FOREST, RANGE AND WILDLAND SOILS

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Summary

Forest, range and wildland ecosystems can be associated with distinct soil types, and these have unique characteristics imparted by climate, vegetation, time, topography and the geologic substrate on which they develop. This chapter describes the main plant

assemblages and soil types of forest, range and wildland ecosystems with a focus on northern and temperate areas, and makes reference to three different soil classification systems. It then describes how the natural disturbance regime of these ecosystems affects soil formation and nutrient cycling.

Organic matter is one of the main factors that contributes to differences in soils of these ecosystems, specifically carbon and nitrogen, which are described in more detail. Fire as a natural disturbance regime is given precedence as a special case in nutrient cycling in these ecosystems. Charcoal plays a role as a substrate with long-term carbon storage capacity, besides its well-known beneficial effect on soil fertility. Finally, management issues in both industrial forestry and rangeland grazing are described briefly.

1. Introduction

Forest, range and wildland ecosystems, and their associated soil types, cover large parts of the earth's land surface and have been used by humans for food, shelter and fuel since the beginning of their existence. The soils of these ecosystems originally had unique characteristics which were later affected more or less intensively by human activities. In fact, much of the original distribution of these ecosystems has been appropriated for human development, and their soils have gradually undergone changes. Intact forest, range and wildland soils in the world have therefore become rare nowadays. They are only conserved where relic hunting grounds in Europe still exist, in woodlots on intensive agricultural lands in North America and where areas have been designated as parks or animal reserves.

Soils are the physical matrix from which plants derive support, mineral nutrition and water resources. Based on the pressure associated with production of food for human populations, soil science owes much of its development to the necessity of understanding how soils provide agricultural plants with the resources to grow. Forest, range and wildland soils have, however, often been separated from agricultural land as they represent distinct soil and ecosystem types that do not produce food for direct human consumption, but may support natural resource extraction or livestock grazing.

The basic principles of soil physics and chemistry applied to both land use types are the same, but there are distinct differences in how these factors affect forest, range and wildland soils. Biogeochemical cycles vary due to natural disturbances and physiological differences between wild perennial plants and cultivated annual plants. Environmental parameters are sometimes harsh and may lead to a reduced decomposition of mineral and organic substrates. In forest soils, there is evidence for a two-phase interaction between disturbance and vegetation-driven nutrient cycling. Finally, invasion of exotic plants, due to human dispersal, may lead to changes in the microbial community and soil-mediated allelopathic interactions.

Historically, many individuals have contributed to a better knowledge and understanding of forest soils. Gessel and Harrison (1999) give an excellent review of forest soil research and development in North America, so it will not be discussed in great detail here. Soils and soil formation are mainly a function of five soil forming factors: climate, organisms, topography, parent material and time. Most forest, range and wildland soils have a low potential for agricultural development due to the constraints of a number of these factors and the soil properties that result from them (see: *Soils and Soil Sciences*).

The physical and chemical conditions that restrict forest, range and wildland soils include: shallow depth, coarse fragment content, low nutrient availability, coarse texture, steep topography and harsh climate. Forest, range and wildland soils occurring in Canada, the USA, Scandinavia and Siberia are typically very shallow due to a limited amount of time for soil genesis after much of the northern hemisphere was covered by glacial ice some 15,000 years ago. Little time since glacial retreat accounts for generally high coarse fragment contents, as is the case for glacial till that consists of unsorted material dominated by coarse sand, gravel and boulders. Time also accounts for poor texture, as primary minerals have not yet been weathered completely to secondary components and clay particles. The reduced soil genesis is partially responsible for low nutrient availability, low clay and (initially) low organic matter content and, therefore, low cation exchange capacity.

There are nevertheless also exceptions to this overall picture, and some forest, range and wildland soils are deep and fertile. Once cleared of trees or converted from perennial grasses to more productive annual grasses, they can support good agricultural crops and livestock. These concepts will be developed in more detail in the sections that follow. The main soil orders of forest, range and wildlands will be described in terms of the ecosystem types that fall under those categories. This chapter also focuses on the main disturbance types associated with these ecosystems and how disturbance affects pedogenic processes. It will examine nutrient cycling in these ecosystems and will briefly examine some problem issues in managing these ecosystems and the current state of knowledge on these problems.

2. Ecosystems and Soil Orders

This section deals with the major ecosystems of forest, range and wildlands and their corresponding dominant soil orders. In this context reference is made to the major forest ecosystems of Fisher and Binkley (2000) and to the higher (order) levels of the FAO, Canadian and USDA-*Soil Taxonomy* soil classification systems (see: *Soil Geography and Classification*). Table 1 shows the approximate land coverage of the different USDA soil orders compared to those of the FAO and Canadian systems of soil classifications.

2.1. Forest Ecosystems

Forests are a dominant ecosystem type in the world, at one time occupying as much as two thirds of the earth's surface, and they impart unique characteristics to the soils they cover. However, much of the original forest areas have been cleared to accommodate the increasing human population, with modifications to these soils that result from agriculture and urbanization. Contemporary forest soils can, therefore, be defined as those soils that currently support natural or managed forest stands. The rest of this paper will be limited to a discussion of forest soils of temperate and northern ecosystems, as tropical ecosystems and their associated soils represent a special case discussed in other parts of this theme (see: *Soils of the Humid and Sub-humid Tropics*).

Forest soils are unique within the forest, range and wildland soils group because of the quite important accumulation of organic residues and leaf litter on their surface. Rates of organic matter deposition can be extremely high in some climates and are punctuated by changing seasons. This seasonal litter deposition results in an accumulation of organic material at the soil surface that is sometimes referred to as the *forest floor*, *litter layer* or *duff* in North America, and the *humus layer* in Fennoscandia and other parts of the world. The organic matter deposited on a forest surface decomposes slowly and develops a horizon sequence of its own.

The organic material accumulated on the forest floor belongs generally to three distinct categories: litter (L) or the un-decomposed material on the surface; fibric (F) or slightly decomposed material that is still recognizable as being of plant origin; and humus (H), being the highly decomposed material that is un-recognizable as plant origin and that has undergone humification processes as mediated by the microbial community. This layer is referred to as Oi, Oe, Oa in the USA soil classification system (Soil Survey Staff, 1999) and L-F-H in the Canadian classification system (NN, 1987). The humus layer is in contact with the mineral soil and organic matter is gradually worked into the upper surface layer, either as particulate matter or as a dissolved fraction, by the pedoturbation action of macro- and micro-fauna, as well as by water percolation. The boundary between the forest floor and the mineral soil below can be diffuse, obscuring where the mineral soil surface starts, and resulting in low forest soil bulk density in the upper 10cm. The addition of organic matter to surface horizons also give forest soils unique properties, as is described below.

Forest floor material can be further differentiated into mull, moder and mor types, representing the different forms of humus developed under different ecosystem types. As a general rule, *mor humus* develops under conifer forests, where the decomposition of evergreen needles is retarded by the chemical nature of the organic residue (high C content, low pH), cold temperatures and low microbial activity. Mor humus has distinct layers with a large L layer, large F and little H development. *Mull humus* develops under broadleaf deciduous forests, where litter decomposition is rapid under favorable climatic conditions and the organic substrate readily disintegrates under the influence of microbes, recycling nutrients back to the plant community faster. Mull humus also has distinct layers, but in this case smaller L and F layers and a more pronounced H layer. *Moder humus* has characteristics in between mor and mull, and is prominent in mixed deciduous forests.

2.1.1. Boreal Systems

Boreal and temperate forests have different structure and species assemblages based on overall climate conditions, and the characteristic species of the stands have an effect on soil genesis. Boreal forests (also known as *taiga* in northern Europe and Asia) have a circumpolar distribution globally and are represented by evergreen or deciduous needle-leaf trees, in some cases forming monospecies stands and in other cases having stands with mixed species. The most commonly encountered genera are: *Pinus*, *Picea*, *Larix*, *Tsuga* and *Abies*. The southern boundary of this ecosystem is called the Aspen Parkland in the USA and Canada, and is dominated by deciduous broad-leaf species including the genera *Betula* and *Populus*.

The first main distinction in terms of soils in the USDA-*Soil Taxonomy* classification is between organic and mineral soils. The former group is characterized as Histosols; they develop where there is a high organic matter input and a low decomposition rate, often due to water saturation, extreme acidity, and low average temperature. To be classified as Histosols, the profile must contain 20% or more organic material by weight, or 30-35% organic matter by volume. Forest stands developed in lowland areas dominated by Histosols are common in some parts of the boreal forest, including peat bogs and fens (Table 1).

The second group of boreal soils (i.e. those that have less organic material) are classified as mineral soils, differentiated on the basis of the dominant soil forming factor that contributes to their development: time, climate, topography or parent material. Although less obvious than in the organic soils, organisms and plants continue to play a role in profile genesis. The most dominant mineral soil orders encountered under a boreal forest canopy are: Spodosols, Alfisols and Ultisols. All of these have a characteristic eluviation soil layer below the topsoil, and a corresponding clay illuviation horizon underneath.

	Soil Classification System			
Land Area* (% of total)	**USDA**	**FAO**	**Canada**	**Ecosystem Type**
1.2	Histosol – dark color, organic soils	Histosol	Organic	Boreal Forest, Tundra
23.4	Aridisol – light color, arid climate, with calcium or gypsum deposits	Solonetz Gypsisol Durisol Calcisol	Brunisol Regosol	Dessert, Grassland, Shrubland, Chaparral, Woodland
2.4	Vertisol – 2:1 clays with cracking	Vertisol Fluvisol	Solonetz	Grassland, Woodland, Broad-leaf Evergreen Forest
11.0	Entisol – un-developed, buried or ancient soils	Regosol Leptosol Cambisol	Brunisol Regosol	Dry Conifer Forest, Boreal Forest, Alpine, Tundra
16.0	Inceptisol – some development, B	Gleysol	Brunisol Gleysol	Dry Conifer Forest, Boreal Forest
13.5	Alfisol – illuvial zone of clay with high base saturation	Luvisol Planosol Albeluvisol	Luvisol Gleysol	Deciduous Forest, Mixed Deciduous Forest, Broad-leaf Evergreen Forest
4.1	Mollisol – dark soils with organic matter to >24 cm	Chernozem Kastanozem Phaeozem	Chernozem	Grassland, Woodland
3.6	Spodosol – illuvial zone of iron oxides and organic matter	Podzol	Podzol	Deciduous Forest, Mixed Deciduous Forest, Temperate Rain Forest
6.0	Gelisol – perma-frost < 100 cm	Cryosol	Cryosol Gleysol	Alpine, Tundra
8.3	Ultisol – illuvial zone of clay with low base saturation	Umbrisol	Podzol Luvisol	Deciduous Forest, Mixed Deciduous Forest, Temperate Rain Forest,

				Broad-leaf Evergreen Forest
1.8	Andisol – volcanic parent material	Andosol	No equivalent	Temperate Rain Forest, Broad-leaf Evergreen Forest
8.7	Oxisol – red soils, highly leached	Ferrasol Alisol Nitisol Acrisol Lixisol	No equivalent	Tropical Forest

* Land cover (%) is based on the USDA system of soil classification

Table 1: Percent land cover per soil order for three different soil classification systems (USDA-*Soil Taxonomy*, FAO and Canadian system) and associated ecosystem types (Adapted from Fisher and Binkley, 2000).

Boreal forests receive on average 500mm precipitation per annum; evapotranspiration demands are generally very low. There is little runoff, and most of the precipitation percolates through the soil profile, translocating finer material to depth. In Spodosols both organic matter and redoxomorphic materials are deposited at depth. In Alfisols and Ultisols the translocation of material concerns mainly clay, with or without high base saturation, respectively.

2.1.2. Sub-Alpine Forest Systems

Sub-alpine forests are reminiscent of boreal forests. They can be found in all mountainous regions of the world. In the (sub)polar areas they are located at comparatively lower altitudes than in the mid-latitudes. The trees that make up this ecosystem are generally evergreen needle-leaf species, though they may also include deciduous needle-leaves as well as species normally found in the boreal zone. The soils below such forests are generally rocky and weakly developed, with minor signs of horizon development; they are predominantly glacial or colluvial in origin. The main soils in this environment are: Inceptisols, Spodosols, Alfisols and Ultisols (Table 1).

2.1.3. Lowland Conifer Forest Systems

This ecosystem type is dominated by evergreen needle-leaf species, associated with a low percentage of deciduous needle-leaves. It occurs in the lowlands of all mountainous areas of the world. The main genera of tree species are similar to the boreal and sub-alpine types, but they also include *Quercus*, *Cedrus* and *Pseudotsuga*. As is the case under sub-alpine forests, the soils are mostly developed from glacial and colluvial material, and they usually classify as Inceptisols, Spodosols, Alfisols and Ultisols.

In the Pacific northwest of North America, inland forests may be very dry (less than 200mm annual precipitation) and then develop a grassy understory which leads to the development of very dark surface horizons characteristic for Mollisols.

2.1.4. Mixed and Pure Deciduous Forest Systems

Conifer forests gradually merge into deciduous forests when either the elevation (in mountainous areas) or the latitude (elsewhere across the globe) decreases. The eastern part of North America is a good example of such a transition with decreasing latitude. Between 40° and 50° North, the forest canopy is characterized by mixed broad-leaf deciduous species and conifers (>20% conifer), while south of 40°N the canopy is almost exclusively composed of pure broad-leaf deciduous trees in the lowland areas. The main genera of broad-leaf deciduous species include *Acer*, *Betula*, *Fagus*, *Quercus*, *Fraxinus*, *Prunus* and *Alnus*. The predominant soils associated with this ecosystem are: Inceptisols, Mollisols, Spodosols, Ultisols and Alfisols (Table 1).

A noted exception to the concept described above is the formation of some deciduous forests in southern Argentina and southern Chile on Andisols developed from volcanic substrata. This parent material is often very deficient in phosphorus because of the high sorption capacity of volcanic glass for phosphorus. Local deciduous species are overcoming this P deficiency through a rapid recycling of soil phosphorus and its maintenance under an available form in the system.

Precipitation in deciduous forests can be quite high and remains uniform throughout the year. Summers are hot and humid, and winters are cold with heavy snow fall. Snowmelt and abundant rainfall enhances soil leaching and leads to the formation of Spodosols in acid environments, and to Ultisols and Alfisols in neutral to slightly acid environments. Because of their rather good fertility and structural properties, many soils in this ecosystem have been converted worldwide into agriculture. However, these soil types may locally include undesirable characteristics such as a cemented layer at depth or face a rapid loss of nutrients after cultivation.

2.1.5. Broad-leaf Evergreen Forest Systems

Broadleaf evergreen forests are locally important in parts of Japan, China, Australia and the US. They include *Eucalyptus*, *Quercus*, *Magnolia* and *Ilex* as main genera. As soils of this ecosystem type are generally more fertile than those of the surrounding areas, many eucalyptus forests in southeastern Australia were cleared during early settlements. Those soils can nevertheless become very dry (mainly because of the very high water demands of the trees) and, thus, become less productive over time. The main soil types associated with this ecosystem are: Alfisols and Ultisols, with a limited amount of Vertisols (Table 1).

2.1.6. Temperate Rainforest Systems

The west coast of North America is an area of high annual precipitation and mild temperatures, leading to the development of extensive evergreen needle-leaf rainforests with trees of more than 1000 years in age. The main genera are: *Thuja*, *Tsuga*, and *Pseudotsuga* in the north, and *Sequoia* and *Sequoiadendron* in the south.

In the southern hemisphere, temperate rainforests occur in Chile, Argentina, New Zealand and Australia. They are dominated by broad-leaf evergreen species of the genera *Nothofagus* and *Eucalyptus*. The dominant soils in these regions are: Alfisols, Ultisols and Inceptisols (Table 1).

2.2. Range Ecosystems

Range ecosystems are those that can support livestock and include both grassland and semi-desert woodlands. They occupy 51% of the earth's surface and 400 M ha in the US alone (Heady and Child, 1994). Range is a bit of a misnomer in this case because, strictly speaking, it implies management. In the next sections the plant cover and soils associated with the unmanaged ecosystems will be discussed.

2.2.1. Grassland Systems

Natural temperate grasslands exist in many parts of the world including the prairies of North America, the pampas of South America and the steppes of central Asia. These areas have hot summers, cold winters and low annual precipitation. They are dominated by perennial and annual grasses with extremely deep rooting systems that can tap into a deep water table during periods of summer drought. The rooting system of these plant communities contributes to the accumulation of a large amount of soil organic matter (SOM) and to the development of Mollisols, which constitute the main soil order of this ecosystem type (Table 1). Mollisols are black to dark brown soils with an obvious SOM accumulation in the surface layers, which makes them highly fertile. These soils are therefore often converted into large-scale agricultural areas with a high potential for cereal production or grazing.

2.2.2. Semi-Desert Woodland Systems

Semi-desert woodlands occur in the transition zone between the lowland conifer forest and grasslands or deserts. They are found all over the world. Xerophyllus species of conifer and broad-leaf evergreen trees of the genera *Quercus*, *Pinus*, *Juniperus*, and *Cerocarpus* dominate this ecosystem. They form mostly open forests with a grass understory, and this makes them ideal for grazing; most natural grasses have, however, been replaced by high volume annual grasses that are actively managed for livestock grazing. The dominant soil types are Mollisols, Inceptisols and Alfisols.

In the drier areas with relatively low precipitation and high evapotranspiration, the soil cover becomes less dense and is then mainly composed of xerophytic and deep rooting species. The dominant soil orders are Aridisols (in the driest areas), Inceptisols and Mollisols, with local patches of Alfisols (Table 1). In areas where the evapotranspiration potential exceeds annual rainfall as is the case in arid and hyper-arid zones (see: *Soils of Arid and Semi-Arid Areas*)**,** accumulations of salts, such as calcium, magnesium and sodium, may be prevalent.

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Biographical Sketch

M. Derek MacKenzie currently has a joint position as a Research Associate with the University of Alberta, in Edmonton and the University of California, in Riverside. He holds a B.Sc. in Physical Geography (1996), an M.Sc. in Physical Geography (1999) and a Ph.D. in Forestry (2004).

He has been pursuing graduate and post-doc studies for the last ten years in forest ecology and soils, and is currently seeking a faculty position with the Department of Renewable Resources at the University of Alberta. His research to date has focused on soil fertility in silviculture, natural disturbance (mainly fire), soil nitrogen transformations and plant community dynamics. In the future, he intends to examine different fractions of the carbon pool in forest soils, nitrogen availability in ecosystems dominated by different disturbance types and the economic potential to convert waste products such as biosolids into soil amendment products. All graduate student inquiries are encouraged.