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Increase of biodiversity in homogeneous Scots pine stands by an ecologically diversified management

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Three important parameters of biodiversity in first generation Scots pine (*Pinus sylvestris*) forests on sandy soils have been evaluated: *herbal layer diversity*, *natural regeneration* and *stand structure*. The study took place in the Belgian Campine region, where the original oak–birch forest, degraded to heathlands in the course of time, were finally replaced by monocultures of Scots pine. These first generation pine forests are characterized by a low biodiversity. In maturing stands of this type, however, a spontaneous increase of biodiversity is noticed. Herbal species richness is very limited in all age classes. Different natural regeneration patterns are found. Referring to stand structure, the lengthening of the rotation favours the ingrowth of several hardwood species. As a consequence, the homogenous Scots pine stands are gradually and spontaneously transformed into heterogeneous mixed stands, featuring a noticeable increase in biodiversity. Selected human interventions may further increase biodiversity. The fundamental management principles are discussed: avoidance of major disturbances, lengthening of the rotation period, use of native tree species and natural re-generation, protection of microbiotopes and permanent monitoring.

Keywords: Scots pine; biodiversity; sustainable management.

Introduction

The UNCED conference in 1992 mainly focused on two keywords: sustainability and biodiversity. The concept of sustainability is well known in forestry, but is not always realized in practice. Moreover, it has to be considered more comprehensively; it should be enlarged from sustained yield to sustainable ecosystem management. The concept of biodiversity is less familiar to forest managers. It mainly corresponds to the conservation of the genetic patrimony. However, there is a clear link between the more familiar notion of sustainability and the new term biodiversity. Indeed, sustainability is not possible without structural and species diversity (Lust, 1993).

Forests are important for the conservation of biodiversity (Boyle, 1991). Bunnell (1990) reports that 76% of Canadian terrestrial mammals and 60% of Canada's breeding bird species are forest dwellers. Rohner (1988) states that 60 to 70% of the species appearing in Switzerland live in forests. Peterken (1981) counted 1856 different species in a mixed hardwood in England (Monks Wood, Cambridgeshire). It is obvious that the number of tree species was only a fraction of the total number of plant species. The latter, in its turn, was only a small fraction of the total number of living organisms in that forest. Insects took up 63.1%, flowering plants and ferns 9.6%, fungi 8.7%, spider species 7.5%, etc. (see also Kennedy, 1984).

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The objective of the research project is the evaluation of three important parameters of biodiversity in first generation Scots pine forests on sandy soils. For this goal, measurements on herbal species diversity, natural regeneration and stand structure were carried out in a number of Scots pine stands.

Research site and methodology

Measurements were executed in different forest stands of the Belgian Campine of first and second generation, mostly established at the beginning of the twentieth century with Scots pine on heathland or drift sands (De Schepper, 1988; Lust *et al.*, 1989).

The forest region is situated at an elevation of 50 to 90 m above sea level. The climate is sub-Atlantic. The soils are poor and dry. Spodosols (on former heathland) and inceptisols (on former drift sands) occur. The sand fraction accounts for some 90% of the total grain size distribution. However, important local differences in the loam and clay contents appear, with a strong influence on the water economy (Maddelein *et al.*, 1992b).

Sample plots were selected in order to incorporate variations in soil and stand age. Important driving factors in the secondary succession are the presence of broadleaved tree belts around the pine stands and the presence of a black cherry (*Prunus serotina*) understorey.

The following measurements were carried out:

(i) Vegetation surveys, according to the Braun-Blanquet method, in four Scots pine stands:

- stand 1: 45 years old, on former heathland;
- stand 2: 75 years old, on former heathland;
- stand 3: 69 years old, on former drift sands;
- stand 4: a one year old ploughed clearcut, on former heathland.

(ii) Natural regeneration was studied in several situations:

- Fifteen even-aged Scots pine stands, established 70 years ago on heathlands and surrounded by a 5 m wide shelterbelt of deciduous trees.
- A one year old ploughed clearcut on former heathland (stand 4 of the vegetation surveys).
- A large burnt area of Scots pine, 6 years after a big fire.
- In all, some 100 plots were established, with a size ranging from 0.5 to 500 m^2, dependent on the dimensions and density of the seedlings. Tree species, height and diameter were recorded for every individual. Age analysis was performed on only a fraction of the trees.

(iii) Stand structure was determined by transect analysis carried out according to the recommendations of Leibundgut (1959), Hallé *et al.* (1978), Koop (1989) and Oldeman (1990). The following data were recorded:

- trees with height < 1.5 m: position;
- trees with height > 1.5 m: position, diameter, height, branch free bole length, height at maximum crown width and crown dimensions.

Results

Herbal species diversity

Before the afforestations, two plant communities dominated the research area (Rogister, 1959): the Callunetum–Genistetum Tüxen (1937) on the spodosols; and the Corynephoretum–canescentis agrostetosum caninae Tüxen (1937) on the inceptisols.

Current herbal species presence is very limited (Table 1). In all, only nine herbal species were counted. Species of the primary succession such as *Corynephorus canescens*, *Festuca ovina*, *Agrostis canina* and *Poa nemoralis* were still common 30 years ago, but have now disappeared. The dominating herb species is presently *Deschampsia flexuosa*, sometimes covering over 80% of the soil. Besides this grass species, only three herbal species (*Vaccinium myrtillus*, *Epilobium angustifolium* and *Dryopteris carithusiana*) are present in more than 50% of all plots.

In older stands, where an understorey of deciduous tree species has developed, the *Deschampsia flexuosa* dominance decreases due to a diminished light penetration.

Moss species are sparsely present in all stands (Table 1). Ground coverage is very low and rarely exceeds 5%. Most species are located on particular microhabitats, such as tree stumps, branches and mineral soil brought to the surface by uprooted trees. Their presence is much lower on drift sands than on former heathland.

Clearcutting and ploughing return the forest stand to a pioneer phase, in which several species of the heathland community reappear (Table 1). Species richness of these stands is much higher than in mature stands and several species apparently survived in the seed-bank. Also typical is the presence of a number of species indicating higher moisture levels (*Juncus squarrosus*, *Molinia coerulea*).

Natural regeneration

The survey of natural regeneration under pine canopy of 70-year-old stands shows the following (Table 1):

- In all four stands a fair occupation of deciduous trees is established with an average density of 7000 saplings ha^{-1}.
- Eighty per cent of the regeneration is black cherry.
- A total of ten tree species regenerated. They can be divided into major tree species, such as red oak (*Quercus rubra*) and pedunculate oak (*Quercus robur*), and secondary tree species, such as black cherry and mountain ash (*Sorbus aucuparia*).
- Apart from black cherry, red oak is found most frequently. It appears almost everywhere, with an average density of 761 trees ha^{-1}.
- Pedunculate oak appears to a lesser degree, although it is found almost everywhere, with an average of 120 trees ha^{-1}.
- The regeneration of Scots pine is very limited. It is only found in stands where black cherry was regularly cut or uprooted.
- On the ploughed clearcut area, Scots pine seedlings are abundantly present (Table 1). Red oak and black cherry seedlings are regularly but scarcely present.

Natural regeneration also occurs abundantly on burnt areas of Scots pine as follows (Table 1):

- The total stem number reaches 18 554 ha^{-1}.
- In all, 11 species occur in the regeneration.

Table 1. Vegetation surveys by the Braun-Blanquet method of four Scots Pine stands

	Stand			
	1	2	3	Clearcut
Age	45	75	69	–
Soiltype	spodosol	spodosol	inceptisol	spodosol
Number of plots	2	4	3	14
Species				
Upper storey				
Pinus sylvestris	3	2	2/3	
Quercus rubra	–	–/1	–	
Understorey				
Betula pubescens	–	–/+	–	
Frangula alnus	–	–/+	–	
Prunus serotina	1	2	1/3	
Quercus robur	–	–	–/+	
Quercus rubra	–	2/3	–	
Herbal layer				
Betula pendula				–/+
Betula pubescens	+	–/+	–/+	–
Frangula alnus	+	–	–/+	
Pinus sylvestris	1	+/–	1	–/2
Prunus serotina	+	+/1	+/1	–/+
Quercus robur	+	–/+	+	–/r
Quercus rubra	+	+/1	–/+	–/1
Sorbus aucuparia	–/+	+	–/+	–/+
Salix sp.				
Agrostis vinealis	–	–	–	–/1
Calluna vulgaris	–/+	–	–	+/1
Carex pilulifera	–	–/+	–/5	+/2
Corynephorus canescens	–	–	–	–/+
Deschampsia flexuosa	5	1/2	+/5	r/2
Dryopteris carthusiana	+/1	–/+	–/+	
Epilobium angustifolium	+	–/+	–/+	
Genista pilosa	–	–	–	–/+
Holcus mollis	–/r	–	–	
Humulus lupulus	–	–/r	–	
Juncus effusus	–	–	–	–/+
Juncus squarrosus	–	–	–	–/1
Luzula multiflora	–	–	–	–/1
Molinia coerulea	–	–/+	–/+	–/+
Ornithopus perpusillus	–	–	–	–/+
Spergula morisonu	–	–	–	–/1
Rumex acetosella	–	–	–	–/1
Moss layer				
Atrichum undulatum	+	+		
Brachythecium rutabulum			+	
Campylopus sp.	+	+	+	
Dicranella heteromalla	+	+		

Table 1. *Continued.*

	Stand			
	1	2	3	Clearcut
Dicranum scoparium	+			
Eurhynchium praelongum	+	+		
Hypnum cupressiforme	+			
Lophocolea heterophylla	+	+		
Orthodontium lineare	+	+	+	
Plagiothecium	+	+	+	
Pleurozium schreberii	+	+		
Pohlia nutans	+	+	+	
Polytrichum formosum		+		
Pseudocleropodium	+	+		

- Almost 95% of the stem number are accounted for by birch and Scots pine.
- The nine other species represent only 5% of the total. They can, however, play an important role in the future stand.
- Regeneration of Scots pine is not always obvious, although it can be observed in many places and under different circumstances:
  - regeneration under its own canopy, whether or not in a dense mat of wavy hair-grass (Table 1);
  - regeneration after fire: 6500 seedlings ha^{-1} were present after 6 years;
  - regeneration on a clearcut and ploughed area; after 1 year the regeneration resulted in 270 000 seedlings ha^{-1};
  - regeneration under canopy, after removal of the organic soil layer: an average of 1.45 million seedlings ha^{-1} were counted after one year.

Stand structure

As a result of spontaneous ingrowth of hardwoods, the original homogeneous Scots pine stands are currently slowly but steadily transformed into heterogeneous mixed stands, as shown by two vertical projections of a 75-year-old Scots pine stand (Fig. 1).

The highest stem number appears in the middle stratum, namely 760 trees ha^{-1} or 42%. Nearly 70% of the trees in this stratum are red oak. The upper stratum contains on average 32% or the stem number. The pines, with 75%, represent by far by the greatest part, but red oak, black cherry, pedunculate oak, black locust (*Robinia pseudoacacia*) and sweet chestnut (*Castanea sativa*) have already penetrated into the upper stratum. The lower stratum is the least represented. Age analysis showed that the pines were some 27 years old when the spontaneous ingrowth of the deciduous trees started.

Discussion

The biodiversity of short rotation Scots pine monocultures established on former heath-lands is low, due to their relatively high stand density and uniform structure. The mature stands, characterized by a spontaneous ingrowth of several hardwoods, a more complex structure, a relatively high herbaceous biomass (2.6 ton ha^{-1}) and a small amount of dead

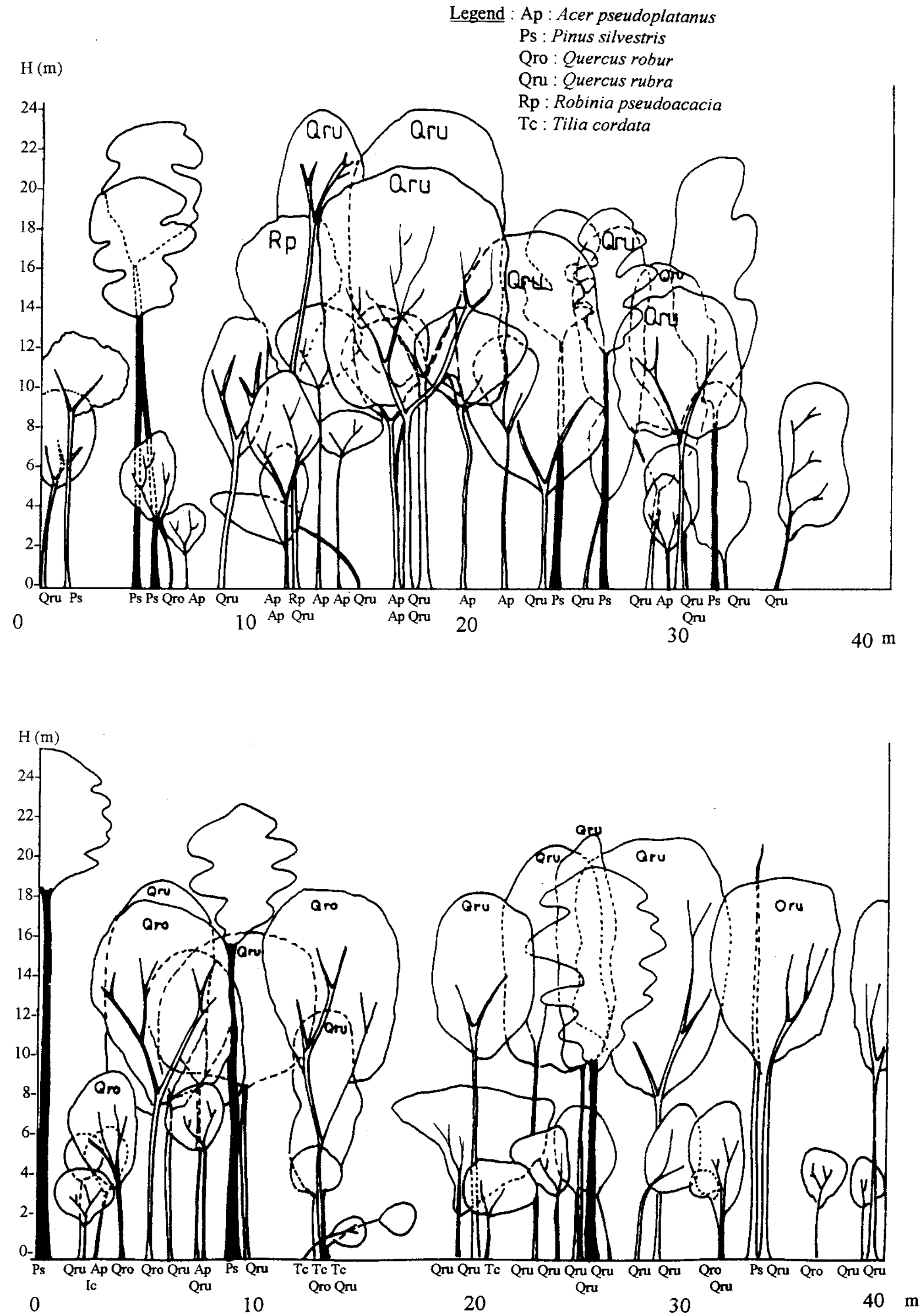

Figure 1. Vertical projections of a 75-year-old Scots pine stand.

wood, are tending to a higher biodiversity. Their biodiversity is probably not lower than in the former heathlands or drift sands (Maddelein *et al.*, 1992a). In many stands however, the process of spontaneous ingrowth of native species is hampered by a successful establishment of two exotic tree species, black cherry and American red oak (Maddelein *et al.*, 1990).

Forest managers can take a number of measures, which significantly increase forest biodiversity, without endangering its economic value. This appears clearly from the seven principles, formulated by Peterken (1981), which stress nature conservation aspects of woodland management, along with the results of this research.

Minimize rates of change

The principle of minimal change is certainly valid for the conversion of even-aged Scots pine stands into mixed well-structured stands of conifers and hardwoods. The transformation period should be long enough and indirect conversion methods should be used (see Fig. 1). It means that clearcuts must be avoided and regeneration under cover must be applied (Kirbach, 1992; Mlinsek, 1992).

Encourage long rotation periods

Lengthening of the rotation period is an important measure (Table 2). Scots pine stands should have the opportunity to reach the mature phase of their life cycle, in which biodiversity increases spontaneously (Weber, 1984; Otto, 1991). Until the 1970s, the rotation length of Scots pine was only 40–50 years. Nowadays, because of the loss of the pit-prop market, it has risen to some 70 years, but observations and studies indicate that rotation lengths of more than 100 years are easily feasible.

Encourage the use of native tree species

The choice of tree species is likely to be one of the most important measures to stimulate biodiversity. Trees should preferably be indigenous and one should strive for species diversity (Maddelein *et al.*, 1993). Scots pine in the Belgian Campine cannot be considered as a native species, although it was present immediately after the last ice ages. However, it is certainly a species appropriate to the site and which enables a high degree of diversity, especially in older stands. Therefore, Scots pine must not disappear, but should be used in a more sustainable way (Otto, 1991).

Among the native species, the most important ones are pedunculate oak and birch. Both are probably able to eliminate Scots pine, therefore, appropriate management should be applied, ensuring the regeneration and development of all tree species. Oak is undoubtedly the main climax species, whereas birch probably cannot be considered as a real climax species. Nevertheless, the latter plays an important role in succession. In that respect, mountain ash should also be mentioned and it certainly deserves more attention. The position of beech (*Fagus sylvatica*) can be discussed. It is nowadays considered to be a climax species on similar sites (Fanta, 1995a,b). However, the rare beech trees and stands which are currently present in artificial forests obviously do not have a positive impact on the soil and stand quality development, including biodiversity. Therefore its use should be restricted to small units in really suitable niches. The possibilities of oak are now more or less accepted, especially in public forest. Unfortunately, there is a lack of seed trees, and planting results are often poor, certainly in open areas. Planting of oak under a canopy of Scots pine succeeds quite well (Maddelein *et al.*, 1991).

Table 2. Stem number of spontaneous ingrowth in 70-year-old Scots pine (No. ha^{-1})

	Stand																
	7	10(A)	10(B)	11	16	17	19	21	22	25	26	28(A)	28(B)	39	54	Avg	%
Pinus sylvestris	–	–	–	323	–	347	–	18	–	–	–	107	–	–	–	56	0.8
Quercus rubra	766	425	844	1354	813	705	964	741	1098	367	359	1027	1547	406	–	761	10.8
Sorbus aucuparia	125	625	703	135	271	63	9	27	125	78	188	36	–	885	1359	309	4.4
Quercus robur	234	263	281	177	94	63	125	36	45	109	47	36	198	94	120	1.7	1.7
Frangula alnus	78	88	219	52	31	27	9	54	9	55	55	18	–	42	31	51	0.7
Betula pendula	–	133	–	113	141	21	31	–	63	36	9	–	8	–	141	46	0.7
Castanea sativa	125	13	16	10	–	45	–	9	9	63	63	–	–	–	31	22	0.3
Tilia cordata	109	–	–	–	–	–	–	–	–	–	–	–	–	–	–	14	0.2
Acer pseudoplatanus	47	–	–	–	–	–	–	–	18	8	–	–	–	–	16	6	0.1
Subtotal	1894	1525	2203	2072	1239	1251	1170	920	1313	680	719	1232	1563	1677	1641	1379	19.6
Prunus serotina	2703	5850	9094	7615	4927	6661	5991	2661	4554	5563	2859	4866	6078	8062	7375	5657	80.4
Total	4187	7375	11297	9687	5166	7912	7161	3582	5867	6243	3578	6098	7641	739	9016	7036	100
% *Prunus serotina*	64.6	79.3	80.5	78.6	79.9	84.2	83.7	74.3	77.6	89.1	79.9	79.8	79.5	82.8	81.8	80.4	

The future position of birch is not clear, as this species is still generally considered as a 'weed' tree. It is a tree species, however, which should be strongly favoured for the following reasons: it improves degraded sites by its litter, it enables a mixture with other light demanding tree species, it regenerates spontaneously and abundantly on open areas and production is fair. Miles (in Muys, 1991) made the following observations after establishment of birch: a higher earthworm density, faster litter decomposition, deeper admixture of the organic matter with the soil, higher soil pH, more roots and increasing diversity of the herbaceous layer.

Huge problems are created by two dominating exotic species, black cherry and red oak. The former must be eliminated completely, as it is too competitive and almost completely without value. The latter, although it has several values, has been the subject of debate in recent years. Indeed, it becomes obvious that its regeneration and competitive capacity will eliminate the native oak (Maddelein *et al*., 1995). Such an outcome would be deleterious to biodiversity.

Encourage structure and habitat diversity

Habitat diversity in Scots pine forests can be realized by creating diversity in horizontal and vertical stand structure and by a complex age class distribution in space and time (Pflug, 1991). Vertical stand diversity is built up by the spontaneous ingrowth of hardwoods and shrubs. Structures, comparable to those in selection forests, can arise in less than 30 years (see Fig. 1). The development of a herbal layer is only possible in open, mature stands or in vertically well-structured stands (see Table 1). In the investigated Scots pine forests, herbal biomass production of up to 3 tonnes ha^{-1} has been recorded. Analyses have shown that the herbal litter is richer in nutrients than the pine needle litter (Muys, 1991). It stimulates the pedoflora and pedofauna and consequently enhances the decomposition process.

As in every forest, forest edges are very valuable biotopes (Aichüller, 1991; Schoop, 1991). Well structured edges, gradually built up by native herbs, shrubs and trees, are highly appreciated. The conservation and management of the original broadleaved belts is therefore very important.

Encourage natural regeneration

Peterken (1981) points out that natural regeneration has several advantages over planting for nature conservation purposes: it favours native species and those species already on the site, and minimizes change; it tends to generate mixed stands; the stand produced tends to have a more irregular structure; natural genetic variety can be better maintained; and the natural distribution of tree species in relation to soil types is favoured. Practice has shown that natural regeneration of former Scots pine monocultures is possible in different ways (Lust, 1987, 1988). It can be realized on clearcut areas, after disturbance by fire or gales and also under a more or less dense canopy (see Table 1).

With respect to the regeneration system, some contradictory data have appeared (Kirbach, 1992). On the one hand, clearcutting obviously causes drastic changes to the forest ecosystem, with dramatic consequences to many organisms. On the other hand, however, clearcutting generates a new juvenile phase, promoting the development of a rich herbal layer and favourable life conditions for all kinds of mammals and birds. On large afforestated areas, featuring mosaic structures, small-sized clearcuttings are not absolutely negative for biodiversity.

Specific measures

Specific measures for the protection of small habitats, valuable for the conservation of endangered species, can be taken without significant impact on the overall economic result. Fens, dishes, glades, roads and rides are important habitats, which increase the range of biodiversity (Aichmüller, 1991). Most are artificial in origin and survive only by active management.

The amount of dead wood should be increased. The standing as well as the lying necromass is important: crown wood and bark should be left and decomposed on the spot; large, old tree bodies should be left standing or lying in the forest (Jedicke, 1991; Otto, 1991; Schoop, 1991).

Infrastructure works should be reduced to a minimum (Lust, 1992). Road paving should be kept to a minimum and certainly avoided on floristically valuable sites. Harvesting operations should lead to a minimal disturbance of the ecosystem. During (re) afforestation, low impact techniques should be stimulated (Leibundgut, 1992).

Records

Records are necessary to evaluate the effect of management on biodiversity. One approach is to maintain control ecosystems which are absolutely or relatively free from human influence. A second approach is either to set up experiments whose results can be assessed in the future, or to study, in permanent plots, the consequences of actions which were taken in the past (Peterken, 1981).

Conclusions

As a general conclusion it can be stated that the principles of a closer-to-nature forestry, favouring biodiversity, are rather easy to realize in the management of traditional Scots pine stands. They should be applied in public and private forests. Logistic and financial encouragement should be given by the forest service. Biodiversity can easily be increased in Scots pine stands with an important wood production function. A system, combining profitability, stability and diversity, must be based on the following practical measures:

- conversion into mixed stands, with use of native tree species and shrubs;
- use of natural regeneration;
- game control;
- use of long rotations;
- small-scale group treatment, leading to a mosaic structure;
- restricting clearcuts, striving for regeneration under canopy;
- creating a diversified age structure and vertically well-structured stands;
- retaining existing habitat diversity by conservation of small biotopes and rare species;
- investigating site characteristics, limiting soil preparations, stopping litter removal, no-burning of timber residues, debarking on the spot, avoiding fragmentation.

Most attention should be paid to the future species composition of the present Scots pine stands, as follows:

- The even-aged, homogenous stands of species must be transformed into more complex mixed stands.

- The admixture of native tree species must be increased significantly. Oak and birch have to play a major role, but other appropriate species must be intermingled as much as possible. At the same time the spontaneous and artificial introduction of native shrubs, mainly of mountain ash and alder buckthorn, must be encouraged.
- A compromise must be sought between the mainly native deciduous tree species and the mainly exotic conifers, such as Scots pine, Corsican pine (*Pinus nigra* ARN. var. *calabrica*) and Douglas fir (*Pseudotsuga taxifolia*).

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