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Research on arid ecosystems in the region: Research potential and possible areas of concentration

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Introduction

In July, 1990, an intergovernmental group of experts on climatic changes summoned by the World Meteorological Organization and the United Nations Environmental Programme, produced a document summarizing what is known at present on the biophysical perspectives of global climatic change (GIESCC 1990, IPCC 1990). One of their main conclusions was that it can be inferred with a good level of certainty that during the next century the average temperature of the Earth will rise steadily at a rate of 0.3°C per decade if the emission of greenhouse gases continues at its present trend. According to this expert panel, the level of the sea will rise approx. 5 cm per decade, natural ecosystems will be affected in different ways, and the water balance will be disrupted in an important manner in many regions of the globe.

Large scale climatic variation is an important element, but by no means the only one, of a series of large scale disruptions in the global environment which are questioning the sustainability of the Biosphere as a whole. Apart from the systemic effect of the emission of gases at a biospheric level, other phenomena are contributing significantly to what is known as "global change". Among these, pollution of air and water resources, soil depletion and erosion, deforestation, overgrazing, and depletion of biological diversity are possibly the most important. J.A. Eddy, vice-chairman of the Scientific Committee for the International Geo-Biosphere Programme (IGBP) has argued that "global change is more, much more, than climate change or global warming. Most would agree that global changes that will strike the hardest blows on people or other living things in the next 20 or 50 or 100 years will not come from those of climate change. If the world is in environmental extremis today it is more through the rapidly changing chemistry of the air and soils and water, and through the inexorable and wide-reaching pressures of urbanization and intensive agriculture and land use" (Eddy, 1991). Arguing along a similar line, Turner et al. (1990) have defined two types of global environmental change: (a) "systemic" change and (b) "cumulative" change. The first category includes driving forces that operate in a general, systemic manner throughout the globe, and can directly affect regions that are removed from the sources that originate them. Such is the case, for example, of CFC's, CO_2, and methane emissions. The second category includes driving forces that operate at a local level, but can affect the environment of the whole planet by sheer quantitative accumulation at a very large scale. This is the case, for example, of deforestation, overgrazing and the loss of biological diversity. Many environmental factors, of course, can operate in both a systemic and a cumulative manner, and the distinction between both types of global change can often become blurred. Nevertheless, the distinction is conceptually important, particularly when trying to understand the question of global change in the less developed nations.

The problem of global environmental transformation has reached such a level of concern in the media in general, that in March 1991 the Ecological Society of America dedicated a significant part of its journal Ecology to publish a special report "The Sustainable Biosphere Initiative" (Lubchenko et al. 1991), by-passing a long tradition on publishing only original papers on basic ecological research. With this report, the ESA tried to draw the attention of ecologists on the need to focus ecological research on three basic priorities: (a) global change, (b) biological diversity, and (c) sustainable ecological systems.

In developing countries, whose proportional contribution to greenhouse gases is still relatively small, the bio-ecological aspects of global change are the main cause of concern (Fulkerson et al. 1989). The loss of vegetation cover and of biological diversity through deforestation, overgrazing, and non-sustainable harvesting in general, together with the uncontrolled growth of large cities, are possibly the main problems associated with global change. These problems are already having strong implications on the levels of equity and well-being that the inhabitants of the non-industrial nations enjoy. The transformation of tropical forests into cattle ranges is a good example of this type of process. In Central America 40,000 km^2 of tropical forests were transformed into grassland between 1961 and 1978. During that period, beef export to the developed world increased 65%, but the per capita meat consumption remained constant at around 10 kg/y (the per capita consumption in the U.S. was 56 kg/y for the same period; Myers 1981). In Brazil, the national cattle herd increased 11% between 1975 and 1981. During the same period the export of raw beef increased 1780% and the export of processed meat increased 360%. The reason why Brazil could manage such an increase was that, during the same period, the buying capacity in the country decreased from 47 kg of beef per minimum wage to 21 kg per minimum wage, and that the average per capita consumption decreased from 21 to 16 kg/y (Anon. 1983). Large part of the Brazilian cattle husbandry has developed in semiarid or dry tropical scrubs and forests (Cerrado, Caatinga and Sertao).

Among the bio-ecological consequences of global environmental change, one of the largest concerns is the loss of biological diversity in tropical countries. The growing awareness of the irreversibility of species extinction is growing hand in hand with the awareness of the rapid and irreversible environmental transition that will transform the world that gave rise to our present cultures. The concern for the future consequences of this change is possibly at the root of the sudden and growing interest that biodiversity is generating in western developed countries. This concern, however, is frequently not shared in the same terms by the less developed nations, which face more immediate and urgent needs to satisfy the growing demands of their impoverished populations. Third World decision-makers frequently argue that the development of their nations has to take place at the expense of a certain amount of environmental damage and a certain level of social inequity, two variables that often go together. It is a common belief among Third World politicians that a cost has to be paid, both socially and ecologically, if economic development is to become a reality.

It is difficult to imagine a scenario of human development that does not deteriorate the environment in some way, and that does not affect biological diversity in particular. In human history, development has usually gone hand in hand with environmental deterioration. It is becoming clear, however, that if postindustrial societies want to be able to control their destiny they should be able to regulate their growth and consumption patterns, they should be capable of obtaining natural products without deteriorating the most important legacy of millions of years of biological evolution: diversity.

In this report I will try to discuss some of these and other questions, specifically for the drylands of Latina America. Confronted with the large-scale deterioration of arid and semiarid ecosystem in Latin America, I shall discuss what should the research agenda include, what main research topics should be considered when organizing research efforts. I shall also discuss what research capacity do Latin American countries have to engage in increased research efforts, and what are the characteristics, strengths and weaknesses of the regional research infrastructure. Finally, I shall analyze how can increased international and regional cooperation be organized around the problems of dryland ecosystems.

The distribution of drylands in Latin America

There are many ways to define aridity in ecological terms. The best way to define and map arid and semiarid regions is to calculate the water balance. A simple way to do this was devised by the German geobotanist S. Walter (see, for example Neilson 1990), who found that in dry environments there is a good relationship between evaporation and air temperature. Thus, he defined the potential evapotranspiration of natural vegetation to be defined by the simple rule

$$PET = 2 \cdot T$$

where PET is the potential evapotranspiration, and T is the mean monthly temperature in degrees Celsius (°C). Walter's rule, forgotten for a long time as an overly simplistic calculation, has recently been revived by many ecologists working at a global scale, as data on temperature are more reliable than data from other more sophisticated weather instruments, and it is fairly easy to obtain for remote and isolated places, and from rudimentary weather stations. According to this rule, a semiarid environment can be defined in terms of its water balance as an area where mean annual precipitation is less than half of the calculated annual PET. This calculation, however, has not been done for Latin America, and simpler definitions of dryland areas have to be sought. In this report I shall define dry regions according to two criteria: biogeographic subdivisions (mostly based on vegetation types) and mean annual rainfall.

Dry regions according to Biogeographic Provinces

One of the best and most detailed biogeographic subdivisions of Latin America has been done by Cabrera and Willink (1973). In this work, the authors recognized 28 continental biogeographic provinces distributed within seven biogeographic domains (Figs. 1 and 2). These provinces are:

North American Pacific Domain

1.- Californian Chaparral Province (defined by Cabrera and Willink with the misleading name of "Bosque Montano")

Caribbean Domain

2.- Mesoamerican Mountain Province
3.- Mexican Xerophytic Province (Mexican Drylands)
4.- Caribbean Province
5.- Guajiran Province (i.e. Venezuelan coastal scrub)

Amazon Domain

6.- Pacific Province
7.- Amazon Province
8.- Cerrado Province
9.- Parana Province
10.- Province of the Yungas

11.- Venezuelan Province
12.- Savanna Province
13.- Atlantic Province (known in Brazil as "Mata Atlantica")
14.- Paramo Province

Guyana Domain
15.- Guyana Province

Chaco Domain
16.- Chaco Province
17.- Caatinga Province
18.- Espinal Province
19.- Monte Province
20.- Prepuna Province
21.- Pampean Province

Andean-Patagonian Domain
22.- Chilean Province (Central-Chilean Matorral)
23.- High-Andean Province
24.- Puna Province
25.- Patagonian Province
26.- Desert Province (also known as the Atacama Coastal Desert)

Subantartic Domain
27.- Subantartic Province (Patagonian Temperate Forests)
28.- Insular Province

Of these provinces, 12 can be defined as being partially or completely arid or semi-arid, basing this definition on the physiognomy of the dominant vegetation type: (1) the California Chaparral, (2) the Mexican Drylands, (3) the Guajiran Coastal Scrub, (4) the Western Chaco, (5) the Caatinga, (6) the Espinal, (7) the Monte Desert, (8) the Prepuna, (9) the Central-Chilean Matorral, (10) the Puna, (11) the Patagonian Steppe, and (12) the Atacama Coastal Desert. In this classification I have divided the Chaco Province in two large subdivisions: the Eastern Chaco, which is humid, and the West, or Dry Chaco, which is semiarid.

These dry areas are not uniformly distributed, but tend to fall primarily in a few countries (Table 1). The Latin American countries with the largest dryland areas are those predominantly in the edge of the tropical belt: Mexico, Argentina and Chile. Those countries within the tropical belt tend to have a much lower proportion of dryland areas (Brazil, Venezuela and Ecuador).

	Mexico	Argentina	Chile	Brazil	Venezuela	Bolivia	Peru	Ecuador
California Chaparral	*	.	.	.	.	.	.	.
Mexican Drylands	*	.	.	.	.	.	.	.
Guajiran Coastal Scrub	.	.	.	.	*	.	.	.
Western Chaco	.	*	.	.	.	*	.	.
Caatinga	.	.	.	*	.	.	.	.
Espinal	.	*	.	.	.	.	.	.
Monte Desert	.	*	.	.	.	.	.	.
Prepuna	.	*	.	.	.	.	.	.
Central-Chilean Matorral	.	.	*	.	.	.	.	.
Puna	.	*	*	.	.	*	*	.
Patagonian Steppe	.	*	.	.	.	.	.	.
Atacama Coastal Desert	.	.	*	.	.	.	*	*

Table 1.- The distribution of arid and semiarid areas in the different Latin American countries that have some of their territory occupied by drylands. The largest proportions of dry territory are found in Mexico, Argentina and Chile. The lowest proportions are found in Brazil, Venezuela and Ecuador.

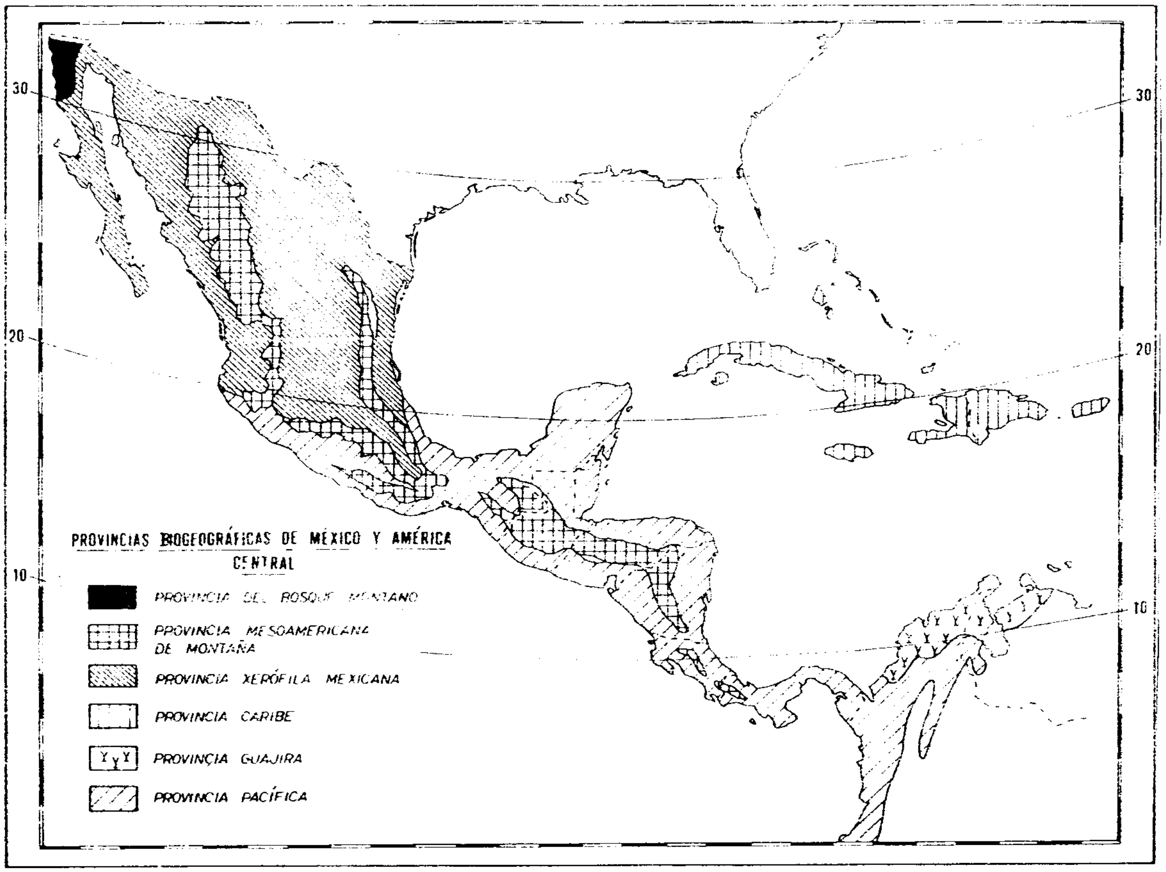

Figure 1. The biogeographic provinces of Mexico and Central America, according to Cabrera and Willink (1976).

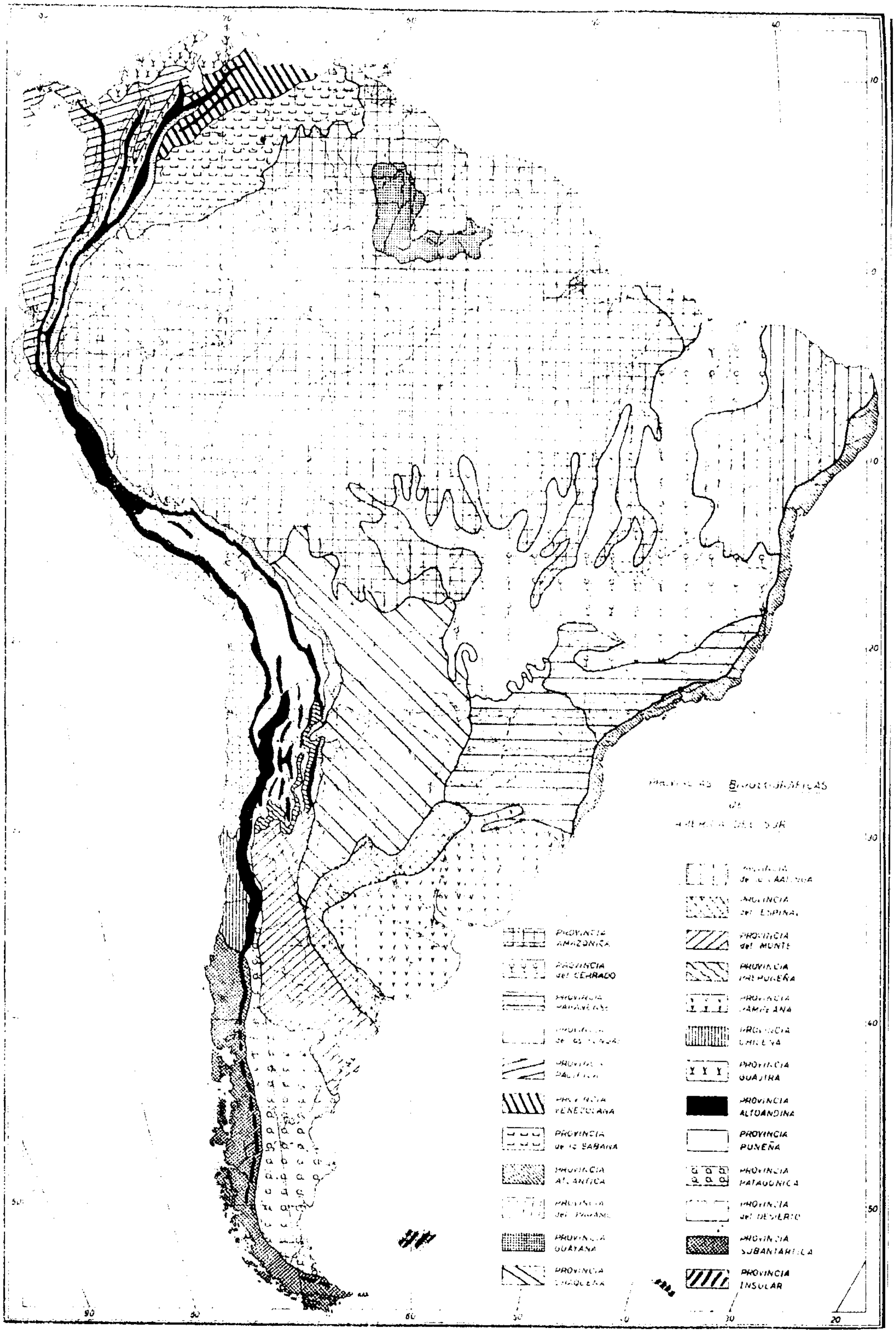

Figure 2. The biogeographic provinces of South America, according to Cabrera and Willink (1976).

Dry regions according to mean annual rainfall

It is not easy to define aridity solely in terms of annual rainfall, because, as was explained earlier, aridity depends on the water balance and not only on precipitation. Seasonality and evaporative demand both have a great influence on water availability for plants and animals. These two factors vary greatly with latitude (Fig.3). As a general rule, at higher latitudes (e.g. the Patagonian Steppe) rainfall is more regular throughout the year, and evaporative demand is lower since temperatures are also low. At low latitudes (e.g. the Dry Chaco or the Southern Mexican Drylands) rainfall is monsoon-type and very seasonal, and evaporative demand is high since temperatures are higher. Thus, 300 mm of annual rainfall in the Patagonian Steppe can mean more available moisture for plants and animals than, say, 700 mm in tropical drylands.

Even so, mean annual rainfall has been used as a gross indicator of aridity, and I will follow this criterion to define drylands in Latin America (Figs. 4 and 5). Operationally, I shall define as an arid or semi arid ecosystem any area in the map with less than 800 mm annual rainfall. According to this climatic definition, in Mexico and Central America, drylands correspond very well with the biogeographic provinces of the Californian Chaparral and the Mexican Xerophytic province (Fig. 4). In South America, drylands occupy Eastern Patagonia, Central and Northwestern Argentina, Central and Northern Chile, a small part of Western Paraguay, Southwestern Bolivia, the Pacific coastal areas of Peru and Ecuador, the Brazilian Northeast, and the Northern Coast of Venezuela. Expectedly, there is a large correspondence between Cabrera and Willink's biogeographic subdivisions and the dry areas defined by mean annual rainfall of less than 800 mm.

The life-form gradient in dry ecosystems

Although lack of rain is the dominant theme around the definition of semiarid ecosystems, the biological response of plants and animals is very different in temperate drylands when compared with tropical dry regions. In Argentina, for example, there is a marked life-form gradient going from the Patagonian Steppe to the Northern subtropical dry systems like the Prepuna and the Chaco. The dominant plant species in Southern Patagonia are tussocky grasses and cushion-type plants, which are replaced northwards by evergreen sclerophyllous plants like Larrea sp. and Condalia sp., and by globular and opuntioid cacti. Near the Chaco and the Prepuna, however, the dominant vegetation is composed mostly by drought-deciduous perennial trees and shrubs, and by columnar cacti of large size. This replacement of the life-form spectrum seems to be associated with the gradient in seasonality already discussed (Fig.3). A similar change in life-forms can be seen in Mexico when traveling from the California Chaparral (a sclerophyllous scrub) or the dry temperate Chihuahuan grasslands, into the tropical dry deciduous scrub of Southern Mexico.

Thus, the ecological problems confronted when dealing with the management of tropical and temperate drylands are likely to be very different, as the life-form and the survival strategies of the organisms that colonize these two environments are very different. Different research questions, priorities and hypothesis are to be expected from research institutions dealing with, say, cold-temperate drylands, high-altitude drylands, and hot tropical drylands.

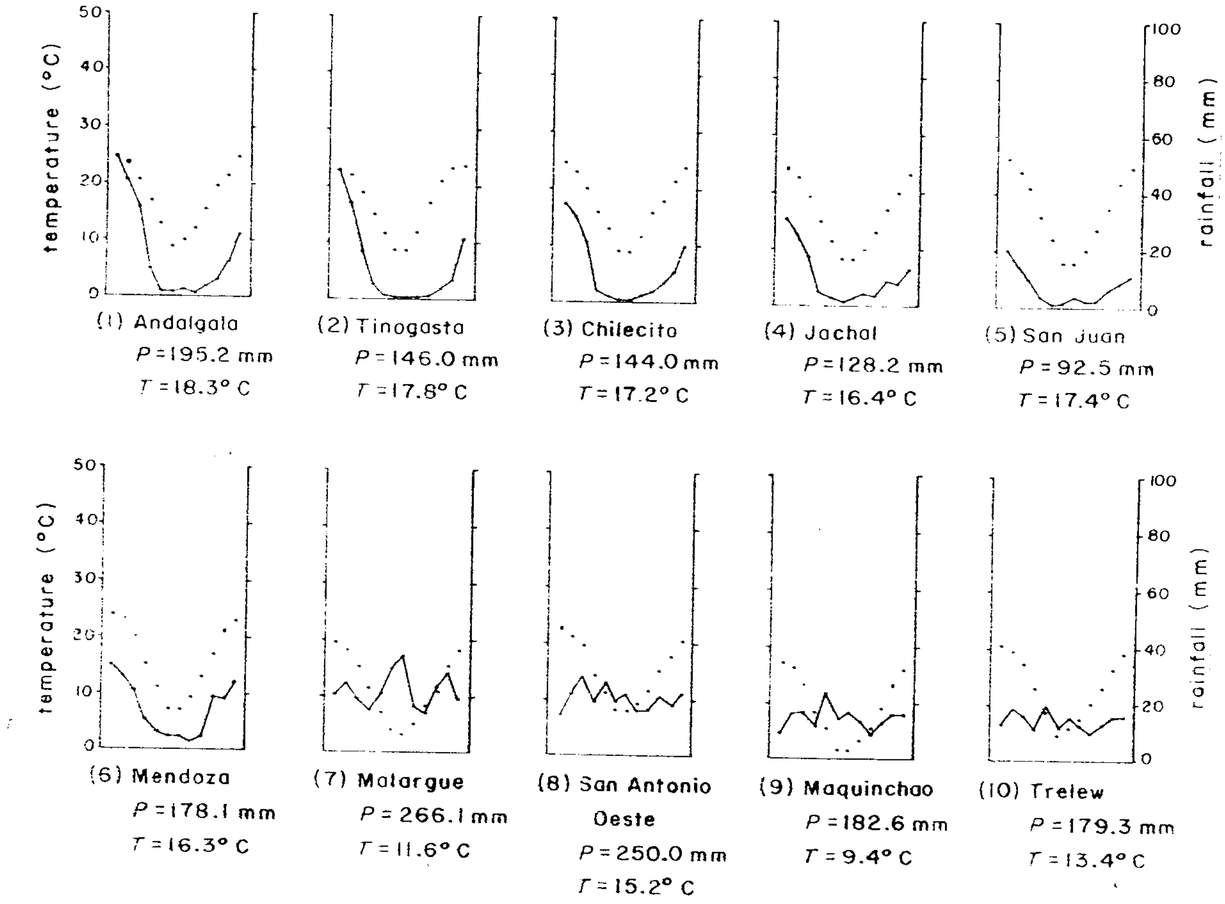

Figure 3. The rainfall gradient in the Monte Desert, from Ezcurra et al. 1991. Note that rainfall is more evenly distributed throughout the year in the Southern (temperate) stations, but is highly clumped in a summer season in the northern (tropical) stations.

Figure 4. Mean annual rainfall in Mexico: to mark the arid and semiarid ecosystems, only the isohyets of 600 and 800 mm are shown (modified from Vidal-Zepeda, 1989).

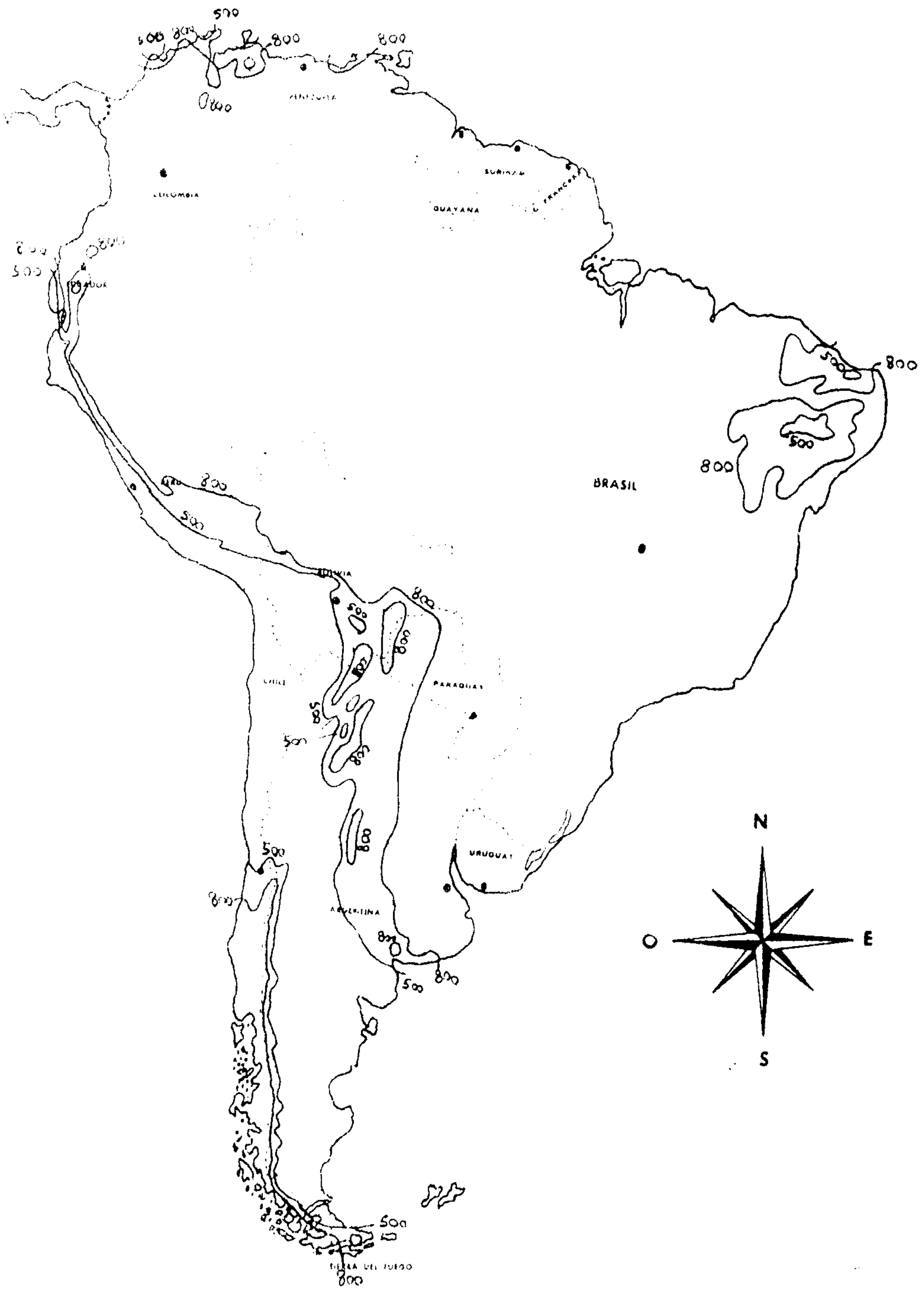

Figure 5. Mean annual rainfall in South America: to mark the arid and semiarid ecosystems, only the isohyets of 500 and 800 mm are shown (modified from Hoffmann, 1976).

The deterioration of Latin American drylands

As we know them today, the arid zones in the American Continent are relatively recent in evolutionary time. Most of the large American Deserts (Sonoran, Chihuahuan, Mojave, Monte and Atacama) show some evidence of having had less arid vegetation than they support now (Axelrod 1983). American Deserts started to develop slowly during the late Cenozoic (ca. 25 My BP), and occupied considerable areas towards the beginning of the Pleistocene (2 My BP). During the Pleistocene, American drylands expanded and contracted according to variations in rainfall and temperature induced by glacial periods, and only until the beginning of the Holocene (ca. 15,000 y BP) they expanded to their present interglacial ranges (Wells 1974, Gilbert & Martin 1984, van Devender & Spaulding 1983). Because of the absence of pastoral use by early human populations, the American drylands that were found by the Europeans were floristically rich, well-preserved and had a large productive potential.

Land use in the drylands of the American Continent, however, changed radically at the beginning of the 20th century, when artificial climate control and modern transportation opened the way for the development of these areas. Disregarding traditional techniques, modern land use in dryland areas has hinged around two main activities: cattle grazing and intensive agriculture under irrigation. Although these activities are often highly profitable, they are also often very demanding on natural resources and their long-term success is failing in many areas, and will possible fail in the next decades in many others. The development of these activities is more a result of market demands than the result of a rationale for an efficient use of natural resources. Indeed, it is the demand of the city markets and the export markets (the modern capitalist sectors in Latin America) what is driving the cultivation of irrigated crops and the increase in grazing activities and animal husbandry (Hewitt de Alcántara 1976, Pearse 1980, and Rutsch 1984).

If efficiency is calculated in terms of natural resource use, instead of monetary estimates, modern dryland agriculture is often highly wasteful. For instance, beef production under irrigated lucerne, a common technique in Mexican dryland areas, demands around 30 000 litres of water per kilogramme of beef produced, and around 50 calories of fossil fuels per calorie of meat, considering an average pumping depth from the underground aquifer of 50 m (Ezcurra & Montaña 1990). In cases in which the underground water is deeper, as is often the case in overexploited aquifers, the energy cost can be much higher.

Cattle husbandry is facing also increasing problems to maintain its long-term success. Cattle-raising in most arid regions in Latin America functions as a subservient activity with respect to the more productive and richer agricultural areas (Machado 1981). Dryland ranching is oriented towards the production of steers and heifers which are sold to the agroindustrial feed-lots, usually in irrigated areas, and represents the most inefficient part of beef production, as the fecundity of cows in dryland environments is usually low (in some cases as low as 30%), and the annual cycle is highly vulnerable to environmental catastrophes like drought or epidemics. Additionally, overgrazing has already affected, often heavily, most of the arid grazing lands in the American Continent. The most conspicuous results of pasture degradation in Latin American drylands have been the invasion of grazing areas by woody shrubs, a marked decrease in palatable grasses and herbaceous plants, and an increase in soil erosion levels (Johnston 1963, Hastings & Turner 1965, Morello et al. 1971).

Biodiversity: a dwindling resource

Biological diversity is the result of the evolutionary process, manifested as the existence of a myriad of different life-forms. It is the result of differences at a genetic level, of differences in morphology, physiology and ethology, differences in life-form and development, in demography and in life histories. Diversity can be analyzed at all levels of the organization of life.

In a strict sense, diversity is simply a measure of the heterogeneity of a system. In biological systems, the concept refers to the amount and proportion of different biological elements. The measurement of biodiversity depends, among other things, on the scale in which the problem is defined. In a biogeographic context, biodiversity is measured by quantifying the heterogeneity of biogeographic zones (e.g. biotic provinces) that occur within a given region. Biogeographic diversity is simply the diversity of biomes and ecosystems that occur within a region. For many ecologists, this level of diversity is defined as Γ-diversity (Table 1).

At the ecosystem level, biodiversity has two well-defined expressions: point-diversity, or α-diversity, and spatial heterogeneity, or ß-diversity. α-diversity is a function of the quantity of species present in a given habitat, and it is the most commonly known and cited component of biodiversity in tropical rain-forests and coral reefs, to mention only two ecosystems with a very high species richness. ß-diversity is a measure of the degree of environmental patchiness, or of the existence of a spatial mosaic of different habitats. This component of diversity is particularly important in traditional farming systems in the tropics, in multiple cropping systems and in multiple-use agroforestry systems, where the lower species-richness of human-managed systems is compensated by a man-made mosaic of crops and trees that generates spatial heterogeneity.

Finally, there is a genetic, or intraspecific, component to biological heterogeneity. Within a single species a large amount of variation can exist, maintained by the heterogeneity of different genetic alleles within the species (genotypic variation), and by the differences in the morphologic characters that are coded by these alleles (phenotypic variation). Genetic diversity, also known as genetic variation, is a fundamental component of biodiversity, it is the building block of biological heterogeneity at all other levels. The crucial importance for mankind of genetic diversity is well-known in the case of cultivated plants and domesticated animals, where a large effort has been made for decades by different agencies to preserve the diversity of the original germplasms for future breeding programs. Without genetic variation the improvement of economically important species is not possible. It is perhaps less known that genetic variation is of crucial importance for the maintenance of natural populations, whose adaptation and survival is frequently conditioned to the maintenance of a minimum population density that can provide an adequate level of outbreeding and heterosis. Below this threshold, many populations become threatened by extinction, simply because they cannot adapt through natural selection to changes in their environment.

Biodiversity depends not only on species richness, but on the relative abundance of each species. Species are usually distributed in a hierarchy of abundances, from very abundant species to very rare ones. The greater the degree of dominance of some species over the rest, the lower the diversity of the community. This is well known, for example, in temperate pine forests where in some cases 90% of the biomass of the community is contributed by only one or two species, and the remaining biomass is formed by a much larger group of low-abundance, rare species. To understand the problem of biodiversity we must understand the problem of biological rarity. We will define as "rare species" all those species that exist in such low numbers or restricted conditions as to represent a conservation problem, and in many cases as to be threatened by extinction.

Rabinowitz et al. (1986) found that, like biodiversity, the causes of biological rarity can be defined at three different scales, i.e. rarity can be interpreted at the biogeographic, the ecological and the demographic level.

<u>Biogeographic</u> <u>rarity</u> (or endemism) is found when species only occur in restricted ranges within a biogeographic region, although they may be locally abundant. These species, defined as <u>endemics</u>, may be endangered if the region where they grow is itself threatened by environmental change at a large scale. Examples of this group are the semiarid plant species of the Tehuacán Valley in Southern Mexico and of the Prepuna in Northern Argentina, some of which are restricted to a single valley within these regions.

<u>Habitat</u> <u>rarity</u> (or stenoicity) occurs when a species is very specific with respect to the habitat it lives on, although it may not be specific with respect to the biogeographic region where it occurs. Narrow-habitat, or stenoic species, are associated to very specific environmental conditions, in contrast with the wide-habitat, or eurioic species, which can prosper in a wide range of environments. Examples of this type of rarity are the riparian (freshwater) organisms in desert oases (Ezcurra <u>et</u> <u>al</u>. 1988), gypsophyllic plants (plants that grow on gypsum soils in many semiarid regions).

<u>Demographic</u> <u>rarity</u> occurs when a species shows very low densities throughout its range, although it may be widely distributed and may show a wide habitat preference. Rarity, in this case, is a result of low population numbers, which necessarily imply high levels of inbreeding and low genetic variation.

	Scale of biological organization	spatial segregation	Type of biodiversity
Biodiversity	Biome (geographic level)		Γ Diversity
	Community (multi-species level)	Between habitats	ß Diversity
		Within habitats	α Diversity
	Population (genetic and demographic levels)		Variation and heterosis

Table 1.- Classification of the different hierarchical levels of biological diversity.

Of course, some species may concentrate more than two levels of rarity, and in some cases rare species may join the three characteristics: that is, being endemic to a small biogeographic area, being highly stenoic in their habitat preferences, and occurring at low population densities. One of the most remarkable example of this type is the recently described Haplopappus thiniicola (Asteraceae), that has the dubious privilege of growing only in a small patch of the Gran Desierto Dunes in the Sonoran Desert (high endemism), associated to desert sandy regosols (an relatively rare soil type in the Sonoran Desert), and in low numbers (demographic rarity).

It is probably obvious, at this point, that the levels of rarity that most matter in relation to global change are the first two, i.e. endemism and stenoicity. Any process likely to change the environment at a global level is likely to produce significant changes in whole habitats, and in some cases, in whole biogeographic subdivisions. Clearly, any species closely linked to a given habitat or to a given biogeographic subdivision will be more vulnerable to large-scale environmental disruption.

Diversity patterns: the temperate-tropical gradient

One of the most often described, but also most poorly understood, pattern of biological diversity is the trend exhibited by most taxa to increase their species richness towards the tropics (Pianka 1966, Gentry 1982). Stevens (1989) has shown that when the latitudinal extent of the geographical range of organisms is plotted against the mean latitude of their distribution, a positive correlation is found in which the geographical ranges of the species decrease towards the tropics (Fig. 6). This pattern called by Stevens "Rapoport's rule" (after Rapoport 1975) indicates in general terms that tropical species have extremely narrow ranges of distribution, while high-latitude organisms have comparably very large ranges. In terms of Rabinowitz's classification of rarity, Stevens' argument means that tropical species have a marked tendency towards high endemism and/or high stenoicity. That is, there is good evidence showing that most of the ecologically and biogeographically rare species concentrate in the intertropical belt.

According to Stevens, the large latitudinal extent (i.e. the low level of endemism) of high-latitude organisms is a consequence of the selective advantage of individuals with wide climatic tolerances in regions with large differences between summer and winter temperatures. In contrast, for tropical organisms selection for wide-tolerance characters is not expected or even may reduce the efficiency of exploitation of particular microhabitats (Stevens 1989). A similar argument was formulated by Janzen (1967), who argued that in the tropics terrestrial temperature regimes are more uniform than in temperate regions, and that this should affect the distribution of tropical plants and animals, which are adapted to the temperatures normally encountered in their habitat. Janzen concluded that mountain ranges are more important elements of geographic isolation in the tropics, where organisms are not so flexible to temperature changes encountered during altitudinal migrations, and that this phenomenon largely explains why the distributional ranges of species are narrower and endemism is higher in the tropics.

In conclusion, the levels of endemism and stenoicity are likely to be higher in tropical organisms than in temperate ones. By "tropical" I am not only alluding to the wet tropics, the most common, almost stereotypical, concept of tropical ecosystems. Tropical areas also include other very important ecosystems, like savannas, tropical dry scrubs, cloud forests, marshes, coastal mangrove forests and high-altitude ecosystems (like the Andean Páramo and the Peruvian Puna), to name just a few. Many of these systems show restricted distributional ranges and are closely associated with very narrow environmental conditions (altitudinal belts, flooding levels, specific rainfall patterns, etc.). These ecological communities are particularly non-resilient to environmental change in general, and it can be argued that they have been up to now the most affected areas by the cumulative driving forces of global change (deforestation, overgrazing, desertification), and that they will very possibly be the most vulnerable ecosystems in the future.

In this report I shall concentrate my discussion exclusively in Latin American drylands, and shall analyze with a few examples the importance of the temperate-tropical diversity gradient in dry ecosystems

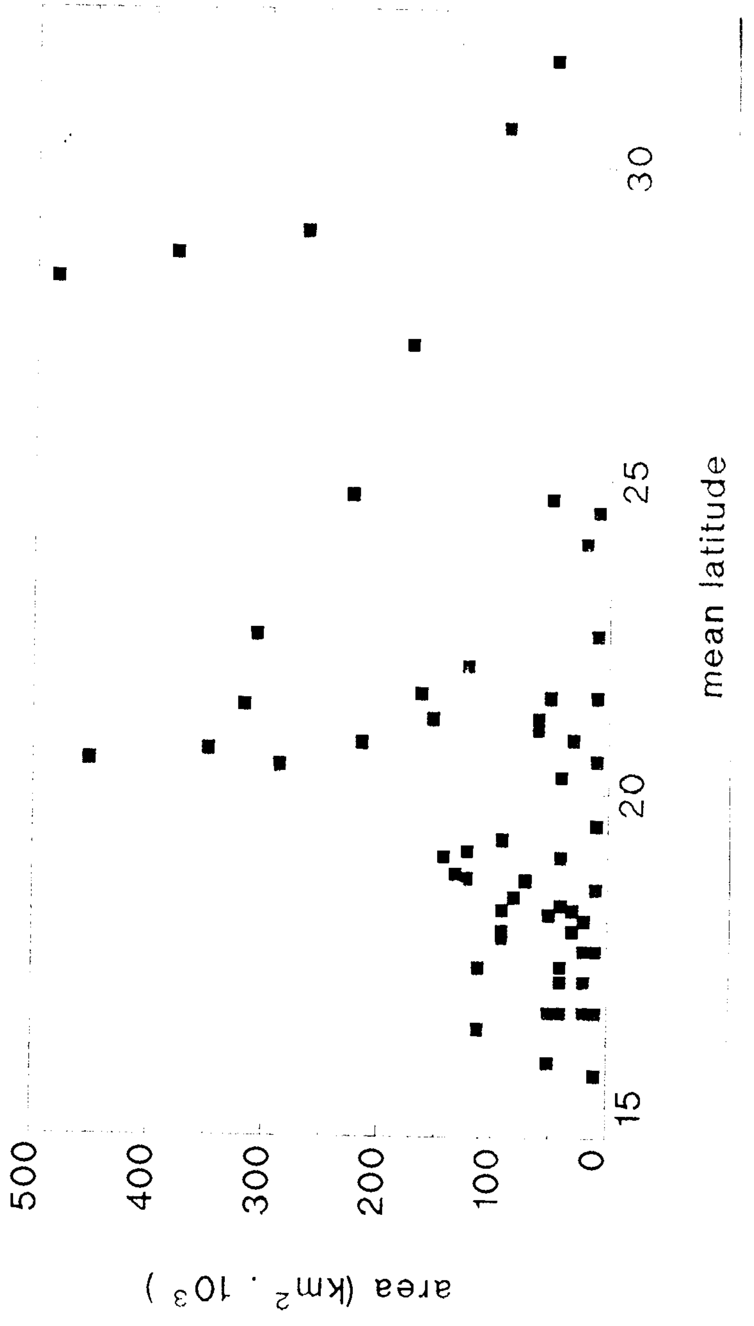

Figure 6. Mean latitudinal extents of Mexican columnar cacti. Note that the mean range decreases as the distribution of the species approaches the tropics.

A case study: Mexican columnar cacti.

The pattern discussed by Janzen, Rapoport and Stevens can be analyzed in detail in certain taxa of particular interest. For this purpose, I chose Mexican columnar cacti. This group of plants (belonging to the subfamily Pachycereae within the Cactaceae; Gibson & Horak 1978), with 69 species in Mexico, is formed by succulent leafless plants with cylindrical stems and in general with a very simple architecture (Cody 1984). Like almost all cacti, they exhibit Crassulacean Acid Metabolism (CAM), characterized by CO_2 fixation at night which minimizes transpirational water loss (Nobel 1988). CAM metabolism has collateral problems such as the high metabolic cost involved in maintaining a large amount of non-photosynthetic tissue. Cacti cannot thermoregulate by transpiration during day, and therefore need passive ways to dissipate heat and to avoid excessive radiation. Variations in body architecture, like the vertical stems of columnar cacti, have been interpreted as adaptations to avoid excessive heat (Gates 1980). Columnar cacti are plants of great importance as a source of food for indigenous populations throughout Mexico and Southwestern U.S. (Felger and Nabhan 1976, Nabhan 1985). Many species of columnar cacti are cultivated for their fruit production and as hedges around houses and fields. A significant proportion of the fruit marketed in indigenous markets in Southern Mexico comes from columnar cacti, both from cultivated and wild species.

The geographical patterns of species richness of these plants in Mexico, when the number of species is plotted in a map with a grid of 1° latitude and 1° longitude, indicate that most of the species have a narrow distribution range and are concentrated in the semiarid, hot regions of central-southern Mexico (Fig. 7a). In contrast, northwestern Mexico, referred as a zone of high diversity of succulents by Burgess & Shmida (1988), has four times less species than the dry tropics. A regression model fitted to the species richness with the mean, minimum and maximum temperatures and with the annual mean precipitation as independent variables, showed that the species richness is limited primarily by low temperatures and either very high or very low rainfall. Therefore, areas with freezing events and low precipitation contain few or no species (e.g. the Mexican Plateau). When the number of species predicted by the model is compared with the observed number of cacti, and plotted on the same grid, the species richness not explained by the model can be analyzed. According to this, it is possible to see in the map areas with a higher number of species than predicted by present climatic conditions (mountains of northern Oaxaca and the Balsas Basin; Fig. 7b). These areas are "hotspots", or biogeographically restricted areas of unusually high diversity and endemism. Thus rarity, in the case of columnar cacti, tends to concentrate in the dry tropics. While the abundance of columnar cacti in other regions can be explained by the prevalent climatic conditions (e.g. Baja California Peninsula), the extremely high species richness in restricted tropical areas can only be explained in terms of historical events and/or in the existence of a large topographic fragmentation in the area (Janzen 1967). The theory of Pleistocene refuges is one of the most plausible and best explanations for this pattern. The present distribution of columnar cacti reflects the concentration of many species in refuge areas during the Wisconsin Glaciation, when the present deserts of northern Mexico and Southwestern U.S. were cooler and moister, and were occupied mostly by grasslands.

Dryland tropical endemism in other groups.

Is the pattern observed in Mexican cacti maintained in other groups? The available information indicates that similar patterns exist and may be common in many other taxa. Several authors have pointed out the importance of biological refugia during Pleistocene glaciations. The refuge theory very robustly explains patterns of tropical biodiversity in restricted areas (Sears & Clisby 1955; Haffer 1982; Toledo 1982). Indeed, some of these areas still at present hold a significant number of endemic species (Rzedowski 1978). Dry tropical areas in Mexico like the Balsas Basin and the southern part of the Tehuantepec Isthmus in Oaxaca have been proposed as refugia of xeric species of birds by Hubbard (1974) and small mammals by Mares (1979).

A detailed study of the biogeographic distribution of endemic reptiles and amphibians in Mexico was recently done by Flores-Villela (1991). It was found in this study that 25% of all the endemic herpetofauna in Mexico has distribution areas of less than 2500 km^2, and that most of these micro-endemics are distributed mainly in two biomes. One biome is formed by the tropical highlands of Central Mexico, associated with temperate forests and with semiarid vegetation types, covering about the 0.5% of the country (Leopold 1950, West 1971). The second biome with high endemism is the dry tropical deciduous forest of the Pacific slopes (about 8% of the vegetational cover of Mexico; Flores-Villela y Gerez 1988). All of the areas of extremely high endemism for the herpetofauna are located in the highlands of central-southern Mexico, which are the most populated sections of the country and concentrate more than half of the total human population. These areas of high endemism for amphibians and reptiles coincide with high-endemism regions for butterflies and birds (Escalante and Llorente, 1985), for mammals (Ramírez-Pulido and Müdespacher 1987), and for birds (Escalante et al. in press).

The results of these studies support the idea that non-resilient, narrowly distributed species concentrate in the tropics, although, as it can be seen from the studies presented here, they do not necessarily coincide with the wet tropical forests, and often seem to concentrate in dry tropical ecosystems. A similar situation occurs in South America, where it has been reported that a large proportion of the highly endemic species occur in different altitudinal belts of the high-altitude ecosystems (e.g. Vuilleumier 1986). It is also interesting to note that many of the modern temperate crops (e.g. maize, potato, tomato and squash, to name just a few) have originated in these high-diversity areas, both in Mexico and in South America.

The idea presented in this report, that dry tropical systems may be highly vulnerable to global change, seems to be in disagreement with the predictions of the general circulation models (GCM's) of the atmosphere, which forecast higher levels of climatic warming in the mid-latitudes (e.g. Southern Europe and Central U.S.; Neilson *et al*. 1989, GIESCC 1990, IPCC 1990). But, on the one hand, these regional predictions have been described as highly unreliable by the WMO-UNEP expert panel (GIESCC 1990, IPCC 1990). On the other hand, our argument describing the existence of a general gradient of increasing vulnerability towards the tropics is not based solely on the predictions of global greenhouse warming, but on the other cumulative driving forces of global change, such as deforestation, erosion and overgrazing, discussed earlier in the introduction.

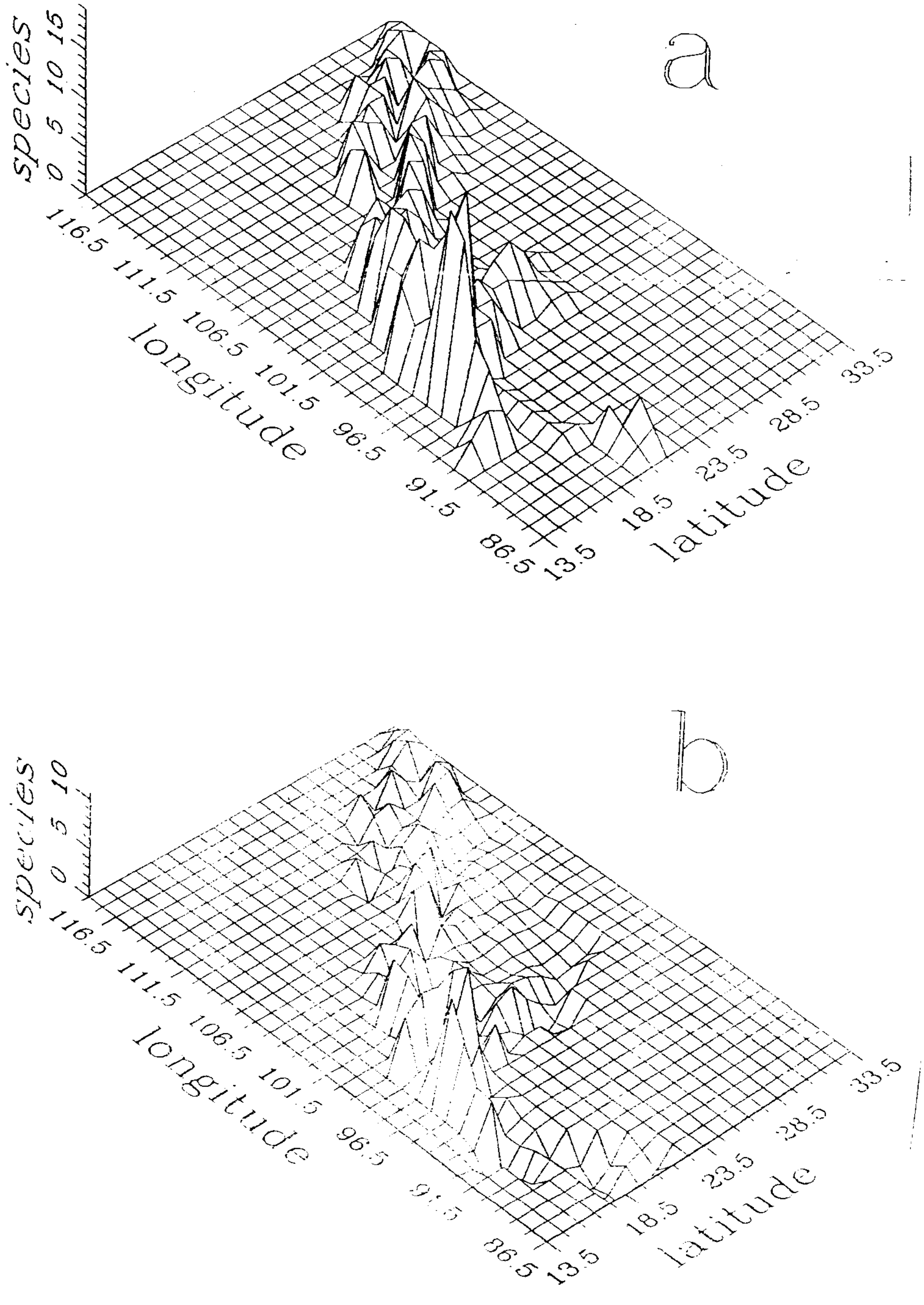

Figure 7. (a) Geographic distribution of species-richness of columnar cacti in Mexico (modified from Briones _et al_. 1988). Note the higher diversity of the southern dry tropics. (b) Geographic distribution of the residuals of species diversity once the best-fit climatic model has been adjusted to the data. Positive residuals mean that present diversity is not explained by climatic variables alone. The high diversity in the south is much higher than would be expected by the present climate.

Prospects for the sustainable use of drylands

Following the Brundtland Commission's definition of sustainability ("meeting the needs of today without compromising the future"), we can conclude at this point that the predominant modes of natural resource use in Latin American drylands are oriented towards short-term economic profit, but seem to be non-sustainable in the long run.

We can visualize the survival strategies of dryland organisms as classifiable into two main categories: (a) adaptation for quick use of ephemerally abundant resources, or (b) adaptation for the efficient use of poor but more permanent resources (Shmida 1985). The first category represents a "maximum variance" behaviour that consists essentially in tracking environmental variation, while the second category is a "minimum variance" behaviour that consists in adapting to the worst possible conditions. In plants, there is a gradient from one strategy to the other. Dryland ephemerals are an example of the first category, while dryland microphyls, sclerophyls and succulents are a good example of the second one. Drought-deciduous perennials and grasses represent a compromise between these two extreme behaviours. Attributes necessary for the quick use of water include rapid growth (often at the cost of a low water use efficiency), abundant seed production, and sometimes heliotropic leaf movement. Attributes for survival with little water include high water use efficiency, slow growth and passive cooling of the chlorenchyma. Drought-deciduousness, as an intermediate strategy, requires the capacity to shed leaves and to quickly recover them when moisture conditions improve, without investing too much physiological effort on support tissue.

The use of drylands by modern 20th century man has concentrated in agricultural plants that are mostly derived from wild annuals, and in grazing the rest of the vegetation, with a large emphasis in the consumption of grasses by the domestic herbivores. In general, the modern attitude towards the more slow-growing succulents, trees or shrubs has been to use as a non-renewable resource for wood or live ornamental specimens. Apart from putting the sustainability of the system under question, this trend has underused many important and potentially profitable plants that belong to the other growth forms. Many perennial dryland trees and succulents have been used by indigenous groups as a renewable source of food and materials, and these species should be protected and stimulated for future use within a more sustainable management system. Some recent success stories, like the jojoba domestication in the Sonoran Desert, and the continuing industrialization of some dryland perennials like wild chiles (Capsicum spp.), wild oregano (Lippia spp.), and the Baja Californian damiana (Turnera diffusa) as food plants, wild yuccas and agaves as fiber plants, and some wax-producing species (e.g. Euphorbia antisyphillitica in Mexican deserts, Bulnesia retama in the Monte desert), suggest that the enterprise is not altogether impossible. Perennial plants can also provide an important source of food for human consumption.

Prosopis spp. (known in North America as mesquites, and in South America as algarrobos) can produce as much as 1000 kg/ha of pods, which are edible and highly nutritious, provided they are properly ground (Felger & Nabham 1980). Cacti in general, and columnar cacti in particular, have edible, tasty, and nutritious fruits with high-quality sugars. Additionally, prickly-pear cacti yield edible cladodes, which are harvested in Mexico for human consumption. Opuntia fruits are now exported to many U.S. markets (apart from being a very common fruit in Mexican markets), and Opuntia cladodes have recently begun to be exported to Japan. This successful experience could be extend to other cactus species with agronomic potential. There are more than 200 species of columnar cacti in the American continent, most of them having edible fruits.

On the other hand, modern agriculture has oriented itself towards yield maximization rather than towards improving the water use efficiency of dryland crops and the likelihood of a successful harvest under dry conditions. Thus, highly efficient dryland crops like tepary beans (Phaseolus acutifolius) have been ignored while the more water-inefficient crops (e.g. commercial cultivars of Phaseolus vulgaris) which need greater amounts of water and fertilizer have been favoured. If energy and water-intensive agriculture in arid ecosystems is to be replaced by a more efficient mode of cultivation, these desert plant species need more investigation. Of particular importance are the dryland amaranths (Amaranthus spp.), the North American tepary beans and the South American quinoa (Chenopodium quinoa), but the list of possible candidates for new water-efficient crops is indeed very large (e.g. Felger & Nabham 1980).

Substantial increases in the biodiversity of arid ecosystems under production can be achieved by increasing both the number of crop species and their growth forms. The use of indigenous dryland plants could lower considerably the present demand for energy and fresh water inputs that is needed by modern dryland agricultural systems. The maintenance of these systems questions the future capacity of dryland ecosystems to maintain sustained levels of production in the long term.

Germplasm resources in semiarid Latin America

Modern agriculture is based on the cultivation of a few high-yield commercial varieties, but it needs of an immense reserve of seeds of different origin from which the new crop varieties are bred. Most of these commercial crops have a life-span of 6 to 15 years. After this period the agricultural pests and pathogens become so adapted to the varieties that they need to be changed. In open contrast, traditional agriculture maintains genetically diverse crops that are often in equilibrium with their pests and do not need periodic replacements. The areas of the American Continent where traditional agriculture survives are a major source of genetic diversity for future breeding programs (Nabhan 1990). Even with the modern techniques of genetic engineering, variation has to be obtained from the field.

The majority of the world crops have originated in tropical areas that make up much of the less-developed countries with nutrition deficiencies. Out of the first 1000 major crops harvested in the US, for example, only three are strictly native to the country (sunflowers, Jerusalem artichokes and cranberries; see Table 2 and Anon. 1981). The world's agricultural production depends fundamentally on wild or indigenous varieties, which are often collected by plant breeders and kept in large germplasm banks. The importance of these germplasm banks is so strategic that in 1977 the U.S. Department of Agriculture decreed that all the seeds contained in the bank at Fort Collins were property of the U.S. government, and that political considerations dictated at times the exclusion of some countries from the free exchange of seeds (Anon. 1981).

Mexico, and particularly the area known as Mesoamerica, is recognized as one of the centers of origin of agriculture and as one of the most important centers of domestication of plants in the world (Mangelsdorf et al. 1967, Byers 1967, Caballero 1990). The center and southwest of Mexico (coinciding mostly with the high-endemism areas described in the previous sections), was aptly described early this century by the great Russian geneticist N.I. Vavilov as "the furnace of creation" (quoted in Rzedowski 1978). At present, between 5000 and 7000 plant species in Mexico are known as sources of food, medicine, fibers, building materials, and other raw materials (Caballero 1990). For thousands of years, mesoamerican cultures have developed an interaction with these plants which has incremented the morphological and genetic intraspecific variability (Nabhan 1985, 1989). Some of the contributions that the mesoamerican cultures have done to crop diversity can be found in the immense genetic variability of maize, bean, chilies, tomatoes, and squash, among many other species, that has been generated over millennia of plant-man interactions.

In particular, the drylands of Mesoamerica and the Pacific Andes have been an extraordinary source of cultivated plants. The oldest maize plants in the American were found in the

Coxcatlán caves, in the heart of the arid Tehuacán Valley (Mangelsdorf et al. 1967, Byers 1967). The dry ecosystems of the American continent have given the world agaves, amaranth, beans, chayotes, chiles, coca, corn, cotton, cucumbers, guayule, luffa-gourds, marigolds, potatoes, prickly-pears, pumpkins, quinine, quinoa, red-peppers, sisal hemp, squashes, sweet potatoes, tepary beans, tobacco, and tomatoes, among many other important crops.

Plant variability has a cultural determinant and a genetic component. In the case of Mexico, the different (ca. 56) ethnic groups that can be found in the country have increased significantly the variability of a great number of useful plants. In annual crops, such as maize, at least 25 races have been recognized, each with a great within-race variability. It is a well-known fact that indigenous groups cultivate and maintain different races according to the environmental conditions (Caballero 1990). In some mountainous parts of Mesoamerica, neighboring valleys can harbor different maize varieties, and at a regional level, the diversity of crop varieties is very high. The same applies to bean crops, of which 427 varieties have been collected and identified in Mexico (Hernández-Xolocotzi 1985). A similar situation occurs in the Andean regions of South America; Camino et al. (1985) have shown that in a small district of the Cuyo province in Peru more than 10 different races of potato are cultivated along the altitudinal gradient. Agricultural production is divided into 7 narrow altitudinal belts of 200-400 m each, and the varieties cultivated in each belt differ considerably.

Table 2. Vavilov centers of crop diversity, with selected species (modified from Juma 1989).

Center of Diversity	Crops
Mexico-Guatemala	Amaranth, avocado, beans, corn, cacao, cashew, cotton, guava, papaya, red pepper, squash, sweet potato, tobacco, tomato, vanilla, tabasco pepper, guayule, luffa gourd, chayote, curuba, prickly pear, sisal hemp, sapote, mamey, agaves.
Peru-Ecuador-Bolivia	Beans, cacao, corn, cotton, guava, papaya, red pepper, potato, quinine, quinoa, squash, tobacco, tomato, begonia, malanga, canna, cucumber, pumpkin, coca, tree tomato, marigold, peach palm, ground cherry.
Southern Chile	Potato, Chilean strawberry, Chile tarweed.
Brazil-Paraguay	Brazil nut, cacao, cashew, cassava, rubber, peanut, pineapple, passion fruit, mate, Surinam cherry, jaboticaba.
North America	Blueberry, cranberry, Jerusalem artichoke, pecan, sunflower, black walnut, black raspberry, muscadine grape, wild gooseberry, wheatgrass.
Ethiopia-Kenia-Somalia	Banana, barley, castor bean, coffee, flax, okra, onion, sesame, sorghum, pearl millet, bread wheat, garden cress, cowpea, mustard, date palm, watermelon, cantaloupe, yam, pigeon pea, Egyptian cotton, tree cotton, short staple cotton, teff, veldtgrass, lupine, safflower, coriander, fennel, khat, spurge, indigo, vernonia.
Central Asia	Almond, apple, apricot, basil, broad bean, cantaloupe, carrot, chickpea, cotton, coriander, flax, grape, hazelnut, hemp, lentil, mustard, onion, pea, pear, pistachio, radish, rye, safflower, sesame, spinach, turnip, wheat, garlic.
Mediterranean	Asparagus, beet, broccoli, cabbage, cauliflower, celery, broad bean, artichoke, dill, fennel, mint, desert date, rape, crimson clover, lavender, crob, chicory, hops, lettuce, oat, olive, parsnip, rhubarb, wheat, flax, carob, savory, thyme, rosemary, sage, hop.
Indo-Burma	Amaranth, betel nut, betel pepper, chickpea, cotton, cowpea, cucumber, eggplant, hemp, jute, lemon, mango, millet, orange, black pepper, rice, sugar cane, taro, yam, balsam pear, Indian lettuce, Indian radish, tangerine, citron, lime, jambolan plum, jack fruit, coconut, bilimbi, safflower, leaf mustard, tree cotton, crotalaria, kenaf, sesbania, cardamom, indigo, madder, henna, Indian almond, senna, croton, cinnamon, Indian rubber, bamboo, palmyra palm

Table 2 (continued).

Center of Diversity	Crops
Asia Minor	Alfalfa, almond, apricot, asine, barley, beet, cabbage, cantaloupe, cherry, clover, coriander, date palm, carrot, fig, flax, grape, leek, lentil, lupine, leaf mustard, oat, onion, opium poppy, parsley, pea, pear, pistachio, pomegranate, purslane, rape, rose, rye, sesame, wheat
Siam-Malaya-Java	Banana, betel palm, breadfruit, coconut, ginger, grapefruit, sugar cane, yam, mung bean, sour orange, air potato, pokeweed, calamondin, jackfruit, durian, salacca palm, candlenut, curcuma, nutmeg, cardamom, clove
China	Adzuki bean, apricot, buckwheat, Chinese cabbage, cowpea, tea, sorghum, millet, oat, sweet orange, peach, radish, rhubarb, soybean, sugarcane, Chinese yam, bamboo, horse radish, cherry, eggplant, hawthorn, arrowhead, walnut, litchi, sesame, mulberry, ginseng, camphor, lacquer, hemp, fiber palm, aconite, ramie

It could be hypothesized that the effect of global climatic change upon annual crops could be of minor importance considering their enormous variability. At present, however, many researchers believe that the main problem related to agroecosystem management in Latin America is the general tendency towards genetic and ecological uniformity, imposed by the development of modern agriculture (Toledo 1989, Caballero 1990). This trend implies the adoption of more technologically developed modes of production, including the use of commercial seeds which have been modified genetically. The cost of this transformation is the abandonment and often the extinction of natural varieties. Several authors have shown how modern commercial varieties, which are genetically uniform, generate good yields under optimum field conditions but can produce catastrophically low yields in less favorable environments. In contrast, local indigenous varieties have small distribution areas and are much more finely tuned to the different environments, where they have been selected for centuries and/or millennia. Like many species of tropical ecosystems, local indigenous varieties are endemics of narrow distribution, but they have a great economic value in plant breeding. Many local varieties of different crops have already succumbed to the growing demand for market uniformity in rural production, dangerously narrowing the gene pool of many crops. What will happen with these varieties in the scenario of global change? It is difficult to say, but as a general rule a higher probability of extinction is expected on local crops with small distribution, than in the widely dispersed, genetically uniform commercial crops.

The economic importance of native crops is still enormous. Early this century, Vavilov recognized 12 "centers of diversity" for crops (Table 2). According to Vavilov, different crops originated in different centers, and each of these regions has contributed to modern agriculture with a large number of crops. The real meaning of Vavilov's model is that crop domestication has been historically associated with certain geographic areas where sedentary agricultural groups have evolved (Juma 1989). Vavilov's work highlighted the uneven geographic distribution of the genetic material supporting the world's crops, and the dependence of some nations on the supply of genetic resources from other, usually tropical, countries. This dependence has been analyzed by Kloppenburg and Kleinman (1987, see Table 3), who calculated how much of the present food production in different parts of the world depends on germplasm (i.e. genetic material) originated in other regions. According to this study, the West Central Asiatic and Latin American regions account for 65.5% of the world's genetic resources for the major crops (Latin America has produced maize, potato, cassava and sweet potato; West Central Asia has generated wheat and barley). Adding to this figure the contribution to the world's food production of germplasm from Africa, China, Indo-China, and the Hindustan region, it can be calculated that the world's poorest nations, as a group, account for more than 90% of the world's genetic resources for food production (Juma 1989).

	Regions of diversity										
Regions of production	Chino-Japan.	Indo-Chin.	Aust.	Hind.	West Cent. Asia.	Medi.	Afri.	Euro-Sibe.	Lat. Amer.	North Amer.	Total Dependence
Chino-Japanese	37.2	0.0	0.0	0.0	16.4	2.3	3.1	0.3	40.7	0.0	62.8
Indo-Chinese	0.9	66.8	0.0	0.0	0.0	0.0	0.2	0.0	31.9	0.0	33.2
Australian	1.7	0.9	0.0	0.5	82.1	0.3	2.9	7.0	4.6	0.0	100.0
Hindustanean	0.8	4.5	0.0	51.4	18.8	0.2	12.8	0.0	11.5	0.0	48.6
West Central Asiatic	4.9	3.2	0.0	3.0	69.2	0.7	1.2	0.8	17.0	0.0	30.8
Mediterranean	8.5	1.4	0.0	0.9	46.4	1.8	0.7	1.2	39.0	0.0	98.2
African	2.4	22.3	0.0	1.5	4.9	0.3	12.3	0.1	56.3	0.0	87.7
Euro-Siberian	0.4	0.1	0.0	0.1	51.7	2.6	0.4	9.2	35.5	0.0	90.8
Latin American	18.7	12.5	0.0	2.3	13.3	0.4	7.8	0.5	44.4	0.0	55.6
North American	15.8	0.4	0.0	0.4	36.1	0.5	3.6	2.8	40.3	0.0	100.0
World	12.9	7.5	0.0	5.7	30.0	1.4	4.0	2.9	35.6	0.0	

Table 3. Global genetic resource interdependence in food production. The columns are Vavilov's regions of diversity, and the rows are the same regions evaluated by their present production. The values in the table indicate the percentages of the present food production in a region that depend on germplasm from different regions of diversity. For example, 18.7% of the food production in Latin America depends on germplasm derived from the Chino-Japanese region (from Kloppenburg and Kleinman 1987, and Juma 1989). The bottom row (World) indicates the relative contribution of each region to the world's crop germplasm. The rightmost column (Total Dependence) indicates how much of the food production in each region depends on germplasm from other regions.

A question of rates and scale

May (1989) has calculated that at the present rate of ecosystem destruction, approximately half of all species on Earth will meet extinction during the next century. It is estimated that biological evolution took between ten to a hundred million years to produce this same number of species through the mechanisms of speciation. This means that the rate at which species extinction is operating at present is around a million times higher than the rate at which new species are being produced by evolution. In short, we are witnessing now one of the greatest biological catastrophes that have occurred since the beginning of life on Earth, and the rate at which this process is occurring completely excludes the possibility that massive extinctions generated by human activities be compensated by the evolution of new species within a sensible time-frame.

Many questions arise when analyzing this problem. If species extinction has been common throughout the evolution of life on Earth (as a matter of fact, 99% of the species that ever existed are now extinct), how worrying is it really that a certain number of species is going to meet extinction during the next century? Furthermore, if it has been clearly shown that complete floras and faunas migrated into refuge areas during other events of climatic change (e.g. the Pleistocene glaciations), will not the same floras and faunas migrate and/or adapt to global change during the coming century?

Gould (1991) has partially answered these questions in a recent essay. The mean duration of a species is in the order of 1 to 3 million years. After periods of massive extinction, the recovery of species diversity to its original levels by evolution and speciation has taken in the order of 10 to 100 million years, as evaluated by the fossil records. That is, biological diversity accumulates at a geologic time scale of millions of years, but is being destroyed at human time scale of decades. If global change has a significant effect on life on Earth, there will be no chance whatsoever for evolution to compensate the loss with the development of new species in a comparable time scale. If we were to represent the scale of speciation and of extinction on a pair of orthogonal axes, the horizontal axis (representing speciation times) would be 10,000 km long, while the vertical axis (representing extinction rates) would be around 10 cm high, not much higher than a matchbox!

A similar argument, of course, can be put forth for the migration of floras. The semiarid, high-endemism relict refuge areas that were discussed earlier indicate that 14,000 years after the last glaciation, floras and faunas still retain a biogeographic "memory" of their Pleistocene refuges. Although we cannot see the process because the time scale is so slow, the clumped distribution of biodiversity in terrestrial habitats (see Fig. 7) indicates that the biota are still far away from biogeographic equilibrium (i.e. there is slow migration radiating from the refugia). The migration rate of groups of organisms is, indeed, very slow. In some long-lived perennial plants, migration may occur at a rate of a few hundred meters per generation, and a generation may take over 100 years. As a matter of fact, generation time for columnar cacti and many other perennial trees of dryland areas, is well above a century. There is, quite obviously, little chance for the refuge mechanism to operate in response to man-induced global environmental change if the latter produces significant transformations in less than a century. The time scales simply do not match.

Conserving the planet's biodiversity is a problem of the highest priority. Mankind needs, in the most urgent manner, to learn how to make the growing needs of human populations compatible with the necessity to conserve the threatened species and habitats, and how to use exploitable ecosystems in a sustained way. Otherwise, future generations will never understand how our legacy was culturally so rich and biologically so degraded.

Research priorities

A few conclusions can be extracted from the previous discussion, which will help to understand the proposed set of research priorities:

a) Drylands in Latin America occupy mostly the middle latitudes (e.g. the Monte Desert and the Dry Chaco in Argentina, or the Chihuahuan Desert and grasslands in Mexico), but some very important dryland areas are found within the tropics (e.g. the Guajiran region, the Pacific coastal deserts, and the Caatinga). The importance of these tropical drylands lies not in their extension but in their extraordinary level of endemism and in their high biodiversity.

b) The Latin American drylands are being degraded rapidly by overgrazing, deforestation and soil erosion. There are few serious evaluations of the importance and rate of degradation of drylands in the continent: most of the efforts in this sense are directed towards the humid tropics. Furthermore, no attempts have been made to estimate the numbers of species that are menaced at present by habitat destruction in dry ecosystems.

c) There is good reason to believe that the tropical drylands are more fragile in terms species extinction and desertification risks than the temperate dry systems.

d) Gathering of natural products in Latin American drylands is still an extremely important source of income for many people. Governments tend to disregard these activities as economically irrelevant for the national economies, and prioritize other resource-degrading activities like cattle and goat grazing and pumping irrigation. No serious evaluation has been made on the cost efficiency of dryland gathering against the modern, highly subsidized alternatives.

e) The Latin American drylands have been the origin of many modern crops, and in many cases they are still an extremely important source of germplasm for crop improvement. Traditional crop varieties are often highly endemic and ecologically rare, and many of them still survive in vulnerable dry ecosystems such as the altitudinal belts of the Andes or the dry tropical plateaus of southern Mexico. Many areas where traditional agriculture survives are a major source of genetic diversity for present and future crop-breeding programs. Global deterioration of these ecosystems could affect the capacity of the world's food system to develop new varieties for future cultivation.

With these conclusions in mind, a set of research priorities can be put forth:

a) Research on biodiversity should be placed in a high priority for Latin American drylands. This is especially true in the case of tropical arid and semiarid ecosystems, where endemism and species richness are both very high. This does not mean that emphasis should be placed on more species inventories (although these are needed), but rather that the ecological and biogeographic patterns of selected taxa with a high number of endangered species should be studied in detail.

b) _In situ_ conservation should be prioritized, both for economic and social reasons. It is cheaper to preserve crop germplasm in the field, it is ecologically more adaptive, and the property of the germplasm source remains in the hands of the indigenous populations. More research is needed on the preservation of local crops and of their genetic variability.

c) Studies are needed to understand and manage better the harvesting of natural populations from the wild without endangering the long-term maintenance of the natural populations themselves. This includes the harvesting of wild plants for food and natural products, the use of wild animals, and the extraction of grasses and shrubs through cattle grazing or goat grazing.

d) Research should be done to understand the effect of climatic anomalies (e.g. El Niño events, tropical cyclones) on the establishment of xeric plants and dryland animals. Future changes in the frequency of these anomalies through the mechanisms of global climatic change may have a strong impact on the renewability of dry environments.

e) Studies of functional morphology and adaptation of dryland plants should be made in areas where information is scanty (most of these studies have been made in the temperate deserts of the U.S. and Israel). How many alternative strategies have plants evolved to cope with drought, and which are more efficient in tropical drylands? A good answer to this question may undoubtly help to design more efficient production systems in the future.

Research in Latin American Drylands

Quite expectedly, the highest level of expertise on dryland ecology is found in the Latin American countries with (a) the highest proportion of arid zones, and/or (b) with a more developed research system. The countries concentrating the best research groups in dryland ecology are Argentina, Chile, Mexico and Venezuela, followed by Brazil and Peru.

In this section, the research capabilities of each of these countries are discussed. The quality of research was judged by the amount of published work that the different research groups produce in international journals. I am aware that this standard of measurement can be legitimately questioned for the reality of Latin America, but unfortunately one of the best ways we have at present to learn about the research done by different groups from other countries is through their published work. Additionally, other research groups that are known to me directly or by reference from third parties are included, even if their publication record is poor.

Two data bases were consulted to prepare this section: the Directory of Latin American Ecologists (DECA), compiled and edited by Dr. Jorge Rabinovich from Fundación Sirena, Buenos Aires; and BIOSIS at the Center of Scientific Information of the Universidad Nacional Autónoma de México. In some cases, the Citation Index, published by the Institute for Scientific Indexation (ISI) was also consulted.

ARGENTINA

1.- Universidad de Buenos Aires

The University of Buenos Aires has two important groups doing research in desert ecology: one is found at the Faculty of Agronomy (Facultad de Agronomía), and the other at the Faculty of Sciences, in the School of Biology (Facultad de Ciencias, Carrera de Biología). Within the Faculty of Agronomy, the most consolidated group, working directly on problems of resource management in semiarid environments, is in the Departments of Ecology and Plant Physiology. The academic leader and founder of these groups is Ing. Agr. Alberto Soriano, one of the most outstanding Argentine ecologists. Within their many research interests, this group has developed a longstanding research line on the range ecology of the Patagonian Steppe, one of the more important semiarid regions in South America. Their study conform by now a series of oft-cited, almost classical research papers on grassland management and plant ecology in semiarid temperate grasslands and steppes. Their research interests include: natural resource evaluation and management in semiarid temperate grasslands, resource partitioning in steppe vegetation, plant establishment in steppe ecosystems, the effect of grazing in vegetation structure, large-scale resource inventory and vegetation mapping through satellite image analysis and GIS's, and water dynamics in the Patagonian Steppe. Without any doubt, this group is one of the best research teams in Latin America, publishing intensely in international journals and high-impact scientific books. One of their principal researchers, Dr. Osvaldo Sala, is very active within the International Geo-Biosphere Programme, apart from being a top-class, renown ecologist in temperate semiarid grasslands. Some of the more outstanding members of this team are the following:

Ing. Agr. Alberto Soriano. Team Leader
Dr. Osvaldo E. Sala. Principal Investigator
Dr. Martín Oesterheld. Principal Investigator
Ing. Agr. José M. Paruelo.
Ing. Agr. Martín R. Aguiar.
M.C. Rodolfo A. Golluscio.

Apart from the above-cited researchers, working chiefly in the Patagonian Steppe, other researchers from this group have also made studies in Patagonia. Within these, two researchers must be mentioned in particular: Drs. Rolando León and Chiara Movia, who work mostly in the floodable ecosystems of the Salado River depression, but have made important contributions to the ecology of semiarid Patagonia. Lastly, and also within the Faculty of Agronomy, Drs. Diego Medán and Roberto Tortosa, from the Department of Botany (Cátedra de Botánica) have studied for almost ten years the reproductive habits of the Rhamnaceae in Argentina. This family of higher plants is basically of semiarid distribution, and their studies are important contributions to the knowledge of tropical drylands in Argentina.

In the Faculty of Sciences, researchers from various Departments make research in arid and semiarid environments. At present, there are two researchers that can be considered academic leaders in their fields. The first one is Dr. Osvaldo Reig, that works in the ecology of small mammals, many of the distributed in dryland environments. The second one is Dr. Jorge Rabinovich, who is not a full-time researcher at the faculty but directs students and frequently teaches at this school. Dr. Rabinovich works in the ecology and demography of game and fur animals, especially of the Patagonian Steppe. These two researchers have published and still publish actively in high-quality international journals, and constitute the strongest academic nucleus of the Faculty; and indeed, they are within the most reputed ecologists in Latin America. Academically younger and less renown than these two researchers, M.C. Jorge Adámoli directs a research group in vegetation ecology, and has done research in the Dry Chaco. In spite of the excellent quality of some of the researchers, no group of the Faculty of Sciences can be defined as dedicated to the ecology of dry regions, in the sense that their research does not hinge around the set of problems dealing with drought as a central environmental problem. Notwithstanding, the research of some members of this faculty is of great importance in the context of Argentine ecology. The research lines of this faculty include: Population biology and evolution of tuco-tucos (Ctenomys), vegetation ecology of the Dry

Chaco, seed predation and dispersion by iguanas and ants in the Dry Chaco, reproductive behaviour of the vicuña, ecology and management of the Patagonian red fox, of the Argentine iguana (tupinambis) and of the Patagonian rhea (Pterocnemia pennata). The most important researchers in this Faculty are the following:

Dr. Osvaldo A. Reig. Group Leader, Mammalogy. Doctor Honoris Causa. Universidad Autónoma de Barcelona.
Dr. Jorge Adámoli. Group Leader, vegetation science.
Biól. María Luisa Bolkovic.
Dra. Bibiana Vila.
Biól. Angel Francisco Capurro.
Biól. Luis Alfredo Alvarez.

The Faculty of Sciences of the University of Buenos Aires has also a number of students doing Ph.D. studies in foreign universities, with the intention of joining the Faculty when they finish their graduate research. The following four are mentioned for the relevance of their work to dry environments::

Biól. Alejandro Travaini (Estación Biológica de Doñana, Spain)
Population ecology of wild foxes.

M.C. Marcelo Adrián Aizen (University of Massachusetts, Amherst)
Habitat fragmentation and reproductive success of plant species in the Chaco.

M.C. Andrés Novaro (University of Florida, Gainesville)
Feeding habitats of the Patagonian red fox.

Biól. Cristina Mourelle (Universidad de México)
Biogeography of Argentine cacti.

2.- **Instituto Nacional de Tecnología Agropecuaria**

The Instituto Nacional de Tecnología Agropecuaria (INTA) is an applied research institute that is financed by an export tax on Argentine agricultural products. It has a large research station in Buenos Aires, and a number of regional research stations throughout the country. It is possibly the best equipped and most affluent research institution in Argentina. The main research stations dealing with arid and semiarid environments are the following: Trelew and Bariloche in the Patagonian Steppe, Anguil and Villa Mercedes in the semiarid Pampas, La Consulta in the irrigated slopes of the Andes in Mendoza, Añatuya in the Dry Chaco, and Cerrillos in Salta, dealing with the both the Puna and the Dry Chaco. Most of the research done at INTA is applied, and in the case of drylands it is directed towards the management of natural vegetation and of wild populations of animals. Among the many research lines of INTA, the most important are the inventory of natural resources at a regional scale, regional floras, satellite image processing and GIS's, soil mapping and inventorying, management of natural ranges, autoecology and phenology of forage species (grasses and shrubs), rehabilitation of saline soils, management of wild animal populations (guanacos, rheas, foxes, etc.), conservation of native range species, and evaluation of the effect of overgrazing in natural ranges. Among the researchers working at INTA, the following are doing research in dry ecosystems:

Dra. Griselda Luz Bonvissuto
Dr. Donaldo Eduardo Bran
M.C. Never Bonino
M.C. Gustavo Daniel Maccarini.
M.C. Nicasio Matías Rodríguez
M.C. Alberto Hans Zappe
Ing. Agr. Rubén Edgardo Godagnone.
Ing. Agr. Roberto Raúl Casas.
Ing. Agr. Oscar Antonio Terenti
Ing. Agr. J. Carlos Bustos
Ing. Agr. Juan Pablo Ghilardi
M.Vet. Daniel Victorino Sarasqueta
Ecóloga Julieta Von Thungen
Biól. Gabriel Esteban Oliva
Vet. Javier P. Bellati
Geól. Juan Carlos Salazar Lea Plaza.

3.- Instituto Argentino de Investigaciones en Zonas Aridas

The Instituto Argentino de Investigaciones en Zonas Aridas (IADIZA) is located within a large research facility in Mendoza, called the Centro Regional de Investigaciones Científicas y Tecnológicas (CRICYT). Its researchers often lecture at the Universidad Nacional de Cuyo. This is the only research institution in Argentina that is exclusively dedicated to the problems of arid environments. Although its researchers do not publish as much as those of the University of Buenos Aires, and many of their research papers come out in local journals, their research is of excellent quality. Additionally, the IADIZA manages the Ñacuñán Biosphere Reserve, a sister reserve of the Mapimí Reserve in Mexico and one of the few successful dryland reserves in South America. They have a joint collaboration programme with the Instituto de Ecología in México, with the objective of doing comparative research in both reserves. This program can be the seed for future studies of global environmental change in Latin American drylands.

The IADIZA is based on three academic leaders that direct different research groups. Dr. Fidel Roig, a reputed arid zone vegetation researcher, heads a group working in natural resource inventories, vegetation analysis, and plant taxonomy. Virgilio Roig, currently at the Universidad de Cuyo, but formerly at IADIZA and still directing students there, founded a group working in animal ecology and management of wild animal populations. Finally, Bruno Cavagnaro, an excellent plan physiologist, founded a group working in grass ecology and water physiology. The main research lines of the IADIZA are: vegetation inventories, ecophysiology of grasses in dry ecosystems, germplasm collection of native grasses, environmental impact assessment in arid ecosystems, granivory in desert ecosystems, ant ecology, ecology of fossorial rodents (Ctenomys), ecology of the guanaco (Lama guanicoe), bird community ecology, desertification, primary productivity of forage species, environmental urbanistic design for dry regions. The main researchers at this center are listed bellow (those currently at the Universidad de Cuyo are marked by an asterisk):

Dr. Fidel A. Roig
M.C. Virgilio Germán Roig (*)
M.C. Juan Bruno Cavagnaro
Dr. Ricardo Alberto Ojeda
Dra. Silvia Puig
Dr. Luis Marone (*)
M.C. Eduardo Martínez Carretero
Biól. Iris Peralta
Zool. Silvia Claver
Biól. Sergio Ramón Camín
Biól. Fernando Videla
Biól. María Irene Rosi
Ing. Agr. Carlos Passera
Ing. Alfredo Estevez Miramont
Arq. Carlos De Rosa

4.- **Centro Nacional Patagónico (CENPAT)**

The CENPAT is located in Puerto Madryn, in the Province of Chubut in Patagonia. It originated as a research center dedicated primarily to the marine environments of the Patagonian coast. Lately, however, the Department of Arid Zones has been growing steadily. This department is dedicated mostly to study the terrestrial ecology of the Patagonian Plateau near Puerto Madryn. Its main research lines are: plant community analysis, range management, shrub ecology, wildlife ecology and management, primary productivity and establishment of range vegetation, soil inventories and classification, soil science, and grazing by wild animals. This group collaborates closely with Dr. Jorge Ares, a prominent range ecologist working currently for Aluminio Argentino S.A. (an aluminum smelter plant). Together they have published a number of papers and a review book-chapter on the ecology of Patagonian grasslands. The most important researchers in this group are:

Dr. Jorge Oscar Ares
Dr. Mario Rostagno
Dr. Jorge Garrido
Dra. Ana María Beeskow
Dra. Mónica Beatriz Bertiller
M.C. Héctor Francisco Del Valle
Dr. Marcelo Osvaldo Camezzana
Dr. Daniel Alfredo Delamo
M.C. Guillermo Emilio Defossé

5.- Universidad Nacional de Salta

The number of researchers doing dryland ecology at the Universidad Nacional de Salta has grown considerably in the last years, after the incorporation of Marta de Viana (M.Sc. University of Jerusalem) and Jorge Protomastro (Ph.D. Univ. of Buenos Aires). Although academically very young, this group is successfully managing and doing research in the Cardones National Park in Salta. Its publication rate is still relatively low, but I would predict that this group is likely to gain presence in the research scenario in the future. Its main research lines are: management of the Cardones National Park, ecology of tinamus, dune ecology, ecology of game animals, and plant-animal interactions in the dry Chaco. the researchers of the University of Salta working in dryland ecology are the following:

Dr. Jorge Juan Protomastro
M.C. Marta de Viana
Ing. Rec. Nat. Sergio Gustavo Mosa
Geól. Felipe Rafael Rivelli
Ing. Rec. Nat. Francisco Ramón Barbarán
Biól. Sandra Mónica Caziani

6.- Universidad Nacional de Córdoba

Dryland ecology at the Universidad Nacional de Córdoba hinges around three important research groups. Zoology and animal ecology is done at the Instituto de Zoología Aplicada, an important research center whose academic leader is Dr. Enrique Bucher. Plant Ecology and Vegetation Science are studied at the Department of Land Botany (Cátedra de Geobotánica) of the Faculty of Sciences, where the founder of the group and academic leader is Dr. Ricardo Luti, a well-known Argentine plant ecologist. Finally, applied aspects of range management and ecosystem use are studied at the Faculty of Agronomy, where the academic leader is a young and enthusiast ecologist, Ing. Agr. Ula Karlin. The interests of the different research groups incorporate the following subjects: population ecology of the parrokeet _Myopsitta monachus_, vertebrate ecology and management in semiarid woodlands, vegetation of the Province of Córdoba, the effect of disturbance on semiarid grasslands, the structure of grassland communities, plant architecture in the semiarid Chaco, gum production in the brea tree _Cercidium praecox_, invasion of grasslands by woody shrubs, and improvement of natural ranges. Some of the researchers at the Universidad de Córdoba are listed below.

Dra. Martín, Liliana Fresia
Dra. Kufner, Maura Beatriz
Dr. Cabido, Marcelo Rubén
Dra. Acosta, Alicia Teresa
Dra. Díaz, Sandra Myrna
Biól. Losano, María Alejandra

M.C. Alessandria, Esteban Emilio

7.- Other Institutions

Many other institutions in Argentina have research lines that deal directly or indirectly with drylands. The Universidad Nacional del Sur in Bahía Blanca has a research group that was founded and is currently directed by Dr. Osvaldo Fernández, a well-known ecologist of the semiarid Pampas. This group is devoted to study range and plant ecology in the dry Pampas. Their research lines include above-ground and below-ground productivity in semiarid grasslands, autoecology of the invader woody shrub Geoffroea decorticans (chañar), mycoflora of Geoffroea, and the effect of grazing on grassland productivity. The group is formed by Dr. Osvaldo Fernández, Ing. Agr. Tomás Montani, Dr. Carlos Alberto Busso, and Biól. María Virginia Bianchinotti.

The Universidad Nacional del Comahue in Bariloche, Province of Río Negro, has a group studying the ecology of weeds under the direction of Dr. Eduardo Rapoport, one of the top Latin American biogeographers. Although this group is not directly devoted to dry ecosystems, they have an enclosure in the Patagonian Steppe where they are studying the establishment of alien weedy species. Also in the Province of Río Negro, the Ministerio de Recursos Naturales has a group of researchers and technicians doing studies in wildlife management in the dryland ecosystems of Northern Patagonia. Among other topics, they are studying the management of guanacos, red foxes, pumas, and coipos (Myocastor coipus).

In the Province of Tucumán, the Universidad Nacional de Tucumán and the Fundación Miguel Lillo, both renown some decades ago for their research in dry ecosystems, have lost much of their interest in this type of environment, and seem to be concentrating more on the wet ecosystem of the Yungas. Some researchers, however, are still working in dry environments: Dr. José Manuel Sáyago of the Universidad is evaluating natural risks in the region including the dry areas, and Dr. Juan Antonio González, is studying the ecophysiology and photosynthetic pathway of high-altitude xeric plants.

In the Universidad de San Juan, a group of architects and engineers is doing research on urban design for dry regions. In the Universidad de San Luis, research is being done on resource use in semiarid systems, physiology of crycetid dryland rodents, natural resource inventorying, and land use planning. The main researchers at this university are Ing. Agr. Enrique Ocampo, Biól. Liliana Ciuffo, Dr. Enrique Caviedes-Vidal, Dr. Héctor Capurro, and Geól. Juan Carlos Trani. At the Universidad Nacional de La Pampa, Héctor Cazenave and Pedro Cuello are studying the hydrology of the semiarid Pampas.

In the Universidad Nacional de Jujuy, a group has formed recently around the academic leadership of M.C. Rolando Braun Wilke, a productive researcher in plant ecology of drylands. The group is formed by M.C. Luis Pablo Picchetti, Biól. Martha Gladys Arce de Hamity, and Biól. Lilia Neder de Román. They have a good connection with the Instituto de Ecología in Mexico, and with the Universidad Nacional Autónoma de México, where one of their researchers (Mr. Picchetti) obtained his Masters degree. Their research interests include management and control of insect pests, resource inventorying in the region, vegetation mapping, genecology and cultivation of Prosopis spp.

At the Centro de Ecofisiología Vegetal (CEVEG), a basic research institution in Buenos Aires, Dra. Marta Beatriz Collantes, Dr. Juan Anchorena and Dr. Ana María Faggi are working in different aspects of range management and plant ecology in the Patagonian Steppe. This research group is quite productive and publishes frequently in international journals.

At the Instituto de Investigaciones Aplicadas en Ciencias Espaciales research is being done on biomass estimation in arid zones through satellite image analysis (Ing. Agr. Guillermo Alberto Ibáñez). At the Universidad de Mar de Plata there is a solid group of palinologists and paleoecologists, some of which are studying the environmental history of arid ecosystems in Argentina (Dr. Aldo Prieto, Dra. María Mancini, and Dra. Marta Páez). At the Universidad Nacional de la Patagonia in Trelew, researchers are studying lichens as indicators of air quality (Oscar Pérez de la Torre), orybatid mites as decomposers of organic matter in arid ecosystems (Biol. Miriam Argañaraz), and the ecology of crycetid rodents and muskrats in the Ptagonian Steppe (Dra. Silvia Dahinten). Finally, at the Universidad Nacional de Santiago del Estero, research is being done on the wood structure of woody plants from the Dry Chaco (Ing. For. Ana María Giménez).

MEXICO

1.- Instituto de Ecología

As many other research centers in Mexico, the Instituto de Ecología is an autonomous research institution, financed partly by government funds and partly by research grants of different origin. It manages the Mapimí Biosphere Reserve in the heart of the Chihuahuan Desert and publishes three journals that frequently include papers dealing with dryland ecology: Acta Zoologica Mexicana, Acta Botanica Mexicana, and Folia Entomologica. It has cooperation programs with research institutions from many countries, including the IADIZA in Argentina. The Mapimí Reserve is linked through this cooperation program with the Ñacuñán Reserve in Mendoza, Argentina. The founder of the Mexican Biosphere Reserves, and also academic leader and Director of the Instituto de Ecología is Dr. Gonzalo Halffter. At present, one of the most productive researchers in the Instituto is Dr. Carlos Montaña, a plant ecologist. Dr. Montaña publishes intensely in very prestigious journals, and has contributed many book chapters on the ecology of the Chihuahuan Desert. The research lines of the Instituto de Ecología in the Mapimí Reserve include: plant community ecology, lizard ecology, ecophysiology of desert plants, conservation science, range management, hydrology, soil science, ecology of granivorous ants and birds, ecology of Escarabeid beetles, ecology of granivorous rodents, conservation of the endangered desert tortoise (Gopherus flavomarginatus), and wildlife management. Among the researchers of the Instituto, the following have done significant work in arid ecosystems:

Dr. Halffter Salas, Gonzalo
Dr. Montaña, Carlos
Dra. Maury, María Eugenia
Biól. Rojas-Fernández, Patricia
M.C. Gustavo Aguirre
Dr. Jorge Nocedal
M.C. Jorge López-Portillo

2.- Universidad Nacional Autónoma de México (UNAM)

The Universidad Nacional Autónoma de México (UNAM) is the largest University in Latin America, and by virtue of its sheer size it concentrates a number of researchers working in dryland ecology. The two main research centers doing environmental research in dry ecosystems are the Centro de Ecología and the Instituto de Biología. Both institutions have a very high quality of research, and in both all researchers being admitted at present must have at least a Doctorate and a good number of original publications in order to be accepted (older researchers may have a Ph.D., but a very high level of published work is demanded to maintain a post).

The Instituto de Biología is oriented mostly towards taxonomy and the curatorship of collections. Their research is oriented towards management of collections and towards the inventory of floras and faunas. Their research lines in arid and semiarid environments include: the flora of the Tehuacán Valley, the flora of Tamaulipas, systematics and biogeography of cacti and dryland legumes, arid land halophytes and gypsophytes, and the mammals of Chihuahua. Their main researchers are M.C. Francisco González Medrano, Dr. Patricia Dávila, M.C. Javier Valdés, M.C. William López-Forment, and Dr. Héctor Hernández.

The Centro de Ecología is oriented towards ecological research, and offers a Ph.D. course in Ecology. It inaugurated recently a regional center in Hermosillo, Sonora, to study the ecology of the Sonoran Desert. Another group (E. Ezcurra) is working in the semiarid Tehuacán Valley in Southern Mexico. The researchers from the Centro de Ecología working in dryland ecology are the following: Dr. Exequiel Ezcurra, Dr. Alfonso Valiente, Dr. Alberto Búrquez and Dra. Angelina Martínez. Their research lines include: structure and functioning of xerophytic woodlands, floral biology and pollination ecology in arid plants, demography of columnar cacti, functional morphology in xeric plants, and biogeography and conservation in arid tropical ecosystems.

3.- Centro de Investigaciones Biológicas de Baja California Sur

The Centro de Investigaciones Biológicas de Baja California Sur (CIB) is organized in a similar way as the Instituto de Ecología. It is an autonomous research institution, financed both by government funds and independent grants. It is located in La Paz, Baja California Sur, and is reputed by its Division of Oceanography, which is one of the best in Mexico. It has also a Division of Biotechnology, and, lastly, a Division of Terrestrial Ecology, which is headed by Dr. Alfredo Ortega. The Division of Terrestrial Ecology is academically very young, most of its researchers are below 30 years of age. It is chiefly oriented towards studying the semiarid woodlands of the Sierra de la Laguna, an endemism-rich region in the tip of the Peninsula of Baja California. The group has also worked in the Vizcaíno Desert in the central part of the Peninsula, and has done research in the Revillagigedo Archipelago, a group of semiarid islands some 400 miles off the Mexican Pacific coast. In spite of its youth, the group is quite active in publishing their research results, and they have also done a number of consulting jobs for government environmental planners. Their research lines include: natural resource management, ecology of desert rodents and small mammals, plant community ecology, ecology of disturbance in dry ecosystems, effect of grazing and range management, alternative dryland crops, water physiology in plants, faunal inventories, reptile ecology, arthropod taxonomy (Diptera and Spiders), control methods for fruit-flies, bird inventory, and ecology of raptor birds. Its most important researchers are the following:

Dr. Ortega Rubio, Alfredo (Director of the Division)
Dra. Jiménez, María Luisa
M.C. Arnaud, Gustavo
M.C. Arriaga-Cabrera, Laura
M.C. Jiménez Sierra, Cecilia
M.C. Troyo-Dieguez, Enrique
Biól. Alvarez Cardenas, Sergio
Biól. Galina-Tessaro, Patricia
Biól. Rodríguez Estrella, Ricardo

4.- Centro de Investigación Científica y Educación Superior de Ensenada (CICESE).

CICESE is located in Ensenada, the main port of Baja California Norte and one of the biggest ports in Mexico. Like CIB, it is renown for its oceanographical research, and terrestrial ecology is fairly new in this center. Even so, the quality of their research is good, and at present the whole department of ecology (which includes a majority of marine biologists), is headed by Dr. Eric Mellink, a desert ecologist. The research interests of dryland ecologists at CICESE include the ecology of the chaparral in Baja California, mathematical models for natural resource management, demography of columnar cacti, assessment of endangered species and habitats, and the management of exotic herbivores in Mexican dry ranges. In close collaboration with this group, Dr. Ileana Espejel at the University of Baja California in Ensenada is doing vegetation studies of the Californian Chaparral, and of the coastal, mediterranean-type vegetation of the northern part of the Peninsula. The Universidad Autónoma de Baja California also offers a Master degree in arid-zone ecology. The main researchers in this group are the following:

Dr. Eric Mellink (Head of the Division)
Dr. Joaquín Sosa
Dr. Echavarria Heras, Héctor
M.C. Solana Arellano, María Elena
Biól. Mario Salazar

Dra. Ileana Espejel (Universidad Autónoma de Baja California)

5.- Centro de Ecología de Sonora

The Centro de Ecología de Sonora is a regional research center financed by the State of Sonora and by local support funds. It was founded in 1985, following the ideas and philosophy of the Sonora-Arizona Desert Museum in Tucson. It consists of a main facility in the outskirts of Hermosillo, with a large natural reserve behind the live museum. Originally it was chiefly dedicated to exhibitions and popularization of desert ecology. In recent years it has initiated a series of research lines on dryland ecology. Its main research lines include:

management and recovery of populations of the Sonoran pronghorn antelope (Antilocapra sonoriensis), the Mexican wolf (Canis lupus baileyi), the Sonoran Desert tortoise (Xerobates agassizii), and the Sonoran quail ("codorniz mascarita" Colinus virginianus ridgewayi), wildlife management, conservation of riparian ecosystems, and inventory, management and conservation of freshwater fishes in the State of Sonora. Its main researchers are included in the following list:

Biól. Castillo-Sánchez, Carlos
Biól. Meléndez Torres, María Cristina
Biól. Campoy Favela, José Rafael
M.C. Garza Salazar, Florentino
Biól. Varela-Romero, Alejandro

6.- Instituto Nacional de Investigaciones Forestales y Agropecuarias (INIFAP)

In a similar way as the INTA in Argentina, the INIFAP in Mexico is a national institute for applied research in management of rural systems. It has a central research station in Mexico City, and a number of research stations throughout the country, two of the which (Zacatecas and Chihuahua) are dedicated to study the management of natural ecosystems in dry regions. A third research station (Ciudad Obregón, in Sonora) is devoted to the study of agricultural systems in dry regions under irrigation. Most of the research done at INIFAP on dryland systems is related to grassland ecology, range management, and watershed management. The founder of dryland ecology at INIFAP is Dr. Ramón Claverán (Ph.D. Tucson, Az), who is also at present the Institute's general research director. Other outstanding researchers at INFAP are Dr. Carlos Sánchez Brito, and M.C. Abraham De Alba.

7.- Other Institutions

Many other institutions in Mexico do research in dry ecosystems. One of the most outstanding ones is the Colegio de Posgraduados, formerly the graduate section of the Universidad Autónoma de Chapingo, and presently and independent research and graduate teaching center at Texcoco, near Mexico City. The Colegio de Posgraduados has an arid zone research station at Salinas, San Luis Potosí, in the Southern part of the Chihuahuan Desert. Two of the researchers exclusively dedicated to dryland ecology are M.C. Angélica Romero Manzanares and Dr. Edmundo García Moya. The first one works in grassland ecology and pinyon-pine demography in arid ecosystems, while Dr. García Moya works halophyte ecology, plant community ecology, and on the autoecology of pinyon pines (Pinus cembroides) and of maguey (Agave spp.). Both researchers are first class in their areas, and have published in prestigious international journals.

Near the Colegio de Posgraduados, at Texcoco, the Universidad Autónoma de Chapingo has a project on rational use of arid shrubs in the North of Mexico, under the direction of Biól. Salvador Valenzuela-Pérez. Chapingo also has an arid-zone field station near Bermejillo, in the State of Durango.

In Mexico City the Universidad Autónoma Metropolitana has a research group working in arid zones. This group is formed by three researchers: M.C. Alejandro Zavala, Biól. Fernando Vite and M.C. Miguel Martínez Armella. Their interest lies in establishment of cactus species, nurse-plant relationships, and demography of xeric plants.

Other universities with a projection towards dry ecosystems are the Universidad Nacional Agraria "Antonio Narro" in Saltillo, Coahuila, the Universidad Autónoma de Nuevo León, and the Universidad Autónoma de Chihuahua. The three of them have some groups working in arid ecosystems: M.C. Julio Carrera leads a group in wildlife ecology at Saltillo, Dr. Jorge Marroquín leads a research group in vegetation ecology both at Saltillo and Linares, Nuevo León, Dr. Salvador Contreras Balderas leads the laboratory of desert fishes at Monterrey, Nuevo León, and M.C. Alberto Lafón studies aquatic migratory birds at Chihuahua.

A research group at the Universidad Autónoma de San Luis Potosí, in the Southern part of the Chihuahuan Desert, is working in propagation and cultivation of arid plants, in desert hydrology, soil science, ecosystem degradation and natural resource management. A small group is starting at the University of Puebla studying cactus demography.

Finally, the Comisión Nacional de Zonas Aridas (CONAZA) must be mentioned as an organization doing research efforts in arid ecosystems. CONAZA does mostly applied research and its members do not publish frequently their results. However, they have a large and important network of researchers in different arid parts of Mexico. Their research interests include: range management and reseeding, erosion control and water casements, family backyard production, natural resource inventories, collection of medicinal and aromatic herbs, production of industrial dye from scales ("cochinilla" Dactylopidus coccus) in prickly-pears (Opuntia sp.). Most of the CONAZA researchers do not have postgraduate studies.

CHILE

1.- Universidad de La Serena

The Universidad de La Serena, near the port of Coquimbo in North-central Chile, is in border of the central Chilean matorral and the northern desert. Its researchers have specialized in the arid-zone ecology of the region. The researchers at La Serena are highly reputed in Latin America for the quality of their work. One of the founders of ecological research at La Serena was Dr. Juan Armesto, now at the Universidad de Chile but still collaborating with the group and doing research in the area. The research interests of ecologists at La Serena include: ecophysiology of desert organisms, thermoregulation in desert lizards, environmental impact assessment of mining industries, trophic relations in the fauna of the semiarid matorral, ecology and evolution of rodents, arthropod ecology, and taxonomy, cytogenetics and evolution of dryland animals. The group at La Serena is formed by the following researchers:

Dr. Julio R. Gutiérrez
Dr. Squeo, Francisco Antonio
Biól. Cortés Maldonado, Arturo
Dr. Contreras, Luis C.
M.C. Palma, Cludio Hernán
Dr. Cepeda-Pizzarro, Jorge G.

2.- Universidad de Chile

The Universidad de Chile concentrates one of the best research groups in the country (the other excellent group is the one from the Universidad Católica). Two of the main academic leaders at this university are Dr. Juan J. Armesto, a highly-reputed dryland ecologist, and Dr. Mary Kalin de Arroyo, a very well-known botanist. Dr. Kalin is the founder and head of the Latin American Botanical Network (RLB), a very successful organization which coordinates graduate studies and cooperation research between botanists and plant ecologists of Latin America. Although not exactly a desert botanist, Dr. Arroyo has done some excellent studies on the distribution of the photosynthetic metabolism of some desert genera (e.g. Callandrinia spp.).

The interests of the research group at the Universidad de Chile with respect to dry environments includes the following topics: energy balance in Akodon desert rats, geomorphology and morphodynamics of dry environments, ecology of Chagas disease and other parasitic diseases, population biology ofTriatomini (the vectors of Chagas disease), management of wild chinchillas in the Andes drylands, management and breeding of native forage shrubs, range management in arid systems, seed-bank dynamics in the Chilean coastal desert, regeneration of degraded desert ecosystems, and soil and water management in drylands. The group at the Universidad de Chile is integrated by the following researchers:

Dr. Mary Kalin de Arroyo
Dr. Juan José Armesto
Dr. Bozinovic, Francisco
Dr. Cattan, Pedro E.
M.C. Durán Ríos, Juan Carlos
Dr. Lailhacar, Emilio Sergio
M.C. Vidiella Salaberry, Patricia
M.C. Castro Lucic, Milka Slavia
Geóg. Ferrando Acuña, Francisco José
M.C. Schenone, Hugo

3.- Pontificia Universidad Católica de Chile

The Universidad Católica de Chile has an outstanding program in Biology, and gives first-rate postgraduate training in Ecology. This is quite unusual for Latin America, where most private universities concentrate in applied, non-scientific careers.

The academic leaders of the ecology group at the Faculty of Biological Sciences of the Universidad Católica de Chile are Dr. Eduardo Fuentes and Dr. Fabián Jaksic, two highly-prestiged ecologists that publish actively in the best international journals. The interests of this group hinge basically around the ecology of the mediterranean scrub (matorral) of Central Chile. In particular, the research at the Universidad Católica includes the following topics: simulation models in tropical savannas, landscape dynamics, vegetation response to human activities, predator-prey interactions, animal guilds, dispersion of woody shrubs, and fire ecology. The group at the Universidad Católica includes the following researchers:

Dr. Fuentes, Eduardo
Dr. Jaksic, Fabián
Dr. Prado, Carlos
Dr. Ernst Hajek
Bot. Alicia J. Hoffman

At the Universidad Católica there also is a Faculty of Agriculture, where Dr. Juan Gastó heads the Laboratory of Ecology. Dr. Gastó worked in Mexico at the Universidad "Antonio Narro" in Coahuila, during the 70's and 80's, and has excellent connections with Mexican agricultural ecologists and range managers. His main interests are the management of arid ranges, and perennial-plant agriculture in drylands.

4.- Other Institutions

Other academic institutions in Chile have an interest in drylands. The Universidad Católica de Valparaíso hosts at present the Chilean chapter of the Man and the Biosphere (MAB) program. Dr. Fernando Cosío, at this University, works in pastoral systems in dry Central Chile. At the Museum of Natural History, Biól. Inés Meza Parra studies the epidermic adaptations of plants in relation to environmental stress, and M.C. Juan Carlos Torres-Mura studies the ecology of Caviomorph rodents in central Chile. Finally, Biól. Rodrigo Alejandro Villaseñor Castro, a professor at the Universidad de Playa Ancha de Ciencias de la Educación, studies the pollination biology of dryland plants in Central Chile, as well as the impact of forest fires in this region.

VENEZUELA

1.- Universidad Central de Venezuela

The Universidad Central de Venezuela (UCV) is the largest University in the country, and the one which concentrates more researchers. Although the UCV is not directly located in an arid region, many researchers have in interest in arid-zone ecology, chiefly in plant ecology. Some students of the UCV are doing postgraduate work with Dr. Ernesto Medina, a plant physiologist from the Instituto Venezolano de Investigaciones Científicas, and the field of water physiology and water ecology is well-developed at UCV. the main researchers with an interest in arid ecosystems and their research subject are listed below:

Biól. Lindorf, Helga. Anatomy of woody plants in relation to environmental stress.
Biól. Tezara Fernández, Wilmer Adelso. Photosynthesis and transpiration rates in xerophytic plants.
Biól. Ríos, Liliana. Osmotic adjustment in Alternanthera crucis.
Biól. Taisma, María Angélica. Reproductive biology of plants in semiarid environments.
Biól. Fernández, María Dolores. Physiology of succulent (CAM) plants.
Dra. Urich, Rosa. Nitrogen fixation and drought resistance in xeric plants.
Dra. Herrera, Ana. Drought resistance in tropical xerophytic plants.
Ing. Agr. Trujillo, Baltasar. Xerophytic Flora of Venezuela.

2.- Universidad de los Andes

The Universidad de Los Andes in Merida has one of the most outstanding group of plant ecologists and phytogeographers in Latin America. Although most of the researchers work either in tropical savannas or in high-altitude ecosystems, which are not considered arid systems in a strict sense, both type of systems have severe problems of water availability at least during part of the year (in the case of savannas) or part of the day (in the case of páramo ecosystems). The ecologists of the Universidad de los Andes are organized in a research center (Centro de Investigaciones Ecológicas de los Andes Tropicales), in which the academic leaders are Dr. Guillermo Sarmiento (a savanna specialist) and Dra. Maximina Monasterio (a high-altitude ecologist). Some of the researchers are working in the arid valley of Lagunillas, near Merida and can be considered dryland researchers in a strict sense. The interests of the group of the Universidad de Los Andes, in relation to dry environments, include: metabolism in small mammals, pollination by bats in columnar cacti, water relations in plants of different life-forms, and vegetation surveys and inventories. The researchers of this group with an interest in drylands are:

Dr. Sarmiento, Guillermo

Dra. Maximina Monasterio
Dr. Mario Ramón Fariñas
M.C. Cabello Vilchez, Daniel Ramón
Lic. Sosa, Maricela del C.
M.C. Rada, Fermín J.

3.- Universidad Nacional Experimental Francisco de Miranda

The Universidad Nacional Experimental Francisco de Miranda is located in the State of Falcón, where the dominant type of ecosystem is a dry tropical thornscrub (Cabrera's Guajiran Province discussed earlier). The problem of aridity is a central question in this regional university, and a large proportion of their research efforts are allocated to study dryland ecology. In contrast with the two universities discussed earlier, however, this a new institution that still has a low impact in the scientific media. The main interests of the group at this university include: survey and inventory of xeric vegetation, biogeochemical cycles in arid ecosystems, inventory of small mammals of the region, tissue culture and clonal propagation of <u>Aloe vera</u>, water relations in xeric plants under natural conditions, thermoregulation in bats, and physiology of Caviomorph rodents and other arid-zone mammals. the group includes the following researchers:

M.C. López González, Lianette M.
M.C. Alarcón Perez, Clara Antonieta
M.C. Díaz, Miriam
Biól. Martino Giacalone, Angela María G.
Dr. Arends Rodríguez, Alexis

4.- Other Institutions

At the Universidad Simón Bolívar, Dr. Moritz Benado is studying the evolutionary ecology of <u>Drosophila</u>, a group with an important cactophyllic subgenera that is endemic to dry regions. M.C. José Antonio Pérez Roas, a researcher at the Centro Interamericano de Desarrollo Integral de Aguas y Tierras (CIDIAT) in Merida, studies the processes of salinization in dry arid soils.

BRAZIL

The Brazilian Caatinga and the driest parts of the Cerrado occupy the Northeastern part of the country, and lie in the states of Rio Grande do Norte, Pernambuco, Paraíba, and Piauí. These areas combine very low rainfall values with highly weathered, lateritic soils of extremely low fertility and high susceptibility of erosion. In a sense, the Brazilian drylands combine the worst of two worlds: lack of water with unfertile soils. The Brazilian drylands are among the poorest and less productive regions of the American Continent. The local Northeastern universities have dedicated a substantial effort to understand the ecology of this region, and should be mentioned in first place among the Brazilian institutions working in arid lands.

1.- Northeastern Universities and Research Centers

Universidade Federal de Piauí: The Universidade Federal de Piauí, in Teresina, is developing a group working in desertification and land use in the Brazilian Northeast. The group is headed by Dr. Valdemar Rodrigues, with the collaboration of Geog. Marta Linhares, and a group of research assistants. Their interest is the control and recovery of desertified areas in the region. Dr. Rodrigues made his Ph.D. at the Instituto Politécnico Nacional in Mexico, and still maintains strong links with Mexican researchers. He has published papers in co-authorship with Mexican desert ecologists, as well as some papers on his own on the causes of desertification in Brazil. He is open and willing to increase collaboration in arid land ecology between both countries.

Universidade Federal de Pernambuco: The Universidade Federal de Pernambuco, together with the Fundaçao de Ensino Superior de Pernambuco, has a research group working on problems of human ecology. The group is lead by M.C. Rachel Caldas Lins and M.C. Solange Fernandes Coutinho. Their research interests include the environmental preservation of slum areas and the evaluation of environmental and life quality in poor, undeveloped human settlements. This university has also a good school of agriculture, where research on the agroecosystems of the region is being carried.

Universidade Federal da Paraíba: In the State of Paraíba, Dr. Pedro Vieira de Azevedo heads a group on agrometeorology in semi-arid regions of the Brazilian Northeast.

Empresa de Pesquisa Agropecuaria do Rio Grande do Norte (EMPARN): The EMPARN is a regional research company, run by the State of Rio Grande do Norte. It is dedicated to agricultural research in the area. In particular, M.C. Luiz Antonio Cestaro, a researcher at EMPARN, is doing a phytosociological survey of the Caatinga in the state. He also works with his research group experimenting different management techniques for the sustainable use of the caatinga.

2.- Other research institutions

Empresa Brasileira de Pesquisa Agropecuaria (EMBRAPA): EMBRAPA is an independent, government-supported research venture dedicated to the promotion of Brazilian agriculture and rural production. It has many different research station throughout the nation, in a similar fashion to INTA in Argentina and INIFAP in Mexico. Although the main emphasis of EMBRAPA is towards the more productive wet tropical ecosystems, some of its researchers have an interest in dryland ecology. For example, M.C. César Domingues Teixeira and M.C. Edison Ryoiti Sujii, are doing research in biological control of weeds and pests for the semiarid lands of Brazil.

Dr. Italo R.A. Sherlock, a researcher at the Fundaçao Oswaldo Cruz (a very prestigious research foundation studying human parasitoses in Brazil), is working in the ecology of vectors of leishmaniasis and Chagas disease in the semiarid parts of the State of Bahia.

At the Universidade Federal de Minas Gerais Dra. María das Graças Sajo the morphological adaptations of some insects to the dry environment of the dry rocky areas ("campos rupestres") of Brazil. Dr. Alexandre Fernandes Bamberg, a professor at the Universidade de Brasilia, studies lizard ecology in semiarid ecosystems. At the Universidade de Sao Paulo, Dra. Sylvia Campiglia directs a research group studying the adaptations of invertebrates to dry environments. Finally, M.C. Walter Alves Neves, a researcher at the Museu Paraense Emilio Goeldi, makes anthropological research at the Atacama Desert in Chile.

PERU

The main research institution in Peru dealing with arid ecosystems is the Universidad Nacional Agraria "La Molina". At this university, the research leader in dryland ecology and management is Dr. Carlos López Ocaña, a highly distinguished specialist on the subject. Dr. López Ocaña heads an Institute within the university that is dedicated to the study of arid regions. Their approach is mostly applied, and the group has produced many interesting reports on arid-zone management. Dr. López Ocaña is also very active in international organizations, and is considered an international expert in arid zone ecology, conservation and management.

At the Universidad Nacional de San Agustín, in Arequipa, a series of studies are being made in dryland ecology. The academic leader of this group is Biól. Percy Carlos Jiménez Milón, Director of the herbarium. Their interests include the organization of a germplasm bank with seeds from native shrubs, the design of restoration techniques for degraded slopes of the Andes, the sustainable use of Andean woody scrubs, vegetation inventories, and wildlife conservation. The other researchers in the group are Biól. José Francisco Villasante, and Biól. Benjamín Davila.

At the Universidad Católica del Perú, M.C. Alejandro Camino is doing research on the ethnobiology of the dry slopes of the Andes, and on patterns of natural resource use by the indigenous population.

Finally, the Asociación Amazonia, an NGO, is promoting applied studies in some dry parts of the country. For example, Ing. For. Luis Alberto Churvinchaico Samaniego, a member of the association, is planning short-term projects fir rural areas in the dry Andes.

BOLIVIA

The majority of the research in dryland systems being done in Bolivia is carried-out at the Universidad Mayor de San Andrés, at La Paz. Professors from many faculties study aspects of dryland ecology, but very few of them publish actively in widespread journals. Hence, it is not easy to make a precise evaluation of the research being done in this country. The researchers of the Universidad de San Marcos with an interest in dry ecosystems are the following:

Geóg. Gonzalo Quintana Penaranda (Soil erosion and vegetation management in the Altiplano)
Bioquím. Ligia Bustamante (Peat-moss Rhizobia in the Altiplano)
Lic. Raúl Altamirano (Pollination ecology and seed dispersion in xeric plants)
Biól. V. Esther Valenzuela Celis (Functional morphology in Compositae. Plants of eroded soils)
Biól Emilia García, Director of the Herbario Nacional de Bolivia (Grass Taxonomy. Flora and vegetation of the Altiplano and the Puna).
Biól. María Cristina Ruiz Sanguino (decomposition of organic matter in desert soils)
Biól. Teresa Erika Tarifa (Ecology of the vicuña)
M.C. Cecile Morales, Director of the Instituto de Ecología (Biological control of pests by means of natural plant extracts)

Prospects for International Cooperation

How can increased international and regional cooperation be organized around the problems of dryland ecosystems? It seems to me that many efforts are already being made, although the chronic scarcity of financial resources in Latin America often cuts these efforts too soon. There have been cooperation efforts between the different countries both in postgraduate education and in joint comparative research. These two aspects seem to be the ones that generate more interest for cooperation programs.

Thus, increased international and regional cooperation should be organized around (a) cooperation efforts in postgraduate education, and (b) joint research projects hinged around the research priorities listed previously.

<u>Postgraduate Education</u>: Some Latin American countries (Argentina, Chile, Mexico and Venezuela) offer postgraduate courses in ecology, and in some of these curricula the students can concentrate his studies in dryland ecology. The quality of some postgraduate courses is very good and have gained international respect (e.g. Faculty of Agronomy, Universidad de Buenos Aires; Universidad Católica de Chile, Universidad de Chile; Centro de Ecología, Universidad Nacional Autónoma de México; Universidad de Los Andes). Scholarships supporting Latin American students studying in other Latin American country could increase in a great manner regional cooperation.

<u>Joint Research Projects</u>: Many researchers ask themselves comparative questions that are relevant to test the generality of their findings. Area patterns observed in, say, the Caatinga, maintained in Mexican tropical drylands? Is the effect of sheep grazing comparable in Atacama and in Patagonia? Answering these questions can be crucial in order to obtain general rules on the behaviour of ecological systems that will allow their long term conservation and their sustainable management. A program stimulating and financing some critical aspects of joint research (e.g. travel, equipment) would have a large positive impact on regional cooperation in a continent isolated by both its economic crises and its great size.

REFERENCES

Anonymous. 1981. U.N. acts to save the world's seeds. New Scientist 92:786.

Anonymous. 1983. Brasil: La recesión económica y el ciclo ganadero. Informe Ganadero (Bs.Aires) 2(34):23-26.

Axelrod, D.I. 1983. Paleobotanical history of the Western Deserts. In: S.G. Wells and D.R. Haragan (eds.) Origin and Evolution of Deserts. pp.113-129. Univ. of New Mexico Press, Albuquerque.

Beard, J.S. 1946. Los clímax de vegetación en la América Tropical. Rev. Fac. Nac. Agron. (Medellín) 6:225-293.

Briones, O, E. Ezcurra, F. García-Oliva, J. López-Portillo, H. Riemann, M.C. Rosas y A. Valiente-Banuet. 1988. Patrones geográficos de diversidad y termorregulación en las cactáceas columnares de México. Simposio Sobre Diversidad Biológica de México. Oaxtepec, Morelos.

Brown, J.H. and A.C. Gibson. 1983. Biogeography. The C.V. Mosby Company. St. Louis, Missouri.

Burgess, T.L. and A. Shmida. 1988. Succulent growth forms in arid environments. In: E.E. Whitehead, C.F. Hutchinson, B.N. Timmermann and R.G. Varady (eds.). Arid lands. Today and Tomorrow. Proceedings of an International Research and Development Conference, Tucson, Arizona 1985. pp.383-395. Westview Press, Boulder, Colorado, and Belhaven Press, London.

Byers,D.S. (ed). 1967. The prehistory of the Tehuacán Valley. Volume one. Environment and subsistence. R.S. Peabody Foundation-University of Texas Press, Austin.

Caballero, J. 1990. El uso de la diversidad vegetal en México: tendencias y perspectivas. In: E. Leff, (ed). Medio ambiente y desarrollo en México. Vol.1, pp. 257-298. M.A. Porrúa Editores, México.

Cabrera, A.L. y A. Willink. 1973. Biogeografía de América Latina. Organización de Estados Americanos (OEA), Monografía no.13. Washington, D.C. 120 pp.

Camino, A., J. Recharte and P. Bidegaray. 1985. Flexibilidad calendárica en la agricultura tradicional de las vertientes orientales de los Andes. In: H. Lechtman and A.M. Soldi (eds.) La tecnología en el mundo andino. Vol.I. pp.169-194. Universidad Nacional Autónoma de México, Mexico, D.F.

Cody, M.L. 1984. Branching patterns in columnar cacti. In: N. Margaris, M. Arianoutsou-Faraggitaki and W. Oechel (eds). Being alive on land. Tasks on Vegetation Science No.13:201-236. Dr. W. Junk, Den Haag, Netherlands.

Eddy, J.A. 1991. Global change: Where are we now? Where are we going? *EarthQuest* 5(1):1-3.

Escalante, P. and J. Llorente. 1985. Riqueza y endemismo de aves y mariposas como criterio para determinar áreas de reserva. Datos del estado de Nayarit, México. *Primer Simposio Internacional de Fauna Silvestre* (México D.F.). The Wildlife Society of Mexico: 12 pp.

Escalante, P., A. Navarro and T.A. Peterson. (in press). A geographic, ecological and historical analysis of land bird diversity in Mexico. In: Ramamoorthy, T.P., R. Bye and J. Fa (eds). *Biological diversity of Mexico: origins and distributions*. Oxford University Press.

Ezcurra, E., R.S. Felger, A.D. Russell y M. Equihua. 1988. Freshwater islands in a desert sand sea: the hydrology, flora, and phytogeography of the Gran Desierto oases of Northwestern Mexico. *Desert Plants* 9:35-63.

Ezcurra, E. & C. Montaña. 1990. Los recursos naturales renovables en el norte árido de México. *In*: E. Leff (ed.) *Medio Ambiente y Desarrollo en México*. Vol.I, pp.297-327. Miguel Angel Porrúa Editores, México, D.F.

Ezcurra, E., C. Montaña y S. Arizaga. 1991. Architecture, light interception and distribution of *Larrea* species in the Monte Desert, Argentina. *Ecology* 72(1):23-34.

Felger, R.S. and G.P. Nabhan. 1976. Tierras desérticas. Una aridez engañadora. *Ceres* March-April.

Felger, R. & G. Nabham. 1980. Agroecosystem diversity: a model from the Sonoran Desert. *In*: N.L. Gonzalez (ed.) *Social and Technological Management in Dry Lands*. AAAS Selected Symposium No.10, pp.129-149. AAAS Selected Symposia Series, Westview Press, Boulder.

Flores, O. 1991. *Análisis de la distribución de la herpetofauna en México*. Unpublished Ph.D. Thesis, Universidad Nacional Autónoma de México, México.

Fulkerson, W., R.M. Cusham, G. Marland and S. Rayner. 1989. *International Impacts of Global Climate Change*. Oak Ridge National Laboratory, Report ORNL/TM-11184. Oak Ridge, Tennessee.

Gates, D.M. 1980. *Biophysical ecology*. Springer-Verlag, New York.

Gentry, A.H. 1982. Patterns of Neotropical plant species diversity. *Evol. Biol.* 15:1-84.

Gibson, A.C. and K.E. Horak. 1978. Systematic anatomy and phylogeny of Mexican columnar cacti. *Ann. Miss. Bot. Gard.*

65:999-1057.

GIESCC (Grupo Internacional de Expertos Sobre Cambios Climáticos) 1990. El cambio climático: Un tema clave de alcance mundial. WMO-UNEP, Report WGES 251 (Spanish version). World Meteorological Organization-United Nations Environmental Programme. Geneva, Switzerland. 37 pp.

Gilbert, B.M. & L.D. Martin. 1984. Late Pleistocene fossils of Natural Trap Cave, Wyoming, and the climatic model of extinction. In: P.S. Martin & R.G. Klein (eds.) Quaternary Extinctions. pp.138-147. The Univ. of Arizona Press, Tucson.

González-Quintero, L. 1968. Tipos de vegetación del Valle del Mezquital, Hgo. Instituto Nacional de Antropología e Historia, Mexico. 53 pp.

Gould, S.J. 1991. En défense de l'ecureuil rouge. Alliage 1(7-8):199-204.

Haffer, J. 1982. General aspects of the refuge theory. In: G.T. Prance (ed). Biological Diversification in the Tropics. pp.6-24. Columbia University Press, New York.

Hastings, J.R. & R.M. Turner. 1965. The Changing Mile. An Ecological Study of Vegetation Change with Time in the Lower Mile of an Arid and Semiarid Region. The University of Arizona Press, Tucson. 317 pp.

Hernández-Xolocotzi, E. 1985. Biología agrícola. CECSA, México.

Hewitt de Alcántara, C. 1976. Modernizing Mexican Agriculture: Socioeconomic Implications of Technological Change 1940-1970. UNRISD, Geneva. 350 pp.

Hoffmann, J.A.J. (comp.). 1975. Atlas Climático de América del Sur. Vol. I. Mapas de temperaturas y precipitaciones medias. OMM-UNESCO. Cartographia, Hungary.

Hubbard, J.P. 1974. Avian evolution of the arid-lands of North America. The living bird. 12th Annual Meeting of the Ornithological Society of America, pp.155-196.

Hunter, M.L. G.L. Jacobson and T. Webb. 1988. Paleoecology and the coarse-filter approach to maintaining biological diversity. Conservation Biology 2(4):375-385.

IPCC (Intergovernmental Panel on Climate Change). 1990. Potential Impacts of Climate Change. Report from Working Group II to IPCC. World Meteorological Organization. Geneva, Switzerland.

Janzen, D.H. 1967. Why mountain passes are higher in the tropics. Am. Nat. 101:233-249.

Johnston, M.C. 1963. Past and present grasslands of Southern Texas and Northeastern Mexico. Ecology 44:456-466.

Juma, C. 1989. The Gene Hunters. Biotechnology and the scramble for seeds. Princeton University Press, Princeton, New Jersey.

Kloppenburg, J. and D.L. Kleinman. 1987. The plant germplasm controversy. Bioscience 37(3):190-198.

Leopold, A. S. 1950. Vegetation zones of Mexico. Ecology 31:507-518.

Lubchenko, J., A.M. Olson, L.B. Brubaker, S.R. Carpenter, M.M. Holland, S.P. Hubbell, S.A. Levin, J.A. MacMahon, P.A. Matson, J.M. Melillo, H.A. Mooney, C.H. Peterson, H.R. Pulliam, L.A. Real, P.J. Regal and P.G. Risser. 1991. The Sustainable Biosphere Initiative: An ecological research agenda. Ecology 72(2):371-412.

Machado, M.A. 1981. The North Mexican cattle industry, 1910-1975. Texas A&M Univ. Press, College Station. 152 pp.

Mangelsdorf, P.C., R.S. MacNeish and W.C. Galinat. 1967. Prehistoric wild and cultivated maize. In: D.S. Byers (ed). The prehistory of the Tehuacán Valley. Volume one. Environment and subsistence. R.S. Peabody Foundation-University of Texas Press, Austin. pp.178-200.

Mares, M.A. 1979. Small mammals and creosote bush: patterns of richness. In: E.L. Campos, T.J. Mabry and S.T. Fernández (eds). Larrea. pp.57-94. Consejo Nacional de Ciencia y Tecnología, México.

May, R.M. 1989. How many species are there on Earth? Science 241:1441-1448.

Mittermeir, R.A. 1988. Primate diversity and the tropical forest: case studies from Brazil and Madagascar and the importance of the megadiversity countries. In: E.O. Wilson (ed.). Biodiversity. National Academy of Sciences Press, Washington, D.C. pp.145-154.

Mix, A.C. 1989. Influence of productivity variations on long term atmospheric CO_2. Nature 337: 541-544.

Morello, J., N.E. Crudeli & M. Saraceno. 1971. Los vinalares de Formosa (Rep. Argentina). La colonizadora leñosa Prosopis ruscifolia Gris. INTA, Serie Fitogeográfica No.11, 111 pp. Buenos Aires.

Myers, N. 1981. The hamburger connection: How Central America's forests became North America's hamburgers. Ambio 10(198):3-8.

Nabhan, G.P. 1985. Gathering the desert. The University of

Arizona Press, Tucson.

Nabhan, G.P. 1989. Enduring seeds. North Point Press, San Francisco.

Neilson, R.P., G.A. King, R.L. DeVelice, J. Lenihan, D. Marks, J. Dolph, B. Campbell and G. Glick. 1989. Sensitivity of ecological landscapes and regions to global climatic change. EPA Report 600/3-89/073. Environmental Research Laboratory, Corvallis, Oregon.

Nobel, P.S. 1988. Environmental biology of agaves and cacti. Cambridge University Press, New York.

Pearse, A. 1980. Seeds of plenty, seeds of want. Social and economic implications of the Green Revolution. Clarendon Press, Oxford. 262 pp.

Pianka, E.R. 1966. Latitudinal gradients in species diversity: a review of concepts. Am. Nat. 100:33-46.

Rabinowitz, D., S. Cairns y T. Dillon. 1986. Seven kinds of rarity. En: M.E. Soulé (ed.) Conservation Biology. pp. 182-204. Sinauer, Sunderland, Mass.

Ramírez-Pulido, J. and C. Müdespacher. 1987. Estado actual y perspectivas del conocimiento de los mamíferos de México. Ciencia 38:49-67.

Rapoport, E.H. 1975. Areografía: estrategias geográficas de las especies. Fondo de Cultura Económica, México.

Rutsch, M. 1984. La ganadería capitalista en México. Editorial Línea, México. 62 pp.

Rzedowski, J. 1978. Vegetación de México. Editorial Limusa, México.

Shmida, A. 1985. Biogeography of Desert Flora. In: M. Evenari, I. Noy-Meir & D. Goodall (eds.) Ecosystems of the World. Vol.12. Hot Deserts and Arid Shrublands. pp. 23-75. Elsevier, Amsterdam.

Sears, P.B. and H. Clisby. 1955. Pleistocene climate in Mexico. Bull. Geol. Soc. Amer. 66:521-530.

Stevens, G.C. 1989. The latitudinal gradient in geographical range: How so many species coexist in the tropics. Am. Nat. 133:240-256.

Toledo, V.M. 1982. Pleistocene changes of vegetation in Tropical Mexico. In: G.T. Prance (ed.) Biological Diversification in the Tropics. pp.93-111. Columbia University Press, New York.

Toledo, V.M. 1989. Naturaleza, Producción y Cultura. Ensayos de ecología política. Universidad Veracruzana, México.

Turner, B.L. et al. 1990. Two types of global environmental change: Definitional and spatial-scale issues in their human dimension. Global environmental change 1(1):

Twiley, R.R., A.E. Lugo, and C. Patterson-Zucca. 1986. Litter production and turnover in basin mangrove forests in Southwest Florida. Ecology 67(3):670-683.

van Devender, T.R. & W.G. Spaulding. 1983. Development of vegetation and climate in the Southwestern United States. In: S.G. Wells and D.R. Haragan (eds.) Origin and Evolution of Deserts. pp.131-156. Univ. of New Mexico Press, Albuquerque.

Vidal-Zepeda, R. 1989. Precipitación media anual y su probabilidad. Atlas Nacional de México. Instituto de Geografía, UNAM. Serie Clima, Mapa IV.4.6 (Precipitación). México, D.F.

Wells, S.G. 1974. Post glacial origin of the present Chihuahuan Desert. In: Transactions of the Symposium on the Biological Resources of the Chihuahuan Desert Region, United States and Mexico. National Park Service, Washington, D.C.