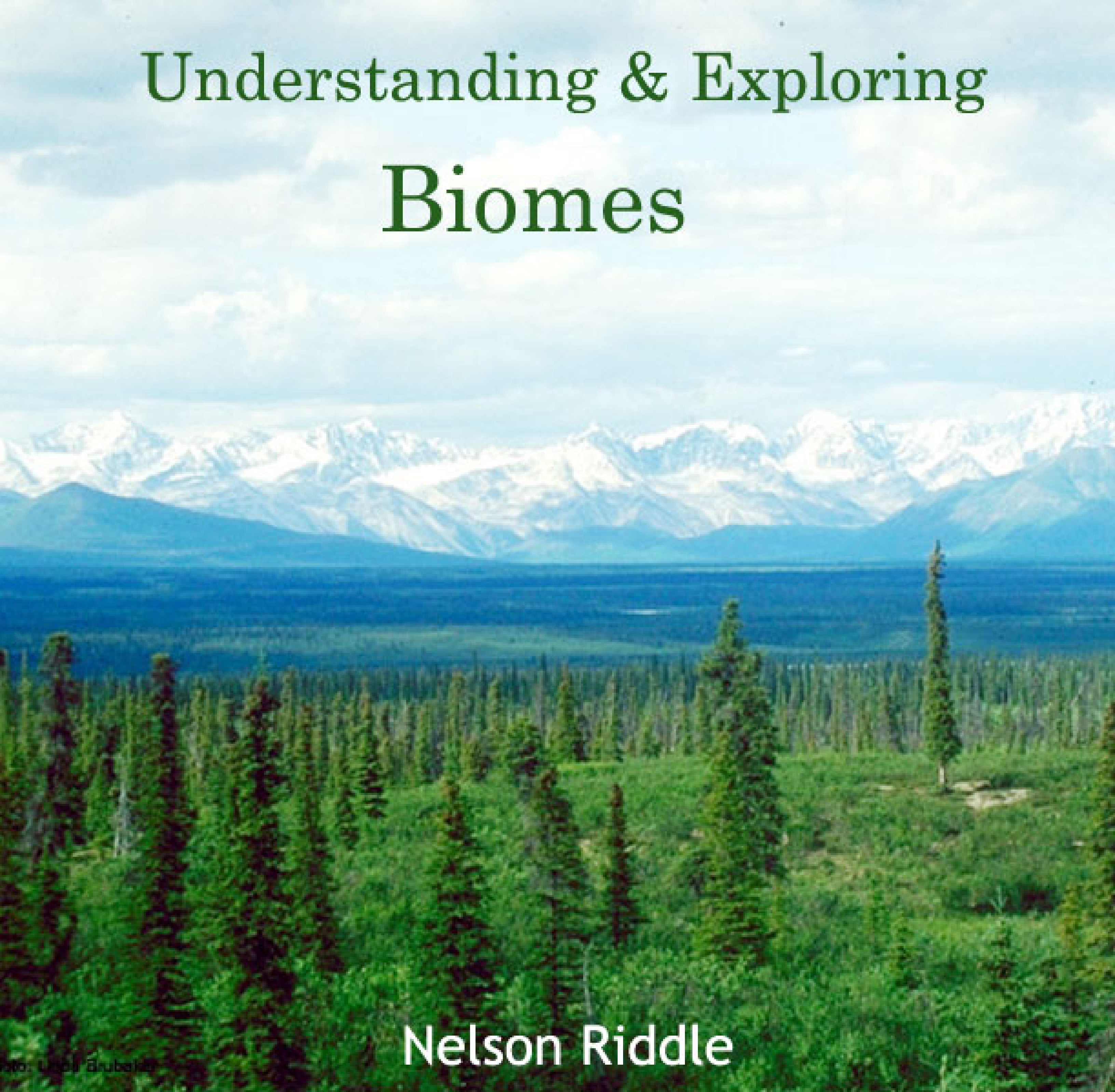
Understanding & Exploring Biomes



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First Edition, 2012

ISBN 978-81-323-4727-9

Published by:
The English Press
4735/22 Prakashdeep Bldg,
Ansari Road, Darya Ganj,
Delhi - 110002
Email: info@wtbooks.com

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Chapter- 1

Introduction to Biome

Biomes are climatically and geographically defined as similar climatic conditions on the Earth, such as communities of plants, animals and soil organisms and are often referred to as ecosystems. Some parts of the earth have more or less the same kind of abiotic and biotic factors spread over a large area creating a typical ecosystem over that area. Such major ecosystems are termed as biomes. Biomes are defined by factors such as plant structures (such as trees, shrubs and grasses), leaf types (such as broadleaf and needleleaf), plant spacing (forest, woodland, savanna) and climate. Unlike ecozones, biomes are not defined by genetic, taxonomic, or historical similarities. Biomes are often identified with particular patterns of ecological succession and climax vegetation (quasi-equilibrium state of the local ecosystem). An ecosystem has many biotopes and a biome is a major habitat type. A major habitat type, however, is a compromise, as it has an intrinsic inhomogeneity.

The biodiversity characteristic of each biome, especially the diversity of fauna and subdominant plant forms, is a function of abiotic factors and the biomass productivity of the dominant vegetation. In terrestrial biomes, species diversity tends to correlate positively with net primary productivity, moisture availability and temperature.

Ecoregions are grouped into both biomes and ecozones.

A fundamental classification of biomes is:

1. Terrestrial (land) biomes
2. Aquatic biomes (including Freshwater biomes and Marine biomes)

Biomes are often known in English by local names. For example, a temperate grassland or shrubland biome is known commonly as *steppe* in central Asia, *prairie* in North America and *pampas* in South America. Tropical grasslands are known as *savanna* in Australia, whereas in Southern Africa it is known as *veldt* (from Afrikaans).

Sometimes an entire biome may be targeted for protection, especially under an individual nation's Biodiversity Action Plan.

Climate is a major factor determining the distribution of terrestrial biomes. Among the important climatic factors are:

- latitude: Arctic, boreal, temperate, subtropical, tropical.
- humidity: humid, semi-humid, semi-arid and arid.
    - seasonal variation: Rainfall may be distributed evenly throughout the year or be marked by seasonal variations.
    - dry summer, wet winter: Most regions of the earth receive most of their rainfall during the summer months; Mediterranean climate regions receive their rainfall during the winter months.
- elevation: Increasing elevation causes a distribution of habitat types similar to that of increasing latitude.

The most widely used systems of classifying biomes correspond to latitude (or temperature zoning) and humidity. Biodiversity generally increases away from the poles towards the equator and increases with humidity.

Biome Classification Schemes

Biome classification schemes seek to define biomes using climatic measurements. Particularly in the 1970s and 1980s there was a significant push to understand the relationships between these measurements and properties of ecosystem energetics because such discoveries would enable the prediction of rates of energy capture and transfer among components within ecosystems. Such a study was conducted by Sims et al. (1978) on North American grasslands. The study found a positive logistic correlation between evapotranspiration in mm/yr and above ground net primary production in g/m^2/yr. More general results from the study were that precipitation and water use lead to aboveground primary production, solar radiation and temperature lead to belowground primary production (roots) and temperature and water lead to cool and warm season growth habit. These findings help explain the categories used in Holdridge's bioclassification scheme, which were then later simplified in Whittaker's. The number of classification schemes and the variety of determinants used in those schemes, however, should be taken as a strong indicator that biomes do not all fit perfectly into the classification schemes created.

Holdridge Scheme

The Holdridge classification scheme was developed by L. R. Holdridge, a botanist. It maps climates based on four categories:

- Average total precipitation (cm) on a logarithmic scale
- Potential evapotranspiration ratio: the potential evapotranspiration divided by the precipitation; the ratio increases from humid to arid regions.
- Potential evapotranspiration
- Mean annual biotemperature (°C): calculated from monthly mean temperatures after converting any mean temperature to 0°C, based on the assumption that temperatures at or below freezing all have the same effect on plants and delineating between -10°C and -30°C would yield unrealistic results.

In this scheme, climates are classified based on the biological effects of temperature and rainfall on vegetation under the assumption that these two abiotic factors are the largest determinants of the type of vegetation found in an area. Holdridge uses the 4 axis to define 30 so called "humidity provinces," which are clearly visible in the Holdridge diagram. While the scheme largely ignores soil and sun exposure, Holdridge did acknowledge that these, too, were important factors in biome determination.

Whittaker's Biome-type Classification Scheme

Whittaker appreciated biome-types as a representation of the great diversity of the living world and saw the need to establish a simple way to classify these biome-types. Whittaker based his classification scheme on two abiotic factors: Precipitation and Temperature. His scheme can be seen as a simplification of Holdridge's, one more readily accessible, but perhaps missing the greater specificity that Holdrige's provides.

Whittaker based his representation of global biomes on both previous theoretical assertions as well as an ever increasing empirical sampling of global ecosystems. Whittaker was in a unique position to make such a holistic assertion as he had previously compiled a review of biome classification.

The Whittaker Classification Scheme can be viewed at the following address: here

Key definitions for understanding Whittaker's Scheme

- **physiognomy**: The apparent characteristics, outward features, or appearance of ecological communities or species.
- **biome**: a grouping terrestrial ecosystems on a given continent that are similar in vegetation structure, physiognomy, features of the environment and characteristics of their animal communities
- **formation**: a major kind of community of plants on a given continent
- **biome-type**: grouping of convergent biomes or formations of different continents; defined by physiognomy
- **formation-type**: grouping of convergent formations

Whittaker's distinction between biome and formation can be simplified: formation is used when applied to plant communities only, while biome is used when concerned with both plants and animals. Whittaker's convention of biome-type or formation-type is simply a broader method to categorize similar communities. The world biome-types, as displayed on a world map, can be viewed at the following link: here

Whittaker's parameters for classifying biome-types

Whittaker, seeing the need for a simpler way to express the relationship of community structure to the environment, used what he called "gradient analysis" of ecocline patterns to relate communities to climate on a worldwide scale. Whittaker considered four main ecoclines in the terrestrial realm.

1. Intertidal levels: The wetness gradient of areas that are exposed to alternating water and dryness with intensities that vary by location from high to low tide
2. climatic moisture gradient
3. temperature gradient by altitude
4. temperature gradient by latitude

Along these gradients, Whittaker noted several trends that allow him to qualitatively establish biome-types.

- The gradient runs from favorable to extreme with corresponding changes in productivity.
- Changes in physiognomic complexity vary with the favorability of the environment (decreasing community structure and reduction of stratal differentiation as the environment becomes less favorable).
- Trends in diversity of structure follow trends in species diversity; alpha and beta species diversities decrease from favorable to extreme environments.
- Each growth-form (i.e. grasses, shrubs, etc.) has its characteristic place of maximum importance along the ecoclines.
- The same growth forms may be dominant in similar environments in widely different parts of the world.

Whittaker summed the effects of gradients (3) and (4), to get an overall temperature gradient and combined this with gradient (2), the moisture gradient, to express the above conclusions in what is known as the Whittaker Classification Scheme. The scheme graphs average annual precipitation (x-axis) versus average annual temperature (y-axis) to classify biome-types.

Walter System

The Heinrich Walter classification scheme was developed by Heinrich Walter, a German ecologist. It differs from both the Whittaker and Holdridge schemes because it takes into account the seasonality of temperature and precipitation. The system, also based on precipitation and temperature, finds 9 major biomes, with the important climate traits and vegetation types summarized in the accompanying table. The boundaries of each biome correlate to the conditions of moisture and cold stress that are strong determinants of plant form and therefore the vegetation that defines the region.

- I: Equatorial
    - Always moist and lacking temperature seasonality
    - Evergreen tropical rain forest
- II: Tropical
    - Summer rainy season and cooler “winter” dry season
    - Seasonal forest, scrub, or savanna
- III: Subtropical
    - Highly seasonal, arid climate
    - Desert vegetation with considerable exposed surface

- IV: Mediterranean
  - Winter rainy season and summer drought
  - Sclerophyllous (drought-adapted), frost-sensitive shrublands and woodlands
- V: Warm temperate
  - Occasional frost, often with summer rainfall maximum
  - Temperate evergreen forest, somewhat frost-sensitive
- VI: Nemoral
  - Moderate climate with winter freezing
  - Frost-resistant, deciduous, temperate forest
- VII: Continental
  - Arid, with warm or hot summers and cold winters
  - Grasslands and temperate deserts
- VIII: Boreal
  - Cold temperate with cool summers and long winters
  - Evergreen, frost-hardy needle-leaved forest (taiga)
- IX: Polar
  - Very short, cool summers and long, very cold winters
  - Low, evergreen vegetation, without trees, growing over permanently frozen soils

Bailey System

Robert G. Bailey almost developed a biogeographical classification system for the United States in a map published in 1976. Bailey subsequently expanded the system to include the rest of South America in 1981 and the world in 1989. The Bailey system is based on climate and is divided into seven domains (Polar, Humid Temperate, Dry, Human and Humid Tropical), with further divisions based on other climate characteristics (subarctic, warm temperate, hot temperate and subtropical; marine and continental; lowland and mountain).

- **100 Polar Domain**
  - 120 Tundra Division
  - M120 Tundra Division - Mountain Provinces
  - 130 Subarctic Division
  - M130 Subarctic Division - Mountain Provinces
- **200 Humid Temperate Domain**
  - 210 Warm Continental Division
  - M210 Warm Continental Division - Mountain Provinces
  - 220 Hot Continental Division
  - M220 Hot Continental Division - Mountain Provinces
  - 230 Subtropical Division
  - M230 Subtropical Division - Mountain Provinces
  - 240 Marine Division
  - M240 Marine Division - Mountain Provinces
  - 250 Prairie Division

    - 260 Mediterranean Division
    - M260 Mediterranean Division - Mountain Provinces
- **300 Dry Domain**
    - 310 Tropical/Subtropical Steppe Division
    - M310 Tropical/Subtropical Steppe Division - Mountain Provinces

WWF system

A team of biologists convened by the World Wide Fund for Nature (WWF) developed an ecological land classification system that identified fourteen biomes, called **major habitat types** and further divided the world's land area into 867 terrestrial ecoregions. Each terrestrial Ecoregion has a specific EcoID, fomat XXnnNN (XX is the Ecozone, nn is the Biome number, NN is the individual number). This classification is used to define the Global 200 list of ecoregions identified by the WWF as priorities for conservation. The WWF major habitat types are:

- 01 Tropical and subtropical moist broadleaf forests (tropical and subtropical, humid)
- 02 Tropical and subtropical dry broadleaf forests (tropical and subtropical, semi-humid)
- 03 Tropical and subtropical coniferous forests (tropical and subtropical, semi-humid)
- 04 Temperate broadleaf and mixed forests (temperate, humid)
- 05 Temperate coniferous forests (temperate, humid to semi-humid)
- 06 Boreal forests/taiga (subarctic, humid)
- 07 Tropical and subtropical grasslands, savannas and shrublands (tropical and subtropical, semi-arid)
- 08 Temperate grasslands, savannas and shrublands (temperate, semi-arid)
- 09 Flooded grasslands and savannas (temperate to tropical, fresh or brackish water inundated)
- 10 Montane grasslands and shrublands (alpine or montane climate)
- 11 Tundra (Arctic)
- 12 Mediterranean forests, woodlands and scrub or Sclerophyll forests (temperate warm, semi-humid to semi-arid with winter rainfall)
- 13 Deserts and xeric shrublands (temperate to tropical, arid)
- 14 Mangrove (subtropical and tropical, salt water inundated)

Freshwater biomes

According to the World Wildlife Fund, the following are classified as freshwater biomes:

- Large lakes
- Large river deltas
- Polar freshwaters
- Montane freshwaters
- Temperate coastal rivers
- Temperate upland rivers
- Tropical and subtropical coastal rivers
- Tropical and subtropical floodplain rivers and wetlands
- Tropical and subtropical upland rivers

- Temperate floodplain rivers and wetlands
- Xeric freshwaters and endorheic basins
- Oceanic islands

Realms or Ecozones (terrestrial and freshwater, WWF)

- NA Nearctic
- PA Palearctic
- AT Afrotropic
- IM Indomalaya
- AA Australasia
- NT Neotropic
- OC Oceania
- AN Antarctic

Marine biomes

Marine biomes (H) (major habitat types), Global 200 (WWF)

Biomes of the coastal & continental shelf areas (Neritic zone - List of ecoregions (WWF))

- Polar
- Temperate shelves and sea
- Temperate upwelling
- Tropical upwelling
- Tropical coral

Realms or Ecozones (marine, WWF)

- North Temperate Atlantic
- Eastern Tropical Atlantic
- Western Tropical Atlantic
- South Temperate Atlantic
- North Temperate Indo-Pacific
- Central Indo-Pacific
- Eastern Indo-Pacific
- Western Indo-Pacific
- South Temperate Indo-Pacific
- Southern Ocean
- Antarctic
- Arctic
- Mediterranean

Other marine habitat types

- Hydrothermal vents
- Cold seeps
- Benthic zone
- Pelagic zone (trades and westerlies)
- Abyssal
- Hadal (ocean trench)

Major Habitats, Non Global 200 (WWF)

- Littoral/Intertidal zone
- Kelp forest
- Pack ice

Summary - Ecological taxonomy (WWF)

- Biosphere (List of ecoregions)
    - Ecozones or Realms (8)
        - Terrestrial Biomes (Major Habitat Types, 14)
            - Ecoregions (867)
                - Ecosystems (Biotopes)
        - Freshwater Biomes (Major Habitat Types, 12)
            - Ecoregions (426)
                - Ecosystems (Biotopes)
    - Marine Ecozones or Realms (13)
        - Continental Shelf Biomes (Major Habitat Types, 5)
            - (Marine Provinces) (62)
                - Ecoregions (232)
                    - Ecosystems (Biotopes)
        - Open & Deep Sea Biomes (Major Habitat Types)
    - Endolithic Biome

Example

- Biosphere
    - Ecozone: Palearctic ecozone
        - Terrestrial Biome: Temperate Broadleaf and Mixed Forests
            - Ecoregion: Dinaric Mountains mixed forests (PA0418)
                - Ecosystem: Orjen, vegetation belt between 1,100-1,450 m, Oromediterranean zone, Nemoral zone (temperate zone)
                    - Biotope: *Oreoherzogio-Abietetum illyricae* Fuk. (Plant list)
                        - Plant: Silver fir (*Abies alba*)

Anthropogenic biomes

Humans have fundamentally altered global patterns of biodiversity and ecosystem processes. As a result, vegetation forms predicted by conventional biome systems are rarely observed across most of Earth's land surface. Anthropogenic biomes provide an alternative view of the terrestrial biosphere based on global patterns of sustained direct human interaction with ecosystems, including agriculture, human settlements, urbanization, forestry and other uses of land. Anthropogenic biomes offer a new way forward in ecology and conservation by recognizing the irreversible coupling of human and ecological systems at global scales and moving us toward an understanding how best to live in and manage our biosphere and the anthropogenic biosphere we live in. The main biomes in the world are freshwater, marine, coniferous, deciduous, ice, mountains, boreal, grasslands, tundra and rainforests.

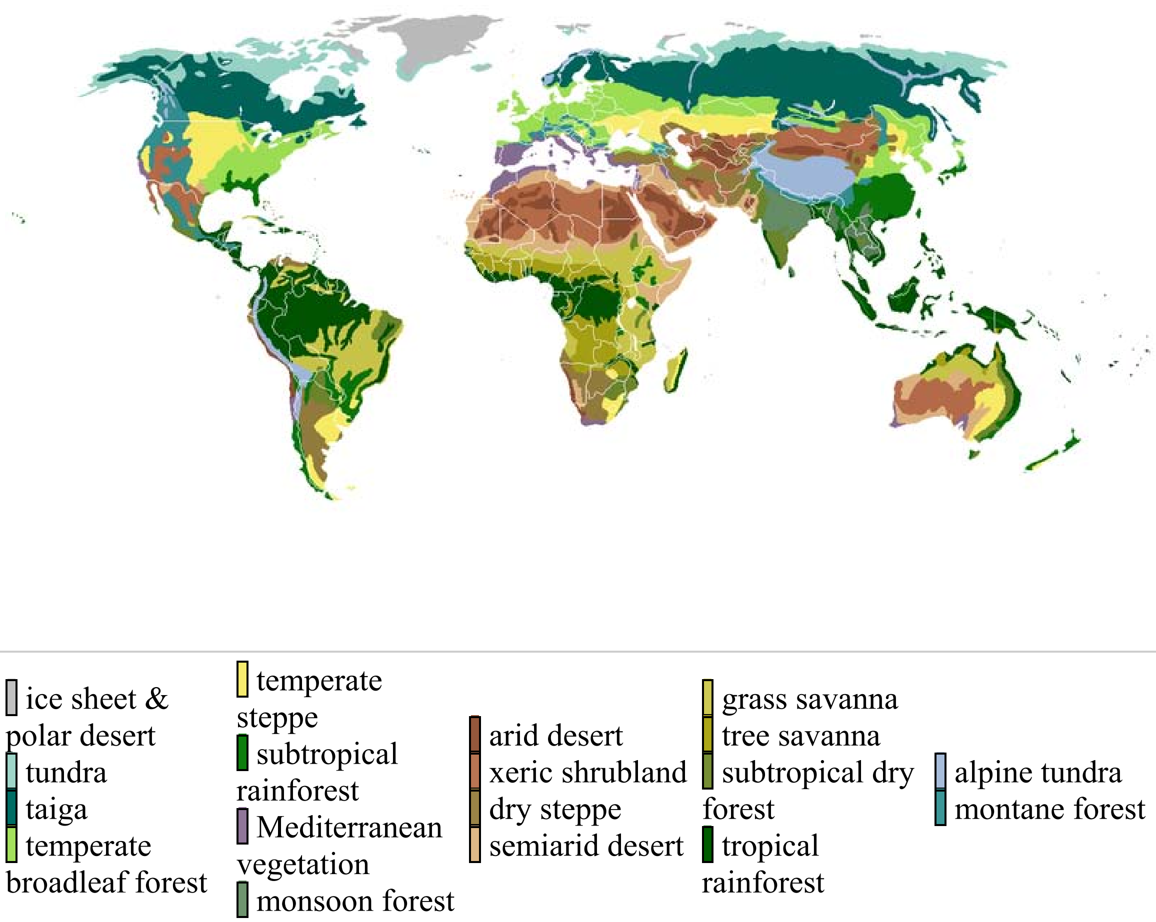
Major Anthropogenic Biomes

- Dense Settlements
- Villages
- Croplands
- Rangelands
- Forested

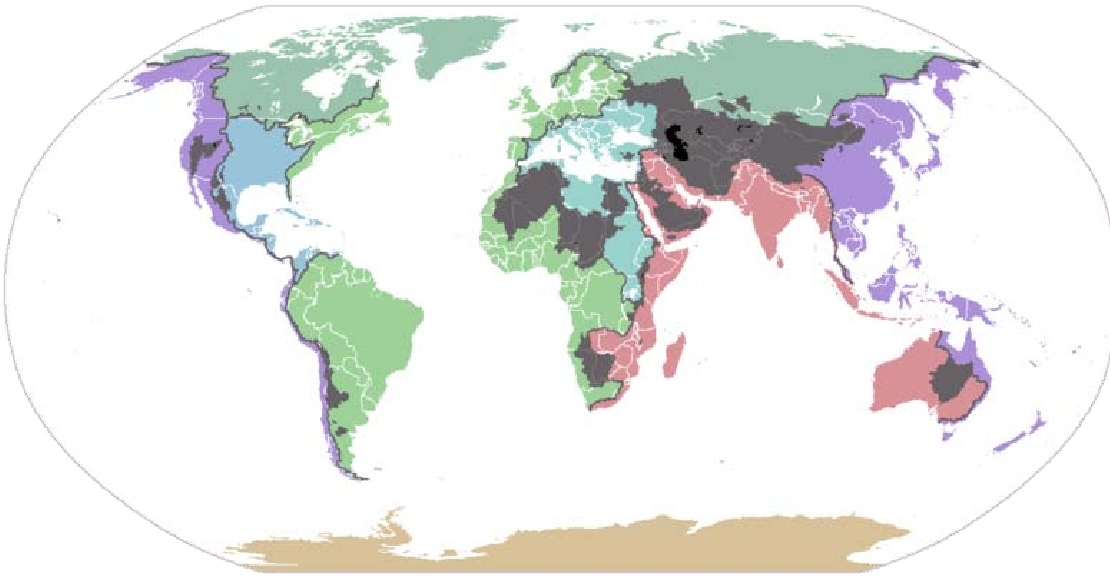
Other biomes

The Endolithic biome, consisting entirely of microscopic life in rock pores and cracks, kilometers beneath the surface, has only recently been discovered and does not fit well into most classification schemes.

Map of Biomes



Freshwater Biomes



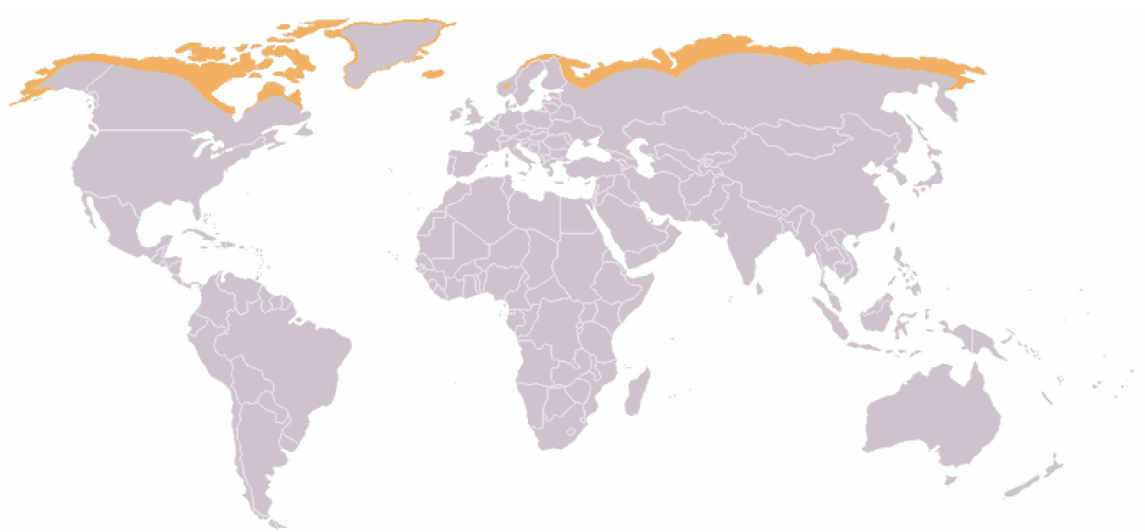
Drainage basins of the principal oceans and seas of the world. Grey areas are endorheic basins that do not drain to the ocean.

Chapter- 2

Tundra

In physical geography, **tundra** is a biome where the tree growth is hindered by low temperatures and short growing seasons. The term *tundra* comes through Russian тундра from the Kildin Sami word *tūndâr* "uplands," "treeless mountain tract." There are three types of tundra: **Arctic tundra**, **alpine tundra** and **Antarctic tundra**. The Tundra climate is designated (ET) in the Köppen climate classification. In tundra, the vegetation is composed of dwarf shrubs, sedges and grasses, mosses and lichens. Scattered trees grow in some tundra. The ecotone (or ecological boundary region) between the tundra and the forest is known as the tree line or timberline.

Arctic



Map of arctic tundra

Tundra in Greenland

Tundra in Alaska

Arctic tundra occurs in the far Northern Hemisphere, north of the taiga belt. The word "tundra" usually refers only to the areas where the subsoil is permafrost, or permanently frozen soil. (It may also refer to the treeless plain in general, so that northern Sápmi would be included.) Permafrost tundra includes vast areas of northern Russia and Canada. The polar tundra is home to several peoples who are mostly nomadic reindeer herders, such as the Nganasan and Nenets in the permafrost area (and the Sami in Sápmi).

Arctic tundra contains areas of stark landscape and is frozen for much of the year. The soil there is frozen from 25–90 cm (9.8–35.4 inches) down and it is impossible for trees to grow. Instead, bare and sometimes rocky land can only support low growing plants such as moss, heath (Ericaceae varieties such as crowberry and black bearberry) and lichen. There are two main seasons, winter and summer, in the polar tundra areas. During the winter it is very cold and dark, with the average temperature around −28 °C (−18 °F), sometimes dipping as low as −50 °C (−58 °F). However, extreme cold temperatures on the tundra do not drop as low as those experienced in taiga areas further south (for example, Russia's and Canada's lowest temperatures were recorded in locations south of the tree line). During the summer, temperatures rise somewhat and the top layer of the permafrost melts, leaving the ground very soggy. The tundra is covered in marshes, lakes, bogs and streams during the warm months. Generally daytime temperatures during the summer rise to about 12 °C (54 °F) but can often drop to 3 °C (37 °F) or even below freezing. Arctic tundras are sometimes the subject of habitat conservation programs. In Canada and Russia, many of these areas are protected through a national Biodiversity Action Plan.

The tundra is a very windy area, with winds often blowing upwards of 48–97 km/h (30–60 miles an hour). However, in terms of precipitation, it is desert-like, with only about 15–25 cm (6–10 inches) falling per year (the summer is typically the season of maximum precipitation). During the summer, the permafrost thaws just enough to let plants grow and reproduce, but because the ground below this is frozen, the water cannot sink any lower and so the water forms the lakes and marshes found during the summer months. Although precipitation is light, evaporation is also relatively minimal.

The biodiversity of the tundras is low: 1,700 species of vascular plants and only 48 land mammals can be found, although millions of birds migrate there each year for the marshes. There are also a few fish species such as the flatfish. There are few species with large populations. Notable animals in the Arctic tundra include caribou (reindeer), musk ox, arctic hare, arctic fox, snowy owl, lemmings and polar bears (only the extreme north).

Due to the harsh climate of the Arctic tundra, regions of this kind have seen little human activity, even though they are sometimes rich in natural resources such as oil and uranium. In recent times this has begun to change in Alaska, Russia and some other parts of the world.

A severe threat to the tundras, specifically to the permafrost, is global warming. The melting of the permafrost in a given area on human time scales (decades or centuries) could radically change which species can survive there.

Another concern is that about one third of the world's soil-bound carbon is in taiga and tundra areas. When the permafrost melts, it releases carbon in the form of carbon dioxide and methane, both of which are greenhouse gases. The effect has been observed in Alaska. In the 1970s the tundra was a carbon sink, but today, it is a carbon source.

Antarctic

Tundra on the Péninsule Rallier du Baty, Kerguelen Islands

Antarctic tundra occurs on Antarctica and on several Antarctic and subantarctic islands, including South Georgia and the South Sandwich Islands and the Kerguelen Islands. Most of Antarctica is too cold and dry to support vegetation and most of the continent is covered by ice fields. However, some portions of the continent, particularly the Antarctic Peninsula, have areas of rocky soil that support plant life. The flora presently consists of around 300–400 lichens, 100 mosses, 25 liverworts and around 700 terrestrial and aquatic algae species, which live on the areas of exposed rock and soil around the shore of the continent. Antarctica's two flowering plant species, the Antarctic hair grass (*Deschampsia antarctica*) and Antarctic pearlwort (*Colobanthus quitensis*), are found on the northern and western parts of the Antarctic Peninsula.

In contrast with the Arctic tundra, the Antarctic tundra lacks a large mammal fauna, mostly due to its physical isolation from the other continents. Sea mammals and sea birds, including seals and penguins, inhabit areas near the shore and some small mammals, like rabbits and cats, have been introduced by humans to some of the subantarctic islands. The Antipodes Subantarctic Islands tundra ecoregion includes the Bounty Islands, Auckland Islands, Antipodes Islands, the Campbell Island group and Macquarie Island. Species endemic to this ecoregion include *Nematoceras dienemum* and *Nematoceras sulcatum*, the only Subantarctic orchids; the royal penguin; and the Antipodean albatross.

The flora and fauna of Antarctica and the Antarctic Islands (south of 60° south latitude) are protected by the Antarctic Treaty.

Alpine

Hikers traversing the Franconia Ridge in the White Mountains, New Hampshire, United States, much of which is in the alpine zone.

Tundra region with fjords, glaciers and mountains. Kongsfjorden, Spitsbergen.

Alpine tundra is an ecozone that does not contain trees because it is at high altitude. Alpine tundra is distinguished from arctic tundra, because alpine soils are generally better drained than arctic soils. Alpine tundra transitions to subalpine forests below the tree line; stunted forests occurring at the forest-tundra ecotone are known as *Krummholz*.

Alpine tundra occurs in mountains worldwide. The flora of the alpine tundra is characterized by dwarf shrubs close to the ground. The cold climate of the alpine tundra is caused by the low air pressure and is similar to polar climate.

Geography

Alpine tundra occurs at high enough altitude at any latitude. Portions of Montane grasslands and shrublands ecoregions worldwide include alpine tundra. Large regions of alpine tundra occur in the American Cordillera in North and South America, the Alps and Pyrenees of Europe, the Rift Mountains of Africa and a large portion of the Tibetan Plateau.

Alpine tundra/grasslands occupy high-mountain summits, slopes and ridges above timberline. Aspect plays a role as well: the treeline often occurs at higher elevations on warmer south slopes. Because the alpine zone is present only on mountains, much of the landscape is rugged and broken, with rocky, snowcapped peaks, cliffs and talus slopes, but also contains areas of gently rolling to almost flat topography.

Climate

Summer in Northern Sweden's Tarfala Valley with its alpine climate

Alpine climate is the average weather (climate) for the alpine tundra ecozone. The climate becomes colder at high elevations—this characteristic is described by the lapse rate of air: air tends to get colder as it rises, since it expands. The dry adiabatic lapse rate is 10 °C per km of elevation or altitude. Therefore, moving up 100 meters on a mountain is roughly equivalent to moving 80 kilometers (45 miles or 0.75° of latitude) towards the pole. This relationship is only approximate, however, since local factors such as proximity to oceans can drastically modify the climate.

Typical high-elevation growing seasons range from 45 to 90 days, with average summer temperatures near 50° F (10° C). Growing season temperatures frequently fall below freezing and frost occurs throughout the growing season in many areas. Precipitation occurs mainly as winter snow, but soil water availability is highly variable with season, location and topography. For example, snowfields commonly accumulate on the lee sides of ridges while ridgelines may remain nearly snow free due to redistribution by wind. Some alpine habitats may be up to 70% snow free in winter. High winds are common in alpine ecosystems and can cause significant soil erosion and be physically and physiologically detrimental to plants. Also, wind coupled with high solar radiation can promote extremely high rates of evaporation and transpiration.

Quantifying the climate

This alpine valley is entirely above the tree line

There have been several attempts at quantifying what constitutes an alpine climate.

Climatologist Wladimir Köppen demonstrated a relationship between the Arctic and Antarctic tree lines and the 10 °C summer isotherm; i.e., places where the average temperature in the warmest calendar month of the year is below 10 °C cannot support forests.

Otto Nordenskiöld theorized that winter conditions also play a role: His formula is $W = 9 - 0.1\ C$, where W is the average temperature in the warmest month and C the average of the coldest month, both in degrees Celsius (this would mean, for example, that if a particular location had an average temperature of −20 °C in its coldest month, the warmest month would need to average 11 °C or higher for trees to be able to survive there).

In 1947, Holdridge improved on these schemes, by defining biotemperature: the mean annual temperature, where all temperatures below 0 °C are treated as 0 °C (because it makes no difference to plant life, being dormant). If the mean biotemperature is between 1.5 °C and 3 °C, Holdridge quantifies the climate as alpine.

Flora

Flora of an alpine environment

In a world of intense radiation, wind, cold, snow and ice, alpine vegetation is close to the ground and consists mainly of perennial grasses, sedges, forbs and low-growing shrubs with prominent inclusions of lichens and mosses. Compared to ecosystems at lower elevations, the alpine tundra contains few plant species; usually there are no more than 200 to 300 species present in the alpine zone of a given mountain range. Perennial herbs (including grasses, sedges and low woody or semi-woody shrubs) dominate the alpine landscape; they have much more root and rhizome biomass than that of shoots, leaves and flowers. The roots and rhizomes not only function in water and nutrient absorption but also play a very important role in over-winter carbohydrate storage. Annual plants are rare in this ecosystem and usually are only a few inches tall, with weak root systems.

Plants have adapted to the harsh alpine environment. Cushion plants, looking like ground-hugging clumps of moss, escape the strong winds blowing a few inches above them. Many flowering plants of the alpine tundra have dense hairs on stems and leaves to provide wind protection or red-colored pigments capable of converting the sun's light rays into heat. Some plants take two or more years to form flower buds, which survive the winter below the surface and then open and produce fruit with seeds in the few weeks of summer.

Alpine areas are unique because of the severity and complexity of their environmental conditions. Very small changes in topography [as small as 1 foot (0.3 m) or less] may mean the difference between a windswept area or an area of snow accumulation, changing the potential productivity and plant community drastically. Between these extremes of drought versus saturation, several intermediate environments may exist all within a few yards of each other, depending on topography, substrate and climate. Alpine vegetation generally occurs in a mosaic of small patches with widely differing environmental conditions. Vegetation types vary from cushion and rosette plants on the ridges and in the rock crannies; to herbaceous and grassy vegetation along the slopes; dwarf shrubs with grasses and forbs below the melting snowdrifts; and sedges, grasses, low shrubs and mosses in the bogs and along the brooks.

An alpine mire in the Swiss Alps

Alpine meadows form where sediments from the weathering of rocks has produced soils well-developed enough to support grasses and sedges. Non-flowering lichens cling to rocks and soil. Their enclosed algal cells can photosynthesize at any temperature above 0 °C (32 °F) and the outer fungal layers can absorb more than their own weight in water. The adaptations for survival of drying winds and cold may make tundra vegetation seem very hardy, but in some respects the tundra is very fragile. Repeated footsteps often destroy tundra plants, leaving exposed soil to blow away and recovery may take hundreds of years.

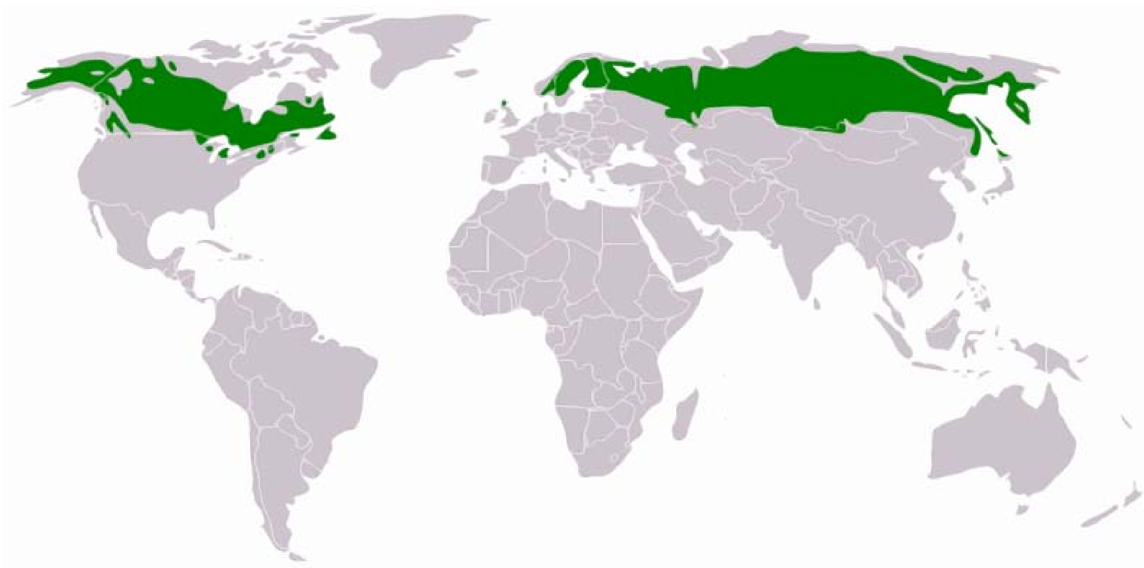
Climatic classification

Tundra climates ordinarily fit the Köppen climate classification **ET**, signifying a local climate in which at least one month has an average temperature high enough to melt snow (0°C or 32°F), but no month with an average temperature in excess of (10°C/50°F). The cold limit generally meets the **EF** climates of permanent ice and snows; the warm-summer limit generally corresponds with the poleward or altitudinal limit of trees, where they grade into the subarctic climates designated **Dfd** and **Dwd** (extreme winters as in parts of Siberia), **Dfc** typical in Alaska, Canada, European Russia and Western Siberia (cold winters with months of freezing), or even **Cfc** (no month colder than -3°C as in parts of Iceland and southernmost South America). Tundra climates as a rule are hostile to woody vegetation even where the winters are comparatively mild by polar standards, as in Iceland.

Despite the potential diversity of climates in the **ET** category involving precipitation, extreme temperatures and relative wet and dry seasons, this category is rarely subdivided. Rainfall and snowfall are generally slight due to the low vapor pressure of water in the chilly atmosphere, but as a rule potential evapotranspiration is extremely low, allowing soggy terrain of swamps and bogs even in places that get precipitation typical of deserts of lower and middle latitudes. The amount of native tundra biomass depends more on the local temperature than the amount of precipitation.

Chapter- 3

Taiga



The taiga is found throughout the high northern latitudes, between the tundra and the temperate forest, mostly from 52°N to 66°N, but with considerable regional variation and reaching 70°N in some areas.

Taiga (pronounced also known as the **boreal forest**, is a biome characterized by coniferous forests.

Taiga is the world's largest terrestrial biome and covers: in North America most of inland Canada and Alaska as well as parts of the extreme northern continental United States (especially northern Minnesota, Michigan's Upper Peninsula, northern Wisconsin, Upstate New York, Vermont, New Hampshire and Maine); and in Eurasia most of Sweden, Finland, inland Norway, much of Russia (especially Siberia), northern Kazakhstan, northern Mongolia and northern Japan (on the island of Hokkaidō).

The term ***boreal forest*** is sometimes, particularly in Canada, used to refer to the more southerly part of the biome, while the term **taiga** is then often used to describe only the more barren areas of the northernmost part of the taiga approaching the tree line.

Climate and geography

White Spruce taiga, Denali Highway, Alaska Range, Alaska

Taiga is the world's largest land biome and makes up 27% of the world's forest cover; the largest areas are located in Russia and Canada. The taiga is the terrestrial biome with the lowest annual average temperatures after the tundra and permanent ice caps. However, extreme minimums in the taiga are typically lower than those of the tundra. The lowest reliably recorded temperatures in the Northern Hemisphere were recorded in the taiga of northeastern Russia. The taiga or boreal forest has a subarctic climate with very large temperature range between seasons, but the long and cold winter is the dominant feature. This climate is classified as *Dfc*, *Dwc*, *Dsc*, *Dfd*, *Dwd* and *Dsd* in the Köppen climate classification scheme, meaning that the short summer (24-hr average 10°C or more) lasts 1–3 months and always less than 4 months. There are also some much smaller areas grading towards the oceanic *Cfc* climate with milder winters. The mean annual temperature generally varies from -5°C to 5°C, but there are taiga areas in both eastern Siberia and interior Alaska-Yukon where the mean annual reaches down to -10°C. According to some sources, the boreal forest grades into a temperate mixed forest when mean annual temperature reaches about 3 °C. Permafrost is common in areas with mean annual temperature below 0 °C. The winters last 5 – 7 months, with average temperatures below freezing. Temperatures vary from −54 °C to 30 °C (-65 °F to 86 °F) throughout the whole year.

The taiga in the river valley near Verkhoyansk, Russia, at 67°N, must deal with the coldest winter temperatures in the northern hemisphere, but the extreme continentality of the climate gives an average daily high of 22 °C in July.

The summers, while short, are generally warm and humid. In much of the taiga, -20 °C would be a typical winter day temperature and 18 °C an average summer day.

The growing season, when the vegetation in the taiga comes alive, is usually slightly longer than the climatic definition of summer as the plants of the boreal biome have a lower threshold to trigger growth. In Canada, Scandinavia and Finland, the growing season is often estimated by using the period of the year when the 24-hr average temperature is 5 °C or more. For the Taiga Plains in Canada, growing season varies from 80 to 150 days and in the Taiga Shield from 100 to 140 days. Some sources claim 130 days growing season as typical for the taiga. Other sources mention that 50 - 100 frost-free days are characteristic. Data for locations in southwest Yukon gives 80 - 120 frost-free days. The closed canopy boreal forest in Kenozersky near Plesetsk, Arkhangelsk Province, Russia, on average has 108 frost-free days. The longest growing season is found in the smaller areas with oceanic influences; in coastal areas of Scandinavia and Finland, the growing season of the closed boreal forest can be 145 – 180 days. The shortest growing season is found at the northern taiga - tundra ecotone, where the northern taiga forest no longer can grow and the tundra dominates the landscape when the growing season is down to 50 – 70 days and the 24-hr average of the warmest month of the year usually is 10°C or less. High latitudes mean that the sun does not rise far above the horizon and less solar energy is received than further south. But the high latitude also ensures very long summer days, as the sun stays above the horizon nearly 20 hours each day, with only around 6 hours of daylight occurring in the dark winters, depending on latitude. The areas of the taiga inside the Arctic circle have midnight sun in mid-summer and polar night in mid-winter.

The taiga experiences relatively low precipitation throughout the year (generally 200–750 mm annually, 1,000 mm in some areas), primarily as rain during the summer months, but also as fog and snow. As evaporation is also low for most of the year, precipitation exceeds evaporation and is sufficient to sustain the dense vegetation growth. Snow may remain on the ground for as long as nine months in the northernmost extensions of the taiga ecozone.

Lakes and other water bodies are very common. The Helvetinjärvi National Park, Finland, is located in the southern boreal forest.

Yukon, Canada. Several of the World's longest rivers go through the taiga, including Ob, Yenisei, Lena and Mackenzie.

In general, taiga grows to the south of the 10 °C July isotherm, but occasionally as far north as the 9 °C July isotherm. The southern limit is more variable, depending on rainfall; taiga may be replaced by forest steppe south of the 15 °C July isotherm where rainfall is very low, but more typically extends south to the 18 °C July isotherm and locally where rainfall is higher (notably in eastern Siberia and adjacent northern Manchuria) south to the 20 °C July isotherm. In these warmer areas, the taiga has higher species diversity, with more warmth-loving species such as Korean Pine, Jezo Spruce and Manchurian Fir and merges gradually into mixed temperate forest, or more locally (on the Pacific Ocean coasts of North America and Asia) into coniferous temperate rainforests.

Much of the area currently classified as taiga was recently glaciated. As the glaciers receded, they left depressions in the topography that have since filled with water, creating lakes and bogs (especially muskeg soil), found throughout the taiga.

Soils

Taiga soil tends to be young and nutrient-poor; it lacks the deep, organically-enriched profile present in temperate deciduous forests. The thinness of the soil is due largely to the cold, which hinders the development of soil and the ease with which plants can use its nutrients. Fallen leaves and moss can remain on the forest floor for a long time in the cool, moist climate, which limits their organic contribution to the soil; acids from evergreen needles further leach the soil, creating spodosol. Since the soil is acidic due to the falling pine needles, the forest floor has only lichens and some mosses growing on it.

Flora

Boreal Forest near Lake Baikal in Russia

Since North America and Asia used to be connected by the Bering land bridge, a number of animal and plant species (more animals than plants) were able to colonize both continents and are distributed throughout the taiga biome. Others differ regionally, typically with each genus having several distinct species, each occupying different regions of the taiga. Taigas also have some small-leaved deciduous trees like birch, alder, willow and poplar; mostly in areas escaping the most extreme winter cold. However, the Dahurian Larch tolerates the coldest winters in the northern hemisphere in eastern Siberia. The very southernmost parts of the taiga may have trees such as oak, maple, elm and tilia scattered among the conifers and there is usually a gradual transition into a temperate mixed forest, such as the Eastern forest-boreal transition of eastern Canada. In the interior of the continents with the driest climate, the boreal forests might grade into temperate grassland.

There are two major types of taiga. The southern part is the **closed canopy forest**, consisting of many closely-spaced trees with mossy ground cover. In clearings in the forest, shrubs and wildflowers are common, such as the fireweed. The other type is the **lichen woodland** or **sparse taiga**, with trees that are farther-spaced and lichen ground cover; the latter is common in the northernmost taiga. In the northernmost taiga the forest cover is not only more sparse, but often stunted in growth form; moreover, ice pruned asymmetric Black Spruce (in North America) are often seen, with diminished foliage on the windward side. In Canada, Scandinavia and Finland, the boreal forest is usually divided into three subzones: The **high boreal** (north boreal) or taiga zone; the **middle boreal** (closed forest); and the **southern boreal**, a closed canopy boreal forest with some scattered temperate deciduous trees among the conifers, such as maple, elm and oak. This southern boreal forest has the longest and warmest growing season of the biome and in some regions (including Scandinavia, Finland and western Russia) this subzone is commonly used for agricultural purposes. The boreal forest is home to many types of berries; some are confined to the southern and middle closed boreal forest (such as raspberry), others grow in most areas of the taiga (such as cranberry and cloudberry) and some can grow in both the taiga and the low arctic (southern part of) tundra (such as bilberry and lingonberry).

The forests of the taiga are largely coniferous, dominated by larch, spruce, fir and pine. The woodland mix varies according to geography and climate so for example the Eastern Canadian forests ecoregion of the higher elevations of the Laurentian Mountains and the northern Appalachian Mountains in Canada is dominated by balsam fir *Abies balsamea*, while further north the Eastern Canadian Shield taiga of northern Quebec and Labrador is notably black spruce *Picea mariana* and tamarack larch *Larix laricina*.

Evergreen species in the taiga (spruce, fir and pine) have a number of adaptations specifically for survival in harsh taiga winters, although larch, the most cold-tolerant of all trees, is deciduous. Taiga trees tend to have shallow roots to take advantage of the thin soils, while many of them seasonally alter their biochemistry to make them more resistant to freezing, called "hardening". The narrow conical shape of northern conifers and their downward-drooping limbs, also help them shed snow.

Because the sun is low in the horizon for most of the year, it is difficult for plants to generate energy from photosynthesis. Pine, spruce and fir do not lose their leaves seasonally and are able to photosynthesize with their older leaves in late winter and spring when light is good but temperatures are still too low for new growth to commence. The adaptation of evergreen needles limits the water lost due to transpiration and their dark green color increases their absorption of sunlight. Although precipitation is not a limiting factor, the ground freezes during the winter months and plant roots are unable to absorb water, so desiccation can be a severe problem in late winter for evergreens.

Moss (*Ptilium crista-castrensis*) cover on the floor of taiga

Although the taiga is dominated by coniferous forests, some broadleaf trees also occur, notably birch, aspen, willow and rowan. Many smaller herbaceous plants grow closer to the ground. Periodic stand-replacing wildfires (with return times of between 20–200 years) clear out the tree canopies, allowing sunlight to invigorate new growth on the forest floor. For some species, wildfires are a necessary part of the life cycle in the taiga; some, e.g. Jack Pine have cones which only open to release their seed after a fire, dispersing their seeds onto the newly cleared ground. Grasses grow wherever they can find a patch of sun and mosses and lichens thrive on the damp ground and on the sides of tree trunks. In comparison with other biomes, however, the taiga has low biological diversity.

Coniferous trees are the dominant plants of the taiga biome. A very few species in four main genera are found: the evergreen spruce, fir and pine and the deciduous larch. In North America, one or two species of fir and one or two species of spruce are dominant.

Across Scandinavia and western Russia, the Scots pine is a common component of the taiga, while taiga of the Russian Far East and Mongolia is dominated by larch.

Fauna

Brown bear, Kamchatka peninsula. Brown bears are among the largest and most widespread taiga predators.

The boreal forest, or taiga, supports a large range of animals. Canada's boreal forest includes 85 species of mammals, 130 species of fish and an estimated 32,000 species of insects. Insects play a critical role as pollinators, decomposers and as a part of the food chain; many nesting birds rely on them for food. The cold winters and short summers make the taiga a challenging biome for reptiles and amphibians, which depend on environmental conditions to regulate their body temperatures and there are only a few species in the boreal forest. Some hibernate underground in winter.

The taiga is home to a number of large herbivorous mammals, such as moose and reindeer/caribou. Some areas of the more southern closed boreal forest also have populations of other deer species such as the elk (wapiti) and roe deer. There is also a range of rodent species, including beaver, squirrel, mountain hare, snowshoe hare and vole. These species have evolved to survive the harsh winters in their native ranges. Some larger mammals, such as bears, eat heartily during the summer in order to gain weight and then go into hibernation during the winter. Other animals have adapted layers of fur or feathers to insulate them from the cold.

A number of wildlife species threatened or endangered with extinction can be found in the Canadian boreal forest, including woodland caribou, American black bear, grizzly bear and wolverine. Habitat loss, mainly due to logging, is the primary cause of decline for these species.

Due to the climate, carnivorous diets are an inefficient means of obtaining energy; energy is limited and most energy is lost between trophic levels. Predatory birds (owls and eagles) and other smaller carnivores, including foxes and weasels, feed on the rodents. Larger carnivores, such as lynx and wolves, prey on the larger animals. Omnivores, such as bears and raccoons are fairly common, sometimes picking through human garbage.

More than 300 species of birds have their nesting grounds in the taiga. This includes Siberian Thrush, White-throated Sparrow and Black-throated Green Warbler, migrate to this habitat to take advantage of the long summer days and abundance of insects found around the numerous bogs and lakes. Of the 300 species of birds that summer in the taiga, only 30 stay for the winter. These are either carrion-feeding or large raptors that can take live mammal prey, including Golden Eagle, Rough-legged Buzzard and Raven, or else seed-eating birds, including several species of grouse and crossbills.

Plesetsk Cosmodrome is situated in the taiga

Threats

Human activities

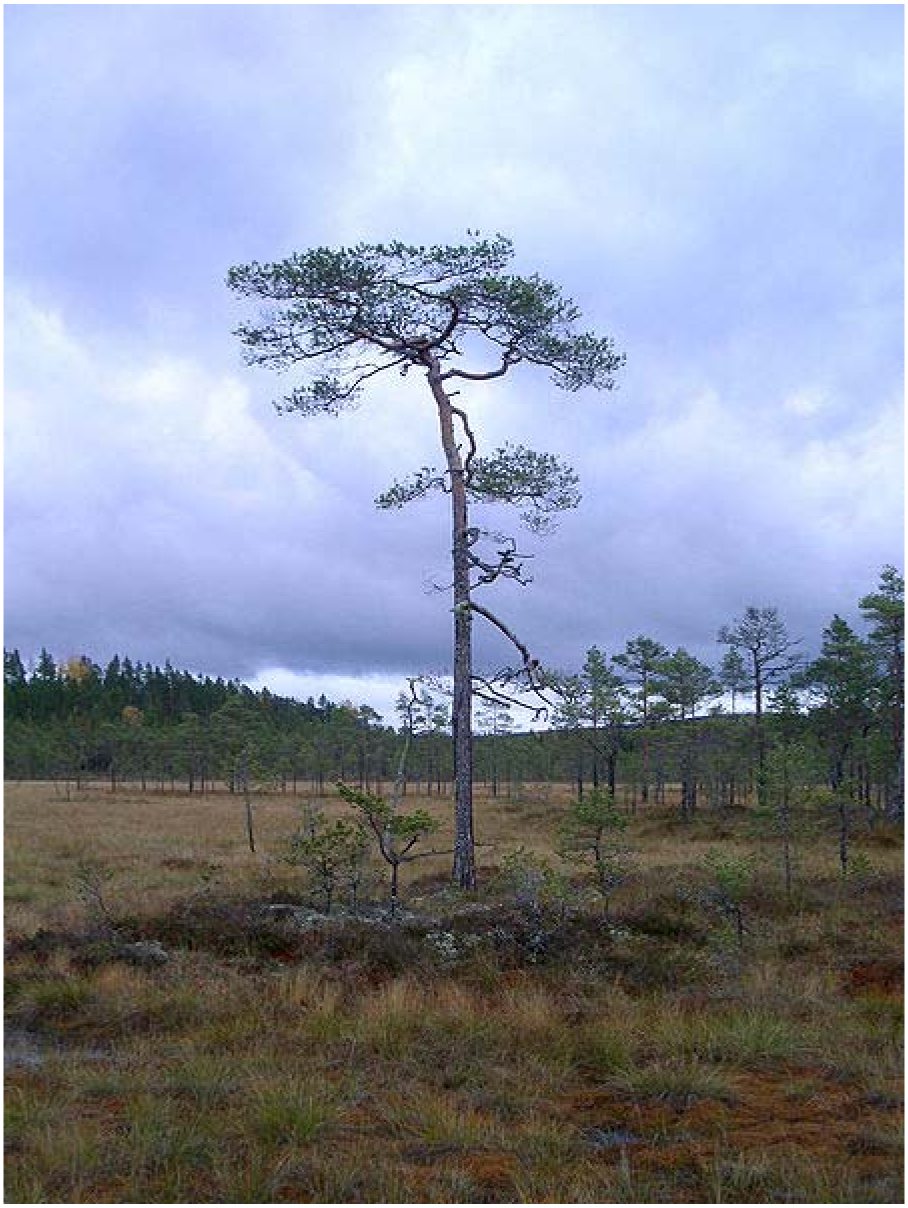
Large areas of Siberia's taiga have been harvested for lumber since the collapse of the Soviet Union. In Canada, less than eight percent of the boreal forest is protected from development and more than 50% has been allocated to logging companies for cutting. The main form of forestry in the boreal forest of Canada is clearcutting, where most if not all trees are removed from an area of forest. Clearcuts upwards of 110 km^2 have been recorded in the Canadian boreal forest. Some of the products from logged boreal forests include toilet paper, copy paper, newsprint and lumber. More than 80% of boreal forest products from Canada are exported for consumption and processing in the United States. Some of the larger cities situated in this biome are Murmansk, Arkhangelsk, Yakutsk, Anchorage, Yellowknife, Tromsø, Luleå and Oulu.

Most companies that harvest in Canadian forests are certified by an independent third party agency such as the Forest Stewardship Council (FSC), Sustainable Forests Initiative (SFI), or the Canadian Standards Association (CSA). While the certification process differs between these various groups, all of them include forest stewardship, respect for aboriginal peoples, compliance with local, provincial and/or national environmental laws, forest worker safety, education and training and other environmental, business and social requirements. The prompt renewal of all harvest sites by planting or natural renewal is also required.

Insects

Recent years have seen outbreaks of insect pests in forest-destroying plagues: the spruce-bark beetle (Dendroctonus rufipennis) in the Yukon Territory, Canada and Alaska; the aspen-leaf miner; the larch sawfly; the spruce budworm (Choristoneura fumiferana); the spruce coneworm.

Protection



Peat bog in Dalarna, Sweden. Bogs and peatland are widespread in the taiga. They are home to a unique flora and store vast amounts of carbon. In western Eurasia, the pine is common in the boreal forest.

Many nations are taking direct steps to protect the ecology of the taiga by prohibiting logging, mining, oil and gas production and other forms of development. In February 2010 the Canadian government established protection for 13,000 square kilometres of boreal forest by creating a new 10,700 square kilometre park reserve in the Mealy Mountains area of eastern Canada and a 3,000 square kilometre waterway provincial park that follows alongside the Eagle River from headwaters to sea. The taiga stores enormous quantities of carbon, possibly more than the temperate and tropical forests combined, much of it in peatland.

Natural disturbance

One of the biggest areas of research and a topic still full of unsolved questions is the recurring disturbance of fire and the role it plays in propagating the lichen woodland. The phenomenon of wildfire by lighting strike is the primary determinant of understory vegetation and because of this, it is considered to be predominate driving force behind community and ecosystem properties in the lichen woodland. The significance of fire is clearly evident when one considers that understory vegetation influences tree seedling germination in the short term and decomposition of biomass and nutrient availability in the long term. The recurrent cycle of large, damaging fire occurs approximately every 70 to 100 years. Understanding the dynamics of this ecosystem is entangled with discovering the successional paths that the vegetation exhibits after a fire. Trees, shrubs and lichens all recover from fire induced damage through vegetative reproduction as well as invasion by propagules. Seeds that have fallen and become buried provide little help in re-establishment of a species. The reappearance of lichens is reasoned to occur because of varying conditions and light/nutrient availability in each different microstate. Several different studies have been done that have led to the formation of the theory that post-fire development can be propagated by any of four pathways: self replacement, species-dominance relay, species replacement, or gap-phase self replacement. Self replacement is simply the re-establishment of the pre-fire dominant species. Species-dominance relay is a sequential attempt of tree species to establish dominance in the canopy. Species replacement is when fires occur in sufficient frequency to interrupt species dominance relay. Gap-Phase Self-Replacement is the least common and so far has only been documented in Western Canada. It is a self replacement of the surviving species into the canopy gaps after a fire kills another species. The particular pathway taken after a fire disturbance depends on how the landscape is able to support trees as well as fire frequency. Fire frequency has a large role in shaping the original inception of the lower forest line of the lichen woodland taiga.

Centuries ago, the southern limits of lichen woodland taiga were only being formed. It has been hypothesized and subsequently proved by Serge Payette that the Spruce-Moss forest ecosystem was changed into the lichen woodland biome due to the initiation of two compounded strong disturbances. The two disturbances were large fire and the appearance and attack of the spruce budworm. The spruce budworm is a deadly insect to the spruce populations in the southern regions of the taiga. J.P. Jasinski confirmed this theory five years later stating "Their [lichen woodlands] persistence, along with their previous moss forest histories and current occurrence adjacent to closed moss forests, indicate that they are an alternative stable state to the spruce–moss forests".

Taiga ecoregions

Palearctic Boreal forests/taiga	
East Siberian taiga	Russia
Iceland boreal birch forests and alpine tundra	Iceland
Kamchatka-Kurile meadows and sparse forests	Russia
Kamchatka-Kurile taiga	Russia
Northeast Siberian taiguhh	Russia
Okhotsk-Manchurian taiga	Russia
Sakhalin Island taiga	Russia
Scandinavian and Russian taiga	Finland, Norway, Russia, Sweden
Trans-Baikal conifer forests	Mongolia, Russia
Urals montane tundra and taiga	Russia
West Siberian taiga	Russia

Nearctic Boreal forests/taiga	
Alaska Peninsula montane taiga	United States
Central Canadian Shield forests	Canada, United States
Cook Inlet taiga	United States
Copper Plateau taiga	United States
Eastern Canadian forests	Canada
Eastern Canadian Shield taiga	Canada
Interior Alaska-Yukon lowland taiga	Canada, United States
Mid-Continental Canadian forests	Canada
Midwestern Canadian Shield forests	Canada, United States
Muskwa-Slave Lake forests	Canada
Newfoundland Highland forests	Canada
Northern Canadian Shield taiga	Canada
Northern Cordillera forests	Canada
Northwest Territories taiga	Canada
South Avalon-Burin oceanic barrens	Canada
Southern Hudson Bay taiga	Canada
Yukon Interior dry forests	Canada

Chapter- 4

Montane Grasslands and Shrublands

Montane grasslands and shrublands is a biome defined by the World Wildlife Fund. The biome includes high altitude (montane, subalpine and alpine) grasslands and shrublands around the world.

Montane grasslands and shrublands located above the tree line are commonly known as alpine tundra, which occurs in mountain regions around the world. Below the tree line are subalpine and montane grasslands and shrublands. Stunted subalpine forests are known as krummholz and occur just below the tree line, where harsh, windy conditions and poor soils create dwarfed and twisted forests of slow-growing trees.

Montane grasslands and shrublands, particularly in subtropical and tropical regions, often evolved as virtual islands, separated from other montane regions by warmer, lower elevation regions and are frequently home to many distinctive and endemic plants which evolved in response to the cool, wet climate and abundant tropical sunlight. Characteristic plants of these habitats display adaptations such as rosette structures, waxy surfaces and hairy leaves. A unique feature of many wet tropical montane regions is the presence of giant rosette plants from a variety of plant families, such as *Lobelia* (Afrotropic), *Puya* (Neotropic), *Cyathea* (New Guinea) and *Argyroxiphium* (Hawaii).

The most extensive Montane grasslands and shrublands occur in the Neotropic Paramo of the Andes Mountains. This biome also occurs in the mountains of east and central Africa, Mount Kinabalu of Borneo, highest elevations of the Western Ghats in South India and the Central Highlands of New Guinea.

Where conditions are drier, one finds montane grasslands, savannas and woodlands, like the Ethiopian Highlands and montane steppes, like the steppes of the Tibetan Plateau.

Montane grassland and shrubland ecoregions

Afrotropic Montane grasslands and shrublands	
Angolan montane forest-grassland mosaic	Angola
Angolan Scarp savanna and woodlands	Angola
Drakensberg alti-montane	Lesotho, South Africa

grasslands and woodlands	
Drakensberg montane grasslands, woodlands and forests	Lesotho, South Africa, Swaziland
East African montane moorlands	Kenya, Sudan, Tanzania, Uganda
Eastern Zimbabwe montane forest-grassland mosaic	Mozambique, Zimbabwe
Ethiopian montane grasslands and woodlands	Ethiopia
Ethiopian montane moorlands	Ethiopia
Highveld grasslands	Lesotho, South Africa
Jos Plateau forest-grassland mosaic	Nigeria
Madagascar ericoid thickets	Madagascar
Maputaland-Pondoland bushland and thickets	Mozambique, South Africa, Swaziland
Ruwenzori-Virunga montane moorlands	Democratic Republic of the Congo, Rwanda, Uganda
South Malawi montane forest-grassland mosaic	Malawi, Mozambique
Southern Rift montane forest-grassland mosaic	Malawi, Tanzania
Australasia Montane grasslands and shrublands	
Australian Alps montane grasslands	Australia
Central Range sub-alpine grasslands	Indonesia, Papua New Guinea
Southland montane grasslands	New Zealand
Indomalaya Montane grasslands and shrublands	
Kinabalu montane alpine meadows	Malaysia
Neotropic Montane grasslands and shrublands	
Central Andean dry puna	Argentina, Bolivia, Chile
Central Andean puna	Argentina, Bolivia, Peru
Central Andean wet puna	Bolivia, Peru
Cordillera Central páramo	Ecuador, Peru
Cordillera de Merida páramo	Venezuela
Northern Andean páramo	Colombia, Ecuador
Santa Marta páramo	Colombia
Talamanca Paramo	Costa Rica, Panama

Southern Andean steppe	Argentina, Chile
Zacatonal	Mexico, Guatemala
Palearctic Montane grasslands and shrublands	
Altai alpine meadow and tundra	People's Republic of China, Kazakhstan, Mongolia, Russia
Central Tibetan Plateau alpine steppe	China
Eastern Himalayan alpine shrub and meadows	Bhutan, Burma, People's Republic of China, India, Nepal
Ghorat-Hazarajat alpine meadow	Afghanistan
Hindu Kush alpine meadow	Afghanistan, Pakistan
Karakoram-West Tibetan Plateau alpine steppe	Afghanistan, People's Republic of China, India, Pakistan
Khangai Mountains alpine meadow	Mongolia
Kopet Dag woodlands and forest steppe	Iran, Turkmenistan
Kuhrud-Kohbanan Mountains forest steppe	Iran
Mediterranean High Atlas juniper steppe	Morocco
North Tibetan Plateau-Kunlun Mountains alpine desert	China
Northwestern Himalayan alpine shrub and meadows	People's Republic of China, India, Pakistan
Ordos Plateau steppe	China
Pamir alpine desert and tundra	Afghanistan, China, Kyrgyzstan, Tajikistan
Qilian Mountains subalpine meadows	China
Sayan Alpine meadows and tundra	Mongolia, Russia
Southeast Tibet shrub and meadows	China
Sulaiman Range alpine meadows	Afghanistan, Pakistan
Tian Shan montane steppe and meadows	China, Kazakhstan, Kyrgyzstan
Tibetan Plateau alpine shrub	People's Republic of China

and meadows	
Western Himalayan alpine shrub and meadows	India, Nepal
Yarlung Zambo arid steppe	China

Chapter- 5

Temperate Broadleaf and Mixed Forests

Temperate mixed forest in Yunnan, southwest China.

Mixed forests are a temperate and humid biome. The typical structure of these forests include four layers. The upper most layer is the canopy which is composed of tall mature trees ranging from 33 to 66 m (100 to 200 feet) high. Below the canopy is the three-layered, shade tolerant understory which is roughly 9 to 15 m (30 to 50 feet) shorter than the canopy. The top layer of the understory is the sub-canopy which is composed of smaller mature trees, saplings and suppressed juvenile canopy layer trees awaiting an opening in the canopy. Below the sub-canopy is the shrub layer, composed of low growing woody plants. Typically the lowest growing (and most diverse) layer is the ground cover or herbaceous layer.

Trees

Characteristic dominant broadleaf trees in this biome include oaks (*Quercus* spp.), beeches (*Fagus* spp.), maples (*Acer* spp.) and birches (*Betula* spp.). The term "mixed forest" comes from the inclusion of coniferous trees as a canopy component of these forests. Typical coniferous trees include: Pines (*Pinus* spp.), firs (*Abies* spp.) and spruces (*Picea* spp.). In some areas of this biome the conifers may be a more important canopy species than the broadleaf species.

Climate

Temperate broadleaf and mixed forests occur in areas with distinct warm and cool season, which give it a moderate annual average temperature (3 to 15.6 °C). These forests occur in relatively warm and rainy climates, sometimes also with a distinct dry season. A dry season occurs in the winter in East Asia and in summer on the wet fringe of the Mediterranean climate zones. Other areas have a fairly even distribution of rainfall; annual rainfall is typically over 600 millimetres (24 inches) and often over 1500 millimetres (60 inches). Temperatures are typically moderate except in parts of Asia such as Ussuriland where temperate forests can occur despite very harsh conditions with very cold winters.

Temperate broadleaf and mixed forest ecoregions

Oceania

Oceania Temperate broadleaf and mixed forests	
Chatham Islands temperate forests	New Zealand
Eastern Australian temperate forests	Australia
Fiordland temperate forests	New Zealand
Nelson Coast temperate forests	New Zealand
Northland temperate forests	New Zealand
Northland temperate kauri forests	New Zealand
Stewart Island/Rakiura temperate forests	New Zealand
Richmond temperate forests	New Zealand
Southeast Australia temperate forests	Australia
Southland temperate forests	New Zealand
Tasmanian Central Highland forests	Australia
Tasmanian temperate forests	Australia
Tasmanian temperate rain forests	Australia
Westland temperate forests	New Zealand

Eurasia

Indomalaya Temperate broadleaf and mixed forests	
Eastern Himalayan broadleaf forests	Bhutan, India, Nepal
Northern Triangle temperate forests	Burma
Western Himalayan broadleaf forests	India, Nepal, Pakistan
Palearctic Temperate broadleaf and mixed forests	
Appenine deciduous montane forests	Italy
Atlantic mixed forests	Belgium, Denmark, France, Germany. Netherlands
Azores temperate mixed forests	Portugal
Balkan mixed forests	Bulgaria, Greece, Macedonia, Romania, Serbia (Kosovo), Turkey
Baltic mixed forests	Denmark, Germany, Poland, Sweden
Cantabrian mixed forests	Portugal, Spain
Caspian Hyrcanian mixed forests	Azerbaijan, Iran
Caucasus mixed forests	Armenia, Azerbaijan, Georgia, Russia, Turkey
Celtic broadleaf forests	Ireland, United Kingdom
Central Anatolian deciduous forests	Turkey
Central China loess plateau mixed forests	China
Central European mixed forests	Austria, Belarus, Czech Republic, Germany, Lithuania, Moldova, Poland
Central Korean deciduous forests	North Korea, South Korea
Changbai Mountains mixed forests	China, North Korea
Changjiang Plain evergreen forests	China
Crimean Submediterranean forest complex	Russia, Ukraine
Daba Mountains evergreen forests	China
Dinaric Mountains	Albania, Bosnia and Herzegovina,

mixed forests	Croatia, Italy, Montenegro, Serbia, Slovenia
East European forest steppe	Bulgaria, Moldova, Romania, Russia, Ukraine
Eastern Anatolian deciduous forests	Turkey
English Lowlands beech forests	United Kingdom
Euxine-Colchic deciduous forests	Georgia, Turkey
Hokkaido deciduous forests	Japan
Huang He Plain mixed forests	China
Madeira evergreen forests	Portugal
Manchurian mixed forests	China, North Korea, Russia, South Korea
Nihonkai evergreen forests	Japan
Nihonkai montane deciduous forests	Japan
North Atlantic moist mixed forests	Ireland, United Kingdom
Northeast China Plain deciduous forests	China
Pannonian mixed forests	Austria, Bosnia and Herzegovina, Croatia, Czech Republic, Hungary, Romania, Serbia, Slovakia, Slovenia, Ukraine
Po Basin mixed forests	Italy
Pyrenees conifer and mixed forests	Andorra, France, Spain
Qin Ling Mountains deciduous forests	China
Rodope montane mixed forests	Bulgaria, Greece, Macedonia, Serbia
Sarmatic mixed forests	Belarus, Estonia, Finland, Latvia, Lithuania, Norway, Russia, Sweden
Sichuan Basin evergreen broadleaf forests	China

South Sakhalin-Kurile mixed forests	Russia
Southern Korea evergreen forests	South Korea
Taiheiyo evergreen forests	Japan
Taiheiyo montane deciduous forests	Japan
Tarim Basin deciduous forests and steppe	China
Ussuri broadleaf and mixed forests	Russia
West Siberian broadleaf and mixed forests	Russia
Western European broadleaf forests	Austria, Czech Republic, France, Germany, Switzerland
Zagros Mountains forest steppe	Iran

Americas

Nearctic Temperate broadleaf and mixed forests	
Allegheny Highlands forests	United States
Appalachian mixed mesophytic forests	United States
Appalachian-Blue Ridge forests	United States
California mixed evergreen forest	United States
Central U.S. hardwood forests	United States
East Central Texas forests	United States
Eastern forest-boreal transition	Canada, United States
Eastern Great Lakes lowland forests	Canada, United States
Gulf of St. Lawrence lowland forests	Canada
Lac Saint-Jean and Saguenay valley forests	Canada
Mississippi lowland forests	United States
New England-Acadian forests	Canada, United States
Northeastern coastal forests	United States
Ozark Mountain forests	United States
Southeastern mixed forests	United States

Southern Great Lakes forests	United States
Upper Midwest forest-savanna transition	United States
Western Great Lakes forests	Canada, United States
Willamette Valley forests	United States
Neotropic Temperate broadleaf and mixed forests	
Juan Fernandez Islands temperate forests	Chile
Magellanic subpolar forests	Argentina, Chile
Polylepis forests	Bolivia, Peru
San Felix-San Ambrosio Islands temperate forests (Desventuradas Islands)	Chile
Valdivian temperate rain forests	Argentina, Chile

Chapter- 6

Mediterranean Forests, Woodlands and Scrub

Mediterranean forests, woodlands and scrub

Eucalyptus forest

A Mediterranean forest, the Upper Galilee

Mediterranean forests, woodlands and scrub is a temperate biome, characterized by dry summers and rainy winters. Summers are typically hot in low-lying inland locations but can be cool near some seas, as near San Francisco, which have a sea of cool waters. Winters are typically mild to cool in low-lying locations but can be cold in inland and higher locations.

Mediterranean forests, woodlands and scrub eco-regions occur in the world's five Mediterranean climate zones, on the west coast of continents in the mid-latitudes.

the 5 Mediterranean climate regions are:

- the Mediterranean Basin
- the Chilean Matorral
- the California chaparral and woodlands ecoregion of California and the Baja California Peninsula
- the Cape Province-Western Cape of South Africa
- the Southwest Australia corner area

Diversity

These regions are home to a tremendous diversity of habitats and species. Vegetation types can range from forests to woodlands, savannas, shrublands and grasslands; "mosaic habitat" landscapes are common, where differing vegetation types are interleaved with one another in complex patterns created by variations in soil, topography, exposure to wind and sun and fire history. Much of the woody vegetation in Mediterranean-climate regions is sclerophyll, which means 'hard-leaved' in Greek. Sclerophyll vegetation generally has small, dark leaves covered with a waxy outer layer to retain moisture in the dry summer months.

All these ecoregions are highly distinctive, collectively harboring 10% of the Earth's plant species.Phytogeographers consider the fynbos as a separate floral kingdom because 68% of the 8,600 vascular plant species crowded into its 90,000 square kilometres (35,000 sq mi) are endemic and highly distinctive at several taxonomic levels).

In terms of species densities, this is equivalent to about 40% of the plant species of the United States and Canada combined, found within an area the size of the state of Maine. The Fynbos and Southwest Australia shrublands have flora that are significantly more diverse than the other ecoregions, although any Mediterranean shrubland is still rich in species and endemics relative to other non-forest ecoregions.

Biome Plant Groups

Major plant communities in this biome include:

- Forest: Mediterranean forests are generally composed of broadleaf trees, such as the oak and mixed sclerophyll forests of California and the Mediterranean region, the *Eucalyptus* forests of Southwest Australia and the *Nothofagus* forests of central Chile. Forests are often found in riparian areas, where they receive more summer water. Coniferous forests also occur. Pine and Deciduous Oak forest are widespread across California

- Woodland: Oak woodlands are characteristic of the Mediterranean Basin and in California, along with pine woodlands and, in California, walnut woodlands.
- Savanna and grassland: The California Central Valley grasslands are the largest Mediterranean grassland eco-region, although these grasslands have mostly been converted to agriculture. Small Woodland area occur mainly oak, walnut, or pine woodlands.
- Shrubland: Shrublands are dense thickets of evergreen sclerophyll shrubs and small trees, called chaparral (California), matorral (Chile and southern Spain), maquis (France and elsewhere around the Mediterranean), macchia (Italy), fynbos (South Africa), or kwongan (Southwest Australia). In some places shrublands are the mature vegetation type and in other places the result of degradation of former forest or woodland by logging or overgrazing, or disturbance by major fires.
- Scrubland: Scrublands are most common near the seacoast and are often adapted to wind and salt air from the ocean. Low, soft-leaved scrublands around the Mediterranean are known as *garrigue* in France, *gariga* in Italy, *phrygana* in Greece, *tomillares* in Spain and *batha* in Israel. Northern coastal scrub and coastal sage scrub, also known as soft chaparral, occur near the California coast; strandveld in the Western Cape of South Africa; coastal matorral in the central Chile and sand-heath and kwongan in Southwest Australia.

Scrubland in Aliso Canyon, Santa Susana Mountains, Southern California

Fire as a medium of change

Fire, both natural and human-caused, has played a large role in shaping the ecology of Mediterranean ecoregions. The hot, dry summers make much of the region prone to fires and lightning-caused fires occur with some frequency. Many of the plants are pyrophytes, or fire-loving, adapted or even depending on fire for reproduction, recycling of nutrients and the removal of dead or senescent vegetation. In both the Australian and Californian Mediterranean-climate eco-regions, native peoples used fire extensively to clear brush and trees, making way for the grasses and herbaceous vegetation that supported game animals and useful plants. The plant communities in these areas adapted to the frequent human-caused fires and pyrophyte species grew more common and more fire-loving, while plants that were poorly adapted to fire retreated. After European colonization of these regions, fires were suppressed, which has caused some unintended consequences in these ecoregions; fuel builds up, so that when fires do come they are much more devastating and some species dependent on fire for their reproduction are now threatened. The European shrublands have also been shaped by anthropogenic fire, historically associated with transhumance herding of sheep and goats.

Geography

Mediterranean eco-regions are semi-arid and often have poor soils, so they are vulnerable to degradation by human activities such as logging, overgrazing and the introduction of exotic species. These regions are also some of the most endangered on the planet and many eco-regions have suffered tremendous degradation and habitat loss through logging, overgrazing, conversion to agriculture, urbanization and introduction of exotic and invasive species. The eco-regions around the Mediterranean basin and in California have been particularly affected by degradation due to human activity, suffering extensive loss of forests and soil erosion and many native plants and animals have become extinct or endangered.

Chapter- 7

Temperate Grasslands, Savannas and Shrublands

A restored Illinois grassland ecosystem at Morton Arboretum

Temperate grasslands, savannas and shrublands is a terrestrial biome whose predominant vegetation consists of grasses and/or shrubs. The climate is temperate and semi-arid to semi-humid.

- Temperature: warm to hot season (often with a cold to freezing season in winter)
- Soil: fertile with rich nutrients and minerals
- Plants: grass; trees or shrubs in savanna and shrubland
- Animals: large, grazing mammals; birds

Steppes/shortgrass prairies are short grasslands that occur in semi-arid climates. Tallgrass prairies are tall grasslands in areas of higher rainfall. Heaths and pastures are, respectively, low shrublands and grasslands where forest growth is hindered by human activity, not climate.

Tall grasslands, including the tallgrass prairie of North America and the Humid Pampas of Argentina, have moderate rainfall and rich soils which make them ideally suited to extensive agriculture and tall grassland ecoregions include some of the most productive grain-growing regions in the world.

Savannas are areas with both grass and trees, but the trees do not form a canopy as they would in a forest.

Temperate grasslands, savannas and shrublands ecoregions

Afrotropic Temperate grasslands, savannas and shrublands	
Al Hajar Al Gharbi montane woodlands	Oman
Amsterdam and Saint-Paul Islands temperate grasslands	Amsterdam Island, Saint-Paul Island
Tristan da Cunha-Gough Islands shrub and grasslands	Tristan da Cunha, Gough Island

Australasia Temperate grasslands, savannas and shrublands	
Canterbury-Otago tussock grasslands	New Zealand
Eastern Australia mulga shrublands	Australia
Southeast Australia temperate savanna	Australia

Nearctic Temperate grasslands, savannas and shrublands	
California Central Valley grasslands	United States
Canadian aspen forests and parklands	Canada, United States
Central and Southern mixed grasslands	United States
Central forest-grasslands transition	United States
Columbia Plateau	United States
Edwards Plateau savanna	United States
Flint Hills tall grasslands	United States
Montana valley and foothill grasslands	United States
Nebraska Sand Hills mixed grasslands	United States
Northern mixed grasslands	Canada, United States
Northern short grasslands	Canada, United States
Northern tall grasslands	Canada, United States
Palouse grasslands	United States
Texas blackland prairies	United States
Western short grasslands	United States

Neotropic Temperate grasslands, savannas and shrublands	

Argentine Espinal	Argentina
Argentine Monte	Argentina
Humid Pampas	Argentina
Patagonian grasslands	Argentina, Chile
Patagonian steppe	Argentina, Chile
Semi-arid Pampas	Argentina
Palearctic Temperate grasslands, savannas and shrublands	
Alai-Western Tian Shan steppe	Kazakhstan, Tajikistan, Uzbekistan
Altai steppe and semi-desert	Kazakhstan
Central Anatolian steppe	Turkey
Daurian forest steppe	China, Mongolia, Russia
Eastern Anatolian montane steppe	Armenia, Iran, Turkey
Emin Valley steppe	China, Kazakhstan
Faroe Islands boreal grasslands	Faroe Islands, part of Denmark
Gissaro-Alai open woodlands	Kyrgyzstan, Tajikistan, Uzbekistan
Kazakh forest steppe	Kazakhstan, Russia
Kazakh steppe	Kazakhstan, Russia
Kazakh upland	Kazakhstan
Middle East steppe	Iraq, Syria
Mongolian-Manchurian grassland	China, Mongolia, Russia
Pontic steppe	Kazakhstan, Moldova, Romania, Russia, Ukraine
Sayan Intermontane steppe	Russia
Selenge-Orkhon forest steppe	Mongolia, Russia
South Siberian forest steppe	Russia
Tian Shan foothill arid steppe	China, Kazakhstan, Kyrgyzstan

Chapter- 8

Tropical and Subtropical Grasslands, Savannas and Shrublands

Tropical and subtropical grasslands, savannas and shrublands are a grassland terrestrial biome located in semi-arid to semi-humid climate regions of subtropical and tropical latitudes. Grasslands are dominated by grass and other herbaceous plants. Savannas are grasslands with scattered trees. Shrublands are dominated by woody or herbaceous shrubs.

Rainfall in tropical and subtropical grasslands, savannas and shrublands is between 450 and 1500 millimeters (20 to 60 inches) a year and can be highly seasonal, with the entire year's rainfall sometimes occurring within a couple of weeks. Tropical and subtropical grasslands, savannas and shrublands occur on all continents but Antarctica. They are widespread on Africa and are also found all throughout South Asia, the northern parts of South America and Australia and the southern United States.

African Savannas occur between forest or woodland regions and grassland regions. The climate varies, with an average temperature of 27°C with peaks of 30°C in April and October and between 300 and 1500 millimetres of rain per year. Flora includes:

- Acacia (Tree)
    - Loses leaves in dry season to conserve moisture
    - Leafy canopy in rainy season (flattened by winds)
- Baobab (Tree)
    - Stores water in trunk
    - Thick bark to protect it from fires in dry season
    - Long Tap roots to reach underground moisture
    - Few leaves to reduce water loss through transpiration
- Grass
    - Grow Quickly to 3 or 4 meters in clumps
    - Shoots die in dry season leaving only roots
- Low Shrubs
    - Drought resistant

- Small
- Thorns not leaves

Tropical and subtropical grasslands, savannas and shrublands ecoregions

Afrotropic Tropical and subtropical grasslands, savannas and shrublands	
Angolan Miombo woodlands	Angola
Angolan Mopane woodlands	Angola, Namibia
Ascension scrub and grasslands	Ascension Island
Central Zambezian Miombo woodlands	Angola, Burundi, Democratic Republic of the Congo, Malawi, Tanzania, Zambia
East Sudanian savanna	Cameroon, Central African Republic, Chad, Democratic Republic of the Congo, Eritrea, Ethiopia Sudan, Uganda
Eastern Miombo woodlands	Mozambique, Tanzania
Guinean forest-savanna mosaic	Benin, Burkina Faso, Cameroon, Gambia, Ghana, Guinea, Guinea Bissau, Côte d'Ivoire, Nigeria, Senegal, Togo
Itigi-Sumbu thicket	Tanzania, Zambia
Kalahari Acacia-Baikiaea woodlands	Botswana, Namibia, South Africa, Zimbabwe
Mandara Plateau mosaic	Cameroon, Nigeria
Northern Acacia-Commiphora bushlands and thickets	Ethiopia, Kenya, Sudan, Uganda
Northern Congolian forest-savanna mosaic	Cameroon, Central African Republic, Democratic Republic of the Congo, Sudan, Uganda
Sahel	Burkina Faso, Cameroon, Chad, Eritrea, Ethiopia, Mali, Mauritania, Niger, Nigeria, Senegal, Sudan
Serengeti	Kenya, Tanzania

Somali Acacia-Commiphora bushlands and thickets	Eritrea, Ethiopia, Kenya, Somalia, Sudan
Southern Acacia-Commiphora bushlands and thickets	Kenya, Tanzania
Southern Africa bushveld	Botswana, South Africa, Zimbabwe
Southern Congolian forest-savanna mosaic	Angola, Democratic Republic of the Congo
Southern Miombo woodlands	Malawi, Mozambique, Zambia, Zimbabwe
Sudan grass-belt	*southern* Senegal, *southern* Mali, Guinea, *northern* Cote d'Ivoire, Burkina Faso, *northern* Ghana, *northern* Benin, *northern* Togo, *central* Nigeria, *northern* Cameroon, *southern* Chad, *southern* Sudan, *western* Ethiopia
Victoria Basin forest-savanna mosaic	Burundi, Kenya, Rwanda, Tanzania, Uganda
West Sudanian savanna	Benin, Burkina Faso, Gambia, Ghana, Guinea, Côte d'Ivoire, Niger, Nigeria, Senegal
Western Congolian forest-savanna mosaic	Angola, Democratic Republic of the Congo, Republic of the Congo
Zambezian and Mopane woodlands	Botswana, Malawi, Mozambique, Namibia, South Africa, Swaziland, Zambia, Zimbabwe
Zambezian Baikiaea woodlands	Angola, Botswana, Namibia, Zambia, Zimbabwe

Australasia Tropical and subtropical grasslands, savannas and shrublands	
Arnhem Land tropical savanna	Australia
Brigalow tropical savanna	Australia
Cape York tropical savanna	Australia
Carpentaria tropical savanna	Australia
Einasleigh upland savanna	Australia

Kimberly tropical savanna	Australia
Trans Fly savanna and grasslands	Indonesia, Papua New Guinea
Victoria Plains tropical savanna	Australia
Indomalaya Tropical and subtropical grasslands, savannas and shrublands	
Terai-Duar savanna and grasslands	Bhutan, India, Nepal, Philippines
Nearctic Tropical and subtropical grasslands, savannas and shrublands	
Pre-Columbian savannas of North America (greatly declined)	Canada, United States
Eastern savannas of the United States (greatly declined)	United States
Central Hardwood Region (greatly declined)	United States
Western Gulf coastal grasslands	Mexico, United States
Neotropic Tropical and subtropical grasslands, savannas and shrublands	
Beni savanna	Bolivia
Campos Rupestres montane savanna	Brazil
Cerrado	Bolivia, Brazil, Paraguay
Clipperton Island shrub and grasslands	Clipperton Island is an overseas territory of France
Córdoba montane savanna	Argentina
Guyanan savanna	Brazil, Guyana, Venezuela
Gran Chaco	Argentina, Brazil, Paraguay
Llanos	Colombia, Venezuela
Uruguayan savanna	Argentina, Brazil, Uruguay
Oceania Tropical and subtropical grasslands, savannas and shrublands	
Hawaiian tropical high shrublands	Hawaiʻi
Hawaiian tropical low shrublands	Hawaiʻi
Northwestern Hawaii scrub	Hawaiʻi

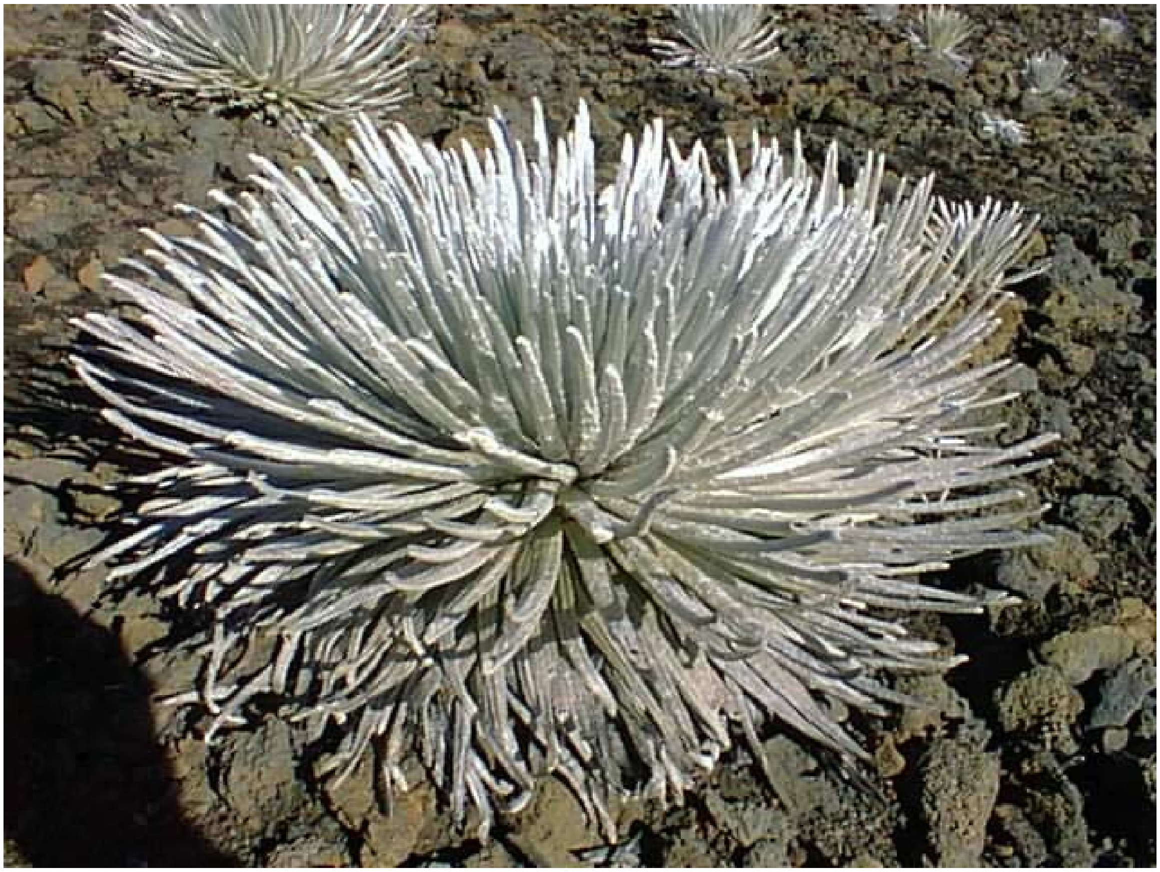
Chapter- 9

Deserts and Xeric Shrublands

Deserts and xeric shrublands is a biome characterized by, relating to, or requiring only a small amount of moisture.

Definition and occurrence

Deserts and xeric shrublands receive an annual average rainfall of ten inches or less and have an arid or hyperarid climate, characterized by a strong moisture deficit, where annual potential loss of moisture from evapotranspiration well exceeds the moisture received as rainfall. Deserts and xeric shrublands occur in tropical, subtropical and temperate climate regions. Desert soils tend to be sandy or rocky and low in organic materials. Saline or alkaline soils are common. Plants and animals in deserts and xeric shrublands are adapted to low moisture conditions. Hyperarid regions are mostly devoid of vegetation and animal life and include rocky deserts and sand dunes. Vegetation in arid climate regions can include sparse grasslands, shrublands and woodlands. Plants adapted to arid climates are called xerophytes and include succulent plants, geophytes, sclerophyll and annual plants. Animals, including insects, reptiles, arachnids, birds and mammals, are frequently nocturnal to avoid moisture loss.



In isolation, Hawai'i's Silverswords have adapted to xeric microclimates within volcanic craters, trapping and channeling dew and protecting leaves with reflective hairs.

Desertification

The conversion of productive drylands to desert conditions is known as desertification and can occur from a variety of causes. One factor is human intervention in imposing intensive agricultural tillage or overgrazing in areas which cannot support such exploitation. Climatic shifts such as global warming or the Milankovitch cycle (which drives glacials and interglacials) also affect the pattern of deserts on Earth.

Chapter- 10

Riparian Zone

A well preserved riparian strip on a tributary to Lake Erie

A **riparian zone** or **riparian area** is the interface between land and a river or stream. **Riparian** is also the proper nomenclature for one of the fifteen terrestrial biomes of the earth. Plant habitats and communities along the river margins and banks are called riparian vegetation, characterized by hydrophilic plants. Riparian zones are significant in ecology, environmental management and civil engineering because of their role in soil conservation, their habitat biodiversity and the influence they have on fauna and aquatic ecosystems, including grassland, woodland, wetland or even non-vegetative. In some regions the terms **riparian woodland**, **riparian forest**, **riparian buffer zone,** or

riparian strip are used to characterize a riparian zone. The word "riparian" is derived from Latin *ripa*, meaning river bank. The riparian is an important feature of a wetland because it allows us to gain an insight of its health.

Characteristics

Roles and functions

Riparian zones dissipate stream energy. The meandering curves of a river, combined with vegetation and root systems, dissipate stream energy, which results in less soil erosion and a reduction in flood damage. Sediment is trapped, reducing suspended solids to create less turbid water, replenish soils and build stream banks. Pollutants are filtered from surface runoff which enhances water quality via biofiltration.

The riparian zones also provide wildlife habitat, increase biodiversity and provide wildlife corridors, enabling aquatic and riparian organisms to move along river systems avoiding isolated communities. They can provide forage for wildlife and livestock.

They provide native landscape irrigation by extending seasonal or perennial flows of water. Nutrients from terrestrial vegetation (e.g. plant litter and insect drop) is transferred to aquatic food webs. The vegetation surrounding the stream helps to shade the water, mitigating water temperature changes. The vegetation also contributes wood debris to streams which is important to maintaining geomorphology.

From a social aspect, riparian zones contribute to nearby property values through amenity and views and they improve enjoyment for footpaths and bikeways through supporting foreshoreway networks. Space is created for riparian sports including fishing, swimming and launching for vessels and paddlecraft.

The riparian zone acts as a sacrificial erosion buffer to absorb impacts of factors including climate change, increased runoff from urbanisation and increased boatwake without damaging structures located behind a setback zone.

Role in logging

The protection of riparian zones is often a consideration in logging operations. The undisturbed soil, soil cover and vegetation provide shade, plant litter, woody material and reduce the delivery of soil eroded from the harvested area. Factors such as soil types and root structures, climatic conditions and above ground vegetative cover impact the effectiveness of riparian buffering.

Vegetation

Riparian zone along Trout Creek in the Trout Creek Mountains; part of the Burns Bureau of Land Management District in southeastern Oregon. The creek provides critical habitat for trout.

The assortment of riparian zone trees varies from those of wetlands and typically consists of plants that either are emergent aquatic plants, or herbs, trees and shrubs that thrive in proximity to water.

North America

Water's Edge

Herbaceous Perennial:

- *Peltandra virginica* - Arrow Arum
- *Sagittaria lancifolia* - Arrowhead
- *Carex stricta* - Tussock Sedge
- *Iris virginica* - Southern Blue Flag Iris

Inundated Riparian Zone

Herbaceous Perennial:

- *Sagittaria latifolia* - Duck Potato
- *Scirpus validus* - Softstem Bulrush
- *Scorpus americanus* - Three-square Bulrush
- *Eleocharis quadrangulata* - Square-stem Spikerush
- *Eleocharis obusa* - Spikerush

Eastern

Typical riparian zone trees in eastern North America include:

- *Populus deltoides* - Eastern Cottonwood
- *Acer saccharinum* - Silver Maple
- *Acer negundo* - Boxelder Maple
- *Ulmus americana* - American Elm
- *Platanus occidentalis* - American Sycamore
- *Juglans cinerea* - Butternut
- *Juglans nigra* - Black Walnut
- *Salix nigra* - Black Willow
- *Betula nigra* - River Birch
- *Fraxinus pennsylvanica* - Green Ash
- *Gleditsia triacanthos* - Honey Locust
- *Tilia americana* - Basswood

Western

In western North America and the Pacific Coast the riparian vegetation includes:

Riparian trees

- *Sequoia sempervirens* - Coast Redwood
- *Thuja plicata* - Western Redcedar

- *Populus fremontii* - Fremont Cottonwood
- *Platanus racemosa* - California Sycamore
- *Alnus rhombifolia* - White Alder
- *Salix lasiolepis* - Arroyo Willow
- *Quercus agrifolia* - Coast live oak
- *Populus tremuloides* - Quaking Aspen
- *Populus trichocarpa* - Black Cottonwood

Other plants

- *Polypodium* - Polypody Ferns
- *Polystichum* - Sword Ferns
- *Woodwardia* - Giant Chain Ferns
- *Pteridium* - Goldback Ferns
- *Dryopteris* - Wood Ferns
- *Adiantum* - Maidenhair Ferns
- *Carex spp.* - Sedges
- *Juncus spp.* - Rushes
- *Festuca californica* - California Fescue bunchgrass
- *Leymus condensatus* - Giant Wildrye bunchgrass
- *Melica californica* - California Melic bunchgrass
- *Mimulus spp.* - Monkeyflower and varieties
- *Aquilegia spp.* - Columbine
- *Ribes spp.* - Gooseberies and Currants
- *Umbellularia californica* - California Bay Laurel

Asia

In Asia there are different types of riparian vegetation, but the interactions between hydrology and ecology are similar as occurs in other geographic areas.

- *Carex spp.* - Sedges
- *Juncus spp.* - Rushes

Australia

Typical riparian vegetation in New South Wales, Australia include:

- *Acacia melanoxylon* - Blackwood
- *Acacia pravissima* - Ovens Wattle
- *Acacia rubida* - Red Stem Wattle
- *Bursaria lasiophylla* - Blackthorn
- *Callistemon citrinus* - Crimson Bottlebrush
- *Callistemon sieberi* - River Bottlebrush
- *Casuarina cunninghamiana* - River She-Oak
- *Eucalyptus bridgesiana* - Apple Box

- *Eucalyptus camaldulensis* - River Red Gum
- *Eucalyptus melliodora* - Yellow Box
- *Eucalyptus viminalis* - Manna Gum
- *Kunzea erocoides* - Burgan
- *Leptospernum obovatum* - River Tea-Tree
- *Melaleuca ericifolia* - Swamp Paperbark

Central Europe

Typical riparian zone trees in Central Europe include:

- *Acer campestre* - Field Maple
- *Acer pseudoplatanus* - Sycamore Maple
- *Alnus glutinosa* - Black Alder
- *Carpinus betulus* - European Hornbeam
- *Fraxinus excelsior* - European Ash
- *Juglans regia* - Persian Walnut
- *Malus sylvestris* - European Wild Apple
- *Populus alba* - White Poplar
- *Populus nigra* - Black Poplar
- *Quercus robur* - Pedunculate Oak
- *Salix alba* - White Willow
- *Salix fragilis* - Crack Willow
- *Tilia cordata* - Small-leaved Lime
- *Ulmus laevis* - European White Elm
- *Ulmus minor* - Field Elm

Repair and restoration

Land clearing followed by floods can quickly erode a riverbank, taking valuable grasses and soils downstream and allowing the sun to bake the land dry. Natural Sequence Farming techniques have been used in the Upper Hunter Valley of New South Wales, Australia to rapidly restore eroded farms to optimum productivity.

The Natural Sequence Farming technique involves placing obstacles in the water's pathway to lessen the energy of a flood and help the water to deposit soil and seep into the flood zone. Another technique is to encourage fast growing plants such as "weeds" to grow, as these can quickly stabilize the soil, place carbon into the ground and protect the land from drying. The weeds will improve the streambeds so that trees and grasses can return and later replace the weeds.

Cottonwood Creek riparian area before restoration, 1988

Cottonwood Creek riparian area after restoration, 2002

Chapter- 11

Cold Seep

Tube worms are among the dominant species in one of four cold seep community types in the Gulf of Mexico.

A **cold seep** (sometimes called a **cold vent**) is an area of the ocean floor where hydrogen sulfide, methane and other hydrocarbon-rich fluid seepage occurs, often in the form of a brine pool. Cold seeps constitute a biome supporting several endemic species.

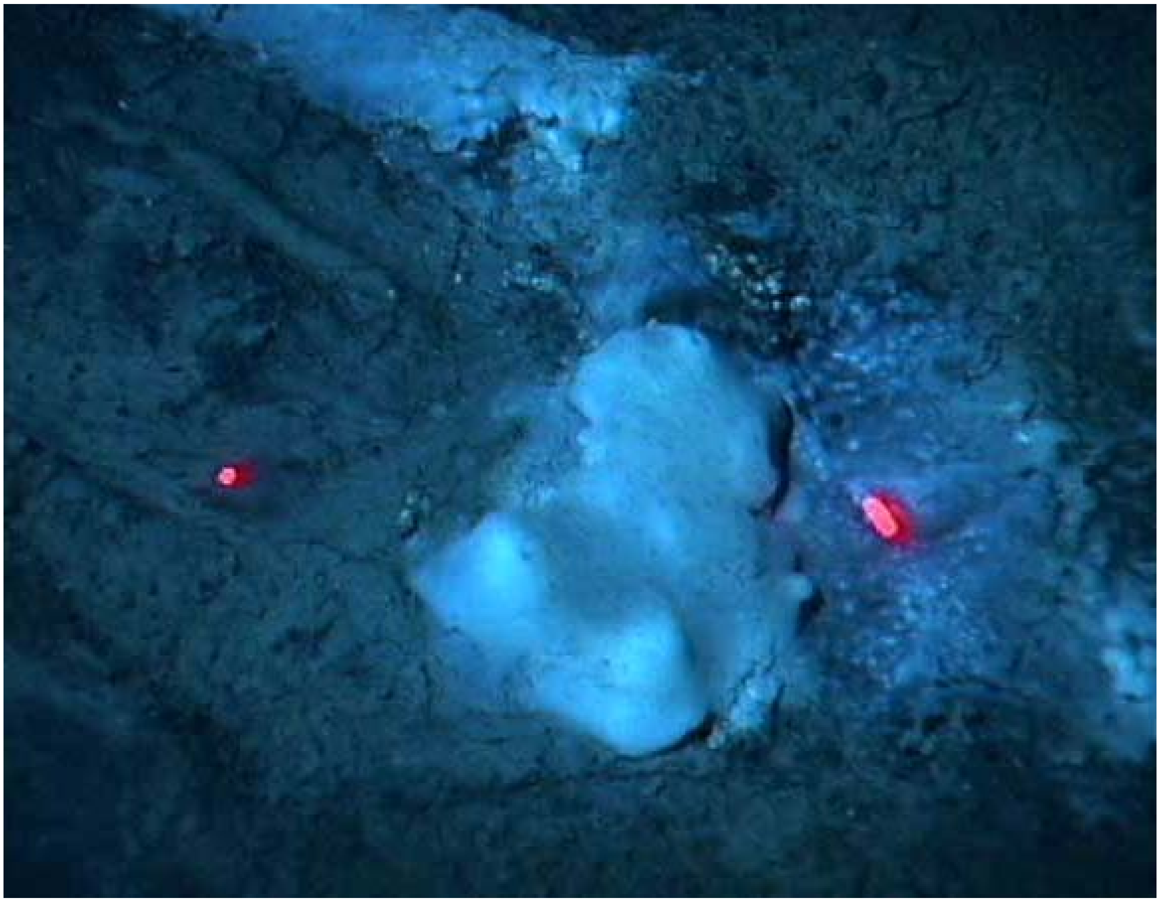
Cold seeps develop unique topography over time, where reactions between methane and seawater create carbonate rock formations and reefs. These reactions may also be dependent on bacterial activity. Ikaite, a hydrous calcium carbonate, can be associated with oxidizing methane at cold seeps.

Chemosynthetic communities

Chemosynthetic communities are associated with cold seeps. They are remarkable in that they utilize a carbon source independent of photosynthesis and the sun-dependent photosynthetic food chain that supports all other life on Earth. Although the process of chemosynthesis is entirely microbial, chemosynthetic bacteria and their production can support thriving assemblages of higher organisms through symbiosis. Organism living in cold seeps are known as extremophiles.

These prokaryotes, both Archaea and Bacteria, process sulfides and methane through chemosynthesis into chemical energy. More complex organisms, such as vesicomyid clams and siboglinid tube worms use this energy to power their own life processes. In exchange, the microbes are provided with both safety and a reliable source of food. Other microbes form mats that blanket sizable areas.

Symbiotic vestimentiferan tubeworm *Lamellibrachia luymesi* from a cold seep at 550 m depth in the Gulf of Mexico. In the sediments around the base are orange bacterial mats of the sulfide-oxidizing bacteria *Beggiatoa* spp. and empty shells of various clams and snails, which are also common inhabitants of the seeps.



Bacterial mat consisting of sulfide-oxidizing bacteria *Beggiatoa* spp. at a seep on Blake Ridge, off South Carolina. The red dots are range-finding laser beams.

Tubeworms, soft corals and chemosynthetic mussels at a seep located 3,000 m (9,843 ft) down on the Florida Escarpment. Eelpouts, a Galatheid crab and an alvinocarid shrimp feed on mussels damaged during a sampling exercise.

Comparison with other communities

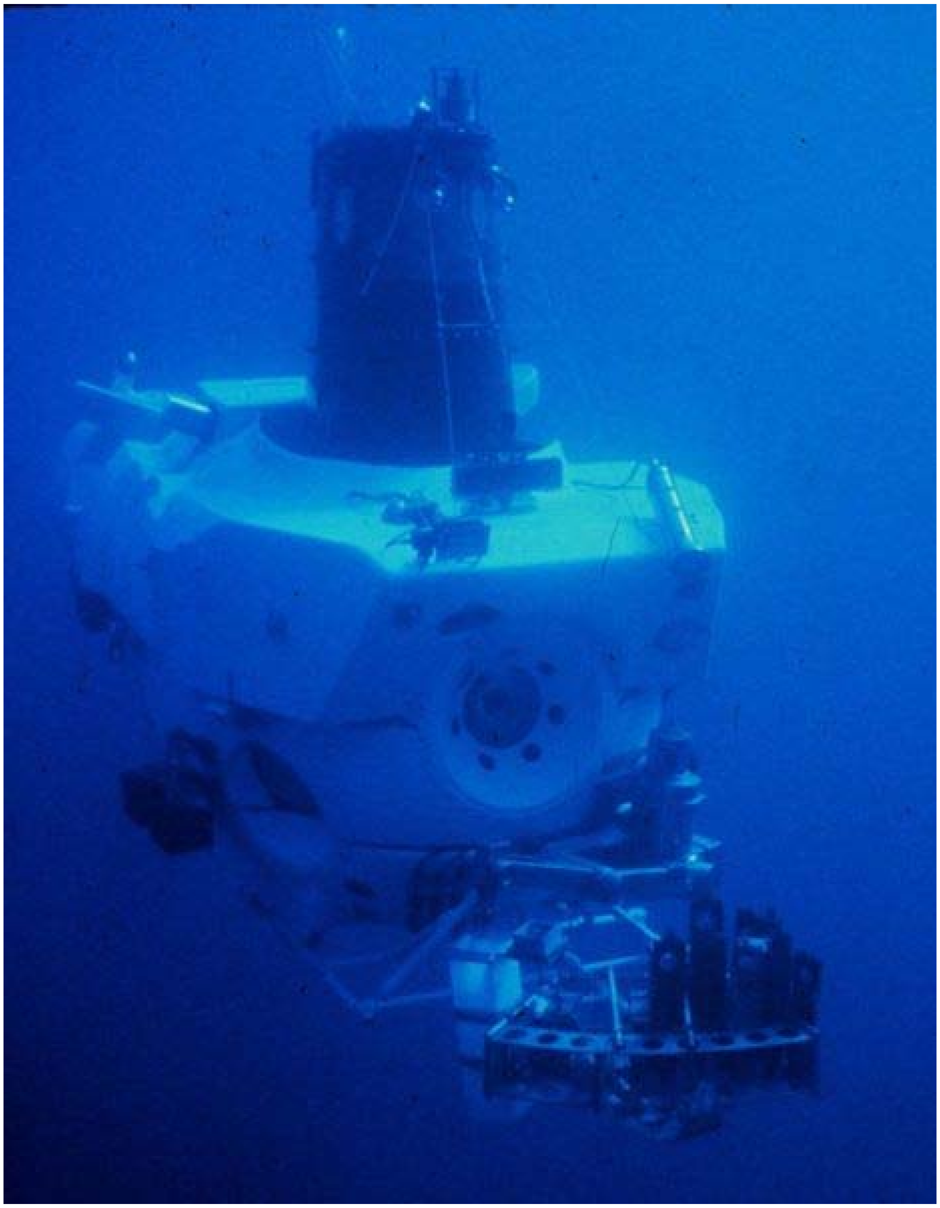
Cold seeps and hydrothermal vents are the only known communities that do not rely on photosynthesis for food and energy production. Unlike hydrothermal vents, which are volatile and ephemeral environments, cold seeps emit at a slow and dependable rate. Likely owing to the cooler temperatures and stability, many cold seep organisms are much longer-lived than those inhabiting hydrothermal vents.

For example the seep tubeworm *Lamellibrachia luymesi* has an estimated lifespan between 170 and 250 years.

Distribution

Cold seeps were discovered in 1983 by Dr. Charles Paull in the Gulf of Mexico at a depth of 3,200 meters (10,499 ft). Since then, seeps have been discovered in other parts of the world's oceans, including the Monterey Canyon just off Monterey Bay, California, the Sea of Japan, off the Pacific coast of Costa Rica, in the Atlantic off of Africa, in waters off the coast of Alaska and under an ice shelf in Antarctica. The deepest seep community known is found in the Japan trench at a depth of 7,326 m (24,035 ft).

In the Gulf of Mexico



The manned submersible *DSV Alvin*, which made possible the discovery of chemosynthetic communities in the Gulf of Mexico in 1983.

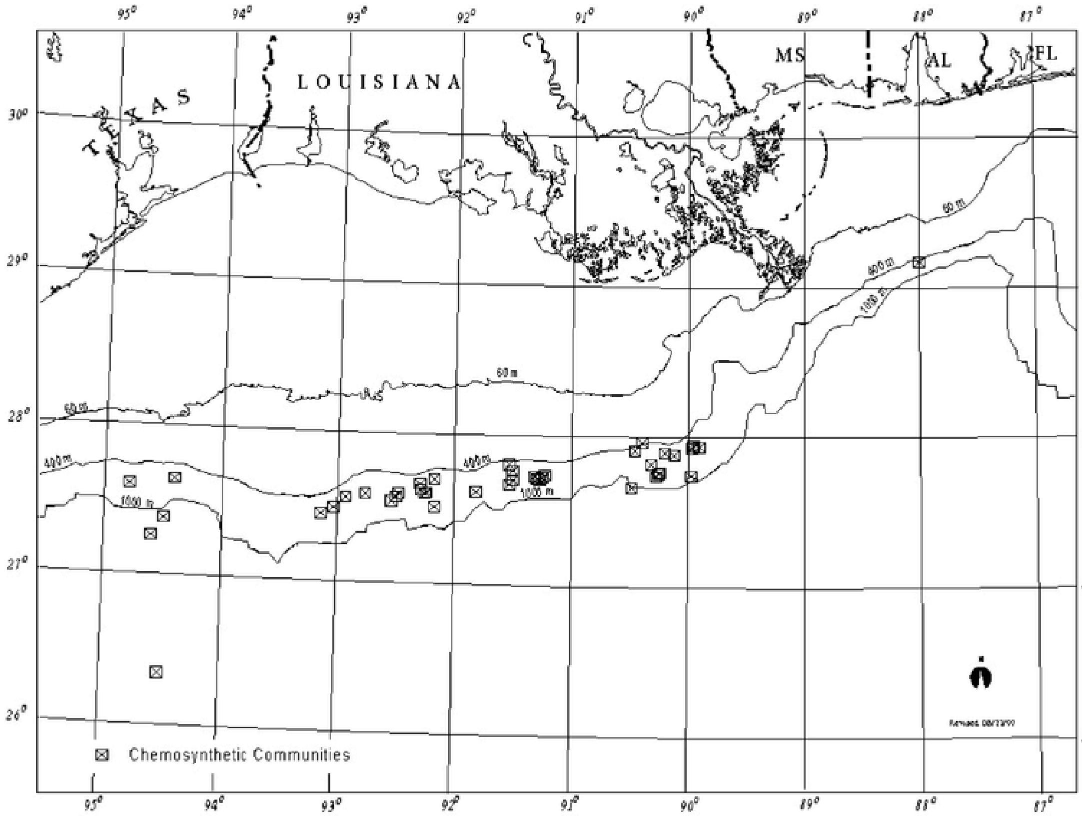
Discoveries in the Gulf of Mexico

The chemosynthetic communities of the Gulf of Mexico have been studied extensively over the past 20 years and communities first discovered on the upper slope are likely the best understood seep communities in the world. The history of the discovery of these remarkable animals has all occurred within the last 30 years. Interestingly, each major discovery was unexpected―from the first hydrothermal vent communities anywhere in the world to the first, cold seep communities in the Gulf of Mexico.

Communities were discovered in the Eastern Gulf of Mexico in 1983 using the manned submersible *DSV Alvin*, during a cruise investigating the bottom of the Florida Escarpment in areas of "cold" brine seepage, where they unexpectedly discovered tubeworms and mussels (Paull et al., 1984).

Two groups fortuitously discovered chemosynthetic communities in the Central Gulf of Mexico concurrently in November 1984. During investigations by Texas A&M University to determine the effects of oil seepage on benthic ecology (until this investigation, all effects of oil seepage were assumed to be detrimental), bottom trawls unexpectedly recovered extensive collections of chemosynthetic organisms, including tube worms and clams (Kennicutt et al., 1985). At the same time, LGL Ecological Research Associates was conducting a research cruise as part of the multiyear MMS Northern Gulf of Mexico Continental Slope Study (Gallaway et al., 1988). Bottom photography (processed on board the vessel) resulted in clear images of vesicomyid clam chemosynthetic communities coincidentally in the same manner as the first discovery by camera sled in the Pacific in 1977. Photography during the same LGL/MMS cruise also documented tube-worm communities in situ in the Central Gulf of Mexico for the first time (not processed until after the cruise; Boland, 1986) prior to the initial submersible investigations and firsthand descriptions of Bush Hill in 1986 (Rosman et al., 1987a; MacDonald et al., 1989b). The site was targeted by acoustic "wipeout" zones or lack of substrate structure caused by seeping hydrocarbons. This was determined using an acoustic pinger system during the same cruise on the R/V *Edwin Link* (the old one, only 113 ft (34 m)), which used one of the *Johnson Sea Link* submersibles. The site is characterized by dense tubeworm and mussel accumulations, as well as exposed carbonate outcrops with numerous gorgonian and *Lophelia* coral colonies. Bush Hill has become one of the most thoroughly studied chemosynthetic sites in the world.

Distribution in the Gulf of Mexico



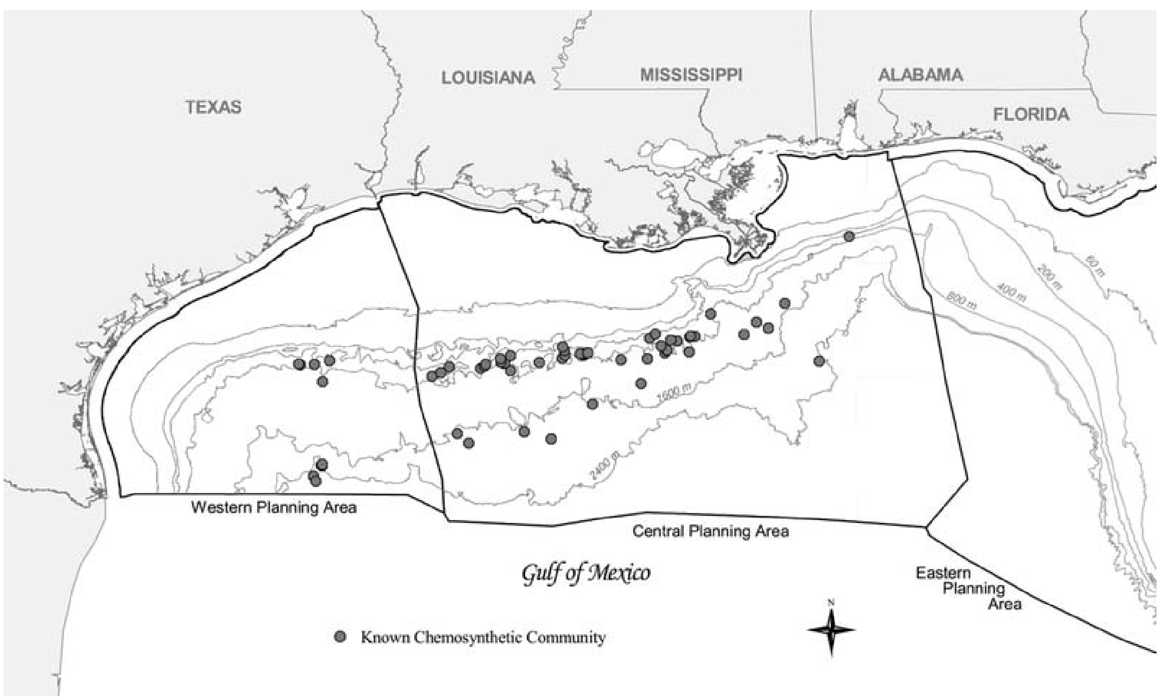
Chemosynthetic communities in the northern part of Gulf Of Mexico around cold seeps known in 2000.

There is a clear relationship between known hydrocarbon discoveries at great depth in the Gulf slope and chemosynthetic communities, hydrocarbon seepage and authigenic minerals including carbonates at the seafloor (Sassen et al., 1993a and b). While the hydrocarbon reservoirs are broad areas several kilometers beneath the Gulf, chemosynthetic communities occur in isolated areas with thin veneers of sediment only a few meters thick.

The northern Gulf of Mexico slope includes a stratigraphic section more than 10 km (6 mi) thick and has been profoundly influenced by salt movement. Mesozoic source rocks from Upper Jurassic to Upper Cretaceous generate oil in most of the Gulf slope fields (Sassen et al., 1993a and b). Migration conduits supply fresh hydrocarbon materials through a vertical scale of 6–8 km (4-5 mi) toward the surface. The surface expressions of hydrocarbon migration are referred to as seeps. Geological evidence demonstrates that hydrocarbon and brine seepage persists in spatially discrete areas for thousands of years.

The time scale for oil and gas migration (combination of buoyancy and pressure) from source systems is on the scale of millions of years (Sassen, 1997). Seepage from hydrocarbon sources through faults towards the surface tends to be diffused through the overlying sediment, carbonate outcroppings and hydrate deposits so the corresponding hydrocarbon seep communities tend to be larger (a few hundred meters wide) than chemosynthetic communities found around the hydrothermal vents of the Eastern Pacific (MacDonald, 1992). There are large differences in the concentrations of hydrocarbons at seep sites. Roberts (2001) presented a spectrum of responses to be expected under a variety of flux rate conditions varying from very slow seepage to rapid venting. Very slow seepage sites do not support complex chemosynthetic communities; rather, they usually only support simple microbial mats (*Beggiatoa* sp.).

In the upper slope environment, the hard substrates resulting from carbonate precipitation can have associated communities of nonchemosynthetic animals, including a variety of sessile cnidarians such as corals and anemones. At the rapid flux end of the spectrum fluidized sediment generally accompanies hydrocarbons and formation fluids arriving at the seafloor. Mud volcanoes and mud flows result. Somewhere between these two end members exists the conditions that support densely populated and diverse communities of chemosynthetic organisms (microbial mats, siboglinid tube worms, bathymodioline mussels, lucinid and vesycomyid clams and associated organisms). These areas are frequently associated with surface or near-surface gas hydrate deposits. They also have localized areas of lithified seafloor, generally authigenic carbonates but sometimes more exotic minerals such as barite are present.



Chemosynthetic communities in the northern part of Gulf of Mexico around cold seeps known in 2006 include more than 50 communities.

The widespread nature of Gulf of Mexico chemosynthetic communities was first documented during contracted investigations by the Geological and Environmental Research Group (GERG) of Texas A&M University for the Offshore Operators

Committee (Brooks et al., 1986). This survey remains the most widespread and comprehensive, although numerous additional communities have been documented since that time. Industry exploring for energy reserves in the Gulf of Mexico has also documented numerous new communities through a wide range of depths, including the deepest known occurrence in the Central Gulf of Mexico in Alaminos Canyon Block 818 at a depth of 2,750 m (9,022 ft). The occurrence of chemosynthetic organisms dependent on hydrocarbon seepage has been documented in water depths as shallow as 290 m (951 ft) (Roberts et al., 1990) and as deep as 2,744 m (9,003 ft) (Allen, personal communication, 2005). This depth range specifically places chemosynthetic communities in the deepwater region of the Gulf of Mexico, which is defined as water depths greater than 305 m (1,000 ft).

Chemosynthetic communities are not found on the continental shelf although they do appear in the fossil record in water shallower than 200 m (656 ft). One theory explaining this is that predation pressure has varied substantially over the time period involved (Callender and Powell 1999). More than 50 communities are now known to exist in 43 OCS blocks. Although a systematic survey has not been done to identify all chemosynthetic communities in the Gulf of Mexico, there is evidence indicating that many more such communities may exist. The depth limits of discoveries probably reflect the limits of exploration (lack of submersibles capable of depths over 1,000 m (3,281 ft)).

MacDonald et al. (1993 and 1996) have analyzed remote-sensing images from space that reveal the presence of oil slicks across the north-central Gulf of Mexico. Results confirmed extensive natural oil seepage in the Gulf of Mexico, especially in water depths greater than 1,000 m (3,281 ft). A total of 58 additional potential locations were documented where seafloor sources were capable of producing perennial oil slicks (MacDonald et al., 1996). Estimated seepage rates ranged from 4 bbl/d (0.64 m^3/d) to 70 bbl/d (11 m^3/d) compared to less than 0.1 bbl/d (0.016 m^3/d) for ship discharges (both normalized for 1,000 mi2 (640,000 ac)). This evidence considerably increases the area where chemosynthetic communities dependent on hydrocarbon seepage may be expected.

The densest aggregations of chemosynthetic organisms have been found at water depths of around 500 m (1,640 ft) and deeper. The best known of these communities was named Bush Hill by the investigators who first described it (MacDonald et al., 1989b). It is a surprisingly large and dense community of chemosynthetic tube worms and mussels at a site of natural petroleum and gas seepage over a salt diapir in Green Canyon Block 185. The seep site is a small knoll that rises about 40 m (131 ft) above the surrounding seafloor in about 580-m (1,903-ft) water depth.

Stability

According to Sassen (1997) the role of hydrates at chemosynthetic communities has been greatly underestimated. The biological alteration of frozen gas hydrates was first discovered during the MMS study "*Stability and Change in Gulf of Mexico Chemosynthetic Communities*". It is hypothesized (MacDonald, 1998b) that the dynamics of hydrate alteration could play a major role as a mechanism for regulation of the release of hydrocarbon gases to fuel biogeochemical processes and could also play a substantial role in community stability. Recorded bottom-water temperature excursions of several degrees in some areas such as the Bush Hill site (4-5 °C at 500-m (1,640-ft) depth) are believed to result in dissociation of hydrates, resulting in an increase in gas fluxes (MacDonald et al., 1994). Although not as destructive as the volcanism at vent sites of the mid-ocean ridges, the dynamics of shallow hydrate formation and movement will clearly affect sessile animals that form part of the seepage barrier. There is potential of a catastrophic event where an entire layer of shallow hydrate could break free of the bottom and result in considerable impact to local communities of chemosynthetic fauna. At deeper depths (>1,000 m, >3,281 ft), the bottom-water temperature is colder (by approximately 3 °C) and undergoes less fluctuation. The formation of more stable and probably deeper hydrates influences the flux of light hydrocarbon gases to the sediment surface, thus influencing the surface morphology and characteristics of chemosynthetic communities. Within complex communities such as Bush Hill, petroleum seems less important than previously thought (MacDonald, 1998b).

Through taphonomic studies (death assemblages of shells) and interpretation of seep assemblage composition from cores, Powell et al. (1998) reported that, overall, seep communities were persistent over periods of 500-1,000 years and probably throughout the entire Pleistocene. Some sites retained optimal habitat over geological time scales. Powell reported evidence of mussel and clam communities persisting in the same sites for 500-4,000 years. Powell also found that both the composition of species and trophic tiering of hydrocarbon seep communities tend to be fairly constant across time, with temporal variations only in numerical abundance. He found few cases in which the community type changed (from mussel to clam communities, for example) or had disappeared completely. Faunal succession was not observed. Surprisingly, when recovery occurred after a past destructive event, the same chemosynthetic species reoccupied a site. There was little evidence of catastrophic burial events, but two instances were found in mussel communities in Green Canyon Block 234. The most notable observation reported by Powell (1995) was the uniqueness of each chemosynthetic community site.

Precipitation of authigenic carbonates and other geologic events will undoubtedly alter surface seepage patterns over periods of many years, although through direct observation, no changes in chemosynthetic fauna distribution or composition were observed at seven separate study sites (MacDonald et al., 1995). A slightly longer period (19 years) can be referenced in the case of Bush Hill, the first Central Gulf of Mexico community described *in situ* in 1986. No mass die-offs or large-scale shifts in faunal composition have been observed (with the exception of collections for scientific purposes) over the19-year history of research at this site.

All chemosynthetic communities are located in water depths beyond the impact of severe storms, including hurricanes and there would have been no alteration of these communities caused from surface storms, including hurricanes.

Biology

The mussel species *Bathymodiolus childressi* is the dominant species in the mytilid type of cold seep communities in the Gulf of Mexico.

MacDonald et al. (1990) has described four general community types. These are communities dominated by Vestimentiferan tube worms (*Lamellibrachia* c.f. *barhami* and *Escarpia* spp.), mytilid mussels (Seep Mytilid Ia, Ib and III and others), vesicomyid clams (*Vesicomya cordata* and *Calyptogena ponderosa*) and infaunal lucinid or thyasirid clams (*Lucinoma* sp. or *Thyasira* sp.). Bacterial mats are present at all sites visited to date. These faunal groups tend to display distinctive characteristics in terms of how they aggregate, the size of aggregations, the geological and chemical properties of the habitats in which they occur and, to some degree, the heterotrophic fauna that occur with them. Many of the species found at these cold seep communities in the Gulf of Mexico are new to science and remain undescribed.

Individual lamellibranchid tube worms, the longer of two taxa found at seeps can reach lengths of 3 m (10 ft) and live hundreds of years (Fisher et al., 1997; Bergquist et al., 2000). Growth rates determined from recovered marked tube worms have been variable, ranging from no growth of 13 individuals measured one year to a maximum growth of 9.6 cm/yr (3.8 in/yr) in a *Lamellibrachia* individual (MacDonald, 2002). Average growth rate was 2.19 cm/yr (0.86 in/yr) for the *Escarpia*-like species and 2.92 cm/yr (1.15 in/yr) for lamellibrachids. These are slower growth rates than those of their hydrothermal vent relatives, but *Lamellibrachia* individuals can reach lengths 2-3 times that of the largest known hydrothermal vent species. Individuals of *Lamellibrachia* sp. in excess of 3 m (10 ft) have been collected on several occasions, representing probable ages in excess of 400 years (Fisher, 1995). Vestimentiferan tube worm spawning is not seasonal and recruitment is episodic.

Tubeworms are either male or female. One recent discovery indicates that the spawning of female *Lamellibrachia* appears to have produced an unique association with the large bivalve *Acesta bullisi*, which lives permanently attached to the anterior tube opening of the tubeworm and feeds on the periodic egg release (Järnegren et al., 2005). This close association between the bivalves and tubeworms was discovered in 1984 (Boland, 1986) but not fully explained. Virtually all mature *Acesta* individuals are found on female rather than male tubeworms. This evidence and other experiments by Järnegren et al. (2005) seem to have solved this mystery.

Growth rates for methanotrophic mussels at cold seep sites have been reported (Fisher, 1995). General growth rates were found to be relatively high. Adult mussel growth rates were similar to mussels from a littoral environment at similar temperatures. Fisher also found that juvenile mussels at hydrocarbon seeps initially grow rapidly, but the growth rate drops markedly in adults; they grow to reproductive size very quickly. Both individuals and communities appear to be very long lived. These methane-dependent mussels have strict chemical requirements that tie them to areas of the most active seepage in the Gulf of Mexico. As a result of their rapid growth rates, mussel recolonization of a disturbed seep site could occur relatively rapidly. There is some evidence that mussels also have some requirement of a hard substrate and could increase in numbers if suitable substrate is increased on the seafloor (Fisher, 1995). Two associated species are always found associated with mussel beds – the gastropod *Bathynerita naticoidea* and a small Alvinocarid shrimp – suggesting these endemic species have excellent dispersal abilities and can tolerate a wide range of conditions (MacDonald, 2002).

Unlike mussel beds, chemosynthetic clam beds may persist as a visual surface phenomenon for an extended period without input of new living individuals because of low dissolution rates and low sedimentation rates. Most clam beds investigated by Powell (1995) were inactive. Living individuals were rarely encountered. Powell reported that over a 50-year timespan, local extinctions and recolonization should be gradual and exceedingly rare. Contrasting these inactive beds, the first community discovered in the Central Gulf of Mexico consisted of numerous actively plowing clams. The images obtained of this community were used to develop length/frequency and live/dead ratios as well as spatial patters (Rosman et al., 1987a).

Extensive bacterial mats of free-living bacteria are also evident at all hydrocarbon seep sites. These bacteria may compete with the major fauna for sulfide and methane energy sources and may also contribute substantially to overall production (MacDonald, 1998b). The white, nonpigmented mats were found to be an autotrophic sulfur bacteria *Beggiatoa* species and the orange mats possessed an unidentified nonchemosynthetic metabolism (MacDonald, 1998b).

Heterotrophic species at seep sites are a mixture of species unique to seeps (particularly molluscs and crustacean invertebrates) and those that are a normal component from the surrounding environment. Carney (1993) first reported a potential imbalance that could occur as a result of chronic disruption. Because of sporadic recruitment patterns, predators could gain an advantage, resulting in exterminations in local populations of mussel beds. It is clear that seep systems do interact with the background fauna but conflicting evidence remains as to what degree outright predation on some specific community components such as tubeworms occurs (MacDonald, 2002). The more surprising results from this recent work is why background species do not utilize seep production more that seems to be evident. In fact, seep-associated consumers such as galatheid crabs and nerite gastropods had isotopic signatures, indicating that their diets were a mixture of seep and background production. At some sites, endemic seep invertebrates that would have been expected to obtain much if not all their diet from seep production actually consumed as much as 50 percent of their diets from the background.

Detection

With continuing experience, particularly on the upper continental slope in the Gulf of Mexico, the successful prediction of the presence of tubeworm communities continues to improve, however chemosynthetic communities cannot be reliably detected directly using geophysical techniques. Hydrocarbon seeps that allow chemosynthetic communities to exist do modify the geological characteristics in ways that can be remotely detected, but the time scales of co-occurring active seepage and the presence of living communities is always uncertain. These known sediment modifications include (1) precipitation of authigenic carbonate in the form of micronodules, nodules, or rock masses; (2) formation of gas hydrates; (3) modification of sediment composition through concentration of hard chemosynthetic organism remains (such as shell fragments and layers); (4) formation of interstitial gas bubbles or hydrocarbons; and (5) formation of depressions or pockmarks by gas expulsion. These features give rise to acoustic effects such as wipeout zones (no echoes), hard bottoms (strongly reflective echoes), bright spots (reflection enhanced layers), or reverberant layers (Behrens, 1988; Roberts and Neurauter, 1990). "Potential" locations for most types of communities can be determined by careful interpretation of these various geophysical modifications, but to date, the process remains imperfect and confirmation of living communities requires direct visual techniques.

Fossilized records

Late Cretaceous cold seep deposit in the Pierre Shale, southwest South Dakota

Cold seep deposits are found throughout the Phanerozoic rock record, especially in the Late Mesozoic and Cenozoic. These fossil cold seeps are characterized by mound-like topography (where preserved), coarsely crystalline carbonates and abundant mollusks and brachiopods.