WORLD NATURAL RESOURCE POLICY AND MANAGEMENT

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Contents

Summary

Fifty-eight academies of science, including the U.S. National Academy of Sciences, point out that humanity is approaching a crisis with respect to the issues of natural resources, population, and sustainability. Science and technology have only a limited ability to meet the basic needs of a rapidly growing human population with rapidly increasing per capita demands on natural resources. Unfortunately, most individuals and government leaders appear unaware, unwilling, or unable to deal with the growing imbalances between human population numbers and the energy and other natural resources that support all life. The interdependence among the availability of life-supporting natural resources, individual standard of living, the quality of the environment, resource management, and population density are neither acknowledged nor understood. Although humans have demonstrated effective environmental conservation in certain natural resources (e.g. water), overall we have a disappointing record in protecting essential resources from overexploitation in the face of a rapidly growing population.

Clearly, human numbers cannot continue to increase indefinitely. Natural resources are already severely limited, and there is emerging evidence that nature is already starting to control human population numbers through malnutrition and other severe diseases. More than 3 billion people worldwide are already malnourished, and 3 billion are living in poverty; grain production per capita started declining after 1983 and continues to decline; irrigation per capita declined 12% during the past decade; cropland per capita declined 20% during the past decade; fish production per capita declined 10% during the past decade; fertilizer supplies per capita essential for food production declined 23%

during the past decade; loss of food to pests has not decreased below 50% since 1990; and pollution of water, air, and land has increased, resulting in a rapid increase in the number of humans suffering from serious, pollution-related diseases.

Historically, decisions to protect natural resources have been based on isolated crises and are usually made only when catastrophes strike. Instead of examining the natural resource problem in a holistic manner, such ad hoc decisions have been designed to protect and/or promote a particular natural resource in the short-term.

With a democratically-determined population control policy that respects basic individual rights, appropriate incentives to reduce the number of children produced per couple, sound resource use policies, and the support of science and technology to enhance energy supplies and protect the integrity of the environment, an optimum population of 2 billion for the Earth could be achieved. With a concerted effort, fundamental obligations to ensure the well-being of future generations can be attained within the twenty-first century. Individuals will then be free from poverty and starvation and live in an environment capable of sustaining human life with dignity. We must avoid letting human numbers continue to increase to the limit of the Earth's natural resources and forcing natural forces to control human numbers by disease, malnutrition, and violent conflicts over natural resources.

1. Introduction

All basic human needs, including food, energy, shelter, and protection from disease, are fulfilled using natural resources. Throughout history, humans have learned to modify natural resources and their ecosystems to better meet their basic needs and desires. Over time, as the human population has grown and used more resources per capita, humans have altered and used ever larger amounts of natural resources. Human settlements are currently found on about 95% of the Earth, and humans utilize more than 50% of the natural biomass productivity.

Human intelligence and technology have developed rapidly, enabling humans to manipulate natural resources more successfully than any other animal species. This advantage has given humans power to control and destroy other species. Species are being lost 1000 to 10 000 times faster than normal. With this forced extinction of plants, animals, and microbes by humans and the addition of greenhouse gases to the atmosphere with projected global warming consequences, humans may be on the path to destroy themselves and many other species.

Humans are one of an estimated 10 million species on Earth. We are an integral part of the planet's natural systems, and we cannot function in isolation of biodiversity and natural environment. Clearly, humans numbers cannot increase forever, because shortages of food, energy, space, and a quality environment will limit the human population—as has occurred with most other animal species in the past.

In this paper, humans and the intrinsic dynamics of natural resources, including land, water, atmosphere, energy, plants, animals, and microbes are examined. Proposals are made concerning world natural resource policy and management for a sustainable human population and natural system.

2. The Structure and Function of Ecosystems and Natural Resources

The basic structure and function of natural biota and their use of resources are examined to identify some of the principles that govern the ecology of sustainable ecosystems. An ecosystem is a network of energy and mineral flows in which the major functional components are populations of plants, animals, and microbes. These organisms utilize the sun's energy to perform different specialized functions in the ecosystem.

All self-sufficient ecosystems consist of producers (plants), consumers (animals, including humans, and microbes, and reducers or decomposers (animals and microbes) (see Figure 1). Plants collect solar energy and convert it into chemical energy via photosynthesis. They use this energy for growth, maintenance, and reproduction. In turn, plants serve as the primary energy source for all other living organisms, including humans, in the ecosystem. Animals and microbes consume plants and other animals, and decomposers break down dead plants, animals, and microbes, and thus recycle the chemical elements of life (carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium, calcium, etc.). Through this process, the elements of life in the biological system are conserved and reused. Therefore, the components of the ecosystem are all interconnected and interdependent, but plants are the basic foundation of the natural system, including humans.

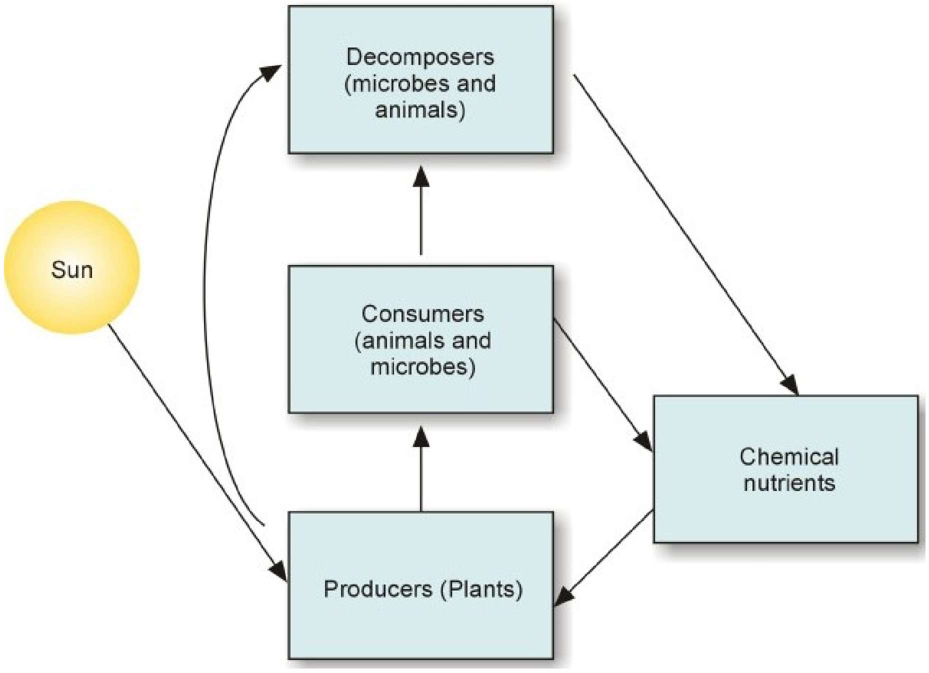

Figure 1: Structure of living systems

The exact number of species needed for a particular self-sufficient ecosystem depends upon many physical, chemical, and biological factors. We cannot predict how many and what kinds of species are necessary for the different components of the ecosystem. In the United States, there are approximately 750 000 species of plants, animals, and microbes; the majority of the approximately 10 million species in the world are vital to the well being of both the natural environment and humans. No one knows how many of these 10 million species can be eliminated before agriculture, forestry, and other essential aspects of ecosystems will be lost and human survival threatened. Thus, clearly humans must exercise great care to avoid the loss of biodiversity. A delicate balance in the use of natural resources has evolved in each ecosystem, and, although there is some redundancy, the linkages in the trophic structure are basic to the ecosystem's functioning.

Elton pointed out that the "whole structure and activities of the community are dependent on questions of food supply." Plants are nurtured by the sun and by the essential chemicals they obtain from the atmosphere, soil, and water. The remainder of the species in the ecosystem depends on living or dead plants and animals. About half of all species obtain their resources directly from living hosts. Parasitism and dependence on living food resources constitute a dominant way of life in natural ecosystems.

However, a host population can support only a limited population of herbivores and/or consumers before it dies or is so damaged that it no longer can provide food for its parasites or dependent species. An individual host utilizes most of its own energy resources for growth, maintenance, and reproduction. For example, on average plants use 40–70% of their energy resources for respiration; poikilotherms, such as insects, use about 50% for respiration; and homeotherms, use 60–75% for respiration. In general, less than 10% of the host's resources are passed on to the parasitic species feeding on the host. A recent survey of 92 herbivores feeding in nature suggested that they consumed only 7% of the plant host's biomass. Because hosts utilize most of their energy resources for themselves and their progeny, even a relatively small amount of herbivore/parasite feeding pressure influences the abundance and distribution of hosts. Therefore, from an ecological and natural resource perspective, host conservation is vital for the survival of dependent parasites, which includes humans.

3. Status of the World's Natural Resources

The quantity and quality of land, water, atmospheric, energy, and biological resources determine the current and future status of the natural support system for humans. Measurable shortages of fertile land, water, and fossil energy now exist in many regions of the world.

3.1 Land Resources

More than 99% of human food comes from the terrestrial environment— less than 1% from the oceans and other aquatic ecosystems. Worldwide, food and fiber crops are grown on 11% (nearly 1500 million ha) of the earth's total land area of 13 billion hectares (Figure 2). Globally, the annual loss of land to urbanization and highways ranges from 10 to 35 million hectares (approximately 1%) per year, with half of this lost land coming from cropland. Most of the remaining land area (23%) (Figure 2), is unsuitable for crops, pasture, and forests because the soil is too infertile or shallow to support plant growth, or the climate and land are too cold, dry, steep, stony, or wet.

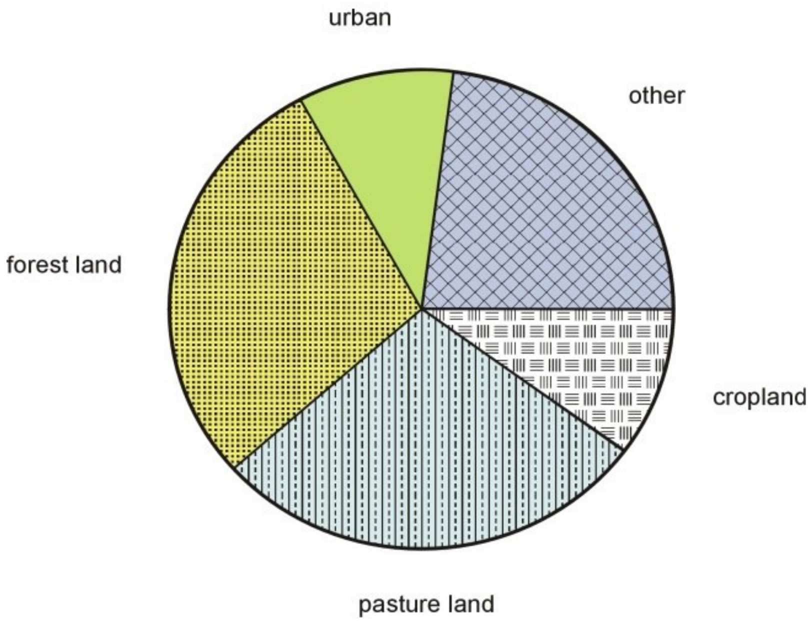

Figure 2: Of the 13 billion hectares of land area on earth, the percentages in use are: cropland = 11%, pasture land = 25%, forest land = 31%, urban = 10%, and other = 23%

In 1960, when the world population numbered about 3 billion, approximately 0.5 ha of cropland was available per capita worldwide. This half-hectare of cropland per capita is needed to provide a diverse, healthy, nutritious diet of plant and animal products—similar to the typical diet in the United States and Europe. The average per capita world cropland now is about 0.25 ha, or half the amount needed according to industrial nation standards (Table 1). This shortage of productive cropland is one underlying cause of current worldwide food shortages and poverty. For example, in China, the amount of available cropland is only 0.08 ha per capita, and is rapidly declining due to continued population growth and extreme land degradation. This small amount of cropland forces the Chinese people to consume a primarily vegetarian diet (Table 2).

Resources	**USA**	**China**	**World**
Cropland (ha)	0.71[a]	0.08[c]	0.27[e]
Pasture (ha)	0.91[a]	0.33[c]	0.57[e]
Forest (ha)	1.00[a]	0.11[c]	0.75[e]
Total (ha)	3.49	0.52	1.59
Water (liters × 10^6)	1.7[b]	0.46[c]	0.64[c]
Fossil Fuel Oil equivalents (liters)	8740[b]	700[d]	1570[f]
Forest Products (kg)	1091[b]	40[c]	70[g]

a) USDA (1993); b) USBC (1996); c) PRC (1994); Bennett, (1995), d) SSBPRC (1990); e) Buringh (1989); f) International Energy Annual (1995); g) UNEP (1985).

Table 1: Resources used and/or available per capita per year in the United States, China, and the world to supply basic needs

Food/Feed	USA[1]	China	World[2]
Food grain	100	387[a]	171
Vegetables	105	198[a]	69
Fruit	125	35[a]	57
Meat and fish	137	62[a]	45
Dairy products	247	7[b]	70
Eggs	14	14[a]	6
Fats and oils	28	5[b]	11
Sugar and sweeteners	62	7[b]	19
Total food	818	406[b]	448
Feed grains	663	70[b]	166
Grand Total	1481	476[b]	614
kcal/person/day	3644	2734[b]	2698

1. USDA (1993).
2. Agrostat Data Base (1992).
a. Wan Baorui (1996).
b. Agrostat Data Base (1992)

Table 2: Foods and feed grains supplied per capita (kg) per year in the United States, China, and the world

Currently, a total of 1481 kg/yr per capita of agricultural products is produced to feed Americans, while the Chinese food supply averages only 785 kg/yr per capita (Table 2). By all measurements, the Chinese have reached or exceeded the limits of their agricultural system. Their reliance on large inputs of fossil fuel based fertilizers—as well as other limited inputs—to compensate for shortages of cropland and severely eroded soils, indicates severe problems for the future. The Chinese already import large amounts of grain from the United States and other nations, and are planning to increase these imports in the future.

Escalating land degradation threatens most crop and pasture land throughout the world. Major types of degradation include water and wind erosion, and the salinization and waterlogging of irrigated soils. Worldwide, more than 12 million hectares of productive arable land are severely degraded and abandoned each year. Most of the 12 million hectares needed yearly to replace lost land is coming from the world's forests. The urgent need for more agricultural land accounts for more than 60% of the deforestation now occurring worldwide.

Agricultural erosion by wind and water is the most serious cause of soil loss and degradation. Current erosion rates are greater than ever previously recorded. Soil erosion on cropland ranges from about 13 tons per hectare per year (t/ha/yr) in the United States to 40 t/ha/yr in China. Worldwide, soil erosion averages approximately 30 t/ha/yr, about 30 times faster than the sustainable replacement rate. During the past 30 years, the rate of soil loss in Africa has increased twenty-fold. Wind erosion is so serious in China that Chinese soil can be detected in the Hawaiian atmosphere during the spring planting period. Similarly, soil eroded by wind in Africa can be detected in Florida and Brazil. On sloping agricultural land under tropical rainfall, as much as 400 t/ha/yr of soil is lost. Under arid conditions with relatively strong winds, as much as 5600 t/ha/yr of soil has been reported lost.

The large amounts of soil that are eroded from the land end up in streams, lakes, and other ecosystems. The U.S. Department of Agriculture (USDA) reports that 60% of water-eroded soil ends up in streams. Further evidence that large amounts of water-eroded soil end up in streams and rivers is the fact that approximately 2 billion t/yr of soil are transported down the Yellow River in China into the gulf.

Some investigators estimate that approximately 75 billion tons of fertile soil is lost annually from the world's agricultural systems, whereas other investigators have estimated that only 24 billion tons of soil are lost each year. In fact, 75 billion tons is a conservative value. Soil scientists Lal, Stewart, and Wen report that 6.6 billion tons of soil per year is lost in India and 5.5 billion tons are lost annually in China. Based on the fact that these two countries occupy about 13% of the world's total land area, an estimated 75 billion tons of soil lost per year worldwide is entirely logical. The amount of soil lost in the United States is more than 4 billion tons per year. In addition, serious soil erosion takes place in other regions of the world.

Currently, about 80% of the world's agricultural land suffers moderate to severe erosion, while only 10% experiences relatively slight erosion. Worldwide, erosion on cropland averages about 30 t/ha/yr and ranges from 0.5–400 t/ha/yr. As a result of erosion during the last 40 years, about 30% of the world's cropland has become unproductive and has therefore been abandoned for agricultural use. The nearly 1.5 billion ha of cropland that are now under cultivation for crop production are about equal in area to the amount of cropland (about 2 billion ha) that has been abandoned by humans since farming began. The abandoned land, once biologically and economically productive, now produces little biomass and has lost most of its initial biodiversity of plants and animals.

The current high erosion rate throughout the world is of great concern because of the slow rate of topsoil renewal; it takes from 500 to 1000 years for 2.5 cm (1 inch) of topsoil to form under agricultural conditions. Approximately 3000 years are needed for the natural reformation of topsoil to the 150 mm depth needed for satisfactory crop production.

The lowest erosion rate on cropland averages about 13 t/ha/yr and occurs in the United States and Europe. However, this relatively low rate of erosion still greatly exceeds the average rate of natural soil formation and sustainability, which ranges from 0.5–1 t/ha/yr. More than 90% of U.S. cropland is now losing soil faster than the sustainable replacement rate.

The fertility of nutrient-poor soil can be improved by large inputs of fossil-based fertilizers. This practice, however, increases dependency on the limited fossil fuels stores necessary to produce these fertilizers. And even with fertilizer use, soil erosion remains a critical problem in current agricultural production. Crops can be grown under artificial conditions using hydroponic techniques, but the costs in terms of energy and dollars is approximately ten times that of conventional agriculture.

The land currently used for crop production already includes a considerable amount of marginal land, land that is highly susceptible to erosion. When soil degradation occurs, the requirement for fossil energy inputs in the form of fertilizers, pesticides, and irrigation is increased to offset the losses, thus creating non-sustainable agricultural systems.

Erosion adversely affects crop productivity by reducing the water-holding capacity of the soil, water availability, nutrient levels and organic matter in the soil, and soil depth. Estimates are that agricultural land degradation alone can be expected to depress world food production between 15% and 30% by the year 2020. These estimates emphasize the need to implement known soil conservation techniques, including biomass mulches, no-till, ridge-till, terracing, grass strips, crop rotations, and combinations of all of these. All these techniques essentially require keeping the land protected from wind and rainfall effects with some form of vegetative cover.

Water is a prime-limiting factor for the productivity of world agriculture, and in fact, in all-terrestrial ecosystems, because all vegetation requires enormous quantities of water for growth and productivity. For example, a hectare of corn producing about 8000 t/ha will transpire about 5 million liters of water during the growing season.

When erosion occurs the amount of water runoff increases from 15% to 400%, and as less water enters the soil, less is available to support the growing vegetation (Table 3). Moderately eroded soils absorb from 1 to 300 mm less water per year from rainfall than uneroded soils. This represents a decrease of 7–44% in the amount of water available to the vegetation. A diminished absorption rate of 20–30% of rainfall represents significant water shortages for all vegetation, including crops. Lal reported that erosion has reduced water infiltration in some tropical soils by up to 93%.

Treatments	**Location**	**% Reduced**	
		Runoff	**Soil Erosion**
4 t/ha mulch/No mulch	India	58	72
Contour cultivation/No contour cultivation	India	--	54
Wheat-oat-barley-hay-hay/Wheat-fallow	Canada	--	89
No grazing pasture/Very heavy grazing	Ethiopia	330	330
No till + cover crop/Conventional till	Brazil	400	130
Cover crop-corn/Conventional	USA	15	110
Cover crop-silage corn/Conventional silage corn	USA	--	244
No till cotton/Conventional cotton	USA	140	900
Alley cropping corn[a]/ Conventional	Philippines	75	99

[a] Alley cropping corn with leguminous tree on 17% slope

Table 3: Water and soil loss related to various conservation technologies that reduce water runoff and soil erosion

In general, when water availability for the agricultural ecosystem is reduced from 20–40% in the soil, plant productivity is reduced from 10–25%, depending on total rainfall, soil type, slope, and other factors. Such major reductions in plant biomass in agricultural and natural ecosystems will reduce soil biota and overall biodiversity within the ecosystem.

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Biographical Sketch

David Pimentel is a Professor of Ecology and Agricultural Sciences at Cornell University, Ithaca, New York. His research spans the fields of basic population ecology, and ecological and economic aspects of pest control, biological control, biotechnology, sustainable agriculture, land and water conservation, and environmental policy. Professor Pimentel has published more than 500 scientific papers and 21 books, and has served on many national and government committees including the National Academy of Sciences, The President's Science Advisory Council, The U.S. Department of Agriculture, The U.S. Department of Energy, The U.S. Department of Health, Education, and Welfare, The Office of Technology Assessment of the U.S. Congress, and the U.S. State Department.