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The History and Philosophy of Silviculture

Introduction

There are three parts to this chapter that describe silviculture as an evolving sub-discipline of applied ecology and its contribution to the well-being of society. The three parts include: (1) history, (2) philosophy, and (3) the literature and sub-disciplines of research relevant to current resource issues. The first part summarizes the origins and evolution of silviculture as a part of an ancient indigenous agricultural practice used by many peoples for production of food and shelter in combination. Silviculture was originally the forest part of swidden systems where forest patches were cleared for agricultural use for a period of years to provide food, before being left fallow and allowed to grow back to trees, and secondary forest that was harvested for timber, fiber, fruits, and medicinals. With the development of permanent agricultural and pastoral fields, silvicultural systems followed suit and forests and woodlands were managed separately from agriculture. There is then a discussion of silviculture's systematic evolution as a science in response to the degeneration and degradation of forest lands associated with the industrialization of economies in central Europe, then in North America, and subsequently elsewhere. A synopsis of silviculture's roots to reforestation and restoration in Germany, British India, and the United States follows. Finally there is a discussion of silviculture as it is practiced at present.

The second part comprises a discussion of the different philosophical approaches of silviculture. It first describes silviculture as an ecological technology. It shows that silviculture has a relationship with the social sciences and contributes to the management discipline of forests and woodlands. It describes how silviculture should be used as part of a long-term economic view for the betterment and sustainability of social values obtained from trees. It then discusses the variations in the intensity of practice in relation to circumstance. This part of the chapter concludes with a philosophical perspective of how silviculture should be applied to forests.

The third part comprises a synthesis of the silvicultural literature as a body of scientific knowledge. It uses

the literature to discuss modern day developments in silvicultural research as a sub-discipline of ecology, and then relates this body of research to today's resource issues.

Silviculture, its Origin and Development as an Applied Ecology

Silviculture is the oldest application of the science of ecology and is a field that was recognized before the term *ecology* was coined (Toumey, 1928). Many of the ways of developing forest stands rest heavily on cuttings that alter or modify the stand environment in order to regulate the growth of remaining vegetation. The reliance on ecological knowledge in silviculture is therefore all the better for not simply resting on philosophical principle. The economic returns from forestry are usually not great enough to protect forests from all the shifts and changes of nature. Therefore, silviculture is usually far more the imitation of the natural processes of forest growth and development, than of completely substituting a new stand for them.

Silviculture as a Preindustrial Construct

Silviculture, as a practice of cultivating and growing vegetation within forests and woodlands, has a much longer history of development and learning over thousands of years than its more recent transformation into a science. The most ancient form of silviculture was, and still is in the more remote forests of the world, a part of what is called **swidden agriculture**. It is a temporary intensive cultivation of a patch of cleared forest for food crops, which is then either abruptly or more slowly relinquished back to forest through succession. It is widely practiced in the more remote forest regions of the world and can be a very sustainable form of agri-silviculture.

Such systems have different lengths of successional development before returning back for cultivation. They are largely dependent upon the soil's inherent capacity to become fertile again. After cultivation of arable crops is stopped, many swidden systems incorporate tree

plantings and intentional natural regeneration methods that are then followed up with the tending and harvesting of tree crops. Trees that provide fruits, medicinals, and building materials can be harvested with the growth of the new forest into the future until the next cycle of forest clearance and cultivation (Box 1.1). People who practiced swidden agriculture knew exactly where, when, and what tree species to cultivate within a swidden. Many swidden systems can be regarded as very sophisticated, much more so than the credit given them by western science and the modern day practice of agriculture and forestry.

In particular regions of the world, agriculture developed into a permanent practice of cultivation allowing

people to settle. These regions can be considered the birth places of modern agriculture and of the origins of civilization (Fig. 1.1). In addition to permanent agriculture came silvicultural practice to produce the goods and services desired from these agricultural systems. Such systems resulted in complex land-use practices with a mixture of intensive to non-intensive treatments reflecting the inherent productivity gradient across a landscape (Box 1.2).

Across most of Europe and the British Isles up to the 18th century, the monarchy, the church, or the nobility held the land rights to hunt and to extract large timbers for shipbuilding and construction. Peasant and tenant

Box 1.1 Examples of preindustrial silviculture.

Swidden Cultivation System of the Yanomami in Brazil

The Yanomami Native Americans are one of the largest tribes in Latin America, straddling the borderlands of northern Brazil and southern Venezuela. The combined Yanomami territories of Brazil, comprising 23.7 million acres (9.6 million ha), and Venezuela, comprising 20.3 million acres (8.2 million ha), form the largest indigenous lands in the world (Chagnon and Gross, 1973). The lands are under threat from goldminers, cattle ranchers, and poor national government enforcement. The Yanomami live in relatively large communal houses called yanos. Men hunt and fish for game, providing about 10% of the food; women farm, providing about 80%. Only about 4 hours of work per day is necessary to maintain their way of life. Villages

periodically move within the territory about every 30 years to accommodate the shifting agricultural systems. Large gardens are cleared by the men from primary forest (old-growth) and crops (cassava, sweet potatoes, plantains, beans, corn, squash) are cultivated by the women for only 2–3 years because the soils are so infertile (Fig. 1). New gardens are then created in another patch of primary forest. Old gardens are used for hunting animals that like early successional habitat, harvesting insect grubs feeding upon young growth, and harvesting fruit, medicinals, and vines for cordage and basketry (Nilsson and Fearnside, 2011). It usually takes no longer than 2 hours walk to get to a garden from the village. Several gardens are worked at the same time. In other areas, the Yanomami have old groves of fruit



Box 1.1 Figure 1 An aerial view of swidden cultivation in the Amazon comprising a patchwork of current and abandoned fields. Source: R. Butler, 2008. Reproduced with permission from Rhett Butler/mongabay.com.

Box 1.1 (Continued)

trees planted and then protected from years ago. The total number of plant species used by the Yanomami is well over 500 and cater to every necessity of life ranging from tooth-picks, to foods, to medicines, to fish poisons. Hunting for different purposes is carefully zoned across the forest for different kinds of game and for hunting at different seasons and even times of day. Other zones are restricted as game preserves. All of this means there is an extensive trail network for the different hunting and gardening practices.

Cultivation Systems of Native Americans in Eastern North American Oak Forests

Indigenous peoples of North America strongly influenced the landscape vegetation of the eastern oak forests of the United States. They did this by cultivating crops. However they also manipulated tree density and species composition to increase mast and game populations, to encourage easy woodland travel, and to reduce pests and diseases. Eastern tribes cultivated maize, beans, squash, and tobacco, often on a large scale, and sited these clearings on fertile soils most suitable for agriculture, usually in large river flood plains. Early explorers reported extensive areas of cultivation. In 1616, Smith remarked that the Massachusetts coast “shewes you all along large cornfields” and “many lles all planted with corne” (Day, 1953). In New England, cultivation shifted after soil exhaustion and more forest had to be cleared for new fields. This kind of cultivation created a patchwork of successional ages and structures (Cronon, 1983). In addition to intensively managing agricultural fields, Native Americans managed forests to create open savannah woodlands with

grassy understories and widely spaced trees. These woodlands were primarily composed of fire-adapted, masting species such as oaks, chestnuts, and hickories. In 1525, Giovanni da Verrazzano traveled 15–18 miles inland from Narragansett Bay, Rhode Island and observed open plains, completely free of trees, extending miles, as well as woodlands that “might well be traversed by an army ever so numerous.” (Verrazzano, 1825 in Day, 1953 p. 334). Other early explorers echoed such reports and also noted the large and numerous fires, which were ignited annually or twice a year in the spring and fall. These fire-maintained savannahs had several purposes, chief among them being the provision of food. Frequent fires favored nut-producing hardwoods, such as oaks, particularly the sweet acorn-bearing white oaks, chestnuts, hickories, walnuts, and butternuts, and maintained them in open conditions, maximizing sun exposure and thus mast volumes. Nut collection was also facilitated by the open understory. The growth of fruit-bearing understory plants such as blueberries, raspberries, strawberries, and hazels was also encouraged. Not only did these savannahs feed humans directly but they also supported abundant game populations (Abrams and Nowacki, 2008). Denton (1670) reported “stately Oaks” with “broad-branched-tops” and “grass as high as a man’s middle, that serves for no other end except to maintain the Elk and Deer, ... then to be burnt every spring to make way for new” forage (Day, 1953). Just as frequent fires increased game populations, they reduced populations of pests such as rodents, ticks, and fleas (Williams, 2005). In fact, the Narragansetts listed the “destroying of vermin” as a reason for burning in their discussions with Roger Williams in 1643 (Day, 1953).

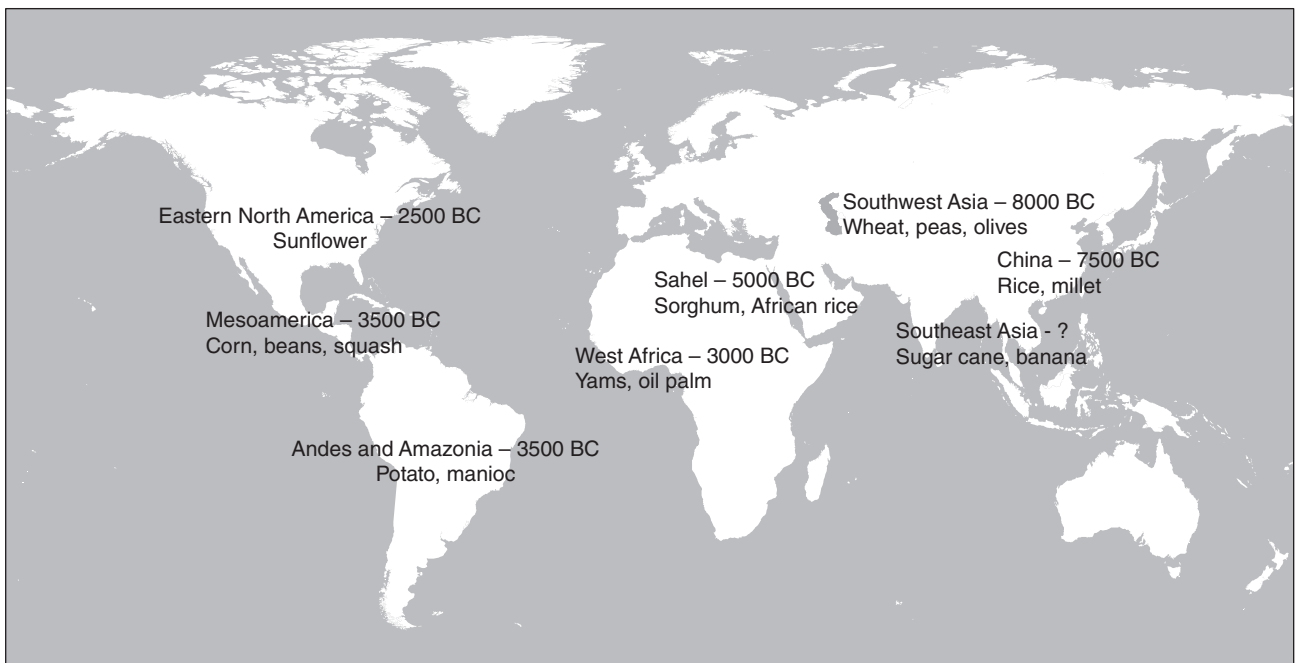


Figure 1.1 Early agricultural civilizations of the world and their main crops. *Source:* Adapted from mapsopensource.com under the terms of the Creative Commons Attribution Licence, CC-BY 3.

Box 1.2 Indigenous silvicultural systems of ancient civilizations.**Maya of the Yucatan, Mexico**

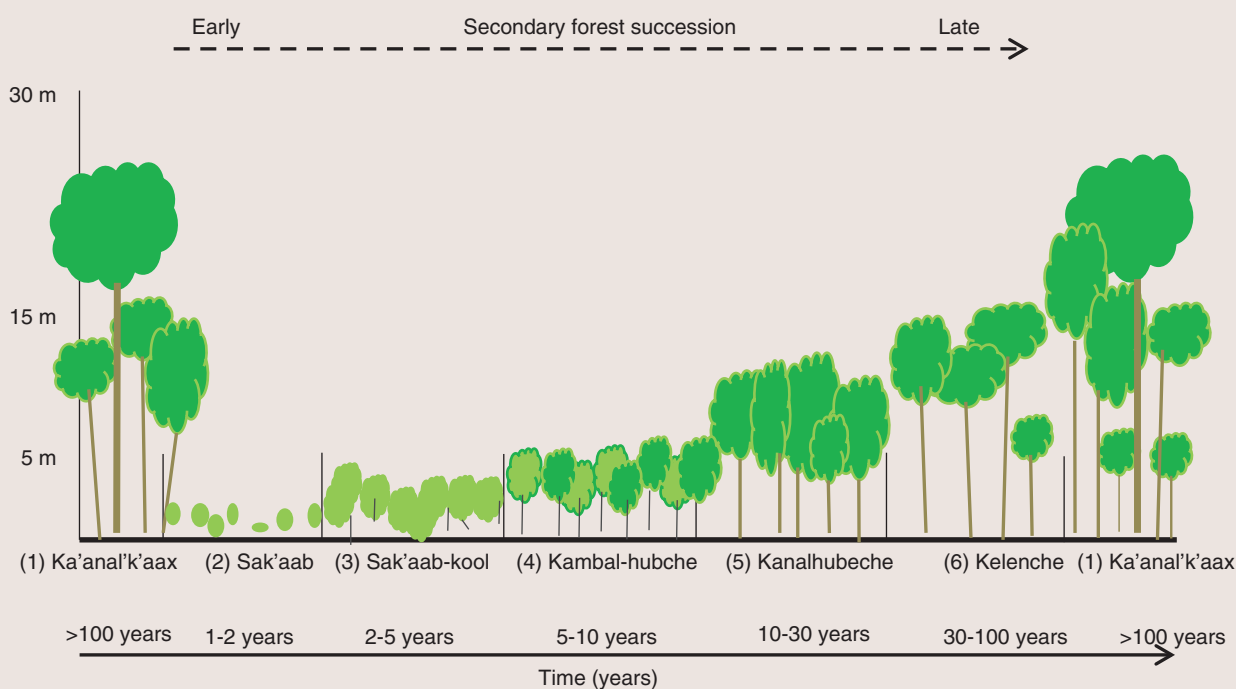
The Maya civilization of Mesoamerica can be defined by two periods: the pre-classic period (2000 BC – 250 AD) established the first complex cities and the cultivation of staple crops (maize, beans, squash, and chili peppers); and the classic period (250 AD – 1000 AD) which saw the rise of a large number of city states interconnected by trade highways. This period was the zenith of complex agricultural and silvicultural systems. Trees were incorporated into almost all components of an intensively managed landscape. Hydraulic systems were used to both drain and irrigate the staple crops of beans and maize. Swamps were drained and fields raised with trees planted along the bunds and the channels used for aquaculture. Upland slopes were terraced and irrigated for cultivation and shade trees used for stabilization and protection. Further away on poorer upland soils, the milpa swidden system (see Fig. 1) that is still used by the descendants of the Maya was widely practiced to cultivate crops (corn, beans, squash) for a short period of time. In preparation, second-growth pioneer species were slashed at about a meter high to open up the ground to sunlight. Annual crops were dibble planted for several years while the pioneers re-sprouted and were used as shade and fuelwood. Enrichment planting of cacao often follows annual crop cultivation using the shade of the second growth for

establishment. Most milpas had an arboreal shelterbelt that was protected around the margin as a conservation strip. Around the households forest gardens cultivated a wide variety of fruit trees (e.g., *Brosimum alicastrum*, *Chrysophyllum cainito*, *Manilkara zapota*, *Spondias* spp.) and medicinal herbs and spices. These tree gardens were called Pet Kot. In addition, the Maya had sacred forests and groves around temples that were protected and where Maya harvested a variety of medical plants. Over one third of the flora have known medicinal value. The Maya civilization collapsed about 12,000 AD from unknown causes – possibly warfare, disease, or from land degradation and soil erosion or some combination. The second growth that has come back within the region is reflective of this historic land use dramatically enriched in species from purposeful Mayan silviculture.

For more information read: Gomez-Pompa, A. 1987. On Maya silviculture. *Mexican Studies*, 3(1): 1–17.

Sinhala of Northeastern Sri Lanka

Southern India has a very sophisticated history of forest and crop cultivation dating back to 2000 BC. The start of civilization in northeastern Sri Lanka dates back to about 500 BC with the arrival of the Sinhala people and the Prince of Vijaya from North India. Northeastern Sri Lanka has a monsoonal climate that comprises a long dry season and a



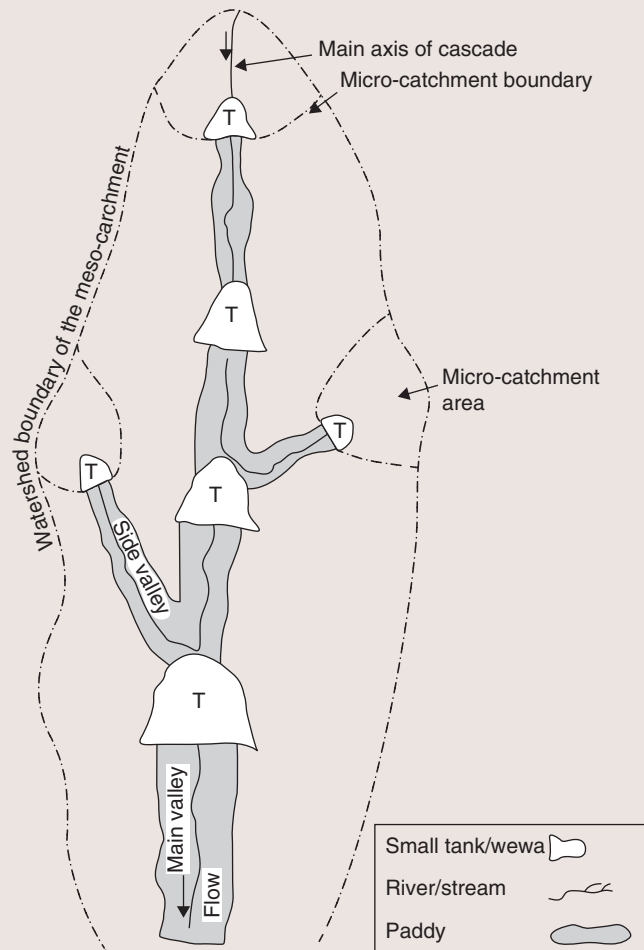
Box 1.2 Figure 1 A diagram depicting Maya swidden succession. Maya succession nomenclature are (1) Ka'an'al'k'aax: old tropical forest (30 or more years old); (2) Sak'aab (or Sak'ab): second year milpa; (3) Sak'aab-kool: Recently abandoned milpa; early succession; (4) Kambal-hubche': 5–10 years old succession; (5) Kanalhubeche': 10–30 years old succession; (6) Kelenche': 30–100 years old succession; (3-6) Hubche': secondary vegetation. *Source:* Adapted from Gomez-Pompa, 1987.

Box 1.2 (Continued)

shorter wet season. The people learned to manage water by a complex system of reservoirs (called tanks) that were arranged as a cascade that comprised an interconnected series of tanks that reused water for irrigation within a single watershed and that gradually increased in size progressing from the upper to the lower parts of the watershed (Figs. 2, 3). These systems developed over a 2000-year period culminating in about 30,000 tanks in a dry zone area of 15,500 mi² (40,000 km²). The undulating topography with its ancient impermeable metamorphic geology and relatively thin to bedrock soils that were weathered *in situ* make this landscape perfect for water capture and irrigation. The Tank Cascade System allowed two to three crops of rice to be cultivated per year in the lower lying land beneath each tank by a system of irrigation channels and fields. Some of the lower lying fields were purposely left for the birds to draw them away from those that were cultivated. The tanks themselves were lined with riparian forests and vegetation that served to protect the sides of the tank and to serve as a wind barrier. Potable drinking water was purified through a system of channels drawn from the tank separate from the irrigation

systems. These channels flowed into small wetlands in which the water was cleansed of sediments and pollutants. The villages and houses were organized immediately outside but adjacent to the floodplain. Individual households had kitchen gardens and patios surrounding the house where many of the perennial light-loving shrubs (banana, plantains, citrus) and herbs (curry plant, cumin, cardamom) could be cultivated. Surrounding the kitchen garden, tree gardens of a variety of shade-loving long-lived species (mango, coconut, jak fruit, tamarind, areca palm) were grown for fruit and timber. Upstream and at higher elevations of the catchment areas beyond the tree gardens, second-growth forests were managed through swidden cultivation (called Chena) for upland dry crops, firewood, and medicinals. Beyond these second-growth forests, in the most remote and highest parts of each watershed catchment, existed relatively undisturbed forests whose main purpose was to yield subsurface water flow into the dry season through deep infiltration. These areas were carefully controlled by the community and by the temple monks. Many of these forests were regarded as sacred and completely protected from use.

Box 1.2 Figure 2 An example of a tank cascade for a single watershed in northeast Sri Lanka. *Source:* Geekiyanage, 2013. Reproduced with permission of Elsevier.



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Box 1.2 (Continued)

Box 1.2 Figure 3 The ancient managed landscape of northeastern Sri Lanka. The tank cascade systems can be seen in the distance. Adjacent and downstream areas to the tanks are the cleared lands for paddy cultivation. The settlements with complex tree gardens are adjacent to the tanks on the upper ends along the margin in the middle of the picture. On higher ground is sacred forest associated with the temple that serves as watershed protection. *Source:* Mark S. Ashton.

farmers had grazing rights for livestock, rights to gather fuelwood and litter, and rights to some timber for building, but they were obliged to pay a fee for these rights. Similar land right arrangements between nobility and the peasants were present in northeast Asia (China, Korea, and Japan) during this time. Particularly innovative and forward-thinking nobles started the systematic and purposeful management of forests for timber on such lands as early as the 14th century in Germany (Nurenburg) and by the 16th century in Japan. Forests were divided into sections, with the ideas of sequentially harvesting for timber over time and purposeful regeneration. In the 17th century, the ideas of John Evelyn and Jean-Baptiste Colbert led to the first plantations in the British Isles and France respectively. Each of these men were sent by their respective governments to assess the depleted state of the forests in their countries.

Prior to the industrial revolution, one predominant form of silviculture and forest type was associated with permanent agriculture. These were coppice or sprout origin forests. Still throughout much of Africa, Asia, and

Central America, forests and woodlands are all managed based on sprout growth to produce fuelwood for cooking and heating, litter and mulch for agricultural fields, timbers for buildings, artisanal wickerwork and poles and posts for farm infrastructure (Box 1.3). It is amazing that in this modern age of technology, the majority of the world's population still relies on fuelwood for energy and forest leaf litter as a source of soil fertilizer.

Silviculture as a Western Construct

It was with the birth of the industrial revolution, particularly in central Europe, that forest lands were decimated for timbers to support underground mining for coal, iron ore, and salt, and for fuelwood. This was to create charcoal to power the furnaces for the smelting of iron ore, evaporating water to extract salt, and to provide heat and cooking fuel for a burgeoning and urbanizing populace that had come for work in the cities. Whole areas of central Europe were converted from subsistence agricultural and coppice woodland systems to waste-

Box 1.3 A coppice and wood pasture system in medieval Europe.

Ancient wood pastures, often identified today by the presence of old pollarded “veteran” trees or land records, were common throughout Europe since at least the Neolithic Age. In England, documentation dates back 1200 years (Rackham, 1996). While the practice was largely abandoned several centuries ago, wood pastures do persist. While most were converted to other land uses, some have “infilled” with younger cohorts of trees and are now barely discernible, while others are preserved as living museums, and fewer still are actively managed as wood pasture.

A rich literature has accumulated, particularly in the British Isles, on the social and ecological history of these wood pastures (Fig. 1) and their role in a complex landscape of commons, forests, parks, and woodlands. The grazing of animals and growing of trees on the same land has been sustainably practiced for centuries (Rackham, 1998). The nuances of these pasture systems vary by region and make use of different species and techniques to meet location specific needs. Two broad categories of wood pastures can be distinguished: (1) coppice meadows and (2) pollard meadows (Hæggström, 1998). Coppice meadows are comprised of multi-stemmed trees that are cut at intervals of some decades to produce stakes, poles, firewood, and wood for carpentry. Hay is produced between the coppice trees. Livestock are often excluded from these meadows at least for a period of several years to give recently cut trees time to grow above the browse line. Pollard meadows are used to produce fodder

from tree cuttings while livestock are allowed to graze between the trees. These trees are cut at 3–5 ft (1–1.5 m) to keep them safe from browse. Cuttings are often dried and stored as winter fodder or used directly. Shredding is an alternative pollarding technique where only the lateral branches are cut and the top of the tree left intact. Differences in pollarding technique arise from variations in species autecology and climate.

A case study by Bargioni and Sulli (1998) on the Valdagno farm on the eastern slopes of the Lessini Mountains, Italy provides an illustrative example of pollard meadow management. The local climate exhibits long, cold winters with short, hot summers and an annual precipitation of 58 in (1489 mm). The farm breeds cows and at any given time has 4–5 milking cows, 2–3 sheep, 25–30 chickens, and one pig. The 10–12 acres (4–5 ha) is 47% grassland, 29% wooded pasture, and 10% coppice woods with the remaining 14% split between high forest and farm infrastructure. The Valdagno farm faces constraints on its productivity. The 4–5-ha farm encompasses only 2 tillable hectares, which significantly constrains total productivity. To help overcome this limitation, vertical space is cunningly utilized to expand animal husbandry.

Between May and October, cows are grazed in the wooded pastures and excluded from the winter hay-producing meadows except for the time following the second mowing. The animals are sustained through the long winters with a mixture of meadow hay and tree fodder. Two kinds of fodder



Box 1.3 Figure 1 An ancient sweet chestnut (*Catanea sativa*) wood pasture in Monmouthshire, Wales. Source: A. Miles, 2012. Reproduced with permission from A. Miles.

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Box 1.3 (Continued)

are produced on the farm. *Broco* is produced by shredding leaves directly from the tree for immediate use, while *frascari*, faggots of branches and leaves, are collected and preserved for winter nourishment. Ash (*Fraxinus* sp.) is the most important species for fodder production, while alder (*Alnus* sp.), poplar (*Populus* sp.), and hazel (*Corylus* sp.) are commonly used to produce *broco*. Beech (*Fagus* sp.) is a common spring fodder as its shoots appear before grass emerges from under the forest cover.

Pollarding commences when trees are between 7 and 12 in (18–30 cm) in diameter and are 7–8 years old. At this time, the leader is cut causing the stem to bifurcate and

all branches along the stem are cut at 6–8 in (15–20 cm) from the main stem leaving stubs. These stubs will produce the *frascari* and can be used as ladder rungs for the farmer to climb the tree in the future. Each year, *broco* is produced from the top crown while every third year the stems, which are 1.5 m long at this point, are cut to produce *frascari* bundles in late August. Trees are cut and replaced when their tops stop producing leaves, usually at a diameter of 10–12 in (25–30 cm). These pollarding techniques have enabled the Valdagno farm to take advantage of vertical space and sustain itself despite a shortage of tillable land.

lands in order to supply the wood necessary for this development. As a result in the state of Hesse, Germany, George Ludwig Hartig envisioned the first school of forestry for reforestation in 1787. Later, Heinrich Cotta, who has been attributed the name “pioneer of forestry”, started a forestry school in 1811, in the town of Tharandt, near Dresden, Saxony. His school and his teaching became the foundation for German forestry and its later

influence around the world. The notion of teaching forestry and the idea of forestry schools spread in the late 18th century to Russia, Austria, Sweden and France. Spain opened its first Forest Engineering School in 1844 in Madrid, and the British government commissioned Sir Dietrich Brandis, a student of Cotta, to start the Indian Forest Service and a School of Forestry at Dehra Dun (Box 1.4).

Box 1.4 The development of the Indian Forest Service and Sir Dietrich Brandis.

Sir Dietrich Brandis was born in Germany where he studied botany at Copenhagen, Göttingen, Nancy, and Bonn (Fig. 1). At the behest of Lord Dalhousie, Governor of British India, he was asked to take on supervision of the famous native teak forests of Burma in 1856 (Milward, 1947, Underwood, 2013). He developed the “taungya system” whereby villagers were allowed to cultivate vegetables in between planted trees and in return they weeded and protected the new plantings (Fisher, 1910). This has now been repeated worldwide and is an agroforestry practice that can involve communities in tree planting. In 1864 he became the first Inspector General of the Indian Forest Service. He founded the Imperial Forest School at Dehra Dun in 1878 to formally educate the local peoples in scientific forestry (Fisher, 1904). He wrote a treatise on Forestry in British India and the book “Indian Trees” and documented and described sacred groves throughout India. He was among the first to acknowledge the relationship between forest protection and involving local peoples. For his service to the British Empire he was knighted and retired back to Germany where he met future German foresters as well as Gifford Pinchot and Henry Graves. Pinchot relied on Brandis for advice in setting up the nascent US Forest Service. He died at the age of 83 in 1907. The model for modern forest management in the United

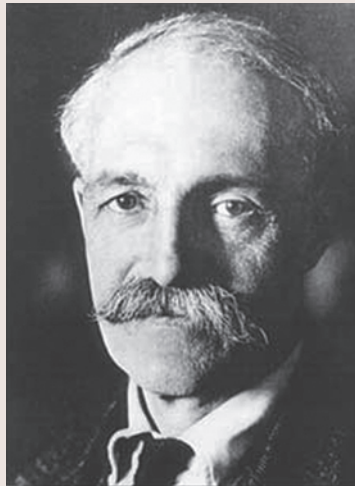
States, Britain, and Australia lies in the practices of the Indian Forest Service (IFS) that Brandis started (Pyne, 1997; Oosthoek, 2007).



Box 1.4 Figure 1 Sir Dietrich Brandis. Source: Forest Research Institute, Dehra Dun, India.

Box 1.5 A brief biography of Gifford Pinchot.

Gifford Pinchot was born in 1865 and grew up in Simsbury, Connecticut (Fig. 1). He attended Yale College. After graduating from Yale he studied forestry at the French National School of Forestry in Nancy. Upon his return in 1892 he was hired by George Vanderbilt, a wealthy railroad tycoon, to manage the Biltmore Forest Estate outside of Asheville, North Carolina. This was under the suggestion of the



Box 1.5 Figure 1 Gifford Pinchot. Source: US Forest Service.

renowned landscape designer, Frederick Law Olmstead (Miller, 2001). He was succeeded by Carl A. Schenk, a German forester, who set up the first School of Forestry at Biltmore in 1898, a few weeks prior to when Bernard Fernow, another German forester, started the New York State College of Forestry at Cornell University. Gifford continued on to succeed Fernow as the Chief of the Division of Forestry that same year, 1898. In 1900 he and his father, James, endowed Yale to create and start the first postgraduate program in forestry at what was then called the Yale Forest School and is now the Yale School of Forestry and Environmental Studies (Miller, 2001). He seconded two US forestry division personnel to be its first Dean, Henry Graves, and faculty member, James W. Toumey. Toumey went on to become a founding member of the Ecological Society of America and wrote the first forest ecology text for the country (Pinchot, 1998). In 1905, Pinchot became the first Chief of the newly made US Forest Service at the behest of then President Theodore Roosevelt. Pinchot is largely responsible for developing the administrative foundation of the Forest Service and the creation of the National Forest System which now comprises the majority of public lands in the US (Meyer, 1997; Miller, 2001). After leaving the Forest Service he went on to become a two-time governor for the state of Pennsylvania. He died in 1946.

By the end of the 19th century the newfound profession of forestry was ripe for development in North America. Gifford Pinchot (Box 1.5) had gained his forestry training in Germany and France. Several German foresters, upon invitation, had emigrated to the USA to introduce forestry. Two such German foresters, Carl Schenck and Bernard Fernow, respectively, started the Biltmore Forest School in Asheville North Carolina, and the New York State College of Forestry at Cornell University in 1898.

Silviculture as a Current Practice

Current silviculture is a much more complex and varied practice than at any stage in its development history. In the more remote forests of tropical Africa and the Amazon, people still practice the silviculture associated with swidden systems. In many populated rural regions of the tropics, coppice systems, once widespread in Europe and northeast Asia, still predominate. Much of the developed world now has intensive plantation systems for wood production, and considerable second-growth forest on more marginal sites that have returned after agricultural abandonment. These forests are managed for multiple benefits often using complex natural regeneration methods.

Silviculture and its association with long-term investment for future products and services desired by the landowner and by society must have social stability. This means that stability and clear recognitions of land tenure, environmental laws, and strong and diverse markets must exist; only under these conditions can silviculture flourish. Without this security it is unlikely to be practiced with any surety or investment of purpose because of a reluctance to invest in the forest for the future (see Fig. 1.2). The most sophisticated silvicultural practices are at both ends of the development continuum. On the least developed end, people can practice silviculture where their land tenures and ways of life, though not necessarily officially codified, have been untouched by the process of development. On the most developed end of the continuum, silviculture can be practiced where economies have developed to create strong values for both services and products from the forest, with healthy and diverse markets, strong enforceable regulations in land use, and formal rights to land tenure. The most difficult place along the development continuum is in the middle, where countries or regions are experiencing social transition like colonization, economic development, poverty alleviation, and political democratization. In these cases, silviculture can be practiced but with a

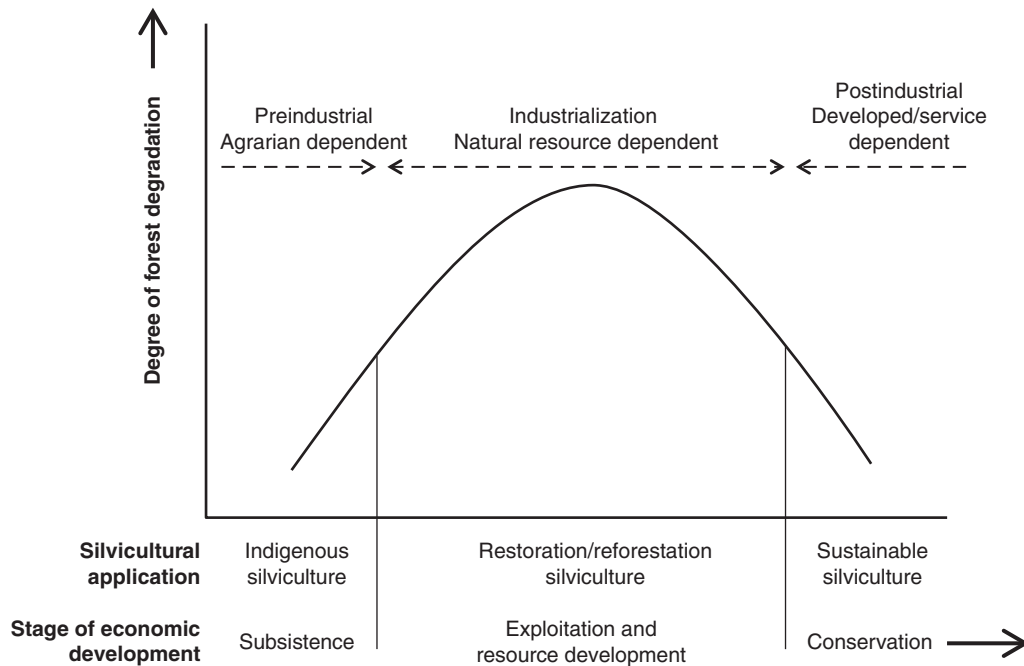


Figure 1.2 Economic and social development process leading to a developed economy and the forms of silviculture practiced.
Source: Adapted from Panayotou and Ashton, 1992.

tendency toward risk-averse investment in time and labor and with a focus on the short term.

The Philosophies of Silviculture as a Practice

Ecological Technology

The necessity that nature should be understood and emulated does not mean that silviculture should slavishly follow either the reality of natural processes or abstract theories about them. Most forests live longer than people. It is difficult to recognize that the natural disturbances that renew forests, often after intervals of centuries, are usually big, such as fires, windstorms, and insect outbreaks (Oliver, 1981; Kimmins, 1987; Oliver and Larson, 1996). Some forests are slowly and continuously renewed by minor disturbances, but these are far from being the norm. The various patterns in the development of forest vegetation over time and after disturbance are discussed in Chapter 4 on stand dynamics.

The web of life is so complicated that it is easy to argue that humans should do nothing to the forest for fear of doing something wrong. However, because of the exploitation of so much of the world's natural resources, humans must develop solutions to counteract the destruction of these natural resources. Tightly controlled **forest research experiments** are the standard for creating new knowledge

in the forestry field, but they are also very expensive. Thus, society requires practitioners of forest science to act without full knowledge. The best that can be done is to proceed by **adaptive management**, in which action can be taken on the most complete knowledge available. This approach has become quite useful. The three steps include:

- 1) **test assumptions:** use the current knowledge regarding the specific site; determine and collect monitoring data to determine if the assumptions are correct;
- 2) **adaptation:** change assumptions if new information has been found from the monitoring and project experience;
- 3) **documentation:** describe the planning and implementation for the specific site, and maintain records of the results.

Silviculture is conducted on the basis of ecological principles. The goods and benefits that flow from forests with proper, long-term management depend on living processes and are thus renewable to the extent that basic productive site factors are maintained and they can even be increased if these factors are permanently improved.

The wood produced by forests is the most important structural substance in human use. Unlike mineral or agricultural materials, its production requires much less energy and does little that would damage or pollute. In fact, the growing of wood increases the stock of resources even as it cleans both air and water. If forest

vegetation were more efficient in yielding human food and in concentrating sources of fuel, the future of the world ecosystem would be much brighter for the human race. It is therefore ecologically ignorant to assume that “saving forests” by substituting wood with substances produced with fossil fuel from mineral resources benefits any human-dominated ecosystem.

Economic and other social factors also affect the silvicultural policy of any given area. The simple objective is to operate so that the value of benefits derived from a forest should exceed the value of efforts expended. The most profitable forest type is not necessarily the one with the greatest potential growth or the one that can be used or harvested at the lowest cost. One must also consider the silvicultural costs of growing the crop or maintaining the stand and the prospective losses to insects and disease. In fact, it is usually the insects, fungi, and atmospheric agencies that ultimately show where silvicultural choices have run afoul of the laws of nature. The majority of the best choices are imitations of those natural communities.

It is also not entirely safe to accept the success of modern agriculture as justification for highly artificial kinds of silviculture. The environment of a cultivated field is much more thoroughly modified and readily controlled than that of a forest stand. Furthermore, forest crops must survive winter and summer over a long period of years, whereas most agricultural crops need survive only through a single growing season. One disastrous year harms the production of just one annual crop, but it can destroy the accumulated production of many years in a stand of trees. Neither economic nor ecological principles permit the forester to engage in the wholesale, routine use of pesticides and fertilizer on which intensive agriculture often rests. Any silvicultural application of refinements borrowed from agriculture must be combined with all the kinds of measures appropriate to the intensity of agriculture imitated. Forestry can profitably borrow much more than it ever has from the science on which modern agriculture is based, but there is little place for uncritical imitation. In addition, silviculture, even in the most intensively managed systems, needs to balance other multiple values that a forest must provide to society (clean drinking water, biodiversity conservation, recreation). Intensive agricultural systems often over-ride or ignore these values.

Some silvicultural measures depart drastically from natural precedent. These usually involve the introduction of exotic species or the creation of communities of native species unlike anything that might come into existence naturally. Departures of this sort cannot be thoughtlessly condemned but should be viewed with reservations until they have been tested over long periods. Otherwise, most of the choices can be thought of in terms of the degree to which natural processes are accepted or arrested, pursued or reversed.

Relationship with Forest Management and the Social Sciences

The decisions made in silvicultural practice are based as much on economic constraints and social objectives as on the natural factors that govern the forest. Recognition of societal objectives and limitations in any given case reduces the silvicultural alternatives that need be considered. Even though intelligent application of silviculture can make a very positive contribution to the management of forests, it is ultimately guided by strategies for solving problems associated with the social sciences. Matters that involve social and economic considerations are more broadly dealt within the interdisciplinary field of forest management. Forest management is concerned with planning, stakeholder analysis, economic analysis, conflict mediation, harvest scheduling, and the administrative aspects of the whole forest area (Davis and Johnson, 1987; Davis *et al.*, 2005; Bettinger *et al.*, 2009). The field of forest policy deals more indirectly with the effects of sociological and political phenomena, as well as economics, on the uses and governance of forests.

Silviculture and forest management are therefore interdependent, and not parallel approaches to the same problem. Because of its dominant concern for efficient application of the natural sciences, silviculture is as “practical” as forest management, with its tendency toward preoccupation with economic considerations. No management plan is better than the silviculture it stipulates, nor is any silvicultural treatment better than the usefulness of the results it produces for management.

Silviculture and the Long-Term Economic Viewpoint

It is said that money does not grow on trees, but it is the bane of forestry that the popular view is that trees exist but do not grow. The short-term outlook of conventional economic theory holds, in effect, that the silviculturist cannot win in growing a forest to reap the long-term benefits while certain naturalistic ecological theories warn against trying. The economic timescale of forestry is so vast and unique that to many investors it really is not profitable.

There is scarcely any part of forestry in which this issue must be faced more squarely than in silviculture, especially when investments in establishing or treating young stands are considered. It takes a certain kind of ambivalence to keep the economics of forestry in perspective. The decision to practice forestry is usually a matter of ethics, politics, and social concern for posterity. It is usually not one of conventional economics unless the product grown is highly valued and grown like an agricultural crop, which in reality is refined to a narrow set of sites and circumstances. In general it is the failure of economics and society to properly value the multiple service

values that forests provide that is the most detrimental to the sustainability and financial integrity of forest management in the long run. However, once the decision is made, it becomes logical to apply economic analysis to determine how best to execute the details. Any conflict is not between “silviculture” and “economics” but between the long-term economic viewpoint of forestry itself and customary short-term outlooks on financial matters. In the long run, short-sighted silviculture and poor environmental management become unprofitable. A forester should be extremely cautious of allowing economics to over-ride silvicultural principles that relate to the constraints of site and ecology. It will usually mean a much larger unrecognized financial disaster for the future with the depletion of the soil and forest resource and little ability to restore this resource for the benefit of society.

The holding of land for future production of wood, non-timber forest products, or other service benefits involves silviculture, even if nothing more is done than to let nature take its course and to harvest trees occasionally. Ownership incurs costs, and these constitute investments in the future even if nothing is invested in treatments to increase future production.

Foresters must ensure that money is spent very efficiently because funds are rarely sufficient for all the silvicultural work likely to be worthwhile. In any situation, it is logical to first apply those treatments that will yield the greatest increase in value of benefits per dollar of investment.

The first stage in the evolution of silvicultural practice is where continued production is actively sought but without any monetary investment (Barnes *et al.*, 1998). This “no-investment” silviculture places emphasis on treatments that can be accomplished by removing merchantable timber without significantly increasing harvesting costs. The removals cannot exceed the productive growth capacity of the forest. Some forests are sufficiently easy to control and give reasonably good results. This kind of silviculture is practiced over wide areas of temperate and boreal native forests and will likely continue for a long time. The idea of taking values out of the forest without really reinvesting anything in future production has a powerful appeal. It almost completely dominated American silviculture for many decades. There are still many instances in which it is consciously or unconsciously regarded as the only economical alternative. Tropical forest has been managed in this way under so-called selective logging but the harvest of timber has generally exceeded the productive growth capacity of the forest, leading eventually to a depletion of standing timber value and land conversion to agriculture.

Orderly policies of long-term investment in silviculture emerge if economic conditions and natural productivity are favorable, and provided that adequate management

experience has developed within the country or region. The kind and amount of investment are limited only by the economic law of diminishing returns. The actual amount expended on this type of silviculture varies widely but can be considerable. Currently, growing and cultivating forests in the developed world, such as in the US, are considered attractive, long-term investments that can provide multiple economic values. The “free” wood of cutting old growth is no longer considered acceptable. Old growth is better preserved for its intrinsic value and for the multiple service benefits that it provides to society.

Variations in Intensity of Practice

The amount of effort expended on the treatment and care of stands – that is, the intensity of silviculture – varies widely, depending chiefly on economic circumstances. The converse of **intensive silviculture** is **extensive silviculture**. The degree of intensity is usually estimated in terms of such things as the amount of money invested in cultural treatment, the frequency and severity of cuttings during the rotation, and the amount of monetary returns accorded to future returns relative to immediate returns. This leads to a debate on how forests should be managed. Some argue that intensive management only for timber on the appropriate sites will conserve most other forests as reserves (Binkley, 1997; Sedjo and Botkin, 1997). Others argue for a more extensive management regime in which timber is a more intimate component of other social and product values (Panayotou and Ashton, 1992; Oliver, 1999).

In reality the appropriate intensity of silviculture varies with accessibility, markets, site quality, management objective, and nature of ownership. The proper level often must be chosen specifically for each stand because the application of a single treatment intensity will not give optimum results throughout a given forest, unless it is exceedingly small and uniform. The more favorable the combined economic effect of all factors, the higher the appropriate level of intensity of silviculture. The place for extensive silviculture is found in remote areas on poor sites, or where owners are not willing or able to make more than minimum investments. It often plays a role where timber production is secondary to other purposes of forest management. Much of the world’s forests are now to be managed in this way since all of the best land has now been largely converted to permanent agriculture (Fig. 1.3; Table 1.1).

In the past, American forests have been exploited in such a manner that the poorest and most ill-treated stands are often found on the best sites and in the most accessible areas, such as those along permanent roads. This situation arises because the best and

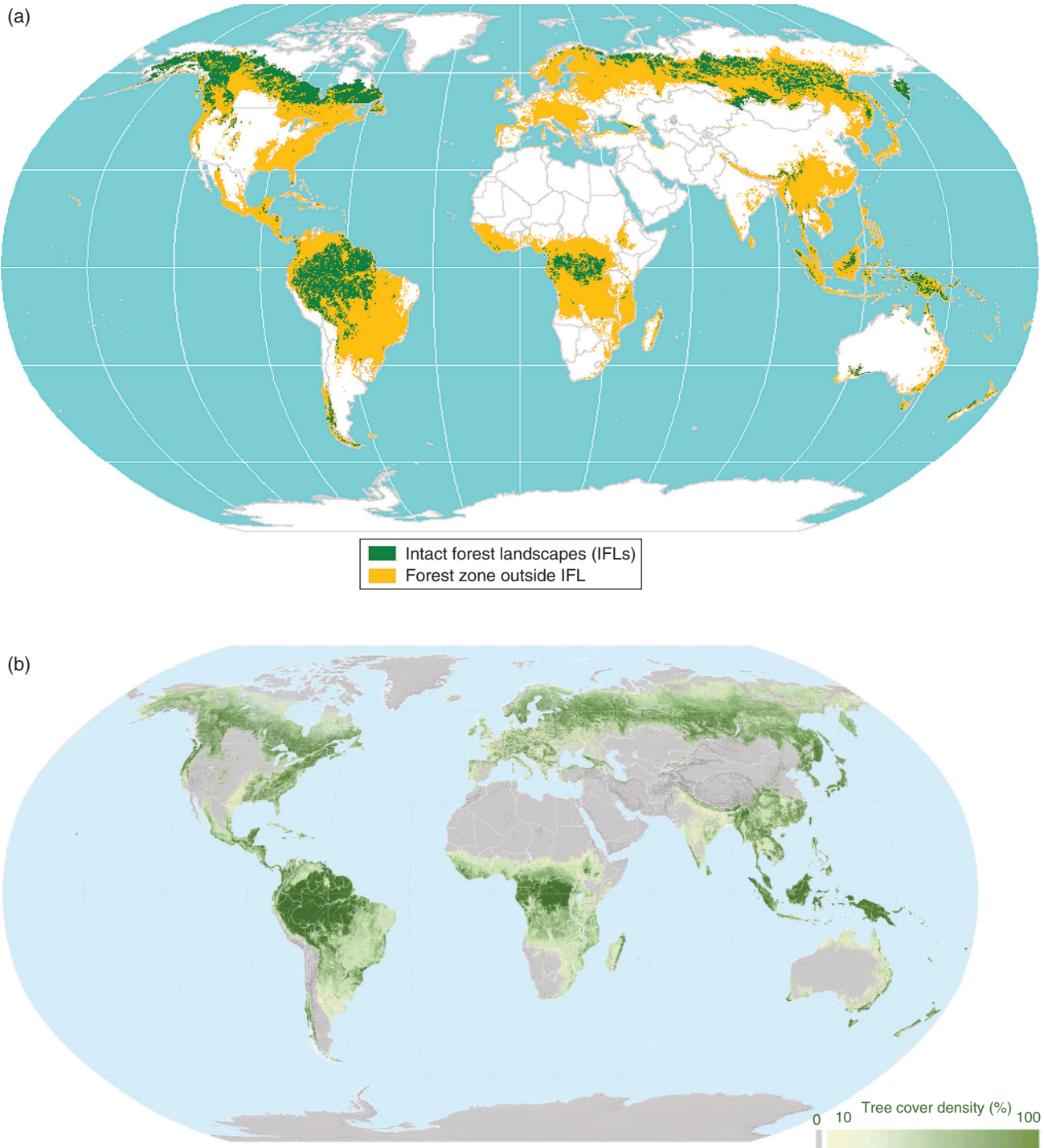


Figure 1.3 (a) A global depiction of the world's original forest (orange shading) and current undisturbed forests that have had little human impact (green shading). *Source:* Potapov, 2009. (b) A global depiction of the world's current forest cover (as measured by tree density) including undisturbed and second growth forests that have been logged or reverted back post land clearance for agriculture. *Source:* FAO, 2010. <http://www.fao.org/forestry/fra/80298/en/>

most conveniently located stands have been exploited first, most heavily, and most frequently. Ultimately, high-intensity silviculture should be practiced in many of these situations. Permanent roads and good markets

for a diversity of forest products do not automatically ensure optimum practice, but they are essential to generate income to profitably pay for the intensive management.

Table 1.1 Hectares¹ of land by geographic region of the world's forests. Forests are defined here as woodlands and closed canopied forests; secondary forests of post agricultural origin or that have been logged and undisturbed forests. Primary undisturbed forest areas and their percent of total forest area are provided in parentheses.

Region	Forest area (in 1000s of ha)	% Land area
Africa – TOTAL	635,412 (37,669)	21.4 (8.7)
North Africa (dry temperate woodland)	131,048 (13,919)	8.6 (11.9)
East and south Africa (dry tropical woodland)	226,534 (12,241)	27.8 (5.7)
West and central Africa (wet tropical forest) ³	277,829 (11,510)	44.1 (11.6)
Asia – TOTAL	571,577 (87,526)	18.5 (15.3)
Western and central Asia (dry temperate woodland)	43,588 (2,810)	4.0 (6.4)
East Asia (temperate broadleaf/coniferous forest)	244,682 (21,808)	21.3 (8.9)
South and southeast Asia (wet and dry tropical forest) ⁴	283,127 (62,908)	33.4 (22.2)
Europe – TOTAL (temperate broadleaf/coniferous)⁵	1,001,394 (263,948)	44.3 (26.8)
North America – TOTAL	705,849 (311,656)	32.9 (44.3)
Caribbean (wet and dry tropical forest)	5,974 (60)	26.1 (1.5)
Central America (wet and dry tropical forest)	22,411 (9,139)	43.9 (40.8)
North America (temperate broadleaf/coniferous) ⁶	677,464 (302,456)	32.7 (44.6)
South America – TOTAL (wet and dry tropical forest)⁷	831,540 (601,689)	47.7 (76.8)
Australasia/Oceania (temperate and tropical forest)	206,254 (35,275)	24.3 (17.2)
WORLD	3,952,025	30.3 (36.4)

1) 1 hectare = 2.471 acres

2) FAO statistics are fraught with potential error but it is the best estimate available. The statistics are dependent upon proper interpretation and supply of information by government officials of each country

3) Most of the primary forest that remains is in the central African country of the Democratic Republic of Congo

4) Most of the primary forest that remains is in Laos and Indonesian Borneo

5) By far the largest proportion of both forest and primary forest is in the Russian Republic

6) By far the largest proportion of primary forest is in the Canadian boreal

7) By far the largest proportion of primary forest is in the Amazon (Brazil, Peru)

Source: FAO², 2005. Reproduced with permission from FAO.

The intensity of timber-production silviculture depends in large measure on the nature and objectives of ownership. Variations in the species and sizes of trees desired may necessitate different procedures on adjoining lands that are fundamentally similar. Stability or longevity of ownership also controls intensity of silviculture. Large corporations and public agencies, which are relatively immortal, are in a far better position to practice intensive silviculture than individuals or small corporations of uncertain stability, though the idea of the immortal corporation has been turned on its head to some degree. Such corporation forestlands have now mostly been sold and are now managed by timber investment management organizations (TIMOs) for a variety of forest investors, such as pension fund investments that generally have a more short- to mid-term perspective.

The intensity of silviculture often depends on the extent to which the owner processes the wood grown in his forest. The more the raw material is processed to its final product, the greater is the ability to capture the “values added” by increases in intensity of practice in the woods. Prices for stumpage (that is, standing trees), do not necessarily reflect all the values that silviculture adds by improving the quality of wood. Therefore, the owner who cannot do more than sell stumpage may not be able to practice silviculture as intensively as owners who also harvest, manufacture, and sell the final product. This relationship is modified, however, by the ability and willingness to make long-term investments. For example, public forestry agencies usually confine their operations to producing stumpage. They may, however, practice intensive silviculture without concern for profit on their investments in order to discharge their long-term responsibilities to the national economy.

Philosophical Application of Silviculture

Given the perspectives in the preceding sections of this chapter, it is clear that the practice of silviculture does not consist of rigid adherence to any set of simple or detailed rules of procedure. For example, this book cannot be used as a manual of operations. Many of the cutting techniques are described in simplified form. Absent are many of the refinements and modifications necessary to accommodate the special circumstances and local variations encountered in practice. Each procedure described in the book is merely an illustration intended to demonstrate the application of a set of treatments designed to meet a uniform set of circumstances. Even though uniform stands have important advantages that make them worthy of creation, the stands encountered in the field will likely lack uniformity and thus call for variation in treatment.

Any consideration of silviculture covers a variety of treatments wider than is likely to be practiced in any locality at a particular time. In times when all the forests of a locality are immature, silvicultural practice may be limited to intermediate cuttings. Anything connected with regeneration may be limited to the reforestation of vacant areas. In localities where it is customary to secure regeneration by planting, the forester may regard methods of natural regeneration only as matters of intellectual exercise. Conversely, where planted stands are an anathema or owners are not ready to invest in them, only natural regeneration may seem important. At times and places where economic conditions support only the crudest kind of extensive silviculture, intensive treatments may seem visionary indeed.

This book contains a wide variation in intensity of silvicultural practice because an attempt is made to describe all known techniques that seem applicable in any significant forest area, especially of North America, within the near future. The procedures characteristic of the more intensive kinds of silviculture cannot be described as briefly as those associated with extensive silviculture, and so they get more attention. This does not mean that a management program must include a long series of different treatments to be silviculture. Some of the most astute silviculture is the kind conducted at low intensity in which much is accomplished with a limited amount of treatment.

The student forester interested in only one particular region should not limit their attention to the kind of silviculture currently practiced there. Foresters move, times change, and ideas from other places are often as fruitful as the indigenous ones. Scientific knowledge and technology also grow at an accelerating pace. The demands that society places on forests continually increase even as that same society places increasing restrictions on the ways of meeting the demands.

In many places, the impractical or impossible of 20 years ago is the routine – yet may prove to be the naive, illegal, or inadequate a decade in the future. Because of cutting and growth, the forests of a locality often change, and this calls forth new methods of treatment. This is especially true in North America, where the forests of localities tend to be in uniform condition, usually because in the past they were all cut over or cleared for agriculture in a short space of time. This book may seem to contain more techniques and ideas than a forester might need in a professional lifetime. Although some may go unused or quickly become outdated, there are really only enough to provide a start.

It is not enough for the forester to know what to do and how to do it. The important questions in silviculture begin with the word “why”. As in other applied sciences, action proceeds from the knowledge represented by the answer, or sometimes the merest inkling of an answer. The forester can find as many solutions in the woods as in the printed word. However, it is necessary to ask oneself the questions that generate the solutions and also to be ready to take the time to observe how the flora and fauna of the forest develop over time.

Silviculture as a Body of Knowledge

Silvicultural Literature

Modern silviculture literature was originally based on a series of treatises that were careful descriptive observations on the nature of light within a forest, the concept of shade tolerance, and on the growth of trees for the propagation of timber (Evelyn, 1664). Such books originally served as the core knowledge base for the early development of silviculture that Hartig (1808) and Cotta (1817) systematized into a discipline. All of this literature came before the German scientist Ernst Haeckel first defined the discipline of ecology in 1866 as “Ökologie”. Ecology (from Greek: οἶκος, “house”; -λογία, “study of”) is the study of interactions among organisms and their environment. As a science it now serves as the foundation for silvicultural application. But ultimately, silviculture goes beyond ecology as an applied discipline driven by social values, as James W. Toumey states so eloquently in his first forest ecology text for North America (Toumey, 1928).

Ralph Hawley wrote the first silviculture text for North America in 1921. It was directly modeled after the German texts and silvicultural systems of the day. This book is the direct lineage of Hawley’s 1921 book, that then evolved to Smith in 1954 (Hawley and Smith, 1954), and to us (Ashton and Kelty) in the 9th edition (Smith *et al.*, 1997). As the 10th edition, this book has evolved a decidedly more nuanced and more North American perspective on

silviculture based upon much more concrete ecological theory and a more sophisticated understanding of social and ecological circumstance. Each chapter of this book ends with a listing of the references cited in that chapter. These references are the most significant and relevant to the topics discussed. Other books that should be recognized as significant regional or resource issue contributions upon which this textbook is based are Kevin O'Hara's 2014 book on *Multiaged Silviculture* and the book by Tappeiner *et al.* (2015) on *Silviculture and Ecology of Western US Forests*, and the work by Savill and colleagues on plantation forestry (Savill *et al.*, 1997). Other texts that should be recognized in the English-speaking literature are works by Daniel *et al.* (1979), Mathews (1991), and Nyland (2016).

The use of computerized information-retrieval systems is growing rapidly. More detailed information and many additional literature references about silviculture in the United States can be obtained from consolidated publications. In *Regional Silviculture in the United States* (Barrett, 1994), various silviculture professors have written about their localities. Research scientists of the US Forest Service (Burns, 1983; Burns and Honkala, 1990) have summarized information about the ecological characteristics of tree species and about the silviculture of the important forest types. One advantage of these sources is that they will help locate many of the large numbers of publications issued by research and extension agencies of governments and universities.

The *Forestry Handbook* of the Society of American Foresters (Wenger, 1984) presents much information about silviculture and closely associated topics, as do similar compendia designed to help the practicing foresters of a locality. The written word can bring the forester ideas from distant places. Not all of the problems of growing loblolly or ponderosa pine have to be solved exclusively by study of these individual species. Much has also been learned about the silviculture of pines in Finland and Australia; knowing about teak in Asia may also help. In fact, new and useful insights often come faster from distant sources. Most of the world literature of forestry is in English, although English-speaking forestry students should be more ambitious about mastering other languages.

A forester should not read about silviculture just to absorb information. Reading should be a stimulus to thought, a way of synthesizing new patterns of understanding, and of both expanding and testing ideas. It can make comprehension of processes seen in the woods surer and more serviceable.

Current Research Issues

The research and topic areas that are at the forefront of silvicultural research are diverse. In the last 30 years the concept and paradigm of stand dynamics have advanced

silvicultural thought on how to treat mixed stands (Oliver and Larson, 1996) (see Chapter 3). This work continues to be pushed and elaborated upon by quantifying relationships that were only conceptual and qualitative such as our understandings of self-thinning and growth-and-yield (O'Hara and Gersonde, 2004). Work has moved forward especially on our understandings of how intimate mixtures of tree species grow in time and space (O'Hara, 2014).

The explosion of computer technology has provided a whole new field of quantifying space and time at stand and landscape scale models of treatments and management impacts (Bettinger and Sessions, 2003). In the last 20 years, a great deal of work has advanced modeling technology for silvicultural application (Pacala *et al.*, 1996; Vanclay and Skovsgaard, 1997).

A third topic is that our understanding of species and structural diversity of forests has also progressed. In the last 20 years, multiple ecological theories have been tested and explored around density dependence, intermediate disturbance, and niche hypotheses, for example. All are providing stronger theoretical arguments for applying silvicultural treatments judiciously based on ecology (Wright, 2002; Puettmann, Coates, and Messier; 2012; O'Hara, 2014) (see Chapters 5, 11, 13, and 28).

A fourth area has been the never-ending work that focuses on reforestation, planting technologies, and forest restoration, now centered particularly in the tropics (Ashton *et al.*, 2014; Griscom and Ashton, 2011) and within North America, particularly in the inland west (Fule *et al.*, 2001; Baker, Veblen, and Sherriff, 2007; Stanturf, Palik, and Dumroese, 2014). This is an old theme that continues to advance given its continuing dominance as an ecological and social issue around the world (see Chapters 16 and 25).

Fifth, great strides have been made in understanding the constraints and drivers of forest productivity, particularly in plantation systems focused on timber, another long-lasting theme of research (Fox, 2000; Fox, Jokela, and Allen, 2007) (see Chapters 16, 18 and 30).

Sixth, given the role of fire, fuels, insects, and climate change in the western USA, understanding this triad of relationships and drivers is critical toward restoring fire and forest health back into more resilient forests that are currently fire and insect prone (Dale *et al.*, 2000; Logan, Regniere, and Powell, 2003; Stephens *et al.*, 2012) (see Chapters 26 and 27).

Finally, a good deal of attention has been focused on the non-monetary service values that forests and trees provide. Whole new themes on urban trees and forests (Dwyer *et al.*, 2000), forest watersheds and drinking water supplies (Naiman, 1992; de la Cretaz and Barten, 2007), forest carbon and climate mitigation (Amato *et al.*, 2011; Ashton *et al.*, 2012), and bioenergy and wood technologies that substitute for other more energy intensive products (Dickman, 2006) have all been strong areas of research focus.

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