Revista Chilena de Historia Natural
64: 597-614, 1991

Some consequences of long-term human impacts on ecosystems

Algunas consecuencias a largo plazo del impacto humano en los ecosistemas

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ABSTRACT

Regional- and global-scale environmental problems potentially can affect North and South Temperate Zone ecosystems differently because of regional differences in population density and growth, and use of resources. Consideration is given to global climate change and various components of global and regional, environmental change, including atmospheric ozone, acid rain, toxic metals and pesticides, eutrophication, and erosion.

Acid rain is a serious environmental problem in industrialized and urbanized regions of the Northern Hemisphere. Long-term data from the Hubbard Brook Experimental Forest in New Hampshire, USA, provide a temporal dimension for this problem. Currently atmospheric deposition of sulfur in the northeastern United States exceeds by three to six times limits established to protect sensitive ecological systems, whereas in southern Chile current atmospheric deposition of sulfur is less than these acceptable limits. Developed, and particularly developing, countries throughout the world face serious questions of resource management as human populations increase, and if regional- and global-scale pollution were to increase accordingly.

Key words: global climate change, acid rain, ozone, Hubbard Brook, Chile.

RESUMEN

Los problemas ambientales a escala global y regional pueden afectar potencialmente los ecosistemas templados de Norte y Sudamérica en forma diferente, a causa de los contrastes en densidad y crecimiento poblacional y en el uso de recursos. Se consideran en este trabajo el cambio de clima global, y sus varios componentes tanto a escala global como regional, incluyendo el ozono atmosférico, la lluvia ácida, metales tóxicos y pesticidas, eutroficación y erosión.

La lluvia ácida es un problema ambiental serio en las regiones industrializadas y urbanizadas del hemisferio Norte. Un estudio a largo plazo en el Bosque Experimental de Hubbard Brook, en New Hampshire, USA, demuestra la dimensión temporal de este problema. Actualmente, la deposición atmosférica de sulfuro en el noreste de Estados Unidos excede en tres a seis veces los límites establecidos para proteger ecosistemas sensibles, mientras que en el sur de Chile la deposición atmosférica actual es menor que estos límites aceptables. Los países desarrollados, y particularmente las naciones en desarrollo, en todo el planeta enfrentan serios problemas de manejo de recursos, al crecer la población, considerando el concomitante aumento en los niveles de polución a escala regional y global.

Palabras claves: Cambio climático global, Chile, Hubbard Brook, lluvia ácida, ozono.

INTRODUCTION

Human societies throughout the world face many regional-scale and global-scale environmental problems, many of which are quite familiar to scientists and to laypersons because of widespread coverage by the news media. I shall briefly review some of these environmental problems in relation to Northern and Southern Temperate ecosystems, but first, however, I want to begin with a quote that typifies the classic conflict between various societal concerns, as well as the naivete about environmental issues.

This quote was reprinted in the Australian Society of Limnology Newsletter (1989) from the National Parks Journal of New South Wales. Mr. Jim Ramsey, spokesperson for the proponents of a multimillion dollar tourist and residential canal estate development said, "Even though the development would mean the destruc-

(Received 15 August 1990.)

tion of fifty-three percent of the wetland (in the Bateman's Bay area), that would be balanced by the construction of a wetland's education centre to teach people of the need to preserve wetlands."

At the base of most environmental problems is the accelerating growth of the human population (Fig. 1). The large potential for increased growth of human populations in developing countries (Fig. 1) is an added complexity. I believe that such projections about population growth and the disproportionate use of resources by people in different regions of the Earth (e.g., developed vs. developing countries) now and in the future, will be critical for making comparisons between Temperate ecosystems in North America and those in South America. The following is a brief description of some of the major environmental problems that are occurring at a regional or global scale, and thus may be impacting ecosystems in both the North and South Temperate Zones now or in the near future.

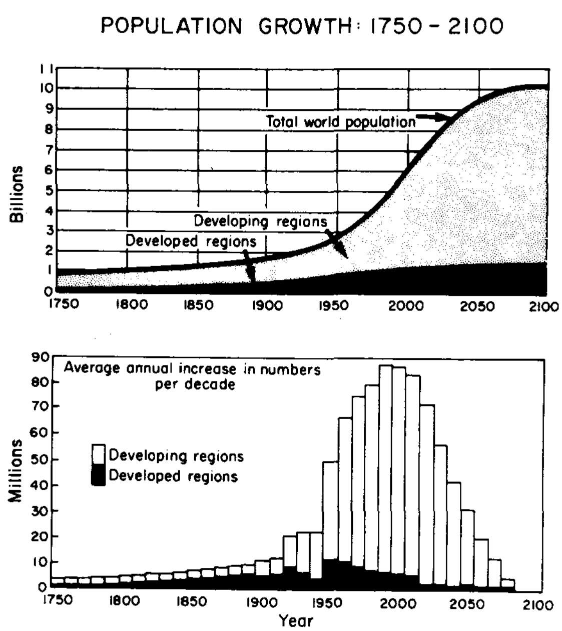

Fig. 1: Population growth from 1750 projected to 2100 for the total world, and developing regions and developed regions of the world (modified from Merrick 1986).

Crecimiento poblacional desde 1750, proyectado al año 2100, para el mundo, para las regiones desarrolladas y para regiones en desarrollo (modificado de Merrick 1986).

When natural ecosystems are degraded or destroyed, then as a Society, we commonly burn fossil fuels to provide energy to replace the functions provided by these natural ecosystems (see Bormann 1976) —e.g., for the construction of flood control dams and levees, for air conditioning systems, and so forth. Burning of fossil fuels leads to air pollution, which can change the climate, increase ground-level concentrations of ozone, and/or acidify ecosystems, all ultimately degrading natural ecosystems. Global climate change, toxic ozone, and acid rain currently are among our most vexing environmental problems. A growing population's insatiable appetite for energy, provided primarily from fossil fuels, is the root cause of each of these environmental problems.

Global climate change

A long-term record of CO_2 concentrations in the atmosphere was started at the Mauna Loa Observatory in Hawaii by Dr. David Keeling in 1958 (Keeling 1960, 1973). This is the longest *continuous* record of carbon dioxide available (Fig. 2). I want to make two major points regarding this particular record. When Keeling began to make CO_2 measurements at the South Pole in 1957 and in Hawaii en 1958, he did one very important thing. He took the calibration and standardization of his instruments seriously. He spent two years in building a device so that he could standardize measurements in the future. Because such precautions are almost never taken in long-term studies, we often have different types of "long-term" measurements, done by different people, by different methods, and we often don't know whether individual data throughout a long-term record are comparable or not. One of the reasons we can trust the CO_2 record from Mauna Loa is because Keeling was careful, and with foresight prepared to calibrate future measurements.

The other point is obvious (with hindsight). After about six years of tedious measurement, I could imagine Keeling saying to himself, "Well, I'm pretty tired

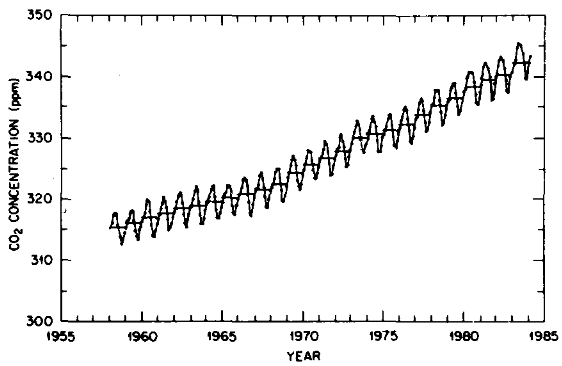

Fig. 2: Concentration of atmospheric CO_2 at Mauna Loa Observatory, Hawaii. The horizontal bars represent annual averages. Data were obtained by D.C. Keeling (from Gammon *et al.* 1985). Concentración atmosférica de CO_2 en el Observatorio de Mauna Loa, Hawaii. Las barras horizontales representan promedios anuales. Datos obtenidos por D.C. Keeling (de Gammon *et al.* 1985).

of making these measurements, and who cares what the CO_2 concentration is anyway; it hasn't gone up very much; why don't I stop?" But he didn't stop, and in spite of much difficulty in trying to maintain funding, he has continued to measure CO_2 concentrations at Mauna Loa until the present. As a result, we now have this long-term record of CO_2 for the atmosphere, which is so valuable in terms of evaluating global climate change. Long-term records of CO_2 concentration also are available for Point Barrow in Alaska, American Samoa, and the South Pole, and they all show similar patterns of increase, and annual fluctuation, in our global atmosphere (Gammon *et al.* 1985). Carbon dioxide is one of the important "greenhouse" gases and is thought to contribute to global warming and climate change (e.g., Ember *et al.* 1986).

Because of increasing population size and increasing demands for energy, there is the potential to increase the carbon dioxide concentration of the Earth's atmosphere in only two hundred years or so by a similar amount to what occurred during the past hundred million years (Gammon *et al.* 1985). That statistic clearly shows the dramatic effect that humans can have on our global environment.

The human population is in fact often the multiplier in these environmental problems. Moreover, the human population in different parts of the globe has different impacts, e.g., in terms of combustion of fossil fuel and release of carbon dioxide into the atmosphere. Industrialized countries of the Northern Hemisphere produce more than 70% of the global emissions of CO_2, yet have only about 25% of the world's population (Gleick 1989). The USA alone contributes almost 24% of the world's total CO_2 emissions, followed by the USSR (~ 19%) and China (~ 11%) (Fig. 3, Table 1). In 1950 the USA was the largest contributor of CO_2 on a per capita basis, but now it has been exceeded by East Germany (Fig. 3). China and South Asia have large populations, but currently contribute relatively small aounts of carbon dioxide per person to the atmosphere (Fig. 3). Two Latin American countries, Mexico and Brazil, are in the top 20 of CO_2 producers; although their per capita rates are relatively low, they have increased significantly since 1950 (Fig. 3). How this pattern changes in the future clearly will have a major overall effect on the global environment, as well as on individual ecosystems in North and South America (Fig. 4).

Carbon dioxide is not the only gas that can contribute to global climate change. Concentrations of chlorofluorocarbons, commonly known as CFC's or freons, are greenhouse gases and have increased dramatically recently in the Earth's atmosphere. Chlorofluorocarbons are used widely as refrigerants, solvents, and aerosol propellants. The United States, Canada, and Western Europe contribute more than 60% of the world's production of CFC's (Table 1). Other greenhouse gases, nitrous oxides, and particularly methane also have increased recently in the atmosphere, but the causes for these increases, particularly for methane, are unclear (see review in Ember *et al.* 1986, Cicerone & Oremland 1988). The effects of CFC's, nitrous oxide, and methane on global warming may be as large as that of CO_2 by the year 2000 (Fig. 5). The overall effects of increases in these gases on global climate change are complex and varied (see, e.g., Ember *et al.* 1986).

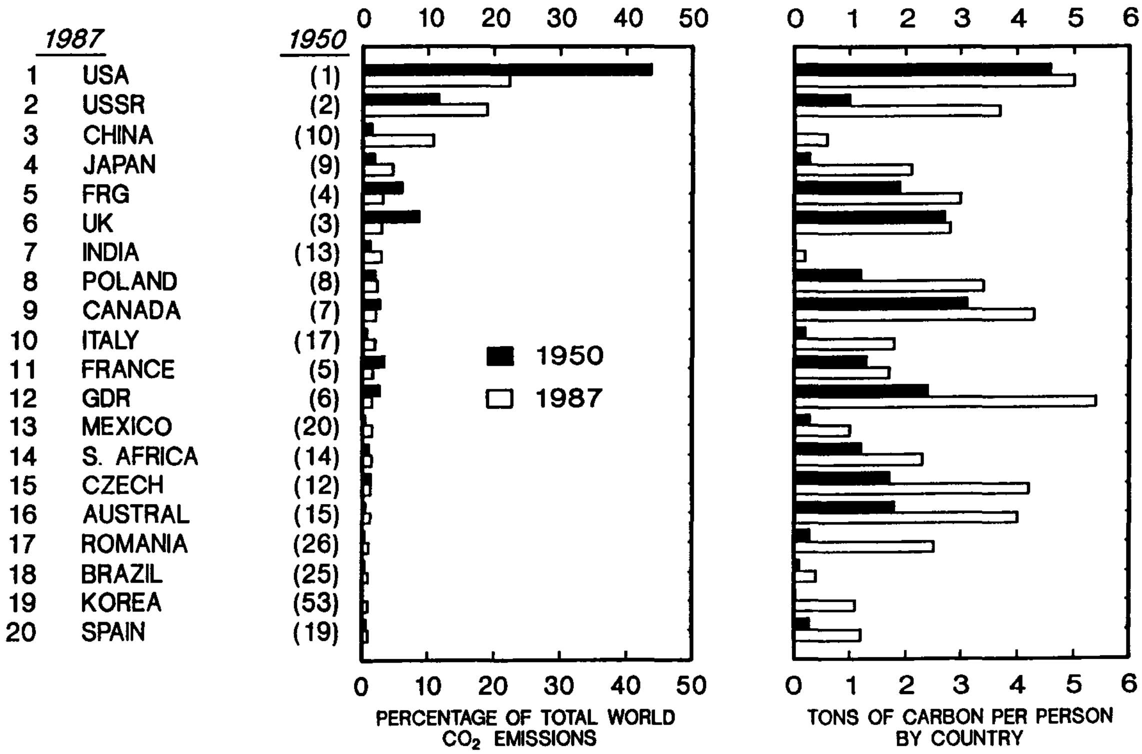

Fig. 3: Comparison of emissions of CO_2 from combustion of fossil fuels by country in 1950 and in 1987. The top 20 countries are shown based on 1987 emission levels (from Marland 1989).

Comparación de emisiones de CO_2 de la combustión de combustibles fósiles por país en 1950 y en 1987. Se muestran los primeros 20 países, basados en los niveles de emisión de 1987.

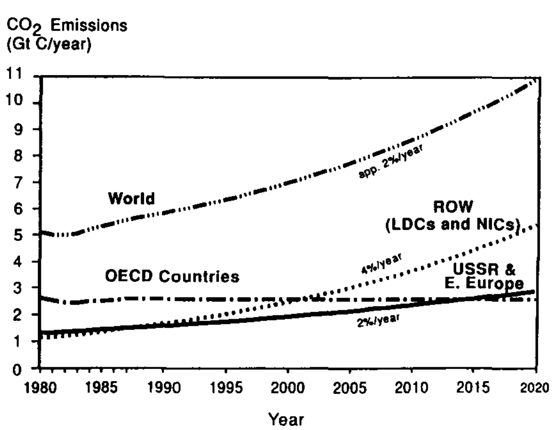

Fig. 4: Projected emissions of CO_2 for the world, for Organization for Economic Cooperation and Development (OECD) countries, for the rest of world (ROW) and for USSR and eastern Europe to the year 2020. NIC's = newly industrialized countries; LDC's = less developed countries. (From Fulkerson *et al.* 1989).

Proyección de las emisiones de CO_2 en el mundo, en los países de la OECD (Organization for Economic Cooperation and Development), en el resto del mundo (ROW), y en la Unión Soviética y Europa del Este para el año 2020.

TABLE 1

Percentage of World Production of Carbon Dioxide and Chlorofluorocarbons (from Gleick 1989)

Porcentaje de la producción mundial de dióxido de carbono y clorofluorocarbonos (según Gleick 1989)

	CO_2*	CFC-11	CFC-12
United States	24	23	30
Western Europe and Canada	16	49	33
Japan, Australia, New Zealand	6	20	15
Soviet Union and other CPE's	26	6	19
All others	28	2	3

* These data include carbon dioxide emissions from fossil fuel combustion and industrial fuel use, but do not include the contribution from biomass burnig.

CPE's: Centrally-planned economies.

There are several model predictions of global climate change. Some global climate model (GCM) projections have shown that summer soil moisture in large areas of the North American Temperate Zone could be 30 to 60 percent drier, whereas that in Chile and Argentina might be 20 percent, or more, wetter (Fig. 6), based upon a

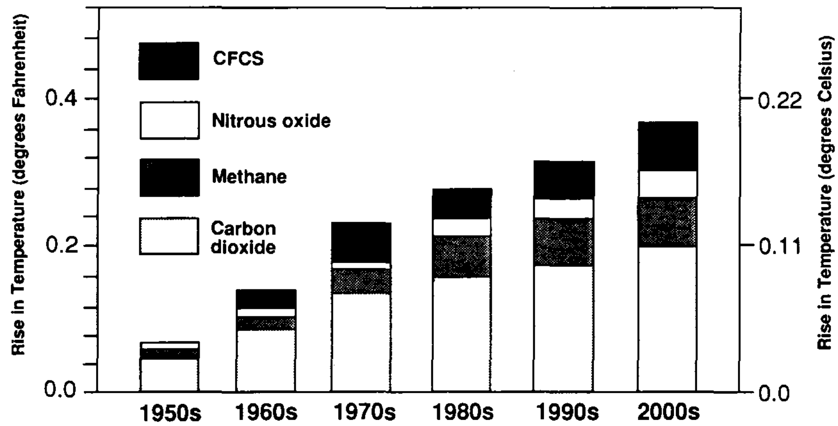

Fig. 5: Projected fractions of global warming caused by different greenhouse gases to the year 2000 (modified from Revkin 1988).

Fracciones del calentamiento global causadas por diferentes gases de "invernadero" proyectadas para el año 2000.

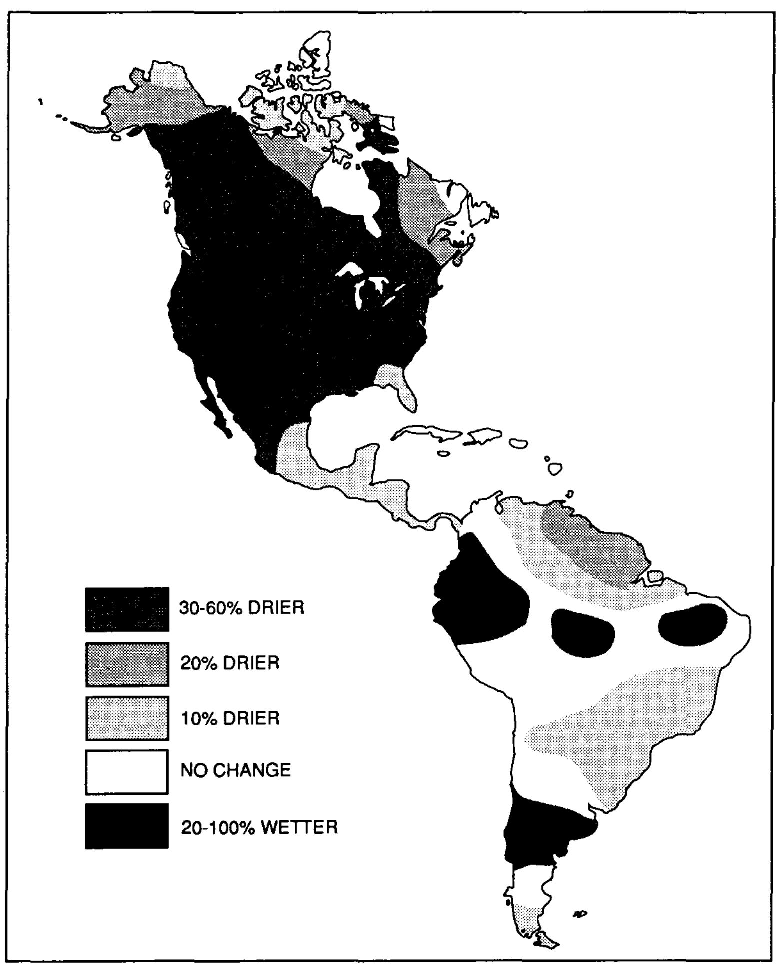

Fig. 6: Model results of the effect of a doubling of atmospheric CO_2 on summer soil moisture in North and South America (modified from Revkin 1988).

Resultados de un modelo del efecto de la duplicación de la concentración de CO_2 sobre la humedad del suelo en el verano en Norte y Sudamérica (modificado de Revkin 1988).

doubling of the carbon dioxide concentration in the atmosphere (Revkin 1988). Many GCM's, however, don't account accurately for the effects of regional geographic barriers, such as the Andes. Although GCM projections are of uncertain validity, they do raise serious political and economic concerns, as well as concerns about ecologic impacts on North American and South American Temperate ecosystems. Given these scenarios about change in the temperature and moisture regime, work is needed on physiological constraints of seeds, seedlings, and plant communities.

Attention to the issue of global climate change (particularly enhancement of greenhouse warming) has become a type of fad in the U.S. and some other countries. Although global climate change is an extremely important environmental issue, I believe that there should be more emphasis on global *environmental* change issues. Global environmental change includes, in addition to global climate change, regional- and global-scale problems that exist currently, such as 1) the toxification of the biosphere by metals, pesticides, ozone, acid rain, etc., 2) landscape modification, including fragmentation, desertification, and pollution of water supplies by urbanization, industry, and agriculture, 3) invasion of exotic species, and 4) loss of species diversity, particularly in tropical regions as a result of human activity (Likens 1991).

Ozone

Another atmospheric component of global environmental change is ozone. There are two kinds of ozone, "good" ozone and "bad" ozone. Good ozone exists at about 20 kilometers above the Earth's surface in the stratosphere, and this ozone absorbs incoming ultraviolet radiation and thereby protects biota at the Earth's surface (Fig. 7). This good ozone is being destroyed by chlorofluorocarbons made by humans (Rowland 1989). The bad ozone accumulates at ground level in urban and industrialized areas, in particular as a part of smog formation. It is well known that many urbanized regions of the Northern Hemisphere, e.g., Los Angeles, have very high concentrations of ozone, but Sydney, Australia, Santiago, Chile, Johannesburg, South Africa, and other major urban centers in the Southern Hemisphere also have similarly high amounts of air pollution, including ozone. It has been shown from a number of experiments in open-topped growth chambers that ozone can reduce greatly net photosynthesis of plants (Fig. 8).

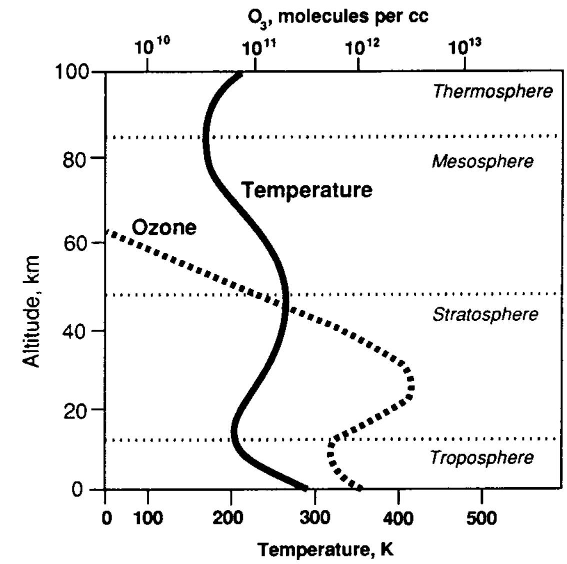

Fig. 7: Generalized vertical profiles of ozone (– – –) and temperature (———) in the atmosphere (modified from Ember *et al.* 1986).
Perfiles verticales generalizados de ozono (– – –) y temperatura (———) en la atmósfera (modificado de Ember *et al.* 1986).

The recent discovery of the "hole" in the good ozone layer above Antarctica has brought about a new urgency to the problem. Warnings about the destruction of ozone in the stratosphere were made some time ago (Molina & Rowland 1974, Rowland & Molina 1975), but were ignored by policymakers. Only recently when the ozone hole became known widely and became publicized by the news media have the public and the politicians taken the matter seriously (see Likens in press). If the ozone hole were to expand from Antarctica northward into regions above New Zealand, Australia, southern Africa, Argentina, and Chile, this change could be very important in the future in terms of environmental impact in these areas.

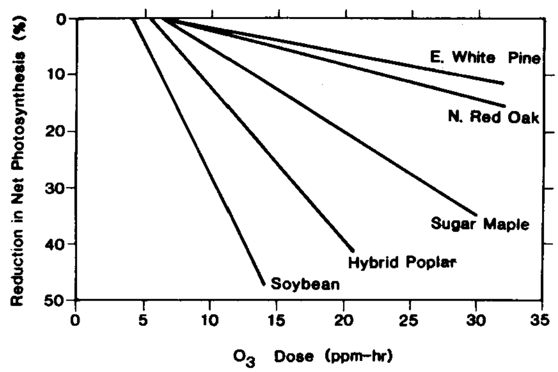

Fig. 8: Percent reduction in net photosynthesis, relative to background dose, for increasing dose of ozone. The natural background of ozone might be about 0.01 ppm or a 10-week dose of 5 ppm-hour (Kulp 1987). By comparison, ozone dose "in most of the eastern United States during a 10-week period in the summer ranges between 30 to 45 ppm-hour" (modified from Reich & Amundson 1985).

Reducción porcentual de la fotosíntesis neta, relativa a la dosis normal, para un aumento en la dosis de ozono. La dosis normal de ozono podría ser cerca de 0,01 ppm, o una dosis de 5 ppm por hora durante 10 semanas (Kulp 1987). A modo de comparación, la dosis de ozono "en la mayor parte de Estados Unidos durante un período de 10 semanas en el verano varía entre 30 y 45 ppm por hora" (según Reich & Amundson 1985).

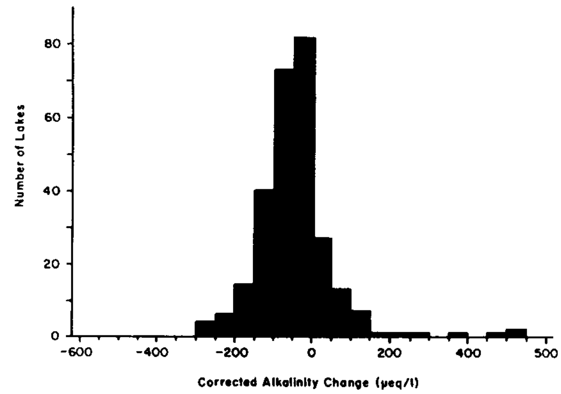

Fig. 9: Frecuency distribution of changes in alkalinity between surveys done in 1929-1934 and surveys in 1975-1985 for 274 lakes in the Adirondack Mountain region of New York State, USA. The data were corrected for methyl orange overtitration (from Asbury *et al.* 1989).

Distribución de frecuencias de cambios en la alcalinidad entre muestreos realizados en los períodos 1929-1934 y 1975-1985 en 274 lagos en las montañas Adirondack, Nueva York, USA. Los datos fueron corregidos para sobretitulación con naranjo de metilo (según Asbury *et al.* 1989).

Acid rain

Large emissions of sulfur and nitrogem oxides, primarily from tall smokestacks, following the combustion of fossil fuels have led to another major component of global environmental change. The effects of these pollutants in acidifying regional landscapes are well known (e.g., Likens *et al.* 1979, Schindler 1988).

Data from lakes in the Adirondack Mountain region of northern New York State in the United States provide and example of the acidification of natural ecosystems from atmospheric deposition (Asbury *et al.* 1989). We found 274 lakes in this area that had high quality chemical data from the 1930's that we could compare with current data. This comparison showed that 80% of these lakes had become more acid; the median loss of alkalinity during the past 50 to 60 years for these 274 lakes was –50 μeq/l (Fig. 9).

All of these lakes did not become more acid, however, only 80% of them did. Some of the lakes even became less acid (Fig. 9). These results illustrate that not all natural systems can be expected to respond in the same way to some general stress. Lakes differ in many respects, for example in depth, in geologic substrate, in clarity, in surrounding vegetation, etc. As a consequence, lakes tend to respond individualistically to an external stress such as acid rain. As ecologists, we are plagued with this variability, and at the same time we are intrigued by it. This kind of variable response of natural ecosystems has been commonly documented in acid rain research in North America and Europe; it is not surprising scientifically, but it is puzzling to the public and to politicians (Likens in press).

Swedish workers (Hallbäcken & Tamm 1986, Tamm & Hallbäcken 1986, 1988) have shown an appreciable acidification of forest soils in Sweden during the past 50 to 60 years from atmospheric deposition (Fig. 10). This result is very important ecologically because soils develop slowly, and presumably would recover slowly

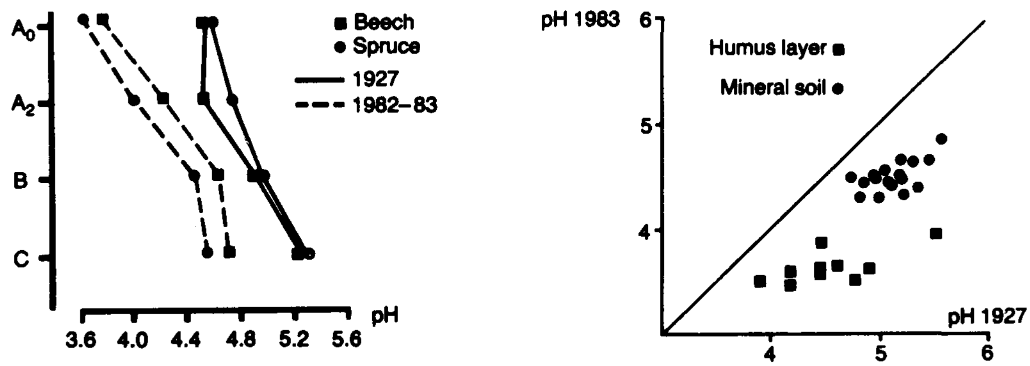

Fig. 10: Fifty-five year changes in the pH of forest soils in Sweden (from Nilsson 1986).
Cambios en el pH de los suelos forestales en Suecia durante 55 años (según Nilsson 1986).

following a reduction in deposition of atmospheric pollutants.

Another feature of regional air pollution is the effect of air pollutants on visibility. Significant decreases in visibility have occurred in numerous national parks in the USA because of air pollution: e.g., a 394-km (236-mile) reduction in visibility (based upon a maximum possible visual range of 417 km (250 miles) occurred in the summer of 1988 because of air pollution in the Great Smoky Mountains National Forest of the southeastern United States (D.L. Dietrich, personal communication, 1990).

Yet another component is the atmospheric dispersion of toxic metals, for example lead from anthropogenic activities. It is estimated that over 300 times more lead is added to the atmosphere each year by human activity than by natural activity (Table 2). Such atmospheric pollution clearly is one measure of the toxification of the biosphere by human activity. At the Hubbard Brook Experimental Forest in the White Mountains of New Hampshire, USA, my colleagues have measured the lead concentrations in rain and snow and other components of the forest ecosystem since 1975 (Siccama & Smith 1978, Smith & Siccama 1981, Siccama *et al.* 1980). In 1975 the lead concentration in rain and snow averaged about 25 μg/l. In 1977 the U.S. Environmental Protection Agency restricted the use of leaded gasoline for health reasons, and as a result lead concentrations in the atmosphere have declined significantly; current values in rain and snow at Hubbard

TABLE 2

Estimated Annual Global Emissions of Selected Metals to the Atmosphere circa 1980 (from Galloway *et al.* 1982b)
Estimación de las emisiones globales de metales seleccionados a la atmósfera, alrededor de 1980. (según Galloway *et al.*, 1982b)

Metal	Human Activity	Natural Activity	Ratio of Human to Natural Activity
		(thousand metric tons)	
Lead	2,000	6	333
Zinc	840	36	23
Copper	260	19	14
Vanadium	210	65	3
Nickel	98	28	4
Chromium	94	58	2
Arsenic	78	21	4
Antimony	38	1	38
Selenium	14	3	5
Cadmium	6	0.3	20

Brook average about 2 μgPb/1 (Fig. 11). This reduction in the dispersal of a toxic metal throughout the landscape of the United States is an environmental success story in which the effects of governmental regulation, which reduced the use of lead in gasoline– and additive that we do not need–can be seen in the rainfall chemistry of a remote area. On the other hand, the United States is now exporting more lead additives on a yearly basis to developing countries than we ever burned annually in the United States (J. Nriagu, personal communication, September 1989).

Forest decline

The effects of air pollutants on forests is varied and complicated (Table 3). Although controversial, the effects in Europe have been described as large and increasing (Table 4). Critical questions include whether this damage has occurred because of anthropogenic pollutants, and whether the damage is outside the range of change that is normal. A common problem is that we ecologists frequently do not have enough data to discriminate between pollution-generated change and normal forest dynamics. Thus, long-term, baseline information is vital in determining whether damage (change) is pollution initiated or pollution enhanced, or is simply a part of the natural variation. What is caused by humans and what is caused by nature? We need to give confidence limits for our answers to policymakers.

Eutrophication of surface waters

The problems of eutrophication of aquatic ecosystems are not new, but continue to be varied and complex (e.g., Hasler 1947, Likens 1972, Hutchinson 1973). When freshwaters are enriched with nutrients, plant growth may become excessive, to levels that humans find undesirable unless they want to grow carp in a fish pond. In that latter case, eutrophication is not viewed as bad; it is desirable. What is meant by "bad" or "good", and what do we want? And who is "we", and how does "we" relate to people in developed versus developing countries?

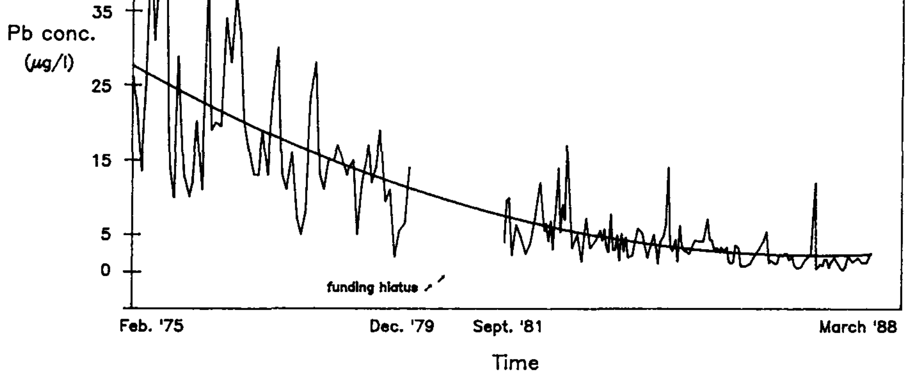

Fig. 11: Concentration of lead in precipitation at the Hubbard Brook Experimental Forest, New Hampshire, USA, from 1975 to 1988 (data from T.G. Siccama).
Concentración de plomo en la precipitación en el Bosque Experimental de Hubbard Brook, New Hampshire, USA, desde 1975 a 1988 (datos de T.G. Siccama).

TABLE 3

Primary agents causing forest decline
(ranked in order of importance)
(modified from Hinrichsen 1986)

Principales agentes causantes de la declinación de bosques (ordenados de acuerdo a su importancia) (modificado de Hinrichsen 1986)

EASTERN EUROPE:	
1.	Gaseous pollutants (e.g., SO_2 and NO_X)
2.	Ozone
3.	Acid deposition, particularly cloud water and fog
4.	Toxic metals
WESTERN EUROPE:	
1.	Ozone
2.	Acid deposition, particularly cloud water and fog
3.	Excess nitrogen
4.	Growth-altering organic chemicals
NORTH AMERICA:	
1.	Ozone
2.	Input of nitrogen
3.	Other phytotoxic gases
4.	Toxic metals
5.	Acid deposition
6.	Growth-altering organic chemicals

Another recent feature of widespread environmental change is the increased concentrations of nitrate in surface waters. High concentrations are appearing throuhgout the heavily industrialized and populated parts of the Earth. Some recent analyses done by scientists at the Institute of Ecosystem Studies show that there is a strong correlation between the density of people living in a catchment and the nitrate concentrations (or export) in river waters (Peierls *et al.* 1991). This is another example of the human multiplier effect.

Lake Vättern, the second largest lake in Sweden, is an oligotrophic lake, similar to many of the lakes in Patagonia, Chile. Recent data show that there has been a steady increase in nitrogen concentrations in Lake Vättern since about 1965 when measurements were begun (Fig. 12). The causes of this long-term increase are unclear, but may be the result of increased use of nitrogenous fertilizers for agriculture, increased sewage, and possibly increased amounts of nitrogen from atmospheric deposition (Persson *et al.* 1989, Fisher & Oppenheimer in press).

Pesticides

Data from Lake Vättern also show long-term changes in the DDT and PCB concentrations (Fig. 13). Decline in DDT and PCB's in the Lake are correlated with Sweden's ban on the use of both PCB's and DDT. This is another environmental success story, in which the effects of go-

TABLE 4

Estimated forest damage in Europe, 1988 (modified from French 1990a)

Estimación del área de bosque dañado en Europa, 1988 (modificado de French 1990a)

Country or Area	Estimated Area damaged	Percent of Total
	(thousand hectares)	
Czechoslovakia	3,250	71
Greece	1,302	64
United Kingdom	1,408	64
West Germany	3,827	52
Norway	2,963	50
Poland	4,240	49
East Germany	1,300	44
Switzerland	510	43
Finland	7,823	39
Sweden	9,243	39
Estonia and Lithuania	1,313	36
Spain	3,656	31
France	3,321	23
Total (Europe)	49,647	35

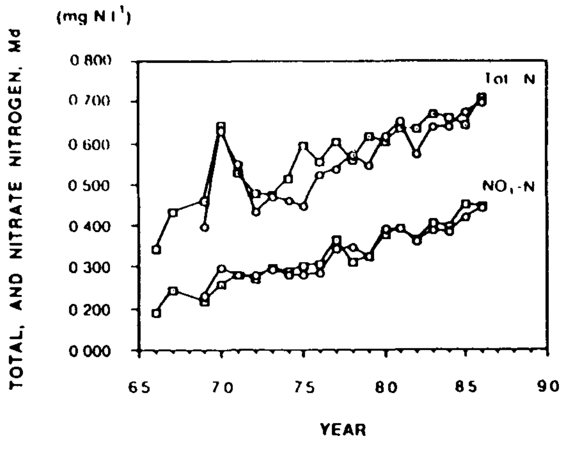

Fig. 12: Median concentrations for total nitrogen and nitrate-nitrogen during the growing season in Lake Vättern, Sweden (modified from Persson *et al.* 1989).

Concentraciones medias para nitrógeno total y nitratos durante la estación de crecimiento en Lago Vättern, Suecia (modificado de Persson *et al.* 1989).

vernmental regulation can be seen in lowered levels of a toxic chemical in the environment.

Erosion

The effects of increased deforestation, agriculture, and/or grazing accelerate erosion (e.g., Likens & Bormann 1974). Such patterns are common throughout both North and South Temperate regions. Changes in human population density, climate, and/or land use will undoubtedly exacerbate these problems in the future. Relative impacts from projected global climate change patterns (e.g., Fig. 6) could differ appreciably between North and South Temperate ecosystems.

Acid deposition – A case study

I want to focus briefly on acid deposition from the atmosphere as an example of a regional/global-scale problem, and will use

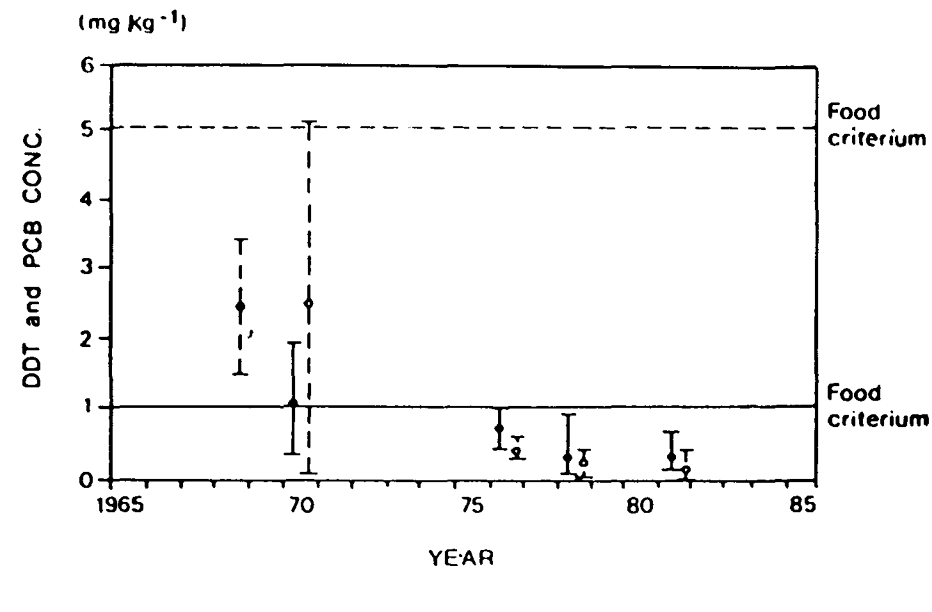

Fig. 13: Concentrations of DDT and chlorinated biphenyls (PCB's) in arctic char from Lake Vättern, Sweden. Broken lines represent DDT and solid lines PCB. Means are shown by dots, and range of variation is shown by vertical bars (from Persson *et al.* 1989).

Concentraciones de DDT y bifeniles clorinados (PCB) en turba ártica del Lago Vättern, Suecia. Las líneas cortadas representan el DDT y las líneas continuas el PCB. Las medias están indicadas por puntos y el rango de variación por las barras verticales (según Persson *et al.* 1989).

results from the Hubbard Brook Ecosystem Study in New Hampshire to illustrate a few major points.

The volume-weighted, average annual hydrogen ion concentration in precipitation has decreased since 1963 when we began our studies; thus the rain and snow now are somewhat less acid than they were 27 years ago when we began our research at Hubbard Brook (Fig. 14). The decline in H^+ is correlated with a decline in sulfate concentrations. In turn the sulfate decline is correlated with a decrease in emissions of sulfur dioxide in the USA because of Federal regulations (Likens *et al.* 1984, Hedin *et al.* 1987, Butler & Likens 1991). There have been other long-term changes in the chemistry of precipitation at Hubbard Brook as well (e.g., Likens *et al.* 1984, Driscoll *et al.* 1989). The Hubbard Brook record is particularly interesting because it represents the longest record of precipitation chemistry in North America.

There have been many short-term patterns within the long-term trend of H^+ concentration at Hubbard Brook (Likens 1989a, Fig. 14). Indeed, it required 18 years before a statistically significant linear regression line could be fitted to these long-term data (Fig. 15). Without such long-term data, it frequently is not possible to determine an actual overall pattern.

We scientists, and particularly graduate students, normally do studies lasting for three, four, or five years. Because of the relatvely large investment of time and energy (relative to our life span) in these studies, it often is presumed that the natural world functions like that discovered during this three- to five-year period. Obviously these short-term patterns may not describe the overall (long-term) pattern. Such a conclusion shouldn't imply that short-term research isn't important; it is important. However, short-term research may be misleading about how natural ecosystems function in the long-term.

As part of the Global Precipitation Chemistry Project (GPCP), my colleagues and I have located sites in the Southern Hemisphere that were as clean as we could find (Galloway *et al.* 1982a). These "remote" sites–remote from human activity–are used to collect samples to obtain a baseline for precipitation chemistry. Using this baseline, we then could determine how much change had occurred in urbanized and industrialized areas of the Northern Hemisphere since the Industrial Revolution. We have established several such sites, including a site in Torres del Paine, Chile (Galloway *et al.* 1982a, Likens *et al.* 1987).

We found that the precipitation chemistry at these remote sites had much lower average concentrations of sulfate, nitrate, and hydrogen ions than did sites in eastern North America (Fig. 16). This comparison provides some indication of how much anthropogenic pollution has occurred in the atmosphere of eastern North America.

One of the GPCP studies focused on The People's Republic of China (Galloway *et al.* 1987). We found that in some locations in China, particularly urban sites, the sulfate levels in rainfall were very high, much higher in fact than in New York City, which is quite polluted. Yet, the acidity of rainfall at these sites in China was not unusually high, and was not as acid as New York City. This discrepancy occurred because currently the presence of high concentrations of particles containing base cations, like calcium, in rainfall neutralized the acidity in China. The particulate matter originates from the incomplete combustion of soft coal (soot) and from soil particles, and these particles themselves represent a serious air pollution problem (Galloway *et al.* 1987, Zhao & Sun 1986a, 1986b). Thus, a developing country like China with high levels of SO_2, *and* high levels of particulate matter (Table 5) has a serious dilemma. Because cleaning up the particle problem could produce a major acid rain problem, the Chinese seem to have a choice: choose between an acid rain problem or a soot problem. Atmospheric particle pollution was one of the first issues that was attacked by Federal regulation in the United States through the Clean Air Act of 1970. Thus, developing countries have some very important choices relative to risks and

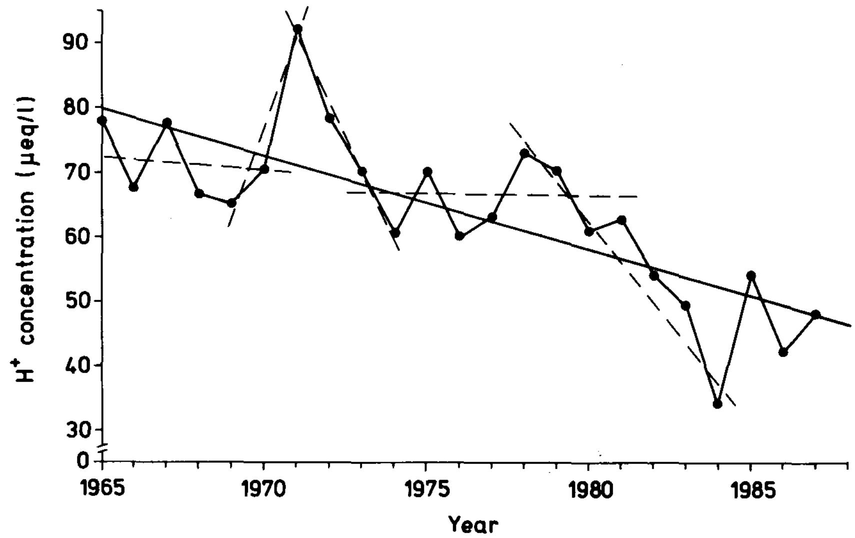

Fig. 14: Annual, volume-weighted concentration (µeq/l) of hydrogen ion for Watershed 6 of the Hubbard Brook Experimental Forest, New Hampshire, USA, during 1964-1965 to 1986-1987. The long-term regression line has a probability for a larger F-value of < 0.05; $r^2 = 0.57$ ($Y = -1.45X + 79.4$). The shorter, dashed lines are fitted by eye (from Likens 1989a).

Concentración (µeq/l) anual, ponderada por volumen, de ion hidrógeno en la Cuenca N° 6 del Bosque Experimental de Hubbard Brook, New Hampshire, USA, desde 1964-65 hasta 1986-87. La línea de regresión para todo el período tiene una probabilidad menor a 0,05; $r^2 = 0{,}57$ ($Y = -1{,}45X + 79{,}4$). Las líneas punteadas más cortas están ajustadas a ojo (de Likens 1989a).

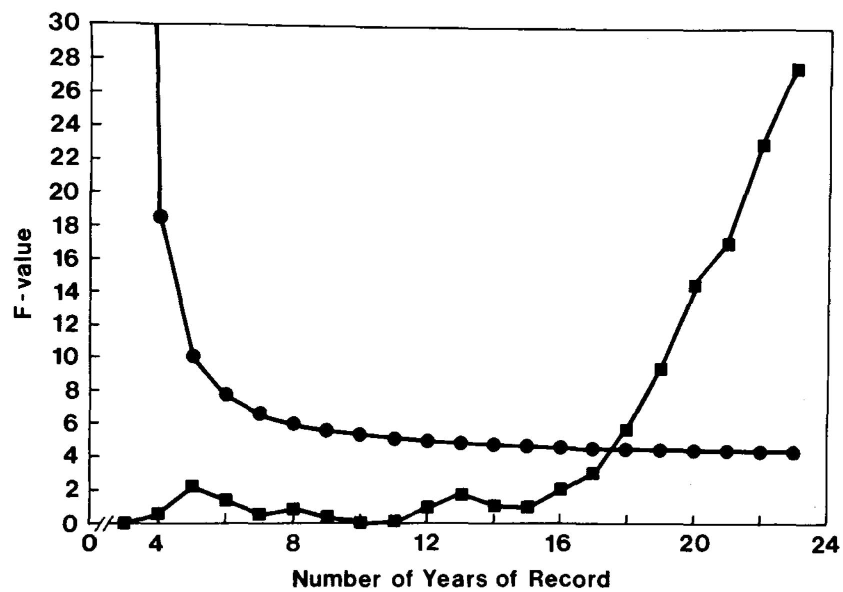

Fig. 15: Critical values of the F-distribution (●—●) for a linear regression at a probability of < 0.05 and calculated F-values (■—■) for an increasing record of actual data (1964-1965 to 1986-1987) for annual, volume-weighted hydrogen-ion concentrations in precipitation for Watershed 6 of the Hubbard Brook Experimental Forest, New Hampshire, USA (from Likens 1989a).

Valores críticos de la distribución de F (●—●) para una regresión lineal, probabilidad menor a 0,05 y valores de F calculados (■—■) para una cantidad creciente de registros (1964-1965 a 1986-1987) de concentración anual de iones hidrógeno, ponderada por volumen, en la precipitación en la Cuenca N° 6 del Bosque Experimental de Hubbard Brook, New Hampshire, USA (de Likens 1989a).

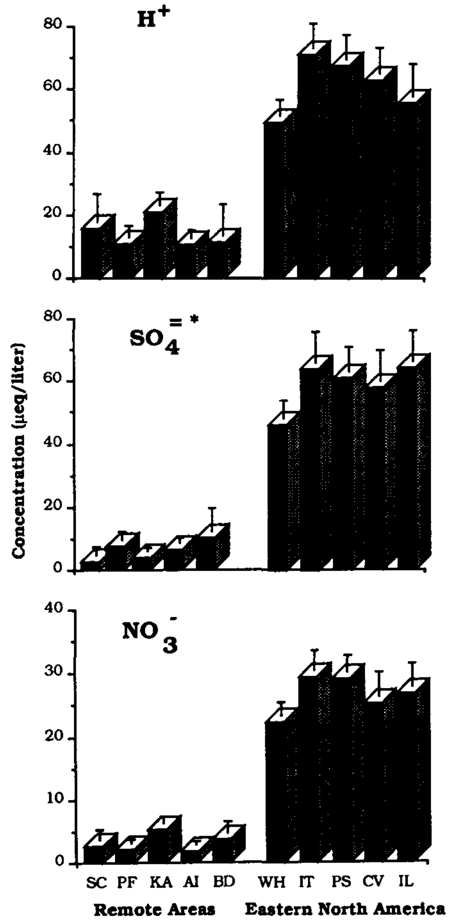

Fig. 16: Volume-weighted mean concentrations with 95% confidence intervals for five sites in remote areas and five sites in the eastern United States. Remote areas: [SC = San Carlos, Venezuela (n = 14); PF = Poker Flat, Alaska (n = 22); KA = Katherine, Australia (n = 125); AI = Amsterdam Island, Indian Ocean (n = 73); BD = Bermuda, Atlantic Ocean (n = 23)]. Eastern North America: [WH = Whiteface Mountain, New York (n = 329); IT = Ithaca, New York (n = 295); PS = State College, Pennsylvania (n = 373); CV = Charlottesville, Virginia (n = 239); and IL = Champaign, Illinois (n = 186)] (modified from Galloway *et al.* 1984).

Concentraciones medias de iones, ponderadas por volumen, con sus intervalos de confianza (95%) para cinco sitios en áreas remotas y cinco sitios en el este de Estados Unidos. Areas remotas: SC = San Carlos, Venezuela (n = 14); PF = Poker Flat, Alaska (n = 22); KA = Katherine, Australia (n = 125); AI = Amsterdam Island, Indean Ocean (n = 73); BD = Bermuda, Atlantic Ocean (n = 23). Este de Norteamérica: WH = Whiteface mountain, New York (n = 329); IT = Ithaca, New York (n = 295); CV = Charlottesville, Virginia (n = 239); and IL = Champaign, Illinois (n = 186). (Modificado de Galloway *et al.* 1984).

TABLE 5

Violations of sulfur dioxide and suspended particulate matter standards for selected cities during 1980-1984 (modified from French 1990b)

Violación de los niveles estándar de dióxido de azufre y material particulado en ciudades seleccionadas durante 1980-1984 (modificado de French 1990b)

City	Number of days above standard	
	SO_2[a/]	Particulates[b/]
Xian	72	273
Beijing	68	272
Shenyang	146	219
New York	8	0

a/ WHO Standard is a daily average of 150 $\mu g/m^3$.
b/ WHO Standard is a daily average of 230 $\mu g/m^3$ for suspended particulates and 150 $\mu g/m^3$ for smoke.

trade-offs, although the answer doesn't need to be either/or; obviously both airborne particulates and acid deposition could be reduced at the same time.

The rainfall at Torres del Paine, Chile, has a pH of about 5.1. The predominant movement of air from the West (from the sea) to Torres del Paine adds much oceanic sodium and chloride to the chemistry of rainfall. The average chemistry of precipitation of Torres del Paine is given in Table 6. A reasonable background pH for unpolluted atmosphere is about 5.1, with low concentrations of sulfate and nitrate (see Likens *et al.* 1987). Torres del Paine is an exceptionally clean site relative to anthropogenic pollutants in precipitation compared to other remote sites in the Southern Hemisphere (Katherine, Australia, and Amsterdam Island in the Indian Ocean) and particularly relative to a rural, forested site in the northeastern United States (Table 6).

We also have measured the chemistry of cloudwater and fogwater throughout the contiguous United States, Alaska, and Puerto Rico. We found that cloudwater and fogwater generally were enriched in acidity, nitrate, sulfate, and toxic metals (Weathers *et al.* 1986, 1988a, 1988b). For example, mean concentrations of H^+ in cloudwater and fogwater were approximately 3 to 7 times higher than in rainfall

TABLE 6

Volume-weighted concentrations in precipitation (μeq/liter) for various remote sites of the Southern Hemisphere and for Hubbard Brook, USA (modified from Likens *et al.* 1987)

Concentraciones (ponderadas por volumen) en la precipitación (μeq/l) de varios sitios remotos del hemisferio sur y en Hubbard Brook (modificado de Likens *et al.*, 1987)

Ion	Torres del Paine, Chile[a]	Katherine, Australia[b]	Amsterdam Island[c]	Hubbard Brook, USA[d]
$SO_4^{=}$	4.4	3.9	31.9	54
NO_3^-	0,5	4.0	1.4	24
H^+	4.9	18.3	9.0	70
NH_4^+	0.7	2.9	2.0	11
Ca^{++}	1.2	1.7	9.8	6.5
Mg^{++}	4.3	1.3	50.2	3.3
Cl^-	21.9	7.7	262	11
K^+	1.4	0.9	4.9	1.5
Na^+	18.7	4.3	225	4.8
Sample No.	23	147	79	> 750

a = 1984-1985
b = 1980-1984
c = 1980-1983
d = 1963-1980

occurring at the same site and at the same time (Weathers 1988a).

Cloudwater concentrations of hydrogen ion, sulfate, and nitrate in the eastern United States are enriched up to hundreds of times over rainwater at remote locations (see Likens 1987). We have limited data on cloudwater in Torres del Paine, but both ammonium and H^+ seem to be enriched relative to rainwater. The chemistry of cloudwater and fogwater potentially has significant ecological implications for vegetation growing in areas subjected to moisture from these sources, both as sources of nutrients (e.g., NO_3^-) and/or pollutants.

It has been estimated that when wet and dry deposition are added together, the total atmospheric input of nitrogen equals about 2 KgN/ha-yr in remote regions (Galloway 1985). The wet plus dry deposition of sulfur would be about 3 KgS/ha-yr (Galloway 1985). Critical limits of deposition have been set to protect sensitive ecosystems, both aquatic and terrestrial, that might be subjected to atmospheric deposition (Nilsson & Grennfelt 1988). The limits for N range between 5 and 15 Kg/ha-yr, and the value for S is > 32 to < 3 Kg/ha-yr, depending upon the geology and soils. Total atmospheric deposition of sulfur in the northeastern United States currently is 3 to 6 times greater than these acceptable levels (see Likens 1989b). In contrast, atmospheric inputs to Torres del Paine, and probably much of Chile, are currently below the < 3 Kg limit—that is, most ecosystems in Chile are not being degraded now from atmospheric pollution. But because it is not possible to protect Chile by building a fence around the country, will it stay unpolluted in the future? It will be bombarded by all of the pollutants that can move readily through the regional and global atmosphere. With increased numbers of people and increased industrial activity in the Southern Hemishere, atmospheric deposition of N, S, and metals inevitably will increase. Galloway (1989) has estimated that emissions of S may increase by as much as fourfold and N by sevenfold by 2020 over 1980 values in South America. Then as a result, it is safe to predict that Southern Temperate ecosystems will change from both of these local and "remote" atmospheric influences.

The GPCP sites in the Southern Hemisphere currently are providing very important comparative baseline information for what is happening in the Northern Hemisphere and what could happen in the Southern Hemisphere in the future.

Policy

Two final points. In the book, *Our Common Future* (Brundtland 1987), it was estimated that countries of the world spend about $ 900 billion (USA, 1985) each year for military security. That amount represents about US$ 2.5 billion each day to protect ourselves from some real or imagined enemy. In comparison, this Brundtland report calculated that an action plan to protect tropical forests would be equivalent to one-half day of these annual military expenses (Table 7). Rectifying the lack of clean water in the Third World would be equivalent to ten days of global military expenditure. I calculated that it would cost an equivalent of two days of the annual military expenditures to deal with the acid rain problem in the United States and three days for the European Common Market countries. As Robert MacNamara, former head of the World Bank, said recently in a talk to the National Press Club in Washington, D.C., "We can afford to clean up our environment". We have enough money to do it; however, there is a critical need to set priorities for the betterment of humankind.

Recently at a Cary Conference on Long-Term Studies in Ecology, a statement in support of sustained ecological research was adopted by the participants (see Likens 1989c). This statement proposed a partnership: "Because they have common long-term goals, we propose a new partnership between scientists and resource managers. Elements of this partnership include:

1. Agreement by scientists to answer the questions put to them by managers, while making clear the level of uncertainty that exists and what additional research needs to be done.

2. Agreement by managers to give serious consideration to these answers and to support the continuing research toward better answers.

Sustained Ecological Research supported by this new partnership can contribute significantly to the resolution of critical environmental problems" (Likens 1989c). The complexity and the uncertainty asociated with large-scale environmental problemas, such as global environmental change, clearly demands the full talents of scientists and manager working *together* over sustained periods. Comparative ecology is an important research tool for this partnership.

TABLE 7

Spending on military versus environmental security (modified from Brundtland 1987)

Gasto militar versus seguridad ambiental (modificado de Brundtland 1987)

Environmental problems	Cost to ameliorate (US$ x 10^9/yr)	Equivalent annual Military expenditure* (Days)
Action plan for tropical forests	1.3	0.5
Lack of clean water in Third World	30	10
Acid rain-halving emissions of SO_2 and NO_X		
– Eastern USA	6	2
– European EEC	5-7	3

* The world spend over US$ 900 x 10^9 on military purposes in 1985, more than US$ 2.5 x 10^9/day.

ACKNOWLEDGMENTS

This is a contribution to the program of the Institute of Ecosystem Studies and to the Hubbard Brook Ecosystem Study. I am grateful for financial support from the National Science Foundation and the Andrew W. Mellon Foundation. The Hubbard Brook Experimental Forest is operated and maintained by the USDA Forest Service, Radnor, Pennsylvania. The Global Precipitation Chemistry Project is funded by the National Oceanic and Atmospheric Administration. Steward T.A. Pickett provided helpful comments on a draft of this manuscript.

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