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Comparing close-to-nature silviculture with processes in pristine forests: lessons from Central Europe

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1 Introduction

The term close-to-nature silviculture already contains some ambiguity since (silvi) culture implies the act of forest use. This notion was coined a long time ago by well-known silviculturists (Gayer 1885; Engler 1905; Leibundgut 1943 and more) to characterise a new form of forest management that differs from plantation forestry and the clear-cut system. The

aim was a paradigmatic alternative to create multi-storeyed and rich mixed forest stands, with forest management emulating natural processes and seamless replacement of generations. Which of these processes should be selected and the degree to which natural forest dynamics should be imitated have not yet been specifically defined because the term was conceived in a general and conceptual sense and, furthermore, the aim has never been to let nature work alone. We can here quote Leibundgut (1943, p. 152) [transl. from German] “The main task of silviculture is to maximise and maintain the value produced by the forest”. Such a formulation is still quite relevant today, when the term “value” is understood in a broader sense. Actually, it would be more appropriate to use the term “utility” (original term “utilité”) in the sense of Biolley (1901).

Meanwhile, the notion of close-to-nature silviculture has been largely accepted and has gained popularity in practice. In an increasing number of countries, close-to-nature silviculture, also known as “continuous cover forestry” (Helliwell and Wilson 2012; Otto 1992), has become the main or only management approach. Close-to-nature management should be considered more as a set of guiding principles that are concerned with the whole ecosystem and with ensuring small-scale heterogeneity and stability, and uneven-aged silviculture systems are used as a means of implementing these principles (Helliwell and Wilson 2012). These general principles were first defined as plenter principles by Leibundgut (1979) and are now well recognised and formalised by ProSilva (2012), the association of European foresters practising management which follows natural processes. See also Diaci (2006) and <http://www.prosilvaeurope.org>. Bauhus et al. (2013) consider the following attributes as particularly representative for characterising close-to-nature management: site-adapted species composition, avoidance of clearfelling, focus on stability, reliance on natural processes and focus on development of

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individual trees and mixed and uneven-aged structurally diverse forests.

Research in pristine forest is necessary to understand the characteristics of natural forest dynamics. For this reason, the founders of the close-to-nature school of thought advocated the preservation of sufficient areas of untouched forests (hereafter pristine forest, even if this term is sometimes criticised because of the inevitable influence of man) in different vegetation types in order to study their particular developmental characteristics. The conservation of adequate areas of protected forests remains valid today (Leibundgut 1959; Parviainen et al. 2000; Nagel et al. 2014; Anderson-Teixeira et al. 2015). To gain insight into developmental processes, an extensive network of permanent research plots has been established. After decades of periodic remeasurements, they have provided a solid foundation for understanding stand development characteristics (e.g. Saniga et al. 2015). Moreover, in the last decades, a number of new techniques such as dendrochronology, canopy gap analysis, remote sensing and LiDAR analysis have been applied, enabling the process of generation renewal to be understood on different scales, from single trees to small clusters.

The best-represented preserved pristine forests in Europe are pure beech and mixed fir-beech forests, particularly in the Carpathians and Dinaric Mountains (Schütz 1969; Leibundgut 1982; Korpel 1995; Šebková et al. 2011; Nagel et al. 2012; Král et al. 2014; Keren et al. 2014). Pure beech forest represents a significant part of potential forest vegetation in Central Europe (Ozenda 1994; Spellmann 1999) and can therefore be used as a representative example for study. In addition, beech-dominated forests represent an interesting case study because of the simplicity of the system in terms of the tree species involved and because seed dispersal and germination do not constrain regeneration to the extent that they do in other species. The main limiting factor in this case is evidently the minimal light requirements for allowing the new generation at the thicket to pole stage to reach the upper storey.

The first pillar of close-to-nature management is stem-by-stem renewal, known as the plenter system (or selection system). It has been proven in practice as well as by scientific analysis, particularly when considering conditions for sustainability, or so-called equilibrium (e.g. Schütz 2001). The plenter model applies mainly to conifer-dominated forests and particularly to shade-tolerant species, such as fir and spruce. Extension of the stem-by-stem renewal system to broad-leaved trees appears much more difficult (Schütz 1992), which is why there are very few examples which have persisted for a long time. Even in regions with a strong tradition of plenter silviculture, such as Canton Neuchâtel (Switzerland), its long-term application within broad-leaved forests has been largely unsuccessful (Peter-Comtesse 1972). The second pillar of close-to-nature management is oriented more towards small collective renewal known as the group

plenter system or irregular shelterwood system (Germ. Femelsystem), depending on the size of the regeneration cohorts (Leibundgut 1946). The latter has been conceived to achieve irregularity, particularly within broad-leaved forests. The main difference between the two approaches lies in an emphasis on individual trees in the plenter system vs. groups of trees in the irregular shelterwood system as well as in the principles for controlling sustainability—on a stand level in the former and on a much larger scale (landscape) in the latter.

The quintessence of close-to-nature silviculture is diametrically different from most other ways of treating forests because of its liberal conception (the free use of felling) and because the silviculture technique is subordinate to the goals. Worldwide, most silviculturists still consider the particular silvicultural system as determinant in deriving the silvicultural tools. The concept of a systemic free and undogmatic silviculture represents a paradigmatic shift in this field. However, there are two important questions that remain open or are misinterpreted: (1) how to apply liberal silvicultural tools based on close-to-nature principles and (2) to what extent can the dynamics in natural forests be mimicked using these tools. Thus, the main aspiration of this paper is to relate close-to-nature silviculture with processes in natural forests and show examples of how to implement site and stand-specific management tools. To achieve this, we firstly present the special case of tree species mixtures in Central Europe, then discuss the results from old-growth forest research regarding stand ontogeny and regeneration patterns for two species with contrasting life traits: beech and sessile oak, and finally, we discuss silvicultural limitations in terms of maximum basal area during stand renewal. We conclude the paper with a historical overview of the evolution of close-to-nature silvicultural tools with particular emphasis on the irregular shelterwood system and the free selection of felling regime.

The specific goals of this paper are the following:

1. To determine, using beech-dominated pristine forests as an example, the main driving forces of generation renewal in terms of life cycle duration and spatial renewal patterns;
2. To illustrate contrasting light requirements during renewal by comparing pristine oak and beech forests;
3. To elucidate the lower limits of stocking and canopy openness for silvicultural renewal in small clusters based on pristine forest research;
4. To present an approach for implementing these findings in a liberal and versatile forest management

2 Tree species mixtures

In some cases, there are great differences in tree species composition and structural traits between pristine forests and

managed forests. This is related to the sociability of tree species and particularly to their tendency to remain dominant over a long period and to outcompete other species. Shade tolerance also plays an important role. Shade-tolerant species such as beech and fir are so well adapted to the small gap dynamic patterns of these pristine forests that they hinder the recruitment of other less tolerant tree species (Nagel et al. 2014). Species composition also correlates with glacial historic migrations. The “climax” forests in Europe are considerably poorer in tree species than forests in other parts of the world because of extinction during glaciation and the dominance of remaining species such as beech and spruce, making them quasi-monospecific. Thus, the tendency to produce mixtures is not a general characteristic of nature. Rather, the opposite is true for Central European temperate forest conditions. In Europe, we find examples of diverse mixtures only in transition zones between the main species belts or outside the distribution range of beech (e.g. in the Białowieża pristine forest, Huntley et al. 1989). The pristine forests in Europe, which are dominated by beech, fir and spruce, are poorly mixed in comparison to the Americas or other regions of the world. Moreover, species diversity in European forests is actually diminishing, with an example being fir decline because of human-induced environmental change (Vrška et al. 2009; Diaci et al. 2011; Keren et al. 2014).

On the other hand, it is well recognised that close-to-nature management allows the establishment of mixed stands by influencing the light conditions during the regeneration process (Schütz 2004) as well as by tending interventions (regulation of mixtures). Engler (1905) expressed it very tellingly [transl. from German] “We are therefore constrained in close-to-nature management to mix tree species in larger groups because our saplings develop under quite different conditions than those in pristine forest, and because we often intend to mix species together which never coexist spontaneously in the considered site conditions”.

3 Duration of the life cycle

In comparison to managed forests, pristine forests (and this is the main difference) exhibit much longer generation cycles (ontogenesis) and thereby the tendency to accumulate large amounts of biomass during longer phases of development. Regeneration dynamics, i.e. generational replacement (so-called reiteration), depends on the vitality and life expectancy of the trees. The age structure of pure beech as well as fir-beech pristine forest is now well documented (Mlinšek 1967; Schütz 1969; Piovesan et al. 2005; Motta et al. 2011; Nagel et al. 2014). Such studies reveal a large age variation because of the capacity of shade-tolerant species to survive long periods under minimal light conditions in a quasi-stationary stage (so-called suppression).

Dendrochronological studies (e.g. Piovesan et al. 2005) demonstrate that beech can stagnate in growth for more than 100 years and subsequently recover to reach the upper storey once the light climate improves. Such capacity to resist excessive shading has some limits. In conditions where light levels are too low, trees lose their ability to grow upright (acrotony) and develop an oblique growth pattern (plagiotropism) (see Fig. 3). They are no longer able to recover and grow upright and thus lose their stability (Kurth 1946; Schütz 1992).

The average age of beech is at least 300 years (Piovesan et al. 2005; Motta et al. 2011), but it can reach more than 400 years, e.g. in Peručica (Bosnia and Herzegovina) (Nagel et al. 2014) or Žofin (Czech Republic) (Šebková et al. 2012). Norway spruce and silver fir reach a similar age in natural beech-dominated forests (Šebková et al. 2012). From this point of view, the life cycle of the main tree species (trees reaching the overmature stage only) in pristine forests can take 300–400 years. This time span is at least 2.7–3.6 times greater than that in production forests in which the rotation period is about 110 years, but this comparison is valid for the main trees species only.

Apart from the regeneration cycle of pristine forests, another question is the life cycle of patches in these forests. Gap dynamics studies have shown that the estimated turnover time in beech-dominated pristine forest is 220 years (Drössler and von Lüpke 2005) or 300 years in mixed coniferous forest (Foster and Reiners 1986). Kenderes et al. (2009) evaluated gap dynamics during 33 years in the Žofin pristine forest and found that if only small-scale gaps were created, the estimated turnover time would be cca. 1000 years. It was confirmed that small-scale gaps (small-scale disturbances) are not the sole drivers of natural dynamics. There are also large-scale disturbances that recur over a longer period than our actual gap studies and steady-state patches (demographic equilibrium—sensu Korpeľ 1995; Král et al. 2010). Small-scale and large-scale disturbances are caused mainly by exogenous drivers (e.g. windstorms) and steady-state conditions by endogenous drivers (e.g. fungal infection of individual trees; sensu Pickett and White 1985). Disturbances create a mosaic of patches that shift in space and time. Developmental (successional) stages are theoretically gradually replaced from the earliest to latest successional stages. But, the natural forest’s life cycle is not so simple. Disturbance resets development in all developmental stages, and the mosaic of patches is very variable in time and space. Only a portion of the whole forest completes the entire cycle. Christensen et al. (2007) presented how the late biostatic phase transitions mainly into the aggradation phase (and does not get through the entire degradation phase). Král et al. (manuscript in prep.) discovered non-cyclic development (incomplete cycle) in five Central European pristine forests during the 1970s–1990s and 1990s–2000s on 35 and 27 % of the area, respectively. From this point of view, we can compare the turnover time of patches in the overmature

stage that have completed the full life cycle of pristine forest. If we assume prevalent endogenous regeneration, which is often the case in mixed mountain pristine forests, then we have to be aware that in managed forests, the life cycle is often shortened by natural disturbance. However, it is also true that managed forests are generally younger and thus less susceptible to disturbance.

4 Gap size and recruitment

One of the main drivers of stand dynamics is the death of one or some overstorey trees because of old age or hazards (storms or other disturbances), which interrupts the canopy and influences spatial and temporal patterns. This produces small interruptions in the canopy (gaps), some larger openings (patches) and sometimes very large openings. Recent studies have provided a good overview of typical gap distributions for different ecosystems. The influence of gaps on stand renewal can be assessed from the proportion of the area under gaps and the yearly gap rate as determined by the age of the second growth or sudden change in the diameter growth of present recruitment (Splechtna et al. 2005; Nagel et al. 2007).

Mortality is due to endogenous (ageing) as well as exogenous factors (storms, etc.). Susceptibility to physical disturbance increases with age (Schütz and Saniga 2011). This implies that in regions with frequent recurrence of disturbances (e.g. fire), the development cycle will be curtailed. Large disturbances occur everywhere, but they are more rare and stochastic and are thus only detectible on very large areas. Nagel et al. (2014) show for instance that intermediate disturbances (corresponding to a patch size of 0.4 ha) have a turnover of 200 years. Larger events (patches of 0.5 ha) occur every 460 years. They suggest that at least one medium disturbance occurs within one life cycle.

Every study on gap distribution in beech-dominated forests reveals the same pattern: a large number of very small gaps due to the loss of one or a few canopy trees with an exponential decrease towards mid-sized gaps. Therefore, the canopy-opening pattern for temperate Central European forests, where extreme disturbances are rarer than in other temperate regions of the world, represents a fine-scale shifting mosaic of small gaps with some mid-sized gaps. The most frequent gap sizes are up to 100 m², but gaps between 200 and 500 m² cover the highest percentage of the area created by gaps (e.g. Kenderes et al. 2009). There are some larger patches up to 0.5 ha (Drössler and von Lüpke 2005; Nagel and Svoboda 2008) and even much larger (several hectares).

For an interpretation of the impact of gap sizes on dynamic of the renewal, should the fate of openings be differentiated depending on their size. The large number of very small gaps is due to the disappearance of one canopy tree (gap size up to 100 m²), which acts like thinning in managed forest, but with

a more irregular and diffuse gap distribution. The canopy after such small interruptions closes in a few years due to the crown expansion of edge trees. Consequently, increased light levels are relatively short-lived. These openings are not gaps in the real sense but interstices of the canopy. Larger gaps are necessary in order to let enough light penetrate to the floor to influence regeneration. The amount of light required for a sapling to grow into the main storey can be estimated at the thicket/small pole stage when young recruits suffer most from shade and become unstable (Schütz 1992). This indicates that small, isolated gaps are often not adequate for successful recruitment.

Webster and Lorimer (2005) showed in mixed conifer-hardwood forest in Wisconsin, USA, that broad-leaved edge trees expand by about 10 cm per year. Such an increment is also valid for European beech (Haywood 2002). Recruitment needs at least 45 years to access the main storey. Thus, Webster and Lorimer (2005) consider gaps of 100–200 m² as marginal for successful recruitment of the mid-tolerant yellow birch and gaps between 200 and 1000 m² as necessary. In the case of beech, the shade limit for a single tree to succeed in regrowth is not exactly known. It should lie below the indication of Webster and Lorimer and may be about 100 m². For collective recruitment, it may be more than 500 m².

Král et al. (2014) estimated the proportion of the four forest stages (aggradation, optimum, single growth and degradation) for Czech pristine forests. The single-growth phase (called steady state in the above study) corresponds roughly to a stem-by-stem change of generations, comparable to the plenter system. Considering the two beech-dominated pristine forests (Salajka and Žofin), this stem-by-stem phase amounted to 20 %. On the rest of the area, there were small clusters of recruitment. Therefore, it may be deduced that the form of recruitment in pristine beech forest forms a roughly 1:3 relationship between stem-by-stem recruitment and that from small clusters, representing a kind of continuum between single recruitment and small collectives (groups).

Gaps amounted to 9–11 % of these pristine forests. This means that 90 % of the area was dominated by stands with high biomass accumulation and compact canopy closure. Results from repeated measured plots (area about 0.5 ha) in pristine beech forests in Slovakia confirm this result if the basal area of the main canopy is considered (Fig. 1). The mean trajectory for pure beech pristine forest (function pristine forest in Fig. 1) was modelled from 86 measurements (Schütz and Saniga 2011) in different developmental phases. At the time of culmination of the basal area, pristine forest attained 45 % more stocking than in close-to-nature managed forest.

In summary, we can consider the renewal in pristine beech forests as a combination of irregular small groups and individual recruitment occurring irregularly in space and time, intermixing with some medium-sized patches. Zuckriegel

(1991) has expressed this in the following terms: “The normal way of regeneration in virgin forests of shade-tolerant species under the normal influence of storms can best be compared with the small-scale shelterwood and femelsystem”. Later, Korpel (1995) made similar description of the process.

The resulting forest structure is formed of fully closed stands on a large scale (about 90 %) with some appearance of regularity (so-called cathedral structure, Fig. 2) even if there is a relatively large diameter amplitude (and possibly age) and stands are intermixed with shifting small-scale irregular patches with large variation in regeneration characteristics (Fig. 3).

5 Optimal stocking density of managed close-to-nature beech forests

From experience of forest management with close-to-nature silviculture, we can consider the following benchmarking characteristics in terms of basal area. The regeneration of beech stands in the shelterwood system targets a basal area in the range of 16–20 m² for starting the regeneration (after Freist 1962). From thicket on, basal area should be reduced to a level of about 12 m² until the pole stage. The plenter system targets a basal area of 22 m² for sustainable renewal (after Schütz 2006). The association for irregular forest treatment in France (Association forêt irrégulière 2011) recommends a

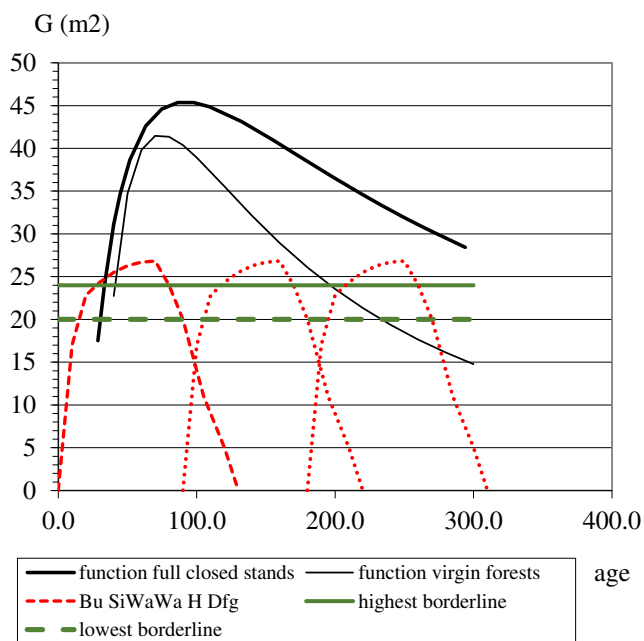


Fig. 1 Development of the basal area (for the main storey) in pristine pure beech forest in comparison to the theoretical maximum closure (black bold line) and to the corresponding model for forests managed with close-to-nature silviculture (Swiss model SiWaWa according to Schütz and Zingg 2007, 2010) and treated with an average thinning from above after Schädelin. The development of pristine forest was determined based on 86 measurements in permanent plots (area 0.5 ha)



Fig. 2 Regular structure in pristine beech forest Havešovà, Slovakia

basal area of 20 m². For the irregular group shelterwood system, regeneration in groups of one to two tree lengths in diameter (about 0.1 to 0.2-ha size) is proposed (Schütz 1998a). A combination of shelterwood and irregular group regeneration appears to be a very efficient way of regulating light for regeneration (Fröhlich 2011). According to theoretical considerations, lower storey structure in the general shelterwood system, gaps experience the same light climate as those that are approximately twice the size in the matrix of fully closed stands.

In synthesis, we can consider a stand basal area of 20–24 m² as appropriate and realistic for successful beech regeneration in a mosaic of irregular groups or in the stem-by-stem system.

Figure 1 presents the mean basal area trajectory of the model SiWaWa (Schütz and Zingg 2007, 2010) corresponding to silviculture with thinning from above (according to Schädelin and the corresponding praxis in Switzerland) and stand renewal in the three step shelterwood system according to the recommendation of Freist (1962) in comparison to the



Fig. 3 Recruitment of insufficient quality and stability (plagiotropic growth) as a result of extensive suppression periods in pristine beech forest in Nera Springs, Romania

stand stocking of pristine pure beech forests. It confirms the long period of growth in heavy shade conditions in pristine forest between ages 30 and 160. During this phase, the density of stocking in pristine forest is at least twice as high as that in close-to-nature managed forest. Thus, pristine forests are overstocked during most of the period of their development, only falling below the stocking target (for sustainable recruitment) of 20–24 m² in basal area in the very late developmental stages after about 200 years. This finding suggests that the stem-by-stem renewal that corresponds to conditions of sustainability is unlikely or only incidental in pristine forests because it needs a basal area of at least 22 m² (Schütz 2006). Thus, silviculture that mimics nature should substantially reduce the stocking when aiming for stem-by-stem renewal. Therefore, regeneration in small gaps or a combination of shelterwood and gaps would be more efficient. Practical experience shows that the minimal opening for ensuring stable and qualitative sufficient beech renewal is 0.1 to 0.2 ha in size (Schütz 1998a). This corresponds to gap sizes exhibiting the greatest possible diversity of light conditions (gaps between 0.07 and 0.14 ha) according to Coates and Burton (1997). Figure 4 presents a typical gap opening for beech regeneration in the irregular group mosaic system (after P. Junod pers. communication).

6 The case of light-demanding species exemplified by pristine oak forests

What applies to beech forests is not necessary applicable to other tree species. Very intolerant pioneer species can only regenerate in an open landscape, at the forest margin or after catastrophic events and large-scale disturbances (Kucbel et al. 2010).



Fig. 4 Regeneration of European beech in small patches within the irregular group mosaic system after P. Junod (see www.ne.ch/forets/Documents/Principes/sylviculturaux) in the Gorgier communal forest, Canton Neuchâtel, Switzerland, compartment 12 (gap of 0.08 ha)

One interesting case is represented by oak, which is an important tree species in temperate Europe because it demands much more light than beech and fir. For our aim to compare pristine and managed forest, we focus on sessile oak [*Quercus petraea* (Mattuschka) Liebl)] forest more than on the riparian pedunculate oak (*Quercus robur* L.). In Slovakia, such pristine sessile oak forests exist on a substantial area and on poor sites as well as on good ones. We refer to the latter in the following. After Korpel (1995), a characteristic of such pristine oak forests is a fairly regular stand structure, at least in the main storey. They feature small age variation and thus are similar to managed oak forests. Beech and hornbeam recruitment, part of which is compact and part of which is in small clusters, can often be found on part of the area. Such an understorey tree layer regenerates two to three times more frequently than the oaks. This is a possible explanation for oaks remaining monospecific in the overstorey.

The gap distribution in pristine oak forest is very similar to that in beech forest (Tomašik and Saniga 2011; Saniga et al. 2015). In the Kašivárová pristine forest in Slovakia, small gaps dominate overwhelmingly. Only 1.2 % of the area is covered by gaps larger than 500 m² (Saniga et al. 2015). Frequent fructification and seedling establishment is crucial for renewal. In contrast to beech, oak seedlings are relatively shade intolerant (Saniga et al. 2015). In shady conditions, they exhibit plagiotropic growth and rapidly lose an upright and stable stem form (see Fig. 5). Unlike beech, they are not able to recover once the light conditions improve. Thus, only seedlings of the last fructification are able to recruit and grow upright once given enough light by larger openings.

In managed forests, the classical method of naturally regenerating oak is the shelterwood system on large areas and sometimes after clear-cutting. In close-to-nature concepts, oak regeneration is possible on a small scale by combining medium-sized gaps with diffusely opened surrounding stands. Target basal area for managing irregular oak forest is about 16 m² (Association forêt irrégulière 2011) for such considered



Fig. 5 Heavy shade suppressed young oak thicket in the Kašivárová pristine forest (Slovakia) with plagiotropic growth



Fig. 6 Effect of shade cast at edge of a gap on height development. Pictured is a small collective of sessile oak in a 0.15-ha gap, from natural regeneration in the Charcotet forest, commune Bevaix, Canton Neuchâtel, Switzerland

forests. This is 25 % less than that for beech. Gaps are necessary to provide sufficient light for recruitment (Leibundgut 1945; Schütz 1992). In fact, von Lüpke (1987) showed experimentally that gaps of at least 0.2 ha are necessary for the correct development of sessile oak plantations until the age of 8. Regeneration in gaps that are too small leads to massive growth depletion towards gap edges (Fig. 6). Shade is associated with increased slenderness and thus vulnerability to snow, ice or even heavy rain damage (Fig. 7). Experience in Switzerland for regenerating oak in small areas suggests a target gap size of at least 0.25 ha when starting regeneration and 0.5 ha at the pole stage (Schütz 1992; Leibundgut 1945; P. Junod pers. comm.) in order to ensure adequate stability and potential for qualitative selection (Fig. 8).

The basal area of the optimal phase in the Kašivárová pristine forest attains 35–45 m² as the results from 10



Fig. 7 Instability of sessile oak poles at the edge of a gap that is too small. The pole stage is the most susceptible to damage associated with slenderness (Schütz 1992). The picture shows a 17-year-old oak cluster towards the edge of a 0.14-ha gap which has suffered snow damage in the Bülach communal forest, Canton Zürich, Switzerland

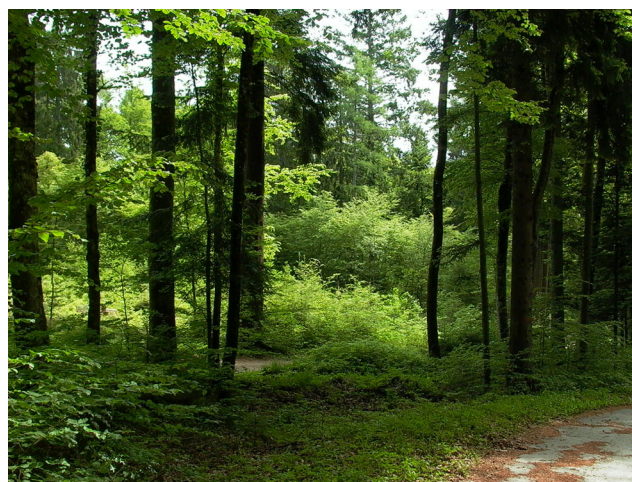


Fig. 8 The irregular shifted mosaic treatment as realised by P. Junod in Canton Neuchâtel in the Bevaix communal forest

measurements of permanent plots shows. In comparison to the 16 m² of managed irregular forests, this is 2.5 times more stocking, which does not allow desired recruitment. Thus, pristine forest can only regenerate when sufficient light penetrates to the forest floor and allows new seedlings to grow upright with enough stability. This occurs when sufficiently large gaps are created once the old generation becomes over-mature and stands break down over larger areas. In oak silviculture, the appropriate management of the light is even more critical compared to shade-tolerant species. In pristine forest, successful recruitment is not possible until the mature forest is sufficiently broken down so that a new sequence of tree regeneration can grow unimpeded. In close-to-nature silviculture, this is done 150 years earlier, with the deliberate optimal management of light, for example, in medium-sized gaps with a combination of partially closed and open canopy areas.

7 History of close-to-nature silvicultural techniques

The emergence of the plenter system applied to broad-leaved species, particularly beech, has been presented elsewhere (Dittmar 1990; Schütz 2001). Because it is less known, in the following, we present the emergence of the small cluster or irregular shelterwood system.

Arnold Engler (1869–1923) should undoubtedly be considered as the originator of the silvicultural tools for creating close-to-nature forests (cf. Engler 1905). The quantum leap was to focus less on the cutting system than on the goal, which is to establish mixed multi-storeyed (wave-like) stands of site-adapted species without large generational interruptions. The idea was influenced by Gayer's proposal to favour mixed forests (Gayer 1885).

For intolerant species, Engler considered gap renewal (called *Femel*) as particularly appropriate. Not only gap creation but also all other principal felling forms (i.e. shelter, edge positions) can be applied locally and conjointly in a very liberal fashion. In order to reach the abovementioned goal, the regeneration process should be delayed in space and time over a relatively long regeneration period. The silviculturist decides this *in situ* and considers the present natural regeneration groups and their potential development. A precondition is the development of appropriate stand structure through previous thinning (from above) to limit the risks incurred by opening the canopy as well as to favour the best-shaped and most vigorous crop trees. Such a free approach to managing regeneration is known in the literature as the improved Swiss irregular group shelterwood system (Leibundgut 1943).

Hence, such a close-to-nature silvicultural treatment does not use only one particular cutting form, but all forms together. After Engler (1905), the silviculturists should have as much freedom as possible to choose the cutting form. This important paradigm primarily characterises this kind of silvicultural treatment. It has since been known as free choice cutting (Germ. *freie Hiebsführung*), later called, and in a more popular sense, as free style silviculture after Mlinšek (1967).

If our main goal is to produce irregularity, regeneration groups should not be continuously enlarged, but only as much as the light conditions are required to attain the silvicultural goals, thus quoting Engler [transl. from German] “The more we are able to encourage different light conditions within the stands and to control light according to our needs, the more we can refrain from working on large areas”. Such a silvicultural approach is similar to the plenter principle. The sole difference is that tending measures are oriented towards collectives of trees rather than the individual shaping principles of the plenter system (Duc 1991).

Otherwise, when regeneration groups are selected (on the transition borderline) such that over time, they can be united together to form larger areas of regeneration, this represents the so-called large-scale regeneration system known as the irregular shelterwood system (*Femelschlag* system) (Leibundgut 1943; Röhrig et al. 2006). This can be considered as a possible management alternative, particularly for light-demanding tree species, when the goal is more on mixture than structure, and regulating the mixture occurs mainly through tending operations. But here too, the principles of free choice cutting are applicable.

In contrast to both of the abovementioned irregular shelterwood systems, the large-scale shelterwood system is not considered to be a form of close-to-nature silviculture because natural regeneration is the main focus while structure is largely ignored. The concern is not the shelterwood cutting scheme, which can be meaningfully used locally on a small scale in close-to-nature silviculture, but its systematic large-scale application. Thus, close-to-nature silviculture and large-

scale regeneration systems are distinguished by the blind application of a particular cutting system by the latter.

The application of close-to-nature silviculture takes advantage of the great variety of silvicultural tools. Within the movement of close-to-nature-oriented forestry, there are different tendencies, some more strict and others more liberal. What is paramount is the goal, which should be achieved in the most efficient way possible. ProSilva, the association of close-to-nature-oriented foresters, accept the use of a whole gamut of intervention forms as long as general principles are respected (see www.prosilvaeurope.org).

Nowadays, we are encouraging the expansion of goals to include ecosystem services such as enhancing biodiversity or capturing CO₂, and favouring adaptation to changing site conditions has become much more important (Brang et al. 2014). Therefore, promoting healthy and stable forests as well as enhancing structural diversity as an important habitat precondition for species biodiversity has become increasingly important. Traditional goals of close-to-nature silviculture are in concordance with these new paradigms. Moreover, intentionally favouring diversity in a purposeful and systematic way, more than before, seems to be the appropriate answer to the new goals (Aplet 1994; Schütz 1999a). In the tradition of European forest management, optimising multi-functionality has always been favoured over separating the functions. This explains why a regularly treated healthy forest such that it can respond to all needs (utility in the sense of Biolley 1901) corresponds to the seminal wisdom in Europe in comparison to the approach in North America which attempts to essentially mimic natural processes (Bauhus et al. 2009).

8 Conclusions

As regards the relationship between pristine forest and close-to-nature management, Leibundgut (1943) argues the following [transl. from German]: “Our quest is to derive from pristine forest such stand forms which are efficient and stable enough but at the same time also satisfy mankind’s interests in terms of sustainable qualitative product (p. 152)”.

In natural forest, we can find a very different kind and form of renewal process that is essentially driven by chance (i.e. disturbance, disease, insect outbreak) and ageing. None of these drivers are reproducible nor are they particularly interesting from the point of view of fulfilling the essential goals of mankind; however, they may be defined. The principal aspiration of responsible and efficient forest management is to choose processes that best achieve target species mixture, growth potential and high-quality stem forms and of course to fulfil the main goals.

The first lesson to be drawn from natural forest observation is that it is possible to considerably shorten the life cycle by initiating the regeneration process through appropriate cutting

in much younger stages and thus to work with more stable, healthy and responsive stands. As a consequence, assuming sustainability, the proportion of the forest area in regeneration is 2.7–3.6 times greater in managed forests because there is a direct relation between cycle duration and necessary regeneration. Since regeneration areas are known to be the interesting stages with respect to habitat characteristics (e.g. Ammer et al. 1995; Scherzinger 1996; Wermelinger et al. 2007), shortening the cycle could be considered as one of the good means of sustaining biodiversity.

In general, regeneration in gaps with enough light is more appropriate for broad-leaved tree species, particularly intolerant ones, than stem-by-stem regeneration. Concerning the choice of gap size, in regions with relatively less frequent large disturbances, as is the case in Central Europe, renewal in pristine conditions generally happens in relatively small gaps. Here, gap size is determined predominantly by chance and is not based on the optimal development of the new generation or on its stability. In comparison, a sound, efficient and proficient silviculture aims at optimising the light conditions according to the needs of the target tree species. Such conditions may be partially fulfilled in larger than average gaps in nature, allowing good shape and stability of small cohorts (Schütz 2002). Practical experience corresponds well to conditions where the light diversity is optimal, which can be found in gaps between 0.07 and 0.14 ha in size, as put forward by Coates and Burton (1997). Through varying gap size, silviculture aims at favouring different tree species or tree species mixtures when possible, which may also contribute to enhanced biodiversity.

Nowadays, forest heterogeneity, as well as internal diversity, represents an important goal (Buongiorno et al. 1994). Heterogeneity implies avoiding the use of the same regeneration pattern over large areas and focusing solely on the minimum acceptable gap size. Combining small and large gaps in a flexible way appears to be a good approach to enhancing habitat diversity.

One of the unapologetic features of pristine forest is the presence of copious amounts of deadwood (Saniga and Schütz 2001). For organism guilds needing these particular biotops, such a spontaneous amount of deadwood is unnecessary, but according to the management aspirations of most owners, just that which is sufficient for maintaining such guilds. This is possible and often also practised through attendant measures such as veteran trees and dying forest clusters in an appropriate network.

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