

2. Studying the Earth: Major Earth Biomes and the Trace Gas Experiment

GLOBE Teacher's Key:

Students will be able to:

1. Characterize the terrestrial biome that they live in.
2. Compare their surroundings with other locations, especially other locations where trace gas and aerosol measurements are made.
3. Make some estimates of what possible global warming would do to the biome they live in, as well as other biomes.

Appropriate grade levels: Middle school and High school.

Prerequisite skills: Students should have some experience with map reading, graph construction, and concept mapping.

Time needed: 2-4 class periods.

1. Engagement

Collect and display visual materials that depict different natural environments around the globe. Materials could be from formal texts, posters, slides, or pictures that students have from vacations, or travel brochures, among other sources. Have the students locate the sites represented in the material on a large map; one that shows some natural environmental attribute of Earth, such as global climates or vegetation, is ideal.

2. Explore

1. Have the students discuss the various natural landscape features depicted on the materials. Ask the students to group together landscape photos, etcetera, which appear to have similar characteristics.
2. Ask the students to develop a simple scheme for characterizing the vegetation and/or landscapes apparent on the materials. Try to include their estimate of whether the landscape looks “dry” or “moist” and “hot”, “cool”, or “cold” as a means of starting a discussion about precipitation and temperature in different regions around the globe.
3. Have the students make a list of the key terms which appear to be important for grouping together similar landscapes; these should include temperature, precipitation, vegetation, and animals.
4. Develop a concept map using the key terms identified above.

5. Have students graph precipitation and temperature data from four different locations that are representative of Desert, Forest, Tundra, and Grassland sites. Select the locations from the student map if possible.
6. Use temperature and precipitation data from the school site or locality to construct a second graph. Compare it with the four other graphs.
7. Ask students to describe and list the vegetation and animals they observe around their local environment.

3. Explain

Earth's Major Biomes

A large, stable terrestrial (land-based) ecosystem is called a biome. Biomes are characterized by functional interaction among specific plant and animal communities and the physical environment; climatic conditions act as a principal element that influence biome characteristics and interactions.

Biomes are typically named for the predominant vegetational form present within the geographical area encompassing the biome. The largest division of Earth biomes would have four categories: Forest, Grassland, Desert, and Tundra. Specific combinations of climate, soils, vegetation, and animals permit further breakdown of biomes into subtypes. About ten such subtypes are frequently used to designate the largest biomes on Earth.

4. Elaborate

GLOBE Teacher's Key

1. You should have students research and discuss what the present weather and climate is like in Australia.
2. Next, if you have access to a WWW net browser, have students visit the ERIN site in Australia. The URL is <http://kaos.erin.gov.au/air/air.html>. Have the students read the section on climate change in Australia. Alternatively hand out copies of the Climate Change in Australia excerpts.
3. You should then have students, working in small groups, develop a scenario or a projection of how their region of the world would look in the year 2030 if carbon dioxide in the atmosphere had doubled and global warming was in evidence.
4. TERC is seeking permission for using the printed version of Grappling with Greenhouse Understanding the Science Change, 1992, Dept. of the Environment, Sports, and Territories, Commonwealth of Australia.

Student Key

1. Research what the present day climate is like in Australia.
2. Read the following article about predicting climate change in Australia.
3. Working in a team, write your ideas of how your region of the world would change if carbon dioxide in the atmosphere doubled by the year 2030. Each team member should research a different aspect. Some might choose agriculture, forestry, sea-level change; others might choose changes in the natural biomes.
4. As a team, prepare some type of visual prop to refer to as you make your group report.

Climate Change in Australia

Improving predictions of climate change is the focus of much of the research into the greenhouse effect being conducted in Australia. Nevertheless, current knowledge of the behavior of the climate system, combined with the magnitude of changes to the large scale patterns of climate evident in experiments conducted with global climate models, enables Australian scientists to be confident of the broad nature and magnitude of climate change in the Australian region. This, together with strong indications of the sensitivity of natural and societal systems to natural variability of climate leads scientists to suspect that changes in the Australian region will be too great to ignore. At this stage there are no reliable predictions of the changes to Australia's climate as a result of global warming. Research is generally summarized in the form of scenarios: plausible, internally consistent descriptions of possible futures based on the best information available from climate models, observations and an understanding of the physical mechanisms of climate. The main purpose of scenarios is to illustrate the type of change which is anticipated and to provide researchers in various disciplines with a basis for assessing the consequences of climate change. Some of this research has been summarized by the CSIRO which has issued scenarios for Australia's climate based on an equivalent doubling of carbon dioxide. Some of aspects of climate change over Australia according to the most recent scenario are outlined in the following paragraphs. The scenario begins by assuming that the patterns of future greenhouse gas emissions will follow the IPCC (1990) Business-as-Usual' Scenario. This means that the effective doubling of carbon dioxide, from pre-industrial levels, would occur by about 2030.

Temperature

The realized surface temperature in the scenario, at the time of effective doubling of carbon dioxide in the atmosphere (2030), may be on average between 2 and 4 degrees C warmer in inland Australia compared with the present-day average. In northern coastal areas yearly average temperatures may be between 1 and 2 degrees C, warmer than at present, whereas in southern coastal areas an increase in temperature

of between 1 and 3 degrees C may occur. Generally temperature rise is likely to be greater in drier areas than in wet areas.

Other features

As with the global picture, the future intensity and geographical extent of tropical cyclones in the Australian region remains uncertain. For scenario purposes, the temperature changes discussed above have implications for the snow-line, which generally rises by about 100 m in elevation for every 1 degree C increase in temperature.

Australia's climate is particularly affected by the El Nino Southern Oscillation (ENSO) phenomenon, which appears to influence a number of aspects of Australia's climate notably drought and flood years. Since the surface temperatures of the Pacific Ocean play an important role in ENSO, climate models which are not joined to relatively high-resolution ocean models cannot reproduce ENSO. Overcoming this limitation is a major objective of present scientific research. No change in ENSO frequency is assumed in the scenario.

The possible impacts of climate change on Australia

The major difficulties in predicting Australia's future climate mean that assessment of the impacts of climate change in Australia cannot be done confidently. Nevertheless, assessing the impacts of climate change is vital for the Australian community to be able to respond to the challenges presented by this uncertain future.

It is easy to overlook the fact that the natural variability of climate already affects the community in a surprising variety of ways. One reason why climate is overlooked is that to a certain extent the Australian community, our agricultural systems, natural ecosystems and the design of our cities all show some degree of adaptation to the existing natural climate variability.

Consider Australia's major cities. They all have urban drainage systems designed to take away flood waters. Sometimes these drainage systems overflow, but most of the time they drain well, keeping water away from roadways and buildings. In a given locality any substantial change in the occurrence of heavy rains would affect the performance of urban drainage systems, but the challenge is to provide assessment of climate change sufficiently reliable to enable the community to decide if the changing climate warrants redesign or modification of the drainage system.

In general, as average climatic conditions change, the frequency of particular extreme events (such as hot or cold days) will change more rapidly. If particular extremes are critical for aspects of human health or crops (for example), then changes in their frequency may have appreciable effects.

Until the regional climate changes are understood better, it is impossible to provide detailed assessments of their costs or benefits. However, at this stage it should not be assumed that the costs of climate change will be more or less than costs incurred by taking action to mitigate climate change.

Cities

People living in cities in the comfort of their houses and living an urban life-style may or may not notice the enhanced greenhouse effect changing the climate they are used to. After all, climate is assessed in terms of decades; nobody will ever be able to state categorically that a particular storm would have been more, or less, severe without the enhanced greenhouse effect. Even so, climate change will affect city life, although in some cities it may have a negligible effect. But in other places, particular problems already in existence, such as shortages of water, may be exacerbated, or alleviated, by changes to the climate. If rainfall were to become more variable, the community may need to consider augmenting water storages to cope with dry spells or to accept water restrictions. Augmenting water supplies can be a costly burden.

Some Australian settlements are accustomed to long sequences of hot days, other places may experience bursts of cold weather. Current climate plays a major part in determining the comfort level for human activity. Large amounts of energy are used to keep people comfortable at different places around Australia: changes to climate imply changes to factors, such as comfort level which then have important implications for other activities such as energy planning.

Research during the past decade or so has enabled scientists to gain a much better appreciation of the weather conditions under which Australia's major cities experience severe air pollution. Higher temperatures and changed wind patterns may alter the number of days in which the weather combines with human activity to produce photochemical smog over our cities. Such changes need to be investigated.

These examples may paint a picture of inconvenience rather than the disaster which has sometimes been (popularly) portrayed. Nevertheless, our cities will need to adjust to changes in climate, and such adjustments remain potentially costly to the community as a whole.

Pests and disease

Many disease-carrying insects are limited by temperature, humidity or other factors which are related to climate. A change in climatic conditions strongly suggests that such insects and other pests may occur in different locations and at different times. One feature common to many pest species is that they are able to multiply very rapidly given favorable conditions. Consequently, climate change may result in more favorable conditions for some pests species in some localities.

Apart from general statements which stem from knowledge of the biology of some pests and diseases, predictions regarding the organisms, localities and potential changes to the incidence of particular pest and diseases cannot be made until the nature of the climate change which would lead to these changes becomes more certain. Despite this problem, it is possible to imagine that if temperatures in a given region became warmer on average with accompanying periods of heavier rain, then organisms such as mosquitoes which are able to multiply rapidly could become much more of a problem than at present. In those areas where mosquitoes carry disease, significant repercussions for human health are possible. Similar results could occur for other tropical pests and diseases, such as those carried by ticks.

Fisheries

Each fishery is the result of particular economic and environmental circumstances. As with other activities which may be affected by climate change, nothing concrete can be stated as yet about particular fisheries or particular locations. However, it is not difficult to understand, however, why scientists believe fisheries are already sensitive to climate and why climatic change may therefore affect fisheries. One example of the sensitivity of a particular fishery to possible climate change can be illustrated by events in the English Channel, where, during the 1930s, the Channel experienced a 0.5 degrees C increase in average temperature and a sudden drop in average level of phosphates. The herring fishery collapsed, herring were replaced by pilchards and there were other dramatic species changes. In 1970 this change was reversed.

Fish species living deep in the ocean may be found only within particular currents or water masses; changes to ocean currents could conceivably shift fisheries or alter the size of fish populations. Nearer to shore, other fisheries may be based on species which spawn in coastal areas such as mangrove forests or tidal wetlands. Sea-level rise, changes to runoff, the salinity of the water, or water temperatures may all affect the ability of a particular species to reproduce. There is little question that spawning grounds and fish nurseries are sensitive areas; other environmental problems such as urbanization and pollution have already shown how susceptible fisheries can be to changes in conditions.

Agriculture and forestry

Since present-day climatic conditions are an important part of agriculture, there is little doubt that changes to climate will impinge upon agricultural activities. Farmers already cope at some cost with the seemingly endless quirks and vagaries of climate, yet climate change adds to this uncertainty. Activities which require long-term planning, such as the planting of horticultural crops (some stone fruits, for example) need to take particular account of possible changes in future climate.

Forest timber may not be harvested for fifty or more years after planting. In some places harvesting may occur where the best wood producing trees are growing at the

limit of their climatic range. In such cases, climate change may mean that regeneration of the site may be difficult, or that different species may need to be planted to ensure the success of future crops.

As has been frequently pointed out, climate change in Australia may not always result in negative impacts; favorable changes are possible. Scientifically, characterizing change as either negative or positive is not always useful. For example, climate change may result in a particular locality becoming less suitable for growing a particular crop, but warmer night-time temperatures may reduce the incidence of frost enabling crops new to the area to be grown successfully. While this change may not be regarded as negative, it may still involve costs as farmers adapt to the new circumstances.

As with other aspects of life significantly influenced by climate, there is a gap between knowing that there will be a change, and understanding the nature and extent of the change well enough to be able to respond effectively and appropriately.

Several commentators and scientists have proposed that the enhanced greenhouse effect will be good for agriculture. They have used a simplistic explanation stating that carbon dioxide is plant food which makes plants grow faster and since carbon dioxide is increasing in the atmosphere this will result in faster crop growth. The ability of carbon dioxide to increase plant growth is often referred to as carbon dioxide fertilization.

This argument ignores fundamental physiological differences between groups of plants. Even so, there is no question that while carbon dioxide does increase photosynthesis and plant growth in the so-called C3 plants when they are grown in the laboratory or glass houses, scientists are increasingly skeptical that carbon dioxide fertilization will necessarily increase crop harvests in the field. Plants respond to a wide range of environmental conditions including the availability of water, nutrients, temperature and light. In some localities changes in these other factors may be more important than carbon dioxide fertilization. Furthermore, an increase in the growth of vegetation may not necessarily mean that crops produce more fruit or seed.

Natural ecosystems

One characteristic of the human species is its extraordinary ability to adapt. Few other species are able to live in as many climatic regimes as we do. Climate change therefore has considerable implications for natural ecosystems. Although different species respond differently to climate, relatively small changes to individual species may be significant to entire ecosystems.

Determining the effects of climate change on natural ecosystems requires more than an assessment of the chances of survival individual species because ecosystems function through complex relationships such as those of predator and prey, pollinator and food source, and parasite and host. Nutrient cycling plays a major role in the way ecosystems function and the essential ratio between carbon and nitrogen may be

affected by climate change. Any climate change which affects these processes would therefore have significant consequences for natural ecosystems.

Future climate change is likely to be rapid. Given regional variations, the rate at which particular ecosystems will have to respond to these changes may be unprecedented. In many instances climate also determines processes of maturation and influences patterns of dispersal. Many ecologists have expressed concern that climate may change faster than species can adapt.

Recent studies in Australia have shown that many of the species which are already under pressure to survive are sensitive to the changes in climate indicated by scenarios of future climate. In some instances climate change will place yet another survival pressure on species which are struggling to cope with competition from introduced species, habitat fragmentation and changes in land-use.

Sea-level rise

Much of the public information on climate change has underscored predictions of a rise in the average sea-level around the globe. As with other predictions of change which are averaged across the world, changes in sea-level will vary from place to place. Coasts which are already eroding are likely to erode more quickly as sea level rises. Increases in sea level may also result in salty water being forced into groundwater aquifers near the coast with resulting in rising saline water in wetlands and under buildings.

Although these impacts are potentially important, sea-level rise is only one aspect of global warming which will affect Australia's coasts. Changes in the pattern of storm surges, or the severity and frequency of storms, may be as important in some areas as the rise in average sea level itself.

Coastal communities may not notice the level of the ocean slowly creeping upward, but should storms become more frequent, or waves become smaller or larger, then it is possible that the character of individual bays or estuaries may change over the decades. Low lying towns may need to respond to more frequent but presently unusual events.

Conclusion

Climate change will impinge upon many aspects of life in Australia: the built environment, water supply systems, coastal environments, fisheries, agriculture, forestry, human health and natural ecosystems. All will be affected in some way.

At this stage, a clear picture of the impacts of climate change in Australia is not available because there are no reliable predictions of climate change at a regional level. Despite this, scientists believe that during the next century climate change will

have significant consequences for Australia. This assessment is based on a realization that many everyday human activities are sensitive to climate and that many human activities are adapted to current patterns of climate.

The impacts of climate change also affect decisions regarding abatement policies. Such policy discussions lie outside purely scientific research, but draw on scientific material and the current scientific understanding of the problem. If climate change is not limited by future abatement policies, it is likely to continue beyond the commonly considered date of 2030. As a result, the impacts of climate change will continue to grow until the concentrations of the greenhouse gases stabilize.

Scientifically, little can more be said about the climatic costs, benefits or impacts of climate change in Australia, other than that they are complex and potentially serious enough to require careful, considered examination.

Australia's research

Research into the greenhouse effect and climate change is conducted in many organizations and institutes around Australia. The CSIRO, Bureau of Meteorology, Australian Antarctic Division and the universities are all actively researching aspects of greenhouse and climate change.

In 1989, the Federal Government commenced funding a core climate change research program. This program builds on many years of established research into climate and the greenhouse effect. Its aim is to investigate some of the fundamental aspects of greenhouse and climate change. The research conducted within this program provides for additional monitoring of the climate system, sea-level measurements, and also contributes to major efforts into modeling future climate change in order to develop a predictive capability for the Australian region.

In this program, research is conducted by organizations mentioned above and the National Tidal Facility. These organizations provide significant additional funds from their own resources to complement the core climate change work. State Governments and authorities have supported work aimed at developing better regional estimates.

The Federal Government also established the National Greenhouse Advisory Committee to provide expert advice on greenhouse issues, advise on research priorities, provide expertise on international greenhouse activities, and promote the dissemination of information on the greenhouse effect to the public. The Committee also sets objectives for the Dedicated Greenhouse Research Grants Scheme to enhance our understanding of the basic science which underlies greenhouse induced climate change. The scheme also addresses the implications of the greenhouse effect for Australia and the region. Particular emphasis in this program has been given to the encouragement and training of researchers: some 26 Ph.D. scholarships having been awarded.

More information on these research programs can be found in 'Tomorrow's Answers' (published by the National Greenhouse Advisory Committee), the annual reports of the CSIRO's Climate Change Research Program, and the annual reports from universities actively engaged in greenhouse and climate research.

Australia's research also aims to assess the sensitivity of Australia's agriculture, coast, water resources, cities, natural ecosystems and health to climate change, so the Government can make appropriate plans for dealing with climate change.

Research is also being directed at obtaining a clearer picture of Australia's greenhouse gas emissions. This work will assist in defining Australia's contribution to the problem and will contribute to identifying the most important areas for minimizing emissions. Working out the ways in which greenhouse gas emissions from Australia's agricultural and energy systems can be reduced without losing productivity or reducing competitiveness is yet another (partly) scientific challenge.

Students have used local observations to place their locality within a larger system based upon a classification of global natural environments. Humans have greatly altered almost all natural ecosystems to some degree. The biomes we observe, therefore, are different from their potential natural state. However, we can still use the global classification in order to gain a better understanding of the natural environment, and those factors which lead to its alteration.

Ask the students to develop a list of differences between what they observe in their local environment, and the "ideal" classification they used for comparisons. What factors might lead to the observed differences? What are the consequences of alteration? Can, and should, changes in the natural landscape be reversed? At what cost, and what would be the benefit(s) of doing so?

5. Evaluation

Have students construct a concept map using the terms they identified as crucial for the classification of terrestrial biomes.

Biome Characteristics

Tropical Biomes

The Tropical or low latitude series of biomes contains examples of three of the four principal biome classes. In this group, we find that thermal and evaporative stresses are high, radiation intense, and productivity variable from low (Savanna, Deserts) to high (Rainforest). Population densities are low, except for urbanized areas and in particularly favorable locations associated with the fertile alluvial soils along river courses or near water sources.

The Biome comprises about eleven percent of the land area of the earth. It is characterized by high average annual temperature, high insulation, high humidity and abundant moisture throughout the year. A great number and variety of food chains and webs, rapid nutrient cycling, and the highest natural biomass productivity of any biome are also characteristic.

Natural vegetation and undisturbed soils are still predominant in this biome, and animal populations are composed of types and numbers similar to those present before human occupation. Most of the biome's nutrients are in the standing crop, not in the soil. This is a major limitation to sedentary agriculture. Also, soils cannot be fertilized using mid-latitude techniques, techniques that work in other biomes. They are highly susceptible to erosion, and may become extremely hard when the vegetation cover is permanently removed.

Natural vegetation is characteristically multi-layered and there are many species. The vegetation is mostly evergreen and often creates a closed cover that limits light penetration to the forest floor. Vines and plants that use other plants for support and nutrients are common and most animal species are arboreal.

The forested landscape produces a great number of kinds of foodstuffs--from nuts (e.g., cashews) to fruits (papaya, mango, banana), leaves, shoots, tubers, small animals--but not large numbers of any one kind within a small area. Food sources are spread over a considerable area, and both animals and man must traverse some distance in the gathering process.

Agriculture is practiced using slash and burn techniques. This is a practice that entails the slashing of trees to kill them, followed by a burning of the dead vegetation to both clear the ground and add nutrients from the ash. Burning allows the sun to penetrate to the forest floor. By breaking down organic matter, burning also transfers some nutrients from the standing crop to the soil. But once the ground is exposed to the sun and rain as well as being tilled, the soil quickly becomes exhausted and the area must be abandoned so that it can recover. Meanwhile, a new area has been cleared in a kind of land rotation. The Tropical Rainforest biome is, thus, a study in contrasts. It looks and is vegetationally lush, diverse, and productive in biomass. Unfortunately, the system is delicately balanced and cannot be made to produce much more, particularly by farming. In order to take advantage of the biome's resources, people must move from place to place. This is a life style that can only support low population numbers and densities.

are characterized by a strong wet/dry cycle. They have a five to nine month rainy season, during which rainfall totals may exceed those in adjacent rainforest areas, and a three to seven month dry period; rainfall totals for these latter months are often less than fifty cm.

The monsoon biome occupies about five percent of the earth's land area; its productivity percentage is about ten. Vegetation in this biome is not as tall as in

Tropical Rainforests. It often is found in fewer layers, and is a mixture of deciduous as well as evergreen species.

Sedentary agriculture in river valleys on alluvial soils is a common practice. Soils away from the rivers and deltas are similar to other tropical soils, but they are slightly more fertile. Animal populations are less diverse than in tropical rain forest areas and are present in fewer numbers. Energy for farming is provided by humans and large herbivores. Rice typically is the staple crop; native populations utilize the lowest level on the food chain.

is a third type of tropical biome. Land area and productivity percentage figures are about ten and twelve, respectively. The climate is characterized by strongly seasonal changes in the amount of solar heating. Rainfall during the three to six month period of high sun exceeds fifty cm. It falls substantially below this figure during drier periods. The result of these cycles is that grasses tend to be the dominant form of vegetation, although small trees may be interspersed at frequent intervals. Soil fertility varies widely, although most soils tend toward low fertility. Extensive populations of herbivores such as zebras typically roam the tropical savanna. Large carnivores, like the African lion, prey upon herbivores in a well-defined food chain. Human efforts to produce food often parallel the natural systems. Agriculture typically is marked by grazing of domesticated herbivores (cattle). Sedentary crop agriculture is limited to areas with reliable supplies of water. In wetter portions, those with a relatively long rainy season, bush-fallow farming is common. This is a technique similar to the rainforest slash and burn practices. It involves tree cutting, stacking of the wood, burning to return nutrients to the soil, and cropping with grains, sugarcane, cotton and other crops. Soils often are exhausted after several seasons and must be allowed to recover. This again means that rotation must be practiced.

Temperate Biomes

A second major biome group consists of the Temperate or Mid-Latitude series of biomes. With temperatures averaging 10°C (50°F), overall thermal stress on the human body is at a minimum. However, as we shall see, certain elements may create stress at various seasons. It is in the temperate biomes that we find the densest concentration of humans.

The biomes are concentrated along the west coasts of continents and are marked by a cycle of cool summers, with little rainfall but much fog and cloudy conditions, and winters that are cool to cold and are accompanied by substantial rainfall. During winter, vegetative growth is minimal and, therefore, transpiration (water loss through plant leaves) is minimal; extensive runoff during the wet season is the result.

Dominant vegetation is tall coniferous trees that effectively block light from the forest floor much as in the Tropical Rainforest. As in the rainforest, this limits plant productivity below the canopy.

Soils are generally acidic and prone to erosion if the vegetation is removed. They are not exceptionally fertile.

Because of the milder temperatures and abundant moisture in the Temperate Rainforest, species diversity is higher here than in other temperate forest biomes. This means that food webs are present. But they are not as complex as in the tropical forests. Typically, elk and muledeer are the major herbivores and mountain lions and wolves act as the major carnivores.

Due to seasonally cool temperatures, decomposition of organic matter (humus) is slower than in tropical rainforests. Plant nutrients are not readily available as a result. Most of the biomass production goes into the growth of large trees. This in turn limits food for the herbivores and animals higher on the food chain.

Agriculture is not widely prevalent. It is confined largely to clearings where sunlight is available. Populations that occupy the Temperature Rainforest typically have used fish as their major source of food. Logging of Douglas fir and Redwood trees, which often reach heights in excess of seventy meters, predominates as a non-agriculture economic activity in coastal areas.

also is found along the west coast of continents, but at lower latitudes than temperature rainforests. A typical example is found around the Mediterranean Basin. The area occupied and this biome's biomass production are about three and five percent of the solid earth's surface and terrestrial productivity, respectively. The major environmental cycle is associated with large latitudinal shifts in the westerly wind belts brought about by seasonal changes in intensity of the Subtropical High pressure cells. High pressure, high temperatures, and clear skies are accompanied by great water stress associated with only minimal rainfall during the dry season (April to September). During the wet season, rain from passing cyclonic systems is common. The cool season extends from November to March and is accompanied by rainfall, which often amounts to as much as ninety-five percent of the annual amount. Unlike the rainforest, soils are alkaline. However, these soils are also low in organic matter, but fertile if moisture is available. Vegetation is composed of short, woody, mostly thicketed evergreen plants that vary in spacing from impenetrable to widely dispersed. Grass occupies the openings between woody species. Productivity is low primarily because of the long, dry summer season; rapid mineral cycling for plant growth and large populations of herbivores and carnivores are not favored by such a regime. Species diversity appears to lie about halfway between grassland and temperate deciduous forested areas. Prehistoric dominant animals included the grizzly, pronghorn antelope, deer and elk. Today herbivores remain as dominants.

Agricultural practices vary widely from place to place within the biome, but similarities are evident. Grapes, orchards, and small grains are common today in all areas; extensive grazing also is practiced in Australia and the valleys along the U.S. west

coast. Because the pleasant climatic circumstances are so attractive to man, much of the original character of this biome has been changed over the centuries, particularly around the Mediterranean Basin.

biomes are regions of high population density and industrial activity. In this biome, climate is controlled by the global Westerlies. Large moving cyclonic storms bring winter rainfall; summer conditions are dominated by warm, moist air invasion from oceans. Precipitation varies from high values (120 cm) in the east to less than seventy five cm along the western border and is fairly evenly spread throughout the year with a bias toward the summer months. Temperatures can reach very low levels at the poleward limits of the biome, at times even lower than those of Arctic or Antarctic regions. High temperatures and high humidities prevail in summer, the region thus is characterized by a distinctly hot-cold cycle of seasons. The biome reaches maximum development in North America in the Great Smoky Mountain region in the United States. Here trees reach maximum size and the multi-layered understory reaches maximum complexity when compared to other locations.

Animal species commonly found throughout the biome include the white-tailed deer, turkey, fox, squirrel, skunk, and, in the last century, the wolf and black bear. Many animals show marked seasonality, with hibernation common in winter as an adaptation against cold stress and lack of food sources. Food chains are well developed and food webs are common in relatively undisturbed areas, although extensive modification has curbed the diversity and numbers of animal species present. The northern limit of the forest is marked by cold conditions and a transition to the Boreal Forest Biome; to the west, moisture proves limiting until only drought tolerant species appear along river valleys in the Prairie and Steppe biomes.

Soils are thin, acidic but reasonably fertile under a typical agricultural regime that includes rotation of different crops on the same field from one year to the next. Agriculture varies from cash grain crops in the western portion to truck gardening in the east and cotton in the south.

lands comprise some six percent of the earth's surface and account for about five percent of terrestrial productivity. The vegetation is predominantly grass. On its wetter margins, the grass is tall and interspersed with forests. Along its more arid margins, the grasses are short, but with cottonwoods in very moist areas such as river beds. The Prairie biome (tall grass) occupies regions where precipitation exceeds evaporation; steppe (short grass) also is found in drier areas where evaporation exceeds precipitation.

The climate of these biomes is marked by great shifts between summer--usually very hot--and winter--markedly colder, e.g., summer average maxima are 26°C (79°F) while winter averages -3°C (28°F). This climatic cycle is created by changes in dominance of cold, dry (winter) and warm, moist (summer) air masses which in turn are manifestations of the general circulation of the atmosphere as it responds to annual

changes in solar radiation. As one would expect, moisture stress is high during the winter months given the dryness of the air and the frequent presence of relatively high winds. Summer is marked by similar stresses, which may become severe if drought, a frequent visitor to such areas, sets in and persists.

Grassland biomes are grain producing areas. Thick soils, rich in organic material and nutrients, provide a firm basis for extensive agriculture. Drought can modify productivity figures substantially, as recent and recurring problems in the Soviet steppes illustrate. Relatively simple food chains composed of large numbers of similar plants and herbivores once prevailed across the North American grassland, but pressure for agriculture has reduced the great herds that once roamed the region. In the Great Plains of the U.S., bison and pronghorn antelope dominated as herbivores; only the pronghorn remains in significant numbers. Carnivores include coyotes, weasels, badgers, foxes, owls, and rattlesnakes, all small and mostly nocturnal to avoid high daytime temperatures. Burrowing is common for insulation from winter cold.

Cold Biomes

High latitude (Arctic areas) and/or high altitude (mountain) biomes comprise a third group of biomes. Cold stresses combined with large seasonal contrasts in insolation, low biomass productivity, short growing seasons, lack of species diversity, and simplicity characterize this group.

The Arctic covers approximately eight percent of the solid earth surface and accounts for seven percent of its area, principally because of its tremendous size. It is an extreme environment with several month averaging above 10°C, many months below 0°C, and a very large range in average temperatures (some 60°C over Siberia). Moisture falls mostly as snow. The growing season is only about sixty days but the daylight of this period is very long.

Soils are very high in near surface organic matter because low temperatures do not allow rapid decomposition. The soils are acidic and not very fertile. Vegetation is composed of predominantly two coniferous tree species, both spruce, an indication of low diversity. There are few food chains, webs, and number of animals. The region is a continentally glaciated landscape and is, therefore, flat. Flatness often means poor drainage and swampy conditions during the warmer season when the frozen ground thaws.

Agriculture is a difficult endeavor and is practiced at risk. Some cereals and vegetables can mature in the long days of summer, but the short growing season places restrictions on the variety of crops that can be grown. For these and other reasons, the region is not densely populated. The cities of large size found within its confines occur principally in the Soviet Union or coastal areas where commercial fishing predominates. Dominant animals include moose, caribou, elk, grizzly, beaver and several species of birds.

The Arctic Tundra is a vast treeless biome region characterized by severe winters and somewhat less severe summers. The growing season is very short although daylength is long. Radiation totals are high during the summer, yet temperatures may fall below freezing any month of the year. Little precipitation is received at daytime. The area is underlain by permafrost; most solar radiation during summer melts the upper layers of soil leaving little energy for heating of the air. The natural vegetation is composed of low-laying grasses and sedges. Accumulation of organic matter at the surface prevails because temperatures are not high enough to allow rapid breakdown of plant materials. Food chains and webs are simple and composed of few species but large numbers. Brown bear, reindeer, caribou, musk ox and wolf are common large animals; hares, owls, lemmings, and waterfowl are also common.

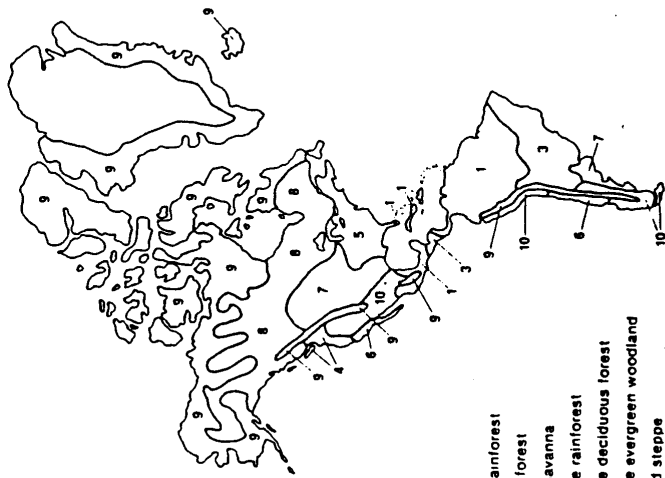
Arctic Tundra shares many of the same characteristics of the Alpine Tundra. In alpine areas, elevation replaces latitude in creating similar environments at a variety of locations. Alpine areas have plant species common to Arctic areas, and often are as severe climatically. However, high elevations have higher radiation loads than their arctic counterparts because of the thin atmosphere at such levels, and they do not always share the long season of light.

Deserts

Desert biomes occur at low, middle as well as at relatively high latitudes. They typically are divided into cold and warm deserts. Warm deserts are found in the latitudes nearest the equator, in the interior of continents and along the western coasts (such as Southern and Baja California). Higher latitude as well as high altitude deserts are much colder than their equatorward counterparts. They lie in the lee of mountain ranges or are far from moisture sources. Examples include Central Asia and Central Canada. Together the warm and cold deserts comprise some twelve percent of the earth's surface but account for only one percent of its productivity.

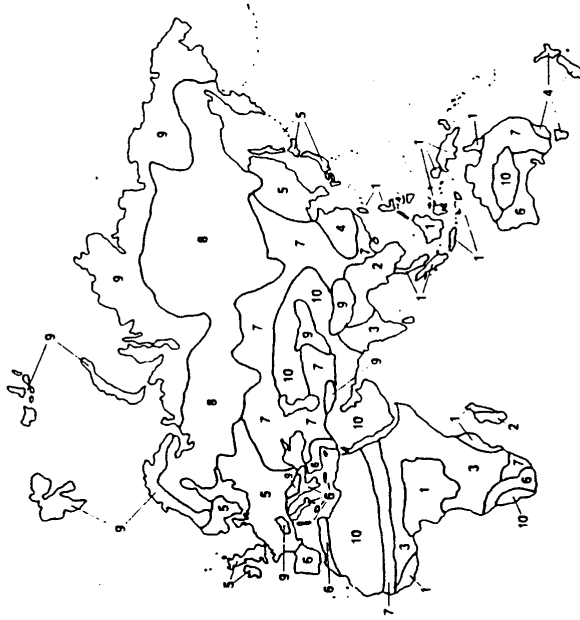
By definition, rainfall is minimal. Due to the lack of moisture, skies are normally clear and insolation is intense. Species diversity is limited and the food chains and food webs are only poorly developed. Both large animals and large plants are uncommon. Due to competition for limited water, vegetation is widely dispersed and made up of species with morphological and physiological adaptations to extreme moisture stress.

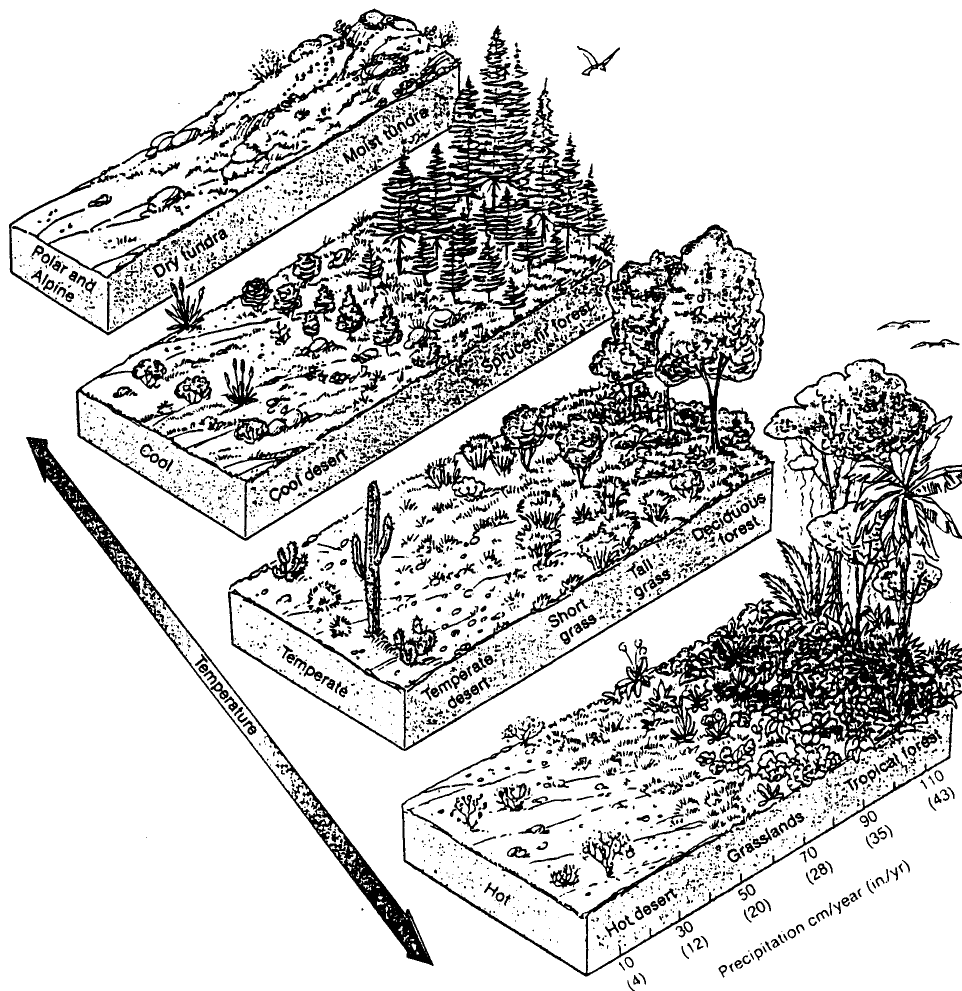
Soils are alkaline and poor in organic matter cycles. Native peoples, like the Kung in Africa, provide their foodstuffs through hunting and gathering. However, the number and kind of edible items is distinctly limited, and natives must move from place to place because food supplies are quickly exhausted. This means low population numbers and few fixed settlements. Some grazing activity does occur but sedentary agriculture is limited to intensively irrigated regions, such as Central Asia, Egypt, where population densities may become very large, but limited in expansion by the desert's margins and its physical limits.



- 1 Tropical rainforest
- 2 Monsoon forest
- 3 Tropical savanna
- 4 Temperate rainforest
- 5 Temperate deciduous forest
- 6 Temperate evergreen woodland
- 7 Prairie and steppe
- 8 Boreal forest
- 9 Arctic and alpine tundra
- 10 Deserts

Generalized model assemblages of climate, vegetation, soils, and animals that interact together to form a biome.





Abiotic climate control of ecosystem types: the generalized relationship among rainfall, temperature, and vegetation. Adapted from Daniel D. Chiras, *Environmental Science*, 2d ed. Copyright © 1988, Benjamin/Cummings Publishing Co., Menlo Park, CA. Reprinted by permission.

Characteristics of Selected Biomes

Name	Characteristics	Name	Characteristics
Tundra (T)*	Long periods of Darkness Followed by Long Days Low Biological Productivity/Short Growing Season/Acidic Soils Very Low Average Temperatures for Long Periods Little Surface Moisture/Most in Frozen Form	Tropical Forests (F)	Rapid Mineral Cycling High Rainfall Totals High Average Daytime Temperatures Cooling Stresses Pronounced Because of High Humidity Soils Impossible to Crop Continuously High Productivity but only Native Flora/Fauna
High Altitude Tundra (T)	Permafrost Little Oxygen Available Great Diurnal Temperature Range/Low Average Nighttime Temperatures Low Biological Productivity/Short Growing Season/Acidic Soils	Boreal Coniferous Forest (F)	Short Growing Season Large Seasonal Changes in Average Temperature Long Cold Periods Low Moisture Totals Highly Acidic Soils Intermittent Permafrost
Desert (D)	Low Biological Productivity/Inefficient Moisture/Low Organic Matter in Soils High Average Daytime Temperatures/Large Diurnal Range Extreme Evaporative Stress on Species Low Average Rainfall/High Variability in Amounts Received High Solar Radiation Loads	Temperate Deciduous Forest (F)	Acidic Soils of Moderate Fertility Relatively Short Growing Season Moderately Low Avg. Annual Temp. High Rainfall During Period of Low Evapotranspirational Stress High Runoff Percentage Low Light Intensities
Prairie/Steppe (G)	Low Rainfall Totals/Periodic Drought Large Diurnal/Seasonal Temperature Range High Evaporative Stress in Summer Seasonality of Vegetative Growth Fertile Soils	Temperate Rainforest (F)	Infertile Soils/Slow Cycling of Nutrients Food Chains not Complex or Represented by Large Numbers
		Temperate Evergreen Woodland (F)	Large Seasonal Differences in Precipitation Amounts Infrequent but intense Droughts High Moisture Stress During Summer Limited Productivity Limited Food Chains and Numbers Slow Mineral Cycling

*T tundra
D desert
G grassland
F forest