1

Introduction

Abstract

The terms 'forest management' and 'silviculture' refer to deliberate, professional human interaction with forest ecosystems, i.e. the direct hands-on human interference with tree vegetation for particular purposes – which, in one way or another, is almost as old as mankind. Over the last 200 years, a wide range of different techniques have been developed, refined, and formalised in forest practice and science with the objective to modify forest structure and thus to steer forest development into certain desired directions.

This chapter outlines the basic concepts and techniques of forest management and silviculture in a changing world. The text provides non-specialists with an easy access to this field of forest ecosystem management by explaining basic terms and definitions. The concept of continuous cover forestry (CCF) is introduced, and how the history of different societies has contributed to its shaping is described. Common misconceptions are explored, and important sustainability concepts are explained. Finally, the place of CCF in a changing world is outlined, and suggestions are made as to how to introduce CCF to a new region or country.

1.1 When Is a Forest a Forest?

Despite their very different plant compositions forests form very characteristic plant communities which set them aside from other vegetation forms (such as grasslands, shrublands, bog vegetation) not only in terms of visual appearance but also in terms of ecology. Trees, as large woody plants, are the most significant element of wooded landscapes. Forest trees are, unlike fruit trees, for example, only rarely genetically modified organisms, whether native to their sites or introduced from another, ecologically similar region. In order to form a forest, trees have to be so close to each other in a sufficiently large land area that they form a common crown canopy which shades the forest floor to a large extent. Only under these circumstances can life conditions be sustained which are very different from any other plant formation. After afforestation or replanting, it takes time for the elements which form the typical characteristics of a forest to appear. Such typical elements are the size of the forest area, canopy closure, forest soils and woodland microclimate and a specific vegetation of vascular plants on the forest floor which only occurs in forests. Natural disturbances and human interventions can destroy some of these elements.

Continuous Cover Forestry: Theories, Concepts, and Implementation, First Edition. Arne Pommerening.

But as long as the tree vegetation is sustained and can again develop a more or less closed formation, the corresponding land area remains a forest (Burschel and Huss, 1997).

> 'In the United Kingdom, a woodland or forest is defined as land with a minimum area of 0.1 ha under stands of trees with, or with the potential to achieve, tree crown cover of more than 20%. Areas of open space integral to the woodlands are also included. Orchards and urban woodland between 0.1 and 2 ha are excluded. Intervening land-classes such as roads, rivers or pipelines are disregarded if less than 50 m in extent'.
>
> National Inventory of Woodland & Trees – Wales

There is no world-wide unique definition of forests. In developed countries, the lower limit in older forest stands is a crown canopy closure of more than 20%, while in many developing countries, only 10% is required. This affects the estimation of deforested areas around the world (Bartsch et al., 2020).

The IUFRO (International Union of Forest Research Organisations) terminology of forest management (Nieuwenhuis, 2000) provided an ecology and a management motivated definition:

> *Forest (ecology perspective)*
> 'Generally an ecosystem characterised by a more or less dense and extensive tree cover. More particularly, a plant community predominantly of trees and other woody vegetation, growing more or less closely together'.
>
> *Forest (silviculture/forest management perspective)*
> 'An area managed for the production of timber and other forest produce, or maintained under woody vegetation for such indirect benefits as protection of catchment areas or recreation'.

Helms (1998) in his dictionary of forestry put forward the following definition of a forest:

> 'An ecosystem characterised by a more or less dense and extensive tree cover, often consisting of stands varying in characteristics such as species composition, structure, age class, and associated processes, and commonly including meadows, streams, fish, and wildlife […]'.

Finally, Thomasius (1990) characterised forests as ecosystems, in which life forms dominate, which

- reach such a height,
- are so close together,
- occupy a sufficiently large area,

so that the spatial occupation by living and dead biomass leads to

- a specific microclimate,
- characteristic soil conditions and
- interactions between the different organisms that influence their onto-, auxo- and morphogenesis.

Consequently, three conditions need to be fulfilled to deserve the status of a forest:

1. The dominant life form must be trees which reach a total height of at least 7 m in their adult stage (under extreme environmental conditions 3 m is often also acceptable).
2. The trees must form stands which shade at least 20% of the soil surface.
3. Stands of trees have to occupy an area A with a radius r which with full crown closure corresponds at least to their height.

These features create a habitat for plants and animals which require the specific microclimatic and/or soil conditions of a forest or which are dependent on other life forms that occur in forest ecosystems (Thomasius, 1990). A forest is a highly interactive community of organisms with the tree life form dominating among the energy-capturing green plants. These plants generate the cascade of energy that supports food webs composed of thousands of species (Franklin et al., 2018).

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. This division of forests into stands is especially important in regulating timber harvests as well as managing wildlife populations and large watersheds. One objective of stand management for timber products is usually the achievement of sustained yield. However, the forest (estate or district), and not the stand, usually is the unit from which this sustained yield is sought. Management studies of prospective growth and yield determine the volume of timber to be removed from the whole forest in a given period (Smith et al., 1997).

Thomas and Packham (2007) and Helms (1998) noted that the terms ‘forest’ and ‘woodland’ are commonly used almost interchangeably. In agreement with public perception, they suggested that a woodland is a small area of trees with an open canopy (often defined as having 40% canopy closure or less) such that plenty of light reaches the ground, encouraging other vegetation to grow beneath the trees. Since the trees are well spaced, they tend to be short-trunked with large canopies. The term ‘forest’, Thomas and Packham (2007) asserted, by contrast, is usually reserved for a relatively large area of trees forming for the most part a closed, dense canopy. Since the terms ‘woodland’ and ‘forest’ overlap, we have used them as synonyms in this book. A forest is made up of a series of more or less homogeneous stands, and the main focus of silviculture is on these forest stands with trees as their main components.

A forest stand is a contiguous community of trees sufficiently uniform in species composition, density, structure and/or age-class distribution, and growing on a site of sufficiently uniform site conditions and site quality, of a sufficient size to be a distinguishable planning and management unit (Thomasius, 1990; Helms, 1998; Nieuwenhuis, 2000; Franklin et al., 2018; Smith et al., 1997).

In continuous cover forestry (CCF), forest managers commonly deal with stands that can be quite diverse in terms of tree species, sizes and dispersal. Consequently, in this book, we used the term 'stand' in its broadest interpretation often denoting a distinctive population of trees (Franklin et al., 2018). In many countries, forest stands usually coincide with sub-compartments, as these administrative units were chosen to reflect the forest stand definition. Tree canopies or crowns of a forest stand can usually be found in one or more canopy levels. The uppermost canopy level is referred to as *overstorey*, the lowest layer of vegetation is the *understorey* and tree canopies in between over- and understorey form the *mid-storey* (Helms, 1998). For a possible quantitative definition of these forest canopy levels see Table 4.3. The vertical tree canopy structure of forest stands plays an important role in CCF, see, for example, Figure 2.15.

1.2 The Nature of Forestry and Forest Management

Nyland (2002) stated that forestry involves the science, business and practice of purposefully organising, managing and using forests and their resources to benefit people. Many authors adopted the anthropocentric view that it is the prime objective of forestry to satisfy the forest-related demands of society in a sustainable way with minimum input of scarce resources, e.g. energy and money (Köstler, 1956; Bartsch et al., 2020). These demands include the provision of various goods and services, namely of raw materials, environmental conservation and the conservation of aesthetical and spiritual properties (see Section 7.3.3). For a long time, the production of timber has been the only or at least the dominant objective of forestry. This has changed significantly in the last few decades in many parts of the world, although timber production will undoubtedly continue to be important. Even many academic educational programmes lag a little behind in this emancipation of forestry.

To achieve the general objectives of forestry, there are a number of academic and practical fields that help deliver them. The most central one is forest management or silviculture. Köstler (1956) wrote that silviculture is the kernel of forestry and forest science, for it includes direct action in the forest, and in it, all objectives and all technical considerations ultimately converge. Silviculture today is still the main academic discipline providing methods and techniques for goal-oriented management of forest vegetation for a wide range of ecosystem goods and services, i.e. the science of deliberate human–tree interaction. This is the main reason why this field is very attractive to students and largely contributes to their decision to enrol on a forest science rather than an ecology or nature conservation degree programme. Similar to the use of the terms 'ecosystem management' and 'conservation management', forest management is often used as a synonym of silviculture and sometimes even of forestry as a whole (Helms, 1998). In this book, both terms are used as synonyms. Silviculture has a long history and is the oldest and possibly most traditional subject of forest science and education. As such it also carries much traditional, inherited 'baggage' that sometimes is more a hindrance rather than a help (see Section 8.3) and hard to leave behind.

The purely natural forest is governed by no purpose unless it be the unceasing struggle of all the component plant and animal species to perpetuate themselves. Human intervention (be it, for example, for timber production or conservation) is characterised by preference for certain tree species, stand structures, or processes of stand development that have desirable characteristics for the purpose in mind. In silviculture, natural processes are deliberately manipulated to create forests that a majority of humans of a given society perceives as more useful than natural ones and to do so in as short a time as possible (Smith et al., 1997; Nyland, 2002). Given the lifetime of humans compared to that of trees, the acceleration effect achieved by silviculture is not unimportant. The primary objective of silviculture is therefore not necessarily the reconstruction of natural forests but, rather, the establishment and management of forests that can satisfy societary needs. This still requires, however, the retention of a forest's functioning as a viable ecosystem.

Silviculture, and particularly CCF, have gradually developed to use natural processes to a large extent in order to meet societary needs. The ability to utilise the forces of nature has improved during the history of mankind through an increased knowledge of natural laws (Thomasius, 1990). The gradual emancipation from agriculture has made room for employing natural processes in forest management. As a result, it is now entirely possible to conduct forestry indefinitely without the degradation of soils that is almost inevitable in most agriculture and in other 'higher' uses of land.

The Roman writer Pliny used the term *silvicultura* for the first time (Mayer, 1984). The German equivalent *Waldbau* was coined around 1764 in a time when large-scale forest restoration took place following long-term devastation (Hasel and Schwartz, 2006). A literal translation would be 'forest building', 'forest construction' or 'forest design'. This rather strange term was used in the Germany of the eighteenth century to label a new discipline, which was initially thought to be the forestry equivalent to *Feldbau*, i.e. agronomy (Cotta, 1816). The strong legacy of agriculture in forestry is still evident in the agricultural term 'crop' that is often used by foresters to refer to a forest stand or to a plantation grown for commercial purposes, whilst using the expression 'crop trees' to distinguish desired trees from less desired trees (Puettmann et al., 2009, see Chapter 3). Early concepts of ensuring sustainability such as the 'normal forest' (see Section 1.8) owe much to agriculture, and this legacy lives still on in plantation forestry (Heger, 1955).

Only gradually it became evident that silviculture had to follow very different lines than agronomy, since long production periods of 100 years (and more) and the limited possibilities of influencing production processes set forestry apart from agriculture (see Table 1.1). In agronomy, with its short production periods and with plenty of opportunities for technical manipulation of production, biological processes are part of an industrial framework. On the other hand, agricultural production is influenced much more by short-term weather fluctuations and extremes than forestry. The same applies to changes in the timber market: A forest company can choose to cut less in one year or even over the course of several years. When the market is ready to take larger quantities of certain timber assortments again, these timber reserves can then be reduced. Such flexibility is difficult to achieve in agriculture.

Successful long-term forest management has to be based on biological–ecological requirements, because there is little scope for technical manipulation which is also increasingly being restricted by law in many countries. Therefore, silviculturists by definition are bound to understand and to employ natural processes to meet economic objectives. Economic objectives have to be based on ecological and environmental site limitations rather than

Table 1.1 Characteristics for agronomy (agriculture) and silviculture (forestry).

Criteria	Agronomy (agriculture)	Silviculture (forestry)
Target plants	Short-lived grass, herb and perennial species	Long-lived trees
Production period	1 year	40–350 (120) years
Objectives	Meeting current well known demand	Speculative anticipation of future unknown demand
Amortisation of investments	Short with average interest rates	Long-term with low interest rates
Production risk	Low (insurance)	High (owner has to take the risk)
Scope for increasing yield	Larger	Smaller
Fertilisation	Standard. Short-term effect, increased yield rapidly available	Uncommon or prevented by law. Short-term effect with little influence on long-term production
Breeding results	Applicable after few years of testing	Applicable only after 1–2 forest generations (130–300 years)
Production	Cultivation, harvesting and processing mostly within one year	Harvest – management result of past forester generations, processing at present time, replanting for future generations, 4–6 generations of foresters in total
Historical aspects	Only present-day conditions matter	Past management has a long-lasting influence (forest development history)
Initial biological conditions	Artificial plant community with short life expectancy (4–6 months), which is kept alive artificially through soil preparation, fertilisation and chemicals. Maximum production expected	Near-natural to semi-natural biocenosis with long life expectancy (80–120 years). Only stable structures are able to provide long-term production, stands far removed from natural conditions can be at a very high risk

Source: Adapted from Mayer (1984).

keeping highly artificial, industrial and risky crops alive by tending symptoms through chemical forest protection, fertilisation and weeding (Mayer, 1984).

The German term, more than the English word, reflects the main task of silviculture – the active building and development of forests following a plan, which is largely determined by societary needs or preferences. Even forest conservation is anthropocentric, as it satisfies a particular societary need for protecting and sustaining nature. Morosov (1959) pointed out that silviculture bizarrely enough owes its existence to large-scale forest degradation and a painful lack of timber resources. Without this cataclysmic forest degradation and timber shortage, which came to the Europeans as a shock and turned into a long-term trauma, there would not have been a need to consider silviculture and to address sustainability. Dengler (1944) noted that silviculture is concerned with the building and design of forests by arranging their individual components, the forest stands, which significantly influence production, health and utilisation of the forest. In Central Europe, Schädelin, Leibundgut, Abetz and Pollanschütz made the next logical step and extended this idea by breaking these individual components even further down to the level of individual trees (Pommerening et al., 2021a, see Chapter 3).

Silviculture as we know it today is a process of forest engineering aimed at creating structures or developmental sequences that eventually serve the intended purposes, whilst being in harmony with the environment and withstanding the loads imposed by environmental influences. Because forests grow and considerably change with time, their design is more sophisticated and difficult to envision than that of static buildings. This complexity and the fact that considerable costs were involved have made foresters uneasy about their investments in the past and, as an expression of this, natural disturbances have often been labelled as 'calamities' and 'risks' (Puettmann et al., 2009).

Furthermore, forest stands alter their own environment sufficiently that the forester is partly creating a new ecosystem and partly adapting to the one that already exists (Smith et al., 1997). Based on Helms (1998) and Nyland (2002), we can summarise these aspects in the following definition:

> The term 'silviculture' or 'forest management' denotes the main activity of forestry to establish new forests and the management and regeneration of existing ones as healthy communities of trees and other vegetation. Silvicultural activities should aim to maintain and improve site quality and growth, resilience, quality and diversity of forest vegetation to meet the targeted diverse needs and values of landowners and other members of society on a sustainable basis.

Silviculture is the oldest conscious application of the science of ecology and is a field that was recognised even before the term 'ecology' was coined. It is concerned with the technology of growing tree vegetation. Silviculture is also a major part of the biological technology that carries ecosystem management into action (Smith et al., 1997) and silvicultural activities reflect the forester's efforts to imitate natural succession and disturbance. As such silviculture is fundamental to sustainable forestry (Nyland, 2002).

Silviculture and forest management heavily draw on a wide range of basic sciences as does practical silviculture carried out by forest managers in the field. These basic sciences include soil science, climatology, geology, dendrology, hydrology, ecophysiology and many more. When talking about silviculture, it can be practical to distinguish different hierarchical levels. These are

- Tree,
- Stand,
- Forest,
- Landscape.

For planning purposes, public and private forest services have other or additional hierarchical levels such as for example sub-compartment, compartment, local area and district.

1.3 Silvicultural Regimes and Types of Forest Management

Silvicultural regimes are technically different methods which give whole forests their specific character (Köstler, 1956). In the Anglo-American literature, both silvicultural regimes and forest regeneration methods are usually lumped together by the term 'silvicultural systems' (see, for example, Matthews, 1991; Nyland, 2002). In this tradition, silvicultural systems are perceived as 'plans for management' (Nyland, 2002) or 'planned programmes of silvicultural treatment' (Smith et al., 1997) including and fully integrating the three main domains of silviculture, i.e. establishment, thinning and harvesting, and extending throughout the life of a forest stand or its present generation. This concept differs from the European view where most silvicultural systems are purely seen as regeneration methods, whilst coppice, coppice with standards and high forest are fundamental silvicultural regimes operating at a higher conceptional level than silvicultural systems, see, for example, Burschel and Huss (1997) and Bartsch et al. (2020). Particularly in the central parts of Europe, it was felt that silvicultural regimes are structural and management archetypes that give all stands subjected to the same regime a similar, general appearance and long-term character. This difference in long-term fundamental appearance sets them apart from the short-term silvicultural systems that they were separated from as a matter of principle (Köstler, 1956; Figure 1.1).

One of the oldest silvicultural regimes is *coppice* or *low forest* (in some of the European terminologies like, for example, in German and Spanish), because they were perceived as being limited in stand height due to vegetative reproduction and short rotation (Smith et al., 1997), i.e. a short production period, cf. Figure 1.4. It is believed that this silvicultural regime was first discovered in the Neolithic as a natural consequence of clearing forest vegetation for settlements (Matthews, 1991). When felled near ground level, some of the trees re-sprouted from dormant, adventitious buds in the cambial layer of the remaining tree stumps (also

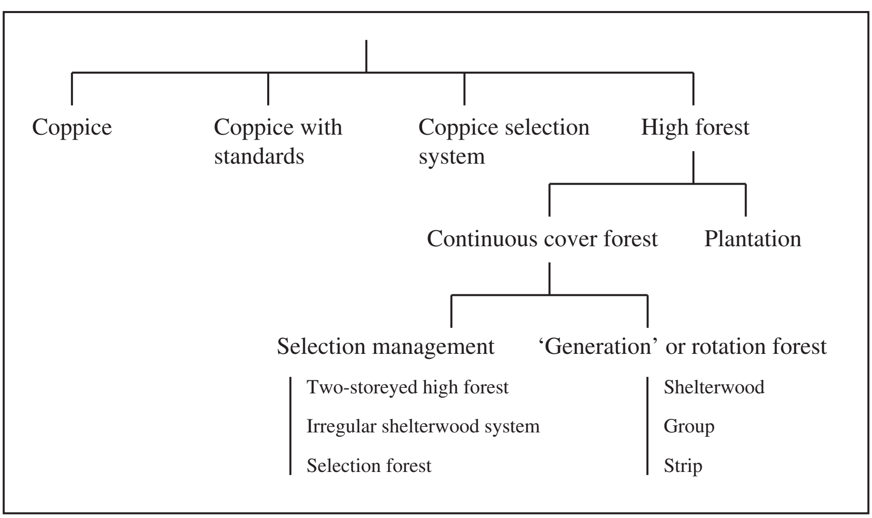

Figure 1.1 The relationship between silvicultural regimes and basic silvicultural systems. Source: Adapted from Pommerening and Grabarnik (2019).

termed *stools*) or at the roots (root *suckers*) and these *shoots* gave rise to a secondary forest that eventually developed into a coppice forest. Layering of trees is another, but rare, technique of coppicing. It naturally occurs in peat bogs where *Sphagnum* spp. moss tends to overgrow the lower branches of trees in open stands so that roots start to form on them with time. Artificial layering is one of the techniques of inducing branches to form roots while they are still firmly attached to the trees. Later, they can be severed and left *in situ* or planted elsewhere (Smith et al., 1997). These processes of vegetative regeneration are collectively referred to as *coppicing* (Nyland, 2002).

Coppicing was well developed in Roman times and often coupled with the introduction of the species *Castanea sativa* Mill.. The method was perfected towards the High Middle Ages (Hasel and Schwartz, 2006). Coppice forests (sometimes also referred to as *copses*) typically have a short rotation length, i.e. all trees are cut every 15 to 25 years because the sprouting ability of trees decreases with age and because traditionally the focus was on small-sized timber assortments (Rittershofer, 1999; Bartsch et al., 2020). New trees of seedling origin occasionally replace worn-out stools. In England, hazel (*Corylus avellana* L.) grown in coppice forests for thatching spars is cut every five to seven years which suggests that many other shrub species may be suitable as well. After coppicing, which essentially is a clearfelling operation, the forest then regenerates from stool shoots and root suckers (Figure 1.2). Coppice woodlands are rarely thinned, but on occasion there may be some merit in removing abundant shoots, thereby improving the growth of the remaining stems (Hart, 1995). It is likely that first concepts of rotation and timber sustainability were developed for coppice forests before they were applied to other silvicultural regimes (Hasel and Schwartz, 2006). Due to their fairly short lifetime, the tree diameters involved remain small. In contrast to trees in high forests, each tree of a low forest typically tends to have multiple stems. These stems form vegetation clusters and share similarities with the basitonic growth pattern of shrubs.

In coppice forests, broadleaved species are predominantly used not least for their prolific resprouting ability. In Europe, tree genera included in coppice forests are *Acer*, *Alnus*, *Betula*, *Castanea*, *Carpinus*, *Corylus*, *Fraxinus*, *Populus*, *Prunus*, *Quercus*, *Robinia*, *Salus*, *Sorbus*, *Tilia* and *Ulmus*. Some species of *Eucalyptus* apparently show phenomenal coppicing potential (Matthews, 1991; Nyland, 2002). The resprouting ability typically decreases with repeated coppicing. Regionally different types of coppice forest exist that favour

Figure 1.2 Resprouting of *Catanea sativa* Mill. trees from coppiced stools in the Swiss canton Ticino. Source: © Arne Pommerening (Author).

different species, are managed in different ways or have specialised on delivering particular timber products. The main products of coppice forests included firewood, fencing material, posts, staves for barrels, tanning agents for leather production, roofing materials, charcoal, bark and other small-sized items. A special form of coppice management is *pollarding*, in which the tops of trees are removed, thus inducing them to sprout at points above the reach of browsing animals (Smith et al., 1997), i.e. coppicing can be carried out at different stem heights. In conservation, the pollarding of *Fraxinus excelsior* L., *Carpinus betulus* L. and *Salix* spp. plays an important role in Europe. Whilst being a simple and ancient regime, coppice forests are currently re-visited as a source for animal fodder and fuelwood contributing to renewable energy. Short-rotation coppice (SRC) forests relying on fast-growing species such as *Salus* and *Populus* on agricultural land have in recent years been much considered throughout Europe for the production of sustainable biofuels and pulp (Bartsch et al., 2020).

By ways of gradual evolution and diversification coppice with standards or middle forest (in some of the Central European terminologies) were developed when the need for larger-sized products arose along with the traditional coppice products. As such this regime is on a continuous scale somewhere between coppice and high forest, but in terms of tree morphology, it is closer to coppice forests. Coppice with standards dates to at least the thirteenth century, and such woodlands were often managed by rural communities. It is likely that the origin of this silvicultural regime lies in France (Bartsch et al., 2020). Essentially, coppice with standards (cf. Figure 1.3) is a combination of trees grown from coppice shoots and from seedlings. Whilst the former would remain comparatively short, the standards (sometimes also referred to as reserves) would become large trees. This combination gives rise to two *permanent* canopy layers. Some main-canopy trees may also originate from former coppice trees that were not coppiced any more. The lower canopy (referred to as *underwood*) serves the same purpose as the trees in coppice forests, while the standards (termed *overwood*) are harvested for producing construction timber and furniture. The standards have shorter stems and a larger proportion of branchwood than trees grown in a comparable close-canopied high forest (Matthews, 1991). Still, Wilhelm and Rieger (2018) pointed out that overwood *Fagus sylvatica* trees of former coppice with standards woodlands often produce high-quality timber.

Since the standards are not coppiced, it is possible to include conifers in the main canopy, e.g. *Pinus*, *Larix* and occasionally also *Picea*. The main canopy in coppice with standards woodlands is comparatively open with distances of 15–20 m between the standards on average to ensure sufficient light conditions to maintain the lower canopy layer (Bartsch et al., 2020; Hart, 1995). Traditionally, management interventions first take place in the lower canopy before considering the main canopy (see Figure 1.3). Coppice with standards follows longer rotations of between 20 and 40 years. There have also been agroforestry variants of coppice, and coppice with standard woodlands where either agricultural crops were temporarily planted between the stools (Mayer, 1984), or cattle or pigs were temporarily driven into the forest to feed on acorns and/or young coppice shoots (Matthews, 1991). Coppice forests with standards have received much attention in recent years because they usually have a considerable biodiversity and conservation value and simultaneously provide fuelwood (see Section 7.3.6) and other timber and non-timber products. Regionally,

Figure 1.3 Traditional coppice with standards with *Catanea sativa* Mill. trees in the Swiss canton Ticino where the underwood has just been coppiced whilst the overwood remained untouched. In Ticino, management of coppice with standards is currently re-introduced in areas where it was used in the past for many centuries. Source: © Arne Pommerening (Author).

like in many parts of France, coppice with standards forests are important characteristics of rural landscapes (Hasel and Schwartz, 2006). Coppice with standards and related coppice selection forests (Matthews, 1991) as traditionally practised in the Swiss canton Ticino (Schweizerischer Forstverein, 1925) can clearly be a management option within CCF, whilst simple coppicing shares many similarities with rotation forestry and clear-felling. Uniform shelterwood systems are often applied for regenerating coppice with standards woodlands (cf. Figure 1.3). Schütz (2001b) stated that many selection systems (see Section 5.4) in Central Europe had their origin in coppice with standards woodlands.

High forest regimes can be characterised as forests regenerated from seeds or planted seedlings (sometimes traditionally referred to as virgin trees). This contrasts with coppice or low forest systems that originate vegetatively through natural sprouts from the stools of felled trees. The name of this regime comes from the fact that trees grown from seeds usually develop larger total heights than those that have regenerated vegetatively. Also, the production period or lifetime of a forest stand (= rotation) is usually longer. In many parts of Europe, coppice and coppice-with-standards forests were converted to high forests towards the end of the nineteenth century, a process which is currently being reversed in some regions.

Many high forests are traditionally dominated by conifers. High forests came into fashion when increasingly a need for construction and sawn timber arose. At the same time, the demand for fuel wood declined due to the discovery and the increasing availability of fossil fuels. High forests also offer a greater choice of species, since it is not necessary

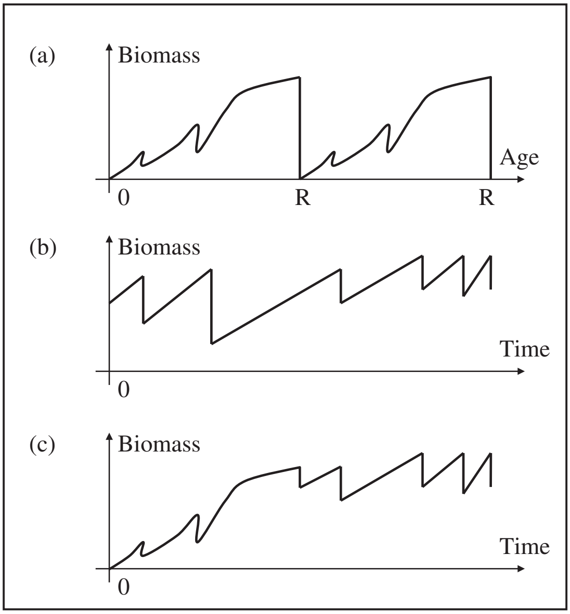

Figure 1.4 Biomass development in different management approaches. Plantation (a), CCF (b) and transformation management (c). R is rotation age. Source: Adapted from Pommerening and Grabarnik (2019).

to rely exclusively on species that are able to regenerate vegetatively (Rittershofer, 1999). The structure of high forests most closely resembles that of natural forests, since trees are usually allowed to have longer lifespans and larger total heights than in the other two regimes. High forest trees typically have single stems that show more or less acrotonic growth in contrast to shrubs and coppiced trees (Pommerening and Grabarnik, 2019). High forest regimes can be further subdivided into plantation forest management and CCF or near-natural forest management, based on the development and continuity of tree biomass over time (Pukkala and Gadow, 2012). Associated with the first type of management is a rather abrupt or sudden transition from one forest generation or rotation to another one, usually by clearfelling all trees of a stand (see Figure 1.4).

In commercial forestry, *rotation* is the period during which a generation of a single forest stand is allowed to grow or in other words the period between establishment and final cutting. It is also known as either economic or natural maturity (Smith et al., 1997). The length of a rotation may be based on many criteria including species, mean size, age, increment culmination, growth rates, wind hazard and biological condition among others. Typical properties of plantation forest management include

- A very short period of stand establishment with instant artificial regeneration,
- The origin of seedlings is often not local and in many cases includes 'genetically improved' material,
- Low genetic diversity,
- Hardly any age difference between trees of the same stand,
- Clearfelling is the predominant harvesting method,
- Highly industrial use of timber products (e.g. pulp and paper, fibreboards).

(a) (b)

Figure 1.5 Examples of broadleaved plantations involving native tree species. (a) A *Betula* spp. plantation in Galicia (Spain) Source: © Arne Pommerening (Author). (b) A *Quercus robur* L. plantation in the Neuhaus Forest District (Lower Saxony, Germany). Source: Courtesy of Paul Cody.

Plantation forest management is the most widespread type of forest management on the planet, but compared with natural forests – that are largely unaffected by human management at least for some time – it is also the most extreme one in terms of species composition and structure. Both tree species and size diversity are low in plantations, as commonly only one species is planted, and the size structure is deliberately homogenised through forest management (see Figure 1.5).

The share of the global timber production coming from plantations is high and increasing (Pommerening and Grabarnik, 2019). However, this forest type remains a small portion of the earth's total forest cover. Plantations often involve non-native species, particularly non-native conifers, for example in Britain, but they do not necessarily need to (cf. Figure 1.5): In the United States, which has a sizeable portion of the world's planted forests, practically all plantations are of native species. In contrast, CCF is usually characterised by selective thinnings and natural regeneration, resulting in diverse horizontal and vertical tree structures and frequently, multi-species forests (see also Section 1.5.4). Since final harvesting in CCF is also selective, the difference between thinning and harvesting operations is often unimportant, particularly in CCF stands with complex structures (cf. Figure 2.15). Stand age is typically undefined in such forests and the growing stock usually oscillates about a specified level (Pukkala and Gadow, 2012). Interestingly, CCF shares similarities with the horticultural concept of *permaculture* (Whitefield, 2013). Both approaches have in common that the soil is never completely exposed at large scale and is always covered by some level of vegetation. In every country, as part of defining CCF certain thresholds for allowable gap size have entered legislation. For example, in Britain, the maximum size of an area permitted to be cleared from tree vegetation is 0.25 ha (Hart, 1995). In this context, it is remarkable that already Anderson (1953) referred to the *permanent forest* when writing about what is known as CCF and near-natural forestry today (Pommerening and Grabarnik, 2019).

Depending on how abruptly the transition from one forest generation to the next is carried out, there are grey zones and overlaps between the *age-class* or *generation*/rotation forest system and the selection forest system at the far end of the range, where no distinct tree generations and rotations exist. In the former, processes of natural regeneration are also used, but forest development still progresses in distinctive generations or rotations usually allocated to two distinctive storeys. The basic variants of shelterwood, group and strip systems are silvicultural systems that more or less propagate age-class or generation forests (see Section 5.3). As a result, the tree biomass development over time is fairly similar to the top graph in Figure 1.4 with the difference that the transition from one generation or rotation to another is smoother and less abrupt than in plantation management. Still there can be considerable age and size differences in such forests. This is contrasted by plantation forestry that can be considered an extreme form of rotation forest management with no temporal overlap at all between two successive forest generations. Also, regeneration in plantation forestry is usually (but not exclusively) established by replanting. The overstorey removals in silvicultural systems often reflect geometric shapes, i.e. in group systems overstorey trees in circular areas are removed whilst in strip systems overstorey trees in rectangles are cut (Pommerening and Grabarnik, 2019). More complex or combined silvicultural systems can include patterns of natural disturbances (cf. Section 5.3).

Selection or '*plenter*' forests (cf. Section 5.4) are a very specific type of CCF management with a wide range of age and size classes, and tree canopies present throughout the vertical growing space (Schütz, 2001b). There is evidence that any attempt to remove the age-class or generation structure of forests, for example, by maintaining a high forest with two permanent storeys (see Section 5.5), ultimately converges towards the structure of a selection system (Sterba and Zingg, 2001). Irregular shelterwood systems usually also come very close to the structure of selection forests. Conifer species appear to play a decisive role in achieving a diverse vertical stand structure, which is more difficult in broadleaved forests without any conifers (Schütz, 2001b). The selection system is the only silvicultural system where sustainability of timber resources applies at stand and not at estate or district level. Also, the selection system is the only silvicultural system that comes close to the Anglo-American view of 'planned programmes of silvicultural treatment' (Smith et al., 1997) because the overall structure of the resulting forest more or less stays the same at all times. It should also be mentioned that the *coppice selection system* (Matthews, 1991, cf. Section 5.4) as a rare exception is an interesting combination of coppicing and selection system. In contrast to conventional coppicing, not all trees are cut at the same time like in a clearfelling operation, but rather individual trees and small groups of trees are coppiced at any one time. This type of short-rotation (12–15 years) selection system was, for example, traditionally practised in the Swiss canton Ticino to produce larger stems and to avoid soil erosion (Schweizerischer Forstverein, 1925).

Often silviculturists are concerned with the *transformation* of one silvicultural regime or system to another (Matthews, 1991), see Section 2.4. As mentioned before, a widespread forestry task of the nineteenth and early twentieth century in many European countries was that of transforming coppice forests to high forests, whereas for environmental and conservation reasons, this process is now being reversed in some countries. The transformation of plantation forests to continuous cover woodlands is currently a frequent activity of silviculturists in countries where CCF has recently been introduced. Some authors give transformation forest management the same attention as plantation and CCF management (Pukkala and Gadow, 2012). This group of activities concerns the active gradual change of woodland structure and or species composition. The biomass curve of transformation management consequently has elements of both, plantation management at the beginning and continuous cover management later on (cf. Figure 1.4).

As shown in Section 1.5, there is altogether a wide range of silvicultural possibilities within CCF including many combinations of silvicultural systems and thinning treatments (Pommerening and Murphy, 2004).

1.4 Silvicultural Analysis and Planning

Silvicultural analysis and planning describe the process of appraising the development of a forest stand to date and prescribing forest management for the next 5–10 years. Long-term plans for each woodland community occurring in the area under study usually exist, and they provide the general framework, see Section 7.2. Operational details are added by the forest manager through silvicultural analysis and planning. An important pre-requisite of any silvicultural plan is a site visit for sampling and for a full appreciation of a stand's condition and potential. The basic method of forest management planning at stand level includes four distinctive steps:

1. **Analysis of current state**
   - Description of site (elevation, exposition, area, climate, soil), vegetation and fauna (if possible and relevant).
   - Expected ecosystem goods and services?
   - Logistics: Extractions racks, access to forest roads.
   - Current state of the forest, stand development stage, stand description, inventory and quantitative analysis.
   - Frame trees (cf. Chapter 3) already selected, time since last frame-tree release?
2. **Anticipation of forest dynamics**
   - 'Anamnesis': What has influenced forest dynamics in the past? Any clues from historical records or current tree morphology? Stand origin, thinning history, silvicultural objectives, past forest development. When was the last intervention?
   - How will the ecosystem change? In which direction and what is the likely pace of change?
3. **Assessment of forest development pathways**
   - Reference scenario: What would happen without human interventions (see Section 2.6)?
   - What vegetation types and forest structures are possible in the future? What should be the target diameter range (cf. Section 3.4), the anticipated lifetime of the current forest generation, if any?

4. **Selecting the silviculturally appropriate techniques to meet the objectives**
   - What are important sustainability criteria for this site?
   - What forest structure should this site develop in the long run?
   - What tree species mixture is intended?
   - What should be the minimum distance between frame trees?
   - How much input is necessary (compared to zero intervention as a reference, see Section 2.6) and justifiable? Do frame trees need to be released? Intervention types, intervention cycles, intervention intensity.
   - When will be the next intervention following this one?
   - Optimising the solution.

A key element of silvicultural planning, and in fact of many aspects of research, is the description of the current state of a given forest unit. This is always the beginning and the basis for subsequent planning and research. After careful observation in the field and a detailed analysis of environmental factors, the analyst starts with a qualitative description of the current state. This provides the reader of the silvicultural plan/the research work with an easy access to the woodland in question (Pommerening and Grabarnik, 2019). There are many possible schemes and templates for stand descriptions, see, for example, Appendix A in Pommerening and Grabarnik (2019).

At the same time, up-to-date sampling data are a great help to analyse the current state of the respective planning unit (Figure 1.6), see also Section 4.4. In the same step, the processes that have led to the current state have to be taken into consideration. Any information on the history of stand development may prove useful in order to get a feeling for the velocity of the dynamics involved. Considering past disturbances and management also ensures that management prescriptions are avoided which may destabilise a forest stand. Particularly, the questions of how the given forest ecosystem is likely to develop with and without forest management, in what direction and how fast, are important in this context.

Information on stand density, height-diameter ratios (Eq. 2.2), crown ratios (Eq. 2.3), and crown damage offer insights on both past management and disturbances. For example, if h/d ratios are high and c/h ratios are low, it is quite likely that there have been high tree

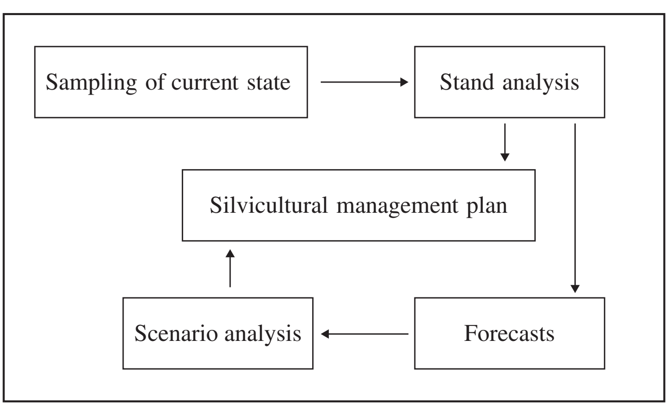

Figure 1.6 The general process of silvicultural planning. Source: Adapted from Gadow (2005).

densities and few interventions in the past. In CCF, the ‘do-nothing’ option is a crucial consideration, as part of the definition of CCF is to carry out interventions only if they are absolutely necessary; otherwise, one should leave woodland development to natural courses. This strategy is often termed *biological automation* or *biological rationalisation*, see Section 2.6. Based on the analysis, projections of potential forest development paths are undertaken which can be model aided (Coates et al., 2003; Wikström et al., 2011). Usually a number of different forest management possibilities or scenarios are explored in such scenario analyses and the best option under the given legal and environmental constraints and management objectives is identified. This process can be formalised by methods of optimisation and operations research that are usually presented in forest planning textbooks (see Bettinger et al., 2017). The silvicultural scenarios include key processes and methods of forest management such as species choice, silvicultural regime, silvicultural system and forest management types (Pommerening and Grabarnik, 2019).

Both the results of the sampling analysis and scenario analysis then feed into the silvicultural management plan. The core part of this plan is a set of silvicultural prescriptions usually for the next 5–15 years. A *silvicultural prescription* is a planned series of treatments designed to change current stand structure to one that meets management objectives (Helms, 1998) and can be part of the planning of a larger forest district or estate. In CCF, the development of silvicultural prescriptions begins with knowledge of the forest ecosystem that is to be managed and its constituent components (Franklin et al., 2018).

After reaching a conclusion, the forest management plan needs to be translated into a clear, transparent and reproducible work description for practical implementation. The practical implementation should ideally be followed by a control or appraisal element. This follow-up is very often neglected in practice, especially in times of excessive work pressure and scarce resources. However, the best scientifically based silvicultural planning is useless if delegated to staff and operators who are not able to implement it because of insufficient training and need advice (see Chapter 9). Follow-ups can help reveal such issues. Control should not be thought of as having negative connotations and can already be taking place while the actual work is under way. In plantings and thinnings, for example, major mistakes can be identified and mitigated during on-site visits. On the other hand, some results will only become evident several years after the actual work has finished, such as the survival rate of plants on a replanting or underplanting site. Long-term monitoring is therefore important, particularly when a type of silviculture new to an area is introduced, and it is crucial to record even seemingly minor details, which help understand *cause and effect relationships* (Pommerening and Grabarnik, 2019). Also, in practical or applied forest management, the benefit of monitoring or control can be enhanced by detailed record keeping that allows further statistical analysis (see Section 1.10). Statistical analysis can provide a better and deeper understanding of advantages and disadvantages of individual components used. In the long run, this can lead to a forest enterprise specific optimisation of silvicultural planning through adaptive management (Thomasius, 1990). Other aspects of silvicultural control include recording the density and height of natural regeneration, the impact of felling and extraction on remaining trees, the impact of browsing and bark stripping by animals, the growth performance, the impact of natural disturbances, and the natural mortality of and the interaction among trees.

The methodology employed for monitoring the implementation of silvicultural plans (see, for example, Gadow and Stüber, 1994) can also be used for quantifying the impact of disturbances and vice versa. Recently, some of this methodology has also been adopted for use in forest management training which has received much attention in forest practice in France, Switzerland, Britain and Ireland. For this purpose, all trees inside a rectangular or circular sample plot are marked with tree numbers and are callipered. These training sites are frequently referred to as *marteloscopes* (Bruciamacchie et al., 2005; Poore, 2011; Susse et al., 2011) (from French *martelage* – marking). Participants of such training seminars are then provided with a list of all trees and are asked to mark trees for thinnings. Methods and strategies that are discussed in Section 8.3 in detail are used after the exercise to assess how each participant has carried out the silvicultural objectives compared to others in their group by quantifying how the marking will modify the current state of the forest after implementation (Messier et al., 2013). Based on these, individual feedback is provided for every participant.

Finally, it should be emphasised that this traditional procedure of preparing silvicultural plans, implementing, checking up on the implementation, and revising the plan after 10–15 years is a good example of what is often described as *adaptive management*, cf. Section 7.2. For more details on silvicultural planning for CCF see Chapter 7. More general information on forest planning and optimising management can be found in specialist literature such as Bettinger et al. (2017) and Franklin et al. (2018).

1.5 Continuous Cover Forestry – Definitions, Terms and Semi-synonyms

CCF or near-natural forestry is not a new phenomenon, but over the last two decades, there has been a renewed world-wide debate regarding its position in forest management (Brang et al., 2014; Cairns, 2001; Gadow et al., 2002; Guldin, 2002; O'Hara, 2002; de Turckheim, 1999; Lähde et al., 1999). CCF has been a standard in Central Europe for more than 50 years. Its comparatively long history, however, stretches over more than a 100 years. In some countries and world areas, CCF is still relatively new, e.g. in the United Kingdom, Ireland, Scandinavia, North America, Australia and China. Currently, CCF is re-visited in many countries around the world for its potential to mitigate climate change, to increase or at least maintain biodiversity in forest ecosystems, to provide valuable tools for forest conservation, and to enhance the appeal of woodlands used for recreation.

Recently, the EU forest strategy for 2030 (European Commission, 2021) stated clearcutting should be 'used only in duly justified cases, for example, when proven necessary for environmental or ecosystem health reasons' and the strategy promotes 'the creation or maintenance at stand and landscape level of genetically and functionally diverse, mixed species forests, especially with more broadleaves and deciduous trees and with species with different biotic and abiotic sensitivities and recovery mechanisms following disturbances'. These political statements clearly support CCF, and a recent policy paper published by the European Forest Institute provided more explicit definitions and implementation guidelines for this strategy (Larsen et al., 2022).

Early concepts of CCF can be regarded as a naïve understanding and application of silviculture practised on an ecological or environmental basis, see the historical review in Section 1.7. The different terms and the wide variety of, sometimes conflicting, definitions can potentially cause considerable confusion among politicians, practitioners, students and scientists and need to be clarified when used. Pommerening and Murphy (2004) grouped the terms and semi-synonyms under six general headings which often highlight only a particular aspect or focus of CCF rather than broadly defining the concept as a whole (Table 1.2). These six categories are *continuity of forest cover*, *ecosystem/natural management*, *structural diversity*, *retention*, *thinning/harvesting methods* and *programmatic semi-synonyms*. The last group of terms include those that are particularly difficult to relate to CCF without an explanation and appear to suggest a new agenda or programme. The semi-synonyms in this category are somewhat philosophical and emphatic. The groups of ecosystem/natural management and retention have received particular attention in the literature. Not all semi-synonyms interchangeably denote exactly the same type of forestry; however, most of them share much overlap and many similarities.

Specific definitions exist for some of the semi-synonyms. For example, Fedrowitz et al. (2014) suggested that *retention forestry* aims to reduce structural and functional contrasts between managed forests and natural forests, mainly by increasing the abundance in harvested stands of key structures important for biodiversity, such as old and dead trees (Figure 1.7). This is contrasted by the term *managed retention* implying that a stand in question is exempt from clearfelling for reasons of biodiversity, visual impact or danger of landslides (Forest Enterprise, 2000). While the former definition implies retention of individual trees, the latter focuses on the retention of whole forest stands. Some distinctions between CCF semi-synonyms have been made somewhat artificially based on misunderstandings or on the authors' understandable desire to coin their own terms and concepts.

Naturalness plays a prominent role in the semi-synonyms of CCF and in general definitions of the concept. Naturalness is a popular term; however, it is very difficult if not impossible to define (Peterken, 1996; Schirmer, 1998). A very common approach is to assess the differences between a forest's current state and the potential natural vegetation (PNV) on the same site in order to define the degree of naturalness. The general idea of near-natural forestry or CCF is to promote managed forests with structures, management practices and/or species compositions that are more akin to the potentially natural stages of development and to the potentially natural processes of tree vegetation on any particular site than those that are commonly observed in rigid plantation management (Pommerening and Murphy, 2004).

It is interesting to note that authorities in countries where CCF has only recently been introduced, often coined a term different from CCF or one of the other more commonly known semi-synonyms. The Forestry Commission in the United Kingdom, for example, adopted the terms *LISS* (low-impact silvicultural systems), *ATC* (alternatives to clearfelling) and *managed retention*, whereas the Forest Authority (Skogsstyrelsen) in Sweden uses the term *non-clearcut forestry* (hyggesfritt skogsbruk). Coining their own semi-synonyms allows these organisations to retain the liberty to deviate from seemingly rigid or too liberal CCF criteria, e.g. in terms of the allowable size of felling coupes or to set

Table 1.2 Synonyms and semi-synonyms used in connection with near-natural forestry or CCF.

Synonym or semi-synonym	Source
Continuity of forest cover	
Alternatives to clearfelling, alternative silvicultural systems to clear cutting, alternative silvicultural practices	Penistan (1952), Hart (1995), Beese and Bryant (1999), Lencinas et al. (2011)
Continuous forest	Troup (1928) and Hart (1995)
Continuous cover silviculture	Yorke (1998)
Dauerwald	Möller (1922), Troup (1928), and Helliwell (1997)
Low-impact silviculture, ~ management approaches	UKWAS Steering Group (2000), Mason et al. (1999)
Permanent forest	Anderson (1953), Häusler and Scherer-Lorenzen (2001)
Ecosystem/natural management	
Close-to-nature forestry/forest management	Mlinšek (1996) and Mason et al. (1999)
Close-to-nature silviculture	Schütz (2001a), Kenk and Guehne (2001) and O'Hara (2016)
Ecoforestry	Drengston and Taylor (1997)
Ecological forestry, ~ forest management	Mason et al. (1999), Seymour and Hunter (1999), Franklin et al. (2018)
Ecosystem (friendly, oriented) management	Thomasius (1992), Grumbine (1994) and Salwasser (1994)
Ecological silviculture/forestry, ecologically oriented silviculture	Benecke (1996), Lähde et al. (1999), Palik et al. (2021)
Forest management based on natural processes	Pro Silva Europe (1999, 2012)
Nature-based forestry/forest management	Diaci (2006) and Larsen and Nielsen (2007)
Natural disturbance-based management	Bose et al. (2014)
Near-natural forestry/forest management	Benecke (1996) and Gadow et al. (2002); Larsen (2005)
Nature-orientated silviculture	Lähde et al. (1999) and Koch and Skovsgaard (1999)
Naturalistic silvicultural systems	Mitchell and Beese (2002)
Restoration forestry	Pilarski (1994)
Sustainable forestry	Maser (1994)

Table 1.2 (Continued)

Synonym or semi-synonym	Source
Thinning/harvesting methods	
Green-tree retention (GTR) harvest	North et al. (1996) and Craig and Macdonald (2009)
Retention harvesting	Craig and Macdonald (2009) and Baker et al. (2013)
Selective cutting/selective timber management	Curtis (1998)
Structural diversity	
Diversity-orientated silviculture	Benecke (1996) and Lähde et al. (1999)
Irregular structure forestry/silviculture	Johnston (1978), Lord Bradford (1981) and Pryor (1990)
Irregular forestry/forests, management of ~	Susse et al. (2011)
Uneven-aged/multi-aged/multi-cohort management/silviculture/forestry	Anderson (1953) and Oliver and Larson (1996)
Retention	
Managed retention	Forest Enterprise (2000)
Overstorey retention	Dovčiak et al. (2006) and Halpern et al. (2012)
Retention forestry, retention harvesting	Craig and Macdonald (2009), Gustafsson et al. (2012), Baker et al. (2013) and Fedrowitz et al. (2014)
Structural retention	Dovčiak et al. (2006)
Tree retention, GTR	Franklin (1989), North et al. (1996), Vanha-Majamaa and Jalonen (2001), Rosenvald and Lohmus (2008), Johnson et al. (2014), Halpern et al. (2005) and Gustafsson et al. (2010)
Variable retention	Mitchell and Beese (2002)
Programmatic semi-synonyms	
Back to nature	Gamborg and Larsen (2003)
Common sense forestry	Morsbach (2002)
(Complex) adaptive systems approach	Bončina (2011a) and Messier et al. (2013)

(Continued)

Table 1.2 (Continued)

Synonym or semi-synonym	Source
Programmatic semi-synonyms	
Excellent forestry	Robinson (1994)
Free-style silviculture	Bončina (2011a) and O'Hara (2014)
Holistic forestry	O'Keefe (1990), Peterken (1996), Koch and Skovsgaard (1999) and Mason et al. (1999)
Lübeck model	Sturm (1993)
New forestry	Franklin (1989) and O'Keefe (1990)
New perspectives	Kessler et al. (1992)
Positive impact forestry	McEvoy (2004)
Systemic silviculture	Ciancio and Nocentini (2011) and Nocentini et al. (2021)

Source: After Pommerening and Murphy (2004) and O'Hara (2014).

their own CCF agenda. Often, these new terms come with a set of more or less strict rules, which are sometimes linked to national legislation or certification.

Of the many other CCF definitions eight examples may be quoted which reflect aspects already identified by the group headings:

1. According to the IUFRO Multilingual Forest Terminology Database the term continuous cover forestry describes a highly structured forest ecosystem managed to maintain continuous tree cover over the total forest area (Nieuwenhuis, 2000).
2. The British silviculturist Professor R. S. Troup was very interested in the Dauerwald idea of the 1920s, and visited German CCF stands. He defined this form of silviculture in the following way (Troup, 1928): 'The [German] term Dauerwald, one of the semi-synonyms (see Table 1.2), may be translated briefly as "continuous forest," that is, forest treated in such a manner that the soil is never exposed, the forest cover being continuously maintained over every part of the area'. Möller (1922) applied the term 'Dauerwald' in general not to any one particular method of treatment, but to any system not involving clearcut and the exposure of soil (Troup, 1928).
3. Mason et al. (1999) stated 'continuous cover is defined as the use of silvicultural systems whereby the forest canopy is maintained at one or more levels without clear felling'.
4. Gadow (2001) came to the conclusion that 'CCF systems are characterised by selective harvesting; the stand age is undefined and forest development does not follow a cyclic harvest-and-regeneration pattern'.
5. Hart (1995) put forward a very detailed definition stating that continuous forest cover [sic] is 'a general term covering several silvicultural systems which conserve the local forest canopy/environment during the regeneration phase. Coupe size is normally below 0.25 ha (50 × 50 m) in group systems; and in shelterwood – where used – is retained for longer than 10 years. The general aim of all systems within the concept is the encouragement of diversity of structure and uneven age/size on an intimate scale'.

Figure 1.7 Retention forestry/green tree retention is often only but a small step from clearfelling towards CCF with very few residual trees (standards) that can hardly maintain woodland climate and forest soil conditions. Example from Järvselja Forest near Tartu in Estonia involving *Betula* spp. and *Pinus sylvestris* L. with closed forest stands in the background. Source: © Arne Pommerening (Author).

6. Franklin et al. (2018) stated that *ecological forestry*, one of the semi-synonyms of CCF, see Table 1.2, utilises ecological models from natural forest systems as a basis for managing forests. The concept incorporates principles of natural forest development including the role of natural disturbances in the initiation, development and maintenance of forests and forest landscape mosaics. Most importantly, ecological forestry recognises that forests are diverse ecosystems and seeks to maintain their fundamental integrity.
7. Palik et al. (2021) defined *ecological silviculture*, another semi-synonym of CCF, see Table 1.2, as an approach to managing ecosystems, including trees and associated organisms and ecological functions, based on the emulation of natural models of development and that explicitly incorporates principles of continuity, complexity/diversity, timing and context.

Most definitions focus only on parts of what the whole concept can include, e.g. on selective interventions and undefined stand age. The definition put forward by Palik et al. (2021) makes an attempt to describe the whole concept of CCF as the authors see it. Many definitions stress the idea of the continuity of woodland conditions over time, hence the name 'continuous cover forestry', a term which has given rise to many misunderstandings. Often, it has been misunderstood as suggesting an intention to create and maintain dense forests with closed canopies, see Section 1.6. The term, however, does not imply any degree of canopy closure and is fully compatible with the creation of gaps for promoting natural regeneration, the conservation of wildlife, or for the establishment of viewpoints or vistas should the necessity arise. CCF does not imply a lack of management but emphasises the need to avoid clearfelling over large areas and within this broad concept, a range of silvicultural systems and thinning methods are possible. However, CCF is more than the mere avoidance of clearcutting (Lähde et al., 1999; Kenk and Guehne, 2001; Nabuurs, 2001; Vanha-Majamaa and Jalonen, 2001), and any particular CCF concept requires a clear description of goals and principles to be transparent (Grumbine, 1994; Brunner and Clark, 1997). Some of the definitions above highlight other important components such as the selective removal of trees, allowable gap size, suitable silvicultural systems and vertical structure. In particular, CCF is being seen as compatible with a holistic approach to forestry with multi-purpose management objectives (Häusler and Scherer-Lorenzen, 2001; Niedersächsische Landesregierung, 1991; Landesanstalt für Wald und Forstwirtschaft Thüringen, 2000; Forestry Commission, 2001; Palik et al., 2021).

Most of the semi-synonyms in Table 1.2 are suitable for describing a general concept of silviculture based on ecological and natural processes. In this book, I have adopted *continuous cover forestry* (CCF) for its appeal and popularity; however, other terms would certainly serve as good descriptors, too. With the choice of name, I do not follow one particular variant of silviculture on an ecological basis but rather all of them collectively. After all, what matters most is the general concept itself and not so much the label assigned to it. Whilst CCF and the practices labelled by other semi-synonyms can and should differ in different parts of the world, there are related principles that form a common denominator. Differences reflect the variation in forest types, in intensity and scale of natural disturbances and in the management history to name but a few (Larsen et al., 2022).

The concept of CCF is usually broken down into themes or components. Palik et al. (2021) referred to them as *tenets*. Many of these tenets or components reflect the general goals of ecosystem management (Grumbine, 1994). In the following, the general tenets of Figure 1.8, which were first published by Pommerening and Murphy (2004), are introduced and outlined in more detail (see also Appendix A for a summary). By arranging them in groups with common headers, the context is indicated.

1.5.1 Continuity of Woodland Conditions

This is the oldest and most important part of the definition of CCF. The idea of the tenet and the associated wording is to encapsulate a number of important ecological conditions. Troup (1928) stated that CCF may be said to include all those silvicultural systems which involve continuous and uninterrupted maintenance of the forest. Franklin et al. (2018) stressed the continuity in forest structure, function and biota between pre- and post-intervention ecosystems. As natural disturbances leave significant biological legacies from the pre-disturbance forest that provide for continuity, CCF emulates that process through the selective retention of tree vegetation and other biological legacies in all silvicultural treatments. This includes the retention of seed dispersal mechanisms, nutrient and water cycles as well as the exchange of genetic material typical of forest ecosystems (Larsen et al., 2022). From an ecological perspective, some tree species require the continuity of woodland conditions with only moderate changes of their habitats, imposed by forest

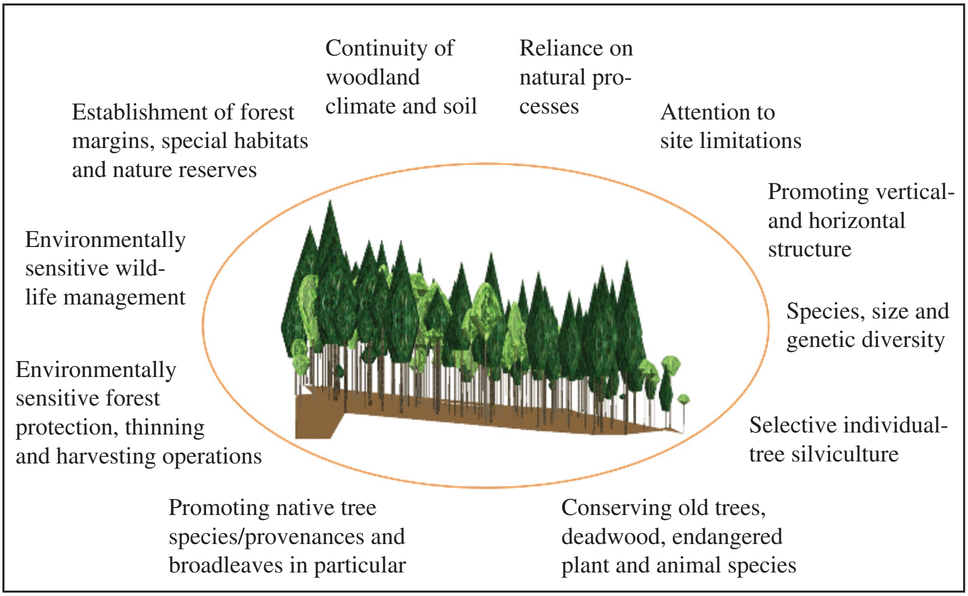

Figure 1.8 The main components or tenets of the contemporary international continuous cover forestry debate. Source: Adapted from Pommerening and Murphy (2004).

management or natural disturbances, to ensure their survival. The same continuity is also an important feature of protection forests securing and stabilising watersheds, mountain slopes, coastlands and woodlands managed for amenity and recreation (Rittershofer, 1999). Historically continuity of woodland conditions has always been an important factor in the timber production of traditional selection forests on the small-sized farm holdings of Slovenia, Switzerland, France, Germany and Austria (Burschel and Huss, 1997).

Almost half of the total organic carbon (C) in terrestrial ecosystems is stored in forest soils. Harvesting, particularly clear-cut harvesting, generally results in a decrease in soil C stocks, with highest C losses occurring in the forest floor and the upper mineral soil (Mayer et al., 2020). The continuity of woodland conditions is therefore crucial for carbon sequestration both in trees and soils and for the conservation of soil processes (Ontl et al., 2019). There is, however, some debate on the size of gaps (i.e. small, localised clearfells) allowed especially because current regulations do not distinguish between tree species and site types involved (see Figure 1.7).

Since the late 1980s and the beginning of the 1990s, new forest legislation in Germany requires special permission by the forestry authority of the respective federal state, if clear-fell coupes exceed a certain size. In Germany, the regulations governing the maximum clearfelling size vary from state to state. For example in the state of Northrhine-Westfalia, clear cutting is limited to a size of three hectares, whereas in Baden-Württemberg, permission is required for clearfelling areas larger than one hectare (Häusler and Scherer-Lorenzen, 2001). Similar legislation is implemented in Austria and Switzerland.

Gresh and Courter (2021) have argued that the North American pursuit of ecological forestry has embraced a natural disturbance paradigm. Europe, in contrast, according to Gresh and Courter (2021), is pursuing ecological forestry by requiring low-intensity harvest protocols which continuously protect the forest canopy. Perhaps prompted by the term ‘continuous cover’, it is clearly one of many misunderstandings (see Section 1.6) that European ecological forestry or CCF allegedly does not incorporate or attempts to mimic natural disturbances. Continuity of woodland conditions is stressed in European CCF policies because clearfellings have in the past been the dominant feature of European forestry.

1.5.2 Reliance on Natural Processes, Promoting Vertical and Horizontal Structure

In CCF, forest managers aim to create a varied horizontal and vertical structure of individual trees and groups of trees in a stand. By allowing a varied amount of horizontal and vertical structural elements, it is possible to save establishment and tending costs apart from obvious diversity and habitat benefits. Experience has shown that forest structures can be managed in such a way that natural processes such as natural regeneration, natural pruning, the development of good stem form and self-thinning (natural stem number reduction) in the early growth stages are stimulated, see Section 2.6. In general, shading provided by tree shelter results in thinner branches, higher wood density and reduced stem taper (Burschel and Huss, 1997; Messier et al., 2013; Rittershofer, 1999; Schütz, 2001a). This form of steered self-regulation is often referred to as biological automation or biological rationalisation and is related to the conservation principle of passive restoration (Newton, 2007, see Section 7.3.3). Smith et al. (1997) referred to this principle as ‘imitating nature through silviculture’. Reliance on natural processes is facilitated by introducing more structural diversity. In terms of stem form and timber quality, a similar effect can be achieved by managing dense plantations with small initial spacing, but there is general consensus that the benefits cannot compensate for the additional costs incurred. Therefore, managing vertical and horizontal structure in conjunction with natural regeneration is a clear alternative to controlling the level of competition through management (Klang and Ekö, 1999). The three tenets of continuity of woodland conditions, reliance on natural processes, and promoting vertical and horizontal structure imply a reliance on natural regeneration. The use of natural regeneration is an advantage where the native parent trees are site-adapted, have a high genetic diversity, and have other desirable qualities (Larsen et al., 2022). Natural regeneration established over long periods from many parent trees maintains high genetic variation (Finkeldey and Ziehe, 2004). The individual-tree and collective resilience of woodlands can be enhanced, and another positive side effect of this strategy is a greater biodiversity. There is a close link between forest structure and diversity, thus diversifying the size and species structure of forests increases the availability of habitats and ecological niches (Pommerening and Grabarnik, 2019). There is also evidence for the fact that forests with high structural diversity are more resistant to wind and pests (Dvorak and Bachmann, 2001; Hanewinkel et al., 2014; Seidl et al., 2018) and enhance adaptive capacity. Well-structured forests like those managed as selection systems are appealing to visitors and have therefore an important recreation and amenity value (Jephcott, 2002; Nyland, 2003) which makes them ideal for community and urban forests. This element of CCF is what Palik et al. (2021) described by the tenet ‘seek complexity and diversity’.

1.5.3 Attention to Site Limitations

As with all good forestry practice, tree species/provenance choice should be made dependent on site. This ensures that species/provenances are used that are well adapted to the particular environmental conditions and therefore can resist biotic and abiotic damage and have high growth rates (Pro Silva Europe, 1999; Burschel and Huss, 1997). With ongoing climate change, this tenet is even more important than ever before. Site conditions should guide species selection in any approach to forest management, but this is particularly important for CCF, given its demanding requirements in terms of stand resilience, diversity, use of natural processes and the idea to deliver multiple ecosystem goods and services (Davies et al., 2008). Traditional CCF techniques have largely been developed for and applied to native species. However, there is usually no reason why CCF should not be practised successfully with non-native species, as long as they are adapted to local site conditions. A tree species is site adapted, if it is able to grow vigorously and to reproduce over a number of generations under the specific climatic, pedological and topographical conditions of the site in question (Bartsch et al., 2020). This implies that

- the species must be capable of reaching its natural life expectancy,
- it should achieve its natural growth and size range,
- it must produce viable natural regeneration,
- it should not lead to any form of site deterioration (e.g. through litter accumulation),
- it must not show invasive behaviour.

Depending on management objectives, the choice of species should take into account both ecological (maintenance of site productivity, biological diversity) and management (stability, yield, resilience) criteria. All involve great uncertainties, as they are partly based on future conditions that may be difficult to predict. In particular, the consequences of climate change are likely to have an impact on the suitability of a species. Although the suitability of some species can already be gauged on the basis of the most likely scenarios for climate change, in general, it will be best to favour species with a greater amplitude of environmental requirements, and to make use of a wider range of species to minimise any risks (Davies et al., 2008). Currently experiments are underway where species provenances that evolved in warmer climates are transplanted into areas which currently still have cooler climates to anticipate future climate change (Brang et al., 2014; Frischbier et al., 2019). Future results from the long-term monitoring of these experiments will reveal whether this is an appropriate strategy for mitigating climate effects. The principle of attention to site limitations is also in the spirit of the tenet 'maintain options for the future' proposed by Palik et al. (2021).

1.5.4 Species, Size and Genetic Diversity

There is potentially a range of benefits to be gained by encouraging mixed coniferous/broadleaved woodlands. These benefits include the reduction of biotic, abiotic and economic risk, for example, diseases and insect calamities cannot spread as easily as in monospecific stands (Duchiron, 2000; Nyland, 2003). One of the aims of CCF is therefore the diversification of monospecies coniferous plantations, which are outside their natural range. Recent research in monospecific and mixed stands of *Picea abies* (L.) H. Karst. and *Fagus sylcatica* L. showed that in such mixed woodlands total volume production does not decrease as stand density approaches the maximum but remains constant (Griess et al., 2012; Pretzsch and Biber, 2016). This contrasts with monospecific stands where total volume production usually decreases after reaching a maximum. These studies also showed that the resilience of predominantly single-species *P. abies* stands can be improved, if unstable spruce trees are replaced by resilient *F. sylvatica* trees. According to the study an important element of resilience to disturbances in these mixed stands is the presence of sub-dominant and co-dominant trees which, therefore, should be retained. These findings revealed that mixed-species stands are much better able than monospecific stands to compensate for impacts on the stand density, such as windthrow or heavy thinnings, through an accelerated growth of the residual stand (Pretzsch and Biber, 2016). The work of Pretzsch and Biber even suggests extending the occurrence of mixed stands for the sake of increasing forest resilience. Therefore, two conclusions can be drawn from this research: (i) Ecosystem productivity increases with increasing biodiversity and (ii) biodiversity enhances ecosystem resilience (Messier et al., 2013). Conclusion (2) is supported by the *insurance hypothesis*, an ecological theory suggesting that species that might be functionally redundant in a given ecosystem increase in numbers to compensate for the reduction in performance of the dominant species thus providing 'insurance' for community productivity (Yachi and Loreau, 1999; Matias et al., 2013).

Mixed species forests also provide a wider range of size classes and timber products allowing flexible and rapid response to market conditions in commercial forestry. They contribute to greater biodiversity and therefore provide more habitats. Studies have shown that mixed woodlands are believed to be more appealing to visitors (Jephcott, 2002; Petucco et al., 2018; Arnberger et al., 2019). Mixtures may also help reduce risk from global or regional climate change (Lindner and Cramer, 2002). Swedish and Danish investigations on the nutrient status of *Picea abies* in monospecies and in mixed-species stands revealed that spruce needles from mixed stands had higher concentrations and ratios to N of K, P and Zn than needles from pure spruce stands. Among the mixed stands, the K status appeared to be positively correlated with the percentage of deciduous tree basal area. Soil samples from mixed stands had a higher Mg concentration and base saturation than soil samples from monospecies stands. The authors came to the conclusion that the positive effects on *P. abies* nutrient status in the mixtures may promote total stand productivity in the long run, increase the resistance to adverse effects of air pollution, and limit the need to counteract ecosystem nutrient imbalance with direct treatments like fertilisation or liming (Thelin et al., 2002).

1.5.5 Selective Individual-Tree Silviculture

In managing stands for CCF, trees are individually selected for thinning and harvesting in an attempt to move a forest stand into a desired direction. This is often accomplished as a compromise between silvicultural, economic and conservation needs (Rittershofer, 1999), see Section 7.1. Originally, individual-based forest management using frame trees (cf. Chapter 3) developed independently of CCF (Schädelin, 1926, 1934), but already Möller (1922) saw a connection between both. In Central Europe, most CCF silvicultural systems now aim at a combination of frame-tree selection, crown thinnings and target diameter harvesting (cf. Section 3.4) (Abetz and Klädtke, 2002, see Chapter 3). Thinning and harvesting decisions are made on a tree-by-tree basis and depend on individual tree size (Messier et al., 2013). In commercial scenarios, they include considerations of size premiums, penalties for very large stem diameters, size-dependent growth rates and production risks (e.g. wind damage, pathogens). The principle implies that rotation ages or periods do not apply. Forest stands become slightly less important as management units and individual-tree management can be considered a bottom-up approach that potentially offers greater flexibility. Interventions typically focus on a subset of trees whilst other parts of the forest largely remain undisturbed (Pommerening et al., 2021a). The individualisation of management also promotes individual-tree resilience through a gradual change of morphology in released trees allowing them to better withstand the forces of wind and snow. This is particularly important in tree species with shallow root systems (e.g. *Picea*, *Betula*). Selective fellings may increase timber quality and are a pre-requisite for many other elements of CCF. As the economic benefits of tourism become better understood, it is important to realise that selective individual-tree silviculture much contributes to winning potential tourists when compared to the effect of clearfelling large patches of trees (Jephcott, 2002; Nyland, 2003; Arnberger et al., 2019).

1.5.6 Conserving Old Trees, Deadwood, Rare and Endangered Plant and Animal Species

Many CCF guidelines suggest retaining a certain amount of downed and standing deadwood in each forest stand for biodiversity reasons. It is also recommended that a certain percentage of old scenic trees and similar natural features are kept for their amenity value. Forest management should also aim at promoting endangered plant and animal species along with other management objectives (Niedersächsische Landesregierung, 1991). Remnant broadleaved trees in conifer plantations should be secured by releasing them from conifer competition. This principle also includes the protection of special biotopes within forests such as wetlands, rocky outcrops and dunes (Otto, 1994). The biodiversity aspect gains some importance because continuous high forests with native species such as European beech (*Fagus sylvatica*) can have a negative effect on tree species diversity because rare and less competitive species tend to be extinguished as opposed to in coppice and coppice-with-standards forests (Kausch-Blecken von Schmeling, 1992). Typical victims of this effect are the native European *Sorbus* species, i.e. whitebeam (*Sorbus aria* (L.) Crantz), true service tree (*Sorbus domestica* L.) and wild service tree (*Sorbus torminalis* (L.) Crantz) and yew (*Taxus baccata* L.). In some countries, policymakers are aware of this effect and therefore explicitly included the conservation of rare and endangered plant species and provenances in their CCF guidelines (Niedersächsische Landesregierung, 1991; Landesanstalt für Wald und Forstwirtschaft Thüringen, 2000; Nyland, 2003).

1.5.7 Promoting Native Tree Species/Provenances and Broadleaves

For centuries fast-growing conifer species were promoted in large areas of Europe beyond their natural range on sites naturally dominated by broadleaves to increase commercial timber production. These secondary coniferous stands mainly in areas below 1000 m asl turned out to be extremely sensitive to environmental stress factors and are highly susceptible to progressive loading by air pollution and climate change. Thus, the restoration of such forest ecosystems originally dominated by broadleaves is an important silvicultural task (Hasenauer and Sterba, 2000).

As there can be silvicultural problems with native tree species, for example, in British upland forestry and in Mediterranean countries, this issue is traditionally contentious, though it is a clear element of international definitions (Pro Silva Europe, 1999, 2012). The idea comes from the assumption that native tree species and provenances are better adapted to local site conditions and have co-evolved with other plant and animal species in a particular country or region whilst exotic species often show faster forest growth and are more productive. Numerous animal and plant species are directly connected to native trees in this co-evolutionary development. The introduction of exotic species potentially disrupts this symbiosis and results in a reduction of biodiversity (Pro Silva Europe, 1999, 2012). Species are considered native, if they have not been introduced by humans, either recently or in the distant past (Peterken, 2001). However, this definition presents some difficulties and the natural range of species cannot always be sharply delimited. There will always be considerable debate over the 'nativeness' of one species vis-à-vis another, and it is questionable whether species which have just been excluded from a certain region by the last ice age, but before that had a long co-evolution with other plant and animal species of the same area, should be termed non-native (Niedersächsische Landesregierung, 1991). The boundaries of areas, which can be described as the native range of a species, change over time even without human influence. This, for example, applies to Douglas fir (*Pseudotsuga menziesii* (Mirbel) Franco) that did not survive the ice ages in Europe, but may be better adapted to climate change than some of the native European conifers. Also, the 'site' at which a species is native can be defined at various scales: From a large region through a discrete wood to each patch of contrasting soil within a wood (Pommerening and Murphy, 2004). Mixing native and site-adapted non-native species in semi-natural woodlands may enhance their adaptive capacity, whilst limiting the potentially negative effects of non-native species and provenances (Peterken, 1996; Vitali et al., 2018). In this context, there is an ongoing debate about *genetically improved* or *genetically engineered* tree provenances. These are tree species provenances resulting from tree breeding, not genetically modified (transgenic) trees. Breeding mainly aims at growth and timber quality properties, and given the concept of CCF, it is questionable whether such provenances should be included in near-natural forest management. In addition, it is uncertain how genetically improved or genetically engineered tree provenances will perform with ongoing climate change. Another consideration here is the consequent removal of invasive non-native tree species. According to Pro Silva Europe (1999) and Pro Silva Europe (2012), exotic tree species should only be planted in situations where this is an economic or other necessity, and then only if the exotics can be mixed with the indigenous vegetation pattern within certain qualitative and quantitative limits. However, the need to move towards a greater use of native tree species is a clear requirement of forest restoration, which forms a part of CCF. The removal of non-native and especially invasive species among natural regeneration might be necessary and underplanting with native species plays an important role in this context (Thompson et al., 2003; Niedersächsische Landesregierung, 1991; Pommerening and Murphy, 2004).

1.5.8 Environmentally Sensitive Forest Protection, Thinning and Harvesting Operations, Environmentally Sensitive Wildlife Management

The idea of this tenet is to reduce human disturbances in the forest ecosystem to a minimum by carrying out only limited forest protection from diseases and promoting biological methods instead. In the same way thinning and harvesting should be conducted in a manner which disturbs the remaining trees and the ecosystem (especially the soils and the ground vegetation) as little as possible. This also includes the avoidance of harvesting and extraction damage. Part of this tenet is, for example, the emphasis on permanent extraction racks, at least 40 m apart, in some countries (see Figure 1.9) and the requirement for harvesters and forwarders not to leave these racks when carrying out their operations. There is a need for highly trained workers and specialised low-impact machinery.

Health and safety considerations may shift and require special attention in CCF, since the average size of trees to be felled increases while visibility within forest stands decreases with increasing structural complexity. There is also a need for a sufficiently dense forest road network (Larsen et al., 2022). Artificial liming of forest soils is often conducted to compensate for soil degradation. Whole-tree harvesting and stump removal are clearly not compatible with CCF. Branches, twigs, barks and tree tips of selectively harvested trees should also be left in the forest, as they contain most of a tree's stored nutrients (Otto, 1994).

Figure 1.9 Example of the marking of a permanent extraction rack on the stem surface of trees bordering the rack in a mixed broadleaved forest in the Reinhausen Forest District (Germany). Source: Courtesy of Paul Cody.

The density of populations of deer and other grazing and bark-stripping animals needs to be in balance with the carrying capacity of the site in order to make the use of natural regeneration feasible. This will also keep fencing costs low which could otherwise be quite high (Palik et al., 2021). In Britain, apart from deer, this also applies to the grey squirrel (*Sciurus carolinensis* Gmelin), the control of which is absolutely crucial to the success of CCF, particularly to forms of CCF involving broadleaved trees.

1.5.9 Establishment and Conservation of Forest Margins, of Other Special Habitats Inside Forests and Networks of Protected Forests

Adopting a holistic approach to forest management by managing the ecosystem rather than just crops, is a very prominent feature of CCF. This tenet also considers the landscape context. One way to contribute to this objective is the establishment of forest margins as transition zones between the open landscape and woodlands.

Here, a certain stage of natural succession is artificially and permanently preserved. Although there would be a strip of 25–30 m at the stand boundary with low or no timber production, this could significantly increase wind firmness and diversity (Burschel and Huss, 1997; Otto, 1994), see Section 7.3.3. Siebenbaum (1965) reported the successful use of such forest margins for the purpose of increasing forest resilience in the windy climate of the German federal state Schleswig-Holstein. In a similar way, CCF guidelines often

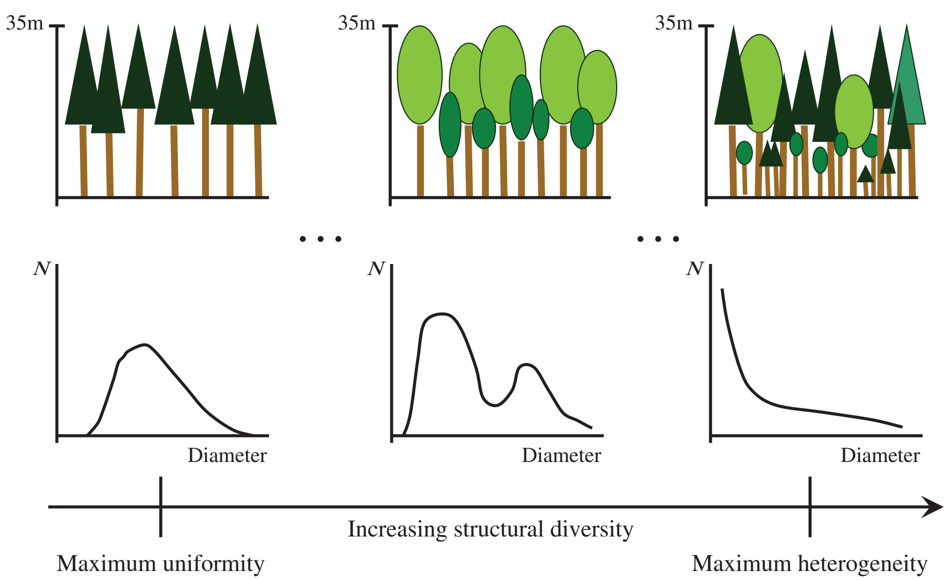

Figure 1.10 The continuum of continuous cover forestry stretching from maximum uniformity (e.g. in an even-aged coniferous woodland managed on a non-clearfelling basis) to maximum heterogeneity (e.g. in a single tree selection forest). Source: Modified from Pommerening and Murphy (2004).

demand that riparian forests and streamsides are restored by appropriate and sensitive conservation management (Forestry Commission, 2000; Nyland, 2003).

This can contribute to decreasing catastrophic flooding events, but most importantly secures water quality and important habitats (Greger, 1998). Other authors additionally suggest the establishment of a network of protected woodlands, including some non-intervention areas, as 'stepping stones' in large areas of commercial forests which would provide areas of retreat and almost undisturbed development for flora and fauna (Niedersächsische Landesregierung, 1991; Otto, 1994). This and the previous element support the fifth tenet proposed by Palik et al. (2021) to practise silviculture in the context of landscapes, i.e. to consider the connectivity between adjacent ecosystems and cumulative impacts. Franklin et al. (2018) proposed the tenet of 'restoring and sustaining the integrity of forest and associated ecosystems'. This is a complex tenet involving that ecosystems in all their complexity and variety are the source of ecosystem goods and services. In the CCF aspects presented here and in Figure 1.8, the *integrity* tenet proposed by Franklin et al. (2018) has been broken down into a number of themes.

1.5.10 In Conclusion

A short overview of these most common CCF principles can be found in Appendix A. Having reviewed these elements or tenets of CCF, it is obvious that many different silvicultural systems can be included under the broad umbrella of CCF, and Figure 1.10 gives an impression of how wide the spectrum of structures and their resulting diameter distributions is. It stretches from an even-aged coniferous woodland managed on a non-clearfelling basis (representing maximum uniformity) to a selection forest (representing maximum heterogeneity), cf. the illustrations of the two extremes in Figure 1.11. This stresses the need for

(a) (b)

Figure 1.11 Illustrations of the two extremes of the continuum of continuous cover forestry shown in Figure 1.10. (a) A stand of *Picea sitchensis* (Bong.) Carr. at Clocaenog Forest (Cefn Du, plot 2, Wales, UK) where clearfelling was replaced by a shelterwood system providing abundant regeneration. (b) A stand of *Picea abies* (L.) H. Karst. and *Fagus sylvatica* L. near Bad Gandersheim (Lower Saxony, Germany) approaching the structure of a selection forest. Source: Courtesy of Stephen T. Murphy.

clear definitions of interventions and envisaged management scenarios when transformation of even-aged stands or afforestation/restocking is proposed. Ultimately, no matter how we define our personal understanding of CCF, the important feature of any CCF variant is the maintenance of continuous woodland cover in space and time whereby natural disturbances such as windthrows, fires and insect calamities can be incorporated.

1.6 Common Misconceptions Dispelled

The term 'continuous cover forestry' and also other semi-synonyms have attracted a number of misconceptions that are summarised in this section (Davies et al., 2008). Most responses presented here can be derived directly or indirectly from the texts in other parts of this book, but it can be useful to study these summaries when preparing oneself for discussions with students, stakeholders, policymakers, or practitioners.

CCF results in dense, unbroken forests without open spaces or vistas. This misunderstanding is partly related to the term 'continuous cover'. Novices often feel that the term suggests dense, unbroken forests. This is wrong; the term is rather a reflection of the continuity of woodland climate and soil preservation as opposed to the climate on bare land such as clearfelling sites. In most cases, CCF stand structures vary in space and time, and this includes differences in tree density and the opening of temporary gaps. Permanent open spaces can and should also be maintained for conservation and amenity. In the same way, natural disturbances are accepted and included. CCF does not imply permanently maintaining mature forest cover either.

CCF results in natural forest structures. CCF is sometimes considered to be synonymous with 'close-to-nature' or 'near-natural' forestry, see Section 1.5, but this statement is potentially misleading. While CCF management makes use of natural processes such as natural regeneration and natural pruning (cf. Section 2.6), and the resulting forest structure often looks more natural than that of plantations, CCF does not necessarily result in natural forest stand structures: Single tree selection, the classical and most extreme CCF method, gives rise to structurally very heterogeneous stands, often of mixed species and may therefore visually convey the impression of very natural forest stands, whereas some European native forests, e.g. involving *Fagus sylvatica*, rather tend towards homogeneity with time (Schütz, 2001a, 2002). Although CCF management is closer to natural forest ecosystems than plantation forest management, a careful examination of each individual case is required when considering this statement.

CCF is possible only with single tree selection. The single tree selection forest is often described as the archetype of CCF implying maximum heterogeneity of tree size and species that many other variants of CCF often converge towards (Pukkala and Gadow, 2012). This is an extreme view and the small area world-wide managed in accordance with this silvicultural system suggests that there are limitations. The single-tree selection system (see Section 5.4) was originally devised by farmers as a special, localised variant of farm forestry or agroforestry. CCF, however, has a very wide range of possible realisations (see Section 1.5) including more or less even-aged forests that can be established under the canopy of existing even-aged stands using shelterwood systems, and it is important to retain this flexibility.

CCF must rely entirely on natural forest processes. There is certainly a strong tendency towards using natural forest processes in CCF (see Section 2.6), and this may alleviate some costs of management, but it is by no means compulsory or exclusive. For example, if there is a desire or a need to introduce new species or provenances into a stand, there is no reason why regeneration should not be achieved by underplanting (cf. Section 2.4.1) rather than naturally. It is also possible to combine natural with artificial regeneration for diversifying a forest stand.

CCF is possible only with native tree species. CCF can be practised with native or non-native species, but all species used should be suitable for a given site and not develop invasive behaviour.

CCF is only possible with shade-tolerant species. In CCF, the main canopy is typically kept much more open than in a plantation forest allowing light-demanding and intermediate species to survive in the under- and mid-stories of light canopies. It is also possible to cut canopy gaps for the regeneration of light-demanding species genera such as *Quercus*, *Pinus* and *Larix*. There are many good examples of CCF in *Pinus* forests. Having said that, CCF involving intermediate and shade-tolerant species may be easier to achieve, particularly for managers new to CCF, and tree density can then be higher than in comparable woodlands that include more light-demanding species (cf. Appendix B).

CCF forests are more natural and therefore require less management. CCF does include an element of biological rationalisation (see Section 2.6), but the use of natural processes does not obviate the need for management input. In particular, continuous cover management is all but impossible without a programme of regular thinning interventions to develop individual-tree resilience among other reasons.

CCF management is more costly than plantation management. The relative costs of CCF have been widely debated without resulting in firm evidence or conclusions that can be generalised (Dedrick et al., 2007; Vítková et al., 2021). Some have suggested that costs will be lower because replanting costs are avoided; others suggested that they will be higher because of higher management inputs, increased needs for motor-manual felling and losses of economies of scale associated with clearfelling. While the costs of establishment are lower, costs of respacing (early thinnings) can potentially be higher when too much regeneration has established. Fellings may be less concentrated than with clearfelling whilst the switch from thinning from below to crown thinning improves the financial returns from early thinning. Selectively managed frame trees should be of greater quality and value.

CCF leads to better timber quality. Research has shown that CCF does not automatically enhance timber quality or results in more trees with good timber quality. If anything then timber quality is more varied. However, by stratifying trees into different functional groups (e.g. frame trees, competitors and matrix trees, see Chapter 3) early in stand development, it is possible to focus on a number of high-quality trees, and the prices they fetch on the timber market often more than compensate for the sacrifice of overall tree density compared to plantations of the same species on the same site (Wilhelm and Rieger, 2018; Pommerening et al., 2021a).

CCF is a silvicultural system. No, it is not. CCF is a fundamental forest management type, see Figure 1.1. Most silvicultural systems are regeneration methods that help a forest manager to move a forest stand from one generation to the next without resorting to clearfelling. As such silvicultural systems play a key role in the transformation of plantations to CCF. In CCF, a forest manager has a wide range of silvicultural systems to choose from. Therefore, CCF is not a silvicultural system, CCF rather involves many different silvicultural systems, but also thinning and even planting methods.

Silvicultural systems deliver CCF. Close to the truth, but this statement still misses the point. Most silvicultural systems (apart from the selection system and the two-storeyed high forest) are short-term regeneration methods and as such replace clearfelling and replanting of rotation forest management (RFM) by selective fellings and natural regeneration. Accordingly, they do not deliver CCF *per se*. Admittedly natural regeneration is a key element of CCF. However, silvicultural systems also provide shelter and other ecosystem services, and it is the long-term, envisaged structure that really delivers and maintains CCF. This long-term forest structure often differs from that adopted in the short-term silvicultural system. Forest structure ensures processes of biological automation (including, for example, regeneration, natural pruning) that are so important to CCF, see Section 2.6.

1.7 The Societies that Shape Us: Contrasting History of Forestry

The question of how much forest cover exists in a given area of the world and what kind of forest management prevails often is the result of complex societal processes that lie in the past and are therefore beyond our influence. These processes typically differ from region to region. Even on the comparatively small European continent, the historical processes that have shaped today's forest management in various countries are vastly different from one another. Societies as they have formed in different countries have not only an influence on the individuals they are composed of and vice versa, but also shape general attitudes towards vital topics such as the environment, climate change, human health, and democracy. They also provide a base opinion on forest management. Depending on this base opinion, certain types of forest management are more acceptable than others. For example, CCF much agrees with the way how Central European societies currently define their relationship with the environment so that it would be utterly impossible to re-introduce industrialised plantation management including clearfelling any time soon. The societies involved would not have it, public resistance would be considerable. In Britain and in Scandinavia, however, it is much more accepted that there are production forests that are clearfelled at the end of their economic lifetime whilst valuable, semi-natural forest ecosystems are set aside and preserved elsewhere in the country. Particularly plantation management of non-native conifers is largely accepted in some of these countries. A society's hold on individual opinions is often so strong that even scientific arguments can be influenced and biased by the opinion of the general public that researchers are naturally part of. It takes great strength of character to develop an alternative view and to communicate it. The strong influence of and indoctrination by society and upbringing can to some degree be overcome when individual researchers spend a few years working abroad in other societies or foreign researchers are invited to work in another country. Therefore, acceptance or rejection of forestry practices needs to be viewed in the context of society. The comparison of the forest histories in Britain and Central Europe attempted in this chapter may help appreciate the influence of society better and serve as a case study.

Contrary to many other European countries, Britain has a relatively short history of state-organised forest management and education. Forest authorities and services as representatives of state-organised forestry usually provide a national or regional agenda promoting the case of trees and woodlands and the comparatively long absence of a forestry agenda and a dedicated forest authority may have significantly contributed to the low woodland cover in Britain and Ireland at the beginning of the twentieth century. The first forest services on the European continent were formed as part of state-owned mines in the sixteenth century in order to provide the recently emerging industry with timber in a sustainable way. First national and regional forest services were founded in Central Europe in the eighteenth century (Hasel and Schwartz, 2006).

Towards the end of the eighteenth century, a shift from exploitation forestry and timber mining to organised sustainable forest management took place in many Central European countries. ‘They went into the hills and mountains to fell trees like others ladle water from a stream’ was apparently a famous expression in canton Neuchâtel in Switzerland to describe the reckless timber-mining attitude towards forests shortly before the introduction of sustainable forestry (République et Canton de Neuchâtel, 2001). As part of this introduction, the new field of silviculture rose from the poor remnants of devastated forests as a ‘child of need’, as Russian forestry professor G. F. Morosov wrote in his textbook (Morosov, 1959). The paradigm shift was initiated by changes in agriculture and the industrial revolution. The changes in agriculture led to a spatial separation of agriculture and forestry, which proved to be very beneficial for forestry. In the wake of the industrial revolution, the demand for timber in general, and for quality construction timber in particular, increased which gave rise to a large-scale transformation of coppice woodlands to high forests. The increased reliance on fossil fuels made the production of wood fuel in coppice woodlands redundant. By contrast, early professionalism in forestry in the Britain of the eighteenth century was built up on private estates, especially in Scotland. As in Germany, forestry in Scotland was often a family profession, in which son followed father. Incidentally, this was an effective and very successful way of passing forestry knowledge and experience down the generations while formal forestry education did not exist or was in its infancy.

Long before sustainable forestry was established in Central Europe and Scandinavia, French foresters pursued a thinning method that is now considered a crucial component of CCF management, *thinning from above* or *crown thinning*. This thinning method, ‘eclaircie par le haut’ in French, targets dominant trees when selecting trees for removal and typically leads to a markedly greater diversity of tree sizes than the traditional method of thinning from below or low thinning (see Section 5.2). According to Bauer (1968), the crown-thinning method was introduced by Tristan de Rostaing in 1560 and promoted by

Duhamel du Monceau in his instructions for quality oak timber production in 1755. Heger (1955) mentioned Varenne de Fenille as an important forestry representative supporting crown thinnings in France. This method has become a bit of a 'national' thinning type in France and was accepted in Central Europe (Germany, Austria, Switzerland) only in the twentieth century after a long domination of the low-thinning tradition. Denmark, however, has also a comparatively long crown-thinning tradition. In other European countries such as Britain and Ireland, the crown-thinning method is still largely a novel method.

While forestry education on the European continent was established in the eighteenth century (e.g. 1763 in Wernigerode by H.D. v. Zanthier; 1785 in Zillbach/Tharandt by H. Cotta) in the wake of industrialisation and an increased timber demand, the first School of Forestry in Britain was established at the University College of North Wales at Bangor in Wales only in 1904 (Linnard, 2000). Other forestry departments at Oxford, Aberdeen, Edinburgh and Newton Rigg followed later. This, however, was preceded by the introduction of forestry courses at the Royal Indian Engineering College at Coopers Hill near Egham in Surrey in 1885. These courses were only available to students who intended to enter the Indian Forest Service (James, 1990).

During the nineteenth century, the increasing sense of professionalism in forestry resulted in the formation of a number of societies devoted to its furtherance in Britain. With the approach of the twentieth century, continental forestry practice began to exert an increasing influence in Britain. Up to this time, English forestry had chiefly consisted of allowing trees to grow and then felling them, and forest management, as it is known today, was non-existent. As a new interest in forestry began to develop in Britain, so a demand arose for more information, improved techniques and a new approach to growing timber.

The obvious source of help lay in the continent, where the French and the Germans had applied themselves to the management of their forests over a long period. However in India, the government in that country had already been actively concerned with the creation of a forest service and, in 1855, a permanent policy for forest administration had been laid down. According to James (1990), the success of the Indian Forest Service was largely due to three German foresters, Dietrich Brandis, William Schlich and Berthold Ribbentrop. It is probable that many of the principles and practices which were followed in German forestry were introduced into the Indian Forest Service and when members of the Service returned to Britain, it is very likely that they were instrumental in dispersing these ideas.

It was Sir William Schlich who made the greatest impact on British forestry in the early years of the last century. When Coopers Hill closed in 1906, the forestry section was transferred to Oxford, where Schlich continued to lecture, while from time to time, he advised landowners on forestry matters and prepared working plans for several large estates. In this way, he was able to pass on much that was based on German forestry practice. Books provided another channel through which German forestry practice was disseminated in Britain and towards the end of the nineteenth century many German forestry textbooks were translated into English (James, 1990). Despite the growing climate of informed opinion favouring major state involvement in forestry, no definite measures were taken until the pressure of the First World War forced rapid action. In 1914, over

90% of Britain's supplies of wood were imported. Britain was not only heavily dependent on imported timber, but most of the supply lay outside the Empire. By 1913, Russia had been supplying Britain with nearly half its total imports of wood (Pringle, 1994). When increasingly cut off from its overseas timber supplies as a result of submarine warfare, the British government hastily established a Timber Supplies Department. Compulsory felling operations were conducted on many British estates.

Out of the trauma of the First World War the Forestry Commission, Britain's state forest service was formed in 1919, initially like a military operation and many former army officers were recruited as staff. Its aim was 'the regeneration of British forestry' (Pringle, 1994) with the primary objective of building up a strategic reserve of timber for the nation. New planting was to be with conifers since the overwhelming demand was for softwood timber. Such demand as there was for home-grown hardwoods could be met by the replanting and appropriate management of existing broadleaved woodland areas (Pringle, 1994). This gave rise to the establishment of large, single-species, even-aged plantations dominated by exotic species. The main tree species of these plantations are Sitka spruce (*Picea sitchensis* (Bong.) Carr.), Scots pine (*Pinus sylvestris* L.) and Japanese larch (*Larix kaempferi* (Lamb.) Carr.) – only Scots pine being native to parts of Britain. This initial forest policy has created a major conifer woodland legacy – sometimes informally referred to as the 'Great Spruce Project'.

The national forest policy, defined in 1919, put forward two objectives. The ultimate objective was to create reserves of standing timber sufficient to meet the essential requirements of the nation over a limited period of three years in time of war or other national emergency. The immediate objective was a ten-year scheme for state afforestation of new land, plus assistance to local authorities and private owners for afforestation and reforestation.

This development finds a parallel in the Central European forest management of the nineteenth and twentieth centuries, when large even-aged coniferous plantations were established to meet the increasing timber demand of growing populations. Coniferous plantations enabled forestry services to provide more timber volume in less time and also helped to put an end to illegal logging and timber thefts due to the uniformity of plantations which make it easier to detect missing trees. Towards the end of the nineteenth century, the disadvantages and dangers of creating large coniferous plantations became more and more evident on the European continent and the advance of soil and site sciences helped to develop a deeper understanding of the adverse effects of rigid plantation forestry. Concerned about the resilience of commercial forests German Professor Karl Gayer (1886) emphasised the advantages of uneven-aged, mixed forests in his seminal book 'Der gemischte Wald' (The Mixed Forest) and encouraged mixtures in groups by applying group shelterwood systems (Bauer, 1968). In the North of the country, his colleague Alfred Möller coined the famous term 'Dauerwald' (continuous or perpetual forest) in 1913. Apparently, at the beginning of the twentieth century, there was a considerable interest in a change of forestry methods in many parts of Europe and North America. For many years, leading continental silviculturists including Hartig and Cotta had vehemently expressed their disapproval of any kind of forest management not following the rigid idea of the normal forest with clearfelling as the only harvesting method. According to Schütz (2001b), one of the main reasons for this was that forest management following the normal forest idea could be controlled more efficiently. This was in fact an important point at a time when illegal logging was still very common in Europe and foresters were poorly paid.

Uno Wallmo, for example, a Swedish forester, promoted 'blädningskog' at this time, often translated as selection forest (or 'Plenterwald' in German); however, what he advocated was selective tree removals as opposed to clearfellings (Krutzsch, 1952; Lundmark et al., 2013). In Switzerland, preceded by forester Henry Biolley in canton Neuchâtel (cf. Figure 1.12) silviculture Professors Arnold Engler and Walter Schädelin acted as pioneers of selective tree management and CCF. In France, towards the end of the nineteenth century, an influential CCF pioneer was Adolphe Gurnaud working in the Vosges Forest (Alsace). This was also the time of Carl Schenck's 'Biltmore Lectures on Sylviculture' and other works in North America where he described forms of selective forest management. He was joined by other American authors such as Graves and Hawley (O'Hara, 2002). In Russia, G. F. Morosov finished the first draft of his silviculture textbook already in 1912. In his text, he pointed out that silviculture first started off completely empirically without the benefit of knowledge from other fields of natural sciences such as soil science or plant science that came into existence only much later. Morosov was one of the first to firmly base silviculture on biological principles. As a consequence he came to the conclusion that working against the nature of a woodland community on a given site is not what silviculture should attempt to do (Morosov, 1959).

In 1922, Möller published his famous book 'Der Dauerwaldgedanke: Sein Sinn und seine Bedeutung' (The Dauerwald idea: Its meaning and significance) which initiated a long running debate. He was among the first forest scientists to understand managed forests as forest ecosystems in a holistic way (Thomasius, 1996) and also was among the first in Germany to consider an individual-tree approach (see Chapter 3) along with the size-control principle (see Section 1.8). This was before ecology officially became an academic field of science. Möller discovered that most of his ideas and principles were

(a) (b)

Figure 1.12 Memorial stone erected in honour of CCF pioneer Henry Biolley in Couvet Community Forest, Val-de-Travers, canton Neuchâtel, Switzerland (a) and a typical snapshot of Couvet forest including *Picea abies* (L.) H. Karst., *Abies alba* Mill. and *Fagus sylvatica* L (b). A marked educational trail dedicated to Biolley's work leads through the forest. Source: © Arne Pommerening (Author).

being practised in the *Pinus sylvestris* forests of the Bärenthoren Estate near Dessau in the modern German state of Sachsen-Anhalt. Clearfellings were replaced by continued thinnings following the principles of individual-tree management (Bauer, 1968). He used these forest estates as management demonstration sites for his Dauerwald concept, which gave rise to a considerable number of 'pilgrimages' by forest managers as well as members of the academia. Möller's ideas were discussed in detail by the British silviculturist Troup in the first volume of the journal *Forestry* in 1927 (Troup, 1927). He even paid a visit to the Bärenthoren Estate and included descriptions and conclusions in his book on silvicultural systems (Pommerening and Murphy, 2004; Troup, 1928). Later other large-scale management demonstration sites were organised in Germany such as Bärenfels (Saxony, south of Dresden), Hohenlübbichow (Pomerania, east of the Oder River) and the Göttingen community forest (Lower Saxony, south of Hanover) (Krutzsch, 1952). The continued professional interest in these management demonstration areas shows how important it is to offer examples of best practice in the field, see Section 1.10 and Chapter 8.

With only a few exceptions, such as the CCF initiatives of Lord Bradford and his forest manager Phil Hutt in Devonshire (Timmis, 1994; Kerr et al., 2017), see Section 2.3.1, and the group selection trials at Glentress in Scotland (Anderson, 1960; Wilson et al., 1999; Kerr et al., 2010), see Section 2.3.2, there was a decline in interest in CCF, following Möller's untimely death in 1922. In Germany, the critics of CCF – especially Afred Dengler and Eilhard Wiedemann – succeeded in discrediting the approaches of Möller and his colleagues. Also, during and after the Second World War, there was considerable resistance from foresters in Germany to CCF, as it had been adopted and compulsorily imposed by the national socialist government during the 1930s and 1940s (Huss, 1990). Only in East Germany, Krutzsch, Blankmeister and Heger continued and refined the CCF principles proposed by Möller and termed them 'stock maintenance forestry' ('vorratspflegliche Waldwirtschaft' in German), while in West Germany, it was mostly private woodland owners and managers organised in a private forestry association, the 'Arbeitsgemeinschaft naturgemäße Waldwirtschaft (ANW)', who kept Möller's Dauerwald ideas alive and opposed state forestry that largely returned to rotation forest management (Bauer, 1968). Interestingly, in those years, clearfelling, as a hot topic, even made it into the communist class-struggle theory:

> 'Rotation forest management including clearfelling is an expression of capitalistic production. In capitalism, forests constituted capital that had to produce maximum interest rates within the shortest time possible. In pursuit of this doctrine, any principles of sustainable silviculture were neglected' (Eisenreich and Nebe, 1967).

In Britain, the first large-scale coniferous plantations were established in various parts of the country in the 1920s. Through considerable land acquisition and planting in Wales, Scotland and England, new commercial forests were created. Sadly ravaged again, as a result of the Second World War, many woodlands had to be restored and land acquisitions for forestry peaked again in the 1950s (James, 1990).

The one-sided commercial character of the Forestry Commission's early work was lamented by Peterken (1996) and echoed the harsh nature of plantation forestry in many countries at that time:

> 'It has been a great pity that the forestry profession developed such a narrow view of its responsibilities after the 1950s. At the height of their imperialist phase, foresters were regarded as "tree farmers" – i.e. those foresters who advocated highly mechanised, short-rotation cropping of genetically engineered, uniform stock. Official forestry talked down the widespread public concern about the dark character and deadening effects of conifer plantations. [...] Increasingly, it failed to deliver the kinds of woodland that people prefer. Not surprisingly, "forester" almost became a term of abuse in some parts of the conservation world'.

Alternative forms of forest management developed largely beyond the influence of British state forestry, sponsored by conservation trusts and councils. Representatives of this alternative forestry are, for example, not only the Woodland Trust and Coed Cymru in Wales but also many conservation bodies (e.g. Countryside Council for Wales, Scottish Natural Heritage, English Nature). Under their influence, many woodland owners rejected plantation forestry and worked within natural constraints (Peterken, 1996).

Outstanding academic British silviculturists include Professors R. S. Troup (Oxford University) and M. L. Anderson (Edinburgh University). Troup compiled a very influential book on silvicultural systems in 1928 which was later revised by Jones (1952) and Matthews (1989). He was steeped in the literature of continental forestry, and his varied experience of silviculture in Western and Central Europe gave authority to his teaching and publications. Anderson pointed out that, in consequence of British foresters' concentration on creating and managing forest on the clearcutting even-aged system, 'there has been little appreciation of the importance of the stand and the site, considered together as a single producing agent and not separately, and of the need for maintaining the production of that combination in perpetuity, or even of increasing it'. He came to the conclusion that a specific modification of the selection system, which he referred to as *group selection system* (see Section 2.3.2), would be the most suitable system for the Scottish uplands. Anderson proposed that dense groups of *Betula*, *Larix* and *Alnus*, spaced quite widely, should be established to suppress the ground vegetation and to provide shelter for the later planting of *Picea abies*, *Abies alba*, *Acer pseudoplatanus* L. and other broadleaved species between the spaced groups in a progressive development towards an uneven-aged structure (Anderson, 1960). Anderson also translated many continental forestry textbooks into English.

The findings of research into forest decline from the 1960s onwards and the certification process starting at the end of the 1980s applied a corrective to academic and practical silviculture on the European continent and turned them into disciplines firmly rooted in forest ecology (Pommerening and Murphy, 2004). Since the 1980s British silviculturists have taken an increasing interest in conservation work and habitat management through research, grants and active management (Peterken, 1996).

Interest in CCF was revived in the 1980s when the discussions on acid rain, forest decline, restoration and certification stimulated debate on concepts of more environmental forestry (Hasenauer and Sterba, 2000). The philosophy, goals and forest management practices of certification schemes such as the *Forest Stewardship Council* (FSC) and the *Programme for the Endorsement of Forest Certification* (PEFC) broadly match those of CCF (Franklin et al., 2018). In 1989, *Pro Silva Europe* was founded as an association of foresters practising management which follows natural processes. Most European countries have joined Pro Silva and established national and regional sub-organisations such as the Continuous Cover Forestry Group in Britain (founded in 1991) and Pro Silva Ireland (founded in 2000). Pro Silva supports the uptake of CCF by exchanging information within regional working groups, by establishing demonstration forests, (inter)national meetings, field trips and through a cooperation with educational and scientific institutions. The association also publishes statements, resolutions and guidebooks.

In parts of Central Europe, the catastrophic storm events of 1984, 1990, 1999 and 2007 repeatedly raised the question of ecosystem resilience; CCF has been identified as a way to increase this resilience (Dvorak and Bachmann, 2001; Messier et al., 2013; Hanewinkel et al., 2014) and the gales thus contributed much to a further promotion of the principles of CCF (Knoke and Plusczyk, 2001). In a similar way, the large-scale flooding events (Otto, 1994) of recent years across Europe and the global climate change debate have stimulated the adoption of CCF (Hasenauer and Sterba, 2000). The revival of the CCF debate also owes much to the United Nations Commission on Economic Development (UNCED) summit at Rio in 1992 when the terms and scope of sustainable forest management were re-defined, and it was suggested that they become an integral part of modern forestry practice world-wide. Naturally, the term ‘sustainability’ is at the centre of the CCF idea. In the narrow sense of sustainable timber yield, sustainability is an old forestry maxim which goes back as far as the sixteenth century (Hasel and Schwartz, 2006). It has received a new emphasis since the summit at Rio. The new definition states that forest resources and forest lands should be sustainably managed to meet the social, economic, ecological, cultural and spiritual needs of present and future generations (United Nations, 2001). Although initially raised as a separate issue, the forest restoration debate is in many regards similar to the continuous cover idea, especially with issues involving native species and stabilisation. Transformation or conversion as methods of establishing CCF woodlands are also techniques used in forest restoration (Thompson et al., 2003).

Subsequently, the Rio–Helsinki process, and requirements of certification also began to stir up concerns about traditional forest management in Britain. This process was given added impetus in 1997 by the start of devolution which led to the establishment of regional parliaments in Scotland and Wales. Devolution has paved the way for new and distinctive agendas for the woodlands of the three nations in Great Britain and separate woodland strategies have been launched for England, Scotland and Wales (Forestry Commission, 1998, 2000, 2001). New CCF programmes were also compiled in Germany, Ireland, Luxembourg and other European countries at this time (Larsen et al., 2022).

The Welsh woodland strategy was the last in this series and contained the strongest commitment to CCF. The ‘Woodlands for Wales’ strategy ‘aimed to convert at least half of the National Assembly woodlands to continuous cover and encourage conversion in similar private sector woodlands’. The document also stated that efforts would be undertaken to

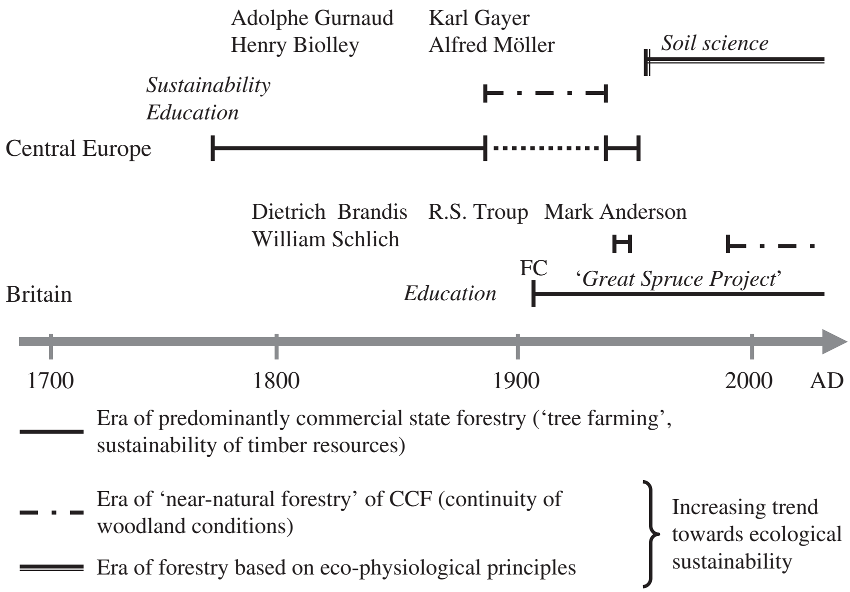

Figure 1.13 Contrasting British and Central European history of forestry.

gather information about continuous cover systems and how best to manage these systems. By 2002, the National Assembly for Wales had established three large-scale trial areas in state and private woodlands, to pioneer techniques for transformation to continuous cover systems and to collect information to guide future transformation in all woodland types (Forestry Commission, 2001), see Section 1.10.

Figure 1.13 summarises this section. British history of organised state forestry often echoes that of continental Europe taking place with a considerable time lag. The concern over sustainability of timber resources led in both places to the creation of a national agenda. In a sense, Britain repeated the course of evolution of European forestry and forest science but in a much shorter time period with less time available for a natural evolution of professional forest management methods. Rigid management of coniferous plantations was the predominant remit of European silviculture of the eighteenth and nineteenth centuries, a phase British silviculture is still very much concerned with. When, with the advent of soil sciences, it became clear that such management can lead to serious soil deterioration and other adverse environmental consequences, academic silviculture went through a serious process of re-thinking. As a result, it has now become a discipline based upon principles of forest ecology. While Britain and Ireland are emerging from a typical afforestation silviculture, a transition to a silviculture of applied ecology has yet to come.

CCF now constitutes the forestry normality in Denmark, Germany, Slovenia, Luxembourg, Switzerland and Austria and is an important part of forest legislation in these countries. CCF is also very popular in France and in Northern Italy. Anglo-American countries and most Scandinavian countries share a lasting RFM legacy, and the uptake of CCF is slow here (Puettmann et al., 2015; Hertog et al., 2022), although fuelled by climate-change concerns, there is an ongoing societal debate in these countries. Recently, China has taken great interest in CCF methods. It is an interesting question why CCF is more prominent in some countries and not in others. In our experience, the question of uptake is not much related to environmental or geographic conditions as one might think. Despite occasional professional prejudices, CCF is in principle possible wherever forest ecosystems can sustain themselves naturally. As alluded to at the beginning of this section, the uptake of CCF is more determined by societal contexts and traditions. In those countries where CCF is dominant now, a strong societal support for environmentally friendly processes has gradually evolved in general and any attempt to change forest policies in favour of RFM would certainly meet fierce public resistance.

1.8 Ensuring Sustainability: Area Control Versus Size Control

When timber shortage and increasing transportation costs became a reality all over Europe at the beginning of early industrialisation, companies and local governments were forced to face the problem of timber sustainability. Bettinger et al. (2017) emphasised that the term 'sustainability' often refers to the general ability to maintain a resource indefinitely into the future, with no decline in quality or quantity, regardless of outside influences. In the eighteenth and nineteenth centuries, a straightforward system was required that would replace forests fast where they were harvested for industrial purposes and ensured that timber sustainability could be monitored easily. The bottom line of any such system was to strike a balance between growth and harvesting, i.e. not to extract more timber than would regrow in any time period.

The question of how to ensure timber sustainability was not trivial and given the technical means at the time rather difficult to implement. Inspired by agriculture (see Section 1.2), the easiest way to achieve timber sustainability was by applying the concept of the *area-control method*. According to this concept, human interventions were spatially disaggregated. Regeneration (artificial [planting] or natural), thinning and harvesting, the main forms of human interventions in forests, were concentrated in designated areas of a larger forest, e.g. a forest estate (Figure 1.14a), whilst in CCF, when moving from left to right on the axis of Figure 1.10, these three types of interventions increasingly merge in space and time (Figure 1.14b, c).

The concept of spatial segregation of human interventions was later refined by the conceptual model of the normal forest (Gadow and Bredenkamp, 1992; Bettinger et al., 2017; Franklin et al., 2018; Smith et al., 1997). According to this model, the total forest area is basically divided into as many equally productive units as there are years or age classes in the planned rotation, and one unit is harvested by clearfelling each year or every five years depending on the width of the age classes.

The system ensured that more or less equal amounts of timber could be harvested every x number of years. Each unit contained monospecies stands where all trees were of the same age; hence, the term 'even-aged stands'. Several stands were often lumped together in spatial units that stretched over a range of stand ages, the so-called 'age classes' (with bins of 5–20 years). This was a rigid system, but it was felt that even-aged monospecies forest stands were easier to comprehend and manage than more complex forest stands that seemed 'irregular' and somewhat 'out of control' at that time. The main advantage was in

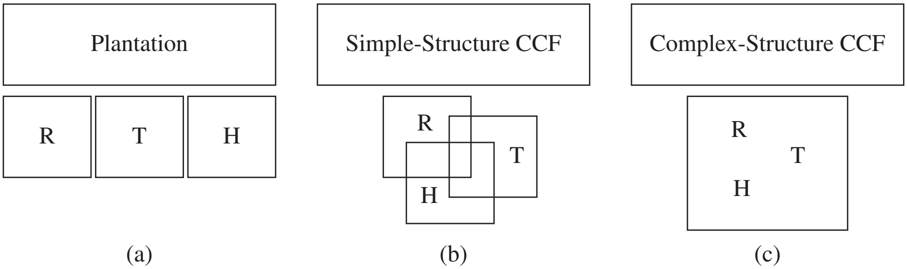

Figure 1.14 Spatio-temporal separation of regenerating (R), thinning (T) and harvesting (H) with increasing complexity of stand structure from (a) to (c). For the definition of simple (b) and complex (c) structure see Figure 2.15. The complex activities regenerating, thinning and harvesting are explored in great detail in Section 5.2. Source: Adapted from Assmann (1970).

the spatial allocation of forest operations to clearly defined areas (Knuchel, 1953). There was no room for doubt which areas had to be treated in what way and when. All trees in the designated areas were managed in more or less the same way. The system also ensured that timber thefts were easier to detect at a time when poaching and illegal logging, particularly in rural areas, was still quite common. This concept was finally formalised and implemented in Germany at the beginning of the eighteenth century and forest scientists such as Hartig, Cotta and Hundeshagen perfected the sustainability principle based on the area control method in the eighteenth and nineteenth centuries.

With time forest management experience grew and the staff involved realised that setting up such a rigid spatial arrangement required great sacrifices compared to the advantages. The method requires uniform growing conditions and thinning regimes throughout the entire forest (Gadow and Bredenkamp, 1992). The regularly formed stands in the long run did not deliver what had been expected of them (Knuchel, 1953). In addition, the area control method proved to be inflexible and could not easily handle unexpected events such as natural disturbances and even benefits such as natural tree regeneration.

The area-control method has been through a considerable process of evolution in many countries (Aplet et al., 1993; Toman and Ashton, 1996). Gradually, the rigid system of spatial arrangement was replaced by a system of individual-stand maturity where population characteristics such as standing volume, stand growth rates, basal area, stand height or economic growth rates were used as criteria for optimum harvesting time (Mantel, 1990). The concept, for example, focussed on how much total stem volume to cut each year and the areas to cut were then selected to satisfy this volume (Franklin et al., 2018). This approach can be referred to as *size-control method*. Also, combinations of area and size control methods were pursued (Franklin et al., 2018). Particularly, in Central Europe subsequently less and less importance was placed on the spatial arrangement of stands and balancing of age classes.

Beginning with the introduction of individual-based forest management by Schädelin, Leibundgut, Abetz and Pollanschütz (see Chapter 3), the next logical step was taken and the size control method was delegated further down to the level of individual trees (Pommerening et al., 2021a). The concept of individual-tree size control was first developed in areas with diverse topography, where area methods were difficult to implement because of variable environmental conditions at small spatial scales. Initially, individual-based forest management was an independent development, but it is now increasingly associated with CCF. Individual-based forest management is sometimes also referred to as *free-style silviculture*, but the term can also apply to a combination of elements from different silvicultural systems (Bončina, 2011a; O'Hara, 2014). Individual-based size control is now the dominant sustainability control method in Central Europe, and a typical application of this method is *target-diameter harvesting* (cf. Section 3.4), where for each site and species stem-diameter thresholds are given which determine when a tree can be considered for harvesting (Figure 1.15).

In conclusion, the advantage of area control is that it is very clear where in the forest (stand) silvicultural input is required at any given time. Also, the type of work necessary is fairly straightforward to explain and more or less comes with the area. Therefore, work in RFM and under the conditions of area control can mostly be delegated even to a lay person. However, this advantage comes at the expense of flexibility due to the rigidity of the area-control method. This flexibility is often needed to respond to rapidly changing, partly unforeseen stand conditions, as, for example, required with ongoing climate change. The flexibility of the size-control method is what makes adaptive forest management adaptive. Naturally, it is possible to combine both approaches temporarily and/or spatially.

Figure 1.15 Current diameters sprayed (in blue paint) onto the stem surface of *Larix decidua* Mill. and *Pseutotsuga menziesii* (Mirbel) Franco trees in the Rosengarten Forest District (Lower Saxony, Germany) for training apprentice forest managers to be able to visually recognise target diameters (cf. Section 3.4) without measuring trees. Source: Courtesy of Paul Cody.

In many countries where plantation silviculture is the dominant forest management type, the area-control method still has a considerable influence on the landscape and on the mindset of forest managers. This is particularly common in Anglo-American countries. Sometimes in these countries, even attempts have been made to apply the method of area control to CCF (Timmis, 1994; Kerr et al., 2010; O'Hara, 2014, p. 56), see Section 2.3. One can understand that the free arrangement of mature, mid-storey and regeneration trees can challenge and confuse CCF novices. Therefore, they can feel the urge to fall back on elements of the area-control method that they are familiar with.

Since area control and size control are fundamental concepts of forest management, they help understand why foresters and researchers think differently in various parts of the world. In the remainder of this book, we will often come back to these principles.

1.9 CCF in a Changing World

In Section 1.7, we traced the eventful history of CCF through the last two hundred centuries and concluded that the concept has seen a gradual evolution with many changes along the way. CCF deliberately broke off from agriculture-influenced types of forestry and pursued a path towards forest management based on ecological principles. The more we will learn about the ecophysiology of trees and other plants in forest ecosystems and about how forest ecosystems including forest soils and tree–soil interactions work in general, the better forest managers are potentially in a position to fine-tune and perfect CCF. Change, uncertainty and surprise will likely dominate the future. Climate change, globalisation, changing policies, social trends and many other changes will affect the future in ways that we can now dimly imagine (Franklin et al., 2018).

A traditional motivation for CCF was the need to diversify timber products. Because of decreasing profits, forest owners and state forestry policymakers intended to move away from maximising overall volume production to maximising the volume production of a smaller subset of trees in each stand whilst rationalising management input at the same time. This subset of trees was selected as the best-quality trees, and their quality was maintained and improved in every management intervention. All other trees in these stands were considered by-products that eventually were sold on the pulp and pallet market. As briefly pointed out in Section 1.6, CCF does not necessarily lead to an improvement of timber quality in a given stand, but by stratifying trees into different functional groups (e.g. frame trees, competitors and matrix trees, see Chapter 3) it is possible to focus on a number of high-quality trees and the prices they fetch on the timber market often more than compensate for the sacrifice of overall tree density compared to plantations of the same species on the same site (Wilhelm and Rieger, 2018; Pommerening et al., 2021a).

In the past 20 years, human-induced climate change has become a reality, and its dramatic consequences have been understood by the overwhelming majority of people on earth. Different measures and policies have been proposed to mitigate the threat to life on our planet. Increases in carbon dioxide (CO_2) in the atmosphere have been identified as a major contributor to climate change. Forests are global carbon sinks and among these measures much emphasis has therefore been placed on increasing woodland cover and on avoiding any kind of forest management that leads to a sudden, large-scale exposure of forest soils to the atmosphere so that carbon emissions are minimised. CCF seeks to create forest ecosystems and landscapes that will be resilient in the face of climate change (Franklin et al., 2018). A standard financial response to risk and uncertainty is diversifying investments. Similarly, ecologists call for heterogeneity at different spatial scales, creating redundancy and increasing resilience to face potential disturbances. Through the diversification of forest structure and tree species that typically is part of CCF, it is perceived that CCF woodlands can be more resilient to destabilising effects of ongoing climate change. This diversification also contributes to increased biodiversity or at least allows a maintenance of current diversity levels in forest ecosystems. A recently debated dilemma is that climate change may challenge the CCF tenet of favouring the regeneration of native and local parent trees. In the past, the convincing rationale for this has been that local provenances are potentially best adapted to a given site for their long co-evolution with the abiotic and biotic environment. As climate change now proceeds at a rate that is considered faster than natural rates of climate change in the past, scientists have suggested introducing provenances of native tree species that have developed in warmer and dryer climates (Köhl et al., 2010; Brang et al., 2014; Frischbier et al., 2019). CCF has also gained wide-scale recognition as an opportunity to respond to unplanned natural disturbances (Messier et al., 2013). With rising sea levels, coastal forests are also likely to play a more important role as sea defences than in the past.

Carbon forestry has now become an established term to denote forest management with the explicit objective of optimising carbon sequestration (Pukkala, 2018). On closer inspection, the strategies suggested for increasing carbon sequestration markedly overlap with the elements of CCF discussed in Section 1.5. These, for example, include increasing the resilience to natural disturbance and enhancing forest recovery following disturbance (Ontl et al., 2019) thus reducing the probability of sudden, large carbon losses. Part of carbon forestry is also increasing structural complexity and increasing thinning frequency and intensity among other strategies such as disfavouring species that are distinctly maladapted. Therefore, carbon forestry can clearly be considered a part of CCF. In carbon forestry, it may also be beneficial to concentrate sequestered carbon in a few large and long-living trees rather than maximising overall carbon sequestration by spreading carbon across many small and medium-sized trees.

At the same time, researchers in conservation science discovered that CCF includes many sophisticated techniques that come very handy when engaging in woodland restoration. In this context, forest restoration refers to the process of assisting the recovery of a forest ecosystem that has been degraded, damaged or destroyed (Mansourian, 2005, cited in Newton, 2007; Franklin et al., 2018). CCF can, for example, contribute to forest restoration by thinning stands that have become overgrown because of fire suppression. Removing small patches of trees can create compositional and spatial heterogeneity in uniform, single-species plantations on ancient woodland sites (Franklin et al., 2018). While restoration measures and silvicultural techniques have had no connection for a very long time, it is now increasingly acknowledged that many forest management methods, particularly the silvicultural systems (see Chapter 5.3), can support restoration and that completely new forest restoration methods often do not necessarily need to be devised entirely from scratch. In contrast to ecology, both conservation and silviculture have in common that they involve at least some degree of management, i.e. the informed, goal-oriented interference with natural processes based on scientific knowledge. Methods of transformation and conversion to CCF have been successfully applied in conservation projects.

CCF can also contribute to keeping groundwater levels low by intercepting rain and snow and taking up the water for transpiration and photosynthesis (Sarkkola et al., 2010). This is different to clearfelling sites, where the water level rises after all trees have been removed. In CCF, tree removals are comparatively moderate in each intervention, and the residual forest canopy keeps the groundwater table unchanged and therefore hardly any leaching of organic compounds, nutrients and sediments occurs. In addition, the residual trees take up any excess nutrients (Nieminen et al., 2018). This improves water quality and the state of aquatic ecosystems. Furthermore, the choice of tree species adapted to a given site reduces the risk of raw humus accumulation and acidification of groundwater. For these reasons, CCF is increasingly favoured in areas where maintaining good water quality is crucial.

There is also a trend towards increasing spare time and a need for outdoor recreation opportunities particularly near urban centres. In some countries, mountain biking has become a thriving business that both private and public forest owners increasingly include in their portfolio as part of business diversification through providing the necessary infrastructure. Recreation in forest landscapes is also beneficial to human health and interaction with trees is often included in therapies. CCF is increasingly considered as a way to make recreation forests more attractive to visitors by introducing more size structure and by increasing tree species diversity. As discussed in Section 1.5, both tree diversity aspects are elements of CCF. Visitors often enjoy seeing large, scenic trees (which they perceive as old trees) next to medium-sized and small trees. Forests with diverse structure also have the benefit that selective forest operations are difficult to notice and stumps of felled trees disappear in the understorey. This is very useful in community and recreation forests near urban centres where visitors often have a negative attitude towards any kind of forest management. Mixed forests that include broadleaved trees, particularly those with beautiful autumn colours, are much appreciated by visitors.

The recent energy crisis has emphasised once more that the quest for sustainable energy is crucial to the survival of mankind and to the ecosystems we inhabit. Here, energy wood production can clearly contribute to reducing our dependency on fossil fuels. Recent advances in wood-burning technology involving low emissions and high efficiency have suggested that wood fuel combustion is a realistic strategy for providing energy (Johann, 2021; Vanbeveren and Ceulemans, 2019). Wood fuel can be sourced from thinning by-products and from road-cuttings, but there is also the possibility of employing traditional wood-fuel production methods such as the coppice-with-standards and coppice-selection system described in Section 1.3.

Another trend of some importance is that of forest cemeteries. In the same way as people enjoy spending time walking through forests, they feel consolation in the thought of eventually being buried in a peaceful, natural environment such as a woodland. To make this possible, cemetery companies have set themselves up and lease forest land from the state forest service. This land is then managed by the cemetery companies. After cremation, people can be buried in biodegradable urns near trees that they themselves or relatives have chosen for them. These trees act as grave markers, and the names of the deceased along with their dates and some comforting words are inscribed on a metal sign that is attached to these trees. The cemetery company ensures that the grave marker trees continue to thrive in the woodland, and that they are not felled or damaged during the contract time of the grave. Such burials have become very popular, since they answer people's longing for nature, and they are comparatively low in maintenance. The latter is increasingly required, since nowadays people are more mobile than in previous decades and tend to flexibly change place of residence. This makes it harder to maintain traditional gravesites, and a forest burial may be a good solution. The relatives of the deceased come and visit the graves of their loved ones from time to time, and these visits should be a pleasant experience, if at all possible. Visits can be combined with leisurely strolls through the woods. Therefore, also here visitors appreciate a continuous, naturally looking forest with a mix of tree species and sizes. Again, this is something CCF can provide.

These different contexts in which CCF is of potential benefit explain why CCF is currently re-visited once again and has been identified as a universal solution for a number of quite different challenges. The question of how CCF management has to be adapted or fine-tuned to present solutions to these very different challenges, is explored in Section 7.3.

1.10 How to Introduce CCF to a New Region or a Country?

In countries with a comparatively long tradition of CCF such as Austria, France, Germany, Slovenia and Switzerland, to name but a few, this forest management type does not need to be introduced and usually is part of the standard silvicultural toolbox. Silviculture textbooks and university lectures in these countries implicitly refer to CCF as the prevailing forest management type without drawing much attention to the concept.

The situation is different in countries where forestry is or until recently used to be dominated by plantations and rotation forest management. Here forest managers, machine operators and researchers with experience in CCF are still comparatively few and continue to be so for some time. The transition towards CCF is so fundamental that even the organisation of large forest companies and state service needs to adapt. In countries where rotation forest management dominates, forestry has often been compartmentalised in an attempt to increase efficiency, i.e. individual staff do not any longer oversee the whole management and production process as the 'traditional forester of old' did but are highly specialised. Some staff, for example, manage Christmas tree sales, others only organise clearfellings, others manage thinning operations in large areas and yet again others only oversee ground preparation and replanting in vast pieces of land. This possibility of organising forestry work is much supported by the area method of control discussed in Section 1.8. However, this specialisation is far from ideal for carrying out CCF, since, for example, the main operations such as regeneration, thinning and harvesting take place in the same stands, and it is crucial to understand the interactions between different management activities, see Figure 1.14. For the same reason, it makes sense to maintain 'sessile' staff, i.e. to give up on frequent staff rotation so that forest managers are granted the opportunity to understand how the trees in their local area respond to site conditions and new interventions. Local promotion schemes can help maintain job satisfaction so that staff rotation is reduced.

Machine operators that are experts in clearfelling or systematic row removals in plantations will not find it easy to change to selective thinnings. Without appropriate training, it is hard for them to perceive differences among the trees. In this situation, training, as outlined in Chapter 8, is a very important part of introducing CCF to a new region or a new country. In general, CCF needs more knowledge, particularly about tree ecology and physiology, and forester skills than plantation management (O'Hara, 2014; Franklin et al., 2018). Models that predict plantation tree growth well, may give less precise results with CCF and traditional sampling designs may also need to be adapted.

One consequence of CCF, for example, is a trend to longer production cycles in managed forests. This implies that at least some trees in such forests are increasingly allowed to approach natural life expectancies. Naturally, trees managed under such conditions also reach larger sizes than those grown in standard plantation regimes even if the target diameter (cf. Section 3.4) is kept low (Bartsch et al., 2020). There is potentially a need to communicate this to the regional timber-processing industry. Yet another consequence of CCF for commercially managed forests is a move away from *maximising volume production* to *maximising timber quality* or other traits in individual trees. Both of these consequences may lead to a species change on many sites. Considering all these implications, it is wise to proceed in small steps and not to set too ambitious targets. For example, it may be a good idea to initially move away from plantation structure only slightly which can be achieved by replacing clearfelling with a simple silvicultural system such as the strip or uniform shelterwood system (cf. Section 5.3). Also, the transformation period (cf. Section 2.4) adopted should not be too short to allow for beginners' mistakes and other unfortunate circumstances. Once the first instances of success have strengthened self-confidence, more ambitious targets can be set.

Because the concept of near-natural forestry or CCF was comparatively new to the United Kingdom and to help improve knowledge and understanding of these new approaches to silviculture, the Forestry Commission established large-scale trial and demonstration areas in the three countries of Great Britain between 2000 and 2002 (see Table 1.3). This is a good way to gain national or regional experience in CCF comparatively quickly and can be recommended to other countries as well. The British CCF trial areas were anticipated to be in excess of 500 ha in forests managed by the Forestry Commission for commercial purposes. A notable exception is the Welsh trial area of Trallwm, which is much smaller in size and privately owned. Here, the owner saw an opportunity to diversify his business by adopting CCF. The Trallwm estate not only produces timber but also includes mountain-bike trails and holiday cottages inside the forest. Another important criterion for the selection of trial sites was easy access and a good representation of major species across a variety of site types. The areas should have transformation to CCF as management objective. In Wales, all trial sites have an almost exclusive focus on non-native *Picea sitchensis*, the main commercial species, and very much reflect initial plantation conditions rather than that they give examples of advanced irregular structures and visions for the future. The main and most intensively studied trial site in Wales is Clocaenog Forest. The trial sites were intended to serve as a long-term resource with appropriate recording and monitoring enabling the Forestry Commission to evaluate the operational, economic, social and

Table 1.3 The GB CCF trial areas.

Trial site		Established
England		
Wykeham	North York Moors FD	
Whinlatter	North West England FD	2000
Dartmoor	Peninsula FD	
Wales		
Clocaenog	Coed y Gororau FD	
Trallwm	Midwales, privately owned	2002
Cwm Berwyn	Llanymyddfri FD	
South Scotland		
Glentress/Cardrona	Scottish Borders FD	
Lochard/Strathyre	Cowal & Trossachs FD	2002
Loch Eck	Cowal & Trossachs FD	
North Scotland		
Inshriach	Inverness FD	
Craigvinean	Tay FD	2002
Morangie	Dornoch FD	

Source: Adapted from Forestry Commission (2008). FD – Forest District.

environmental impacts of CCF and to compare it with standard plantation management (Forestry Commission, 2008). The trial areas were also envisaged to demonstrate the potential of CCF and the different approaches being used.

In the 2003 version of Forestry Commission (2008), an operational guidance booklet, a wise statement was made that is even more important in a time where silvicultural research attracts less and less research funding:

> 'We are unlikely to have meaningful comparative information [on CCF management] in the next ten years. So for some time to come, management decisions will have to be based on local experience and professional judgement supported by forest research information where available. An essential principle is a close relationship between researchers and managers and a willingness from both parties to make changes as knowledge grows'.

In this context, it is crucially important that forest managers engaging in CCF keep good records on why they decided to adopt CCF, management objectives and plans, past and future interventions and monitoring information. These records should be kept safe and be passed on to successors.

Generally speaking, it is a good idea to choose trial areas for diverse environmental conditions, which are typical of a particular region or country, e.g. lowland and upland sites. Including different ownerships and associated problems is also a good way of identifying useful trial sites. This can be combined with differing general objectives such as timber production, conservation, or carbon forestry.

If any mistake was made in the British selection of trial areas, then that often sites were selected that were very uniform and only in early stages of transformation to CCF. As discussed in Section 2.4, the more uniform and plantation-like a stand is, the longer the transformation takes. This implies that meaningful results and demonstration forests are not available for some time. Therefore, it may be useful to also include forest stands in the selection of trial areas, where transformation or conversion started earlier or where 'accidents' (natural disturbances; seemingly inappropriate, heavy management interventions) happened that have given rise to a diverse stand structure, see Section 2.2. Such sites are ideal for demonstration of future CCF situations, deliver early results, and promise success.

In the author's experience, it has also proved useful to offer field trips to regions and countries, where CCF has been taken up and implemented earlier so that the participants can develop a better vision of what is possible and what lies ahead. This usually gives forest owners and managers vital inspiration and help. Here, it can be recommended to choose neighbouring countries where CCF has been introduced not a very long time ago. The reason for this is that the CCF sites in the host country are then more comparable to the situation in the home country or region and the field trip participants can better understand the road ahead. Visiting areas with refined, long-standing CCF application can discourage novices and make them conclude that these concepts will never work at home. Such visits, however, should be coupled with a network of management demonstration sites in the home country or region, since otherwise the perception may develop that certain methods work fine in the country the participants visited, but it is uncertain whether they are suitable to their home range. The Association Futaie Irrégulière (AFI), for example, is an officially registered association set up by a group of forestry experts and forest owners in 1991 in France in order to study and to develop continuous cover forest management techniques. The association has established a network of permanent management demonstration sites to illustrate and study best-practice silvicultural techniques. AFI now has a network of roughly 90 research stands spread over 15 French regions, Belgium, Great Britain, Ireland and Luxembourg (Susse et al., 2011).

Trial areas and field trips should be accompanied by regional and national workshops and conferences. Any research project related to CCF that attracted national funding should be associated with a dissemination part where the latest findings are thoroughly and comprehensively communicated to forest owners and forest managers. Since silviculture is a subject area that has suffered from recent academic trends in many countries, the field received decreasing funds and lost staff. As a consequence, important forest-management skills and knowledge are often no longer taught at universities. This is particularly unfortunate for the uptake and continuation of CCF. Since silviculture is a core competence of forest managers, the Swiss federal government, for example, counteracted this development by funding two silvicultural competence centres, one for lowland forestry at Lyss and another one for upland forestry at Maienfeld. Both competence centres are supposed to maintain the high professional standard of CCF in Switzerland by advising practitioners, publishing silvicultural guidelines and most importantly by running forest management courses. Many of these courses include marteloscope exercises, see Section 8.3, and the competence centres established a national network of marteloscope plots. The Technical Development Department of Forest Research at Ae (Scotland, UK) is a similar institution and regularly carries out training courses and marteloscope exercises for forest practitioners.

Since thinnings are a crucial instrument of bringing CCF about by modifying forest structure, a government considering the introduction of CCF can substantially contribute to the uptake of this management type by contributing to the costs of thinnings through an appropriate grant scheme. The introduction of such a scheme has considerably helped make transformation to CCF possible in Britain and Ireland (Forestry Commission, 2008).