurance for properties in designated high flood-risk areas, which is often required in order to obtain a mortgage or institutional financing for property in such areas. Flood insurance is not otherwise mandatory, and so where it is not needed for financing purposes, participation in the plan tends to be low (Pynn and Ljung 1999; Browne and Hoyt 2000). A possible reason is that floodplain residents expect that, should a flood event occur, *ad hoc* disaster relief can be expected from government agencies. Given past government practices, this expectation is a realistic one.

People purchasing federal flood insurance pay less than 40%, on average, of the actual cost of coverage, with the remainder being subsidized by the federal government (Burby, 2001). Premiums are based on a combination of factors, including the value of the property insured and the probability of flooding in that particular area. Owners of existing structures in a floodplain pay lower premiums than do owners of newer structures (Burby, 2001) providing a small incentive to continuing to own and operate older structures that may have been flooded previously. Purchase rates of flood insurance tend to be related positively with the income levels of purchasers (Browne and Hoyt, 2000). This can be interpreted a number of ways. Flood insurance purchase patterns in Grand Forks, North Dakota, suggest that the higher the value of the property, the more likely flood insurance would be obtained, with property value being a more significant factor in the decision to purchase flood insurance than the proximity of the property to the source of flooding (Pynn and Ljung 1999). In other words, the availability of government flood insurance may help maintain the presence of higher value properties in areas at risk of flooding, thereby increasing the level of exposure in terms of value of property at risk to flood damage.

Even though it may seem counter-intuitive to reducing exposure to flooding, the National Flood Insurance Plan is based on the premise that continued occupation of floodplains is in America’s economic interest (Burby, 2001). This assumption runs counter to initiatives that may be taken at other levels of government to reduce exposure to flooding. Another phenomenon that emerges is that purchasers of flood insurance may take few or no other measures to reduce the risk of flood damage to their property, such as landscaping or storing valuable items only above grade (Blanchard Boehm et al 2001). It appears the attitude of insured property owners is that having insurance precludes the need for any other actions.

This simple case shows that, even institutional measures that at face value appear to reduce the impacts associated with a natural hazard, and may be designed with the intention of helping people adapt after an event has occurred may actually increase levels of exposure to that hazard, as a consequence of the resulting interactions of geophysical, socio-economic and institutional processes.

To sum up, this section has suggested that a simple set of metrics of vulnerability can indeed be fashioned to describe the range of factors that influence vulnerability to natural hazards such as flooding. In the following section, we look more closely at the interplay of these factors in the creation and realization of vulnerability, and look outside the natural hazards literature to consider to the case of the collapse of a natural resource stock, that of the North Atlantic cod fishery.

4 Vulnerability and Collapse: The Case of the Northern Cod

4.1 Summary

In this section, we consider the collapse of the northern cod fishery, and argue that economic rationality, biological processes and ecological changes (in the form of cooler weather and an expanding seal population) conspired to produce a cascading effect in the northern cod fishery, which led to a total moratorium on northern cod fishing in the north Atlantic fishery. Confounding this process, the techno-rational approach to the management of the northern cod was deeply constrained by a science that failed to account for the illegal (and thus unreported) actions of individual resource users.

World fisheries have undergone severe depletion since the end of the Second World War. The Millennium Ecosystem Assessment (Reid et al. 2005) reports that global aggregate catch rates have been falling consistently since the late 1980s. More disturbingly, the "trophic level," or the level of the organism in the food chain, has dropped since the 1950s, suggesting that world fisheries have been using increasingly destructive technologies to capture smaller and smaller sized fish. Such findings are consistent with other studies; Myers and Worm (2003), for instance, collected data from four of the world's major continental reef fisheries and nine deep sea fisheries. Their findings were suggest that the global ocean has lost more than 90 per cent of large predatory fishes. Industrialized fisheries "typically reduced community biomass by 80 per cent within 15 years of exploitation," (Myers and Worm 2003: 280), meaning that 80 per cent of the entire stock was depleted within this period of time. More dauntingly, they suggest that future management of global fish stocks suffers from a substantial lack of data for open ocean systems; moreover, the data which exist for coastal and shelf ecosystems are largely derived from government trawler surveys and the catch of commercial vessels.

In this section, we consider the collapse of the northern cod fishery, a case that embodies many of the elements we find in these global assessments, including a catastrophic rate of exploitation, the industrialization of commercial fishing, extensive government intervention and resource shortages arising as a result of poor data, malfeasance on the part of resource users and a fair amount of political pressure. What makes the collapse of the northern cod so important is that it occurred during a period in which the fishery was *relatively* well-managed. Regulatory instruments, such as total allowable catch (TAC), entry limits and licensing were introduced in the early 1970s (see below). Moreover – and unlike many commercial fisheries (particularly ones in low income countries) – the northern cod was the subject of frequent studies and stock assessments. Hamilton et al. (2004: 201) estimate that the Department of Fisheries and Oceans conducted as many as 3,000 separate surveys of the Grand Banks between 1983 and 1994. As we shall see, the reliability of these assessments was far from perfect. However, the fact that a fishery with (relatively) sophisticated management and assessment capabilities could collapse in such a spectacular way illustrates both the complexity of fisheries management and the vulnerabilities which can arise in the context of imperfect knowledge and self-maximizing behaviour.

The value of selecting a single case in this instance is that it provides an important opportunity to understand the complex ways in which ecological disturbances, imperfect science, rent seeking, and institutional inertia led to highly unsustainable rates of resource extraction, which ultimately resulted in the economic and ecological collapse of a fishery on which human and marine populations were highly dependent. The collapse of the northern cod fishery entails a number of factors (such as an unusually large continental shelf and overlapping jurisdictions which are unique to Canadian federalism), which are unique to the particular case. However, it should be stressed that the collapse of the northern cod shares many features which are consistent with the collapse of other commercial fisheries, most notably the collapse of the Northeastern Atlantic herring fishery in the 1950s and 1960s (Myers et al. 1997), the collapse of the Californian sardine fishery in the 1960s and the collapse of the Peruvian anchovy fishery in the early 1970s (Deligiannis 2000). In all of these fisheries, the introduction of new technologies (particularly large-scale commercial trawlers with refrigeration capabilities), the use of increasingly complicated management practices and imperfect knowledge about the state of the fishery led to the collapse of the fishery.

4.2 Explaining the Collapse

In 1992, the Department of Fisheries and Oceans (DFO) of the Government of Canada closed the northern cod fishery, responding to a mounting body of evidence which suggested that the fishery was no longer able to support any form of commercial activity. At the peak of their productivity (in the 1960s) groundfish landings in the Atlantic fishery exceeded 1.5 million tons per year, 40 per cent of which were cod (Brethes 1998: 136-7). By 1995, this figure had dropped to 12,000 tons, reflecting the federal government's decision to close the northern cod fishery in 1992. For the communities living along the Northern Peninsula of Newfoundland and Labrador, the moratorium and, more generally, the costs of over-fishing have been catastrophic. Brethes (1998: 136) estimates that at the height of the fishery, commercial landings accounted for more than a billion dollars (Canadian) in annual revenue, and employed more than 100,000 people. Conservative estimates suggest that as many as 40,000 people were directly affected by the 1992 closure (Brethes 1998: 177). Evidence also suggests that decades of industrial/commercial fishing have seriously transformed the marine ecosystem. Marine surveys show that in spite of a decade-long moratorium on cod fishing, northern cod stocks have failed to rebound (Hamilton et al. 2004: 198; Brethes 1998: 143). Other groundfish stocks were maintained after the moratorium (Brethes 1998: 137), although access to these areas was severely restricted (Hamilton et al. 2004: 198). In 2003, the federal government decided to close the entire cod fishery (Hamilton et al. 2004). Experts now predict that if all fishing were stopped on the Atlantic coast, recovery would still take a matter of decades (Hamilton et al. 2004: 198).[3]

Unlike the collapse of the Peruvian anchovy and Californian sardine fisheries, the collapse of the northern cod entails an added international dimension, which has become particularly important in the management of coastal fisheries around the world. In 1977, Canada (among many coastal nations) negotiated territorial rights to offshore fishing areas, known as Exclusive Economic Zones (hereafter EEZs). EEZs typically cover a 200-mile area of sea off the coastline of maritime nations, and entitle the coastal nation to manage entry and utilization of maritime resources in this area, using instruments like quotas and gear restrictions on its own boats and those of foreign vessels.

A key point to keep in mind about the northern cod fishery is that first of all, cod tend to follow migratory patterns which straddle the 200-mile limit. The migratory patterns of this straddling stock complicate the (already complex) management of the northern cod fishery (see below). Second, the northern cod fishery is the site of long-term historical use, which pre-dates the formation of modern nation states. Partly for this reason, maritime societies, such as Portugal and Spain, have maintained a presence in the fishery, which has

[3] Although devastating for the northern cod, the removal of a major predator has fuelled the growth of the crustacean population, primarily shrimp and crab, producing a viable crustacean fishery (Hamilton et al., 2004).

complicated the management of the fishery. Third, new actors, particularly the Soviet Union and, after 1991, former Soviet republics, have entered the fishery. Fourth, certain areas of the EEZ which Canada negotiated in 1977 do not cover the 200 mile distance from the coast. Particularly important in this context were the 200 mile areas extending beyond the Grand Banks (the so-called "nose" and "tail"). Here problems of straddling stocks and excessive fishing outside of the EEZ (i.e. outside of Canada's jurisdiction) are particularly important (Sullivan, 1989). Finally, and like many of the world's commercial fisheries, the pursuit of the northern cod has in a relatively short period of time transformed from what was once a small and seasonal occupation into a major commercial enterprise, involving vessels from around the world. The most important – and most destructive – technology in this respect is the trawler, which is extremely efficient at "dragging" the sea bed to capture "demersal" or bottom-feeding species of fish, as well as everything else in its wake. Extractive capacity in the trawling industry expanded greatly with the introduction of refrigeration and other processing technologies, which enable super trawlers to remain at sea for weeks at a time.

The factors which led to the collapse of the northern cod fishery are a matter of some debate. Although excessive fishing effort and an inability to manage this effort are widely cited as causes which contributed to the collapse of the Atlantic cod (e.g. Myers et al. 1997; Brethes 1998; Hinds 1995; Hamilton et al. 2004), there is evidence to suggest that other ecological factors may have been at play. One hypothesis is that the northern cod experienced poor rates of "recruitment" during the period leading up to the declaration of the moratorium in 1992. The argument here is that a drop in survival rates among juveniles younger than three years reduced the size and reproductive potential of the fishery.[4] Ecological explanations for poor recruitment include abnormally low temperatures in the north Atlantic between 1984 and 1998 (Myers et al. 1997; Hamilton et al. 2004: 204), low salinity levels (Myers et al 1997), an expanding seal population, and a dearth of prey.

The notion that climatic change was the only or principal cause of the collapse has been challenged by Hamilton et al. (2004: 204), who argue that the "distribution of dangerously cold water" in the North Atlantic was "patchy" and left many areas habitable for groundfish. Moreover, they argue that the northern cod has experienced cold periods in the past without

[4] Sexual maturity and productivity among the northern cod occurs at roughly 7 years, making it extremely important that survival rates among younger members of the population remain high (Hinds, 1995: 279).

experiencing a collapse of the scope or the scale of that of the early 1990s (Hamilton et al. 2004: 204). Myers et al. (1997: 103-4) question the seal hypothesis, arguing that cod represent only a small percentage of the diet of harp seals, "the most numerous seal in the region," (Myers et al. 1997: 103). Moreover, they note, the cod which harp, grey and hooded seal do consume tend to be very young (i.e. younger than one year), suggesting that the depletion of standing stock cannot be attributed to a rising seal population alone.

More convincing is the notion that colder conditions and an expanding seal population were contributing factors (necessary but not sufficient), which in turn reduced growth rates, productivity and recruitment among the cod population. Myers et al. (1997) argue that the principal factors which led to the collapse of the northern cod were (1) an overestimation of abundance and an underestimation of mortality within the cod population; (2) highly efficient technologies, which were able to maintain and expand catch rates in spite of falling populations; and (3) widespread discarding and non-reporting of small fish as the population declined and fishing mortality increased. Underlying these inter-related factors were socio economic and institutional factors, which we turn to now.

4.3 Exposure: Economic Incentives and Resource Dependence

A number of factors explain the expansion of fishing effort in the northern cod fishery. One relates to the psychology of capture, which tends to pervade marine fisheries. In Section 2, we introduced a number of propositions about the ways in which institutions and uncertainty affect incentives to manage and respond to environmental pressures. Coastal fisheries are particularly susceptible to dilemmas of this kind. First, the costs of allocating property rights over fish and other marine resources are generally prohibitively high (Ooi 1990: 22). Although particular species will breed, spawn and mature in certain areas, their position within these areas can vary greatly and exogenous shocks (such as changes in rainfall, variable sunlight, water pollution) can disrupt these patterns considerably. Second, a fishery can only be maintained if there is a mature standing stock which is left to reproduce – or in the terminology of fisheries management, "recruit" – new stocks after harvest (Ooi 1990: 23). Both of these factors foster uncertainty in the sense that they make it very difficult to predict how many fish (and therefore, how much income) one will bring in on any given day. This, in turn, creates strong incentives to pull in as many fish today because there may be none tomorrow, or (significantly) because your competitors may beat you to it. It also creates incentives to invest in labour and technology that will reduce the uncertainty and risk that your boat will come home with empty nets.

In the case of the northern cod, dwindling stocks and increasingly efficient technologies combined to create a perverse set of incentives whereby investment in new technologies served to compensate for declining rates of biological productivity (a phenomenon which is not at all unique to the Atlantic fishery). Unsustainable rates of extraction were punctuated by the introduction and/or expansion of increasingly destructive forms of capture technology. A "killer spike" of peak catches in the Grand Banks and the northern Gulf of the St. Lawrence River occurred between 1968 and 1970, three years after the widescale adoption of trawler technology.[5] Many observers argue that the northern cod was at its maximum productivity before the killer spike of the late 1960s, after which point rates of recruitment and the overall size of the stock went into decline. Record harvests in the late 1970s and the 1980s were therefore a result of improvements in technology, not gains in biological productivity.

A second factor was public subsidy. The federal government actively supported the adoption of trawler technology in the 1960s, "providing financial resources to fishermen who were willing to take the risk of investing in new gear and larger boats," (Hamilton et al. 2004: 209-10). Provincial governments also provided generous subsidies to the processing industry, and to populations living along the Atlantic coastline. During the 1960s and 1970s, for instance, the Government of Newfoundland and Labrador subsidized the development of larger ports, replacing small and scattered "outports" and facilitating the consolidation of fishing and processing (see below). Incentives of this kind kindled a growing population; between 1949 (the year Newfoundland joined Confederation) and 1990, the population of Newfoundland grew from 320,000 to 570,000 (Hamilton et al. 2004: 198). Before the collapse of the cod fishery in 1992, 20.5 per cent of the population of the Northern Peninsula of Newfoundland was directly dependent on coastal fishing (Hamilton et al. 2004: 208). During this period, 32.2 per cent of the population was dependent on income from

[5] Although the pulling mechanism can vary, trawlers operate by towing a "cod-end" mesh on rollers along the bottom of the sea floor. Otter board trawlers use "otter boards" to keep the mouth of the net open while towing. With pair trawlers, two boats tow either end of the mouth of the net. The "target species" for the trawler is demersal (bottom dwelling) fish. The globalization of trawler technology was particularly widespread during the 1960s.

government transfer payments, compared with 11 per cent for the rest of Canada (Hamilton et al. 2004: 208).

A third explanation for expanding effort was the changing structure of the fishing industry, particularly after the introduction of trawler technology. Before 1965, the cod fishery was essentially a summer industry (Hamilton et al. 2004: 209), in which fishermen used income from the fall herring catch and from forestry to supplement their summer income from cod. Northern cod typically migrate inshore (for feeding) between May and September, after which point they move offshore (Hinds 1995: 279). Until the 1960s, the main participants in the cod fishery were part time operators, using inshore boats and rudimentary technologies, such as cod traps or hook and line (Hamilton et al. 2004: 209). Facilitated by government subsidy, the introduction of large boats and synthetic nets transformed the cod fishery into a single occupation. The new technologies allowed boats to follow the stocks as they moved offshore in September. The introduction of unemployment benefits in 1965 allowed individuals to work in coastal fishing, without having to supplement their income – and divert their personal investment – into alternative occupations (Hamilton et al. 2004: 209).

Finally, as noted earlier, expanding effort in the Northwest Atlantic reflected the growing presence of foreign fleets. Factory freezer trawlers (FFTs) from Spain, Portugal and France appeared as early as the 1950s (Sullivan 1989: 120-1). These were soon followed by the appearance of vessels from the USSR, the Federal Republic of Germany, Poland, Iceland, Norway and the UK in the late 1950s and early 1960s. There is strong evidence to suggest that overfishing in the 1960s was largely the result of an expanding foreign presence (Sullivan 1989; Hinds 1995). As noted earlier, the “killer spike” of fish catches peaked in the late 1960s. According to Sullivan (1989: 121), roughly two-thirds of the total biomass was extracted in 1968 alone. During this period, total northern cod landings dropped from a peak of 783,000 tons in 1968 to 214,000 tons in 1976 (Sullivan 1989: 121).

The declaration of the 200-mile EEZ in 1976/7 changed this dynamic in a number of ways. First, it created a protected rent for Canadian vessels, restricting foreign quotas and expanding government support for domestic vessels. Unsurprisingly, Canadian catches and capacity reached unprecedented levels during the late 1970s, lasting well into the late 1980s (Sullivan 1989: 121; Hamilton et al. 2004: 200). An important point to stress, however, is that expanding catches were the result of re-allocated rent, not expanding biological productivity. The gains to be made from this rent were large: during the "glory years" (1982-87), it was estimated that a trawler captain could make between 350,000 and 600,000 Canadian dollars per year from cod alone (Hamilton et al., 2004: 210). Labourers could make as much as 50,000 per year. Government subsidies during this period covered as much as 40 per cent of the cost of technological innovation and improvement.

A second implication arising as a result of the EEZ is that it created a new *inter*national dynamic, in which the management of the straddling stock was now subject to the management decisions and individual decisions taking place in two jurisdictional domains: the area within the EEZ (managed by the DFO) and the area outside of the EEZ ("managed" by foreign boats and their home nations, including the European Union). Sullivan (1989) argues that poor management practices outside of the EEZ, primarily on the part of European vessels and the European Union, help to account for the collapse of the northern cod.[6]

Throughout the post-war period, we therefore have an image of a fishery in which extractive capacity has steadily outstripped the reproductive capacity of the ecological system. Driving much of this expansion were "naturally-occurring" incentives, such as uncertainty and technological innovation, and *state-sponsored ones*, such as government subsidies and domestic quotas. After the negotiation of the EEZ, domestic capacity underwent a period of significant expansion, creating new pressures for Canadian fisheries managers, whose principal responsibility was to manage the northern cod.

4.4 Adaptive Capacity: Regulation and Assessment

As McCay and Finlayson (1995: 1) have argued, fisheries management is "a thoroughly modernist venture" in the sense that it requires highly accurate information that is often difficult or impossible to attain. Undermining the quality of information about standing stocks, rates of recruitment, mortality rates and ecological well being are (1) the inherent limitations of stock assessments; (2) the behaviour of resource users; and (3) the interaction between resource users and the individuals and agencies responsible for managing their behaviour. Efforts to discard or under-report the extent of small and by-catch on the part of resource users undermined the quality of information fisheries managers had about the state

[6] Challenging this position, some officials within the DFO have argued that a majority of the catch in cod traps – a technology widely employed in the inshore fishery – is undersized cod (Finlayson, 1994).

of the fishery. Erroneous data then inflated the estimates managers made about abundance of the population and underestimated fishing mortality, thereby exacerbating the risk of ecological collapse.

The foundation of modern fisheries management is the stock assessment, which gives scientists, managers and politicians the statistical basis upon which total and individual harvesting efforts can be allocated and regulated. Canada adopted a "total allowable catch" – or TAC – in 1974, an international practice which sets a maximum or "optimal" level of stock mortality resulting only from fishing effort (Brethes 1998; Finlayson 1994). TACs are adjusted on an annual basis, which gives fisheries managers the capacity to compensate for fluctuations in natural mortality, poor rates of recruitment and other changes in stock assessments. The annual TAC for the northern cod increased from 160,000 tons in 1977 to 266,000 tons in 1985 (Sullivan 1989: 121). It remained at this level until the moratorium in 1992.

The logic by which Canada's TAC is established is a formula known as "F0.1," where "F" represents the total quantity of fish caught by commercial activity and the numbers represent the weight of the total catch in relation to what is thought to be the weight of the entire stock or the "exploitable biomass," (Finlayson 1994: 28). The number is entirely arbitrary (Sullivan 1989: 121-2), and is roughly equivalent to 20 per cent of the exploitable biomass (i.e. cod older than four years of age). The decision to adopt F0.1 was a conscious effort on the part of fisheries managers to improve the reliability and predictability of fishing effort.[7] Prior to the adoption of F0.1, fisheries in Canada (and elsewhere) were typically managed on the basis of "maximum sustainable yield" (MSY), which calculates catch limits by estimating the total biological productivity of the fishery and then establishing limits on fishing effort (Finlayson 1994; Sullivan 1989). The main problem with MSY is it is exceedingly difficult to calculate "natural" fluctuations within fish populations, particularly the relationship between stock size and new recruitment (Sullivan 1989: 121-2; Finlayson 1994: 28-9). F0.1 avoids this problem by establishing a conservative limit on human-

[7] The idea of using $F_{0.1}$ was originally adopted by the International Convention for the Northwest Atlantic Fisheries (ICNAF), which was replaced by the North Atlantic Fisheries Organization (NAFO) in 1977 (Finlayson 1994: 29).

induced mortality, which can be adjusted in relation to the estimated size of the exploitable biomass and of the entire stock.[8]

Because F0.1 is intended to be directly proportional to the size of the stock, the means by which scientists establish the size of the stock from year to year is crucial. One of the principal methodologies employed by the Science Branch of the Department of Fisheries and Oceans is the virtual population analysis (VPA). The VPA uses landing surveys to track and calculate the annual mortality of each age group or "year-class" of fish. Finlayson (1994: 33-4) explains:

> By counting the number of 1982 year-class fish caught in each successive year until no more of these fish are caught and adding to this the *estimated* number of 1982 fish that died of natural causes, one can, by 1995 or so, know approximately how many fish were in the 1982 year-class (emphasis added).

Note that natural mortality is assumed to occur at a constant rate of 20 per cent per year, and that the VPA methodology is directly dependent upon the content of the commercial catch (Finlayson 1994: 34). To compensate for inestimable fluctuations in natural mortality, for the illegal discarding of small and non-economic species of fish (see below), and for the time lag, the DFO uses sample surveys to estimate current rates of fishing mortality. These entail the use of government research vessel (RV) surveys and sample surveys of commercial vessels, measuring the catch per unit of effort (CPUE) produced during a sample period (Finlayson 1994: 34-5).[9] Extrapolations of average size and weight are then used to estimate the current size of the population. On the basis of these numbers and with subsequent landing figures, fisheries scientists will continually revise (or "hindcast") their estimates until members of a particular year-class no longer appear in the landings (Finlayson 1994: 34-5; Sullivan 1989: 124).

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[8] To reiterate, the principal distinction between $F_{0.1}$ and MSY is that the latter estimates total productivity (maximum biological yield) in a given period of time. It then determines the proportion of standing stock which can be safely removed from the fishery. $F_{0.1}$ on the other hand estimates the size of the fishery and the exploitable biomass (fish aged four years and older), from which managers then calculate the 20 per cent allowable catch.

[9] CPUE can be calculated in a number of ways. One very basic way is to fish for a set period of time and compare the catch with landings captured (using the same technology and same period of time) in the past. A more sophisticated method is to calculate all of the costs of a fishing boat (e.g. fuel, nets, etc.) and compare them with the total value of the catch. The value of using this measurement is it illustrates change in economic value over time.

Estimates of the overall size of the stock or of individual year-classes are obviously subject to the same errors that plague any form of random trial. First, there is the possibility that the samples provide an inaccurate representation of the wider population. Second, and related to this, there is the possibility that the trials were not carried out properly or consistently. Both of these factors may account for the fact that during the period immediately preceding the moratorium, research vessel surveys showed a cod population in steady decline, whereas the commercial sample data suggested a "considerable increase," (Finlayson 1994: 34-35, citing the Harris Report). Similar factors help to explain the fact that government assessments of the northern cod went from "ecological disaster" in 1990 to "on the road to recovery" in 1992 and finally closed due to collapse in 1993/94 (Hamilton et al. 2004: 201). Further complicating matters, independent or third party surveys are rare (or they were before the time of the moratorium) and even these have to rely on the official data provided by the DFO (Finlayson 1994: 36).

Measures to control the size of the catch include gear restrictions (such as minimum mesh size), vessel restrictions (vessels must be under 65 feet in length), seasonal restrictions, geographical restrictions and quotas, the latter of which limit the total amount of fish a single boat can *land* during the course of a season.[10] Proprietary rights to quotas are established with licenses, which are allocated on the basis of auctions or annual lotteries, and vary according to species and season. Because quotas entail restrictions on the weight of the annual catch, boat owners have considerable incentive to under-report their landings, and to discard small or uneconomical fish while they are still at sea.[11] To counteract this incentive, the DFO started placing government observers on all boats over 100 feet in length fishing the EEZ after 1986 (Finlayson 1994: 70). However, before this time, coverage was "highly variable" (Finlayson 1994: 34) and opportunities for under-reporting were vast. Moreover, the inshore fishery – which accounted for as much as half of the annual cod harvest – was largely ignored by this management regime (see below).

It is now widely acknowledged that excessively optimistic assumptions about the size of the cod stock were adversely affected by the illegal actions of individual boats, which regularly discarded and therefore failed to register the capture of undersized fish (Finlayson 1994;

[10] Note that before the early 1990s, quotas in the northern cod fishery were typically measured and enforced on the basis of landings, not capture.
[11] These incentives would change as smaller fish began to account for larger proportions of the overall catch and, as a result, obtained new value in downstream markets – see below.

Hinds 1995; Myers et al. 1997; Hamilton et al. 2004). The principal problem this created for fisheries managers is that it produced a situation in which official estimates of annual harvests were far lower than what was actually the case. As a result, assumptions about the size and potential productivity of the younger classes of fish were greatly exaggerated.

The vulnerability of the northern cod fishery can therefore be understood at least partly in terms of the very imperfect science of estimating and managing the size of the annual harvest. What makes the collapse of the northern cod particularly important is that scientists, managers, politicians and operators knew that the science was imperfect and that stock sizes and catch rates were dwindling (Finlayson 1994; Hamilton et al. 2004). To better understand the vulnerability that emerged in this context, it is crucial that we investigate the ways in which scientists, managers, politicians and boat operators responded when faced with evidence that stocks were in decline.

4.4.1 Adaptive Capacity: Inertia, Malfeasance and Cascading Effects

During the 1980s, evidence began to emerge that the government's estimations of the size of the stock had been excessively optimistic. First, in spite of increasing effort, commercial landings remained "essentially static" (Finlayson 1994: 9) through most of the 1980s. Second the inshore catch (i.e. that of the smaller boats) declined steadily throughout the 1980s (Finlayson 1994: 9). Third, the estimated weight of individual cod underwent significant reductions during this time (Hamilton et al. 2004: 202). As early as 1983, government trawler surveys showed a consistent drop in the number of cod being caught through random efforts (Hamilton et al. 2004: 199). These were supported by other government surveys and by testimonial evidence of individual boat operators (Hamilton et al. 2004: 202). Outside of the cod fishery, other species of fish were suffering the effects of excessive depletion. Hamilton et al. (2004: 203), for instance, use the DFO's own survey data to track the aggregate weight of nine "indicator species" of commercial and non-economic fish in the northern Gulf. For all of these species, official catch rates show a significant drop after the early 1980s.

There is ample evidence to suggest that government projections were inaccurate and that the fishery was in decline well before the moratorium in 1992. Moreover, there is very good evidence to suggest that government and independent assessments continually underplayed the likelihood that the means by which they had arrived at annual assessments were seriously flawed. Finally, and perhaps most tellingly, the DFO continued to support the expansion of the commercial fishery during this crucial period. Between 1983 and 1992, for instance, the number of groundfish licenses remained "more or less stable" (Brethes 1998: 138) when a skeptical reading of the scientific assessments would have suggested a reduced capacity. During the same period the total number of fishing licenses increased from 45,949 to 58,630, an increase of 27 per cent (Brethes 1998: 138).[12] How do we account for these actions and inactions?

Finlayson (1994) argues that the inability of the DFO to recognize and respond to evidence of a fishery in decline was the result of a combination of factors: imperfect information, bureaucratic rationality and political pressure. As the preceding suggests, the methodologies by which scientists arrive at annual stock assessments were by no means free of error. Although scientists and managers within the DFO were well aware of these problems, the bureaucratic structure in which they were required to work deterred the articulation of misgivings and alternative assessments. Beyond the confines of the Department of Fisheries and Oceans, other institutional pressures mitigated against the ability to articulate misgivings about the state of the fishery. As Finlayson (1994: 46) points out, the members of the various independent task forces, which provided assessments of the fishery and scientists within DFO, were part of a wider epistemic community of fisheries scientists and managers, and were therefore understandably disinclined to criticize their peers in a way that would affect their reputations and career prospects.

Beyond the pressure of institutions and peers, Finlayson (1994) identifies an element of "techno-utopianism" on the part of fisheries scientists and managers. Dealing in statistics which were inherently prone to error, fisheries scientists were under great pressure – from senior bureaucrats, politicians and interest groups (see below) – to produce some kind of assessment which could be used to determine the allocation of individual quotas. Driving scientists and managers to act in this way were a number of political and socio-economic factors. One was the vast opportunity created by the negotiation of the EEZ. An assumption which Canada used to justify its claim to manage the 200-mile area was that historical

[12] As Brethes (1998: 138) points out, these increases do not imply an increase in the number of operators. Rather they indicate diversification in the industry, whereby individual operators are purchasing more licenses for different species than they did in the past. The total number of operators actually declined during this period (although capacity to harvest multiple species expanded through the increased allocation of fishing licenses).

exploitation of the Atlantic fishery was primarily geared towards the maximization of economic returns from an open-access resource. By establishing control over the Grand Banks and the Northern Gulf of the St. Lawrence River, Canada argued, exploitation of the northern cod would now be governed by a regime in which the application of science and the regulation of fishing effort would be central.

A second and related factor was the impact of political pressure from industry groups and politicians. As noted earlier, public subsidies and structural transformations in the fishing industry had created a national and international economy in which large numbers of people were now highly dependent on the cod harvest for their annual income. However, the industry was stratified in a way (which is not at all unique to the North Atlantic) that created very different interests and very different types of pressure on the scientific establishment. As noted earlier, the declaration of the EEZ in 1977 resulted in a reallocation of rent, which was highly favourable to Canadian *offshore* vessels. To compensate for the large imbalance of storage and harvesting capacity, the Newfoundland Inshore Fisheries Association lobbied the provincial government of Newfoundland and Labrador in the 1980s to reduce the TAC for the northern cod and to expand the quotas available to the smaller inshore fleets. The provincial government supported this initiative, and lobbied the federal government to reduce overall effort to a level below F0.1 and to allocate 85 per cent of the TAC to the inshore fishery. Not only did the Canadian Atlantic Fisheries Scientific Advisory Committee (the CAFSAC) ignore the provincial government's demands, it instead recommended in 1988 that the TAC be raised from 266,000 to 293,000 tonnes, reflecting the (considerable) influence of the offshore fishery and the processing industry (Sullivan 1989: 124-35; Brethes 1998: 139).[13]

In short, the criteria on which managerial decisions and scientific assessments were being made were quite clearly influenced by wider socio-economic and political pressures. These in turn created an inertia that prevented officials at multiple levels from taking decisions that would err on the side of caution and reduce the amount of effort in the Atlantic fishery. However, the adaptive – or in this case, *mal-adaptive* – capacity on the part of government

[13] Finlayson (1994: 104) argues that through the use of campaign contributions and other forms of political pressure, Fishery Products International (FPI) and National Sea Products (NatSea) – the two principal seafood companies in the Atlantic fishery – were able to influence the decisions of scientists and managers within the Department of Fisheries and Oceans.

was only part of the equation. Equally important were the highly decentralized incentives and decisions of the operators themselves.

It is now widely acknowledged that boat operators responded to smaller catches (measured in terms of volume and the size of fish) by routinely discarding small and under-sized species of fish (Hamilton et al. 2004; Myers et al. 1997; Finlayson 1994). As a way of maximizing their economic returns (and reducing their losses), strategies of this kind were perfectly reasonable; as noted earlier, individual vessel quotas were allocated on the basis of species and weight. Boat operators (of all sizes) therefore had a very large incentive to fill as much of their quota with species that were of economic value. Moreover, as the fishery went into decline many boats started shifting into other downstream markets, in which the value of juvenile and other forms of "trashfish" was high (Hamilton et al. 2004: 202, citing Palmer and Sinclair 1997).

The practice of actively targeting juvenile fish had the added effect of undermining the reproductive potential of the standing stock. Sexual maturity for the northern cod occurs at roughly 7 years, making it extremely important that survival rates among younger members of the population remain high (Hinds 1995: 279).[14] By illegally removing young fish from the system, boat operators were unwittingly causing a major non-linear effect in the North Atlantic.

In short, economic rationality, biological processes and ecological changes (in the form of cooler weather and an expanding seal population) conspired to produce a situation in which the northern cod fishery was placed under substantial ecological stress. Confounding this process, the techno-rational approach to the management of the northern cod was deeply constrained by a science that failed to account for the illegal (and thus unreported) actions of individual resource users.

Beyond the political and economic pressures that influenced the incentives and decisions on which government scientists and managers managed (or failed to manage) the fishery, a final factor which helps to explain their inability to act upon or respond to the situation was the relationship between "expert" scientists and managers within the Department of

[14] To improve the prospects of strong reproductive capacity and recruitment, the DFO restricts the capture of cod to the age of four and up.

Fisheries and Oceans and boat operators themselves. Finlayson (1994) argues that cultural differences between the DFO and the inshore fishery were partly to blame. As noted earlier, the virtual population analysis (VPA) is a principal means by which the federal government collects information about the size and content of the commercial catch. Although the inshore fishery accounted for an estimated one-third to one-half of the entire northern cod harvest, the fishery was “routinely ignored” (Finlayson 1994: 102) by the scientific establishment within the DFO. Finlayson (1994) contends that this was largely due to the fact that the “cognitive realities” of the inshore fishermen were substantially different from those of DFO scientists, whose emphasis on rigor and scientific method devalued or dismissed other, “non-scientific” claims about the state of the fishery.

5 Vulnerability to Climate Change

5.1 Summary

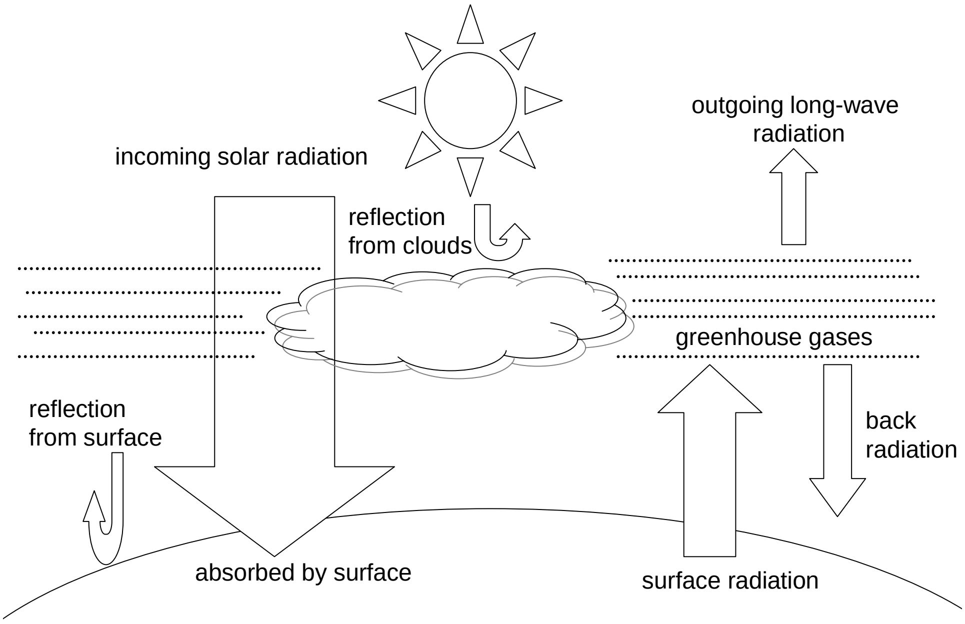
This section investigates the understanding of vulnerability to climate change and its policy implications. Comparison is made between international efforts to reduce the emissions of greenhouse gases and emissions of ozone-depleting substances. For the latter, international efforts have been swift and effective, while the former remains contentious and with substantive actions yet to be taken. Differentials in risks and in the degree of uncertainty of underlying processes may contribute to difference in responsive action.

In this final major section we consider the case of vulnerability to climate change, a case that differs from those previously considered in several key ways. Unlike fisheries or flood hazards, for example, climate change is a phenomenon that arises from human modifications to a global environmental system and not a regional one. That said, the impacts of climate change are expected to vary from one region to another, and some regions might conceivably benefit (in which case, the term "opportunity" would be a better one than "vulnerability"). Unlike natural hazards, the ramifications and potential impacts of climate change are not readily identifiable and, in some cases, openly contested.

5.2 Exposure: Biophysical Dimensions of Climate Change

It has been known since the early 19th century that particular gases naturally present in the atmosphere, particularly water vapour, carbon dioxide, methane and nitrous oxide, have the effect of elevating temperatures at the earth's surface (Figure 4). Simplified, the process is that incoming solar radiation is of a shorter wavelength than that which is reflected from the earth's surface. Radiation of shorter wavelengths passes unhindered through these gases unhindered, but longer wavelengths are partially absorbed and re-reflected (referred to as "back radiation" in Figure 4). In other words, the presence of these gases cause solar radiation to linger in the earth's atmosphere longer than it otherwise would, and maintaining surface temperatures roughly 30 degrees Celsius warmer than would occur in their absence. The analogy of a greenhouse, where glass panels have a similar effect on temperatures inside the greenhouse, has long been used to describe the effects of these atmospheric gases, giving rise to the terms *greenhouse effect* and *greenhouse gases* (or GHGs).

Figure 4: radiation transfers, simplified



The earth's climate has never been in a static state, but changes continuously over time. Variations in the Earth's orbit, fluctuations in levels of incoming solar radiation, changes in atmospheric consistency as the result of volcanic eruptions are just some of the natural processes that are believed to effect climatic conditions on an ongoing basis. In addition to temporal variations in climate, there are obviously considerable spatial variations in climatic conditions at any given point in time. Variations in climatic conditions are manifested in different ways, such as changes in air temperatures, precipitation levels or distribution, ocean currents and surface temperatures, and so on. Some variations occur repeatedly with relatively brief intervals, such as the El Niño Southern Oscillation, which seems to occur every decade or so. Others occur over the course of centuries or longer, such as inter-glacial periods, the last "Ice Age" having ended about 18,000 years ago.

Climatic "change" is, in this sense, simply a description of an ordinary and naturally occurring state of affairs. The concern that has arisen in recent decades centers on the extent to which human activity has altered the processes that influence climate and the impacts that may result; that is, *human-induced climate change*. Key ways in which human activity has modified atmospheric processes include the production and emission of non-naturally occurring gases such as chlorofluorocarbons (CFCs), the combustion of carbon-based fuels, the production of cement or concrete, and the removal of forest cover.

Early in the 20th century, CFCs (also known as “halons”) were invented by human chemists and found to have numerous practical applications as refrigerants, aerosol propellants and industrial solvents. Their use in consumer items such as automobiles, refrigerators, and spray cans expanded rapidly after World War II. In the 1970s it was realized that once released, CFCs accumulate in the stratosphere, where they begin to break down into their constituent components and interact with ozone that naturally accumulates there. Stratospheric ozone is believed to reduce the passage of incoming wavelengths of solar radiation in the ultra-violet spectrum, wavelengths that are harmful to human health. When it was reported in the 1980s that a hole had developed in the layer of stratospheric ozone over the southern hemisphere, the international community moved quickly to reduce production of CFCs under a UN-sponsored agreement known as the Montreal Protocol (we will return to this later). While ozone depletion does not necessarily have a clear and direct link to the atmospheric processes that affect climatic conditions at the earth’s surface, it has also been found that CFCs have radiation-forcing properties similar to naturally occurring greenhouse gases (Houghton et al. 2001).

The combustion of carbon-based fuels, particularly wood and charcoal, has been an ongoing human activity for millennia. With the onset of large scale industrial production in the 19th century in Europe and North America, the combustion of coal, oil and its derivatives has increased continuously. The combustion of carbon-based materials has the effect of transforming carbon in its solid state to a gaseous state. The wide-scale use of carbon-based fuels therefore has the effect of increasing the amount of carbon-based gases in the atmosphere than would otherwise be present. Oxides of nitrogen and other elements present in these fuels are also produced during combustion, and the growing accumulation of these greenhouse gases in the atmosphere has been recorded by direct instrumental observations since the 1950s.

The removal of forest cover by human populations has also been occurring for several millennia, beginning in Europe and Asia. Forest clearances spread with European settlement to the Americas in the 18th and 19th centuries, and in the 20th century to Africa, the South American interior and South-east Asia. Intensive commercial harvesting for export markets is an important driver of contemporary deforestation in developing countries.

There are three biophysical effects of deforestation that feed directly back into the atmospheric processes that influence climate. First, the use of wood for fuel transforms solid carbon into carbon-based greenhouse gases. Second, as they grow, plants take in gaseous carbon and fix it in their tissues. Forests thereby act as enormous carbon "sinks"; that is, mechanisms for removing carbon-based greenhouse gases from the atmosphere. A net loss in forest cover means a net loss in sinks and a net increase in atmospheric carbon. A third effect is that removal of forests tends to alter the albedo or reflectivity of the earth's surface. Forests tend to directly absorb larger quantities of incoming solar radiation than do other surface types, thereby reducing the amount of reflected, longer wave radiation exposed to the effect of greenhouse gases. Removal of trees does not necessarily lead to a directly proportional increase in greenhouse gases. For example, a tree cut down and made into furniture removes that tree's continued participation in the forest sink effect, but the carbon material of the tree is not directly converted to a gaseous state.

Few aspects of the processes described so far are subject to debate within the scientific community. They do not, however, represent all the factors or processes that are believed to influence climate, many of which *are* still subject to ongoing scientific discussion and research. For example, more needs to be known about the extent to which oceans may take up heat from a carbon-enhanced atmosphere and thereby possibly moderate air temperatures (Prentice et al. 2001). Similarly, the effects of aerosols (small liquid or solid particles that are suspended in the air for short periods of time, often in large quantities) on solar radiation passing through the atmosphere are not well known, and effects seem to vary considerably depending on the size and makeup of the particle (Penner et al. 2001). Should air temperatures become warmer, increased evapo-transpiration rates might lead to increased cloud cover, thereby reflecting much incoming solar radiation before it has the chance to contribute to surface temperatures (see Figure 4). Plant growth might thrive in a carbon rich, warmer atmosphere, causing sinks to flourish and increase their intake of gaseous carbon. These are but a few examples of why prediction of how the earth's climate will respond to human modification of the atmosphere remains difficult.

5.3 The Fine Art of Measuring and Predicting Climate Change

By the late 1980s, sufficient interest and concern about climate change had arisen outside the scientific community, and the World Meteorological Organization and United Nations Environment Program established the Intergovernmental Panel on Climate Change (IPCC).

Not itself a research body, the IPCC sets out to systematically assess scientific research on climate change and report periodically on the existing state of knowledge. An objective behind this is to provide public policy-makers with science-based climate change information on which to base public policy decisions. Because of its organizational structure and the principles guiding its work, the reports of the IPCC tend to be very conservative in their outlook and predictions. Most of the information it considers is drawn from peer-reviewed, scientific journals; information gathered and reported outside the traditional mechanisms of academic and research institutes is typically not considered. With peer-review and publication of research often taking a year or years from the onset of data collection, this means that much of the information considered in the formation of the IPCC's most recent assessment report, in 2001 (the next report is due in 2007), was actually collected in the late 1990s.

The method of prediction of future climatic conditions that is presently most influential within the scientific and public policy communities is based on the General Circulation Model (GCM). GCMs are similar in origin to the computer-based models used to forecast weather conditions, but serve a different purpose in that GCMs model average climatic conditions and ranges of variability for extended periods of time. There are many different types; the most sophisticated and most recently developed ones are 'coupled', in that they contain models of atmospheric processes and of ocean circulation and attempt to capture the interactions of the two. GCMs tend to capture a small number of climatic variables, such as average land surface temperatures, better than others, such as precipitation patterns and distribution.

Several criticisms have been leveled against the methodology and epistemology of the IPCC and, more generally, of mainstream climate policy. First, it has been argued that the data being used to inform GCM experiments is too broad to generate accurate predictions about climate variation and change (Demeritt, 2001; Essex and McKitrick, 2002). GCM calculations are typically based on grid points of 1-3 degrees of latitude and longitude, although regional models run for shorter duration forecasts may drill down to smaller units. In the case of small island states, entire countries may lie within a single grid segment of a GCM. Another limitation is that the outputs that are generated with most confidence, such as long-term average surface temperatures, are not typically climatic variables that have the greatest influence on human well-being, a point we will return to in greater detail below.

Yet another limitation is the quality of observational data that goes into them, for even relatively minor differences in input variable can lead to large variations in outputs from the model. Reliable instrumental observations of climatic variables are not available for many parts of the world, and especially for areas over open ocean. Moreover, instrumental records date back in most cases for no more than a century, a very brief period in the context of atmospheric change.

While the prediction of future climatic conditions may be an imperfect science, there is considerable bio-physical evidence generated from a range of disciplines and sources that is consistent with the basic premise that we have entered a period of climatic change occurring at a pace unprecedented since human life on Earth began. Samples from tree rings, retreating glaciers, changes in coral reefs, volcanoes and other sources of evidence point to a long term (i.e. one-thousand year) trend of variation, followed by a “sharp upturn” in the 20^{th} century. Other evidence comes from sources as diverse as analyses of ice cores from the Greenland icecap (Barlow 2001) to samples of bison teeth found at pre-European contact Native American kill sites (Wilson 1999). Bison teeth and ice cores are similar in that there are layers in the component material that, not unlike tree rings, vary in size and constituency with climatic conditions.

The most persuasive evidence presently comes from high latitudes and high altitude areas. In the North American Arctic, average temperatures, permafrost conditions and sea ice conditions have been observed to be changing rapidly (Ford and Smit 2004). Coastal erosion along Arctic coasts has accelerated because of increased exposure to open as opposed to frozen water (Shaw et al. 1998). Glaciers throughout the world have been retreating at tremendous pace in the past century (Motyka et al. 2003; Leiva 1999). These are just a few of the western-style scientific observations of changing climatic conditions. Traditional communities such as Canada’s Inuit people have long been aware of a rapid transformation of their environment, from changing sea and ice conditions to changes in prevailing wind directions (Krupnik and Jolly 2002); only recently have western scientists attempted to capture this information systematically as well.

5.3.1 Vulnerability to Climate Change

Given that we have entered into a period of unprecedented climatic change, the question has become one of the potential effects of such changes on human populations and their well-being. Climate change researchers and the IPCC have adopted widely the concept of vulnerability as described in the preceding section on natural hazards and employed it as a means of describing and assessing the potential impacts of climate change. The Smit and Pilifosova model (*V* = *E*, *A*) introduced previously is representative of the various interpretations of vulnerability employed in climate change research, in that it recognizes that vulnerability is not simply the product of changing climatic conditions and their manifestations, but the combination of these with historical and prevailing social, economic and cultural processes at a given place and over a given period of time.

A simple example illustrates this point. A rise in average sea levels is widely believed to be one of the possible manifestations of climate change. As water increases in temperature its volume expands; this is a known relationship on which the belief in sea level rise is partly based. The concern therefore is that, should ocean surface temperatures increase as a result of climate change and sea level, many low-lying coastal regions and islands may become inundated, that storm surges may penetrate farther inland, and/or that soils and groundwater in low-lying areas may become contaminated with salt water. This logic has been employed in a number of studies since the 1980s, which seek to predict the impacts on heavily populated, low-lying areas such as Bangladesh or the Nile Delta. The impacts are calculated by identifying such things as the number of people residing within a certain distance from present average sea level, the economic cost of relocating them and the losses to the economy that may be generally expected (Milliman et al. 1989; El-Raey et al. 1999). A limitation of such studies is that they may focus on exposure to particular biophysical attributes of climate change such as sea level change, without considering the range of possible adaptive measures that might be employed by exposed populations.

It was in a series of oft-cited studies on the potential impacts of climate change on agriculture in the American Midwest (Easterling et al. 1992) that the assumptions researchers make about adaptive behaviour were shown to have a considerable effect on the projected impacts of climate change on a given population. To illustrate, the authors selected a set of predictions of future climatic conditions and projected the impacts on crop yields depending on whether farmers did nothing to adapt (also known as the “dumb farmer scenario”) or whether farmers correctly anticipated conditions for each new growing season and selected crops and practices accordingly (the “clairvoyant farmer scenario”). As might seem intuitive, “dumb” farmers would be expected to experience crop failures and lose money under changed climatic conditions, while "clairvoyant" farmers would continue to farm profitably. With few farmers being either dumb or clairvoyant, the most likely outcome under that set of forecasted climatic conditions was believed to lie somewhere in between. The key point from this research was that the impacts of climate change depend not only on the physical changes but also on the adaptive measures taken by those exposed.

As research into adaptation to climate change has expanded, it has also been recognized that the capacity to adapt – that is, the range of potential adaptive options and the means to implement them – varies considerably from one place to another and changes over time as socio-economic processes evolve. For example, coastal areas of the island of Samoa are already exposed to high rates of erosion and storm surge-related damage, conditions expected to worsen as a result of climate change. Research suggests that coastal villages are presently able to adapt to such climatic events, and that this capacity is highly dependent on tight social networks maintained through village councils and church groups, supplemented by remittances from extended family members living away from the village (Sutherland et al. 2005). Maintaining the future capacity of the village to adapt, especially to an increased frequency of cyclonic storms, will depend to considerable extent upon the maintenance and, perhaps, strengthening of this traditional social fabric. Should the supply of remittances or the existing sense of community service diminish, the assistance of government institutions would be necessary. Already, recent increases in rates of coastal erosion are leading villagers to call for outside agencies to construct engineered sea wall defenses.

The island of Samoa provides a useful illustration of another fundamental dichotomy in the case of climate change: those who are expected to be most vulnerable to the manifestations of human-induced climate change also tend to be those who benefit the least from the historic and prevailing economic processes that create the problem in the first place.

The population of Samoa is approximately 175,000, and its gross domestic product estimated at USD1 billion (Central Intelligence Agency 2005). Its nationwide emissions of GHGs amount to a fraction of one percent of global emissions. With its distance from world markets, small population base, and modest affluence, Samoans are unlikely to engage in levels of personal consumption or industrial activity to an extent where Samoa ever becomes a meaningful contributor to atmospheric GHG accumulations. And yet, the biophysical impacts of atmospheric GHG accumulation are expected to be pronounced and severe in Samoa, especially in coastal areas where most of the population lives. The lack of industrialization that constrains Samoa's GHG emissions also constrains its affluence, and so elaborate infrastructure projects to protect coastal settlements, such as those in place or envisaged to protect European coastal settlements such as Venice or coastal Netherlands from storm damage are beyond the means of Samoans.

The Earth's atmosphere is a commons in the same sense as pastureland in Hardin's classic "Tragedy of the Commons" study (1968). The benefits of building a new coal-fired electrical plant in the United States accrue to those who own and operate the plant and those who obtain power from it. The GHGs emitted from that plant and the costs they will impose in terms of climate change-related impacts are not just shared with remote peoples such as the Samoans, but in large part transferred to Samoans. That is because the coal plant is a product of and contributor to increasing economic prosperity for the population that constructs it, thereby adding to that population's capacity to adapt to climate change, while doing nothing for the economic wealth of Samoans. This makes the atmospheric "commons" a much more tragic one than envisaged by Hardin, whose working assumption was that degradation of open-access resources would be a tragedy for all users, regardless of wealth or power.

5.3.2 Adaptive Capacity: What's Being Done? What's Not Being Done?

The international community has taken some steps in response to human-induced climate change. Most western governments and many developing nations now earmark funds for research related to climate change, be it for ever more powerful GCMs, for studies of potential impacts of climate change on particular groups or sectors of the economy or for development of alternatives to carbon-based fuels. In the lead up to the Earth Summit in Rio de Janeiro in 1992, widespread international support was found for an international convention to address climate change. The subsequent *United Nations Framework Convention on Climate Change* (UNFCCC) was signed by most of the world's nations, including the United States, and took effect in 1994. The ultimate objective stated in the UNFCCC is the "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system". The UNFCCC recognizes that the Earth's climatic system is a common resource, and prompts governments to conduct research on climate change, develop policies and strategies for reducing GHG emissions, and provide technical and financial support for developing nations.

The Kyoto Protocol was the first step in negotiating detailed commitments toward the objectives of the UNFCCC. Signed in 1997, the Kyoto Protocol established a list of primarily developed countries that would be expected to make the first scheduled reductions in GHG emissions, and set specific targets for each. These targets typically represent a reduction to between 90 and 100 percent of each country's estimated 1990 GHG emission levels. Emission reductions are to be achieved rapidly enough that average emissions for the period 2008-2012 should achieve or surpass the Kyoto target. The Protocol also suggested alternative mechanisms of meeting emissions targets, such as giving credits for expanding forest cover (i.e. increasing carbon sinks) and allowing countries to count investments in emission-reducing technologies made in less-developed countries towards their own emission targets.

This response to human-induced climate change is comparable in its origins to past international efforts to deal with a range of global environmental problems, such as ozone depletion, biodiversity loss, trade in endangered species, deforestation, and desertification. Once sufficient information and research has accumulated to suggest that the problem exists and that some form of collective action is warranted, a United Nations agency or secretariat is established, usually accompanied or followed by an international convention or treaty that outlines broad objectives and a later period of negotiations that fix national goals or targets to be achieved.

This approach works better in some cases than in others. The 1985 *Vienna Convention for the Protection of the Ozone Layer* is one of the more notable successes. The treaty has had widespread buy-in around the world, and atmospheric concentrations of most ozone-depleting substances have stabilized or decreased since the Montreal Protocol was implemented (Fahey 2002). International action against desertification has, on the other hand, been more lethargic. The first UN-sponsored conference on desertification, held in 1977, established a plan of action to combat desertification. By 1991, desertification at a global scale was found to have worsened. Several reasons for the failure of the Plan of Action have been identified, including divergent definitions and views of causation of desertification, lack of available data for setting baselines and monitoring changes, the absence of universal remediation techniques and technologies, and, perhaps most importantly, few economic incentives to act (Glenn et al. 1998). At the Rio summit a renewed commitment was made to a UN *Convention to Combat Desertification*, which entered into force in late 1996. Despite this, desertification continues to be an ongoing problem and appears likely to increase in many parts of the world in coming years (World Resources Institute 2005).

Why has action on CFC reduction occurred while action to combat desertification foundered? One simple reason may be that cost-effective alternatives to many CFCs were already available at the time the Montreal Protocol was adopted. DuPont Corporation, which held the patents to over one-quarter of CFCs in production, including the well-known product Freon, reports that it patented twenty non-CFC refrigerants in 1989 alone. Technologies were also developed to capture and recycle refrigerants in existing consumer products. The economic cost of reducing CFC emissions was, consequently, a relatively inexpensive burden for signatories to the Protocol to bear, and the transition from CFC to non-CFC products has not caused great hardship. Desertification, on the other hand, has no simple quick-switch solution. It is the by-product of over-intensive land use in an area where precipitation levels do not support such intensity, and often goes hand in hand with rural poverty, social or political instability and other environmental problems like deforestation. Addressing the socio-economic problems that typically underlay desertification requires long term commitment, investment and economic diversification. The countries most adversely affected by desertification are among the world’s poorest, and national governments often lack the means of responding. For wealthier countries with no pressing self-interest, the rationale and incentives for helping poorer ones respond to desertification tend to be mixed in among those for providing development assistance generally, if they attract attention at all.

The UNFCCC seeks to emulate the Vienna Convention on ozone protection, indeed making specific reference to it in its preamble. The UNFCCC is already showing signs, however, of being considerably less successful, and this goes beyond the obvious problem that the United States, the largest single GHG emitter, and Australia, one of the top per capita GHG emitters, have refused to ratify the Kyoto Protocol. There are some fundamental differences when we compare the Montreal Protocol on CFCs and the Kyoto Protocol on GHGs. (Table 5).

Table 5: Key Elements of UN Conventions on Ozone Depletion and Climate Change

	Greenhouse gases/UNFCCC Kyoto Protocol	**CFCs/Vienna Convention/Montreal Protocol**
Universality	Reduction targets exist for some countries on the basis of their level of economic development	Reductions targets are set by type of CFC and are to be met by all signatories
Transition costs	No immediate substitutes for fossil fuels, concrete, forest products; enormous transition costs	Substitutes available; transition costs are moderate
Incentives for action	Impacts of climate change not well known, yet to be felt in countries that are largest emitters	Measurable, rapid decrease in atmospheric ozone experienced prior to ratification
Costs vs. benefits of compliance	Largest per capita emitters to bear significant direct economic costs; large emitters like India, China bear no costs; benefits to be realized in distant future and shared by all	Costs of eliminating CFCs moderate for all; human health risks of increased UV exposure considerable and pressing
Causal linkages	Multiple, unclear, disputed: complex linkages between various human activities may interfere with atmospheric processes, but degree and extent of interference is debated	Simple, clear, direct: scientific evidence shows that CFCs interfere with atmospheric ozone; evidence widely accepted

As Table 5 shows, there are a number of key reasons why CFC reductions have been achievable. All parties to the Vienna Convention have an identifiable stake in compliance. Enhanced exposure to ultra-violet radiation is known to be harmful to human health, and atmospheric ozone is known to screen the Earth's surface from such radiation. At the time the Montreal protocol was drafted, a rapid decrease in atmospheric ozone had already been measured, raising considerable fears about the near-term consequences of inaction. At the same time, alternatives to many CFCs had been developed or were in development, as were methods of capturing CFCs in existing appliances and recycling their use. This provided a means of reducing CFC emissions without having to reduce the economic activities that required their use, meaning the economic costs of compliance with the international agreement are not unpalatable. Because of these reasons, and with funds being made available to developing countries to assist them with making the economic transition, it has been possible to get widespread agreement and compliance from most countries.

In the case of GHG emissions, the fundamentals are very different. Getting agreement within the scientific community, let alone the international policy-making community, on the ramifications of atmospheric GHG accumulation has been a slow and ongoing exercise. The effects of increased atmospheric GHG levels on precipitation patterns in a given place over a given period of time are not as evident or as measurable as the effects of enhanced UV exposure on incidence rates of skin cancer. At the same time, the use of carbon-based fuels for energy is such an essential underpinning of economies worldwide, there is no economically painless way of reducing their use in the short term. Substitutes such as solar, tidal and wind-generated energy are still underdeveloped and can not replace more than a fraction of existing worldwide consumption of carbon-based fuels. Moreover, governments whose power is based to some degree on support from the fossil fuel industry, such as the Kingdom of Saudi Arabia or the Canadian province of Alberta, may actively oppose action on GHG emissions and question the validity of the science so as to protect the interests of their supporters. The Premier of Alberta, Ralph Klein, for example, is famous for having dismissed global warming when speaking before oil industry groups as being the result of "dinosaur farts". Hence compliance with the Kyoto Protocol is far less easy to achieve than with the Montreal Protocol.

Even in the unlikely event that all signatories to Kyoto as well as the US and Australia were to comply with the emission targets set in that document, global GHG emissions would continue to rise. While the Montreal Protocol calls for universal reductions in CFC emissions, only the largest per capita GHG emitters (i.e. developed countries) are required to make reductions under Kyoto. Countries like India, China and Brazil, which are low per capita emitters but have high and rapidly increasing gross levels of GHG emissions, have no reduction commitments. This imbalance in commitments to action may be equitable, in that historical emissions from developed countries have created the present state of affairs, and they should therefore bear the greatest responsibility for responding. However, the imbalance also guarantees that global emissions will continue to rise in spite of the Kyoto Protocol, and provides an argument for those that oppose Kyoto, namely that Kyoto compliance would create an economic disadvantage relative to China, India and Brazil.

Beck's (1992) ideas on distributions of risk within society are helpful in distinguishing the effectiveness of international action to reduce CFC emissions versus GHG emissions. In the case of CFC emissions, the risk posed by rapid ozone depletion is relatively equally distributed across all nations: the potential for increased incidence of cancerous melanoma would be the same for citizens of a wealthy nation like Australia as it would be for its impoverished neighbours in East Timor. In fact, the risk may be felt strongest by the wealthier of the two nations. Caucasian residents of that region, concentrated primarily in

Australia and New Zealand, may be more susceptible to cancerous melanoma than regional indigenous peoples, creating a biological differential in this risk (Giles et al. 1988). Besides this, an elevation of the rate of skin cancer is probably a minor risk for the average East Timorese relative to other daily risks of social unrest, food security and so forth. Unlike many environmental risks, the risk of increased rates of cancerous melanoma could not be transferred to future generations of Australians or East Timorese: the rate of ozone depletion in the absence of the Montreal Protocol would be too pronounced. In other words, the risks associated with CFC emissions are borne currently and directly by those countries with high rates of CFC production, providing direct impetus to act.

Not so with GHG emissions. At present, it is not clear that those countries with the highest levels of GHG emissions will bear the greatest risks – and their present behavior certainly implies this. As we have shown in the case of vulnerability to flood hazards, increased economic prosperity is believed to enhance the capacity of populations to adapt to hazards; yet another incentive to go full steam ahead with a carbon fuel-based economy. The risks of climate change get transferred to less prosperous nations and to less prosperous groups within our own nations. Moreover, the worst manifestations of climate change seem far off; economic and social policy decisions are typically made with timeframes of weeks, months or, at most, a few years in mind. Climate change projections are typically made in decadal terms or longer, a significant disjoint. Hence, vulnerability to climate change is reduced for one segment of society by transferring the risks associated with inaction on GHG emissions to other members of society and to subsequent generations. Until something occurs to alter the present distribution of climate change risks, there is every reason to believe that compliance with Kyoto will be low, that GHG emissions will grow, that human alteration of the biophysical processes that influence climate will be ongoing, and that this process of reducing vulnerability through transfer of risk will continue.

6 Conclusions: Environmental Vulnerability in Comparative Perspective

A central aim of this paper was to develop an enhanced general framework of the factors influencing vulnerability that is applicable across scales, regions, and socio-economic activities. Drawing upon rational actor, systems and structural/historical theories of environmental degradation and change, we expand upon the idea that environmental vulnerability can be understood primarily as a function of exposure and adaptive capacity. In particular we argue that exposure and adaptive capacity can be more effectively understood in terms of ecological, socio-economic and institutional dimensions. Moreover, we argue that conceptualizations of adaptive capacity can be enhanced by distinguishing between *ex ante* and *ex poste* forms of preparation and response. By comparing ecological, socio-economic and institutional dimensions of hazards in river valleys and coastal areas, the collapse of the northern cod fishery and climate change, we draw the following conclusions about physical, socio-economic and institutional dimensions of exposure and adaptive capacity.

First the exposure to flooding, over-fishing and the possible calamities which may arise as a result of climatic change are all a product of socio-economic path dependencies and institutional incentives which reflect and further exacerbate these dependencies. Human settlement in flood plains and coastal areas, for instance, reflects long-standing patterns of human consumption, irrigation, transportation and other forms of resource use. These dependencies have been further exacerbated by public and private forms of insurance, which compensate property-owners for losses incurred during cataclysmic events, such as cyclones and floods. Public policies which support the development of infrastructure in areas that are particularly prone to natural hazards and public insurance programs, which compensate property owners for losses incurred as a result of unsafe or unsustainable behaviour have exacerbated exposures of this kind. We have seen this played out in overwhelming fashion in the destruction caused by Hurricane Katrina along America’s Gulf coast. Similar assertions can be made about government programs which encouraged the development of the commercial industry in the Atlantic groundfish fishery and those which continue to subsidize and encourage the burning of fossil fuels.

Second, and directly related to this last point, the ability to prepare for and respond to uncertain and potentially cataclysmic environmental events is seriously constrained by the dependencies and political interests which emerge as a result of human settlement, industrial organization and government subsidy. In the case of the northern cod, economic and political pressure to maintain and even expand the status quo quite clearly undermined the government's ability to understand, assess and act upon a fishery which was in the throes of substantial ecological decline. The case study suggests that socio-economic and political pressures created an inertia that prevented officials at multiple levels from taking decisions that would err on the side of caution, and reduce the amount of effort in the Atlantic fishery. However, the adaptive – or in this case, *mal-adaptive* – capacity on the part of government was only part of the equation. Equally important were the highly decentralized incentives and decisions of the operators themselves.

In Section 1 we introduced five metrics of vulnerability, which were developed by Woodrow and Liedtke:

1. Measures of Source and Agency – whether individual human action or out of control forces are at work in explaining exposure to and impact of particular vulnerabilities, as exemplified by distinctions such as *deliberate/accidental*, *voluntary/involuntary*, *chance/skill*, etc;
2. Measures of Scale, Scope and Intensity – whether the range and impact of particular vulnerabilities can be characterized in terms of dichotomies such as *discrete/widespread*, *limited/extensive*, *intense/*weak, etc;
3. Measures of Explanation -- whether the origin and evolution of particular vulnerabilities are best explained by *causality/correlation, endogenous/exogenous*, *circumstantial/deductive*, etc;
4. Measures of Interconnectedness – whether the various elements and linkages involved in particular vulnerabilities, are *simple/complicated/complex, loosely/tightly coupled*, etc;
5. Measures of Criticality – whether the seriousness and acuteness of particular vulnerabilities can be treated as *non-critical/critical*, *stable/unstable, evolutionary/transformative*, etc.

All of the vulnerabilities we consider in this paper can certainly be measured or understood in terms of their source, agency, scale, scope, intensity, explanation, interconnectedness and criticality. However, the very task of establishing an empirical measurement of vulnerability raises difficult epistemological and ontological questions about the characterization of risk, vulnerability and the natural world. In the following table (Table 6) we summarize some of the major conclusions as they relate to the metrics set out in the original matrix. As noted in Section 1, we add two additional factors, the reversibility of the underlying condition and the reversibility of the behaviour that leads to the underlying condition. In the remainder of this concluding section we reflect critically about the epistemological and ontological challenges of measuring vulnerability, and the problems these create for the study of vulnerability.

Table 6: Summary of Conclusions

Metrics	Flood hazards	Cod Stocks	Climate Change
Source/agency	Combination of individual decisions and structured incentives	Combination of individual decisions and structured incentives; commercial fishing and industrial technology; government incentives; consumer demand; management failures	Combination of individual decisions and structured incentives; fossil fuel economy; political pressure and dependence; apathy; collective action dilemmas; complexity
Scale, scope, intensity	Relatively discrete – i.e. localized flooding, damage, etc. but widespread replication of zoning practices and widespread settlement patterns in river valleys and coastal areas amount to a widespread phenomenon and therefore extensive vulnerability	Relatively discrete in terms of scale, but scope was widespread in the region	Relatively widespread with localized and variable impacts; intensity and scope potentially catastrophic; potential for cascading effects on other human systems; also possible opportunities.
Explanation	Failure of planning; inductive explanations – case-by-case;	Failure of management versus failure of science; deductive models with inductive corrections	Uncertainty regarding underlying physical processes; reliability of models as predictive tools questionable
Interconnectedness	Interconnectedness is relatively simple (i.e.	Ecosystem and human	Ecosystem and the management of the

	identifiable causal relationships, observable impacts/ potential impacts) when compared with climate change	environment relationships within the ecosystem are highly complex, creating many cascading effects	ecosystem are highly complex and uncertain; interconnectedness is a matter of uncertainty and debate
Criticality	Homes, property, livelihoods, infrastructure most critical element of vulnerability Primarily human populations	Assets, lifestyle, livelihood; human and eco-systemic impacts	Homes, property, livelihoods, infrastructure, lifestyle Human and non human populations are critical, although great debate about relative weighting
Reversibility of underlying condition	Challenging, but feasible given that human settlements are so closely governed by zoning regulations, etc.	Uncertain – debate about whether the cod stocks can or will recover	Uncertain – great debate about resilience of global and regional ecosystems
Reversibility of behavior which leads to the underlying condition	Possible if there is political will	Outright ban easy; more difficult when managed; difficult to regulate taste and structure of the global seafood industry	Very difficult to regulate polluting industries and individual actions; tragedy of the commons scenario; risks not equal among nations

In *Collapse* (2005), Jared Diamond argues that one of the principal reasons societies experience environmental collapse is that they fail to recognize the risks of environmental degradation until it is too late. The case studies of natural hazards, over-fishing and climate change suggest that the ability to make this connection is seriously constrained on one hand by the limitations which are inherent to modern science and the management of naturally-occurring processes and events and on the other by the strategic behaviour of individuals and groups whose interests, decisions *and indecisions* discourage actions that would prevent or mitigate the causes and effects of environmental change. We have seen a variation on this theme in our case study of climate change, namely, that getting agreement on the nature of environmental risks is not necessarily straightforward. Despite overwhelming evidence that human activity has added and continues to add ever-increasing amounts of greenhouse gases to the atmosphere, there continues to be debate over whether this phenomenon poses any significant risks to human well-being.

We dare to go further by suggesting that this obfuscation on the nature of the risks hides a more distasteful reality in that those who benefit most from the status quo – developed nations – are essentially indifferent to the risks and will continue to be so long as it is less developed nations that are most likely to bear the cost of those risks. This belief is borne out by our comparison of international responses to ozone depletion versus the comparative lack of response to greenhouse gas accumulation. Part of this difference in action may be attributed to factors such as the clearer causal link between ozone depletion and subsequent risks of enhanced UV penetration on human health; there is indeed much still to be learned about the responses of many natural systems to enhanced greenhouse warming. However, most scientific predictions about the likely outcomes of climate change amount to little more than exacerbations or enhancements of existing climatic conditions which already present environmental risks to human well-being.

Risk differs from uncertainty in the sense that it entails the ability to calculate the probability of an undesirable outcome or event, in which the consequences are well specified. Uncertainty, on the other hand, suggests a condition under which the probability of any occurrence or event – as well as its specific consequences – is effectively unknown. It is the ability to speculate and – on the basis of a statistical probability – calculate future undesirable outcomes that distinguishes risk analysis from other forms of forecasting, such as gambling, guessing, or even speculating. As Beck (1992) has pointed out however, the ability to calculate the probability of future undesirable events and outcomes is directly dependent on the quality of information one has at one's disposal, as well as the subjective value one places on various outcomes and events.

In all three of the cases we consider in this paper, human understanding of the various causal mechanisms, outcomes and events was relatively clear. Although meteorological variation is by no means an exact science, the range of undesirable outcomes – e.g. flooding, destruction of homes, loss of life, etc. – is well understood, as are the causal mechanisms. To borrow an analogy from the insurance industry, knowledge about the risks of excessive speed, drink driving, etc. is well understood. Likewise, knowledge about the negative impacts of excess capacity in commercial fishing and greenhouse gas emissions is extensive. Where the management of risk becomes problematic, however, is in relation to the calculation of probability, which requires a data set that is both accurate and sufficiently large to generate inductive conclusions about cause and effect.

Efforts to understand the potential impact of climate change and efforts to manage the northern cod fishery illustrate the challenge this entails. In both of these cases, scientists, modelers and managers encountered problems which arise from the non-testability of natural or complex impacts and events, such as thunderstorms and the "true" catch rate within the commercial fishery. Lacking the ability to conduct experimental trials, modelers, scientists and managers are forced to rely on a combination of informed estimates and historical data. In the case of stock assessments and general circulation models, estimation entails a fair degree of course correction, whereby past projections about future outcomes and events become quickly updated (or, more accurately, outdated). Such practices are not substantially different from humanly devised technologies, such as nuclear reactors or DDT. In both of these examples, experimental trials on human subjects are effectively impossible, creating a situation in which managers are forced to rely on consistent monitoring and assessment (as was the case in the Atlantic fishery) or on proxies, such as non-human trials or, in the case of climate change modeling, parameterizations.

However, unlike humanly-devised systems, such as nuclear reactors or commercial air travel, environmental phenomena entail a wide range of naturally-occurring feedbacks and phenomena, which make the management of human technologies and activities within these systems less controllable, and more complex. The assessment of risk in the automobile insurance industry provides an interesting case in point. Because information about car collisions and fatalities is collected by public authorities and by the insurance industry, the calculation of probability events – as well as the factors which may lead to such events – is a relatively well-developed science. The same however, cannot be said of many environmental phenomena, including the three we consider in this paper. First whereas the ability to recognize and record an automobile accident is relatively clear and uncontested, the ability to identify evidence that would suggest environmental degradation is far less straightforward. This is due in part to the fact that natural processes entail cycles and feedback mechanisms, which allow the possibility that evidence being presented as a change in the Earth's climate is in fact a fluctuation that will eventually lead back to a steady state. Second, the ability to identify evidence of environmental degradation is undermined by the fact that perceptions of what constitutes environmental degradation vary greatly.

Note the difference between these two types of problem. The first, which for the sake of clarity we will call "contentious problems", imply that although agreement exists about what environmental degradation entails (e.g. a rise in the earth's temperature) there is disagreement about whether and to what extent this process has occurred. The second, "consensus problems," suggests a more fundamental disagreement about what degradation actually entails (i.e. there is a fundamental difference about the definition and existence of the problem).

One could argue that many of the climate policy debates that have transpired among scientists, lobbyists, politicians, etc. are of the "contentious" category, in the sense that these are disagreements about whether and to what extent "the problem" has in fact occurred. The definition of the problem in these instances is relatively clear; it is the evidence that is a matter of debate. For consensus problems, the ability to reach consensus and therefore calculate probability and manage risk is far less straightforward. Demerrit's critique (2001) of GCMs used to predict climate change, for instance, suggests that available, influential *and fashionable* modes of professional and scientific practice have in effect defined the problem of climate change, including the abstraction that is "climate." Radical constructivists would on this basis argue that terms like climate, climate change, degradation, etc. are all socially constructed by the lenses through which we interpret reality and – in the context of this paper – calculate risk. Escobar (1996) goes so far as to suggest that managing human-environment relationships has become the "White Man's Burden" for a new century, reflecting the predominance of western educated, primarily male scientists driving debates such as that over climate change and the types of international policies and actions warranted.

However, the inability to reach consensus about what constitutes an environmental problem goes well beyond post-modern discourse. Consensus problems, for instance, help to account for the fact that Canada's Department of Fisheries and Oceans collected virtually no information about the inshore fishery, despite the fact that this sector accounted for a considerable percentage of landings in the 1980s and 1990s. As Finlayson (1994) has argued, the decision to ignore the actions and output of the inshore fishery reflected a desire on the part of government scientists and managers to work with the tools and data that best reflected their training, experience, practice and knowledge, which – it must be stressed – was very different from that of the inshore boat operators.

Consensus problems also highlight the difficulty of establishing normative consensus about what constitutes acceptable change, a theme we have raised a number of times in this paper. Although car accidents produce impacts whose costs are widely appreciated and understood (e.g. loss of property, livelihood and life; long-term physical and psychological effects), the negative impacts of an altered ecology are neither universally shared nor understood. Again, this is due in part to the inability of science and other forms of knowledge media (e.g. the news media) to understand and assess the future environmental costs of human agency. It also reflects the perceived resilience of ecological systems, such as a fishery or the earth's climate, which are able to undergo numerous shocks and changes while still providing traditional services, such as fish (although the dominant species may change) or a warm growing season (although the traditional climate patterns may change). Coupled with the short-termism that has been a defining feature of most human history, the inability to reach consensus about the undesirable nature of environmental change constitutes a substantial obstacle to behavioral change (see below). Indeed, calls for radical change, which typically follow cataclysmic events, such as the Asian tsunami or Hurricane Katrina, quickly fall under the weight of political interests and everyday life.

In short, contentious and consensus problems complicate the ability to calculate probability and manage risk because they compromise the ability of scientists, managers, politicians, etc. to reach consensus about the nature of the problem and whether the problem has in fact occurred. Contentious and consensus problems clearly complicate the task of establishing metrics for environmental vulnerability. As the automobile insurance example helps to illustrate, humanly-devised technologies provide a language and design through which statements about explanation, interconnectedness and criticality can be made with relative ease. Environmental phenomena on the other hand present their own challenges, particularly in relation to explanation and preventative action.

The ability to generate a reliable understanding of vulnerability and risk is plagued by many of the factors we address in this study: uncertainty about naturally-occurring processes, uncertainty about human-environment interaction, malfeasance, politics and the limitations of science. The collapse of the northern cod and the example of climate change provide additional and important insights about the complexities which arise as a result of human efforts to understand and manage non-human processes. As Demeritt (2001) argues, GCMs have incorporated so many variables and parameterizations that the ability to discern which causal variables are having which effect on the climate system is almost impossible. Along similar lines, Healey and Hennessey (1998) argue that efforts to regulate capacity and ensure fairness (of access) in the Atlantic groundfish fishery and the Fraser River salmon fishery made the system so complex that fisheries managers were effectively unable to manage levels of exploitation. In other words, systems of measurement, description, explanation *and regulation* become so complex that they render the management of the resource and with it the ability to adapt to unforeseen processes and events increasingly difficult and complex.

The collapse of the northern cod and the example of climate change also illustrate the different epistemological assumptions that underlie the study and management of environmental risk and vulnerability. In the work of some authors (e.g. Brethes 1998; Schneider 2001; Wolfson and Schneider 2002) we can detect a modernism that is decidedly optimistic about the ability of science to inform the management of human-environment relationships. Here the ability to represent the complexity and diversity that is reality is only constrained by the ability of scholars to construct models which are more representative and, consequently, more complex. Others take a more critical reflection about the viability or desirability of such an exercise (Beck 1992; Finlayson 1994, Demeritt 2001). More to our purposes, critical reflection about the ability of scientists, managers, politicians and the public at large to understand and interpret increasingly complex models of reality appears nothing more than a marginal issue on which scholars of science and technology can pass their time. However, as the debate about GCM reliability and the collapse of the northern cod illustrate, efforts to capture the complexity of reality are and were a major part of the challenge facing scientists, managers and politicians. Moreover, as Demeritt (2001) has pointed out, the complexity of reality and the reluctance on the part of many scientists (social and natural) to state with 100 per cent certainty that a particular event will happen as a result of a particular set of conditions creates sufficient ambiguity for defenders of the status quo to argue that it is too early to take drastic action (creating a wide array of consensus dilemmas – i.e. climate change does not exist; what is change? etc.).

This last insight raises a final and crucial point about the social and political context in which the interpretation and management of human-environment relationships take place.
GCMs offer a sophistication and power of prediction that is perceived to be at the cutting edge of science (cf. Sarewitz and Pielke Jr 1999). For policy makers and politicians, GCMs

legitimate current and future policy decisions, however imprecise and unrealistic the evidence and projections may be. However, to suggest that models are constructed and methodologies adopted only in order to serve a wider political interest understates the institutional pressures and normative ideals that influence the behaviour of politicians, managers and scientists (cf. Schneider 2001). As noted earlier, public subsidies which promote unsafe settlement in river valleys and coastal areas and unsustainable fishing practices can certainly be explained in terms of self interest, political pressure and so on. However, they also reflect an effort on the part of political authorities to protect people from the impact of an unbridled market, which is affected in no small way by ecological disturbances.

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VULNERABILITIES IN TECHNOLOGICAL SYSTEMS
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