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Close-to-Nature Forest Management: The Danish Approach to Sustainable Forestry

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1. Introduction

How should tomorrow's forests look and which future climatic conditions should they prevail? What kind of goods, services and experiences should they be able to provide; what kind of functions should they be able to perform? These are some of the multifaceted questions forest management faces today.

Forestry policy objectives have grown into a broad range of benefit provisions, other than serving exclusively as the traditional timber suppliers. Today we thus address multiple-use forestry. Production of wood commodities and securing carbon storage is central, but does not necessarily rate above the creation of non timber forest products. Increasingly highly esteemed qualities, such as protecting landscape amenities and cultural heritage, nature conservation and environmental protection, as well as the entire chapter of recreational interests are considered. Consequently, economic and technical efficiency is still prioritized, but ecological and social parameters are progressively taken into account to ensure the multiple use.

For these reasons, silvicultural strategies are required to develop economically productive forests with a high potential for nature conservation, ecosystem protection, and social values. One promising management strategy is to incorporate structural qualities and functional features of natural forest ecosystems – "to follow and assist nature in her development" as already stated 230 years ago by the Danish forester von Warnstedt (Decree of 1781 regarding the management of the Royal forests). This approach can be summarised by the term "nature-based silviculture" or "close-to-nature management" (Gamborg & Larsen, 2003). In North America, on a more general forest management level, 'ecosystem management' and 'adaptive management' can be recognized as part of this trend (Franklin et al., 2002). The aim is to reform current practices so that they are still profitable, but more environmentally benign and even more sensitive to the complexities of nature conservation and the multiple, varying and steadily increasing demands of society by mimicking natural forest structures, their processes as well as their dynamics (Angelstam et al., 2004; Lindenmayer, et al., 2006; Hahn et al., 2007; Larsen et al. 2010).

The disturbances and regeneration processes in natural forest ecosystems, which cause structural heterogeneity at both large and small scale levels are linked to regional characteristics of climate, soil, and species compositions. These processes are being expressed as e.g. infrequent, large-scale storm and fire-driven disturbances in boreal ecosystems and as frequent, small-scale disturbances in Central-European forests. Hence models, describing the region-specific disturbance patterns, such as the forest cycle model, should be used in the development of applied silvicultural methods in such natural ecosystems (Hahn et al., 2005).

In central and western Europe the forest cycle models have been successfully applied to describe the temporal and spatial dynamics and cyclic preoccupation of a specific forest type in natural forest reserves (Leibundgut, 1984; Christensen et al., 2007; Larsen et al., 2010). Such models could serve as an adequate basis for close-to-nature forest management.

The use of natural disturbance regimes to guide human management (i.e thinning and cutting systems) must, however, be complemented with other measures to restore naturalness in forest management. Lindenmayer et al. (2006) emphasize the importance of maintaining aquatic ecosystem integrity for biodiversity protection in managed forests. Hence, maintaining and restoring natural hydrology in forests previously subjected to stand management operations (such as drainage) is important. Therefore promoting species and forest structures that reflect and emphasize the variation in hydrology is an integral part of close-to-nature management, thus contributing to habitat richness in forest landscapes.

One of the basic axioms of nature-based forestry is the mimicking of natural structures and processes in order to obtain a high degree of stability within the ecosystem and thus a high degree of flexibility. All of this necessary to opening up for possible future demands and needs from various players, such as landowners, interest groups and society in general. The logic of this assumption might be best illustrated by considering the contrary position: *without stability – which functions will we be able to sustain in the future.*

One of the major problems experienced with the classical forestry approaches, is the lack of ecological and structural stability and the limited flexibility, towards addressing various at present unknown future demands (who would 20 years ago have predicted the present focus on biodiversity in forest management?). An approach, which has alerted us of the necessity to search for better management systems aiming at increasing functionality as well as flexibility in forest ecosystems; both in relation to multiple uses. In other words: We seem to face a high potential for both ecological adaptability (resilience) and functional flexibility of forest ecosystems, when opening up for greater functional integration – a central aspect of close-to-nature management.

To illustrate the differences between the traditional plantation approach, the close-to-nature approach, and a strict nature protection approach, a "goal-fulfilment assessment" and comparison of the three different management approaches is shown in table 1.

Table 1 indicates that the plantation approach and the conservation approach both are rather narrow and inflexible in their goal-fulfilment, while the nature-based wood production approach is broad and flexible in its goal-fulfilment. The weaknesses of the plantation approach focussing on timber in short rotations and neglecting most natural, cultural and social values are clearly reflected in the table. Further, the plantation approach often leads to less robust forests stands. The conservation approach obviously performs strongly in all nature protection goals but is consequently not, or less able, to deliver on socio-economic goals thus scoring rather low in terms of flexibility to changing goals.

The maintained focus on production economy in combination with relative high scores in ecological as well as social values addressing the needs for stability, explains why the nature-based approach to sustainable forest management has been chosen in many countries. The integrative ability and flexibility of the nature-based approach to fulfil different management goals is a key feature of this management type. Because of this feature, it is possible to gradually adjust the course of management to address the ever-changing objectives and aspirations of society.

Management approach	**Plantation (production) approach**	**Nature-based (integrative) approach**	**Nature protection (conservation) approach**
Specific management goals	Focus on timber production and direct economic outcome	Flexible wood production, nature protection and recreation	Strict forest reserves following natural structures and processes
Production of timber	+++++	++++	+
Economic outcome, long term	+++	+++++	+
Economic outcome, short term	+++++	+++	+
Production of quality timber	++++	++++	+
Biodiversity protection	+	+++	+++++
Protection of wetlands	+	+++	+++++
Ecosystem integrity	+	++++	+++++
Aesthetic qualities	+	+++++	+++++
Landscape integration	++	++++	+++++
Historical and cultural values	+	++++	+++
Space for public recreation	++	++++	++
Place of quietness/meditation	+	+++	+++++
Hunting qualities	+++	++++	+
Robust and resilient forests	+	++++	+++++
Flexibility to changing goals	+	+++++	+

Table 1. Different management approaches and their respective fulfilment of different specific management goals. The scale from 1 to 5 plusses, and '+' = low goal fulfilment, whereas '+++++' = high goal fulfilment.

2. The history of nature-based forest management – In short

In Europe there have been attempts and local traditions to literally follow nature-near principle, to follow and steer the natural development in order to meet some more or less specific goals (Leibundgut, 1984; Schütz, 1990; Otto, 1993). However, the main trend in European forestry has followed the principles of organised forestry with a strong emphasis on clear-cutting, planting, thinning, homogenisation of structures, as well as rationalisation of working procedures. Organised forestry has had longstanding strong advantages in terms of overview, planning, standardisation, prediction and control.

While organised forestry has become the dominating concept in most parts of Europe, the more nature-inspired forestry approaches have been left to survive in the shade. Such concepts have not been given much attention, nor has much research been carried out to highlight possible advantages of this branch of silviculture. The ideal "to follow and assist nature in her development" has often been cited – but in reality rarely been followed in practice. Until recently, most attempts to apply nature-based forestry have been mainly exceptions from the rule. They have been carried out under special conditions and have been conducted by individuals mainly driven by conviction. A belief which has led to the assumption that nature-base forest management could turn out to be a more promising approach than traditional plantation forestry. People practising nature-based forestry have thus in the recent past often been given the image of being some kind of "religious freak" (Heyder, 1986).

Close-to-nature forestry is unquestionably focused around the idea of selection forest. The single tree and group selection system represent a clear contrast to the even-aged forests of organised forestry. Many foresters have tried to develop such uneven-aged mixed forests and have searched for appropriate methods to evaluate management successes, in order to compare them objectively to even-aged systems. The French forester Adolphe Gurnaud (1825-1898) once succeeded with the French *Méthode de contrôle*. His method based on regular inventories of forests parameters, especially diameter distribution and increment. Although not successful in implementation of his ideas, Henri Biolley (1858-1939) later succeeded in managing the community forest of Couvet with this "modern" selection system (Biolley, 1920).

Another important source of nature-based forestry started around the ideas of Karl Gayer (1822-1907), a silviculture professor in Munich. At that time, organised forestry with clear-cut systems and introduction of conifers had already expanded over large forest areas. Consequently, following this process, soil degradation, fungi and insect outbreaks, as well as frequent windbreaks had been observed in those areas. As a reaction, Gayer then developed his idea of mixed forests, which were about to be achieved merely through natural regeneration (Gayer, 1886), often in combination with the irregular shelterwood system. Using irregular regeneration over a longer time-span would thereby enable various different species to establish and thereby creating mixed forest structures.

His ideas were further developed in Switzerland. At that time Swiss forests suffered severely from torrents, landslides and windbreaks, as a result of spruce monocultures and clear-cut management systems. Arnold Engler (1858-1923) succeeded in gradual change of the Swiss forestry paradigm, which was untied from the regeneration scheme of organised forestry.

Today, variations of the Swiss irregular shelterwood systems are the most widely applied nature-based silvicultural systems all over Central and Eastern Europe. This is mainly thanks to the great flexibility of the system, which is based on the principles of adapting the felling temporally and spatially to the regeneration ecology of various tree species. Apart from the selection system, the irregular shelterwood system for nature-based forestry and the "free-style silvicultural technique" are significant as well; especially when it comes to managing degraded forests or transforming uniform and even-aged forests into mixed uneven-aged forests.

The third "wave" of nature-based forestry has developed arund 1920 in northern Germany when Alfred Möller published the book "Der Dauerwaldgedanke" (Möller, 1922). His paradigm of a continuation forest differs essentially from other nature-based concepts. Möller's approach is based on an organismic and holistic conception of forests and it follows stricter felling rules. His ideas had been shaped in forests where careful, continuous forest cover forest management had been applied for many years (Bärenthoren in eastern Germany). Möller carries out different inventories and publishes his results in favour of continuous forest cover management (German: Dauerwald), which, according to his conviction, offer improved forest sites, abundant regeneration as well as increased wood production.

Möller's forest approach was welcomed with great sympathy during the first years after his book had been published. 'The Dauerwald concept' was embraced with great enthusiasm all over Germany. When Möller died soon after publishing his book and his ideas proved unable to deliver the hoped success in the field, his approach became increasingly questioned and in the end even doubts about his scientific credibility ended this chapter of nature-based forestry in Germany during the 1930's.

With the foundation of a working group for close-to-nature forestry (Ger. Arbeitsgemeinschaft naturgemäße Waldwirtschaft - ANW), in 1950 yet another force steps onto the forest management scene. The ANW was rooted in the Dauerwald movement, and the groups ideas based on a set of principles rather than a management system. The group's members are mainly practising foresters and forest owners. Decisions on how to manage forests and strategies are empirical and often intuition based.

The call for for expanding the ANW-movement outside Germany resulted in the foundation of Pro Silva Europe in Slovenia in 1989. Pro Silva advocates close-to-nature forest management based on natural processes. Most European countries (at present 24) have joined and established national, independent Pro Silva sub-organisations. Their common ground on the national level is to develop and promote the principles of sustainability. These principles are considered to allow for the full development of the forests ecological and social roles, while a simultaneous economic production of high quality forest products can take place - all by mimicking natural processes. Members are forest owners, foresters, students and others who wish to practice and learn more about nature-near forestry.

2.1 The toolbox of classical and nature-based forestry

Basically classical plantation silviculture and close-to-nature approaches make use of the same toolbox in managing forests. However, the importance of single tools differs between the two concepts. Table 2 illustrates how different silviculture tools can be applied and combined under different management approaches. The plantation approach is displayed in two versions: traditional and modified (to achieve a higher degree of sustainability). Accordingly, the nature-based approach is displayed in a more economic, and a conservation focussed version.

Table 2 shows how management approaches determine what tools might be appropriate and most widely used. It further shows that although it is meaningful to differentiate between the various management approaches, it is neither possible, nor is it meaningful to draw a strict watershed line between those definition categories. Naturally transgression corridors occur. For each strategy however, it is possible to provide a set of relevant silviculture tools. Depending on management styles and aims within plantation, respectively nature-based management, the relative importance of the different tools can be adjusted. Each forest owner and each policy maker must critically choose his or her favourite tools for the situation and objectives which are being focussed upon.

Silviculture tool / Anticipated stand structure	Traditional plantation (production) approach	Modified (sustainable) plantation approach	Nature-based economic production approach	Nature-based nature conservation approach
Clear cutting at rotation age	+++++	++++	++	+
Single tree/group cutting	+	++	+++++	+++++
Planting or sowing	+++++	++++	++	+
Natural regeneration	+	++	++++	+++++
Use of soil preparation	+++++	++++	++	+
No soil preparation	+	++	++++	+++++
Use of pesticides	+++++	++	+	+
Ban of pesticides	+	++++	+++++	+++++
Use of exotic species	+++++	++++	+++	+
Use of native species	+	++	+++	+++++
Stand management	+++++	++++	++	+
Single tree management	+	++	++++	+++++
Harvest when ripe	+++++	++++	++++	+
Preserving old trees	+	++	++	+++++
Wood salvage	+++++	++++	++++	+
Leaving dead wood	+	++	++	+++++
Draining for production	+++++	++++	+++	+
Maintain wet habitats	+	++	+++	+++++
Monoculture	+++++	++++	++	+
Species mixtures	+	++	++++	+++++
Even-aged stands	+++++	++++	++	+
Uneven-aged stands	+	++	++++	+++++

Table 2. Examples of silviculture tools and anticipated stand structure and their relative importance in nature-based as well as classic (plantation) forest management:
+++++ greatly used, ++++ frequently used, +++ regularly used, ++ rarely used;
+ hardly ever used

Nature-based approaches in general refrain from larger clear cuts, but in specific cases - often in order to promote light demanding (pioneer) species - clear-cuts can be applied. Nature-based management relies heavily on natural regeneration but includes planting or direct seeding if natural regeneration is insufficient and/or if desired species are missing (enrichment planting). Nature-based approaches often make use of single tree selection based on target-diameter cutting, which should not be misinterpreted as "high grading" known from overexploitation of natural stands. Thus we here focus on a system to provide a sustained yield by making thinning among the various age classes in order to ensure their desired proportions and to maintain a suitable mixture of species. It should further be stressed that the heterogeneity of the stands is not just an end in itself, but rather a way of allocating species to various soil conditions and creating good forest floor conditions for natural regeneration.
The toolbox concept implies the refrain from any specific (religious) interpretation of what nature-based forest management is or should be - rather, the toolbox should be open to anyone finding the tools appropriate for any use he or she might wish for. The tools from

this nature-based toolbox can be used for nature-protection, for wood-production or to develop new types of urban forest (Larsen and Nielsen, 2011).
However, the main prerequisite for defining an approach "nature-near" or "close-to-nature" should be *that the practices are founded in, or inspired by, the structures and processes that occur in natural forests of a specific (reference) region.* This principle can be used to achieve all kinds of different management goals and objectives, including timber production, nature protection and social values.

3. Close-to-nature forest management in Denmark

The forests in Denmark amount to a total area of 570.800 ha, equivalent to some 13 percent of the total land cover. Originally, most of the land has been forested, but after centuries of uncontrolled logging and deforestation for agriculture, forest areas begun to decline drastically and consequently collapsed to a mere 2 to 3 percent around the 1820's. Since then the forest area is increasing due to large forestation efforts from 1860 and onwards and expected to reach around 20 % within this century.
Originally the Danish forest consisted mainly of deciduous trees - especially beech and oak. Over the past 200 years of forest management - including the large forest plantings in Central and West Jutland – the species distribution changed radically. Today, more than 50 % of forested areas are covered with non native conifers such as Norway and Sitka spruces, Douglas fir, as well as different Abies-species. Deciduous forests cover not more than 44 %, with beech and oak as the most common species, and ash, sycamore maple, Norway maple, birch, alder, wild cherry and lime as minor species.
As a general trend, forestry in Denmark has followed the overall European development when focussing on timber production in mostly plantation like structures. As a result, highly productive forests have been promoted, a process, which simultaneously created the matrix for increasingly intense conflicts with nature protection interests. First and foremost, the stability of the forests suffered through the development of even-aged monocultures. During the last 40 years, in 4 storms (1967, 1981, 1999, and 2005) a total of 15 million m^3 were blown down, whereas "only" 1 million m^3 fell down during the first 60 years of the past century. Hence, a major reason for the increasing impact of storms in Danish forests is the increasing use of storm sensitive conifer species.
In order to realize sustainable forestry at the management unit level (to achieve a proper balance between economic, ecological and social functions), a set of overall aims and operational guidelines has been developed in a stakeholder driven process during 2001. The National Forest Programme (Skov- og Naturstyrelsen, 2002) now consequently prescribes that Danish public forests should be managed in accordance with close-to-nature principles. The essence in these close-to-nature principles can be summarized as follows: Increase the stability and prepare the forests for an unknown future of changing climate, changing values and a variety of goals.
This close-to-nature approach is in particular focussed on:

1. Creating optimal conditions for natural regeneration by maintaining the permanent forest climate by refraining from clear-felling.
2. Stability improvement and risk diversification (resilience) through the creation of uneven aged mixed forest stands of site-adapted tree species.
3. Active stand improvement through frequent and weak thinning.

4. Protection of natural equilibriums among forest organisms, including pests, with the aim of promoting biodiversity and avoid the use of pesticides.

The close-to-nature forest management, combined with an increased use of climate robust deciduous and coniferous species and the reduction of climate change intolerant conifers (i.e. Norway spruce and Sitka spruce), are here identified as the overarching principles to secure sustainability, safeguard stability, and prevent the negative effects of climate change. Consequently, The Forest Act from 2004 supports the change from classical mono-species and even-aged management of stands into close-to-nature management characterised by more single tree and group management, incorporating and supporting natural regeneration and structural differentiation.

This decision to transform ''classical'' age-class forests (plantation forestry) towards nature-based forest stand structures implied no less than a paradigm shift in the management of state owned forests. Realizing that the complex character of these near-natural forest structures and dynamics require integrative and flexible management frameworks, as well as tools, a two step process was established: Firstly, the need for defining and describing long term goals for nature-near stand structure and dynamics was recognized and taken into the picture (where are we going?). Secondly, methods for transformation from plantation to nature-near structures were specified (how do we get there?).

3.1 The long-term goals – Creating Forest Development Types (FDT)

The concept "Forest Development Type" (FDT) was considered as an adequate framework for advancing and describing long-term goals for stand structures and dynamics in stands subjected to close-to-nature management (Larsen and Nielsen, 2007). An FDT describes the direction for forest development on a given locality (climate and soil conditions) in order to accomplish specific long-term aims of functionality (ecological-protective, economical-productive, and social-/cultural functions). It is based upon an analysis of the silvicultural possibilities on a given site in combination with the aspirations of future forest functions. It will serve as a guide for future silvicultural activities in order to "channel" the actual forest stand into the desired direction. Such a common understanding and agreement upon the desired development is crucial, since the conversion from age-class to nature-based stand structures is a continuous process.

In Denmark, a participatory process lead and described by Larsen and Nielsen (2007) resulted in the creation of 19 FDT's, which can be grouped into 9 broadleaved dominated, 6 conifer dominated, and an additional 4 "historic" types (Table 3). Whereas all "nature-based" FDT encompass a balance between productive, protective and recreational/social functions, the other four "historical" types mainly serve to protect recreational, natural and cultural functions. Especially the historical Forest Pasture (FDT No. 92) and Forest Meadow (FDT No. 93) can be actively used to create habitat diversity and experiential richness in forest landscapes.

Each FDT is described as follows (See also Figure 2, describing FDT No. 12 "Beech with ash and sycamore"):

- Name: The name encompasses the dominating and co-dominating species. The first digit in the FDT-number indicates the main species (1 = beech, 2 = oak, 3 = ash, 4 = birch, 5 = spruce, 6 = Douglas fir, 7 = true fir, 8 = pine, and 9 indicating a "historic" FDT). The second digit is numbered at random.
- Structure: A description of how the forest structure could appear when fully developed. This description is supplied with a profile diagram depicting a 120 m transect of the

anticipated forest structure at "maturity" (In Figure 1 profile diagrams of all 19 FDT´s are displayed and in Figure 4 the profile diagrams of four FDT´s are with different forest-edge types shown: No. 11-Beech, No. 21-Oak with ash and hornbeam, No. 71-Silver fir and beech, and No. 92-Forest pasture).

- Species distribution: The long-term distribution of species and their relative importance.
- Dynamics: The regeneration dynamics described in relation to the expected succession and spatial patterns (species, size).
- Functionality: Indication of the forest functionality (economic-production, ecologic-protection, and social/cultural functions).
- Occurrence: Suggested application in relation to climate and soil. For this purpose the country is divided into 4 sub-regions each with their typical climatic characteristics. Further, the application of the specific FDT in terms of soil conditions is stated in relation to nutrient and water supply.

Broadleaved dominated:		**Conifer dominated:**	
11	Beech	51	Spruce with beech and sycamore
12	Beech with ash and sycamore	52	Sitka spruce with pine and broadleaves
13	Beech with Douglas fir and larch	61	Douglas fir, Norway spruce and beech
14	Beech with spruce	71	Silver fir and beech
21	Oak with ash and hornbeam	81	Scots pine with birch and Norway spruce
22	Oak with lime and beech	82	Mountain pine
23	Oak with Scots pine and larch	**"Historic" forest types:**	
31	Ash with alder	91	Coppice forest
41	Birch with Scots pine and spruce	92	Forest pasture
		93	Forest meadow
		94	Unmanaged forest

Table 3. The 19 Danish Forest Development Types.

Matching forest development types to site

While different forest development types possess different site requirements it is possible to address and utilise potential variation in site conditions by matching FDT to site. This requires a thorough site survey, in which analyzing the basic growth conditions such as geology and soil types, nutrient and water supply, as well as specific site factors (such as compact layers and insufficient drainage) are taken into account. A hydrological status analysis on site is necessary, and it should include a survey of existing drainage systems, in combination with a plan of the historic landscape with former wet-lands, prior to any draining process. This hydrological analysis will provide an important tool and inspiration for delineating the landscape into ecological functional units. The site classification map works correspondingly as a frame for applying FDT to the site, thus facilitating the creation of forested landscape where site adapted forest and nature types reflect and emphasize variations within landscape.

Further, different FDTs possess different combinations of goal fulfilment - some are more production oriented, some more oriented towards nature/biodiversity protection, while others focus on enhancing landscape and recreational values. This variation in goal achievement can correspondingly be used to select FDTs - all according to specific functional requirements defined by the forest owner and - in case of public forest - by society/interest groups.

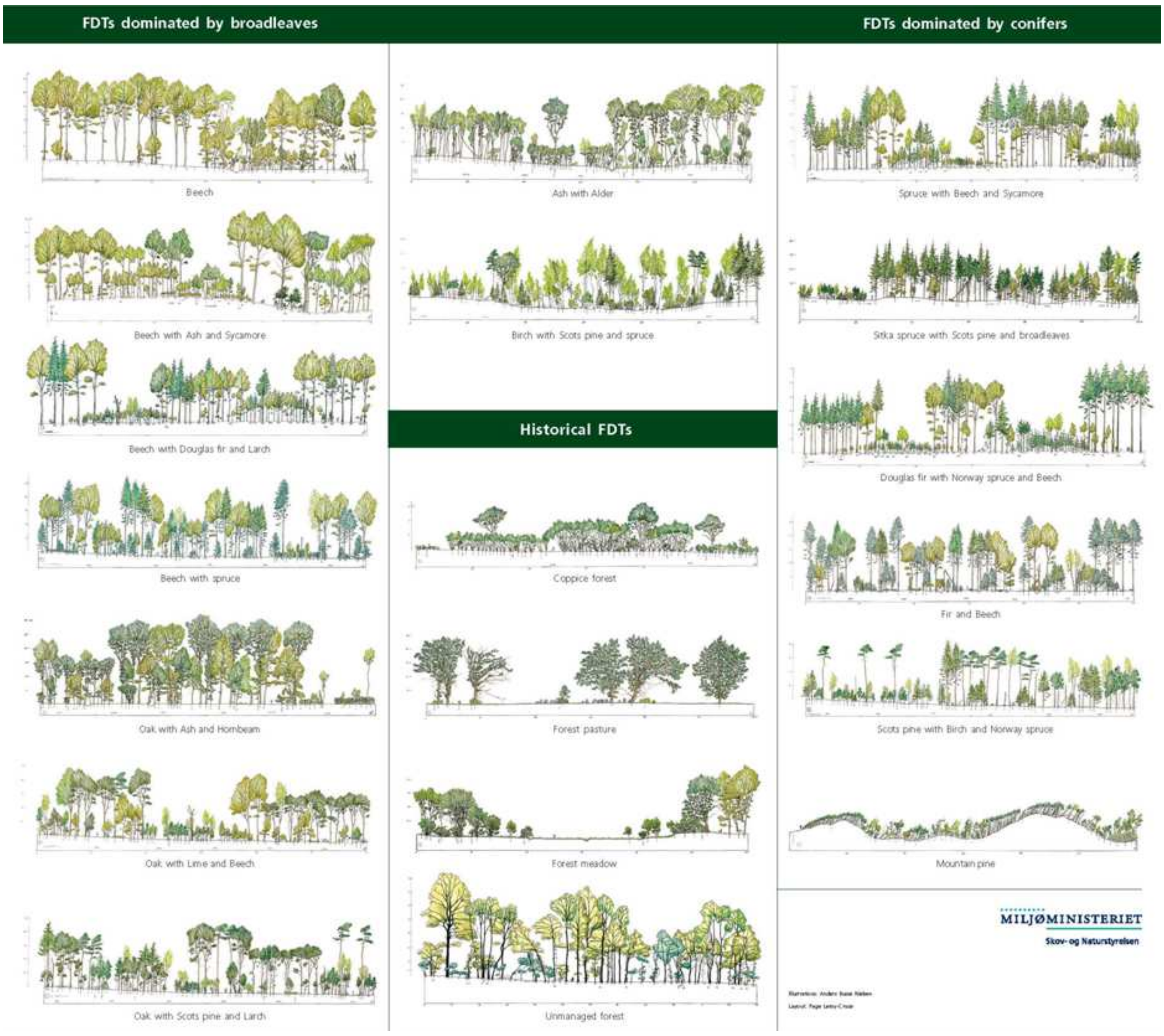


Fig. 1. Profile diagrams of the 19 Danish Forest Development Types.

At present the Nature Agency, responsible for the management of the Danish state forests, is laying out a grid system of forest development types on all public forests. This grid system will provide the local forest manager with information about the long-term goals he should aim at in each and every part of "his" forest. The managers job as local silviculturist will consequently be to observe the natural development and only then, after having conducted his observational research, to start making adjustments (cutting, planting, weeding, fencing, soil scarification etc.) in case the stand is due for short-term economic intervention (commercial thinning) and/or the actual development compromises the long term goal, as described in the attributed forest development type.

As mentioned above, the process of marking out FDTs on a management unit level is at present ongoing in Denmark. To illustrate this process, as well as the outcome, an example will be shown below. This example inspects the FDT-plan for the eastern part of Vestskoven as proposed by a group of students attending the international master course in Urban Woodland Design and Management (plan described in detail in Larsen & Nielsen, 2011).

Vestskoven was established in the 1960´s west of Copenhagen to create a large recreational forest that could separate and structure the intense and rapid urban sprawl, and provide for

Forest Development Type 12: Beech with ash and sycamore

Structure: Species rich, well structured forest with beech as dominating element mixed with ash and cherry and in south-eastern Denmark additionally with hornbeam and lime. The in-mixed species occur mainly in groups. The horizontal structures arise between groups of varying size and age. Where the light demanding species such as ash, sycamore and cherry dominate, vertical structures occur periodically with shade trees (beech, hornbeam, elm, and others) in sub-canopy strata.

Species: Beech. 40 – 60 %, ash and sycamore: 30 – 50 %, cherry, hornbeam, oak, lime, and others up to 20 %

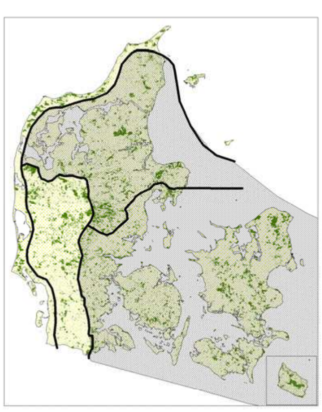
Dynamics: Beech regenerates mainly in groups and smaller stands. Ash and sycamore as gap specialists regenerate in openings later followed by beech. Hornbeam belongs to the sub-canopy stratum and regenerates under shade, whereas the pioneer species (cherry and oak) only regenerate after lager openings and/or in relation to forest edges.

Functions: Productive: The forest development type has a high potential for production of hardwood in larger dimensions and of good quality.

Protective: In most parts of the country the beech dominated forest represents the potential natural vegetation; consequently, many indigenous species are connected to this forest development type. It has a great potential for conserving biodiversity connected to the NATURA 2000 habitat type 9139 and 9150.

Recreational: Through ist mixture of (indigenous) species in combination with pronounced variation in size the forest development type gives a multitude of recreational experiences and intimacy.

Occurrence: The forest development type belongs on protected sties in the eastern and northern parts of Denmark on rich, well drained soils with good water supply as illustrated below.



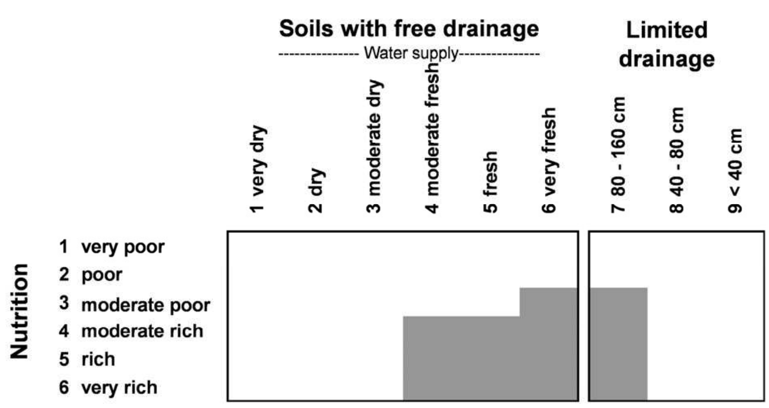


Fig. 2. Description and illustration of Forest development Type 12: Beech (*Fagus sylvatica*) with ash (*Fraxinus excelsior*) and sycamore (*Acer pseudoplatanus*).

important recreational qualities for the 300.000 new citizens in the western parts of Copenhagen. Fields were planted successively as they were purchased; little consideration was given to the overall composition and interlock zones between stands, or those parts dividing forested from open areas. The fields were planted according to traditional manuals with monoculture stands or simple species mixtures, using the species that were available at nurseries. The forest thus consists of small stands with abrupt species transitions and edges, all together lacking valuable interlock zones between the forested and more open areas. Today the area functions as a traditional Danish timber production forest with some large open spaces for recreation sprinkled onto it (Figure 3).

Fig. 3. Photo (from east towards west) of the eastern part of Vestskoven, showing the fragmented composition of uniform blocks of geometrically shaped stands and open spaces.

The above description demonstrates that Vestskoven incorporates most of the potentials, but even many problems, which urban woodlands inherited from the commercial forest management tradition with its uniform stand structures and its fragmented blocks of geometrically formed stands and open areas. The absence of smaller openings and glades, and the lack of valuable wetlands thus mould a fragmented, disconnected forest landscape.

Since Vestskoven is a public forest it will be managed according to close-to-nature principles and it is currently in the process of being charted into the FDT grid. Figure 4 presents a conversion/restoration plan where four Forest Development Types (FDT´s) have been laid out in respect of existing values in the young plantations and adjacent plains. The four selected FDT´s (FDT 11, Beech; FDT 71, Silver fir with beech and spruce; FDT 21, Oak with ash and hornbeam; FDT 92, Grazing forest), each with distinct experiential and ecological characteristics, unify the many small stands within larger units. The variety of size in open areas is increased by adding small, intimate glades in the forested parts. Some of the open areas have been linked to add further spatial variation and to increase coherence.

Parts of the forested, as well as the open areas have been converted into grazing forest through heavy thinning and some additional planting of trees. The borders between forested parts and open areas have been re-shaped organically by cutting out some of the existing stands, and instead giving room for edge species in those corridors. Thereby important interlock zones are being shaped between the denser forested and the more open areas, allowing for more diverse and complex edge structures. Ponds have been restored at emerging wetlands to render valuable landscape attractions, both in regard to landscape interpretation by visitors, as well as in regard to biodiversity in general. This landscape re-shaping takes place in the vicinity of small glades, at forested edges and in larger plains.

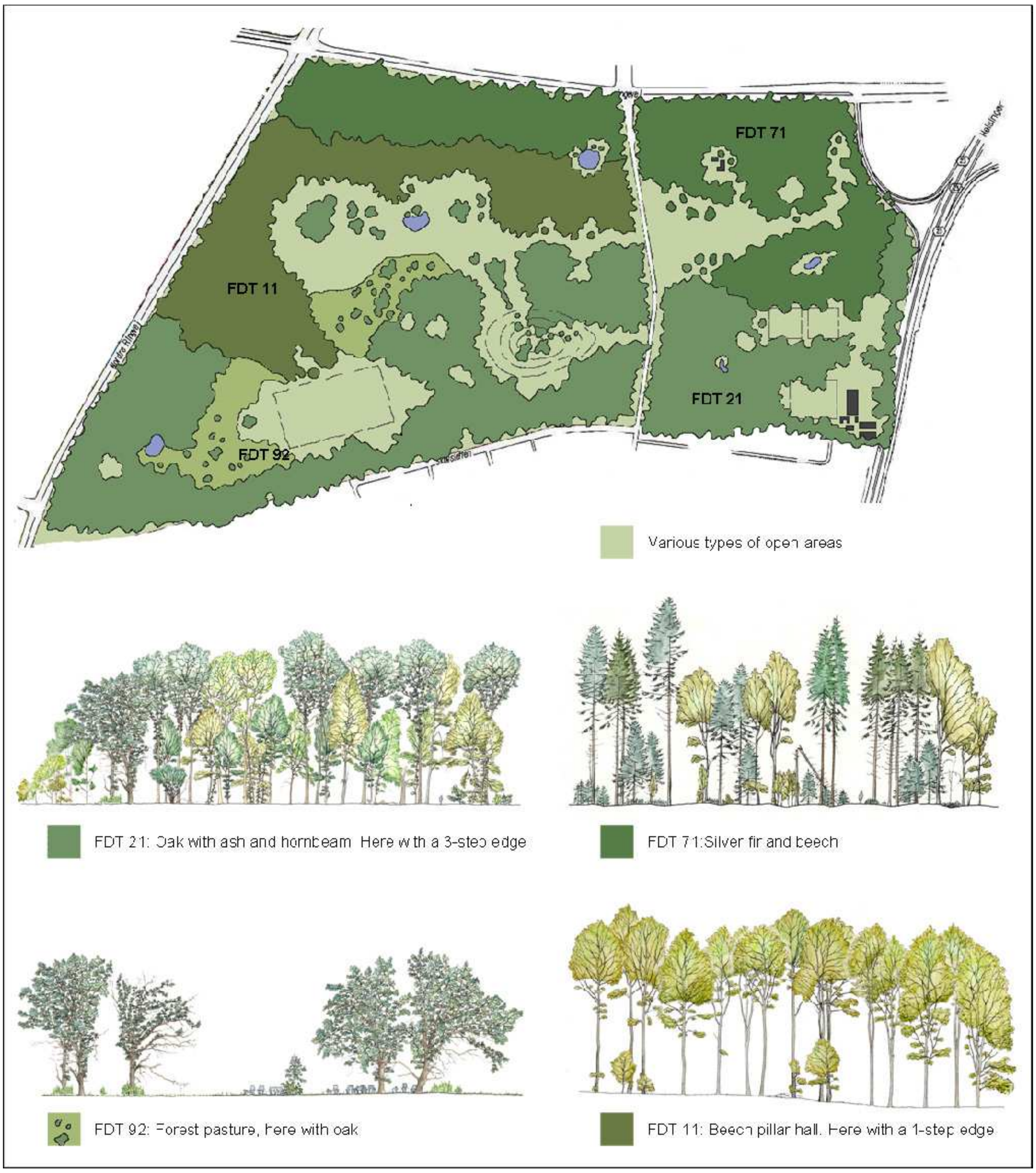


Fig. 4. Restoration plan for the eastern part of Vestskoven:

This plan was developed by a group of students attending the international master course in Urban Woodland Design and Management (Larsen & Nielsen, 2011). The chart, in combination with the profile diagrams of the four FDT´s, including examples of different edge-types, gives an instant impression of the anticipated urban forest landscape goals.

Furthermore, it provides an outline for appropriate developments in different parts of the forest. Such a developed and augmented plan, in combination with an FDT-map and profile diagrams of the different forest development types applied, can be used in multiple participatory planning processes.

3.2 Conversion principles and methods

Having defined the long-term goal at each part of the forest, the practitioners' principal task is to "guide" the forest from the current structure toward the targeted FDT. To help the local manager in this new endeavour, a number of conversion models haven been developed through a participatory process with local practitioners, forest workers and entrepreneurs. The primary purpose of this process is to come up with ideas as to how the conversion of a number of typical output models toward the desired forest type of development can take place. Since the conversion of uniform stands of spruce and beech are the main challenges in the transition to close-to-nature forest management in Denmark, the emphasis is on models for these species. Therefore, it is important to emphasise that these models are intended only to be used as inspiration, and they will always have to be adapted to any local situation, as well as to the concrete economic and technical possibilities. Especially the pace, at which the conversion is to be preformed, must be thoroughly analysed in regard to any economic aspects, paying special attention not to compromise expectation values for wood production in the transition phase. Therefore, in most cases, the full transformation to nature-near structures might take up to one or two tree generations.

Deciding on conversion strategy and tools there are two fundamentals, which must be kept in mind: Firstly, stand stability must be ensured and natural regeneration conditions must be improved. Thus creating various options and "freedom," timely to initiate rejuvenation (including bringing in new species), if required. Secondly, it is essential to initiate these elements at the ecologically and economically right moment in time. Thus, we speak of 1) a preparation phase, where the forest is stabilised and prepared for regeneration - mainly through selective thinning operations, and 2) a transformation phase, characterized by passive or active initiated regeneration, respectively by introduction of new species (and the procedure of ensuring their development). The preparation phase is usually associated with income (or at least cost neutrally implemented); whereas the transformation phase often entails costs (investments). Although, according to the principles of biological rationalization (a central economic aspect of close-to-nature-management), these costs could be kept on minimized levels by letting nature itself do as much of the "work" as possible.

If the forest development type prescribes species which are not present, or their genetic constitution (provenance) is not acceptable, additional seeding or planting (enrichment) in groups (typically, beech, ash, maple, birch, bird cherry, fir, larch, Douglas fir, etc.) is foreseen. These groups can later on contribute to a more widespread distribution of the species (done through seed dispersal). In order to allow rejuvenation of stable, but often frost-sensitive species (beech, firs including Douglas fir, etc.), a continued forest climate is regarded vital. Under such circumstances a stable forest canopy is paramount; especially in critically exposed, storm sensitive spruce monocultures. If a more complete conversion to new main tree species is aimed at already in the first generation, an extra widespread planting or seeding is envisaged, but often at higher cost. However, the close-to-nature approach is in general more inclined to exploit cheap regeneration methods, thereby accepting a longer conversion phase.

Generally, we distinguish between passive and active conversion strategies. The passive strategies are primarily based on existing vegetation, in order to convert as economically efficiently as possible. This implies mostly long conversion periods (up to several tree generations). The active approach is used where stability does not allow a slow (pending) conversion and/or there are other motives (ecological, aesthetical, and recreational) that advocate for a fast conversion.

Passive strategies

The purpose of the passive strategies is to implement as low-cost rejuvenation as possible, while maintaining optimum production in the upper canopy and the area as a whole.
Exhibit stands a high degree of stability; a passive strategy can be used that largely exploits the stand productive potential for transition to target diameter cutting without losing the possibility of a conversion. Transition phase can likewise extend over a long period of time, utilizing the system's own forces (natural regeneration), supplemented with scattered introduction of "new" species, if needed in the emerging gaps. Under such conditions, there are usually no major conflicts between the long-term objectives and the operating economy of the conversion phase. Gap size, and thus the potential light radiation, plays a crucial role in the choice of implanted species where they do not appear spontaneously. Thus, light demanding species such as larch, Douglas fir, oak, birch etc. require larger gaps (above 0.4 ha), while in the smaller gaps (0.1 - 0.2 ha), more shade tolerant species such as beech, maple and fir will be suitable.

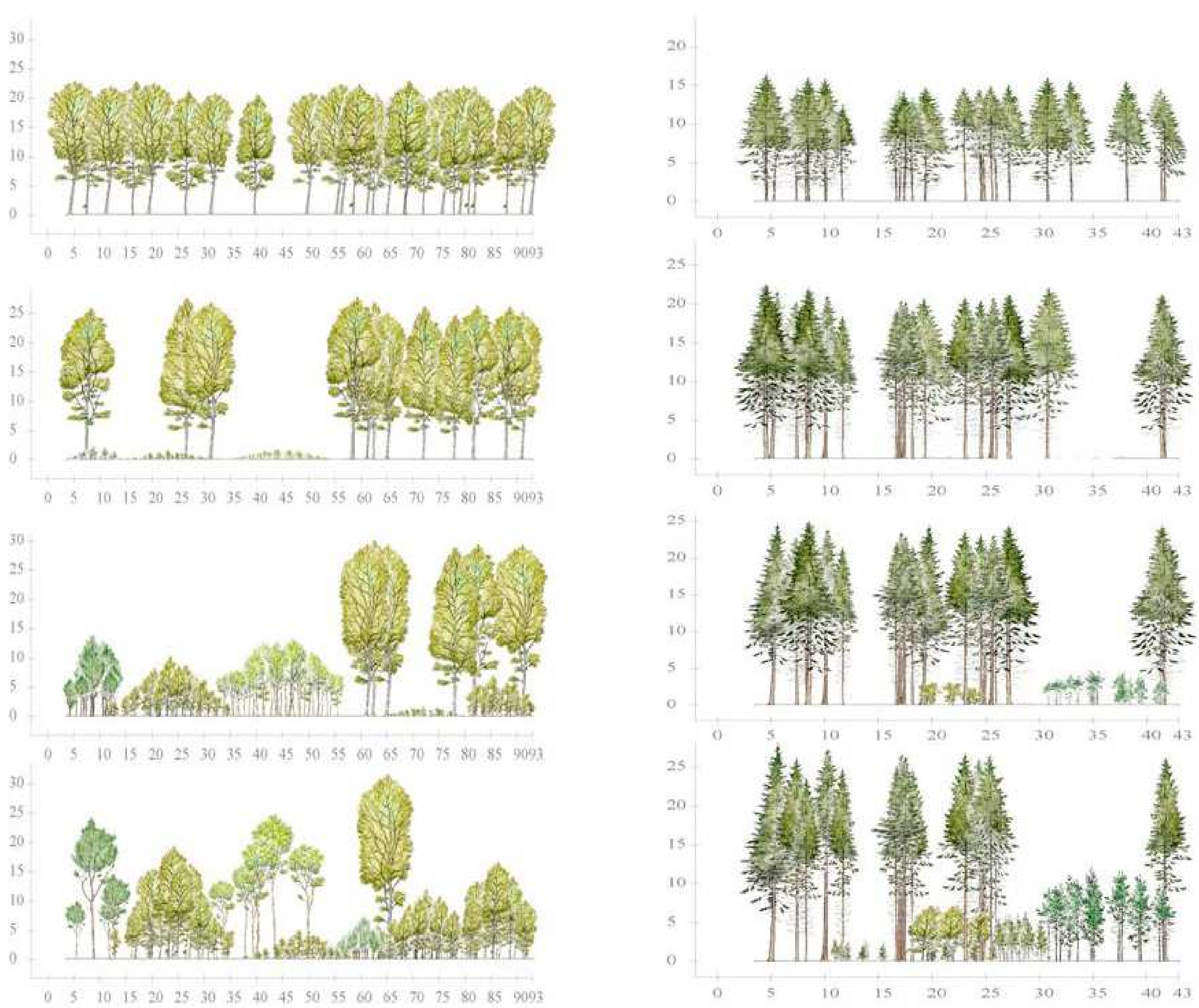
Fig. 5. Passive approach; Spontaneous regeneration of fir, spruce, birch, larch and Mountain ash in wind-throw gaps in a Norway spruce stand (group regeneration), Klosterheden Statsskovdistrikt. Photo: J.B. Larsen

Active strategies

The active conversion approach is used under conditions, where lack of stability does not allow a passive conversion. Active strategies are used in unstable stands primarily of spruce. In potentially unstable stands which have not yet reached a height that makes them storm exposed (below approx. 14 m), it is important to conduct an active thinning to promote stability and structural variation. This can happen partly through an early shelterwood formation or by liberating a number of future trees, thereby creating stable single trees (anchor trees). Important is that the thinning is conducted "from above" (removing dominating and co-dominating trees) thereby promoting variation in tree size (diameter, height) and a more heterogeneous stand structure. Group felling, in combination with early introduction of regeneration are also examples of active strategies. It is common to these approaches that a portion of the potential production in the stand will be sacrificed to safeguard the success of regeneration. In some cases the only economically realistic approach for regeneration/conversion of unstable spruce stands will be a clear cut; a measure, which also can be considered as an active strategy. In situations, when clear-cutting is the only way to regenerate the stand, frost hardy pioneer species such as Scots pine, oak, larch and birch will be introduced by planting/sowing to supplement, to improve the frequent natural regeneration of spruce and birch, thereby increasing future silvicultural options and thereby successively moving towards the planned long term goal – the FDT.

Fig. 6. Active approach; 9-year old beech planted under a canopy of Norway spruce (shelter-wood regeneration). Klosterheden Statsskovdistrikt. Photo: J.B. Larsen.

The choice of conversion strategy depend on the starting point including the potential stability of the concrete stand, the objective defined by the FDT, and the time available for the conversion according to the economic perspective of net-present values of anticipated functions, together with the conversion costs. In total 10 different conversion and regeneration models have been developed for converting monocultures of beech, spruce and oak into nature-near structures. In Figure 7 such two models are displayed by means of



Left: Passive approach showing the conversion of a 54-year old even-aged beech stand to FDT 12 – Beech with ash and sycamore maple. The so-called “qualitative group cutting” is applied. Thinning is preformed by cutting trees according to their quality disregarding an even distribution of the remaining trees. This will create openings in the closed beech stand, where ash and maple is introduced. The regeneration is completed by natural regeneration slowly creating a group-wise structure of beech, ash and maple.
Right: Active approach showing the conversion of a 24-year old Norway spruce plantation to FDT 61 – Douglas fir, Norway spruce and beech. The thinning regime aims at creating variation in the overall thinning density in the area. It is done to open up for creation gaps, to be filled with Douglas fir and beech. The rest of the area is regenerated naturally with spruce and birch.

Fig. 7. Conversion models displayed with profile diagrams.

profile diagrams, depicting a possible development from a uniform plantation like structure towards the decided nature-near forest development type.

4. Conclusion

The management of forests "closer to nature" has increased significantly in recent decades, simultaneously accompanied by ever more reliable and refined models, promoting its efficient implementation. The basic idea is to reach a better balance between productive, protective and social functions. Other important goals are to increase economic competitiveness by cost reduction and increase robustness to climate change.
In Denmark, the Nature Agency started to manage all public forest according to close-to-nature principles in 2005. To facilitate the transition from classical even-aged plantation forestry to close-to-nature silviculture a total of 19 Forest Development Types (FDTs) and different conversion models have been developed in a participatory process with forest practitioners, scientists, forest workers, contractors and other stakeholders.
Now, almost 10 years after the political initiation, and 6 years after the state forest once started to be managed according to close-to-nature principles, the picture is multifaceted: The conversion process in the state forests is continuing with special focus on developing nature rich recreational forest landscapes, by means of the FDT planning scheme. A massive effort to restore natural hydrology is one of the most significant ingredients in the process; as well as the integration of permanent open spaces in the forest (forest meadows – FDT 93), the introduction of grazing animals (forest pasture – FDT 92), and the delineation of larger reserves (unmanaged forest - FDT 94). Furthermore, different methods and models for converting spruce plantations have been used. Still, it seems too early to draw any final conclusions in regard to his last aspect. The lack of funding for a scientific follow-up is a potentially jeopardising aspect.
Many forests belonging to municipalities have also changed management strategies fundamentally and they now apply the close-to-nature silviculture guidelines. Especially the FDT planning tool-box has proven highly effective to generate discussion platforms to define goals and ways of forest management among various stakeholders in urban forests.
The private forest sector is still rather reluctant in applying close-to-nature management. Some forest owners are doing it with great enthusiasm, while a majority still sticks to the classical age-class plantation system. However, the running debate about the pros and cons has had its effect on the size of clear-cuts and the use of natural regeneration.
We are learning by doing: Some of the pending issues are: How much reduction in professional input/contribution is possible without loosing the advantages of close-to-nature management? To what extend is it possible to educate private forest contractors to apply close-to-nature silviculture with their big machines? Is it possible to create the same high wood quality in un-even aged forest systems as in plantation like structures – and to what costs? How can the close-to-nature managed forest cope with the increased need for bio-energy production?

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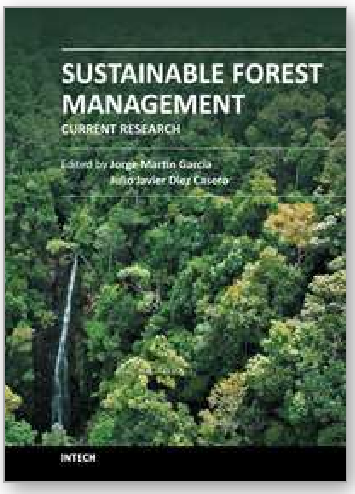

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Sustainable forest management (SFM) is not a new concept. However, its popularity has increased in the last few decades because of public concern about the dramatic decrease in forest resources. The implementation of SFM is generally achieved using criteria and indicators (C&I) and several countries have established their own sets of C&I. This book summarises some of the recent research carried out to test the current indicators, to search for new indicators and to develop new decision-making tools. The book collects original research studies on carbon and forest resources, forest health, biodiversity and productive, protective and socioeconomic functions. These studies should shed light on the current research carried out to provide forest managers with useful tools for choosing between different management strategies or improving indicators of SFM.