Analyses of Changes in Forest Structure and Function at Multiple Time and Space Scales

INVESTICE DO ROZVOJE VZDĚLÁVÁNÍ

Tento projekt je spolufinancován Evropským sociálním fondem a Státním rozpočtem ČR InoBio – CZ.1.07/2.2.00/28.0018

Lesson content

- Hierarchy and behaviour of the system **in space and time**
- Principles in ecosystem behaviour
- Ecosystem structure and layering
- Data collections, calculations, simulations and modelling, synthesis
- Site factors, soil and vegetation
- Typical case studies in Europe

Differences between Woodlands and Forests

(Thomas et al. 2007)

- **Woodlands** is small area of trees with an open canopy (often defined as having 40% canopy closure or less, i.e. 60% or more of the sky is visible) such that plenty of light reaches the ground, encouraging other vegetation beneath the trees.
- **Forests** are usually reserved for a relatively large area of trees forming for the most part a closed, dense canopy. A forests does not have to be uniform over large areas, and indeed is often made up of a series of stands, group of trees varying in such as medows and lakes and areas where grazing animals are limiting tree development.

Dehesa, Portugal
Source: C Steenmans

Box 23B The abandonment of the dehesas and montados in Southern Europe

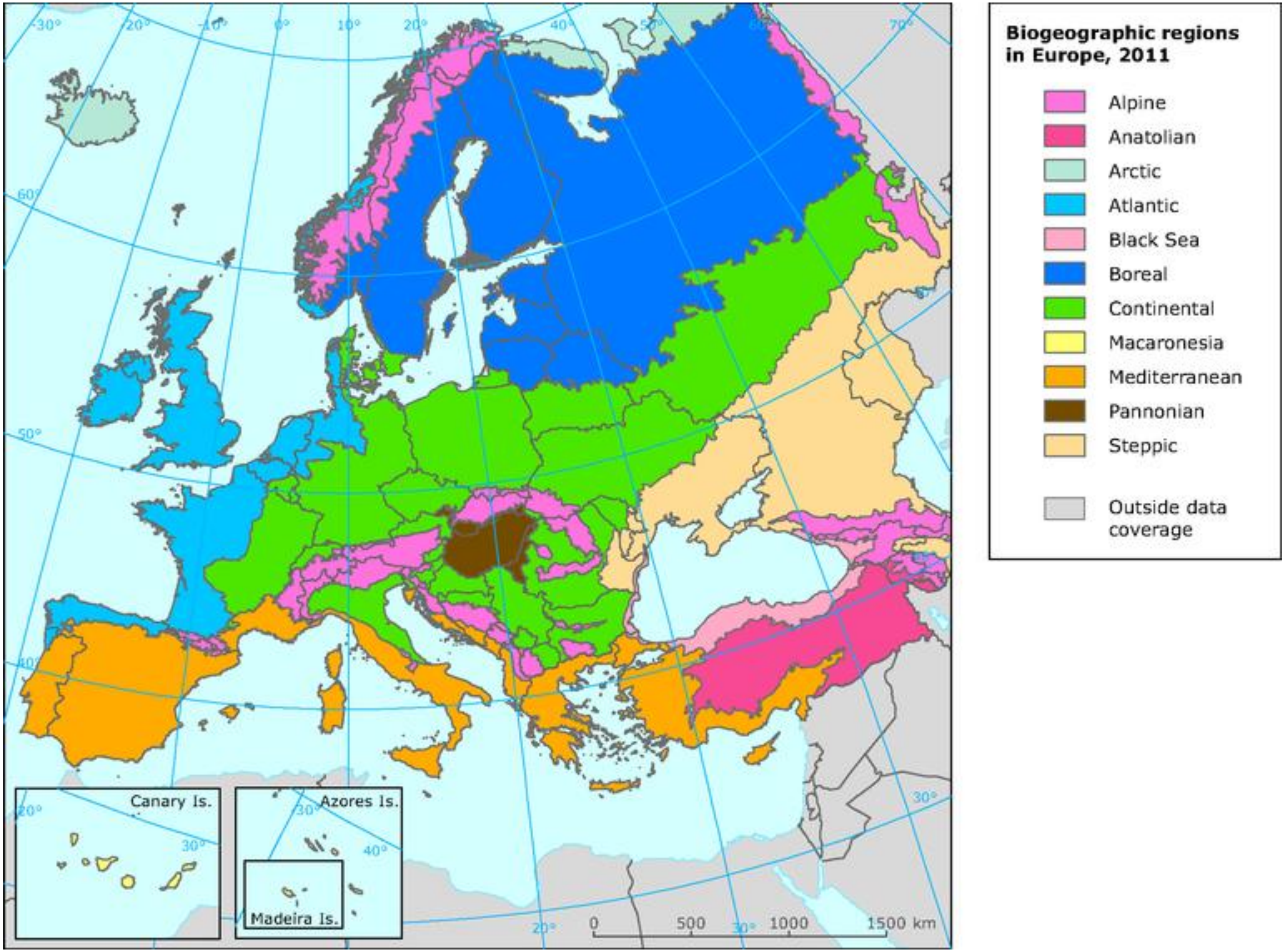
In Spain and Portugal, multi-purpose ecosystems called dehesas and montados were traditionally used and formed a valuable landscape of pastures mixed with open woodland: the open tree stratum dominated by oak species (*Quercus suber*, *Quercus ilex*, *Quercus pyrenaica* and *Quercus rotundifolia*) was grown for cork, timber, fuel and charcoal, but also tannin and acorns, together with shifting cultivation of cereals, and grazing of pigs, sheep, goats and cattle on fallow land. This has led to an artificial system with a high degree of patchiness and characterised by a tree cover of 10 to 80 trees per hectare at most (Joffre, 1992). These mixed systems were ecologically rational and economically productive, but required intensive recurrent management practices, including the use of fire (Catarino, 1992). Since the 1970s and the rapid development of intensive animal husbandry, these agroforestry systems were progressively abandoned. This led to the invasion of the open landscape by shrubs, therefore increasing fire risk. These systems still cover almost 5 million hectares in southwestern Spain and more than half a million hectares in Portugal, but are under tremendous pressure. Despite their ecological importance in the Mediterranean area (for maintaining greater water availability), the remaining dehesas and montados undergo steady erosion due to the combined pressures of livestock grazing, frequent fires and urban and rural development (Catarino, 1992). (See also Box 8F, Chapter 8.)

High forest, Condroz, Belgium
Source: Walphot

Stanners et al. 1995

Biogeographic regions in Europe

(EEA, 2001)



The global distribution of major biomes and the seasonal patterns of monthly average temperature and precipitation

(Bailey 1998)

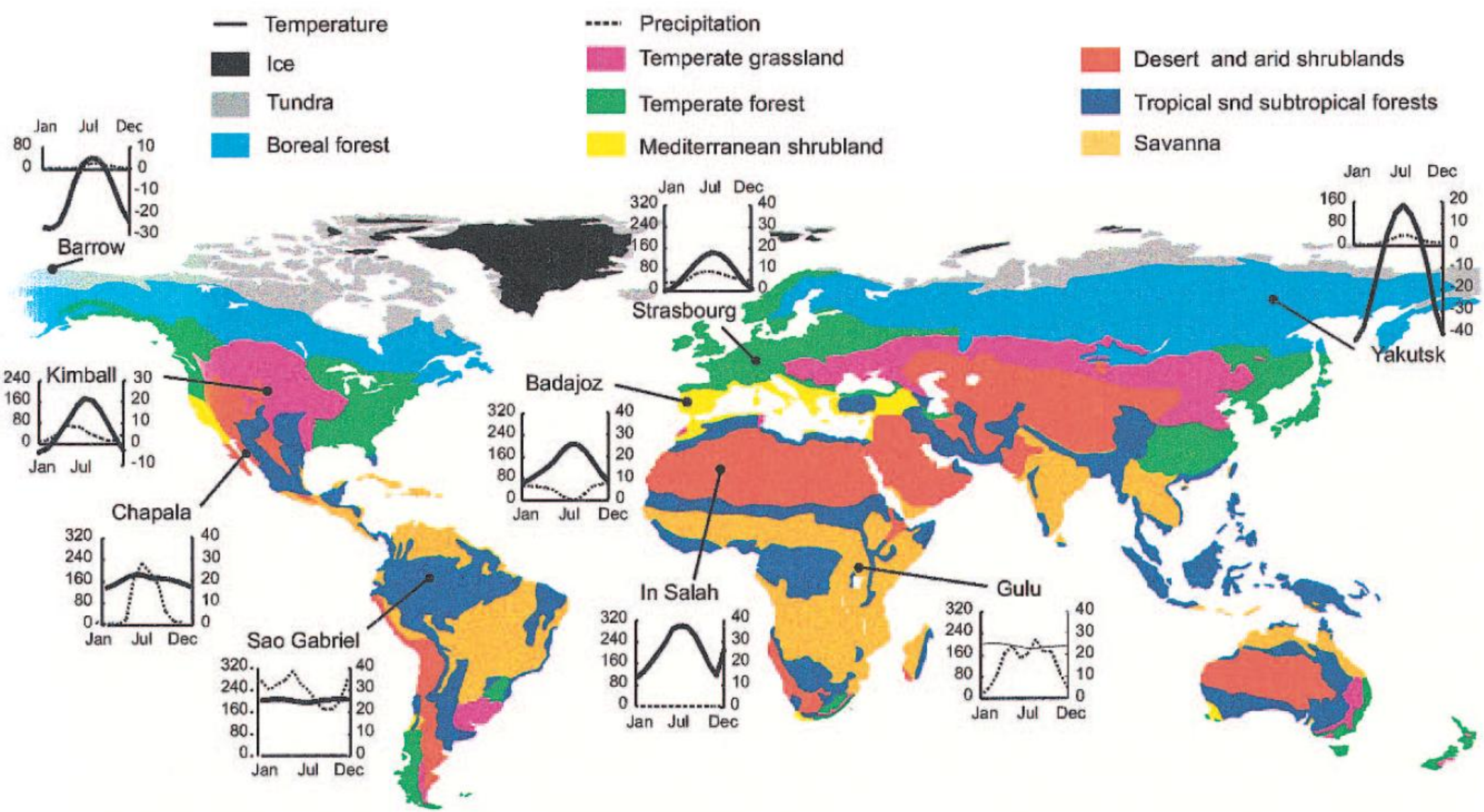
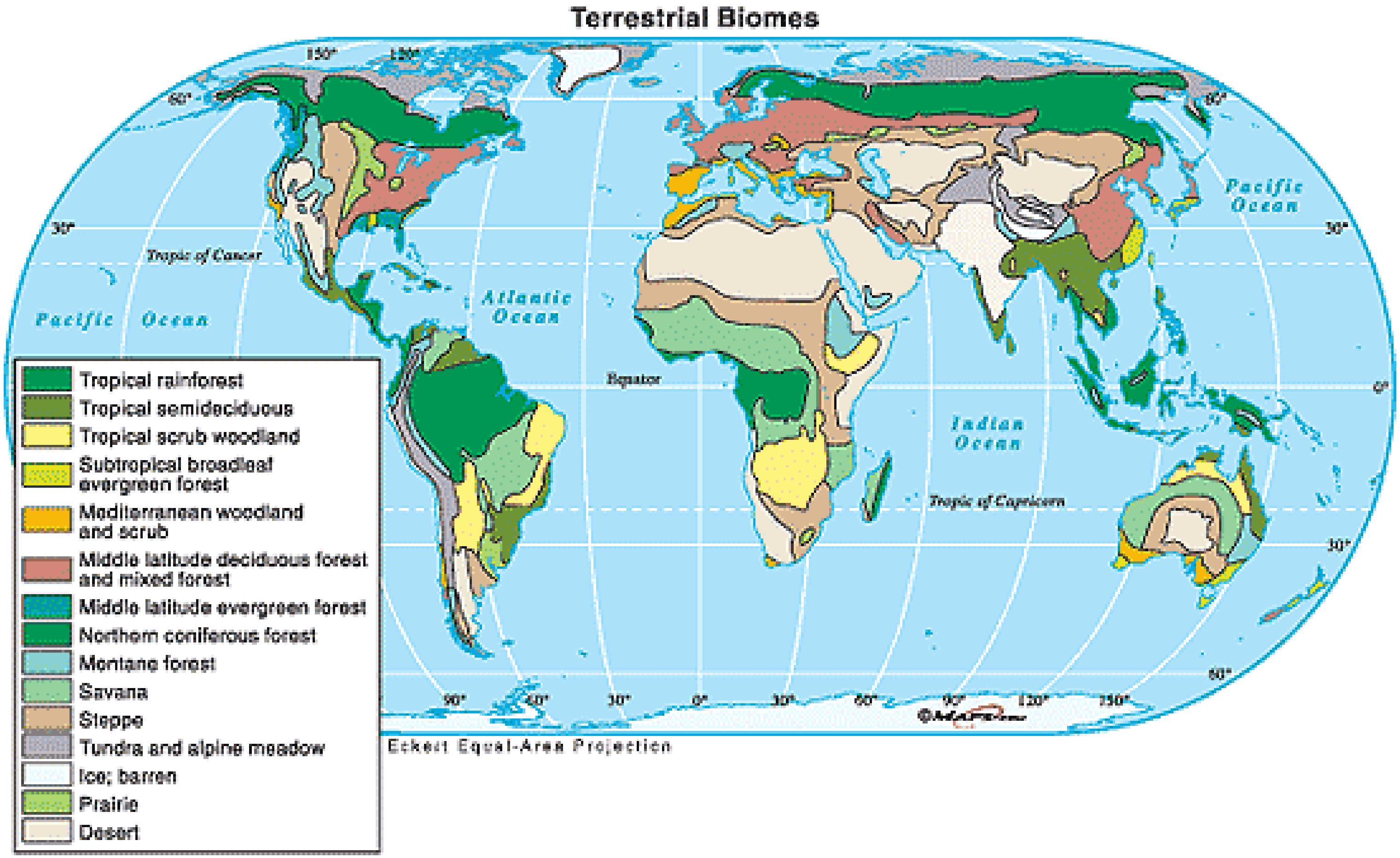


Plate 1. The global distribution of Earth's major biomes and the seasonal patterns of monthly average temperature and precipitation at one representative site for each biome (Bailey 1998). Climate data are monthly averages of the entire period of record for selected sites through the year 2000 (http://www.ncdc.noaa.gov/ol/climite/research/ghcn/ghcn.hlml).

World Vegetation (Terrestrial Biomes) Map

(http://www.maps.com/ref_map.aspx?pid=12881)



Diagrams of bioms in relation to precipitation and temperture

(Aber, Melilo 2001)

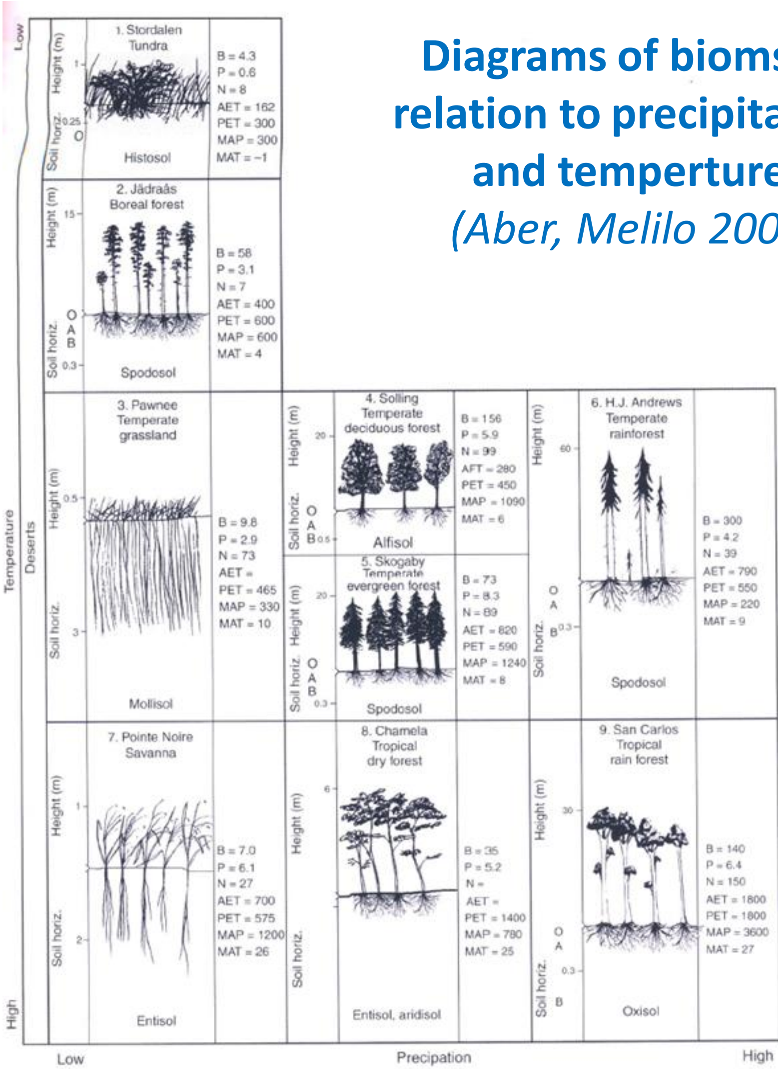
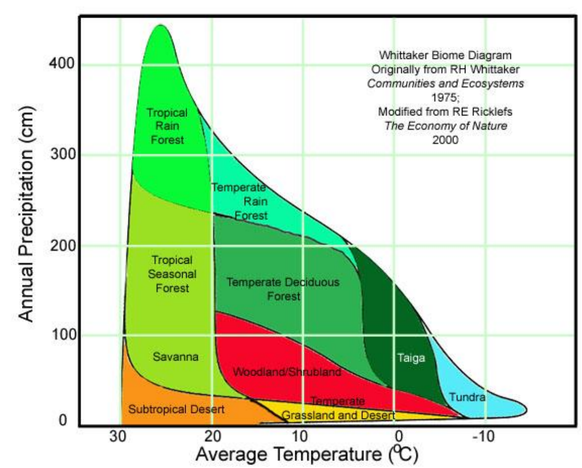


Figure 4.10 Idealised diagrams of biomes in relation to precipitation and temperature and their structure and function. Original idea from Aber & Melillo (2001) applied to selected ecosystems and biomes used in this book. Note that the vertical scales for above- and belowground are different in forest ecosystems. Photographic illustrations of the biomes can be found in the colour plate section and additional data on the ecosystems are given in Appendix 4.

B = total (aboveground + belowground) biomass in Mg C ha^{-1}; P = total (aboveground + belowground) production in Mg C ha^{-1} yr^{-1}; N = total nitrogen uptake (aboveground + belowground) by plants in kg ha^{-1} yr^{-1}; AET = actual evapotranspiration mm yr^{-1}; PET = potential evapotranspiration mm yr^{-1}; MAP = mean annual precipitation mm yr^{-1}; MAT = mean annual temperature in °C.

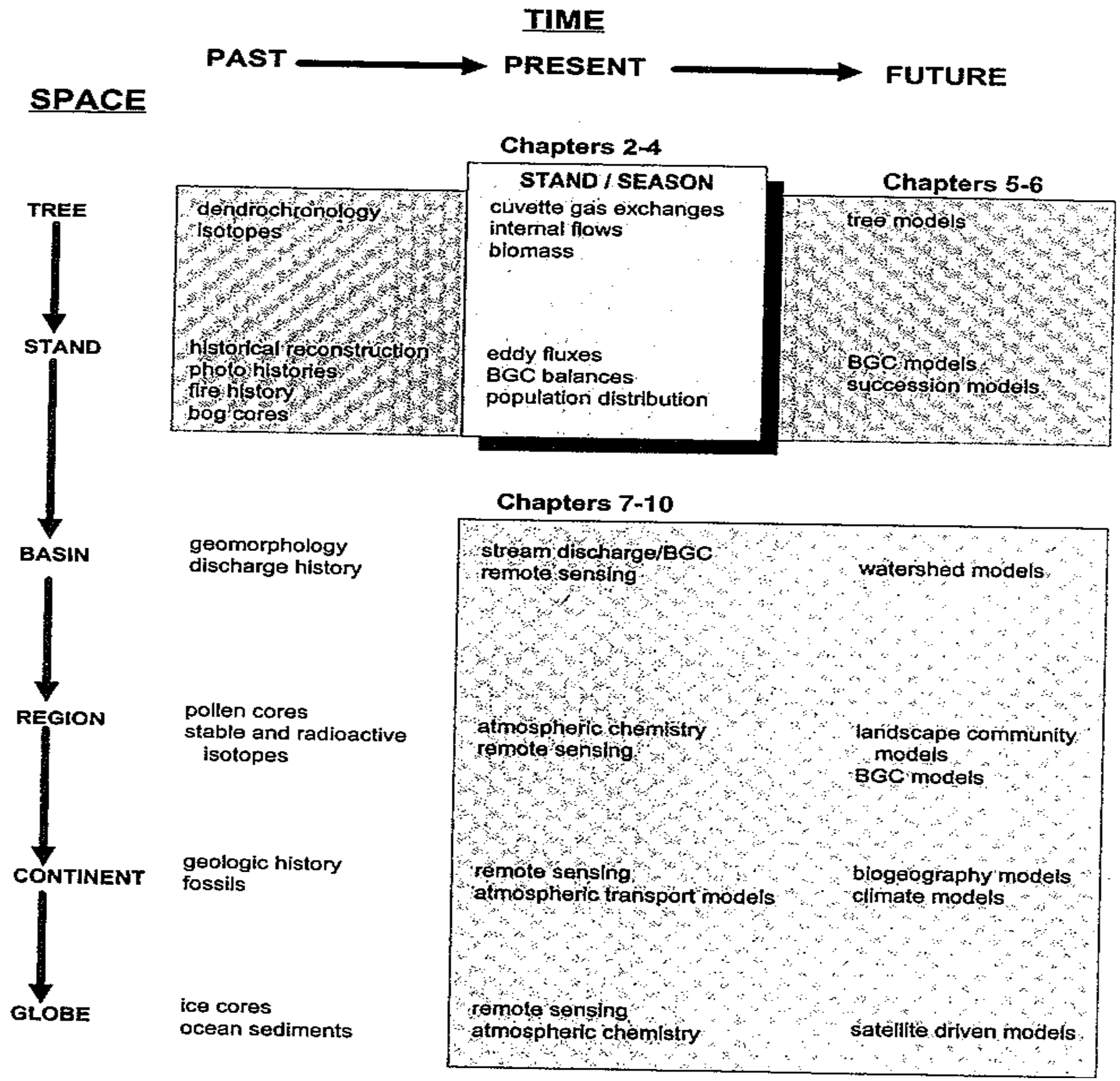


Ecosystem concept

(see also lesson 1)

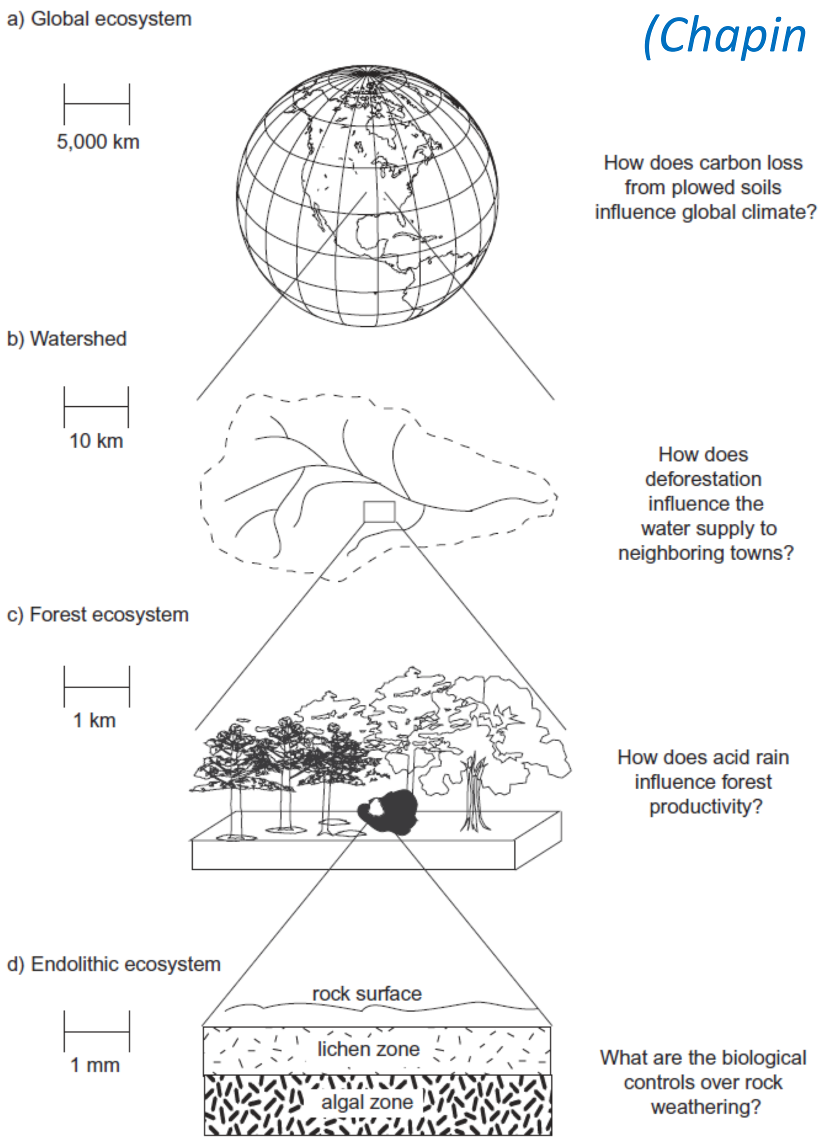
- Forest ecosystems are often studied in watersheds draining to a monitored stream
- The structure is then defined in vertical and horizontal dimensions.
- Usually the canopy of the tallest trees forms the upper ecosystem boundary, and plants with the deepest roots form the lower boundary.
- The horizontal structure is usually described by how individual trees, shrubs, herbs, and openings or gaps are distributed
- Plant ecologists study forest in functioning of the system= energy and matter flows, biogeochemical cycles, biodiversity…)
- Wildlife ecologists study the relation of stand and landscape patterns to habitat conditions for animals.

Hierarchy and behaviour of the system in space and time *(Waring, Running 1998)*



Ecosystem processes can be studied at many spatial scales

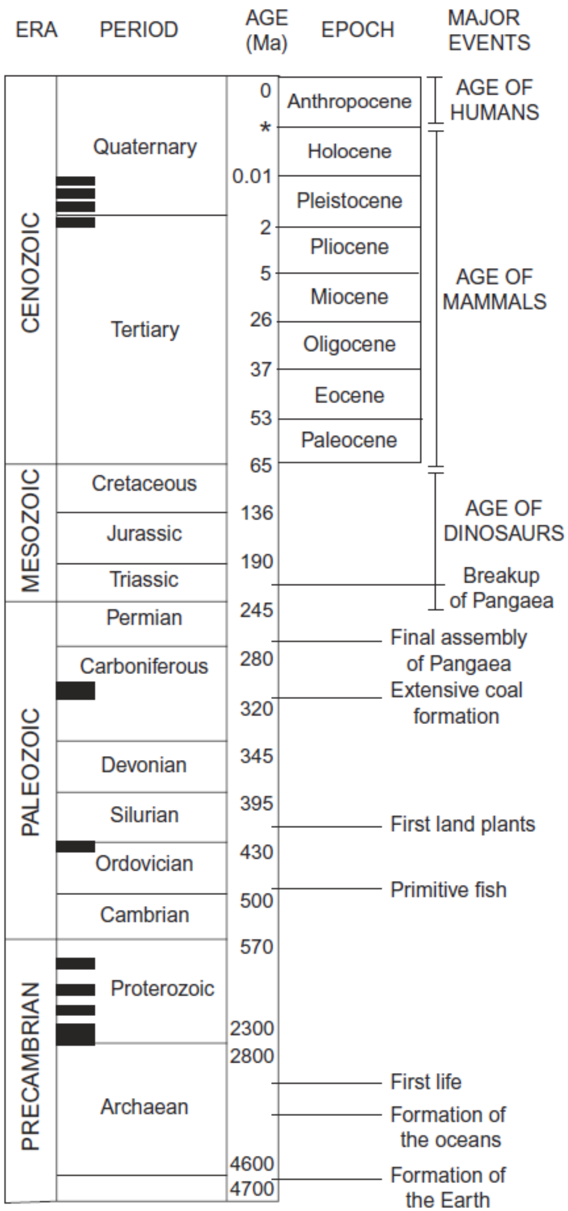
(Chapin et al. 2002)

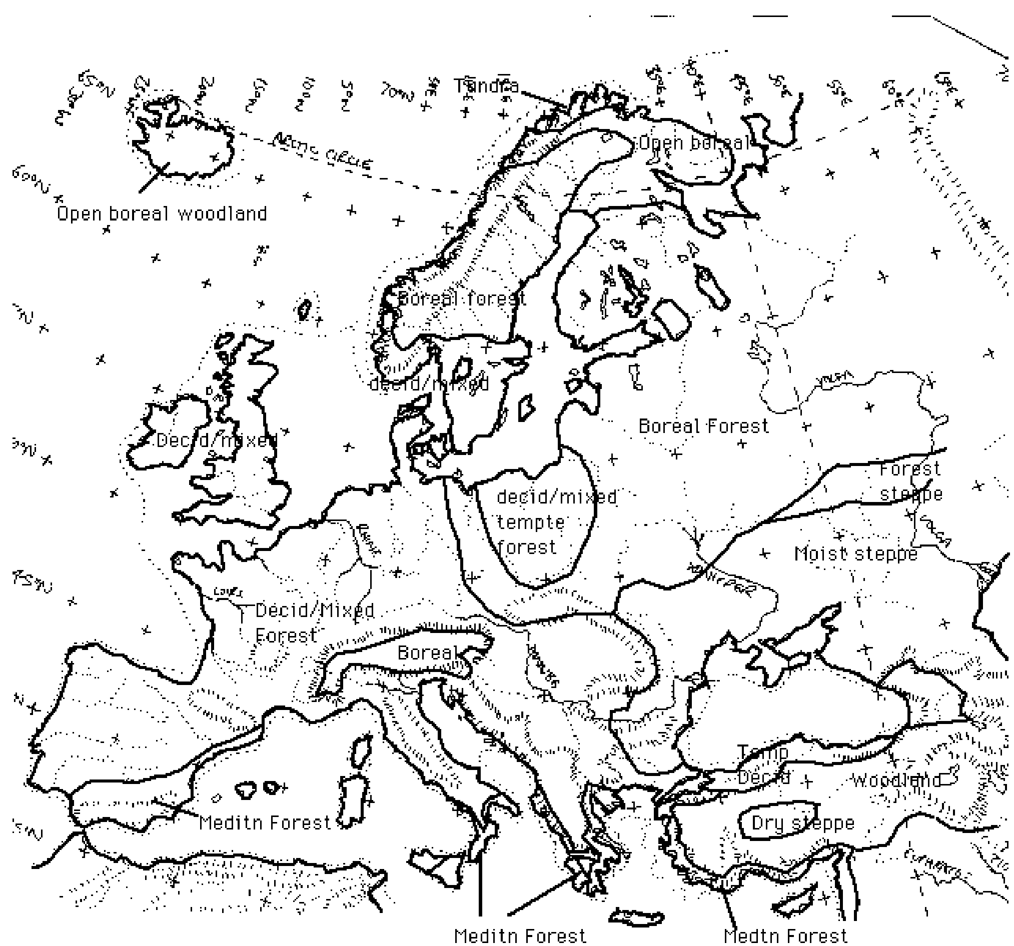


How big is an ecosystem?

Geological time period in Earth´s history

(Chapin et al. 2011)





9,000-8,000 14C years ago; forest had by now returned to most of Europe after the end of the cold Younger Dryas at 10 kyr. At 9 ka, however, the forest cover was rather more open than at present with more herbaceous glades. By 8 kyr the forest was closed, but with conifers more abundant than at present in eastern Europe.

Terrestrial ecosystems and site factors

Terrestrial ecosystems are shaped and governed by a number of interacting factors – sites factors. These can be summarised in the following expression (Jenny 1941, Amundson, Jeny 1997):

$$E = f\,(c, o, r, p, t \ldots)$$

where:

E = ecosystem

c = climate

o = organisms

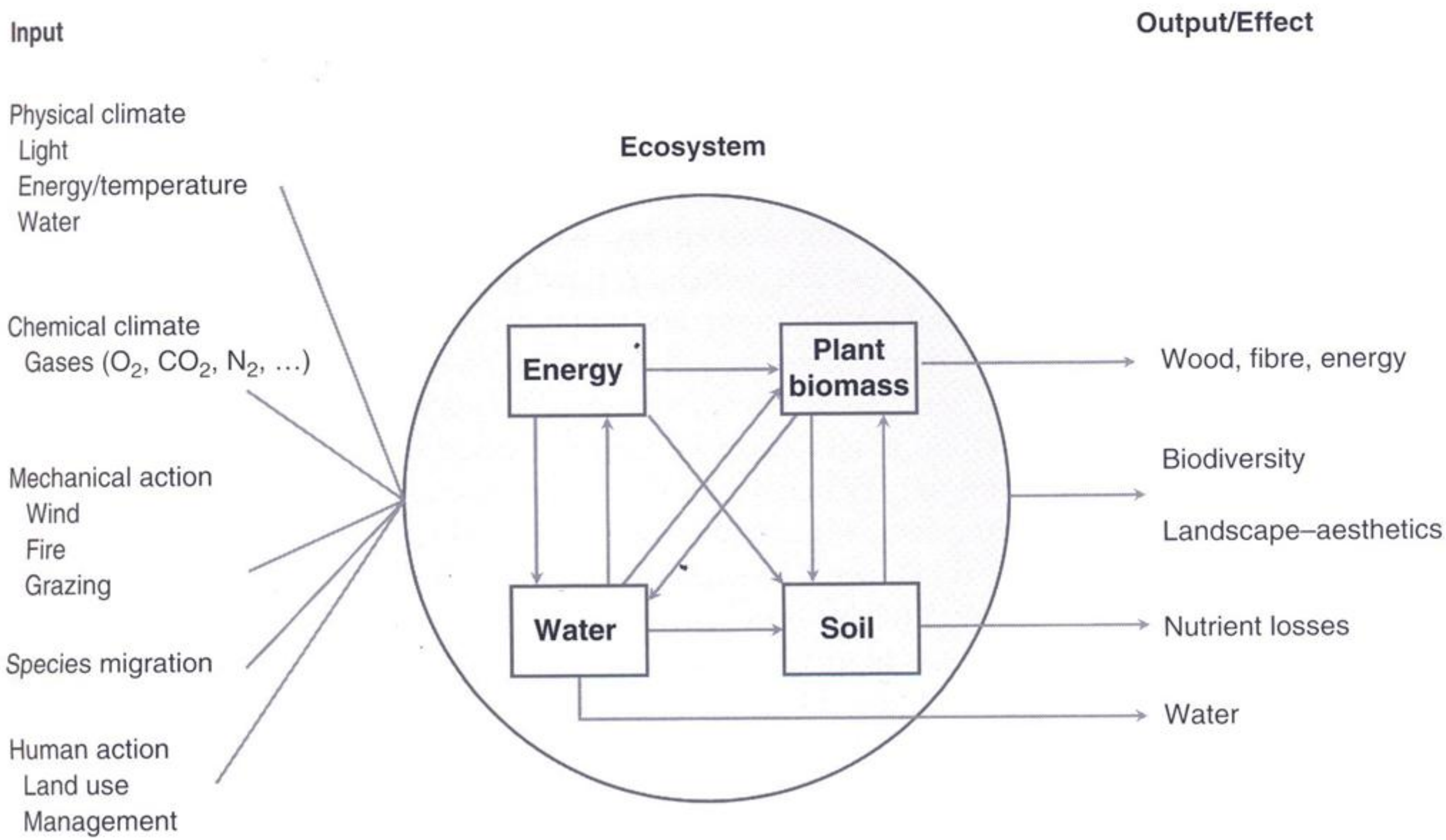
r = topography

p = parent material or bedrock, with changes into soil

t = time

Factror shaping terrestrial ecosystems

(Agren, Anderson 2012)



The relationship betwen state factors, interactive control and ecosystem processes

(Chapin et al. 2006)

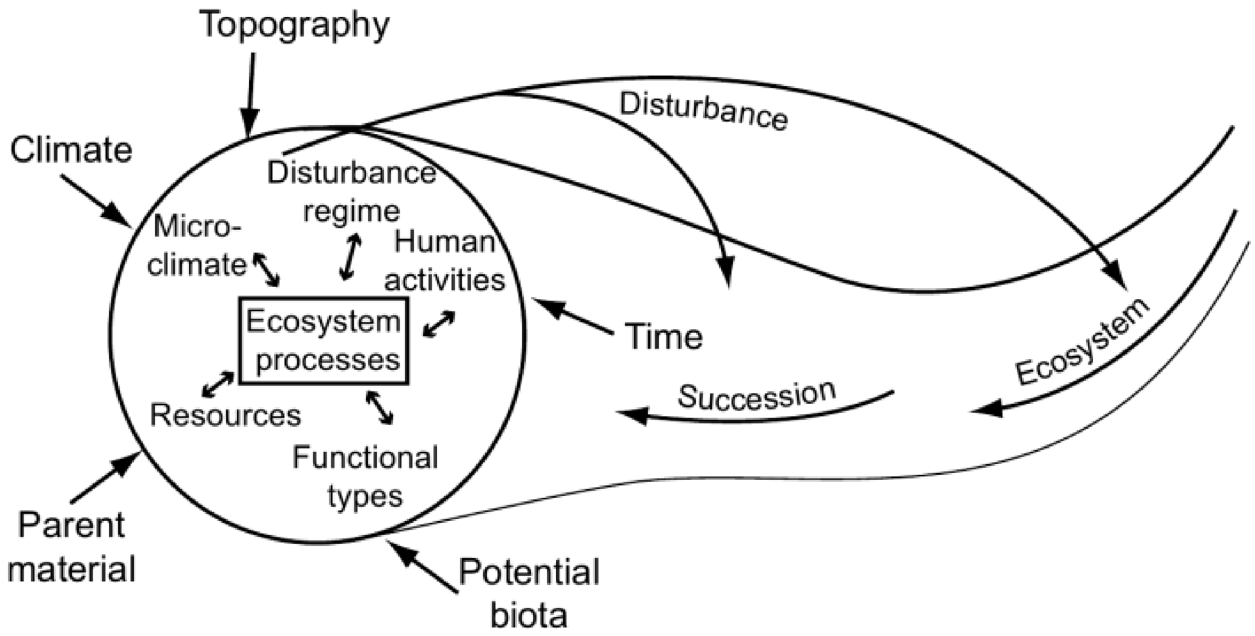


Figure 1.2. The relationship between state factors (outside the circle), interactive controls (inside the circle), and ecosystem processes (inside the box). The circle represents the boundary of the ecosystem, whose structure and functioning respond to and affect interactive controls, which are ultimately governed by state factors.

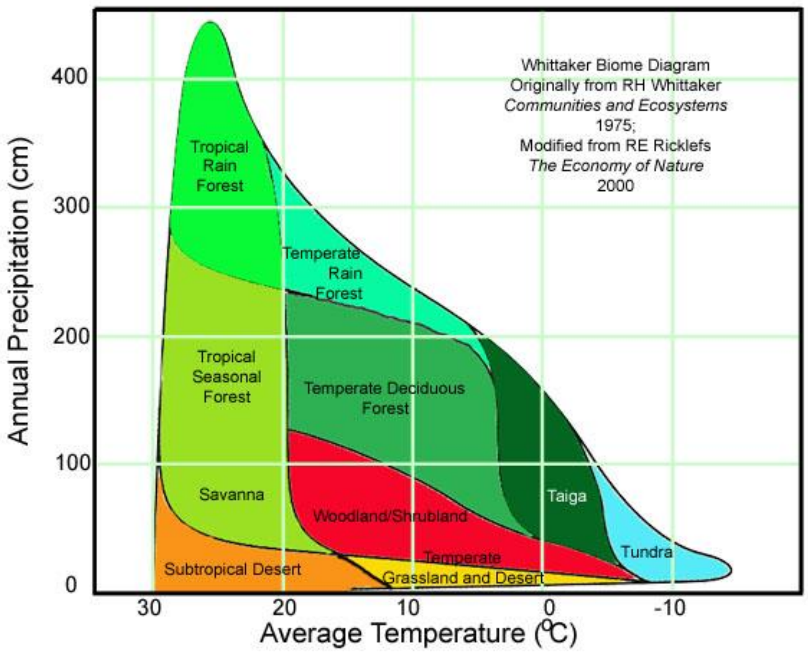
What is climate?

Climate in a narrow sense is usually defined as the "average weather," or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period ranging from months to thousands or millions of years. The classical period is 30 years, as defined by the World Meteorological Organization (WMO). These quantities are most often surface variables such as temperature, precipitation, and wind. Climate in a wider sense is the state, including a statistical description of the climate system.

Physical climate
Light
Energy/temperature
Water
Wind

Chemical Climate
Gasses (O2, CO2, N2, …)

Macroclimate
Mezoclimate
Microclimate
Weather



What is soil?

Soil is multiphase system.

A typical, productive soil has roughly 50 percent pore space by volume, with about half of this pore space occupied by water and the other half occupied by air.

The remaining 50 percent of the soil is solids, generaly, a majority of these solids are in the mineral form, with organic materials comprising perhaps 5 percent of the total soil volume.

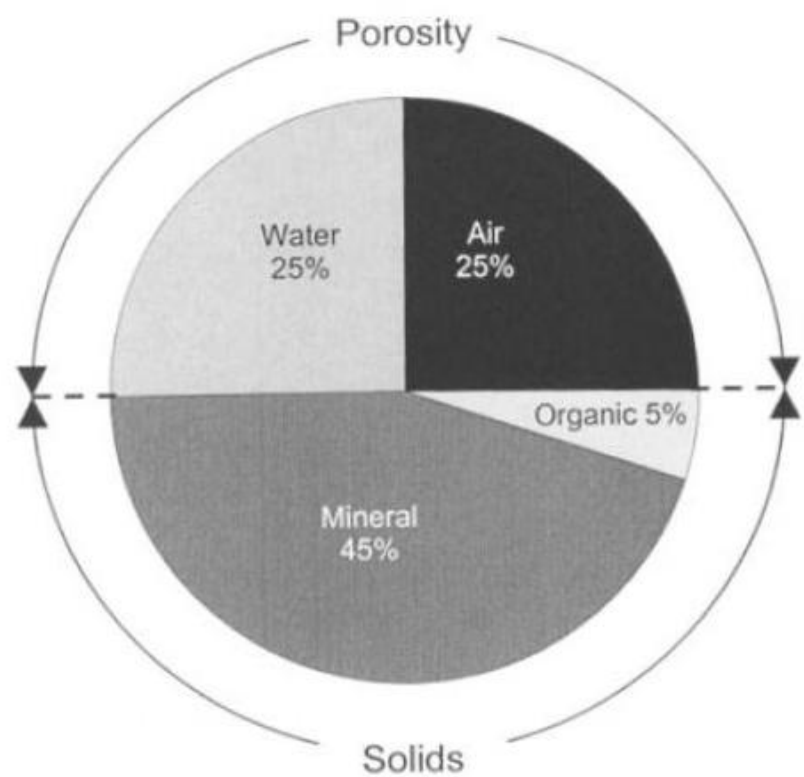


Figure 14.1. Soil is a multiphasic system that includes solids (mineral and organic material), gases (air), and liquid (water). An ideal volumetric distribution of these components for plant growth is shown for a typical agricultural surface soil with a loam texture. The relative amounts of water and air (the sum being soil porosity) vary inversely as the soil wets and dries. Surface forest soils typically contain more organic matter than agricultural soils. (Modified from Brady and Weil 2002)

Cornerstones of ecosystem analysing

- Mass balance

  - mass balances of each and every element involved in life

- Steady state

  - fluxes between different compartments of the ecosystem and over the ecosystem boundery are at ***steady*** state

- Limiting nutrients

  - limiting elements will determine the potential for the development of the organism

- Optimality

  - properties of organisms that give them maximal reproduction

Principles in ecosystem behaviour - part I

- **Principles pertaining to boundary conditions (B)**
  - B I. On boundaires and storage
  - B II. On perturbing boundaries
  - B III. On Nitrogen vs. Phosphorus limitation
  - B IV. On production and openness
- **Principles pertaining to energy and water (A)**
  - A I. On climate and ecosystem distribution
- **Principles pertaining to plant processes (P)**
  - P I. On element availability
  - P II. On light limitation
  - P III. On nutrient limitation
  - P IV. On water limination
  - P V. On resource use efficiency and acquisition

Principles in ecosystem behaviour - part II

- **Principles pertaining to soil processes (S)**
  - S I. On decomposition – energy limitation
  - S II. On nitrogen fixation
  - S III. On nitrogen leaching
- **Principles pertaining to element cycles (E)**
  - E I. On openness of element cycles
  - E II. On element distributions
  - E II. On ecosystem carbon storage

Principles - scheme

(Agren, Anderson 2012)

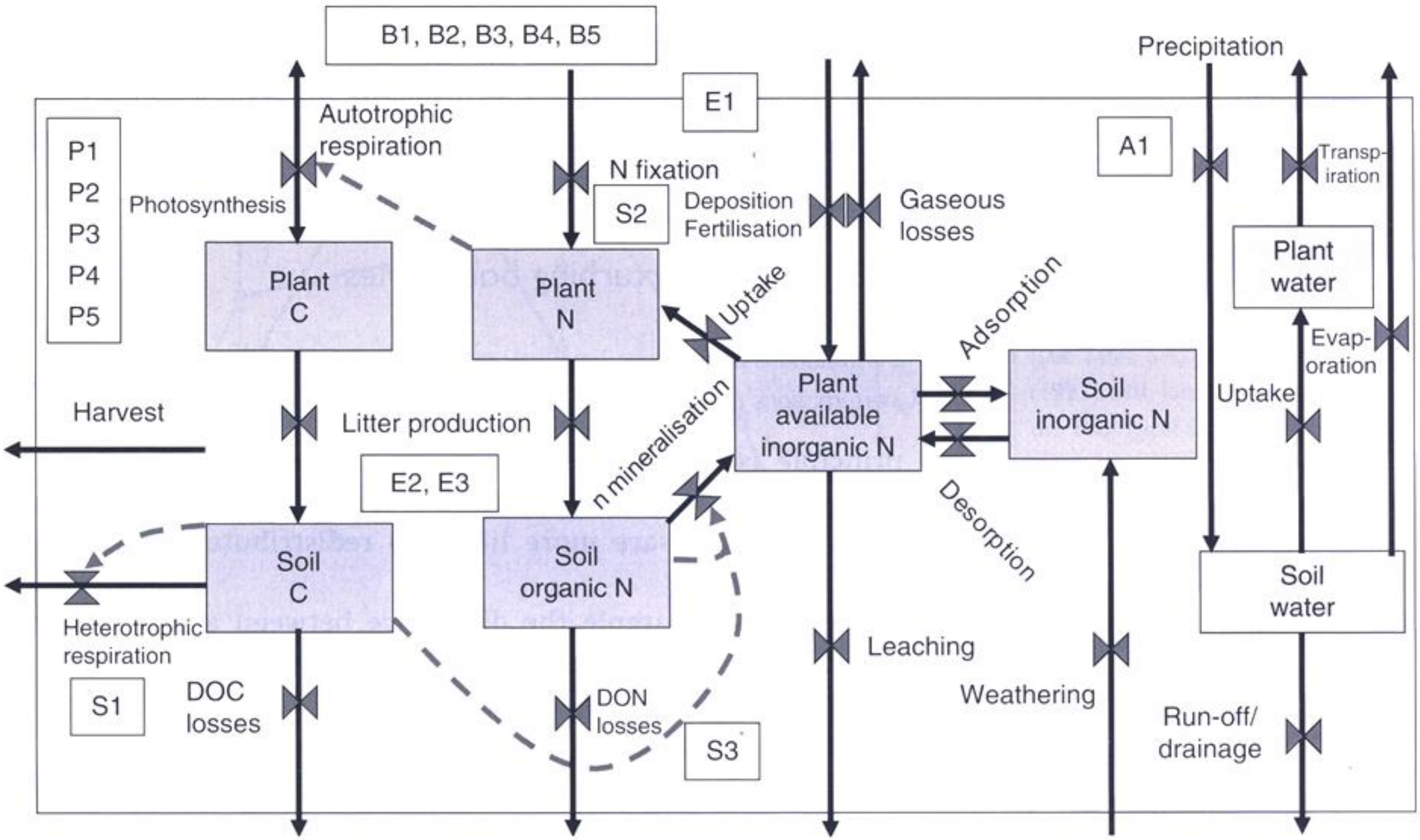


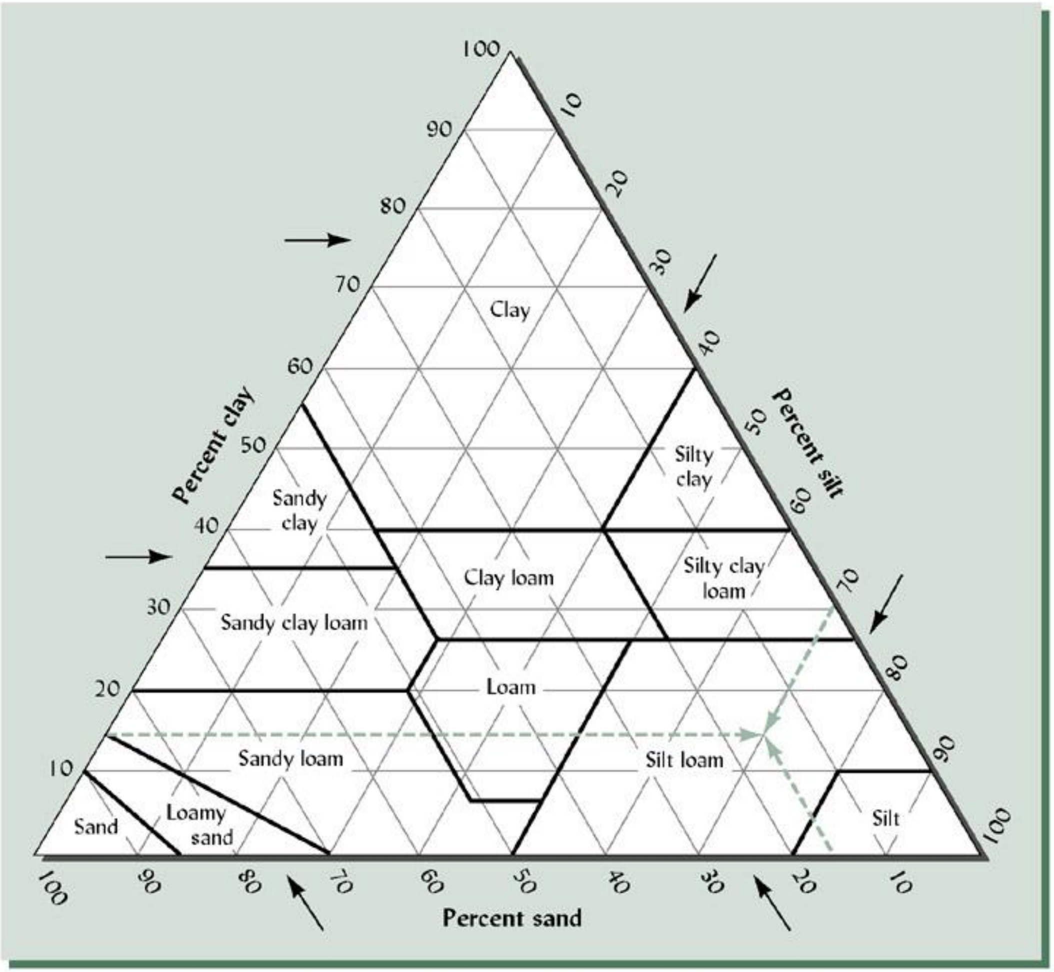
Figure 10.1 A number of principles can be coupled to the terrestrial cycles of carbon, nutrients, and water. We have grouped these into five different categories: boundary conditions (B), energy and water – abiotic (A), plant production (P), soil processes (S) and element cycles (E).

Soil physical and chemical characteristics

- **Soil physics** (texture, porosity, structure, water content, hydrolimits, bulk density, …)
- **Soil chemistry** (pH, cation exchange capacit (CEC), buffering capacity, available nutrients, total nutrients, content of carbon, nitrogen, C/N ratio, content of humic and fulvic acids, HA/FA ratio, DOC, DON, …)

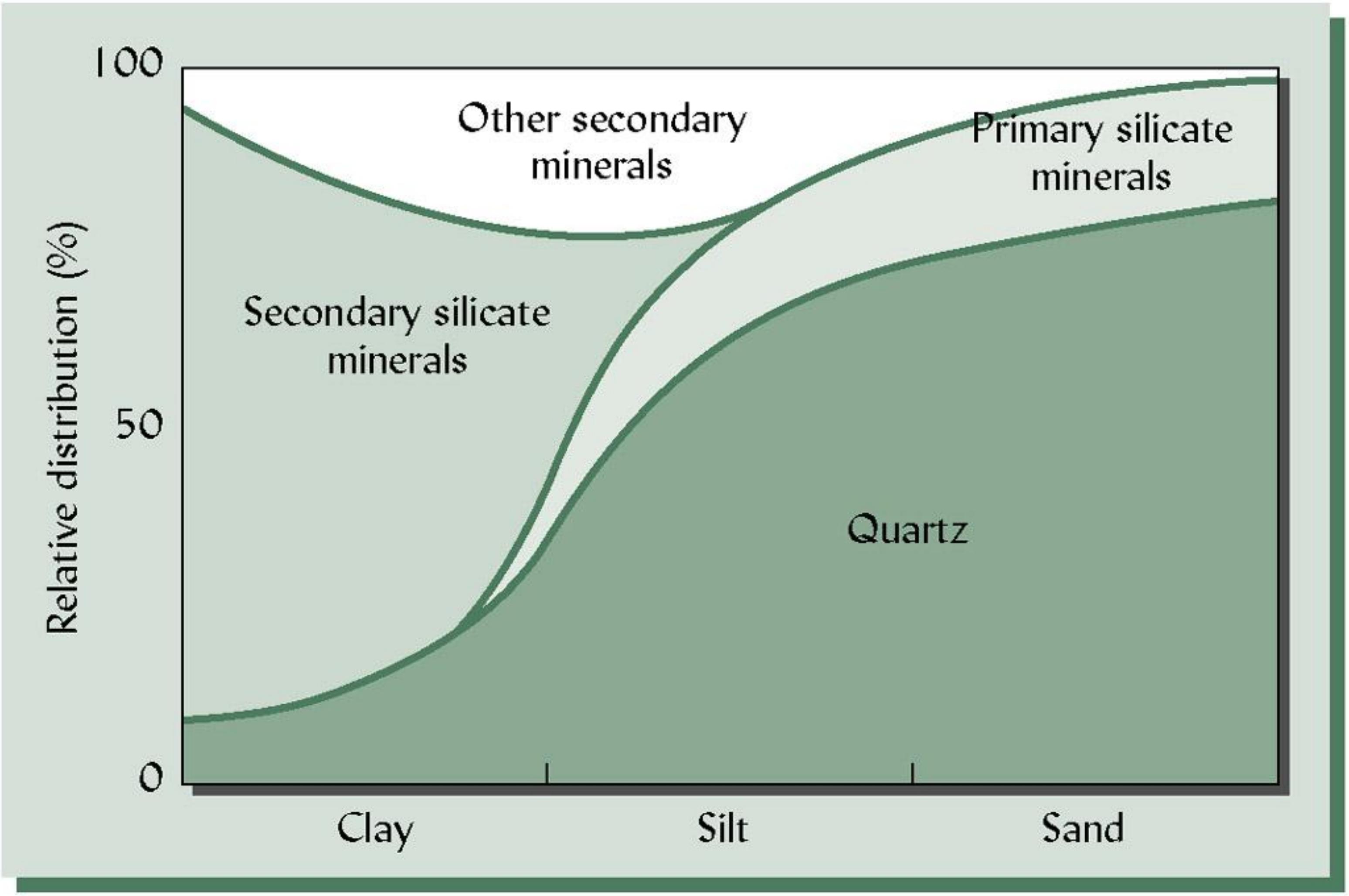
Percentage of sand, silt and clay in major soil textural classes

(Brady, Weil 2008)



General relationship between particle size and kids of minerals present

(Brady, Weil 2008)



Soil Development Formation

(Chapin et al. 2011)

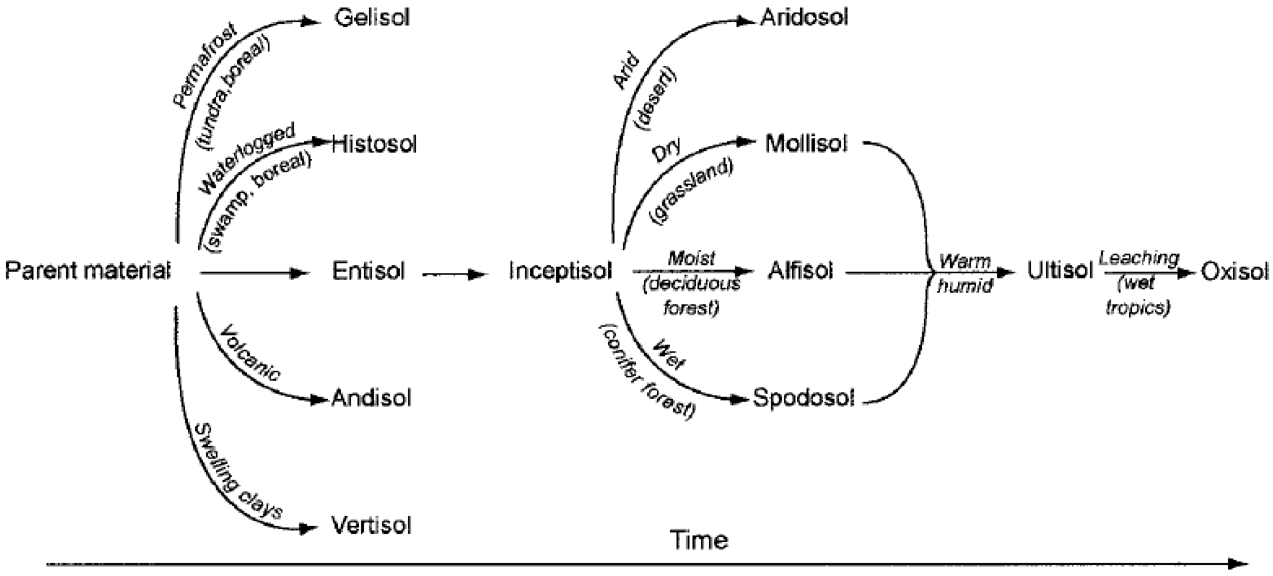


FIGURE 3.10. Relationships among the major soil orders, showing the conditions under which they form, the relative time required for formation, and the types of ecosystems with which they are commonly associated (Birkeland 1999).

Process leading to additions, transformations, transfers, and losses of materials from soils

(Chapin et al. 2011)

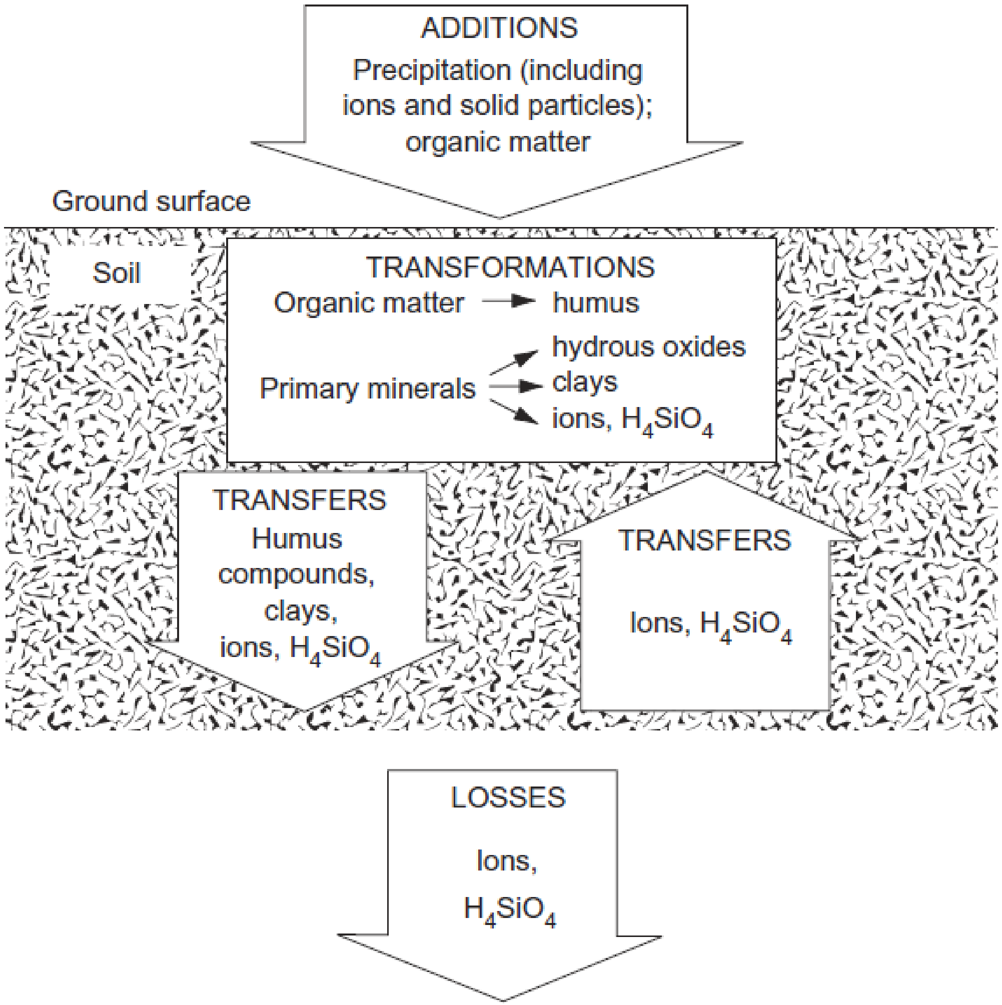


FIGURE 3.6. Processes leading to additions, transformations, transfers, and losses of materials from soils. Silica is H_4SiO_4. (Redrawn with permission from *Soils and Geomorphology* by Peter W. Birkeland, © 1999 Oxford University Press, Inc.; Birkeland 1999.)

Soil Texture

(Brady, Weil 2008)

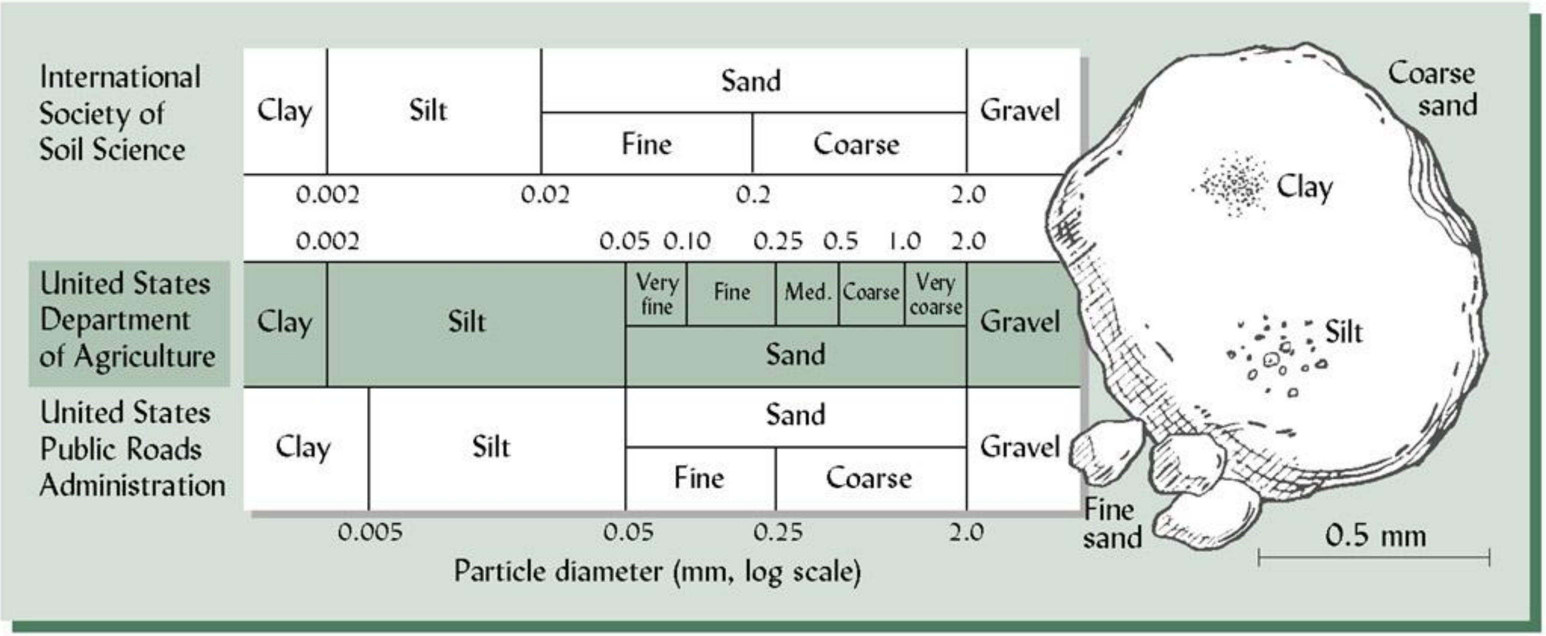
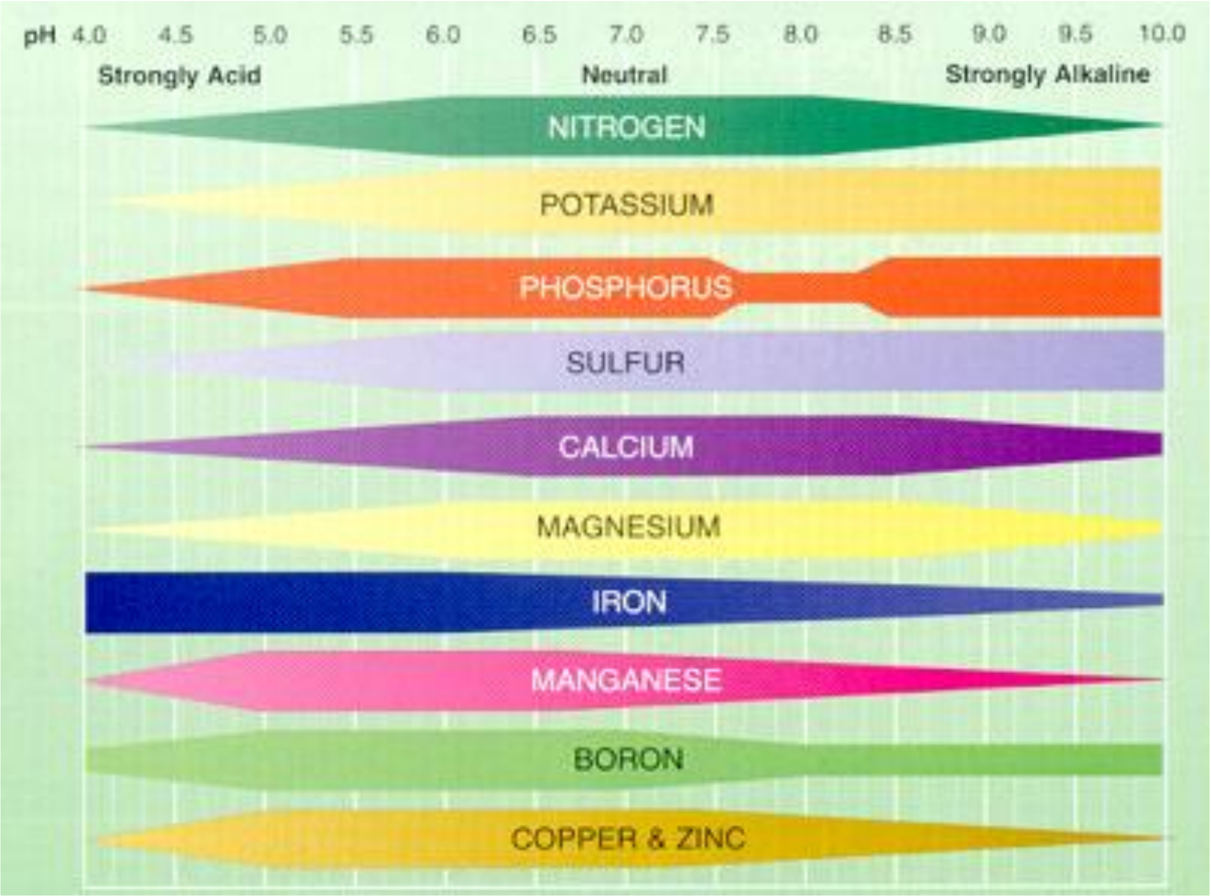


Table 3.3. Names of the soil orders in the United States soil taxonomy and their characteristics and typical locations.

Soil Order	Area (% of ice-free land)	Major Characteristics	Typical Occurrence
Entisols	16.3	no well-developed horizons	sand deposits, plowed fields
Inceptisols	9.9	weakly developed soils	young or eroded soils
Histosols	1.2	highly organic; low oxygen	peatland, bog
Gelisols	8.6	presence of permafrost	tundra, boreal forest
Andisols	0.7	from volcanic ejecta; moderately developed horizons	recent volcanic areas
Aridisols	12.1	dry soils with little leaching	arid areas
Mollisols	6.9	deep dark-colored A horizon with >50% base saturation	grasslands, some deciduous forests
Vertisols	2.4	high content (>30%) of swelling clays; crack deeply when dry	grassland with distinct wet and dry seasons
Alfisols	9.7	sufficient precipitation to leach clays into a B horizon; >50% base saturation	humid forests; shrublands
Spodosols	2.6	sandy leached (E) horizon; acidic B horizon; surface organic accumulation	cold wet climates, usually beneath conifer forests
Ultisols	8.5	clay-rich B horizon, low base saturation	wet tropical or subtropical climate; forest or savanna
Oxisols	7.6	highly leached horizon with low clay; highly weathered on old landforms	hot humid tropics beneath forests
Rock and sand	14.1		

Data from Miller and Donahue (1990) and Brady and Weil (2001).

Soil pH and availability of nutrients



Generic soil profile

(Chapin et al. 2002)

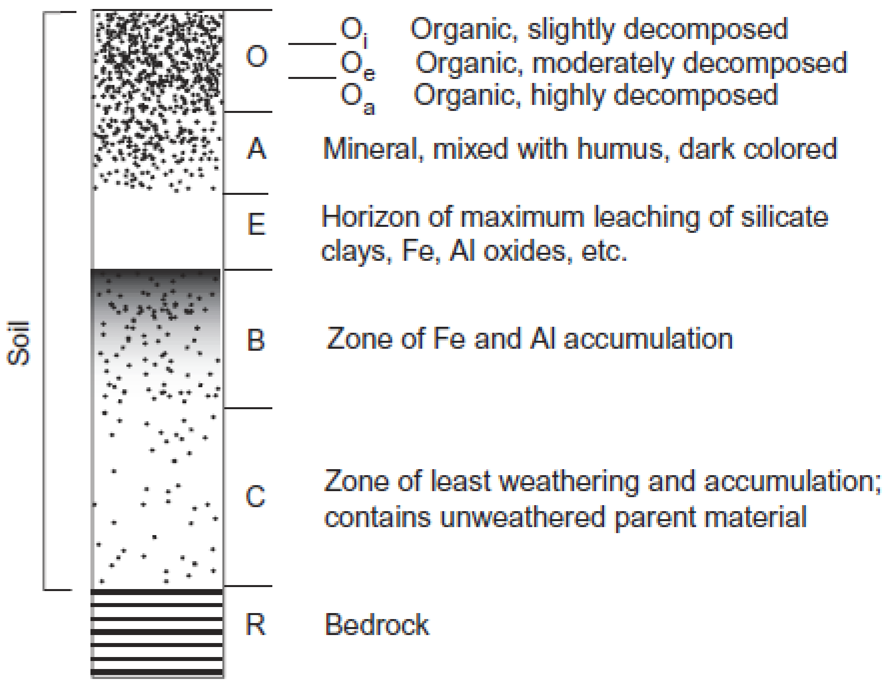
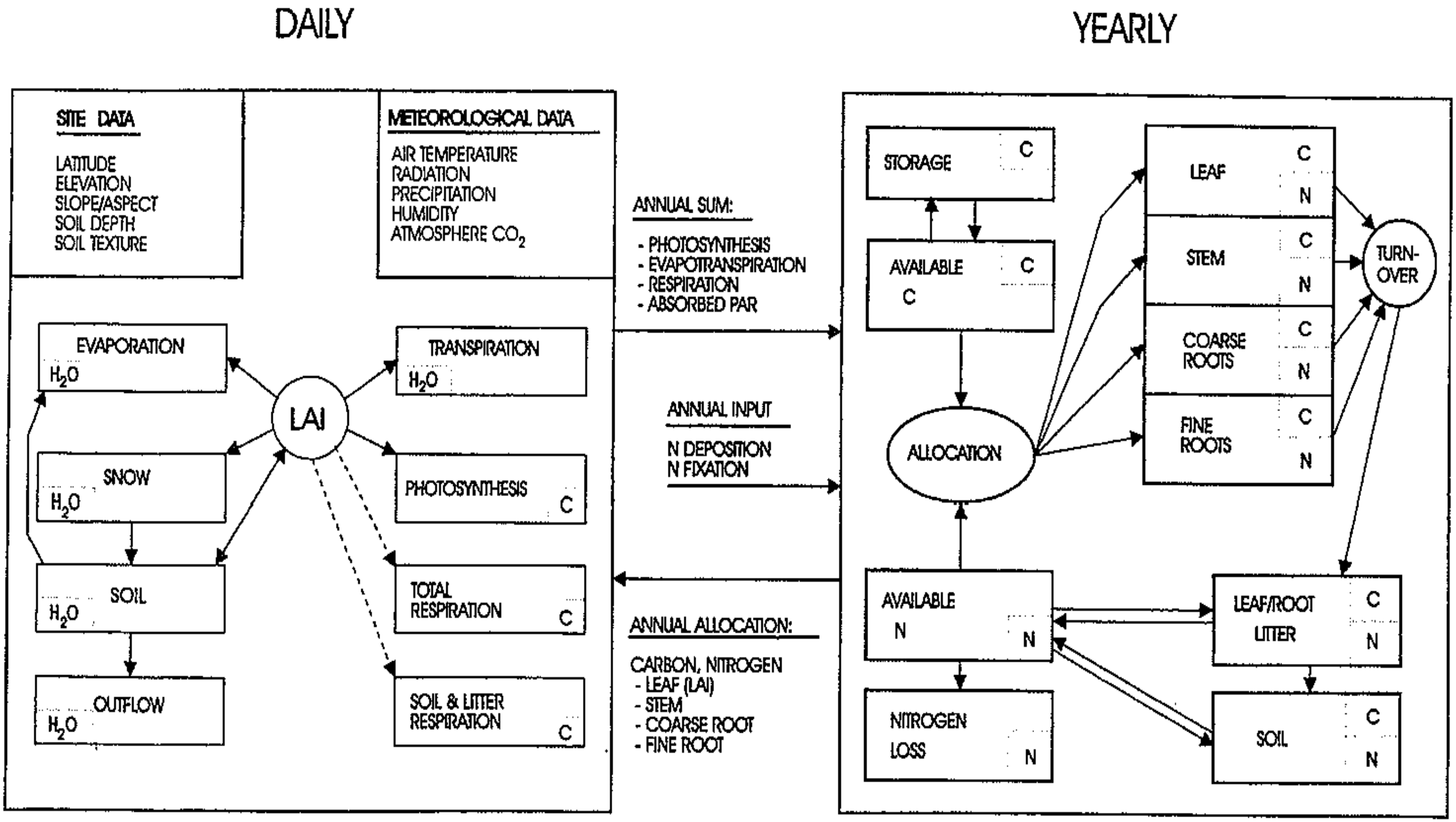


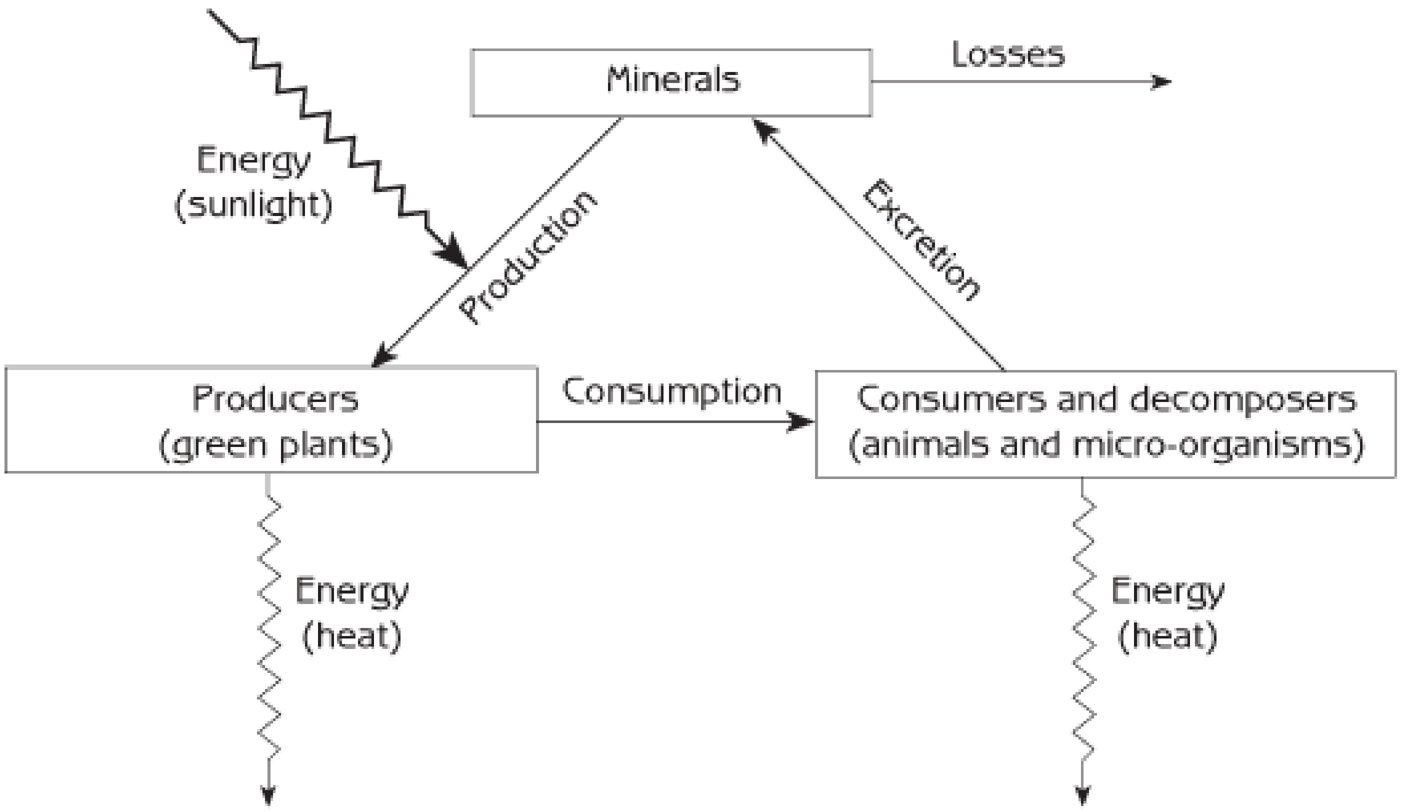
FIGURE 3.9. A generic soil profile showing the major horizons that are formed during soil development. Density of dots reflects concentration of soil organic matter.

Multiply space and time scaling

(Waring, Running 1998)

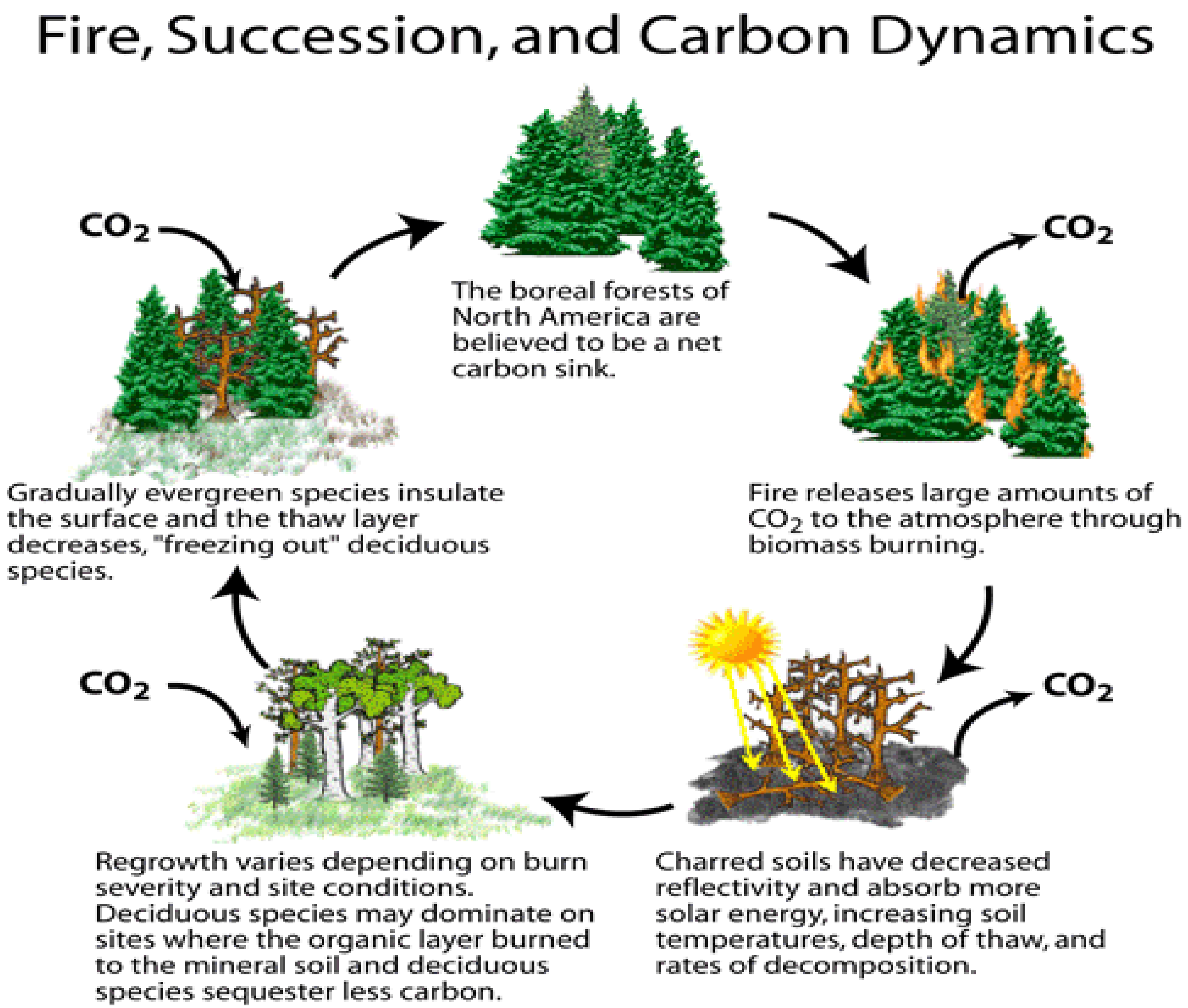


Energy and material transfers



Dynamic of processes in forest ecosystems

example : borel forest



Data extrapolations, simulations and mathematatic modelling

Component Processess of a Comprehensive Ecosystem Biogeochemical Model

Energy balance
- Short-wave radiation balance (incoming—outgoing)
- Long-wave radiation balance (incoming—outgoing)
- Sensible heat flux
- Latent heat flux
- Soil heat flux

Water balance
- Precipitation partitioning (snow versus rain)
- Canopy and litter interception and storage
- Soil surface infiltration
- Soil water content
- Subrooting zone outflow
- Hill slope hydrologic routing
- Evaporation
- Transpiration

Carbon balance
- Photosynthesis, gross primary production
- Maintenance respiration
- Growth respiration
- Photosynthate storage
- Net primary production
- Carbon allocation
  - Leaves, stem/branches, roots, defensive compounds, reproduction
- Phenological timing
  - Canopy growth/senescence
  - Litterfall of leaves, turnover of stems and roots
- Decomposition
- Net ecosystem production

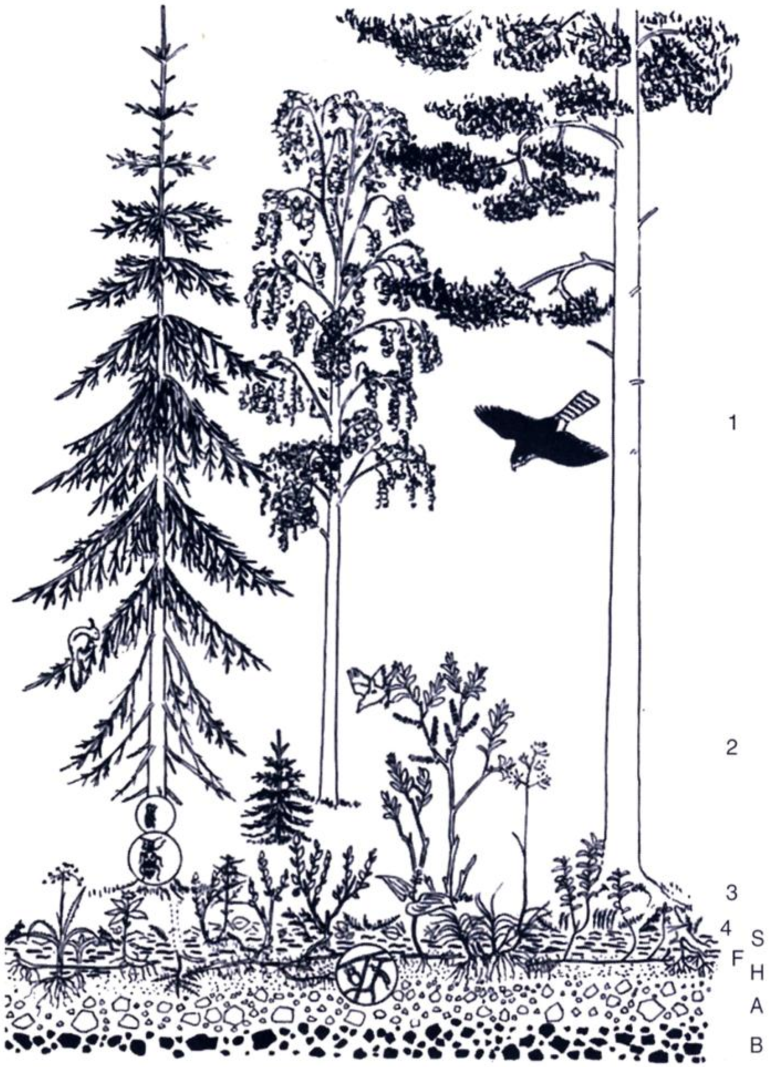
Elemental balance
- Sources (atmosphere, rock weathering, biological fixation)
- Soil solution transformation
- Immobilization, nitrification, denitrification
- Mineralization
- Root uptake
- Tissue storage
- Internal recycling
- Volatilization
- Leaching
- Export through harvesting and erosion

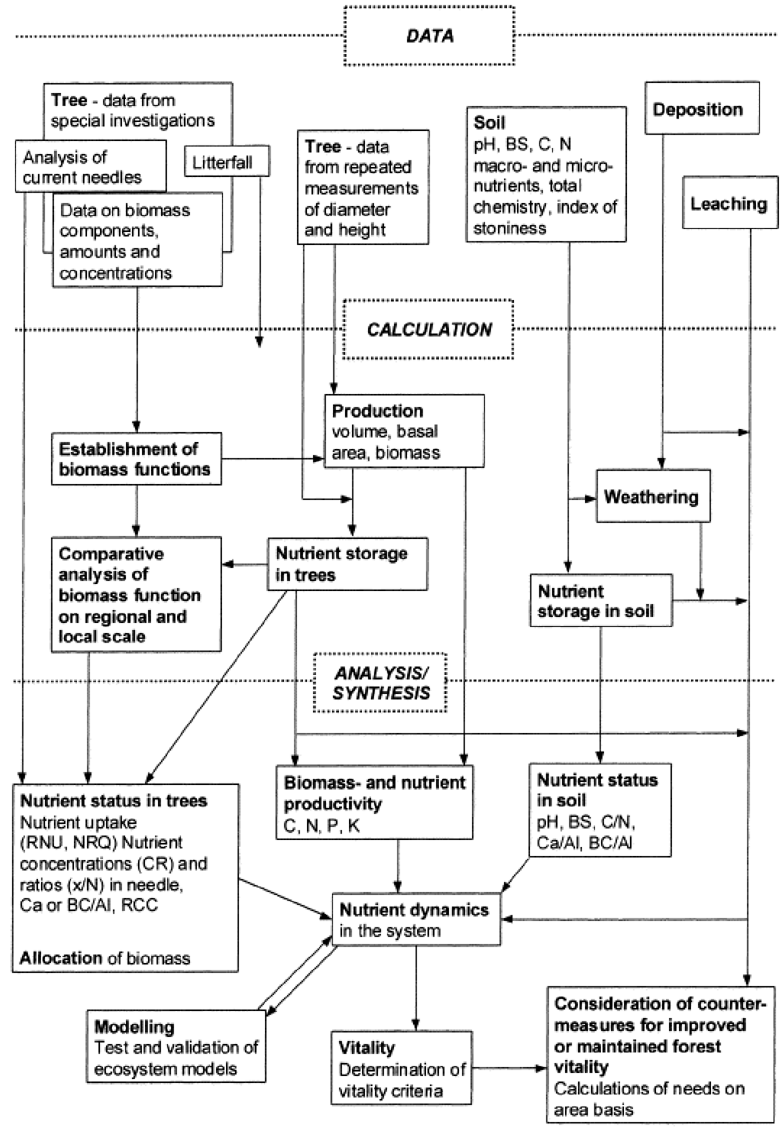
Simulation models (deterministic relationship)

Stochastic models (if even only one precesses is describes mathematically)

Ecosystem structure and layering

(Sjors 1967, Anderson et al. 2000)

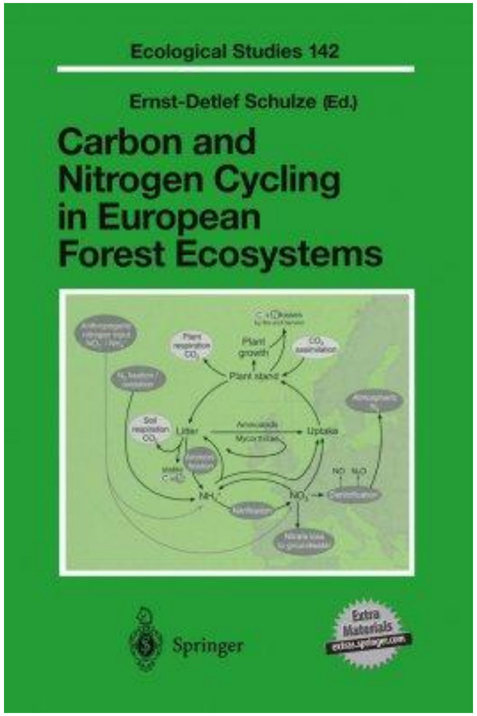


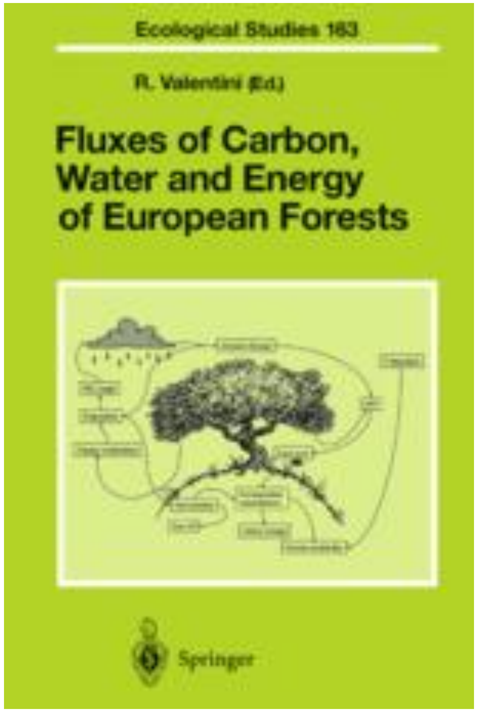


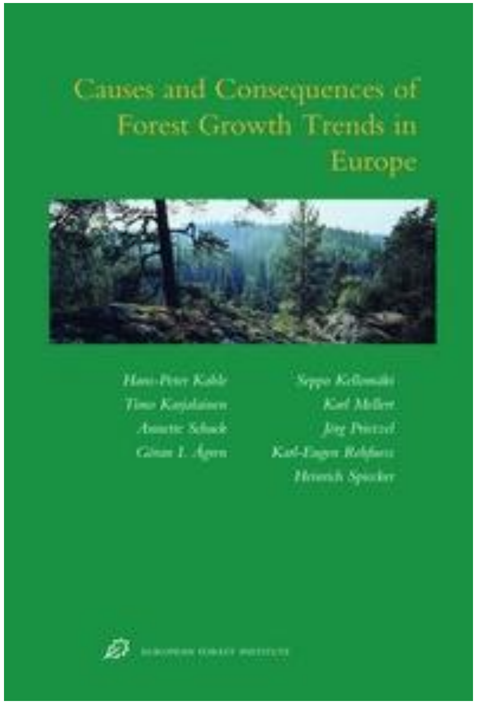
Review Questions

1. What is an ecosystem? How does it differ from a community?
2. What is the difference between a pool and a flux? Which of the following are pools and which are fluxes: plants, plant respiration, rainfall, soil carbon, consumption of plants by animals?
3. What are the state factors that control the structure and rates of processes in ecosystems?
4. Using a forest or as an example, explain how climatic warming or the harvest of trees by people might change the major interactive controls.
5. Use examples to show how positive and negative feedbacks might affect the responses of an ecosystem to climatic change.
   What processes are responsible for the cycling of rock material in Earth's crust?
6. Over a broad geographic range, what are the state factors that control soil formation?
7. What processes determine erosion rate? Which of these processes are most strongly influenced by human activities?
8. What processes cause soil profiles to develop?
9. What are the processes involved in physical and chemical weathering? Give examples of each.
10. How is soil texture defined? How does it affect other soil properties? What is cation exchange capacity (CEC), and what determines its magnitude in temperate soils?

Typical case studies in Europe

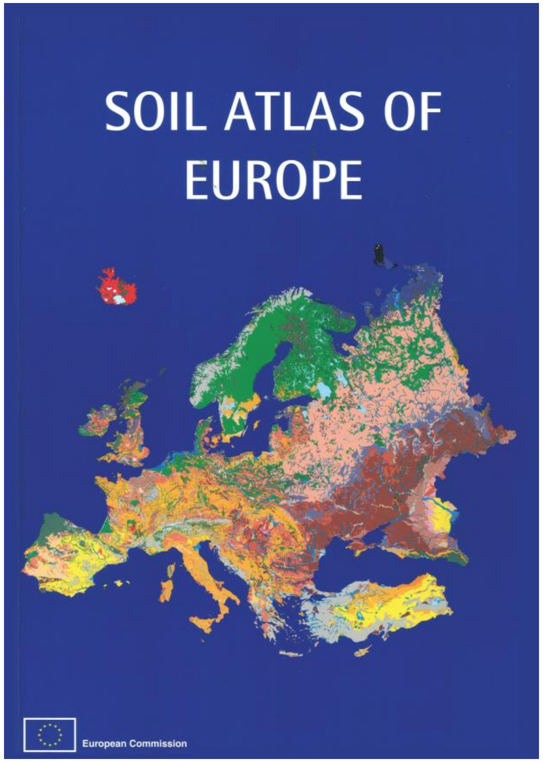






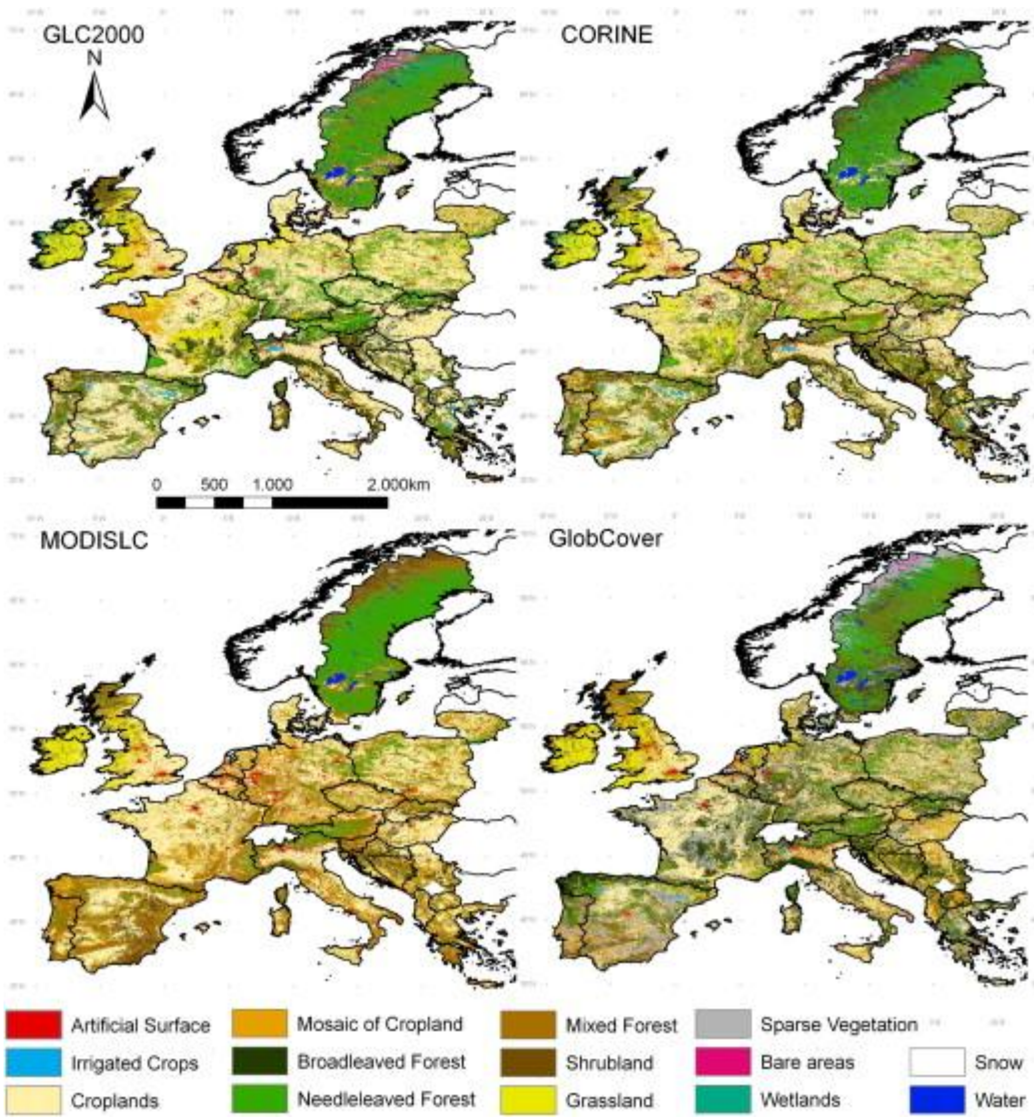
Related text books

- Soil Atlas of Europe - http://eusoils.jrc.ec.europa.eu/projects/soil_atlas/Download.cfm



The four land cover maps of Europe reconciled through a generalized nomenclature of 14 classes. covered by CORINE 2000

(Pérez-Hoyos et al. 2012)



Summary – Ecosystem concept

Ecosystem ecology addresses the interactions among organisms and their environment as an integrated system through study of the factors that regulate the pools and fluxes of materials and energy through ecological systems. The spatial scale at which we study ecosystems is chosen to facilitate the measurement of important fluxes into, within, and out of the ecosystem. The functioning of ecosystems depends not only on their current structure and environment but also on past events and disturbances and the rate at which ecosystems respond to past events. The study of ecosystem ecology is highly interdisciplinary and builds on many aspects of ecology, hydrology, climatology, and geology and contributes to current efforts to understand Earth as an integrated system. Many unresolved problems in ecosystem ecology require an integration of systems approaches, process understanding, and global analysis. Most ecosystems ultimately acquire their
energy from the sun and their materials from the atmosphere and rock minerals. The energy and materials are transferred among components within the ecosystem and are then released to the environment. The essential biotic components of ecosystems include
plants, which bring carbon and energy into the ecosystem; decomposers, which break down dead organic matter and release CO_2 and nutrients; and animals, which transfer energy and materials within ecosystems and modulate the activity of plants and decomposers. The essential abiotic components of ecosystems are the atmosphere, water, and rock minerals. Ecosystem processes are controlled by a set of relatively independent state factors (climate, parent material, topography, potential biota, and time) and by a group of interactive controls (including resource supply, modulators, disturbance
regime, functional types of organisms, and human activities) that are the immediate controls over ecosystem processes. The interactive controls both respond to and affect ecosystem processes. The stability and resilience of ecosystems depend on the strength of negative feedbacks that maintain the characteristics of ecosystems in their current state.

Summary - Soil

Five state factors control the formation and characteristics of soils. Parent material is generated by the rock cycle, in which rocks are formed, uplifted, and weathered to produce the materials from which soil is derived. Climate is the factor that most strongly determines the rates of soil-forming processes and therefore rates of soil development. Topography modifies these rates at a local scale through its effects on microclimate and the balance between soil development and erosion. Organisms also strongly influence soil development through their effects on the physical and chemical environment. Time integrates the impact of all state factors in determining the long-term trajectory of soil development. In recent decades, human activities have modified the relative importance of these state factors and substantially altered Earth's soils. The development of soil profiles represents the balance between profile development, soil mixing, erosion, and deposition. Profile development occurs through the input, transformation, vertical transfer, and loss of materials from soils. Inputs to soils come from both outside the ecosystem (e.g., dust or precipitation inputs) and inside the ecosystem (e.g., litter inputs). The organic matter inputs are decomposed to produce CO_2 and nutrients or are transformed into recalcitrant organic compounds. The carbonic acid derived from CO_2 and the organic acids produced during decomposition convert primary minerals into clay-size secondary minerals, which have greater surface area and cation exchange capacity. Water moves these secondary minerals and the soluble weathering products down through the soil profile until new chemical conditions cause them to become reactants or to precipitate out of solution. Leaching of materials into groundwater or erosion and gaseous losses to the atmosphere are the major avenues of loss of materials from soils. The net effect of these processes is to form soil horizons that vary with climate, parent material, biota, and soil age. These horizons have distinctive physical, chemical, and biological properties.