Module 7

Observations, Sustainability, and the Impacts of Change

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Key Terms and Concepts

- Arctic haze
- aerosols
- bioaccumulate
- biomagnify
- biosphere
- causation
- cryosphere
- endocrine disruption
- epidemiology
- false negative
- false positive
- fossil fuel
- greenhouse effect
- persistent organic pollutants (POPs)
- precautionary principle
- radiative properties

Learning Objectives/Outcomes

Upon completion of this module, you should be able to

1. describe the scientific method, its origins and the meaning of uncertainty in real systems;
2. explain the interrelationships between people and ecology, including public perceptions of ecological values;
3. explain the general concepts of environmental health and stewardship;
4. identify the organizations of circumpolar governance involved in environmental policy development;
5. describe the importance of science to international policy-making regimes.

Overview

The concept of long-term human and ecosystem health generally refers to the protection of natural systems. Long-term stewardship issues have been discussed since the Second World War, often in the context of military or industrial sites contaminated with petroleum, chemical, or radiological waste. When contaminated sites are recognized as hazardous, a management plan is created to reduce risks to humans and ecosystems though remediation.

Different people, of course, have different ideas of what environmental stewardship means and how best to provide it, but definitions tend to share the idea of caretaking. (See box 7.1.) Generally, the protection of natural systems is implied. The term sustainability is often used to describe the goals of stewardship—stability and health for unlimited time. When people obtain their food from the wild, as they do in the Arctic, their health is directly linked to the condition of the land and the animals. Long-term stewardship of any environment must ultimately consider human health for future generations, especially if the people live off the land.

Box 7.1 One Example of Stewardship

The Yukon River Inter-Tribal Watershed Council (YRITWC) is a group of more than 40 Alaska indigenous tribes and Yukon First Nations that have joined in an effort to practise environmental stewardship at the local, regional, and international scale. With Canada's invitation, the YRITWC presented a case study at the World Summit on Sustainable Development.

The group's vision is "to be able to drink water directly from the Yukon River," and their activity is focused on that goal.

At a workshop in September 2000, environmental technicians from the tribes and First Nations spent time creating images of a "healthy watershed." When groups shared their drawings, one major theme was evident in all: a healthy watershed is not just about clean water, but many other things as well:

- healthy animals
- interactive people (hunting, fishing, picking berries, etc.)
- beauty
- abundance and diversity
- unity and the cycle of life

The discussion that developed these criteria was key to creating a framework for long-term monitoring and assessment of ecosystem health. The capacity building and technical assistance provided by the YRITWC has enabled communities to participate in data collection and evaluation, and the *Unified Watershed Assessment* was completed in 2002. Community actions to improve conditions in this watershed include recycling programs, lead-battery and waste-oil collection programs, emergency preparedness training, landfill and sewage-lagoon relocations, and prohibitions on expanded polystyrene (Styrofoam) and plastic shopping bags.

The YRITWC has also increased government-to-government dialogue regarding local and regional issues from the management of living resources, such as moose and forests, to the legacy of pollution left over from past resource extraction and US military activity. Gold rushes and weapons testing have inflicted some of the most serious damage in the watershed area.

Government regulations regarding pollution are one example of stewardship in practice, though methods and effectiveness vary. The growing sustainability movement enabled by the United Nations promotes resource development that maintains environmental integrity and enables cultural continuity. Many organizations dedicated to sustainable development include stewardship in their mission statement but leave the term itself loosely defined. One group, "dedicated to the principles of free enterprise and limited government," asserts that stewardship entails affordable and abundant supplies of energy (CEI). Affordable and clean energy *are* critical to economic stability and health, but the sustainability of current rates of **fossil fuel** consumption is limited. Debate over the volume of remaining petroleum and coal reserves goes on, with advances in technology promising to recover more and more of it—but supplies are definitely not renewable on our time scale. Further, fossil fuel extraction often impairs environmental quality, and the major waste product of fossil fuel combustion, carbon dioxide (CO_2), contributes to global warming. This module will attempt to describe the complexities of environmental science, with particular reference to climate change and persistent organic pollution, both expected to have dramatic effects in the Arctic. (See box 7.2.)

Box 7.2 Organic Chemistry and Persistent Organic Pollutants (POPs)

While *all* matter is made of chemicals, the term "organic" was first used to distinguish biological material from all other (inorganic) matter. Organic chemistry—what we now know as chemistry involving carbon molecules—was problematic outside the living organism. Organic material decayed too quickly and behaved unpredictably in the lab, making experimentation and replicable results difficult for chemists. Biochemistry—organic chemistry within organisms—was entirely mysterious. Perseverance paid off, and by the middle 1800s chemists were learning to manipulate carbon bonds and molecules by controlling conditions and using reagents (Voet et al. 1999).

With chlorine as one of their tools, chemical engineers have created all kinds of new organic compounds. Chlorine continues to be a major industrial tool, common in many production pathways. Large quantities of chlorine are produced; most is used in the synthesis of plastics, especially polyvinyl chloride (PVC) and other high-volume products (Thornton 2000, 203–330). Organochlorines were the first major large-volume pesticides; they were introduced to improve both health and agricultural productivity. Laboratory and factory techniques continued to evolve, and synthetic organic chemistry gave rise to the chemical revolution—which is still going on. Over a similar time span, but especially in the last twenty or so years, biochemistry has become an umbrella field, with enzymologists, nutritionists, toxicologists, and so on, learning exponentially about the complex relationships between molecules within cells and creating modern biotech industries (Rifkin 1998).

To say that the practice of chemistry has improved human health and enabled productivity would be a major understatement. Just over a century since its induction, everything about modern life, from antibiotics to word processors, thoroughly depends on synthetic organic chemistry. Our standards of civilization are not without costs, however, and at least one of these is just coming to light. Many new organic compounds have become ubiquitous in the environment (including human tissue) and have the capacity to influence cellular biochemistry. Indigenous Arctic peoples have not, in general, enjoyed the wealth generated by the remarkable benefits of synthetic chemistry (not to deny that gear and conveniences are being adopted), but their children are apparently at increasing risk from the pollution from lower latitudes.

Lecture

Health and Protection of the Arctic System

Responsibility for the health of living systems on Earth has fallen to humankind. People (some more than others) have taken charge of the **biosphere**—sowing and reaping, cutting and digging—to meet growing needs and wants. Recently, scientists and governments have begun to recognize that the total effect of human activities is threatening sustainability on a global scale. Global efforts towards long-term stability and health have begun, as demonstrated at the United Nations World Summit on Sustainable Development in Johannesburg, South Africa, in 2002 (http://www.johannesburgsummit.org/).

Arctic Pollution

The phrase “Arctic haze” was coined by Murray Mitchell in 1956 to describe dirty layers of air that had begun to appear in the Arctic atmosphere each spring (Mitchell 1956). Arctic haze was formally demonstrated to be the accumulation and layering of global air pollution in 1972. No major health problems were documented, as none had yet become apparent. Concern was focused on acid rain chemistry and the physical properties of the **aerosols** transported to the Arctic. Studies were directed towards learning how changes in the **radiative properties** of the Arctic atmosphere—changes in how heat and light are absorbed or transmitted—might affect regional, and even global, weather and climate (Shaw 1980).

In the late 1970s, scientists documented a direct relationship between sulfur emissions in continental Europe and acid levels in Scandinavian lakes (Clapham 1981). International action was taken through the United Nations; the Convention on Long-range Transboundary Air Pollution (LRTAP) entered into force in 1983 and has since served as a model in the development of international environmental law. Over the decades, other examples of Arctic vulnerability to global pollution became clear, as atmospheric and oceanic currents were documented in delivery of other anthropogenic particles and compounds to the Far North. Among these, radionuclides, heavy metals, and **persistent organic pollutants (POPs)** generated the most concern, as will be further discussed. Complexity is now expected and, in order to mitigate threats promptly, many treaties, such as the LRTAP, are designed to adapt to changing conditions and new discoveries in environmental chemistry. Monitoring and research of environmental and human health, and climate, are complicated by multiple confounders, but studies continue to shed light on patterns and processes occurring in the Arctic and around the world.

Formation of the Arctic Council

Atmospheric nuclear weapons testing and the Chernobyl disaster in 1986 resulted in radioactive fallout across the North, especially in Scandinavia. Following Chernobyl, thousands of Scandinavian and Alaskan reindeer were destroyed because the meat had dangerously high levels of radioactive elements (O'Neill 1994). This event contributed motivation to the formation of an independent forum called the Working Group on Arctic International Relations (WGAIR). With members from each of the eight Arctic nations—Canada, Denmark (as "sovereign" of Greenland), Finland, Iceland, Norway, the Soviet Union, Sweden, and the United States)—the group began to explore the potential for international co-operation in the Arctic "by providing early warning of emerging Arctic issues, devising innovative policy options, and serving as an informal channel for communications among the Arctic states" (Young 1992).

In 1991, recommendations of the WGAIR resulted in an historic meeting in Rovaniemi, Finland. Ministers of the "Arctic Eight" and three indigenous groups of "permanent observer" status adopted the Arctic Environmental Protection Strategy (AEPS), which addressed six problems in particular: persistent organic contaminants, heavy metals, acidification, radioactivity, oil pollution, and underwater noise pollution's effect on whales. The AEPS established four working groups: the Arctic Monitoring and Assessment Programme (AMAP), Conservation of Arctic Fauna and Flora (CAFF), Protection of the Arctic Marine Environment (PAME), and Emergency Prevention, Preparedness, and Response (EPPR). The Arctic Council was formed in 1996 and assumed the responsibilities of the AEPS. Since then, the Arctic Council has studied issues and communicated the results effectively (e.g., AMAP 1997; CAFF 2001) but has had only limited success in international politics (Nowlan 2001). (For a good overview of Arctic Council activities and working groups, see Tennberg 1998.)

These efforts at international co-operation have grown, and the working groups have produced excellent documentation to inform decision making, but the Arctic has a "soft" legal regime—none of its agreements are legally binding. A common feature in each of the sovereign Arctic nations is that political power tends to be dominated by larger populations to the south. Iceland is the least extreme case, with all of its population in the Arctic. The United States is the most extreme, with a distant and effectively disconnected central government; even the State of Alaska has a capital (Juneau) outside Arctic Council working group boundaries. Efforts are continuing toward an Arctic treaty that would empower the region as a whole with legally binding agreements to protect the Arctic environment with development mandates that promote sustainability (Young 1992; Nowlan 2001).

Student Activity

1. Soft legal regimes tend to be developed by sub-national groups and hard legal regimes tend to be developed among nations. Why?
2. Which are the most effective regimes, soft or hard ones? Explain your answer.

Observations and Risk

Of course, people have been making observations, trying to explain them, and making predictions for much longer than "science" has existed. People have always had questions and answers about the way things are and how they came to be; we probably always will. The systematic documentation of observations that came with the scientific method has enabled many discoveries, and science is widely accepted as a reliable method to evaluate information.

Most scientists now recognize that communities have long made legitimate observations, though documentation is often lacking. Recognition that community members often have reasonable hypotheses that are important to research is also growing. New partnerships between institutions and communities are integrating local wisdom (traditional knowledge) with the scientific method to try to answer complicated questions. This makes sense: local people generally have a deep and long-term understanding of the natural systems they depend on.

The Scientific Method

Science is a set of rules regarding general research approaches, established in the early 1600s, to increase the accuracy of theoretical explanations. Sir Francis Bacon is credited with designing the "scientific method"; he hoped to improve the human condition by gaining knowledge. Only with an understanding of nature's laws, he reasoned, could man take full advantage of nature for his own benefit, often with little regard for nature itself (Bajaj 1988). Science has, indeed, greatly empowered people and often damaged the environment—if in unexpected ways. Many environmental scientists now try to understand nature in order to protect it, and science still provides effective tools for discovering the way nature works.

There are three general rules in scientific studies: (1) a hypothesis must be tested; (2) methods and results must be well documented and peer-reviewed; and (3) results should be reproducible if the methods are exactly followed by another scientist. As results accumulate, trends and patterns emerge—but they must be interpreted with care. Ideally, science works as follows: A question or problem strikes curiosity or concern, so a researcher documents the team's observations and tries to explain them with the simplest possible reasoning. This explanation serves as a working hypothesis, and the scientist designs experiments intended to test it—looking for evidence that affirms or contradicts the explanation; often several hypotheses compete. Designed experiments are events where some variables (e.g., temperature, moisture, light) can be controlled, so that the influence of each variable can be quantified with some amount of certainty. Data from experiments either (fully or partially) support or refute the hypothesis—providing insight and directing new lines of inquiry. Some experiments are inconclusive, indicating poor methods, poor reasoning, or poor luck. Data that does not meet expectations is acknowledged, and the negative findings are well described—including an explanation for the results, if possible. Findings are reported through a process of peer review, where methods and results are scrutinized by independent experts to ensure integrity.

The scientific method was designed for the laboratory—a place where variables can be controlled and changed one at a time to discover the influence of each. Environmental problems have forced scientists out to the "field" where they have limited control over variables. Often, the best we can do in the real world is to measure and document variables and compare them to conditions to see what variables are associated with what conditions and then to explain those trends with the simplest-possible reasoning. Environmental questions and problems are highly complex and no answer is simple. Often, "competing hypotheses" are equally legitimate and the explanation lies in a combination of causes. Science requires that there be always room for correction. Researchers test the limits of their proposed explanations; theories continually improve as new data are collected. Modelling techniques have allowed "testing of hypotheses" in that they provide predictions, but those predictions can only be as good as the data that go into them, which are often incomplete or uncertain.

Standards of evidence are quite high, making a **false positive** much less likely than a **false negative**—in other words, it is much harder to accept a bad idea than it is to doubt a good one. This leads to uncertainty in legitimate theories, and fewer false conclusions. If supportive findings accumulate, a hypothesis gains strength and credibility as limits and terms are developed. Working hypotheses maintain legitimacy by accounting for evidence as it becomes available and by reasonably explaining and incorporating what at first appear to be contradictions. If a hypothesis holds up through this extended period of rigorous testing, having taken new shape along the way, it becomes a theory (Bauer 1992). Here we find such reasonable ideas as plate tectonics, which will never be proven but rather will be continually improved by modification, leaving it the best possible explanation. The method is thereby designed to disprove incorrect hypotheses and support correct ones—never proving anything.

Inductive and deductive thought are two typical patterns of reasoning used in science. Deductive thinking draws conclusions from evidence without going beyond observations: for example, people have hearts and lungs and reproductive parts very much like many animals; thus, people must be a kind of animal. Inductive thinking is a less certain form of understanding because it requires some assumption (beyond trust in the truth of the facts under consideration) and can thereby lead to false conclusions: for example, every time I drop my toast, it falls; does that mean every time I drop my toast in the future, or somewhere else in the universe, it will fall? Gravity is a well-studied force that is now predictable, but assumptions need to be made to trust those predictions. Deductive reasoning is more broadly accepted among scientists, but hypotheses (such as "people are a kind of animal") must be clearly demonstrated by the systematic rejection of other possibilities.

Complex Systems and Uncertainty

Complex environmental issues have raised many questions—prompting research and generating a need for predictions. For instance, certain gases (that we can study in the lab) tend to transmit light but reflect heat. Earth's envelope of air includes such gases, allowing energy to enter but not to exit the atmosphere, creating the **greenhouse effect** that keeps Earth hundreds of degrees warmer than the moon and makes life here possible. As we raise the concentration of those gases, the climate will warm. This is solid deductive thinking, but only time will clearly demonstrate the process, so predictions of how much and with what effect are highly uncertain. Even now, with evident warming, we cannot be sure of the level of contribution from other factors, like solar cycles and other natural variation.

In environmental science, numerical data like temperature or species abundance are collected and statistical methods are used to evaluate the data for trends. Reason must then be used to explain any outstanding trends. There are many factors, and they tend to influence each other, resulting in complicated outcomes. When applied to environmental data, the scientific method results in explanations and predictions with a high degree of uncertainty—not proof, not ever. In most sciences, 95% certainty is considered "proof." In environmental and human health sciences, 95% certainty is usually out of the question because of the severe limitations on experimentation: we simply cannot recreate the world in a laboratory, and neither do we want to experiment on people with toxic chemicals to document the effects. Even 75% probability is considered significant—but can always be discredited as uncertain. Difficulties involved with establishing **causation**, being sure that one thing causes another, are a recurring theme in environmental and health sciences. The relationship between greenhouse gas emissions and climate change is an excellent example.

Another important example of complex system interference by human activity is the phenomena of **endocrine** (hormone) **disruption**. Many synthetic chemicals are hormonally active, and scientists have established that such "endocrine disruptors" can be found in every living organism. Legal regulation of these compounds (some of which are persistent and some of which are not) is a politically difficult issue, just like regulation of greenhouse gas emissions. People who discredit the endocrine disruption thesis (which is more than a hypothesis because it has been so well demonstrated, but is not yet a theory because the limits and definitions have not been established) as "alarmist" often do so in economic terms that make chemical regulation itself seem dangerous. Moreover, they point out that many natural compounds are hormonally active as well. This is true, but those have been part of biochemistry and evolution all along—and they do not accumulate in biological tissue throughout the biosphere.

The idea that ubiquitous pollution threatens entire populations, human and otherwise, with subtle, long-term, adverse, hormonally mitigated effects is not something that anyone wants to believe. Industries that benefit economically from inadequate control of pollution continue to claim that nothing has been proven, and this is true. What is often not acknowledged, however, is the weight of the evidence and the shear impossibility of generating "proof." Science is a means of explaining, but environmental data analysis is fraught with uncertainties and uncontrollable variables. Science provides data, correlations, and reason—evidence, not proof. Evidence demonstrating endocrine disruption is extensive and well documented (Krimsky 2000; Damstra et al. 2002). Given the physical extremes, the sparse populations, and complex mixtures of chemicals in biological tissue, strong certainty is especially difficult in the Far North; but expectations are that the Arctic is vulnerable to the global phenomena of endocrine disruption—indeed, evidence already suggests that subtle effects on the immune function of Inuit children in Nunavik, Quebec, are already occurring (Dewailly and Weihe 2003). Calls for the precautionary principle are often described as irrational responses to exaggerated threats, but most people want to *avoid* definite proof that their children's reproductive, immune, and neurological functions have been impaired by pollution. For more information about the Inuit response to the accumulation of POPs in the Arctic, *Northern Lights against POPs: Combatting Toxic Threats in the Arctic* (2003), edited by David Leonard Downie and Terry Fenge (Montreal: McGill-Queen's University Press) is strongly recommended.

Student Activity

Science, because of irresolvable uncertainty, can only disprove hypotheses and theories. Therefore, scientists use a weight-of-evidence approach to judge what is most likely.

1. Identify a complex system in your community. Discuss some of the uncertainties you would encounter, and some of the assumptions you would

have to make, to model that system. Try to include both scientific and social aspects of the system. (A model is a description that accounts for dynamic changes. Don’t worry about making or drawing the model; just think about the uncertainties involved.)

2. Do the people in your community recognize the complexity of the systems? Ask a few people (including at least one elder) for their ideas on describing the system. How does it change from year to year and over long periods of time?

Risk Management

Risk management in the Arctic, as anywhere, is a delicate mix of science (assessment) and policy (legislation). Where ecotoxicology is concerned, researchers like toxicologists, ecologists, and engineers provide information, and law makers decide what should be done. The implications of the tendency for various persistent compounds to travel pole-ward demand international collaboration in science and policy-making at regional and global scales. While the societies of temperate regions reap most of the benefits of modern chemistry, traditional Arctic peoples stand to pay an unacceptably high cost: a poisoned food supply.

Risk assessment attempts to define and quantify the character and magnitude of a threat. Although risk assessment is ideally a scientific process (data collection and reason), the kind of scientific research actually performed depends on politics and economics. The other major actions of risk management—policy development and implementation—are even more heavily influenced by politics and economics. The Arctic is composed of states and territories that are politically dominated by people and interests of southern latitudes; this affects the processes of risk management, including data collection.

Toxicological risk assessment follows three basic steps: determination of dose-response relationships; exposure evaluation; and risk characterization. In other words, determine what levels cause toxic effects, compare that to what people are actually exposed to, and decide whether the people are at risk. The steps of risk assessment for ubiquitous, variable, low-level mixtures of persistent pollution that may cause next-generation effects are heavily confounded—especially in the Arctic. These steps, and their limitations, are further described here.

Determining Dose-Response Relationships

In any assessment, the endpoint, or response, must be defined. Historically, toxicology focused on occupational risks, where adult men were exposed to high levels of toxic materials, or accidents, and the endpoint of concern was cancer. This information was supplemented with controlled studies of effects on laboratory animals, such as rats, mice, and monkeys. “The dose makes the poison” has been a motto of toxicology for centuries (Newman 1998), but some findings have called the “response-will-be-proportional-to-dose” assumption into question.

In recent decades, with the dispersal of contaminants throughout the environment, the vulnerability of the young and unborn has become apparent and has presented many more questions about actual effects. So-called “developmental effects” that occur during the construction and programming of tissue, in the womb and early life, have proven to be extremely difficult to evaluate—in part because they are not necessarily obvious. Given that most events of gestation only happen once, over some fairly brief duration, the *timing* of the exposure is apparently as important as the dose. Such effects can be subtle: damage to neurological function, changing attention span or intelligence; reproductive dysfunction that may not be discovered for decades; or immunological deficits that make children mysteriously prone to infection. Lab animal experiments produce the only data where variables can be carefully controlled, and this data must then be extrapolated with the inclusion of uncertainty factors. These findings support the idea that for some toxins at very low levels, exact dose and the timing of the exposure act together to generate responses that vary by type, rather than magnitude. Testing on humans and endangered (or photogenic) animals must not be destructive; non-destructive biomarkers are being developed but need much improvement.

Several toxins found in the Arctic are at levels that can be expected to, and may already, show effects on people, though population outcomes are hard to predict or observe (Dewailly and Weihe 2003). Questions of dose are further complicated by the influences of contaminants on each other (additive, subtractive, synergistic, etc.). Dose-response information for northern people and wildlife is being documented very slowly; and the value of combined methods (lab, semi-field, and field) is becoming apparent. In recent studies, relevant concentrations (those found in the umbilical cord blood of birthing women from Alaska’s Arctic) of two chemicals (HCB, an insecticide; and DDE, a breakdown product of DDT) were shown in the laboratory to have toxic effects on cells and genetic material in embryonic cells (Salmon et al. 2002), but what that means for the population will take decades to figure out. HCB and DDT are still being used and will continue to accumulate in Arctic food webs.

Evaluating Exposure

In the second step, exposure evaluation, one needs to consider various “routes,” like breathing (inhalation), eating (ingestion), and touching (dermal contact). One needs to quantify the exposure in terms of concentration and duration. While the atmospheric and oceanic currents are the primary sources of pollution to the Arctic, ingestion of contaminated foods is the primary source of exposure to people. The storage of toxins in fatty tissue, particularly in the females of upper trophic-level species, creates exposure for the neonate that complicates the process of assessment during a critical life stage. The prenatal amniotic bathing of mammals and subsequent ingestion of mother’s milk is under new scrutiny. Exposure to the mother’s lifetime accumulation of contaminants (body burden) puts the first-born at highest risk, since the female will transfer a portion of her body burden through lactation. The breast-feeding infant, such as a Steller sea lion pup—whose central nervous system, immune system, and reproductive system are still developing—receives a relatively high dose during these early months. The same is true for human infants.

A molecule has no effect in the fatty tissue where storage occurs, but it can be released to the blood stream during times of high-energy demand. Starvation, overwintering, and gestation can be expected to release fat-bound molecules to the blood stream. Once in circulation, they, like natural hormones, can affect homeostasis (internal, self-regulated chemistry). For example, the effects of organochlorine mobilization in Arctic animals that seasonally store large fat deposits for energy and insulation are poorly understood, but they are under study. Further, low levels and complex mixtures make exposure data expensive to collect and vulnerable to high margins of error. Exposure data is quite difficult to collect in the North, with information on contaminant levels in subsistence foods and dietary intake being necessary. Long-term monitoring of populations will be the first step in developing “circumstantial” evidence.

Risk Characterization

The Arctic Monitoring and Assessment Programme (AMAP) began documenting and quantifying the situation with their reports, the *Arctic Pollution Issues* (1997, 1998), and continued with their further assessments, including one on human health (AMAP 2003) and one on persistent organic pollutants (AMAP 2004). The science clearly indicates that the Arctic is at risk, and some species (such as glaucous gulls, polar bears, and some people) are already thought to be affected to varying degrees (Dewailly and Weihe 2003; AMAP 2004, 163–193). Levels of some POPs, radionuclides, and lead are steady or declining in Arctic biota, while other POPs (especially those not yet regulated) and mercury are on the rise. Geographical variation has been demonstrated but not thoroughly described; uncertainties are impossible to eliminate; and ironclad proof of the cause of harm will never be had.

Policy-Making

Policy-makers work in law, where proof is an ideal. The irony of depending on science for environmental policy-making is that science is intended to provide evidence—not proof. Despite the accumulation of voluminous evidence, decision makers are sometimes dissuaded from action by a lack of “proof” in the form of 95% certainty. The precautionary principle—based on an old idea, “better safe than sorry”—was developed in response to this fundamental dilemma in environmental policy-making. The idea is that when risks are very high and very likely, a thorough understanding of the processes should not be required for legal action to be taken to protect against the risk.

Student Activity

Whether exposure to a risk (e.g., smoking, eating contaminated food) is voluntary or not can affect our perception of the risk, and many people believe that we each have a right to take voluntary risks but that involuntary risks are not ethical to impose.

1. Identify a risk (other than smoking) taken in your community that is perceived by the risk takers as acceptable. Describe the reasons they see it that way. What kinds of benefits do they get from taking that risk?

2. Identify a risk imposed on your community (other than contaminated food) that you/they do not see as acceptable.

3. Which risk is actually greater? What is the difference in how people feel about the two risks?

Impacts of Change

As a global rule, the environmental impacts of local efforts to provide food, shelter, and clothing for small communities were much more limited than those of today’s economically motivated agricultural, forestry, and textile industries. Indeed, the very nature of materials has changed with the advancement of chemical and industrial technologies. Chemistry has enabled the creation of thousands of new compounds used for the production of food, the construction of cities, the fabric of textiles, and more. The contribution of chemistry to higher standards of living and better medical care in many parts of the world can hardly be overestimated. The consumption of energy has also changed dramatically in the last century, with rapid growth in human populations, huge increases in general productivity, and the introduction of personal motor vehicles.

With all this growth, environmental impacts have expanded beyond local sites, which often recovered over time, to include impacts on global systems that are difficult to measure or even estimate and may not be recoverable. The time scale of change has grown as well, from years to decades and longer. The vast and picturesque Arctic seems remote to the bustling activity of the industrial revolution in southern latitudes, but deep and rapid changes in the Arctic are becoming more and more apparent. While these are concerns at local and regional levels all over the world, the Arctic has a unique and not well-understood position in global environmental processes. Indeed, with global human activity effecting change in the Arctic Eight nations, these issues are beyond international—they are global. Two important issues to Arctic sustainability are climate and pollution. Given the magnitude of the predicted changes, sustainability will depend on resilience and adaptation.

The Arctic is a major component of the frozen portion of the biosphere, the **cryosphere**, which plays a critical role in the regulation of weather and climate around the world. Arctic pack ice, the Greenland Ice Sheet, glaciers, and frozen ground are clearly exhibiting sudden and rapid melting or warming. An average warming of the planet will involve warming in some regions and cooling in others. Rates will be variable, and parts of the Arctic are expected to warm dramatically. At the same time, persistent pollution will continue to accumulate in the Arctic—though climate change will alter the pathways that pollution follows (MacDonald et al. 2002).

While assessing the risks faced by Arctic peoples is critical, actions must be taken to allow for adaptation in management decisions and international policy. One area where such adaptation is already occurring is in the scientific method itself. More and more, traditional knowledge is being integrated with science, with contributions from communities providing vital information and researchers enabling communities to direct and participate in research. All participants are being empowered by the increasing depth of understanding.

Health and Environment

The tendency of air in temperate regions—some of which is heavily polluted—to warm, rise, and move towards the poles results in the Arctic serving as a global sink region for certain kinds of pollution. The kinds of pollution that have been and continue to be problematic to Arctic health include radionuclides, heavy metals, and many persistent organic pollutants. While not defined as pollution in the United States, carbon dioxide and methane are the primary waste products of fossil fuel combustion and are contributing to rapid climate change. Rapid climate change in the geological record is generally associated with mass extinction, mostly because of alterations to habitat that outpace evolution. Indeed, a recent study found that 15%–37% of extant species will be "committed to extinction" by 2050 specifically because of climate change; in conjunction with deforestation, agricultural expansion, pollution, and other forms of habitat destruction, the number will likely be higher (Thomas et al. 2004).

Linking a specific cause to a health effect is the identification of a toxicological hazard. Suspicions regarding the connection of POPs to health effects in Arctic populations run high, while "significant" certainty is rare and extremely expensive; indeed endocrine disruption is a particularly difficult phenomena to trace. Understanding the diet, metabolic processes, and endocrine function of any species takes extended research. Even the identification of sentinel species requires knowledge of the ecosystem. There are dozens to hundreds of species in any given food web, and studies have been quite limited in the North.

A true understanding of the health threats of pollution that **bioaccumulates** and **biomagnifies**, including mercury, needs to include data from several trophic levels, beginning with the microscopic organisms that often serve as gateways to the food web and ending in predators like otters, killer whales, and polar bears (AMAP 2004, 194–212). Subsistence users depend on wildlife and fish for financial and cultural survival; they are also an endpoint for bioaccumulation. Subtle, next-generation effects may be profound for small populations, such as those of Arctic people.

In some situations, the identification of chemical species present can occur and be correlated with observed health effects, especially if mechanisms are known. However, in most situations, linking observed effects with any certain chemical is impossible because of highly variable *mixtures* of chemicals—whose interactions and combined effects are unknown—that are now found around the world, and throughout the Arctic.

A major hurdle to conclusive studies of long-lived mammals is the lag time involved in subtle developmental effects. Reproductive tract abnormalities, compromised immune systems, and neurological deficits in intelligence are not generally apparent at birth, but they disrupt function later in life. Causation is difficult, if not impossible, to tease out from Arctic field and **epidemiological** data. At best, findings are reported as correlations, since proof of cause and effect is not possible, nor even the goal of the scientific method.

Progress may be measured in terms of cost and benefit: when total benefit overruns total cost, progress is being made. But cost-benefit analysis of industrial activity has generally been an economic consideration, while the long-term costs to environmental and human health have been ignored—in part because they were not, and are not, clearly recognized. The irony is that our own health can only be as good as the health of our environment, and the harm of our progress has long been underestimated. Human activity has become destructive to the very ecosystem services that maintain the biosphere; that is, forests clean air, wetlands clean water, and so on.

In the mid-1980s, researchers in southern Quebec, Canada, were studying rates of breast cancer and suspected that exposure to pollution might be an important risk factor. To test their hypothesis, they compared the rates to those of women farther removed from the industrial activity (assuming that those remote women would have lower exposure to the suspected contaminants). What they found was that the women in northern Quebec had *higher* levels of persistent organic pollutants in their blood than the southern group (Dewailly et al. 1983). This was found to be a result of biomagnification of these contaminants in the Arctic marine food web, raising concern all over the North. POPs are an issue all over the world, but their disproportionate occurrence in the Arctic indicates that Arctic people are at elevated risk.

People concerned about synthetic toxins in the environment are often portrayed by opponents as emotional and unscientific. The development of the endocrine disruption thesis is, however, a model of the scientific method in the information age. In 1962, Rachel Carson, having observed the negative effects of organochlorines on birds, wrote the book *Silent Spring*. In the first chapter, she asks, “What has already silenced the voices of spring in countless towns in America?” Her answer is an eloquent description of the impacts of some pesticides and other “chlorinated hydrocarbons” on environments. Her question, a set of observations (including those of other scientists), and an explanation (based on a dearth of data 30 years ago) prompted the field of ecotoxicology.

Our Stolen Future (Colborn et al. 1996) theorized that various severe population crashes in the wild, as well as apparently increasing endocrine and developmental disorders in people (decreasing sperm quality, reproductive cancers, metabolic dysfunction, learning disabilities, etc.) are best explained as effects of low-level exposure to complex mixtures of endocrine disrupting chemicals. The endocrine disruptor hypothesis is well on its way to becoming a theory, as it is increasingly supported by evidence from controlled lab studies, as well as field and health-clinic observations, but limits and definitions need to be established first. The still poorly defined framework of endocrine disruptor theory, which has developed dramatically in the last several years, consists of an explanation—that certain population crashes in the wild and increasing related disorders in people are being caused by synthetic endocrine disruptors—and an expectation—that all populations are threatened with these kinds of disorders. Neither the hypothesis nor the expectation is refuted by the increasing body of evidence, and apparent contradictions are being explained.

Around the world (though not consistently), sperm quality is down from 50 years ago (Swan et al. 2000); complicated pregnancies and infertility are up (Schettler et al. 1999); and more children are born with poorly differentiated sex parts or develop behaviour disorders (Guillette 1999). Puberty is occurring earlier for boys and girls in the United States (Herman-Giddens et al. 2001; Kaplowitz et al. 2001). The evidence indicates that the ubiquitization of hormonally active pollution has begun to influence health and physiology in certain human and wildlife populations. The Far North, still portrayed in popular literature as pristine, has been vulnerable to global pollution all along. However, details such as chemical behaviour in extreme cold, the intense annual fat cycles of resident species, and specific effects of variable chemical mixtures will require decades of study to determine. Questions regarding the adequacy of historical and current methods have been raised and methods are improving (Monosson 2003). If policies are not adjusted before all such evidence is in, the results of this uncontrolled experiment will likely be devastating to future generations in the Arctic. And even still, nothing will be proven.

Extensive research activity is being directed to fill the gaps in our understanding of hormone function, including the ways in which it can be disrupted, by what chemicals, at what doses, and in what species. Unfortunately, a virtually infinite amount of money could be spent on risk assessment of individual chemicals and chemical families before their threats could be quantified and managed properly (Monosson 2003). The precautionary principle—which advocates the prevention of harm rather than reparation—may not be science, per se, but is entirely logical. Alternatives to current consumptive and wasteful practices exist and could be much further developed (Thornton 2000, 363–407).

The United Nations Stockholm Convention (UNSC) on Persistent Organic Pollutants (UN 2001) is a groundbreaking treaty that will restrict or eliminate POPs around the world. This treaty has been signed by more than 150 nations since May 2001; and now that it has been officially adopted by 50 of those nations, it has “entered into force” (UN 2004). The requirements for inclusion are stringent: a chemical must be extremely stable, fat soluble, toxic, and prone to long-range transport. The treaty goes further and embraces precaution, for it not only regulates 12 of the nastiest known persistent organics, but it also describes the conditions and evidence required for the addition of new chemicals before the full extent of their toxicity is known. The “dirty dozen” have been fairly-well regulated in the developed world for some time, but, unfortunately, the United States has not ratified the UNSC. The United States has proven unwilling to adopt the precautionary measures and regulation of “new POPs.” The United States will be under considerable pressure from other nations to comply with new rules, and US export of these kinds of chemicals will be severely limited by the treaty, especially as it grows to include new compounds.

Adaptation

The Arctic is rich in biological, physical, and intangible resources. Millions of animals (birds, fish, and marine mammals) migrate to the Arctic to reproduce; resident and migrating animals feed hundreds of thousands of people dispersed in small villages throughout the circumpolar North. Several nations have significant oil and mineral deposits in the Arctic. The Far North also has tremendous strategic importance and the space needed for military training and testing. The migratory nature of many species and the shared ecosystems (the Arctic Ocean and the boreal forest) in Earth's largest remaining regions of wilderness require resource management in the Arctic to operate at an international scale.

All over the world the idea of stewardship is being reinvestigated with new understandings of complexity and recognition of harm done. While the primary goal of environmental stewardship in the Arctic may be environmental protection for generations to come, the Arctic will be developed. None of us can or wants to simply put an end to all development, but the goal needs to be focused on sustainability rather than growth of the profit margin.

Industry gets paid to take the risks involved in extractive resource development—but corporations often do not pay the long-term costs to health and well-being that accompany industrial development. Concurrent goals of improving Arctic health and regional sustainability while empowering Arctic peoples with economic stability are complicated and seem contrary, yet they must become one in the same, or Arctic people will pay the cost. A major achievement towards that end will be the "internalization" of the true, long-tern costs by industry—meaning that the cost of development would fall to the corporations that benefit, rather than to the public at large.

Both terrestrial and ocean environments must be managed in a way that will leave a positive legacy for future generations. Recent and projected population growth and development in the Arctic and Subarctic regions may affect productivity of ecosystems through increased local sources of pollution, loss of habitat, and over-exploitation. This may result in a reduction of human food resources, or their acceptability. While the accumulation of many infamous contaminants has begun to slow or even reverse (because they were widely regulated in the 1970s), new persistent compounds are accumulating and can be expected to have similar behaviours and effects.

Student Activity

1. Important questions for students today regard the distinction between, and integration of, science and policy. At what point do the questions surrounding these issues become political?
2. How can science be more effectively incorporated into policy?
3. How risk-averse should society be?

Wild foods are a critical resource for many Arctic people. They provide important nutrition, including plenty of the high-quality fat that has long enabled survival in the Far North. The quality of their fat (high omega-3 content), protein, and trace elements makes many northern species extremely healthy food. The nutritional and economic values of these foods are emphasized when the low relative nutritional quality and high economic cost of store-bought replacement foods are considered. The cultural value of intergenerational sharing and physical value of time on the land during subsistence harvests may be difficult to overestimate. Given increasing contaminant loads in Arctic foods, residents will need to stay well informed of specific organs or species that should be avoided, and they may increasingly rely on alternate food sources (which impose health risks of their own). Likewise, resource management will have to be adaptable, allowing hunting rights to shift with changing population distributions and conditions of access (e.g., pack ice). Intergenerational relationships and cultural heritage may continue to erode.

Health-risk assessments are expensive and notoriously uncertain, particularly in very small populations. The speed with which adaptation will have to occur may prove a major challenge for long-lived, slow-to-evolve animals, including humans. Subsistence living in the Far North may be one of the healthiest livelihoods on the planet, but it will be seriously threatened by the continued accumulation of contaminants. Cultural evolution in response to contact with western societies is well underway, but the introduction of contaminants to biological systems has been sudden (in genetic evolutionary terms). Physiological and cultural resilience will depend on the accurate identification of threats and local empowerment through co-operative research and information distribution. Further, the United States and other non-members of the Stockholm Convention on Persistent Organic Pollutants and Kyoto Protocol should work towards joining the global movement that embraces precaution in response to threats like POPs and global warming. Agreement regarding global regulation of mercury is under development and likewise should be promptly adopted (UN 2003).

Summary

Governments are responsible for the health and prosperity of their people, but often there is strong disagreement over the best methods to achieve these goals. The complexity of dynamic systems has become more and more evident with advances in science and the documentation of unexpected effects of human activity. The concept of stewardship has likewise changed to include an obligation to recognize the unpredictable nature of the effects of human activities. Economic development and environmental protection are often seen as contrary goals, but they must become one and the same for sustainability to be achieved. Part of managing such complex systems is beginning to include policies that remain flexible enough to be adjusted as surprises occur and new information is documented. Such “adaptive management” methods have become popular in theory, but truly adaptive policies remain controversial because of the economic benefits of risky behaviour.

Study Questions

1. Discuss the growth of the scientific inquiry and importance of hypothesis testing.

2. Give an example of how the uncertainty inherent in the scientific process can affect (i.e., slow down) the development of policy and social action.

3. A group of subsistence fishers are concerned that they are subjected to high levels of PCB exposure from their diet. What data do they need to demonstrate that this is true? If they are exposed, how will that affect the social organization of the community?

4. Why are behavioural abnormalities used less often in evaluating the effects of contaminants on individuals?

5. Is life stage an important aspect of endocrine disruption? Discuss and give an example.

6. What are the qualities of a good risk assessment? Would you expect the findings of risk assessments to always be accurate?

7. Why are sustainability and stewardship difficult policies for society to establish?

Glossary of Terms

aerosols	tiny airborne particles.
bioaccumulation	the tendency for certain persistent compounds to build up in biological tissue, where it is not broken down by normal metabolic processes.
biomagnification	the process by which predators accumulate higher contaminant levels than their prey. Micro-organisms → plants → herbivores → omnivores → carnivores → top predators.
biosphere	the biological zone of Earth, including all living organisms and their environments.
capacity building	the networking of and training for various skills and services required to make something happen; here, the tasks are environmental monitoring and protection.
causation	a definite and demonstrable relationship of cause and effect.
cryosphere	the frozen portion of Earth (glaciers, ice sheets, permafrost, and pack ice).
endocrine disruption	a broad term applied to interferences with hormone and other endocrine function. The primary concern with endocrine disruption is that hormones control the construction and programming of tissue during fetal and youth life stages; therefore, substances that interfere with hormone function can cause developmental problems.
epidemiological	having to do with epidemiology, in turn the study of the origin of human disease (in animal populations, this is called zooepidemiology.
false negative	an interpretation that implies an hypothesis is wrong, despite its validity.
false positive	an interpretation that implies an hypothesis is right, despite its lack of validity.
fossil fuel	literally, fossilized energy. Living organisms generate much organic material. If this material is buried, pressurized, and heated properly, it turns to coal (peat bogs and forests) or oil (shallow marine environments). The process takes hundreds of thousands to millions of years.

greenhouse effect	the warming effect that certain gases in the atmosphere have. Greenhouse gas concentrations have changed, in cycles and trends, over time. Currently, human contributions of carbon dioxide and methane are increasing the greenhouse effect, which has always been vital to the ability of life to thrive on Earth.
persistent organic pollutants (POPs)	these fat-soluble and stable compounds are all human made. Some have the capacity to travel long distances.
radiative properties	the characteristics of a gas, liquid, or solid that determine how energy passes through the substance. Greenhouse gases, for instance, transmit light energy (short-wave radiation) but reflect heat (long-wave radiation). This makes the atmosphere capture energy and get warmer.
remediation	refers to chemical and physical methods of treating or containing contamination (when the site cannot be cleaned up). See RESTORATION.
restoration	returns a remediated site to a functioning ecosystem. See REMEDIATED.

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