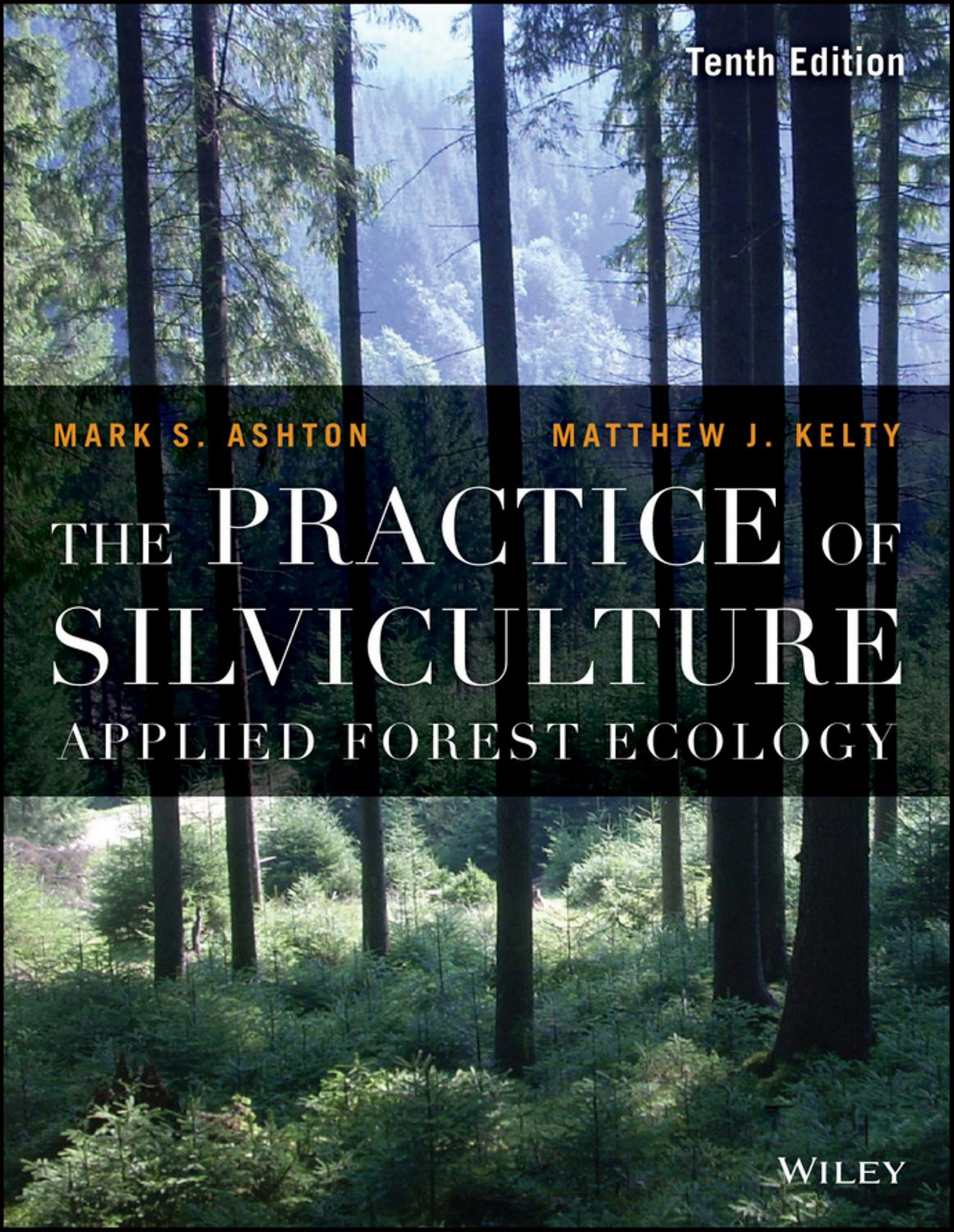


Tenth Edition

MARK S. ASHTON MATTHEW J. KELTY

THE PRACTICE OF SILVICULTURE

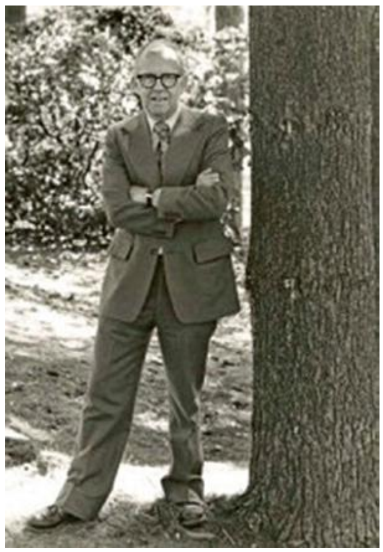
APPLIED FOREST ECOLOGY

WILEY

The Practice of Silviculture

Dedication

DAVID MARTYN SMITH
March 10, 1921–March 7, 2009



(*Source:* Reproduced with permission from E. Smith)

David M. Smith, longtime Professor of Silviculture at Yale University, was our mentor and our friend. We dedicate this 10th edition of *The Practice of Silviculture* to his memory, in thanks for all he gave to us.

Dave was born in Texas and raised in Rhode Island. After graduation from the University of Rhode Island, he served as a meteorologist for the US Army Air Force during World War II. He earned his masters and doctorate degrees from Yale University under the guidance of Professor Harold Lutz. Dave quickly became a faculty member in the School of Forestry and Environmental Studies at Yale. One of his most notable contributions involved helping to found the sub-discipline of silviculture known as *forest stand dynamics*, which uses stand reconstruction to evaluate the past and to project the future of forest growth. During his years at Yale, Dave served as the Director of School Forests and as the Morris K. Jesup Professor of Silviculture. His wit and wisdom are fondly remembered, as are the many lessons taught in the classroom and in the field. Dave educated a legion of professionals who have had a lasting impact on forests throughout the world.

David Smith worked with Ralph C. Hawley as co-author of the 6th edition of this book, and then went on to author the 7th and 8th editions alone. He was lead author on the 9th edition, working with three of his former students. In his field trips and teaching, Dave showed his students how a practical knowledge of botany, ecology, and geology could allow a forester to look at a stand of trees, pick out clues, and make deductions about the forces shaping the forest. His skills in this area led some students to dub him "Sherlock Holmes of the forest." We are ever grateful for his wisdom and guidance.

Mark S. Ashton
Matthew J. Kelty

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Applied Forest Ecology

Tenth Edition

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Contents

Preface

The late Ralph C. Hawley, one of the pioneers of American forestry, wrote the first edition of this book in 1921. He based it on knowledge imported from Europe and on what he, and a few hundred foresters, had learned by managing the limited tracts of forest on which true long-term forestry was being practiced. At the time, American society regarded forests only as a source of timber, and the book focused on timber production silviculture that would be financially sound in the long run. Professor Hawley went on to revise the book four times. David M. Smith became a co-author on the 6th edition, published in 1956. Emphasis was placed on presenting the scientific basis for silvicultural practice. Professor Smith wrote and edited two more editions as sole author. In the 9th edition, Professor Smith brought on three colleagues, all of whom were his past students: Bruce C. Larson, Matthew J. Kelty, and Mark S. Ashton. His intent was to carry on the tradition of the text in the same manner in which Professor Hawley had worked with him. In the 9th edition, published in 1997, the phrase *Applied Forest Ecology* was added to the title. The basic purpose was to call attention to the fact that foresters should design forests based on sound ecological theory. This applied ecology is concerned with managing the interactions among organisms and their environment, regardless of the degree to which the forests are managed or devoid of human influence.

This 10th edition is a significant revision of the 1997 text. The contents have been completely restructured to further emphasize the ecological basis for silviculture, as well as to expand the relevance of silviculture to a range of forest and tree-related resource management issues. In this edition there are six parts: (1) an introduction and history of silviculture, (2) a summary of the ecological foundations for silvicultural practice, (3) methods of regeneration, both natural and artificial, (4) post-establishment (intermediate) treatments, (5) silvicultural considerations for forest management, and (6) examples of applications for different land ownerships and uses. The previous edition began with intermediate treatments; this book starts with concepts and treatments for regeneration, then progresses to intermediate treatments. The text ends with a new and more elaborate section on applications of silviculture to different resource issues: industry and industrial management, public lands and ecosystem management, restoration and forest health, watershed management, wildlife habitat, agroforestry, urban environments, and climate mitigation.

The 10th edition has been expanded and largely rewritten with clearer language and explanations, updated references, and new photographs, tables, and figures. Boxed inserts have been added to provide greater detail on particular silvicultural treatments or examples of their use. Each chapter strives to provide regional examples for the southern, northeastern and western United States. The glossary contains words and phrases which are highlighted in the text using bold color font. Words in black bold font are for emphasis only.

The book still has a strong North American focus, but contains more examples from across the world to provide a more global perspective of silvicultural use for the North American forester or student. This may be the most expansive book on silviculture yet, and covers a wide range of topics and resource issues that are currently faced by the forester or resource professional. It does not lose its strength in explaining the principles for silvicultural treatments.

Work on this 10th edition began over 10 years ago. The long process has involved many people acknowledged elsewhere in these initial pages. It is hoped that this effort will be well received and appreciated by the forestry community. We thank our families for their patience and the time we have been allowed in preparing this book.

Mark S. Ashton, Morris K. Jesup Chair of Silviculture and Forest Ecology, Yale University
Matthew J. Kelty, Professor Emeritus, University of Massachusetts Amherst

Acknowledgements

There are many individuals who have helped in a variety of ways with this book. We would not have been able to do this book without the fundamental and ever present help of D'Ann Kelty. We would also like to thank our close colleague Bruce Larson at the University of British Columbia, who helped with initial writing of Chapter 24 and provided many helpful suggestions and edits throughout the text as this book was being developed. Each chapter was reviewed by students from Mark Ashton's silviculture class at Yale University, and by many of our colleagues at universities in North America. In particular we would like to acknowledge the silviculture instructors and researchers who reviewed multiple chapters of the book and provided many, many helpful comments. In alphabetical order they are: Heidi Asbjornsen (University of New Hampshire), John Bailey (Oregon State University), Graeme Berlyn (Yale University), Craig Brodersen (Yale University), Wayne Clutterbuck (University of Tennessee), Phil Comeau (University of Alberta), Kristofer Covey (Yale University), Anthony D'Amato (University of Vermont), Tom Dean (Louisiana State University), Mark Ducey (University of New Hampshire), Marlyse Duguid (Yale University), David Ellum (Warren Wilson College), Andrew Ezell (Mississippi State University), Michael Ferrucci (InterForest LLC), Alex Finkral (The Forestland Group), Thomas Fox (Virginia Polytechnic Institute and State University), Brent Frey (Mississippi State University), John Goodburn (University of Montana), John Groninger (Southern Illinois University), James Guildin (US Forest Service), Jefferson Hall (Smithsonian Tropical Research Institution), John Hodges (deceased, formerly of Mississippi State University), Jennifer Hoyle (Yale University), Steven Jack (Jones Ecological Center), Thomas James (Hama Hama Forest Resources), Eric Jokela (University of Florida), Shibu Jose (University of Missouri), Kathleen Kavanagh (Texas A & M), David Kittredge (University of Massachusetts), Karen Kuerrs (University of the South), David Larsen (University of Missouri), Xuhui Lee (Yale University), Victor Lieffers (University of Alberta), Brian Lockhart (US Forest Service), James Long (Utah State University), Doug Maguire (Oregon State University), Florencia Montagnini (Yale University), David Moorehead (University of Georgia), Colleen Murphy-Dunning (Urban Resources Initiative, Yale University), Linda Nagel (Colorado State University), Kevin O'Hara (University of California, Berkeley), Klaus Puettmann (Oregon State University), James Saiers (Yale University), Mike Saunder (Purdue), Oswald Schmitz (Yale University), Robert Seymour (University of Maine), David Skelly (Yale University), Steven Tesch (Oregon State University), Geoff Wang (Clemson University), Kristen Waring (Northern Arizona University), and Eric Zenner (Pennsylvania State University).

A core group of Yale University graduate students reviewed and provided edits on the chapters. They include: Karin Bucht, Vihn Lang, Anthony Mecum, Serena Liam, Nicholas Olson, Frances Sawyer, Kristina Solheim, and Sabrina Szeto. We would like to thank them most sincerely for their efforts. They were very important in making sure the book read well, and was understandable, for the main audience and readership it is intended for. We also thank Julius Pasay for preparing the information for several of the boxes in Chapters 1 and 2.

Finally we would like to thank Yale University and the US Forest Service and many other organizations and individuals who have been credited with photographs and figures within the book.

Part 1

Introduction to Silviculture

A history of silviculture and the philosophical approach taken in this book.

1

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

The Practice of Silviculture: Applied Forest Ecology, Tenth Edition. Mark S. Ashton and Matthew J. Kelty.

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 toothpicks, 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 Iles 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).

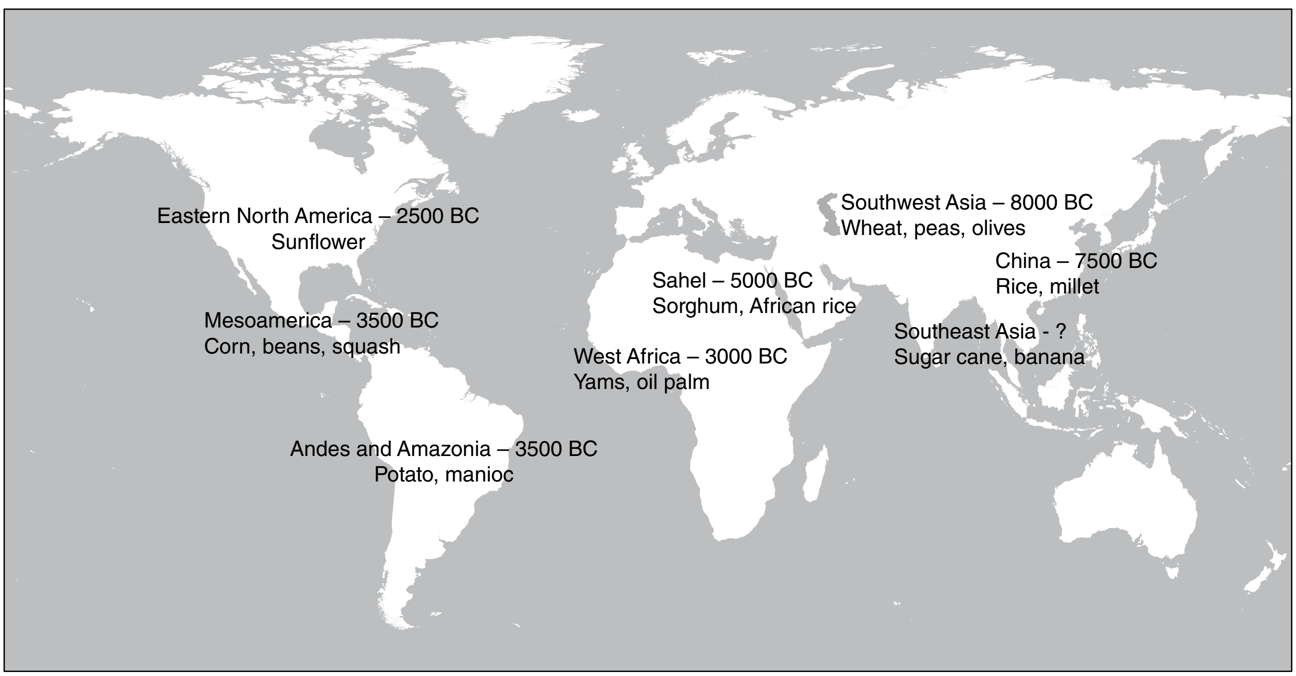


Figure 1.1 Early agricultural civilizations of the world and their main crops. *Source:* Adapted from mapsopensource.com under the terms of the Creative Commons Attribution Licence, CC-BY 3.

Box 1.2 Indigenous silvicultural systems of ancient civilizations.

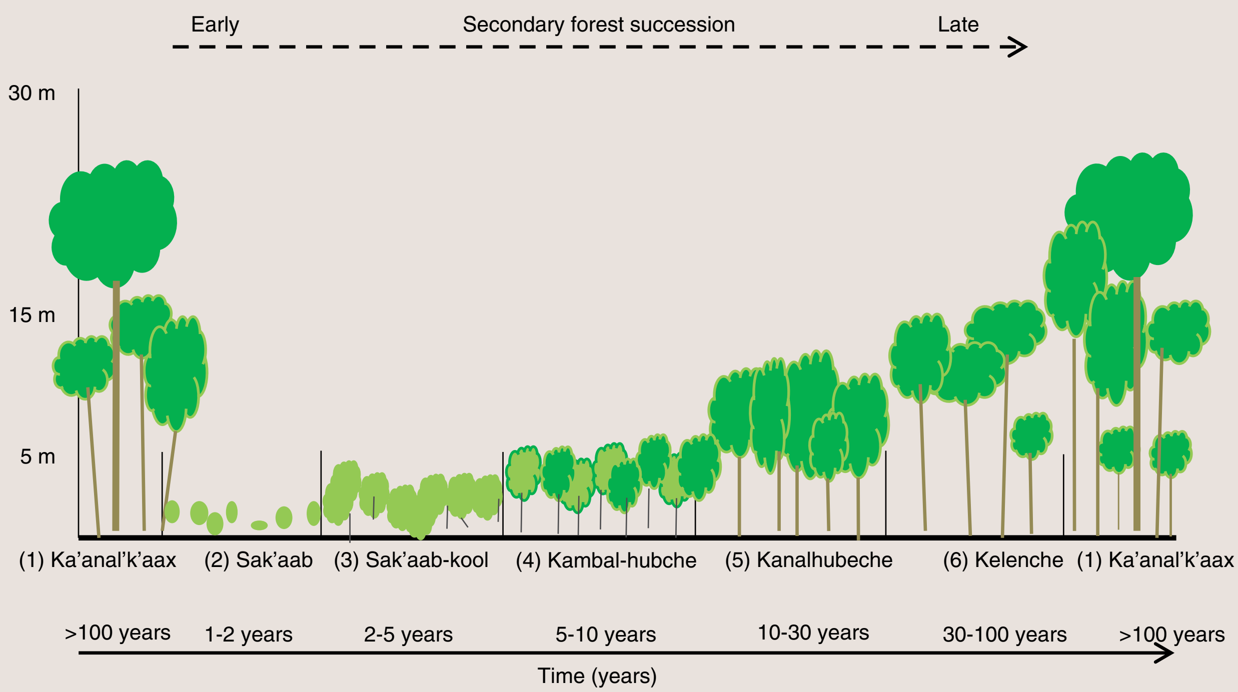
Maya of the Yucatan, Mexico

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 cainto*, *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

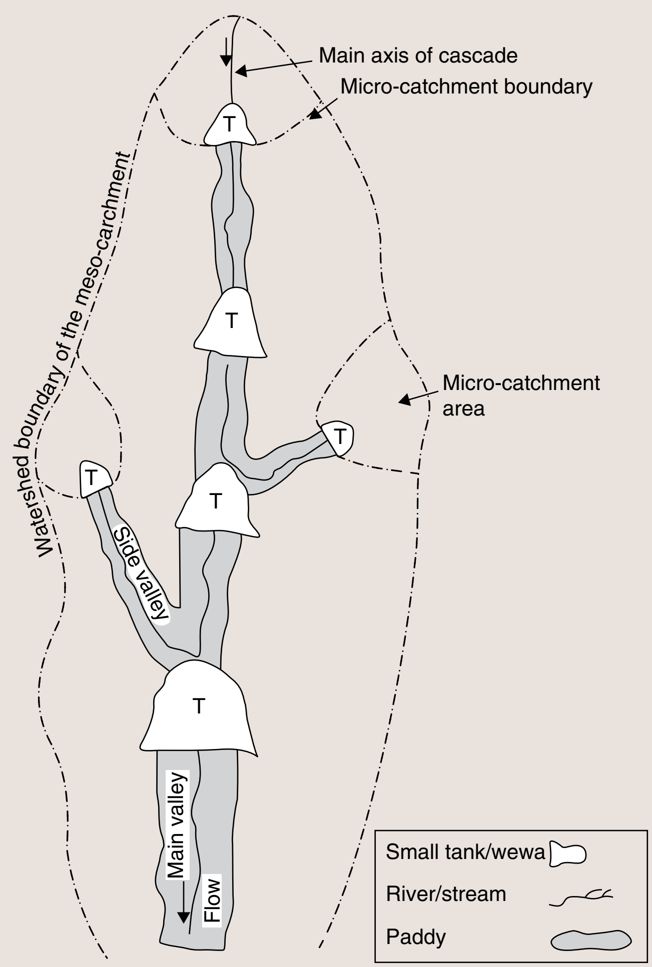


Box 1.2 Figure 1 A diagram depicting Maya swidden succession. Maya succession nomenclature are (1) Ka'anal'k'aax: old tropical forest (30 or more years old); (2) Sak'aab (or Sak'ab): second year milpa; (3) Sak'aab-kool: Recently abandoned milpa; early succession; (4) Kambal-hubche': 5–10 years old succession; (5) Kanalhubche': 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 mi^2 (40,000 km^2). 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.



(*Continued*)

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.

(*Continued*)

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 stumps 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 Dietch Brandis, a student of Cotta, to start the Indian Forest Service and a School of Forestry at Dehra Dun (Box 1.4).

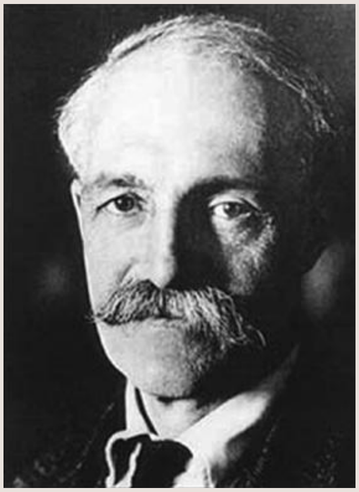
Box 1.4 The development of the Indian Forest Service and Sir Dietrich Brandis.

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 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.



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

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

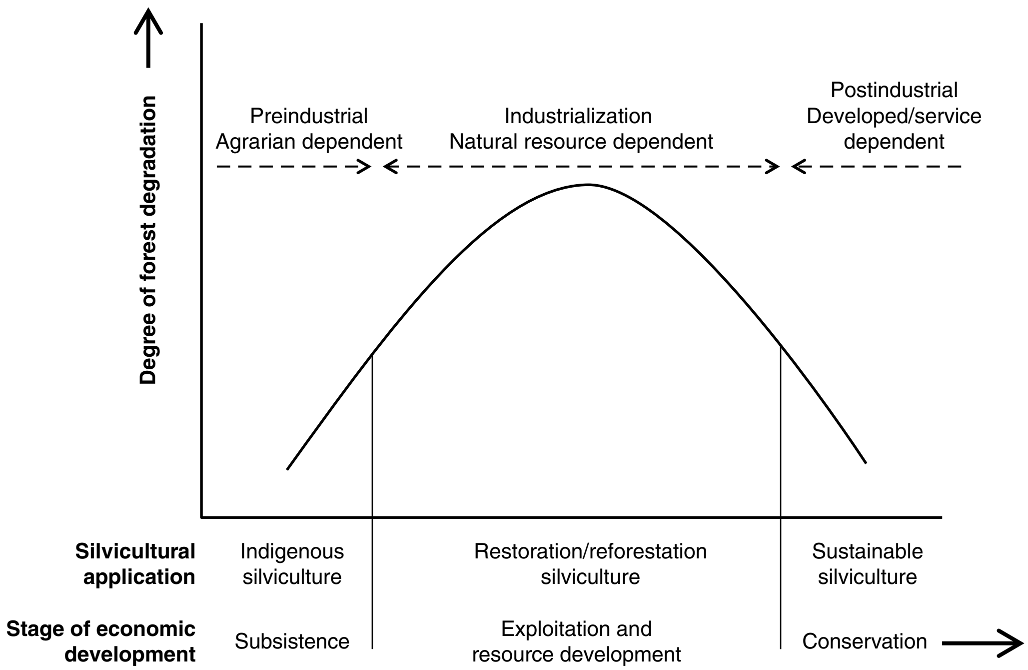


Figure 1.2 Economic and social development process leading to a developed economy and the forms of silviculture practiced. *Source:* Adapted from Panayotou and Ashton, 1992.

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

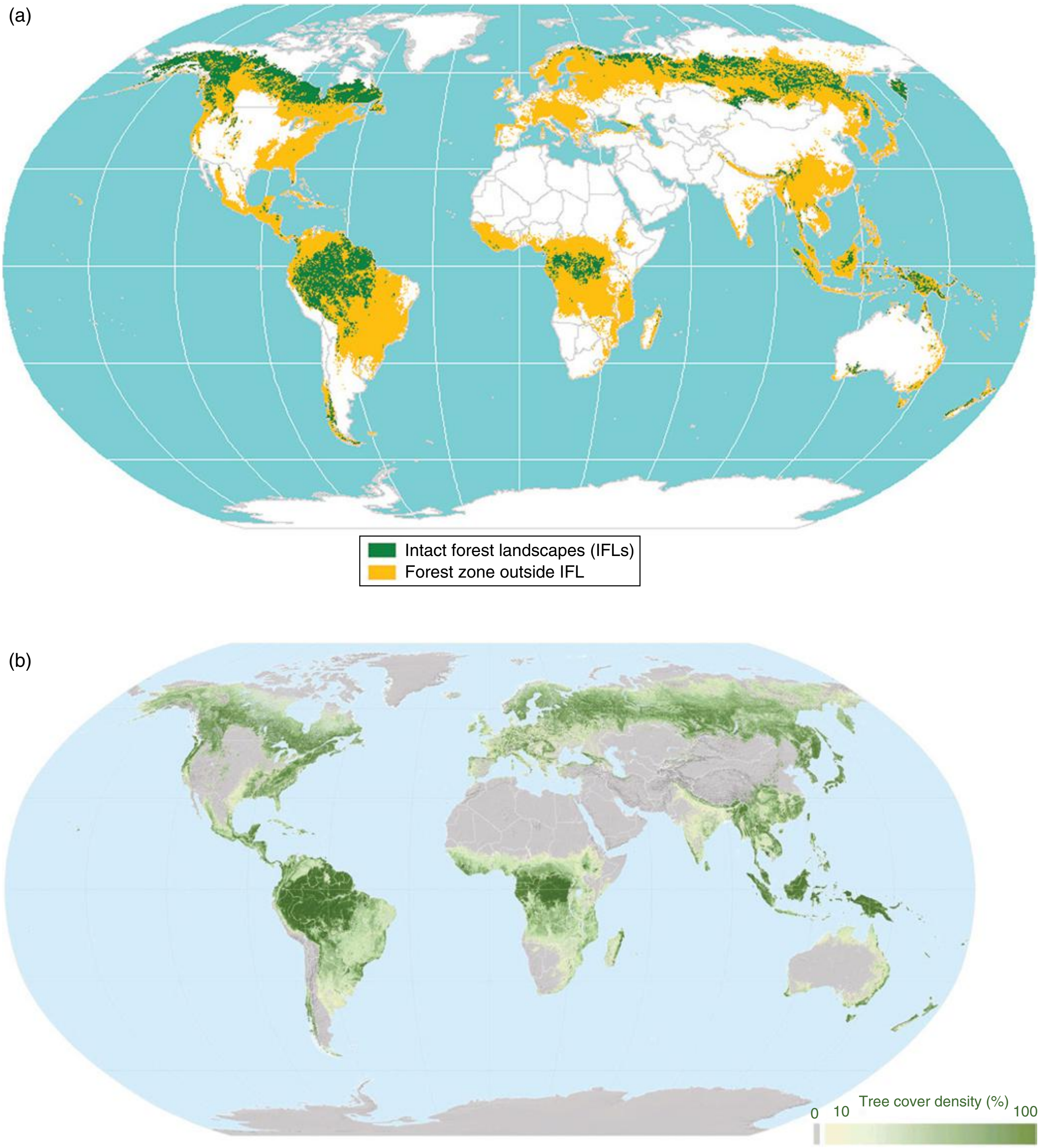


Figure 1.3 (a) A global depiction of the world's original forest (orange shading) and current undisturbed forests that have had little human impact (green shading). *Source*: Potapov, 2009. **(b)** A global depiction of the world's current forest cover (as measured by tree density) including undisturbed 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 Hectares[1] 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: FAO[2], 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.

References

Abrams, M. D., and Nowacki, G. J. 2008. Native Americans as active and passive promoters of mast and fruit trees in the eastern USA. *The Holocene*, 18: 1123–1137.

Amato, A.W., Bradford, J.B., Fraver, S., and Palik, B.J. 2011. Forest management for mitigation and adaptation to climate change: insights from long-term silviculture experiments. *Forest Ecology and Management*, 262: 803–816.

Ashton, M. S., Goodale, U. M., Bawa, K. S., Ashton, P. S., and Neidel, J. D. 2014. Restoring working forests in human dominated landscapes in tropical South Asia: an introduction. *Forest Ecology and Management*, 329: 335–339.

Ashton, M. S., Tyrrell, M., Spalding, D., and Gentry, B. (eds.). 2012. *Managing Forest Carbon in a Changing Climate*. Springer-Verlag, New York.

Baker, W. L., Veblen, T. T., and Sherriff, R. L. 2007. Fire, fuels and restoration of ponderosa pine–Douglas fir forests in the Rocky Mountains, USA. *Journal of Biogeography*, 34: 251–269.

Bargioni, E. and Zanzi Sulli, A. 1998. The Production of Fodder Trees in Valdagno, Vicenza, Italy. In: K. J. Kirby and C. Watkins (eds.). *Ecological History of European Forests*. CAB International, New York, pp. 43–52.

Barnes, B. V., Zak, D. R., Denton, S. R., and Spurr, S. H. 1998. *Forest Ecology*. 4th ed. John Wiley and Sons, New York. 774 pp.

Barrett, J. W. (ed.). 1994. *Regional Silviculture of the United States*. 3rd ed. John Wiley and Sons, New York. 643 pp.

Bettinger, P. and Sessions, J. 2003. Spatial forest planning: To adopt, or not to adopt? *Journal of Forestry*, 101: 24–29.

Bettinger, P., Boston, K., Siry, J., and Grebner, D. L. 2009. *Forest Management and Planning*. Academic Press, New York. 360 pp.

Binkley, C. S. 1997. Preserving nature through intensive plantation forestry: the case for forestland allocation with illustrations from British Columbia. *The Forestry Chronicle*, 73(5): 553–559.

Burns, R. M. (ed.) 1983. *Silvicultural Systems for the Major Forest Types of the United States*. USDA Agriculture Handbook, 445. 191 pp.

Burns, R. M. and Honkala, B. H. (eds.). 1990. *Silvics of North America*. 2 vols. USDA Agriculture Handbook, 654. 1552 pp.

Chagnon, N. A. and Gross, D. R. 1973. The culture-ecology of shifting (pioneering) cultivation among the Yanomamo Indians. In: *Peoples and Cultures of Native South America*. American Museum of Natural History Press, New York, pp. 126–142.

Cotta, J. H. 1817. *Anweisung zum Waldbau* (Instruction on forestry). Dresden.

Cronon, W. 1983. *Changes in the Land: Indians, Colonists and the Ecology of New England*. Hill and Wang, New York. 241 pp.

Dale, V. H., Joyce, L. A., McNulty, S., Neilson, R. P., Ayres, M. P., Flannigan, M. D., Hanson, P. J., Irland, L. C., Lugo, A. E., Peterson, C. J., Simberloff, D., Swanson, F., Stocks, B. J., and Wotton, B. M. 2001. Climate change and forest disturbances: climate change can affect forests by altering the frequency, intensity, duration, and timing of fire, drought, introduced species, insect and pathogen outbreaks, hurricanes, windstorms, ice storms, or landslides. *BioScience*, 51: 723–734.

Daniel, T., Helms, J. and Baker, F. 1979. *Principles of Silviculture*. 2nd ed. McGraw-Hill, New York. 512 pp.

Davis L. S. and Johnson, K. N. 1987. *Forest Management: Regulation and Valuation*. 3rd ed. McGraw-Hill, New York. 790 pp.

Davis, L. S., Johnson, K. N., Bettinger, P., and Howard, T. E. 2005. *Forest Management*. 3rd ed. Waveland Press, Long Grove, IL. 804 pp.

Day, G. M. 1953. The Indian as an ecological factor in the northeastern forest. *Ecology*, 34: 329–346.

de la Cretaz, A. L. and Barten, P. K. 2007. *Land Use Effects on Streamflow and Water Quality in the Northeastern United States*. CRC Press, Boca Raton, FL. 344 pp.

Dickman, D. I. 2006. Silviculture and biology of short-rotation woody crops in temperate regions: then and now. *Biomass and Bioenergy*, 30: 696–505.

Dwyer, J. F., Nowak, D. J., Noble, M. H., and Sisinni, S. M. 2000. Connecting people with ecosystems in the 21st century: an assessment of our nation's urban forests. *General Technical Report*, PNW-GTR-490. 483 pp.

Evelyn, J. 1664. *Sylva: A Discourse of Forest Trees and the Propagation of Timber*. John Martin Publ., Royal Society of London.

FAO. 2005. *Global Forest Resources Assessment: Progress Toward Sustainable Forest Management*. Food and Agricultural Organization, Rome.

Fisher, W. R. 1910. Recent progress in Indian forest technology. *Nature*, 83(2119): 428.

Fisher, W. R. 1904. Education in forestry. *The Indian Forester*, 30: 429–433.

Fox, T. R. 2000. Sustained productivity in intensively managed forest plantations. *Forest Ecology and Management*, 138: 187–202.

Fox, T. R., Jokela, E. J., and Allen, L. H. 2007. The development of pine plantation silviculture in southern United States. *Journal of Forestry*, 105: 337–347.

Fule, P. Z., Walt, A. E. M., Covington, W. W., and Heinlein, T. A. 2001. Measuring effectiveness in reducing hazardous fuels. *Journal of Forestry*, 99: 24–29.

Geekiyanage, N. and Pushpakumara, D. K. N. G. 2013. Ecology of ancient tank cascade systems in island Sri Lanka. *Journal of Marine and Island Cultures*, 2: 93–101.

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

Griscom, H. P., and Ashton, M. S. 2011. Restoration of dry tropical forests in Central America: A review of pattern and process. *Forest Ecology and Management*, 261: 1564–1579.

Hæggström, C.A. 1998. Meadows: Multiple Use of Human-made Nature. In: K. J. Kirby and C. Watkins (eds.). *Ecological History of European Forests*. CAB International, New York, pp. 33–41.

Hartig, G. L. 1808. *Lehrbuch für Förster und die es warden wollen*. (3 vols.) Stuttgart.

Hawley, R. C. and Smith, D. M. 1954. *The Practice of Silviculture*. 6th ed. John Wiley & Sons, New York. 525 pp.

Kimmins, J. P. 1987. *Forest Ecology*. Macmillan, New York. 531 pp.

Logan, J. A., Regniere, J., and Powell, J. A. 2003. Assessing the impacts of global warming on forest pest dynamics. *Frontiers in Ecology and the Environment*, 1: 130–137.

Matthews, J. D. 1991. *Silvicultural Systems*. Oxford Science Publications, Oxford.

Meyer, J. M. 1997. Gifford Pinchot, John Muir, and the boundaries of politics in American thought. *Polity*, 30: 267–284.

Miles, A. 2012. *Heritage Trees Wales*. Graffeg, Wales, UK. 260pp.

Miller, C. 2001. *Gifford Pinchot and the Making of Modern Environmentalism*. Island Press, Washington D.C.

Milward, R. C. 1947. The Indian Forest Service: its origin and progress. *The Empire Forestry Review*, 26: 184.

Naiman, R. J. (ed.). 1992. *Watershed Management*. Springer-Verlag, New York.

Nilsson, M. S. T. and Fearnside, P. M. 2011. Yanomami mobility and its effects on the forest landscape. *Human Ecology*, 39: 235–256.

Nyland, R. D. 2016. *Silviculture: Concepts and Applications*. 3rd ed. Waveland Press, Long Grove, IL.

O'Hara, K. L., and Gersonde, R. F. 2004. Stocking control concepts in uneven-aged silviculture. *Forestry*, 77: 131–143.

O'Hara, K.L. 2014. *Multiaged Silviculture: Managing for Complex Forest Stand Structures*. Oxford University Press, Oxford, UK.

Oliver, C. D. 1981. Forest development in North America following major disturbances. *Forest Ecology and Management*, 3: 169–182.

Oliver, C. D. 1999. The future of the forest management industry: highly mechanized plantations and reserves or a knowledge-intensive integrated approach? *The Forestry Chronicle*, 75(2): 229–245.

Oliver, C. D. and Larson, B. C. 1996. *Forest Stand Dynamics*. John Wiley and Sons, New York. 544 pp.

Oosthoek, K. J. 2007. *The Colonial Origins of Scientific Forestry in Britain*. Environmental History Resources.

Pacala, S. W., Canham, C. D., Saponara, J., Silander, J. A., Kobe, R. K., and Ribbens, E. 1996. Forest models defined by field measurements: estimation, error analysis, and dynamics. *Ecological Monogaphs*, 66: 1–43.

Panayotou, T., and Ashton, P. 1992. *Not by Timber Alone: Economics and Ecology for Sustaining Tropical Forests*. Island Press, Washington D.C. 302 pp.

Pinchot, G. 1998. *Breaking New Ground*. Island Press, Washington D.C.

Potapov, P. 2009. *The World's Intact Forest Landscapes (IFLs)*. Wikimedia Commons, Free Media Repository.

Puettmann, K.J., Coates, K.D., and Messier, C.C. 2012. *A Critique of Silviculture: Managing for Complexity*. Island Press, Washington D.C.

Pyne, S. J. 1997. Counter Fire. *Vestal Fire: An Environmental History, Told through Fire, of Europe and Europe's Encounter with the World*. University of Washington, Seattle. pp. 486–488.

Rackham, O. 1996. *The History of the Countryside*. Weidenfeld & Nicolson, London.

Savill, P., Evans, J., Auclair, D., and Falck, J. 1997. *Plantation Silviculture in Europe*. Oxford University Press, Oxford. 297 pp.

Sedjo, R. A. and Botkin, D. 1997. Using forest plantations to spare natural forests. *Environment: Science and Policy for Sustainable Development*, 39(10): 14–30.

Smith, D. M., Larson, B. C., Kelty, M. J., and Ashton, P. M. S. 1997. *The Practice of Silviculture: Applied Forest Ecology*. 9th ed. John Wiley and Sons, New York. 560 pp.

Stanturf, J. A., Palik, B. J., and Dumroese, R. K. 2014. Contemporary forest restoration: a review emphasizing function. *Forest Ecology and Management*, 331: 292–323.

Stephens, S. L., McIver, J. D., Boerner, R. E. J., Fettig, C. J., Fontaine, J. B., Hartsough, B. R., Kennedy, P. L., and Schwilk, D. W. 2012. The effects of forest fuel-reduction treatments in the United States. *BioScience*, 62: 549–560.

Tappeiner, J. C., Maguire, D. A., Harrington, T. B., and Bailey, J. D. 2015. *Silviculture and Ecology of Western U.S. Forests*. 2nd ed. Oregon State University Press, Corvallis, OR.

Toumey, J. W. 1928. *Foundations of Silviculture upon an Ecological Basis*. John Wiley and Sons, New York.

Underwood, R. 2013. *Foresters of the Raj – Stories from Indian and Australian Forests*. Self-published. 308 pp.

Vanclay, J. K. and Skovsgaard, J. P. 1997. Evaluating forest growth models. *Ecological Modelling*, 98: 1–12.

Wenger, K. F. (ed.). 1984. *Forestry Handbook*. 2nd ed. John Wiley and Sons, New York. 1335 pp.

Wright, S. J. 2002. Plant diversity in tropical forests: a review of mechanisms of species coexistence. *Oecologia*, 130: 1–14.

2

Silviculture and its Place in Managing Current Forests and Woodlands

Introduction

This chapter provides an introduction to the book and its contents. It first defines the purpose of silviculture in context with examples of its application to current resource issues. The scope of silviculture and the use of its terminology is then described by providing the overarching theme that silviculture should: (1) imitate as much as possible the processes of nature, and (2) maintain and protect the inherent productivity of the site. Within this construct there are four guiding principles that silviculture can potentially strive to achieve, given both social and economic objectives and values. They are: (1) control structure and process; (2) control composition; (3) control stand density and spatial arrangement; (4) control rotation length, harvest intervals, and the life cycle of the forest. Then a framework is described to implement these principles within the construct of emulating nature and maintaining site productivity. This is done by: (1) defining the spatial scale at which silviculture is applied by introducing the concept of the stand; (2) defining the two basic sets of silvicultural treatments applied within stands, namely: regeneration methods and post-establishment treatments; and (3) defining treatments to the individual tree (e.g., pruning).

The Purpose of Silviculture Today

Definition of Silviculture

Silviculture has been defined in various ways, including the art and science of producing and tending a forest for the various social and economic values demanded by individuals and society. It has also been defined as the application of knowledge of autecology or silvics in the treatment of a forest. Finally, it has been defined as the theory and practice of controlling forest establishment, composition, structure, and growth. Since silvicultural practice is applied forest ecology, it is also a major part of the biological technology that carries ecosystem management into action.

Silvicultural practice consists of the various treatments applied to forests to maintain and enhance their utility or service for any purpose. The forester must analyze the natural and social factors that affect each stand, and then devise and conduct the silvicultural treatments most appropriate to meet the objectives of the landowner. Silviculture is to forestry as agronomy is to agriculture, in that it is concerned with the technology of growing vegetation. Like the rest of forestry itself, silviculture is an applied science that rests on the more fundamental natural and social sciences. The immediate foundation of silviculture in the natural sciences is **silvics**, which deals with the growth and development of single trees and other forest species as well as whole forest ecosystems. Among the sources of information about silvics is a very long legacy of books upon which silviculture is based by: Daniel, Helms, and Baker, 1979; Spurr and Barnes, 1980; Kimmins, 1987; Burns and Honkala, 1990; Oldeman, 1990; Whitmore, 1990; Kozlowski, Kramer, and Pallardy, 1991; Lassoie and Hinkley, 1991; Packham, *et al*., 1992; Barnes *et al*., 1998; Kimmins, 2003; Waring and Running, 2007; and Perry, Oren and Hart, 2008.

The competent practice of silviculture, whether it be crude or elaborate, demands that a forester acquire as much knowledge as possible of ecology and all its subdisciplinary areas (e.g., population, community, ecosystem), as well as fields such as plant physiology and morphology, entomology and pathology, biogeochemistry, hydrology, biometeorology, and soil science. It is also through silviculture that a major part of the growing store of knowledge about trees and forests is applied. In addition, it is essential to understand the fundamentals of individual human community and society behaviors, their cultural and religious values, and their economics, if silviculture is to achieve the goals and objectives of managing forests, woodlands, and trees successfully. This knowledge is not learned once for a lifetime. The forestry practitioner must keep abreast of new information and ideas through communication with other members of the profession and maintain familiarity with the results of research. Silviculture can therefore be considered a sub-discipline that is at the very heart of training a forestry professional (Fig. 2.1).

The Practice of Silviculture: Applied Forest Ecology, Tenth Edition. Mark S. Ashton and Matthew J. Kelty.

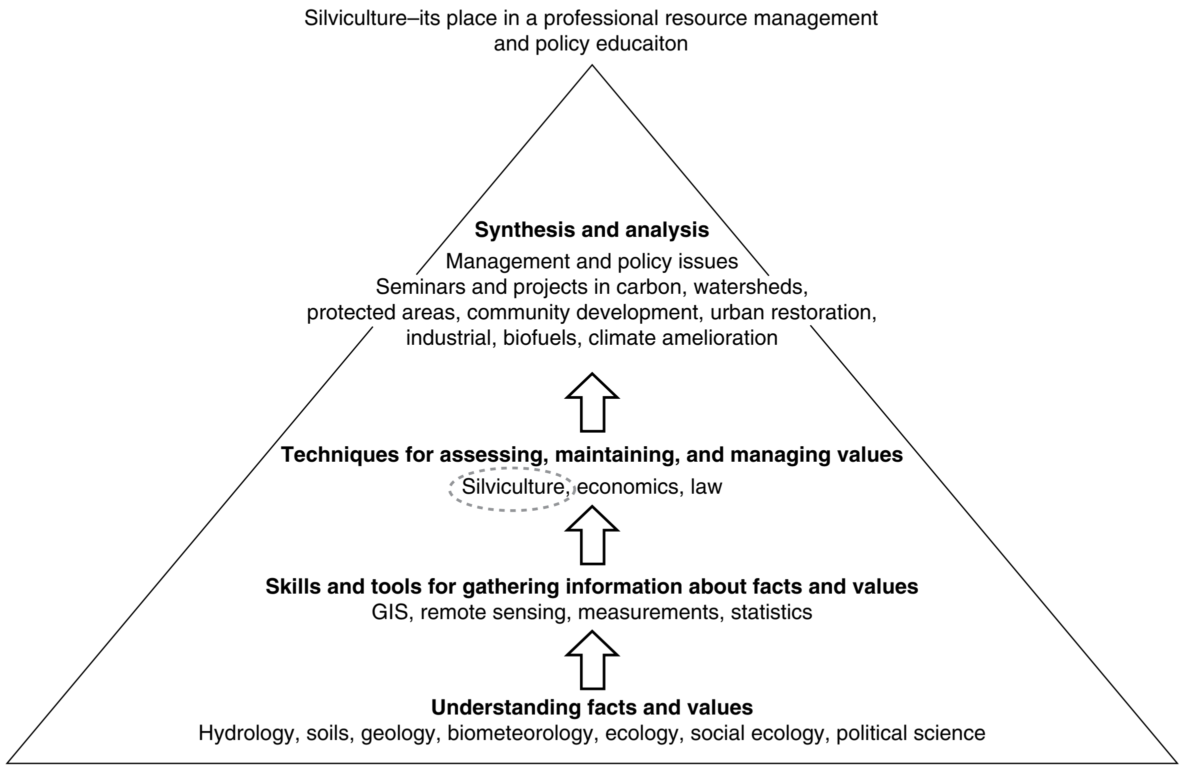


Figure 2.1 A graphical depiction of where the subject lies within the multi-disciplinary training of a professional forester. *Source:* Mark S. Ashton.

Although formal research is indispensable, it does not lead to total knowledge, nor does it relieve the forester of responsibility for additional thought and continual observations in the forest. In applied sciences, such as silviculture, in the absence of total knowledge we are always condemned to act on the basis of thoughtful judgment. Skillful practice itself is a continuing, informal kind of research in which understanding is sought, new ideas are applied, and old ideas are tested for validity. The observant forester will find answers to many silvicultural questions in the woods by examining the results of earlier treatments of the forest and accidents of nature. This component of silviculture can be considered the art of silviculture and is based on the forester's inherent adaptive learning experience, intuition and understanding of the science, keen sense of observation about the natural world, and ability to understand human behaviors and desires as well as translate this understanding into practice. The forester is a naturalist in the broadest sense of the word, and every forester should strive for these attributes.

The Purpose of Implementing Silviculture

Silviculture is designed to create and maintain the kind of forest that will best fulfill the objectives of the owner and the governing society. The production of timber, though a common objective, is neither the only nor necessarily the dominant aim in silviculture. Frequently, especially with public forests and private non-industrial forests, benefits such as recreation or aesthetics may be more important, and water and wildlife always have to be taken into account.

Most silvicultural practices are applied in the course of timber harvesting because the value of the wood removed greatly reduces the cost of the operations. It is through the manipulation of growing space by removing trees that much of the other values such as improving wildlife habitat, creating vistas, or encouraging a vigorous groundstory for surface watershed protection can be achieved. This is true even if timber production is only a secondary or tertiary objective of management. Silviculture for the cultivation of both wood and non-wood products (fruits, fiber, resins) is also the most intricate kind because the species and quality of trees are of greater concern than they would be with other forest uses. Designing silviculture for wildlife management is also complicated, but mainly because of the difficulty of determining the kinds of vegetation that mobile and elusive animal populations require. Once the kind of required habitat is selected, the silviculture is not difficult to design.

Some of the biggest problems in silviculture include getting owners and society to define their management objectives and, especially, the degree of priority attached to various uses. It is the responsibility of foresters to work out the details, which include the design and implementation of silvicultural treatments, but owners, the public, and legislative bodies must determine the actual policies about allocations. Management cannot continue if the difficult and often argumentative decision making is left to single-minded user groups. Even worse problems can be caused by amateur prescription of silvicultural practice through simplistic rules ordained by legislatures, courts, or accountants.

Resource Issues Applicable to the Use of Silviculture

Resource issues are extremely varied given the enormously wide social and economic circumstances within which forests and woodlands can be found. Forests are: used for subsistence living in remote regions; irresponsibly cleared for unsustainable agricultural projects (and thus threatened with destruction and degradation); managed for intensive industrial use; conserved as wildlife habitat; maintained as a source of drinking water for downstream cities; and developed for open-space recreation and city parklands. Important resource values are listed below by the products and services that trees and forests provide and for which silviculture is directly applicable.

Products

1) Biomass and wood fuel. Two-thirds of people in the world, mostly from developing nations, are still dependent upon fuelwood or charcoal for cooking and heating. Now coming full circle, modern technologies are being developed to use biomass, primarily from fast-growing biomass plantations, but also a secondary product from other forest harvest operations, as an energy source in developed nations.
2) Fiber. Paper, ropes, and other fiber products were predicted at the start of the computer age to dramatically decrease in use. Instead they have significantly increased and are projected to continue to do so. Though recycled paper products have become much more common, even recycled paper requires replenishment with virgin fiber.
3) Composite materials. Over the last 50 years, technology has developed a variety of composite wood products (plywood, particle board, and oriented-strand board) that are cheaper substitutes for dimensional sawtimbers and that are derived from what was once considered waste. Such materials are now widely used. More recently, wood–plastic composites have been developed for a range of uses that were formerly restricted to plastics, ranging from shoes to the bodies and interiors of cars, planes, and boats.
4) Dimensional construction and support timbers. Worldwide, demand for timber products for building construction will continue to increase. Timber products are one of the most carbon-neutral and energy-efficient products. These timbers are increasingly coming from intensively managed plantations (e.g., Douglas-fir, *Eucalyptus* spp., loblolly pine, and radiata pine).
5) Luxury timbers and veneers. High-value woods used for furniture, artisanal products, musical instruments, flooring, paneling, and building interiors will always be demanded by society. These timbers continue to come from native forests, and are increasingly from second-growth origin. Plantations of luxury timber are rare (e.g., teak), because of their time to reach maturity.
6) Tree fruit and nut crops. Cultivation of fruit and nut trees requires silviculture treatments in native forests, mixed tree gardens, and orchard plantings. Such treatments focus on the condition of individual tree crowns to maximize nut and fruit productivity.
7) Tree resins, oils, and saps (e.g., rubber, maple syrup, turpentine). Trees managed to produce resins, saps, and oils from the stem need specific silvicultural treatments for both native forests and for their cultivation in plantations.
8) Lianas and vines. Many products (rattan, basketry, medicinals, cordage, vegetables) are garnered from vines. However, vines and lianas require trees and shrubs for support and stages of successional habitat that silviculture can provide.
9) Understory plants. Understory plant crops (e.g., spices, medicinals, coffee, cacao) of forests, plantations, and agroforestry systems require shade and soil-fertility conditions that trees can provide.

Services

1) Supplying clean water. The cleanest water comes from forested watersheds that act to filter and/or sequester pathogens and pollutants from water and air. Many urban areas are focused on acquiring and protecting upstream land from development in order to manage it as forest for drinking water supplies to reservoirs.
2) Stormwater mitigation. At a regional scale, forested swamps and floodplains are usually the frontline for mitigating stormwater and flooding events and controlling shoreline erosion caused by typhoons and storms. In addition, wetlands, swamplands, and forests can control and regulate seasonal meltwaters and monsoon or rainy season floods. At a more local scale, trees and woodlands within cities can mitigate local stormwater runoff, reducing downstream pollution and excessive discharge. At both scales, silviculture is needed to actively reforest and create the optimum conditions for mitigation.
3) Carbon sequestration. Since the 1990s, the focus in reducing atmospheric greenhouse gases has shifted towards natural carbon sequestration by forests and trees, which depends on minimized deforestation, reforestation, and management practices that delay harvesting and increase growth.
4) Urban climate and environmental mitigation. Within cities and towns, trees and woodlands can be planted

and cultivated to locally reduce glare, sound, temperatures, and winds.

5) Open-space recreation. Silviculture can be used to create vistas, screens, and recreational trails for biking, hiking, and skiing.
6) Wildlife habitat. Forests and woodlands provide critical habitat for all sorts of wildlife. Particularly important to some societies are the opportunities to hunt game animals, and mandates to conserve endangered species. Silviculture can be used to both create the habitat and maintain it through manipulating forest structure, composition, and site.
7) Forest health and restoration. Silviculture can be applied for: (a) controlling invasive plants, insects, and diseases; (b) regulating and controlling fires; (c) restoring and conserving biodiversity; and (d) stabilizing and protecting fragile landscapes.

The products and services listed can often be produced together in a stand within the forest, plantation, or agroforestry system. In other circumstances they are incompatible and have to be managed separately. Different regions of the world, and even within the same region, have very different sets of priorities and values because of social, economic, and biological circumstance.

Scope and Terminology of Silvicultural Practice

Silvicultural practice encompasses all treatments applied to forest and woodland vegetation and their sites. Although there is much more to the understanding of these treatments than their definitions and nomenclature, the terminology must be understood and used carefully and precisely. **Sloppy use of the terms causes all manner of misunderstanding within the forestry profession and in dealings with the general public. For example, some foresters categorize all cutting as either "clearcutting" or "selective cutting." This not only stunts the development of their own understanding of forestry practice and causes blunders, but also generates continued confusion.** The terminology in this book generally adheres to that promulgated by the Society of American Foresters Silviculture Instructors Sub-Group (1994) and the Commonwealth Forestry Bureau (Ford-Robertson, 1978). It departs only where further improvement in clarity or precision seems imperative.

Silviculture should be governed by several guiding principles. The first two are of the greatest importance, dealing with the imitation of nature and the conservation of site productivity. The other four principles are to be used as reminders to forest practitioners by serving as a check for potential unintended consequences of poor silviculture judgment. The following is a brief description of each of the six principles.

Principle 1: Imitating Nature Through Silviculture

The most magnificent forests that are ever likely to develop were present before the dawn of civilization and grew without human assistance. It is therefore wise to recognize that nature's forests and woodlands are the result of millions of years of exposure to risks of climate, disease, pestilence, and disturbance. Therefore, dramatic silvicultural deviations in species composition, successional process, and stocking can often have detrimental consequences. Human purpose is introduced by preference for certain tree species, stand structures, or processes of stand development that have desirable products and/or services. Where fine forests have developed in nature, they are usually found to have been the result of disturbances followed by long periods of growth. In silviculture, natural processes are deliberately guided to produce forests that are more useful than those of nature, and to do so in less time. Silviculture is therefore an anthropocentric discipline guided by ecological constraints. Whatever society or individuals demand of a forest, whether utilization or preservation, with active or passive management approaches, those decisions are human ones, and they all have immediate consequences and future impacts on a forest that should be recognized.

Principle 2: Conservation of Site Productivity

Paramount among the objectives of forestry in general and of silviculture in particular is the maintenance of the productivity of the living forest. The site is the total combination of the factors, living and inanimate, of a place that determines this productivity. The site factors that are most subject to long-lasting harm are those of the soil, which is one of the least renewable resources used in silviculture (see Chapter 5).

Forests are usually the result rather than the cause of geographical precipitation patterns, though recent evidence is suggesting that forests that are large enough most definitely mitigate climate change and can promote processes of local precipitation such as convectional thunderstorms. However, the basic supply of solar energy is the most vital site factor and is beyond silvicultural control. Silviculture therefore rests heavily on manipulation of the microclimate of a site. Its effects on the macroclimate are limited to those caused by photosynthetic removal of carbon dioxide from the atmosphere and by transpiration of humidity into it.

The living organisms of a place are site factors themselves. However, they can reproduce themselves and are thus the epitome of the renewable resource. If none are rendered extinct, damage to these living components of the site is not likely to be permanent, even though it can be serious and long-lasting. There are always uncertainties over the extent to which silviculture should discriminate against "undesirable" forms of life.

The most obvious and least repairable kind of damage to the soil is physical erosion. Careless treatment, especially when associated with roads and trails used for timber extraction, can cause accelerated erosion that may negate the soil formation processes of a thousand years. A more subtle kind of chemical erosion can result if the remarkable capacity of forest vegetation to recycle nutrients in place is so impaired that large amounts of vital chemicals are lost to surface runoff or leaching. These two kinds of erosion cause double harm because they reduce not only the productivity of the soil but also the quality of the water that flows from it. Soil damage impairs the capacity of the site to yield all of the primary tangible benefits of the forests – vegetation, animal forage, and good water.

It is entirely possible to conduct forestry permanently without the degradation that is almost inevitable in most agriculture and in other "higher" uses of land. However, realization of this potentiality is not automatic. The productivity of the managed forest as a whole is improved through attainment of the four guiding principles described in the next few sections.

Principle 3: Control of Stand Structure and Process

Silviculture is a kind of process engineering or forest architecture aimed at creating structures or developmental sequences that will serve the intended purposes, be in harmony with the environment, and withstand the burdens imposed by environmental influences. Because stands grow and change with time, their design is more sophisticated and difficult to envision than that of static buildings. Furthermore, stands alter their own environment enough that the forester is partly creating a new ecosystem and partly adapting to the one that already exists.

As will be described in more detail in Chapter 4, the possible variations in stand structure and process are almost infinite. The shapes and sizes of stands can be altered for many purposes. Among these are controlling silvicultural treatments and harvesting, creating attractive scenery, altering animal habitat or controlling pest populations, trapping snow, and reducing wind damage. The shapes of stands should be fitted to the patterns usually already found in nature that are dictated by soils and terrain. While the arrangement of stands in checkerboard patterns has a certain administrative appeal, the natural characteristics of land are not, and should generally not be arranged in ways that conflict with the topography of the land.

The internal structure of a stand is determined by considerations such as variation in species and age classes, the arrangement of different layers or stories of vegetation (usually differing as to species), and the distribution of diameter classes. Much of this book is concerned with the purpose and means of achieving these kinds of variations in structure and developmental process.

Principle 4: Control of Composition

One important objective of silviculture is to restrict the composition of stands to what is most suitable to the location from economic and biological standpoints. This frequently means that the total number of species in a managed stand or forest is less than that of the natural forest at that site.

Species composition can be controlled basically by regulating the kind and degree of disturbance during periods when new stands are being established. In this way, environmental conditions can be adjusted to favor desirable vegetation and exclude undesirable species. Regulation of the regeneration process by itself is not always sufficient to provide adequate control over stand composition. It is often necessary to supplement this approach by removing the undesirable vegetation during or after periods of stand establishment. Cutting, poisoning, controlled burning, or regulated herbivorous browsing may be used to restrict the competition and regeneration capacity of undesirable vegetation.

Desirable species and genotypes can be favored in a more positive way by planting or artificial seeding. In some circumstances it is also possible to improve on nature through the introduction of species that do not occur in the native vegetation (e.g., timber and fruit trees; nurse trees in agroforestry), provided that they are adequately adapted to the environment and do not become invasive.

Principle 5: Control of Stand Density

Managed forests are often too densely or too sparsely stocked with trees. This is subjective based upon what human values are being managed for. If stand density is too low, the trees may be too branchy or otherwise malformed, and the unoccupied spaces are likely to be filled with unwanted vegetation in wetter climates. This condition arises from failure of natural regeneration or establishment of planted seedlings. This phenomenon of unoccupied growing space is therefore most common in the early life of a stand, but its consequences may linger after the surviving trees have grown to occupy all of the space available. Excessively high stand density causes the production to be distributed over so many individual trees that none grow at an optimum rate and too many decline in vigor. Unless stand density is controlled at the time a stand is established or during its development, it is almost sure to depart from optimum density for growth at some stage of its life.

Without proper management, many areas of land potentially suited to growth of forests tend to remain unstocked with trees (Fig. 2.2). Legacies of past land abuse (fires, destructive logging, grazing, agricultural

(a)

(b)

Figure 2.2 Much of silviculture has always consisted of rehabilitation efforts and of knowing what will happen as a result of treatments of the forest. This sequence of pictures from 1938, 1949, and 1969 shows a planted stand at a National Forest in northern Idaho, in three stages of development. The tract had been cut-over from a logging railroad in 1930–1931 and was both burned and acquired just before the first picture **(a)** was taken. Planting of western white pine and Engelmann spruce was done in 1939 and 1940. The subsequent pictures **(b** and **c)** show the development to age 30, of the mixture of planted trees and other conifers that seeded-in naturally. *Source:* **(a–c)** US Forest Service.

(Continued)

(c)

Figure 2.2 (Continued)

clearances, and other kinds of forest devastation) have already created many large open areas that can be reforested only by planting. In many regions, **restocking** of deforested areas can be considered a common silvicultural goal.

In many stands, severe losses are caused by damaging agencies such as insects, fungi, fire, and wind. Substantial increases in merchantable production may be achieved merely by salvaging material that might otherwise be lost, but this decision needs to be considered carefully. Jumping into action too quickly to salvage forests sometimes can further exacerbate such issues by causing severe erosion or facilitating further spread of insect or disease. Protection from damaging agencies can result in further increases in production. Forest protection often involves modification of silvicultural techniques. Those areas set aside for wilderness, scenery, or scientific study clearly require protection. Sound policies about the stewardship and use of these preserves inevitably involve something other than leaving them absolutely alone.

Principle 6: Control of Rotation Length

Stands of trees are not immortal. In most commercial situations, there is an optimum size or age to which trees should be grown. The period of years required to grow a stand to the desired condition of either economic or natural maturity is known as the **rotation**. Controlled reductions of stand density or such measures as fertilization and drainage can shorten rotations by making the final-harvest trees grow to the desired sizes at earlier ages. Trees in commercial circumstances allowed to grow beyond the optimum size do not continue to increase in value at rates sufficient to provide an acceptable return on either the costs of growing them or the investment represented by their own value. The risk of decay or other damage may increase the possibility that the trees will decline in value, be lost, or become a hazard. The reservation of overmature trees or even of dead trees is now the norm to maintain some element of structural diversity even within the most intensively managed forests. This is to benefit some wildlife species, microbiota, or simply for scenery or cultural legacies. Increased sequestration and storage of carbon can also be a financial incentive to lengthen rotations in many commercially managed forests.

In the virgin forest, large timber, like gold in the hills, is usually first exploited. The greater the amount extracted, the more difficult and expensive it becomes to find and extract more. It can be extremely difficult to correct the impacts of exploitation in forests that are intended to be sustainably managed for products (timber or non-timber). In fact, many are simply converted to other forms of land use because their commercial timber value has been so depleted. In a managed forest, the growth of stands can be planned so that any use of them is on a more efficient, economical, and predictable basis. It helps to create good stands that are so located that the cost of transporting timber from them is kept under control. Planned reductions in the number of trees on an area not only makes them reach merchantable size more quickly but also leaves more space between trees for extraction of logs during partial cutting.

The Silviculture Framework for Managing a Forest

This section provides a conceptual framework for thinking about how silviculture should be implemented using the guiding principles that are listed and described in the preceding section. Taken together, this provides the forester a guide upon which to develop a silvicultural set of treatments for the unique biophysical and social circumstance that they face. The set of treatments devised by the forester is defined as a **silvicultural system**. The framework should be based upon the ecological and social knowledge and experiences of the forester. The system devised is by no means taken as a general recipe equivalent to a "cook book." Unfortunately too many of these "recipes" exist in forestry and land management.

Defining the Spatial Scale of Management: The Stand and the Forest

A **stand** is a contiguous group of trees sufficiently uniform in species composition, arrangement of age classes, site quality, and condition to be a distinguishable unit. It is the basic and usually the most refined management unit upon which silvicultural treatments can be applied. The internal structure of stands varies mainly with respect to the degree that different species and age classes are intermingled. The simplest kind of structure and developmental pattern is that of the pure, even-aged plantation. The range of complexity can extend to a wide variety of combinations of age classes and species in various vertical and horizontal arrangements. The development of stands over time, or **stand dynamics**, is considered in Chapter 4.

From the standpoint of forest management, the term "forest" has a special meaning and denotes a collection of stands administered as an integrated unit, usually under one ownership. Putting stands together into forests is especially important in regulating harvests of products (timber and non-timber), as well as managing wildlife populations and large watersheds.

One objective of this type of planning for timber is to achieve a sustained yield of products. The forest, not the stand, is the unit from which sustained yield is sought. Management studies of prospective growth and yield determine the volumes of the products to be removed from the whole forest in a given period. The silvicultural principles listed earlier should govern the sequence and manner in which individual stands reproduce the required structures, yields and compositions. The tendency to treat large groups of dissimilar stands as if they conformed to a uniform, hypothetical average should be studiously avoided. However, a decision must be made regarding the minimum size of stand delineation.

Silviculture that is concerned with natural processes involving wildlife, flowing water, and whole landscapes also involves the arrangement and juxtaposition of stands. Differences between adjacent stands and the distribution of stands across landscapes need to be taken into account as part of the management of forests or ecosystems at much larger landscape, watershed, and regional scales.

The size and number of stands recognized depend on the intensity of practice, the economic values and social drivers of the stands, the diversity of site conditions, and the ease of mapping. Where intensive forestry is feasible, stands as small as 0.6 acres (0.25 ha) may be recognized. But under crude, extensive practice, the same forest might be divided into units no smaller than several hundred acres. The best policy is to recognize the smallest stands that can be conveniently delineated on the maps of forest types and age classes used in administration. Even after stand maps have been put on paper, the forester must still deal with variations that actually exist within each stand. From a technical perspective, each portion is best treated separately, although acceptance of too many variations would eventually create a mosaic of conditions that would be awkward for most operations. With remotely sensed data that can be obtained to the nearest 10 ft^2 (1 m^2), technologies make the identification and delineation of stands almost a continuous process as forests change and develop over time. This makes silviculture and its associated treatments more harmonious with the continuums and gradients of ongoing natural processes.

The production of benefits by forest stands is controlled by the stand developmental processes, whether these benefits be wood, wildlife, water, forage, or scenery. The processes start with the birth of the stands, continue with competition between trees, and end with the death of old trees and their replacement. The simplest kind of stand development process is that of the **pure even-aged stand** in which the trees are "pure," that is, all of one species, and start together after the previous stand is removed. Such stands are often ones that have been planted. **Uneven-aged stands** (two to three age classes are considered **multi-aged**; more than three age classes are considered **all-aged**) have trees or (more commonly, groups of trees) of different ages and much more complicated developmental patterns. **Mixed stands** have more than one tree species, and the interaction between them makes their development even more complicated, especially if they also have more than a single age class of trees. The development of these different kinds of stands is discussed in Chapters 4 and 5 and Chapters 8–13.

Defining Kinds of Silvicultural Treatments

The act of replacing old trees, either naturally or artificially, is called **regeneration** or **reproduction**. These two words, which are synonymous in this usage, also refer to the new growth that develops.

There is also the question of the terminology used for silvicultural treatments. There are two broad categories: (1) **methods of reproduction** refer to treatments of stand and site during the period of regeneration or establishment, while (2) **tending** or **intermediate cutting** refers to post-establishment treatments that occur at other times during the rotation (Fig. 2.3).

Reproduction or **regeneration cuttings** are made with the twin purposes of removing the old trees and creating environments favorable for establishment of regeneration. The period over which such regeneration treatments extend is the **reproduction** or **regeneration period**. Regeneration cuttings range from one to several in number, and the regeneration period may extend from several years to several decades. In truly uneven-aged stands, regeneration is almost always underway in some part of the stand. The regeneration period begins when preparatory site and cutting treatments start, and it ends when young trees, free to grow, are dependably established in acceptable numbers. The **rotation** is the period during which a single crop or generation is allowed to grow.

The names of the various methods of regeneration (see Chapter 6) are primarily defined by regeneration origin and secondly by the patterns of cutting in time and space that determine the structure of the new stands created. They distinguish between reliance on reproduction from seeds or reproduction from vegetative sprouts and may tell a little about the degree of shading of new seedlings. Later chapters describe how clearcutting is associated with pure, shade-intolerant even-aged stands (Chapter 8); seed trees with a dependence on a nearby seed source (Chapter 9); shelterwood methods and their uneven-aged (multi-aged) variants, with advance regeneration (Chapters 10 and 11); coppice methods, with sprout regeneration (Chapter 12); and the selection system, with uneven-aged (all-aged) stands (Chapter 13). The names of the methods, systems, and kinds of stands usually only begin to describe fully the details of silvicultural management programs.

Silvicultural treatments are not limited to ensuring regeneration. Other treatments may be applied after the stand is established and during the long period that elapses while the stand grows through various stages until it is ready for replacement. Various **intermediate cuttings** or **tending operations** are conducted to improve the existing stand, regulate its growth, create particular structure, treat individual trees, and/or provide for early financial returns, without any effort directed at regeneration. Sometimes these treatments are referred to as **stand improvement operations** or **timber stand improvement (TSI)**, when they yield no products or services (Chapters 19 and 22).

Intermediate cuttings that are aimed primarily at controlling the growth of stands by adjusting stand density or species composition are called **thinnings** (Chapters 21 and 22). Treatments conducted to regulate species

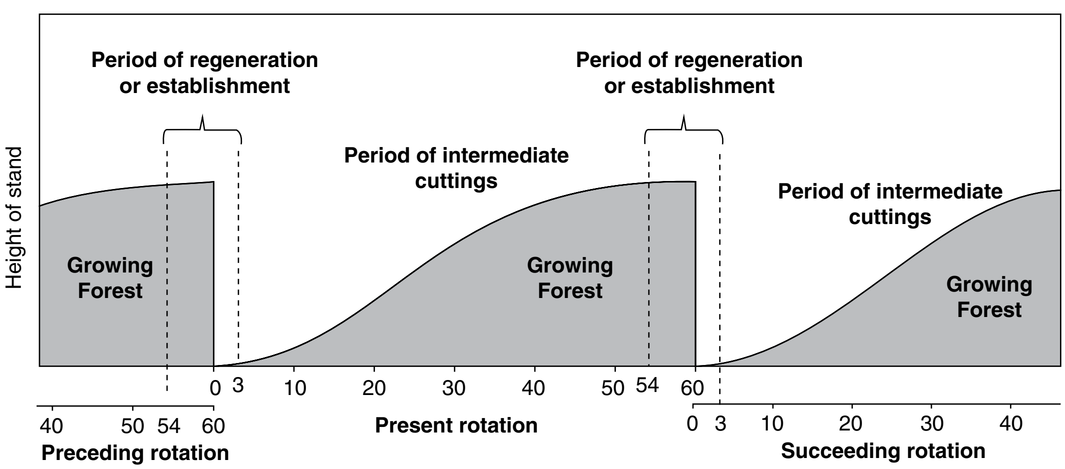


Figure 2.3 The relationship between the period of regeneration and the period of intermediate cuttings is shown for a sequence of even-aged stands managed on a 60-year rotation according to the shelterwood system. In this system the new stand is started before the older one is completely removed. *Source:* Yale School of Forestry and Environmental Studies/Mark S. Ashton.

composition and improve very young stands are **release operations** (Chapter 20). Those that involve only the branches are **pruning** (Chapter 19). Many kinds of intermediate cutting or tending can now be accomplished without actually cutting down trees, for example, by girdling and use of herbicides.

Protection against injury is as much a part of silviculture as harvesting, regenerating, and tending of forests. It is so important that it has led to fields of specialization in forestry such as restoration ecology, entomology, pathology, control of invasives, and fire control, and now impacts of climate change. Chapters 25, 26, and 27 are devoted to outlining the silvicultural aspects of these fields. The details of almost any successful silvicultural system include significant modifications designed to reduce injuries. Where such measures fail or are inadequate it is sometimes desirable to conduct **salvage cuttings** to recover the values represented by damaged trees or stands.

A program for the treatment of a stand during a whole rotation is called a **silvicultural system**. The silvicultural system is usually given the same name as the regeneration method that is used during stand replacement. This is because these regeneration methods determine the kinds of stands and stand developmental processes that occur during a whole rotation.

Role of Cutting in Silviculture

The techniques of silviculture proceed on the basic assumption that the vegetation on any site tends to extend itself aggressively to occupy the available growing space. The limit on growing space is usually set by the availability of light, water, inorganic nutrients, or carbon dioxide. Generally, the most limiting of these factors will determine the available amount of growing space, although an abundant supply of one factor can partially offset deficiency of another. If the vegetation nearly fills the growing space, the only way that the forest can be altered or controlled is by removing trees and other plants to open up growing space. In reproduction cutting, this is done to provide room for the establishment of new trees; in intermediate cutting, it is done to promote the growth of desirable trees already in existence. Paradoxical as it may seem, useful forests are created and maintained chiefly by judiciously choosing and destroying some of their parts. One of the characteristics of life is death; if there were no death, there would be no space for new life. Simply put, silviculture usurps nature's role by creating new trees rather than waiting for disturbance and by facilitating the survival of chosen existing trees by intentional thinning rather than natural self-thinning.

The ax and other means of killing trees can, in other words, be used for the construction as well as the destruction of the forest. What is left or what replaces what is harvested is more important silviculturally than what is cut. Unfortunately, much of the general public as well as some loggers have eyes only for what is cut and regard the harvests as simply the mining of a non-renewable resource.

Preoccupation with the trees should not cause foresters to overlook the lesser vegetation and the animals that are a part of the forest community. The animals ultimately depend on the vegetation for food and thus do not compete directly for the growing space. However, whether they be defoliating insects or carnivores that feed on herbivorous mammals, they exert major influence on the nature of the vegetation even as they are, in turn, controlled by it. The fauna and non-woody vegetation of the forest are as affected by cutting as the trees are.

Effect of Cutting on Growing Stock

Cutting trees controls not only the composition and structure of forest stands, but also the relationship between trees reserved for continued growth and the space created for new trees. It is therefore important to understand the long-term, cumulative effect of cutting operations in building or degrading a forest.

The trees that must be reserved somewhere in the forest to continue production are the **growing stock** or **forest capital**. The volume of wood that is grown in the future depends on the quantity and condition of growing stock that is maintained. Cuttings regulate the amount of this growing stock and its distribution within individual stands or among the various stands that comprise the forest. The regulation of growing stock is of most crucial importance in silviculture when partial cuttings are applied within stands.

References

Barnes, B. V., Zak, D. R., Denton, S. R., and Spurr, S. H. 1998. *Forest ecology*. 4th ed. John Wiley and Sons, New York. 774 pp.

Burns, R. M., and Honkala, B. H. 1990. *Silvics of North America*. Vol. 2. USDA Forestry Service Agriculture Handbook, 654.

Daniel, T. W., Helms, J. A., and Baker, F. S. 1979. *Principles of Silviculture*. 2nd ed. McGraw-Hill, New York. 500 pp.

Ford-Robertson, F. C. (ed.). 1978. *Terminology of Forest Science, Technology, Practice and Products*. Society of American Foresters, Washington, D.C. 349 pp.

Kimmins, J. P. 1987. *Forest Ecology*. Macmillan, New York. 531 pp.
Kimmins, J. P. 2003. *Forest Ecology*. 3rd ed. Macmillan, New York. 542 pp.
Kozlowski, T. T., Kramer, P. J., and Pallardy, S. G. 1991. *The Physiological Ecology of Woody Plants*. Academic Press, San Diego. 657 pp.
Lassoie, J. P. and Hinckley, T. M. (eds.). 1991. *Techniques and Approaches in Forest Tree Ecophysiology*. CRC Press, Boca Raton, Fla. 599 pp.
Oldeman, R. A. A. 1990. *Forests: Elements of Silvology*. Springer-Verlag, New York. 624 pp.
Packham, J. R., Harding, D. J. L., Hilton, G. M., and Suttard, R. A. 1992. *Functional Ecology of Woodlands*. Chapman & Hall, New York. 208 pp.
Perry, D. A., Oren, R., and Hart, S. C. 2008. *Forest Ecosystems*. 2nd ed. Johns Hopkins Press, Baltimore. 632 pp.
Society of American Foresters, Silviculture Instructors Sub-Group. 1994. *Silviculture Terminology*. Society of American Foresters, Bethesda, Md. 14 pp.
Spurr, S. H. and Barnes, B. V. 1980. *Forest Ecology*. 3rd ed. John Wiley and Sons, New York. 687 pp.
Waring, R. H. and Running, S. W. 2007. *Forest Ecosystems*. 3rd ed. Academic Press, New York, 440 pp.
Whitmore, T. C. 1990. *An Introduction to Tropical Rainforests*. Oxford University Press, New York. 226 pp.

Part 2

Ecological Foundations of Silviculture

The ecological foundations for silvicultural practice through understanding the complexities of site and scale; the development and dynamics of forest stands; and the nature of forest regeneration in relation to disturbance.

The Practice of Silviculture: Applied Forest Ecology, Tenth Edition. Mark S. Ashton and Matthew J. Kelty.

3

Ecological Site Classification, Stands as Management Units, and Landscape-Scale Planning

Introduction

The Ecosystem Concept

It was recognized long ago that both study and application of ecology suffered from excessive compartmentalization. The total flora of interacting forest plants is far more than just trees; the total biota of a place includes not only plants but all the orders of the animal kingdom that are present. An ecosystem, however, is more than just the living organisms. It also includes the non-living physical and chemical factors that interact with the living organisms (Tansley, 1935).

In applying silvicultural treatments, a forester is, in some degree, manipulating many sizes of ecosystems simultaneously (Reichle, 1981; Perry, Oren, and Hart, 2008). At one extreme are the world cycles of carbon, oxygen, and water; the microenvironment around a pine seedling in the shade of a log is at another; and in between are the cycles of mineral nutrients and the combination of different kinds of forest stands on a hillside. **Forest ecosystem management** includes the design and application of silvicultural solutions that are based on analysis of all the ecological factors known to operate in the system involved. In other words, silviculture has always been ecosystem management, provided that it is conducted on the basis of such analysis. Ecosystem management is one of the keys to maintaining biodiversity for it requires consideration of the interaction and habitat requirements of all living organisms.

Silvicultural treatments achieve their results through deliberate manipulation of the forces represented by physical, chemical, and biological processes that alter ecosystems in somewhat the same manner that purely natural forces produce changes in ecosystems. In ecosystem management, it is necessary to consider the spatial arrangement of stands of differing ages and species composition and how they vary within an ecological site condition. In other words, it is best if silvicultural planning and forest management are not restrained by boundaries of stands and ownerships. Insofar as possible, such planning should consider the landscape scale in which ecosystem boundaries are defined by watersheds, climate, topography, and the ranges of plant and animal species.

All good ideas survive to be overdone, and the ecosystem concept is no exception. It is too easily translated into the philosophically attractive concept that each biotic community is a superorganism in which each constituent species is indispensable and somehow depends on every other species. Although it can perhaps be said that every part of an ecosystem has some effect, even if minuscule, on every other part, each part does not depend on every other part. There are many important interactions between particular species, such as symbiosis and competition, predation and parasitism, or simply shading of one plant species by another. Although these interactions need to be recognized (and used) in silviculture, they do not mean that all parts are like essential cogs in a whole engine. The vast majority of species are adaptable to many different conditions and often move around independently of their associates. If two different species are dependent on each other, they are usually adapted to move or respond to change together.

Natural disturbances and subsequent development processes commonly lead to the development of particular combinations of species of trees, lesser plants, animals, and other forms of life on particular kinds of sites in a given climatic region. These are called **communities**. Some species within them are dependent on others. For example, pines depend on mycorrhizal species of fungi; herbivores, on the foliage; and bark beetles, on dead or dying trees. However, most of the trees and other organisms are not dependent on each other, and the weight of evidence is against the idea that they have, as is often claimed, lived in association and been dependent on each other for millions of years.

Evidence from pollen deposits shows that most tree species have moved around quite independently of each other since the continental glaciers started to shrink about 15,000 years ago. Most modern plant communities, including those in the tropics, are less than 8000 years

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