HABITAT AND SPECIES MANAGEMENT

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Old-Growth Forests

CHARACTERISTICS, CONSERVATION AND MONITORING

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Forward

For the public at large, a forest is synonymous with wilderness. It covers vast areas, is seldom visited, and forms the ultimate refuge for numerous large mammals and predators.

Existing forests, however, do not have very much in common with the original and intact forests that covered Europe up until the beginning of the Neolithic period. Most of them have since been logged, fragmented and disturbed by human activities.

However, there are still some vestiges of the large, original silva in France and Europe. There are also certain forests that, having been hardly disturbed or left completely unexploited for a very long time, have maintained or regained an aspect, composition and functioning close to the original natural forests.

These forests, known as "old-growth forests", have numerous ecological, scientific, economic, social, cultural, and other qualities. Characterized by, among other things, substantial quantities of dead wood, they are home to numerous species of flora and fauna that have disappeared from managed forests.

Despite their scarcity (they represent no more than 1 to 3% of European forests), these forests are only partially protected and their surface area continues inexorably to diminish.

Given their interest, scarcity and fragility, there is an urgent need to adequately protect all the old-growth forests of France and Europe. As these old-growth forests are often small and isolated in managed forest massifs, it would also be advisable to increase the naturalness of adjoining managed forests into the future to thwart the harmful effects of their fragmentation.

To attain such objectives, forest actors and managers of natural areas should, first of all, be informed and made more aware of these issues. This is one of the main aims of the "Forest group" of the French Nature Reserves (RNF) and of this book. Hopefully it will contribute to highlight and help protect old-growth forests, which are such marvellous natural gems.

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European expert on natural forests (GB)

"It goes without saying that in a natural forest we should preserve those features which are not of man's doing. As an instance of this may be mentioned the importance of retaining trees which are decaying, trees which are dead, trees which have been overthrown by the forces of nature, as well as those which are in full vigour. I have recently spent a fortnight in exploring one of the largest natural forests in Eastern Europe. Here, to my mind, the chief beauty resides, not in the standing trees, but in the giants that lie prone among their roots. Many of them have lain for several centuries. They are gorgeous with moss and lichen; their great trunks are seedbeds for their descendants, and they tell a story of mighty hurricanes and snowstorms which we should miss, if it had been possible to remove them. Our Forest is also a document of nature with its tale to tell. Its failures, its ruins should be preserved, as well as its vigorous youth. It should not be trimmed and garnished."

Edward NORTH BUXTON (1898)[144]

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Old-growth forests

CHARACTERISTICS, CONSERVATION AND MONITORING

1 Introduction

This technical report, intended for current and future managers of protected areas and forest areas, has the following objectives:

- to describe the functioning of old-growth forests and clarify the concept of naturalness;
- to present the reasons that prompt us to protect them, as well as the different means available to managers of natural areas to study and protect them.

Of the various functions of forests, that of production has always been privileged at the expense of ecological functions.

Forest managers today wish to combine different objectives in "multi-functional" areas. This is the case in suburban forests, where the social role is predominant. It is also the trend in protected areas where ecological functions are highlighted.

For scientists, the ecological* optimum, that is the situation where the environmental factors are most favourable for its development, is represented by the "primary" forest: a forest in equilibrium with its environment, which is not subjected to any anthropogenic* disturbances. As long as such a forest is sufficiently vast, it allows all species that comprise it (biodiversity) to survive in the long term. The natural functioning of these forests is characterized by a constant struggle between trees and disturbances (§ 2.2).

These primary forests, which covered more than 80% of the European continent at the end of the last glaciation, have continuously declined as a result of human pressures. And yet these rare relict fragments (there remains less than 1%) are still not completely protected (§ 2.3).

Lacking the ability to replace a large, original forest, certain measures of protection and management, such as increasing the "naturalness" of a forest (§ 3), can nevertheless restore ecological characteristics and functioning. It is from this point of view that the concept of naturalness should be adopted. The degree of naturalness of an ecosystem corresponds to its degree of similarity with the "original" ecosystem, the one that would have existed if no anthropogenic* disturbance had modified the forest dynamics, structure and composition. To increase forest naturalness requires increasing this similarity, in reducing the gap between the actual state of forests and their original state. Naturalness is thus measured along a gradient and not in a binary way. Increasing the degree of naturalness can be achieved in the long term by letting forests evolve freely or to a lesser extent by favouring certain forest components that are characteristic of "primary" forests: dead trees, large-diameter trees, etc.

If old-growth forests (a term that indicates forests with a high degree of naturalness) are now a focus of attention[187], it is because they are remarkable in many ways (§ 4.1). They provide the silviculturist with the keys to a better understanding of forest dynamics. They enable a multitude of specialized species to find their particular habitat. Other aspects should also not be overlooked, including their potential as source of wonder, of getting (back) in touch with one's inner self and sometimes even of revenues.

Nevertheless, their protection and management pose a certain number of questions (§ 4.2) that are today in urgent need of being answered with conservation strategies (§ 4.3) and specifically adapted research programs (§ 5).

The asterisk placed after a technical or unusual term refers to the glossary (§ 7), the numbers in superscript refer to bibliographical references (§ 8).*

What is an old-growth forest?

No one can claim to effectively manage an environment they are unable to identify or whose basic functioning they are not at least able to understand in general terms. The identification and functioning of "old-growth forests" are remarkable and deserve to be presented in detail[156]. The term "old-growth forests" characterizes above all a state of conservation (resulting from the forest's history), not a habitat determined by site conditions.

2.1. Several definitions

The first obstacle to presenting "natural" forests arises from the multitude of definitions. Several hundreds of definitions have been proposed to define "ancient forests", "climax", "primary", "natural", "virgin", "pristine" and "old-growth forests» (see e.g. http://www.fao.org/DOCREP/005/Y4171E/Y4171E34.htm).

Most authors limit the use of "virgin, primary or natural forest" to forests that have never been subjected to significant human impact. This definition still corresponds fairly well to certain tropical forests (where man's impact has been negligible).

[95,127]The North American term "old-growth forest" describes forests in which certain valuable trees have, at times, on an ad hoc basis, been removed, but without the original composition or physiognomy of the forest being modified[90].

British authors often speak of "ancient woodlands" to designate the most natural types of forests on their islands. Nevertheless, this term does more to characterize forest continuity (for several centuries) than naturalness (as some of these forests are managed).

In France, different terms are used: "virgin forest" (not altered by modern man), "primary" (having an uninterrupted natural dynamics since their spontaneous origin), "natural" and "original" are a few examples. French forests have all or almost all been altered by human activities (even if only ancient activities, atmospheric pollution or the elimination of large carnivores), the most conciliatory terms of "forêt à caractère naturel", "subnatural forest" or " subprimary forest" have been suggested to designate those that still have a high degree of naturalness (§ 3). The designation "subprimary" or "subnatural" seems somewhat pejorative and too dualistic, so we have chosen the first term (translated as "old-growth forest" throughout this book) to define French forests that have a high degree of naturalness.

The term "old-growth forests" used in this technical report characterizes:
- *ecosystems that are differentiated by the presence of old trees and by the structural characteristics that are included;*
- *forests including the final stages of site development, stages typically different from more recent stages by tree size, the accumulation of large quantities of dead wood, the number of arborescent storeys, specific composition and ecological functions;*
- *forests without signs of recent logging and comprised of native species.*

The designation "strict forest reserve" refers to a strict protected status that prohibits silvicultural operations and most other uses. This type of reserve usually protects forests with a high degree of naturalness. Yet in certain cases, it refers to forests that have been managed up until now but where the intention is to increase their naturalness in the future.

2.2. A complex functioning

2.2.1 The unit of regeneration and the sylvatic mosaic

Since Jones[90], who in 1945 suggested the first analysis of the structure and dynamics of temperate forests, Oldeman[138] is probably the one who has given the most complete description of the functioning of forest ecosystems, by specifying the concepts of "eco-units" and "sylvatic mosaic".

Old-growth forests are organized according to the layering of different units:
- ecotope: space occupied by a tree during its lifetime;
- regeneration unit or eco-unit : "area where, at one point, development of vegetation has begun" (site liberated by the death of one or several trees simultaneously);
- sylvatic mosaic (or eco-mosaic): a set of regeneration units, often of different ages.

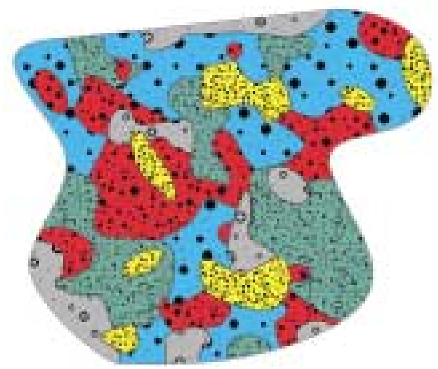
2.2.2 Silvigenetic phases and cycles

During the course of its development, the eco-unit (§ 2.2.1) will go through several stages: youth, characterized by regeneration and vertical growth of the young trees; maturity, characterized by growth in thickness (trunk) and breadth (crown); and old age, when tree growth slows and mortality increases, thus allowing a new youth stage to appear.

These stages are comprised of 5 different silvigenetic phases: regeneration, initial (or growth, optimum, ageing and decay.

In the case of forests with "patch dynamics" (the majority of European temperate forests), the eco-units are small (usually less than 50m²). As soon as a disturbance generates the creation of a new eco-unit, a new cycle begins. In this type of forest, the new cycles usually start before the old ones are completed. Several phases can thus overlap on the same unit: the regeneration phase of a new cycle begins as soon as the first dead trees of an old cycle (in ageing phase) allow light to penetrate the canopy.

Inspired by Leibundgut[111], Korpel[101] organized his five silvigenetic phases in three successive stages:
- the regeneration or degeneration stage, simultaneously includes:
  - the ageing phase comprised of dying trees of cycle 1
  - the regeneration phase comprised of young seedlings of cycle 2
- the growth stage, simultaneously includes:
  - the decay phase comprised of dead trees of cycle 1
  - the initial phase comprised of young trees of cycle 2
- the optimum stage, includes:
  - the optimum phase represented by fully-grown trees of cycle 2



Sylvatic mosaic
Sylvatic mosaic refers to a macroscopic vision of the forest. It includes eco-units (areas represented here by different colours according to the silvigenetic phase; § 2.2.2) that, seen from above, would appear as so many groups of similarly-aged trees. The trees (black dots), whose average size differs in each silvigenetic phase, and each occupies its own space called ecotope.

Eco-units are variable in size. In boreal regions where fires are regular disturbances (large-scale dynamics; § 2.2.5), it is not unusual that the same regeneration unit covers several tens or even several hundreds of km². In temperate European forests where the eco-unit corresponds most often to the location of one or a few downed trees (patch dynamics; § 2.2.5), the units of regeneration usually have a diameter of 15 to 50 m.

In the old-growth forest of La Tillaie in Fontainebleau, 90% of the eco-units have a diameter between 15 and 30 m[55]. In the old-growth forest of Neuenburg in northern Germany, 45% of the eco-units have a diameter of 15 to 30m, the others are divided into different classes between 30 and 75m[100].

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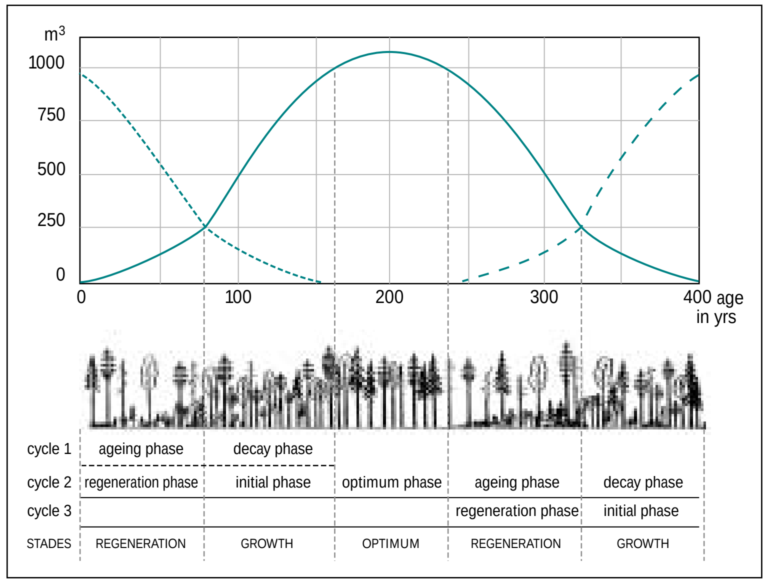
• once again the regeneration stage, simultaneously includes:
- the ageing phase of cycle 2
- the regeneration phase comprised of young seedlings of cycle 3



Model of silvigenesis for a beech-fir plantation[101] with patch dynamics.
The figure shows the succession of silvigenetic stages and phases and (in the upper part) the evolution of biomass (in m³/ha) for three successive silvigenetic cycles. End of cycle 1 (dotted line); cycle 2 (continuous line); start of cycle 3 (dashed line).

The study of silvigenesis already enables us to distinguish certain features of old-growth forests with patch dynamics compared to managed forests (see also § 2.2.6):
• all stages are present and certain phases are encountered simultaneously on the same eco-unit;
• certain phases are specific to natural forests (ageing and decay);
• at the scale of an eco-unit, total biomass is always high (varying in this example between 500 and 1000 m³/ha);
• a complete cycle is very long (400 years in this case).

This example is given for a mixed stand of beech, silver fir and spruce but this functioning is relatively universal for temperate forests with patch dynamics. Only the values will change depending on the species and site conditions.

When forest dynamics are of the “large-scale” type (severe disturbances: fires, violent storms, shifting riverbeds), the silvigenesis is rather different. After the brutal and swift death of all trees in large areas (eco-unit of several ha), there is an initial regeneration of heliophyte* species (softwood species in alluvial forests, birch and aspen in European boreal forests, etc.). When these pioneer species attain a certain stage of development, climax species (whose regeneration usually requires shade or semi-shade) will appear in the undergrowth and will gradually replace the pioneer species: this is the “transition” phase[157]. This transition phase will be followed by the optimum phase where the pioneer species will have practically all disappeared. Then, depending on

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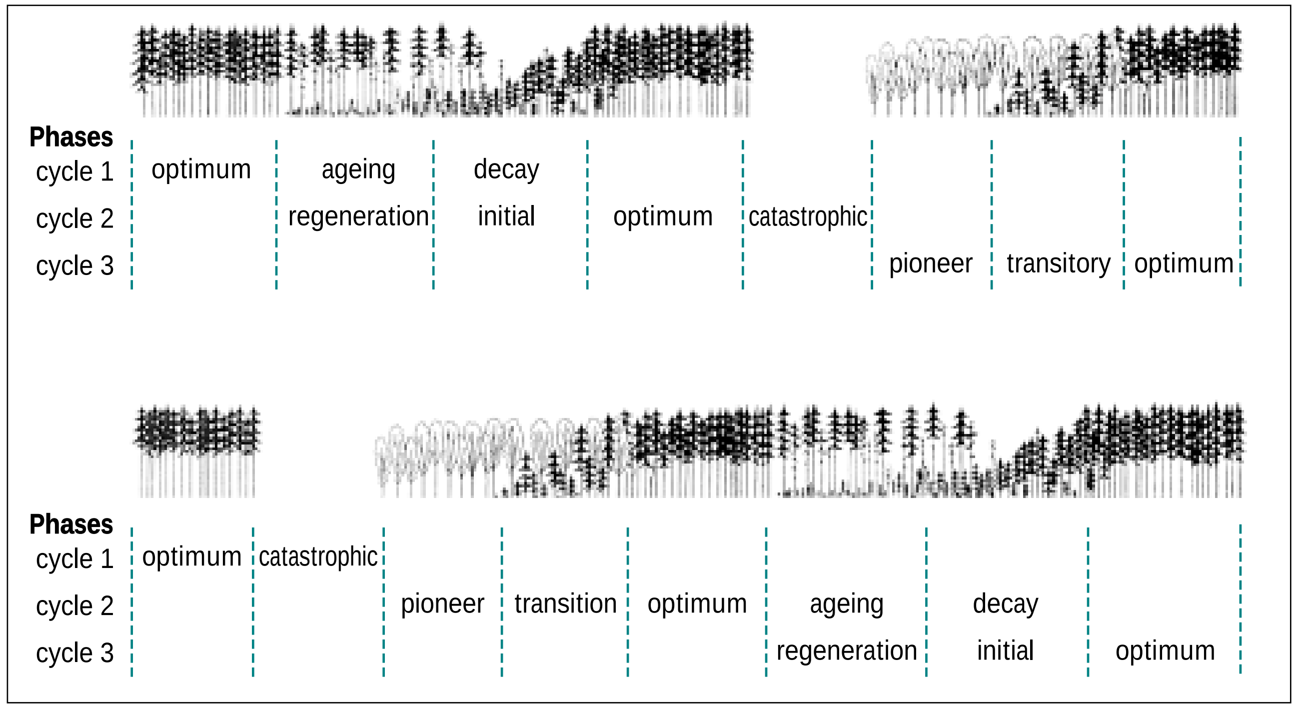
the new disturbances, the silvigenesis will continue with phases of ageing and decay (patch dynamics) or by a new colonization of the eco-unit by pioneer species in the case of a new catastrophic disturbance.

Depending on the type and frequency of the disturbances, the silvigenesis can easily proceed from a patch to a large-scale dynamics and vice versa (see figure here-below), even if one of these two dynamics is usually dominant.

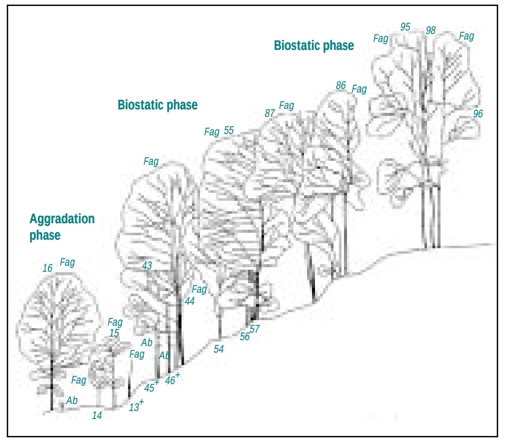
Model of silvigenesis for a boreal spruce forest passing from patch to large-scale dynamics (above) and vice versa (below)[157].



2.2.3 Architectural approach

In the preceding section, silvigenetic processes were only considered at the level of eco-units. A stage of development is attributed to each unit according to its physiognomy, and the silvigenesis is understood through the succession of silvigenetic phases. This approach, easy to understand and study, does not explicitly show the relationships between the three hierarchical levels (ecotope, eco-unit, eco-mosaic), and yet these relationships are the true driving forces of silvigenesis.

The architectural approach developed by Oldeman and Hallé[73,138], although more difficult to implement, enables one to fill this gap. By analysing the horizontal and vertical architectural profiles, it helps determine objectively the silvigenetic phase of each eco-unit.



Architectural profile of a beech-fir stand in the Massif du Grand Ventron Nature Reserve (D. Closset, unpublished).

The first level of this analysis is the tree and the architecture that it develops. This architecture, programmed genetically and subjected to environmental conditions, reveals changes to the environment and the possible traumas suffered by the tree. During its lifetime, the tree acquires a different status shown notably by the relationship between its height (H) and its diameter at breast height (DBH). When H << 100.DBH, the tree is said to be "of the past". It reaches the end of its life and is often sick or damaged. When H > 100.DBH, it is regarded as a "potential tree": there is still an substantial vertical growth potential to reach light and acquire the status of dominant tree as quickly as possible. When H ≈ 100.DBH, the tree is considered a "tree of the present": it has attained the canopy and privileges growth in the thickness of its trunk and crown. It is the detailed analysis of this first level of organization and its being taken into account to interpret the two following levels (eco-unit and sylvatic mosaic) that constitute the main difference between the traditional approach (§ 2.2.2) and the architectural approach.

2.2.4 Disturbances: driving forces of forest dynamics

Forest dynamics is not immutable. It is subject to variations that depend on the forest species, their longevity, site conditions, disturbances and, of course, human activities that amplify or attenuate the impact of these disturbances.

Disturbances influence the dynamics primarily by modifying the duration of the phases, even eliminating certain phases. A storm could, for example, precipitate the regeneration phase.

Certain disturbances lead to a weakening of the species and the ecosystem, rendering them more susceptible to other disturbances (cascading effect). Conversely, a disturbance could contribute to reinforce and stabilize the ecosystem (when species develop defensive and adaptive strategies: reinforcement of immune defences, selection of resistant ecotypes, etc.). Resistance of the forest ecosystem to disturbances depends mainly on the general condition of the trees including, most importantly, their: adaptation to the site, water and food supply, vital space, regenerative capacity and state of health[139].

To determine the naturalness of a forest ecosystem (§ 3), it is essential to clearly distinguish between natural and anthropogenic* disturbances.

Floods, for example, are natural disturbances. However, when their frequency or intensity increases due to the development of catchment areas (urbanization, cultivation or intensive logging), their marked impact is of an anthropogenic* origin.

Damage caused by storms, and breaking due to snow and late frosts are also natural disturbances whose impact can be worsened by humans, for example, when species are ill suited to a site.

Each hierarchical level transfers ecological functions to higher hierarchical levels, functions that help lead to the very stable general organization of old-growth forests. These interactions are fundamental for the organization of the system[137].

The impact of a disturbance will depend on its intensity, from the moment it occurs (frost and storms are more severe in May when trees are in leaf than in December), and on the ability that disturbed individuals, populations and communities will have to defend themselves.

What is an old-growth forest?

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Flooded alluvial forest (willow woods in the Delta de la Sauer Nature Reserve; photo: Bernard Boisson)

Damage from the storm Lothar in 1999 (Rambouillet Forest; photo: Bernard Boisson)

Mediterranean forest fire (Photo: Bernard Boisson).

Fire, an essential element of forest dynamics in certain regions, especially in boreal forests, is a supposedly rare natural disturbance in temperate Europe. Since lightning in these forests normally only entails the loss of a few trees, its impact appears negligible. The history of fires, nevertheless, deserves to be studied in our temperate forests since without logging, the volume of dead wood (combustible potential) was formerly much higher and fires, even sporadic ones, have continued to play an important role in forest dynamics. It should be noted that in the Mediterranean zone, fire is very often an anthropogenic* disturbance (criminal or accidental in origin).

Damage caused by fungi, pathogenic insects, rodents and large herbivores are natural disturbances but they can also be worsened by Man's actions. Spruce plantations that are poorly suited to the site will be more susceptible to downed logs leading to the opening of forest edges and an overheating of the cambium, conditions favourable to bark beetle outbreaks. Normally "peaceful", scolytids could, in the case of an outbreak, infest healthy trees (§ 6.1.2).

A dense, herbaceous cover, favourable to rodents, can also be the result of a natural disturbance (logs downed by wind or snow) or an anthropogenic* one (clearcut, nitrogenous pollution).

Lastly, in the case of damage by large herbivores, one must acknowledge that the great majority of disturbances that cause silvicultural-hunting imbalances are anthropogenic*: improved habitat (edges), feeding, fertility and winter survival thanks to feeding, extinction of predators and disturbance (stress) being the most aggravating factors.

In this context, the type of silvicultural management should also be considered as a "disturbance" (very often the most significant) of the natural functioning of forests. Since this is related to a specific and extremely important point determined by managers' actions, a separate section has been devoted to it (§ 2.2.6).

2.2.5 Main types of forest structures in France

The structures observed in old-growth forests depend largely on a disturbance regime. Some arise from "patch dynamics" where disturbances, of a low intensity, create small openings. Others are shaped by disturbances that affect large areas ("large-scale dynamics"). "Patch dynamics" produces "irregular" structures where trees of different sizes are closely mixed. "Large-scale dynamics" generates "regular" structures with trees of the same age that cover vast areas (§ 2.2.2).

Examples of structures resulting from "patch" dynamics include:

MIXED FORESTS RICH IN OAK[56]:

The dynamics of oak trees, often in low density, are superimposed and dominate that of less long-lived species (beech, hornbeam, maple, lime, etc.) that will be replaced several times during the life of an oak. Owing to its great longevity, several dozen seedlings per hectare and per century are sufficient to ensure, with the help of occasional large gaps, the long-term survival of oaks.

Large herbivores, by their significant action on the process of regeneration, are an integral part of the forest ecosystem and its dynamics. The impact of large herbivores, whether wild or domesticated (grazing land in forest), results in profound alterations of the forest ecosystem: modification of flora and trophic networks, regeneration limited to certain species (selective browsing), physical (logs) and functional destabilization of the ecosystem. Nonetheless, it is wrong to think that their densities (and their impacts) are systematically higher today than they were in the original forests. The diversity of species was much greater (bisons, wild ox, tarpans) and the "damage", deplored today, is perhaps much less than what it was long ago. Moreover, the prevalent image of the large, dense and uniform forest from the beginning of the Neolithic is more and more contested by those who prefer the image of a semi-open forest (pasture-woodlands, thickets)[191].

Structures resulting from "patch" dynamics:
Alluvial forest (Offendorf Nature Reserve),
Mixed forest rich in oaks (Tronçay),
(Photos: Bernard Boisson)

HARDWOOD ALLUVIAL FORESTS[28,34]:

Situated at the edge of a floodplain, these forests show a similar dynamics to the preceding type: pedunculate oak establishes itself as soon as the pioneer stages are generated by fluvial dynamics and maintains itself thanks to its great longevity. It is accompanied by numerous "post-pioneer" species (ash, elm, lime, maple, etc.) and pioneers (black or white poplars) that regenerate themselves in small gaps created when trees die or by erosion during floods. Regular flooding is an essential disturbance to maintain this structure because it prevents the establishment of shade-tolerant species (beech and hornbeam), the colonization of which would lead to a substantial closing of the structure.

Structures resulting from "patch" dynamics:
Forest under severe ecological constraints (Grand Ventron Nature Reserve) and mixed mountain forest (Jura) (Photos: Bernard Boisson)

MIXED MOUNTAIN FORESTS (BEECH-FIR-SPRUCE FORESTS)[158,124]:

The determining element of these forests is the ability of the seedlings (of fir and to a lesser extent of spruce and beech) to be able to wait in the undergrowth for more than a century before accelerating their growth with the help of a gap to reach the canopy. The growth of a tree is therefore determined by its location and not by its age. Thus, a 250-year old fir can be "ageing" if it has had a short lag phase or "young" if it has remained under the crown cover.

FORESTS WITH SEVERE ECOLOGICAL CONSTRAINTS:

As a result of severe edaphic*, climatic and/or biological constraints, the stand is very open to light. Every tree grows freely (no competition from neighbours) and ensures its own stability (tree with a large diameter, often not very high, with many low branches). This structure tends to be found at the subalpine level (*Pinus cembra* and spruce forests) owing to the severity of the climate, and on scree or at the foot of a cliff because of the instability of the substrate and the falling of boulders.

Structures arising from "large-scale" dynamics

Monospecific stands tend to evolve towards "regular", closed structures that simultaneously collapse over large areas due to severe disturbances (storms, fires). Examples include some upland beech groves, subalpine spruce forests on peatlands, boreal forests (often regenerated by fire) and *Pinus uncinita* forest (example of the Swiss National Park). Regeneration is most often done by pioneer species (larch in spruce forests and subalpine *Pinus cembra* areas, birch and aspen in upland and boreal contexts, willows in an alluvial context, etc.) before the return of species from mature stages (see also end of § 2.2.2).

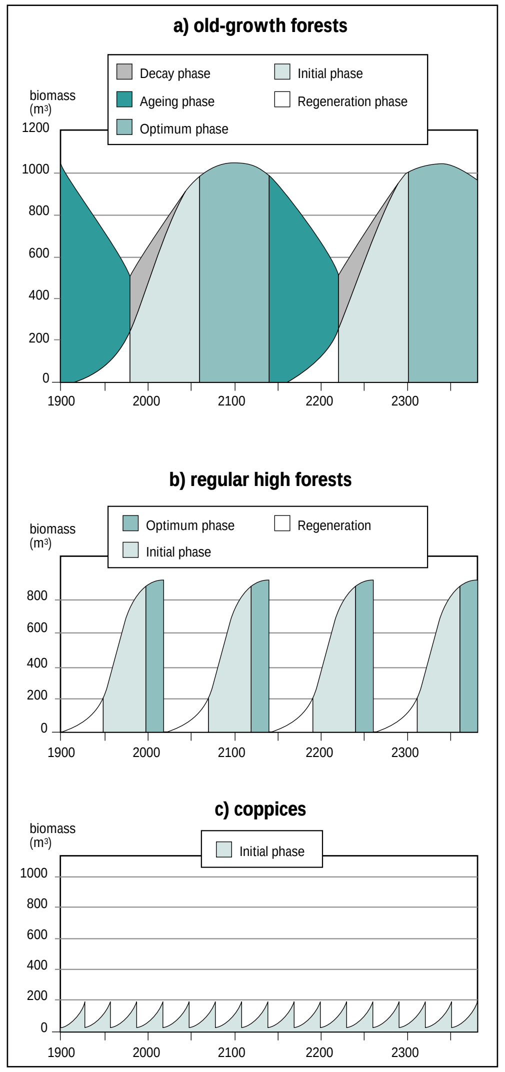
2.2.6 Silviculture put to the test by silvigenesis

Certain characteristics have already been attributed to natural forests with patch dynamics (predominant in France): specific phases (ageing and decay), high biomass, large-scale (§ 2.2.2).

Structures and silvicultural management
Regular high forest (Brocéliande Forest), high irregular forest (Eastern Pyrenees), coppice (Aveyron) and old-growth forest (Biological Reserve of Fontainebleau; photos: Bernard Boisson)

How do the main management modes used in production forests differ from these characteristics?

- In forests managed as regular high forests, ageing and decay phases are absent and each stage only has one phase. After logging, wood biomass reaches values close to zero. Since logging occurs before the stand reaches maturity (200 years in our example), the phases are abridged and the duration of the cycle is



Models of succession of silvigenetic phases according to type of management
High regular forests (b) distinguish themselves from old-growth forests (a) by the absence of certain phases, the brevity of the cycles and the drastic decline in biomass at the end of each cycle. The coppices (c) have even shorter cycles, a single phase and very low levels of biomass considering the brevity of the rotations (cutting cycles).

OLD-GROWTH FORESTS WITH PATCH DYNAMICS DIFFER FROM MANAGED FORESTS BY:

- *Total duration of the cycle (longer);*
- *Substantial biomass (even during the regeneration phase);*
- *Simultaneous presence, at the regeneration unit scale, of several phases (except for the optimum stage);*
- *The presence of terminal (ageing and decay phases, and thus a high level of necromass*.*

shorter (often less than 150 years). This silvicultural treatment is similar to the dynamics of forests subject to large-scale dynamics, but differs by the brevity of the cycles (no old trees) and the low amounts of necromass at the end of the cycle. These high forests cover more than 45% of France's total forested area.

- The coppice can be compared to a regular high forest with an even shorter cycle (15 to 30 years); the optimum and regeneration phases are absent. The second growth of trees is ensured from stumps, only the initial phase is present.
- The impact of silviculture in irregular high-forests (5% of French forests) is identical to that described for regular high-forests. The only difference lies in the size of the units of regeneration ("patches" or "clumps"; called "parquets" or "bouquets" in France). Smaller in size (several tens or hundreds of m²) than in regular high forests, these cuts will have a limited ecological impact because the distances that forest-restricted species will have to travel to find the necessary cover for their survival will be shorter. Species of limited mobility are only able to survive if the spatial-temporal continuity of their micro-habitat is ensured on a small scale (§ 5.4.2); they will therefore maintain themselves better in these high forests than in regular high forests.
- Selection high forests are managed "tree by tree" and the unit of regeneration thus corresponds to the "ecotope" (§ 2.2.1). Having trees of very different ages on small areas confers a structure to these forests reminiscent of old-growth forests with "small patch" patch dynamics (certain sites with severe constraints). While salutary for many species, a continual presence of trees can be harmful to others (heliophytes*) and the estimation of the naturalness of these forests should thus take into account the dominant type of dynamics in the region under consideration. Selection high forests will actually have a functioning similar to that of natural forests in regions with "small patch" patch dynamics (for example, slopes protected by the Vosges massif), not in regions subject to large-scale dynamics.
- There is a final type of management that combines several storeys on a single parcel: the coppice-with-standards system. In these stands, which are quite widespread in France (oak forests), there is an attempt to encourage a storey of dominant trees (timber) along with an understorey of firewood (hazel, hornbeam, chestnut, etc.). Since the lower stratum is treated with stumps, it only follows an initial phase, unlike the dominant trees that follow the three phases of high forests (regeneration, initial, optimum). The originality of this silvicultural treatment, compared to natural forests, lies in the fact that there is a superposition of two units of regeneration of different sizes. For the coppice, the unit of regeneration will generally be the size of the parcel (as in a regular high forest), whereas trees grown in high forests will be

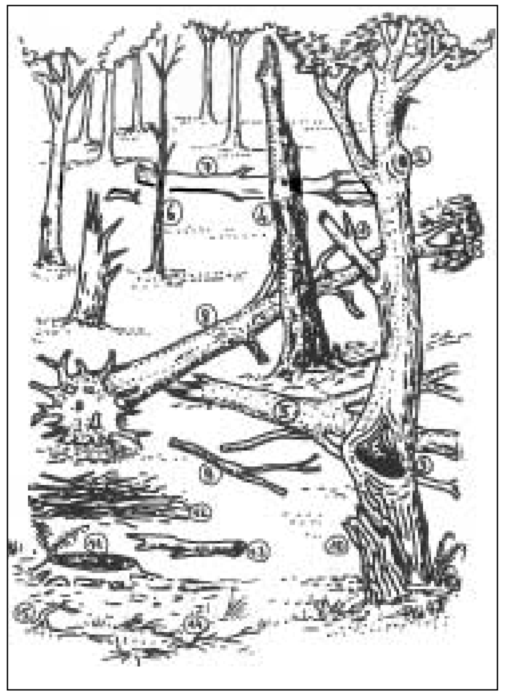
There are at least as many micro-habitats specific to saproxylic specie as there are types of dead wood found in a forest (standing, down, more or less decomposed and colonized by mosses, fungi and insects) (Massane, Grand Ventron and Frankenthal nature reserves, and the Biological Reserve of Fontainebleau; photos: Bernard Boisson and Olivier Gilg*)*

regenerated at the ecotope level (tree by tree) as in the uneven-aged high forest. The living conditions in these forests remain very different from those of natural forests since the environment is either totally open (after coppice exploitation), or totally closed (after second growth).

2.2.7 Dead wood, source of life

Without ageing phases in managed forests, the volume of dead wood is at times a sufficient variable to distinguish these forests from old-growth forests[65]. Its scarcity is not surprising: the aim of the silviculturist is to put wood to better advantage, not to let it decompose or provide a home to wood-eating (xylophage) insects. The forests are thus logged before the trees die, and those that are destroyed before their time (knocked down by storms, for example)

In temperate old-growth forests, one often encounters several dozen dead trees (50 to 150 m^3) per ha[4,63,65,78,139,144]. In mixed mountain forests, these figures can reach 300 m^3/ha[3] , and in the old coniferous forests of North America, they sometimes even exceed 1000 m^3/ha[139] due to the high productivity and low decomposition rates (<1%/year; see § 2.2.8). Even in boreal forests, which are less productive, the volume of dead wood can exceed 150 m^3/ha[60,163,186] (average of 60-90 m^3/ha in the south and 20 m^3/ha in the north[164]).



Main types of "dead wood" micro-habitats of a forest

1: dead branches of living trees; 2: small cavities; 3: large cavities filled with decomposed wood or humus; 4: big standing dead tree (snag); 5: big dead tree broken by a storm or the fall of another tree (volis); 6: small standing dead trees (selection during initial phase); 7: dead trees on the ground (logs); 8: down dead tree with only one extremity touching the ground (conditions of intermediate hygrometry between snag and log); 9: dead branches on the ground; 10: bark of dead trees more or less detached; 11: logging stump; 12: fine logging woody debris (pile of branches); 13: coarse logging woody debris (portion of decayed trunk); 14: litter and fine woody debris (small branches and twigs); 15:dead roots.

usually provide economic benefit (20% or more of harvested wood in certain forests can be derived from logs and snow damage[139]). In France, 75% of forests thus have volumes of dead wood that are virtually nil and more than 90% of the volumes < 5 m^3/ha[190].

In forests with low yields, harvesting of dead wood is sometimes done at a loss. Dead wood "disturbs", "dirties the forest" and endangers walkers "as the sword of Damocles" one can still sometimes hear. The removal of logs is thus justified by social arguments (maintaining employment), sanitary (§ 6.1.2) or security arguments (§ 6.1.3), rather than let them decompose in place. In certain regions (the Mediterranean, for example), fear of fires is another argument to remove dead wood (combustible potential) from forests.

Dead wood can have different shapes and is inhabited by numerous taxa*. Its abundance and its distribution vary in time and space, according to the disturbances and silvigenesis. As a general rule, the accumulation of dead wood is greater in coniferous forests (more dead wood produced and slower decomposition rate) than in broad-leaved forests (warmer climate accelerates decomposition). Dead trees uprooted by storms can be recognized by the large log stumps, mounds of earth sometimes as high as several meters. Strongly rooted trees sometimes break at mid-height (volis), thus producing standing and down dead wood. When they decay upright, the trees begin to lose some of their branches. With the wind less able to get a hold, such trees can thus remain several years before collapsing once their roots have rotted.

Dead wood ensures several functions in a forest:

- Its decomposition releases carbon and the mineral elements stored in cellulose to once again make them available to plants. These elements are often redistributed evenly around dead trees owing to the action of saproxylic* fungi and their mycelial networks (§ 5.4.2). Dead wood can also act as a nursery for seedlings of certain species (particularly in mountain forests and boreal forests with a thick litter).

- Trunks lying on the ground (logs) also affect geomorphology by limiting soil erosion during heavy rains. Erosion on the slopes of Mount St Helens was, for example, more severe after felling than after the 1980 volcanic eruption that, having indeed caused the death of all the trees in a radius of several kilometres, left them in place[144]. Logs lying crosswise to the slope also limit rocks from falling below[66].

- For ecologists, dead wood is above all an unique habitat that provides lodging and cover to certain species. Life and death are intertwined in a natural forest. Since logging eliminates the silvigenetic cycle's phases of ageing and decay (heterotrophic* phases) to the sole benefit of autotrophic* phases (primary

Dead wood serves as a nursery for many woody species: spruce, birch or alder, as shown here
(Photo: Daniel Vallauri).

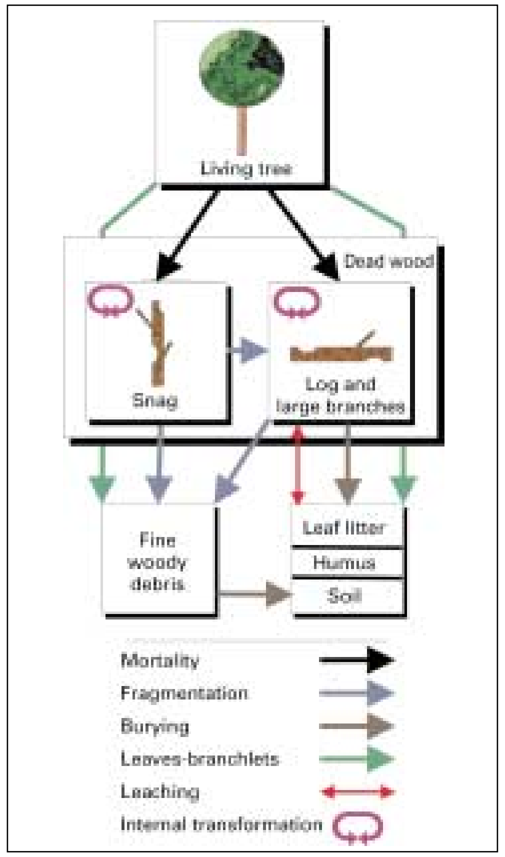
production linked to photosynthesis), it is no exaggeration to state that silvicultural management, by removing dead wood, eliminates more than half the micro-habitats of a natural forest[5] (figure p.17). The loss of species is slightly less significant considering the ubiquitous nature of certain among them (present in both young and old phases) but can nevertheless exceed 30% for certain taxonomic groups, particularly insects that comprise 90% of animal species (§ 5.4.3). As certain authors have shown, dead wood is often the variable that best expresses forest biodiversity[38,135]. The more the dead wood is varied (different micro-habitats) and the greater the number of large-diameter dead trees, the higher the diversity will be[135,136] and the greater the number of remarkable species (for example, threatened at the regional level)[11].

- Cavity nesting birds are often associated with the presence of dead wood. Secondary cavity nesters (owls, tits, stock doves, tree creepers, nuthatches, garden dormice, martens, bats) use either the natural cavities they find in partially dead branches or trunks, or the cavities excavated by primary cavity nesters, which excavate their own tree cavities (woodpeckers). The latter, capable of boring into healthy wood, prefer dead trees or those with a rotted core to excavate their nests. Cavity nesting birds each use several cavities (successive nidifications, to roost) and trees with a diameter less than 10 cm are of little interest to them. Their survival is therefore dependent on a high density of dead trees or large-diameter trees (with cavities). When the availability of cavities is limited, reproduction will be mediocre (nests poorly oriented, humid, far from feeding zones) and predation will be greater. Even after having fallen, hollow trees will continue to be used by certain vertebrates (amphibians, reptiles, mycophagous rodents, etc.) for feeding, reproduction or resting.

- Saproxylic* fungi and insects are very large forest taxa (several thousand species). Their richness is mostly dependent on the

Fungi, mosses and saproxylic insects are often associated with dead wood*
(Photo: Bernard Boisson).

Dead trees often provide shelter and cover to cavity-nesting birds, especially woodpeckers
(Photo: Bernard Boisson).



Simplified cycle of dead wood[78]

To advocate keeping dead trees without specifying their diameter is of limited interest in increasing the naturalness of a forest. In fact, the number of dead trees is sometimes inversely correlated to the degree of naturalness[65] and to the presence of remarkable species[161], particularly during the initial phase (death of many young trees even in managed forests). The volume of dead wood, on the contrary, is a good indicator of naturalness.

tree species. Saproxylic* Coleoptera are thus more numerous on oak (900 species) than on birch (700), beech (600) or spruce (300)[139]. Each taxon* plays a specific role in the decomposition cycle of dead wood. Fungi transform successively the sugars, cellulose and then lignin. Certain insects eat the wood directly (xylophages), others consume fungi on the dead wood (mycophagists); still others are predators of the former, etc. These species also have specific requirements. The most tolerant could survive in the few stumps and small dead branches still present in managed forests. Others, more demanding or of limited mobility, will only survive if there are substantial and homogeneous quantities of dead wood. Variations of humidity and temperature are of little importance in large-diameter dead wood; these habitats are essential to the survival of certain species whose larvae develop over several years or which only colonize dead trees after 4-5 years[41].

As dead wood is one of the main characteristics of old-growth forests, it will be mentioned on several occasions in the following chapters. Chapter 5 will describe the typologies of dead wood (§ 5.3.2), as well as examples of studies and management.

2.2.8 Dead wood dynamics and decomposition rate

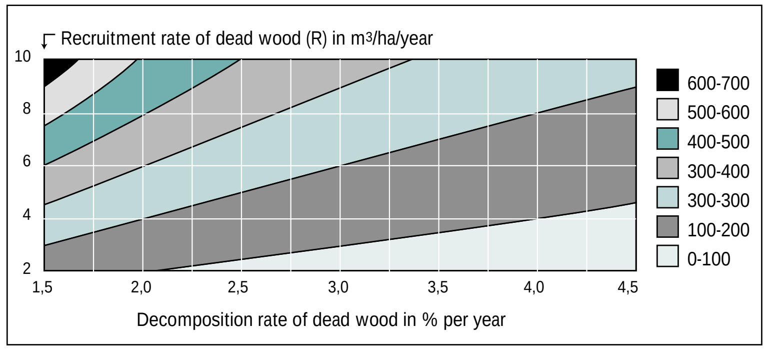
The volume of dead wood in a natural forest depends on forest productivity, speed of decomposition, and on the type and intensity of disturbances. It is often closely correlated with the volume of living wood and normally represents between 20 and 40% of the total volume (living and dead wood; extreme values: < 10 to 50%65)[53,78,164,170]. In forests disturbed by fires, the variations of necromass are significant, the necromass* can be multiplied by 5 after fire[164]. As a general rule, the volume of dead wood reaches its maximum after a disturbance, decreases during the optimum phase, then increases once again during the ageing and decay phases. The volume of dead wood evolves naturally towards a stable situation. This "equilibrium volume" depends on the recruitment rate of dead wood (tree mortality rate x forest productivity) and the decomposition rate of dead wood. In a natural forest, the recruitment rate of dead wood (at the sylvatic mosaic level) is equal to the productivity of the site, a value generally well known by foresters. The decomposition rate, which is a function of the species and local climate (temperature and precipitation), also varies according to trunk diameter, its contact with the ground and soil humidity. The "equilibrium volume" (Ym) can be determined by the formula: Ym = 100R/k (R = recruitment rate in m^3/year; k = decomposition rate in %/year).

The decomposition of dead wood only takes a few years for small branches and other woody debris but can exceed a century for certain species, particularly in cold, dry and impoverished sites. Certain oak trunks can take up to 200 years before disappearing

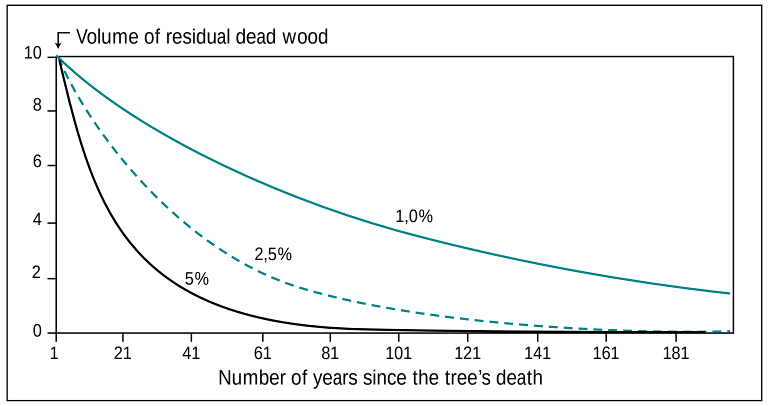
2

completely[118] and certain conifers are still visible 400 years after their death[144]. More commonly, the trunks of beech and softwoods are almost completely recycled after 10-20 years, and those of oaks before 100 years.

During its decomposition, dead wood goes through different stages, more or less attractive to saproxylic* species. These stages and the different classifications used to describe dead wood will be presented in § 5.3.



Equilibrium volume of dead wood (in m³/ha) relative to recruitment and decomposition rates.
According to this graph, the volume of dead wood in equilibrium is greater than 100 m³ in a low production spruce or pine forest (recruitment of 4m³/year and decomposition rate of 3.5% per year). In a birch forest (decomposition rate of 4.5% per year) with the same productivity, this volume of dead wood is less than 100 m³.



Recycling of dead wood relative to decomposition rate.
The volume of residual dead wood at year t (Y_t) can be estimated with the equation: $Y_t = Y_0 e^{-kt}$; in which Y_0 corresponds to the initial volume of dead wood, k is the decomposition rate, and t is the year for which the residual volume is desired[78]. With a decomposition rate of 5% per year (black curve: soft wood, warm or humid climate), 10m³ of dead wood will be recycled in one century, while it will take more than two centuries to recycle the same volume with a decomposition rate of 1% (green curve: hard wood, dry or cold climate). The dashed curve simulates the recycling of dead wood with an average decomposition rate of 2.5% per year.

Stumps are often the only refuge for certain saproxylic species in managed forests (Photo: Olivier Gilg).

In the temperate zone, the rate k of decomposition of dead wood varies from less than 1% to more than 5% per year. European species usually decompose faster than North American species, which partly explains the higher volumes of dead wood found in North American old-growth forests. It should be noted that decomposition is much faster in hot and humid tropical regions (k = 11.5% on average for 5 species in Puerto Rico and 46.1% for 9 sp in Panama).

Average values of k according to the species and regions studied[78,163,178,180]:

Abies concolor (California/USA):	4.9%
Betula pendula (NW Russia):	4.5%
Populus tremula DBH > 25 cm (Russia)	4.4%
Pinus sylvestris (NW Russia):	3.4%
Picea abies (NW Russia and Norway):	3.3%
Abies balsamea (New Hamp./USA)	2.9-3%
Quercus spp. (Indiana/USA):	3.0%
Picea abies (St Petersburg/Russia)	1.6%
Pinus sylvestris DBH > 15 cm (Russia)	1-2.7%
Pseudotsuga menziesii (Oregon/USA):	0.5%

2

2.3. The last virgin forests of Europe

The state of European old-growth forests has been the subject of numerous studies[2,60,69,141,155,157], the most recent and comprehensive of which is that of the WWF[72]. The quality of the data nevertheless remains very varied depending on the country.

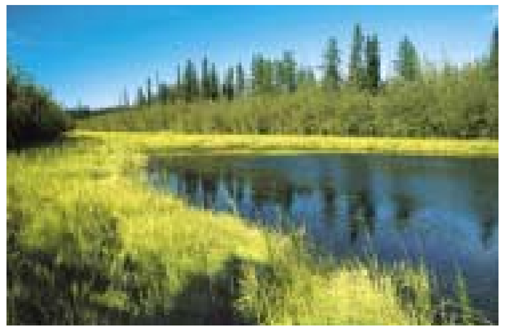
Nowadays, old-growth forests only represent 1 to 3% of Western European forests and are highly fragmented.

2.3.1 Areas in constant decline

Deforestation (at its maximum 100 years ago) has left only 23% of the territory of the European Union wooded compared with 80 to 90% at the end of the last glaciation. If one includes western Russia, Europe nevertheless still has more than 10% of the world's forests.

In Finland and Sweden, forests still cover more than 60% of the territory, while in Great Britain, Ireland and the Netherlands, it has been reduced to less than 10%.

Our current forests are very different from the original forests that, by disappearing, have taken a large portion of Europe's biodiversity. The greatest reduction has affected Mediterranean and alluvial forests, certain of which have been destroyed by more than 99% during the last 50 years.



Boreal forests, often strewn with humid zones (here in Siberia), are the only ones in Europe that still show significant areas of old-growth
(Photo: Olivier Gilg).

In total, the European continent would harbour another 15-20 million ha of old-growth forests (an area equivalent to all French forests) but their distribution is unequal. Europe's remaining old-growth forests are most abundant in Northern and Eastern Europe, particularly near the Ural mountains.

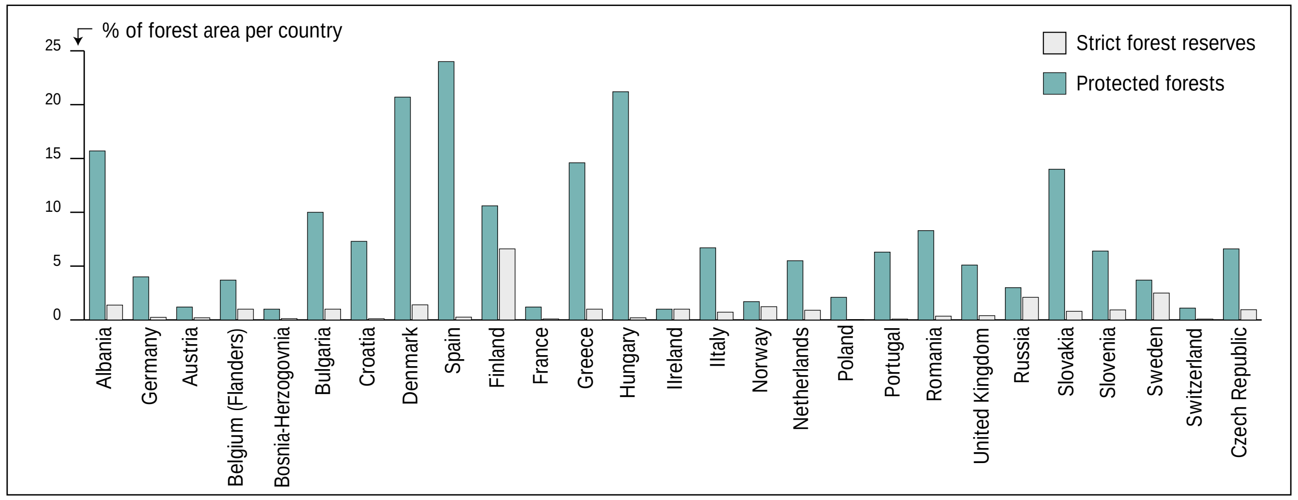
Current protection of 6.3% of European forests only covers half of the identified old-growth forests. Their destruction continues each year[72].

2.3.2 Insufficient protection

The strategies needed to be implemented to protect old-growth forests vary depending on the country. In Europe where old-growth forests are generally fragmented and small in area, it is advisable first to protect the still existing relict "islands", and then to restore the naturalness of certain managed forests, in particular those with habitats not represented in the network of existing old-growth forests.

The protection rate is also very variable in Europe where 1 to 10% of forests are normally protected depending on the country. The current state is worrying for old-growth forests that require strict protection since, with the exception of the Scandinavian countries, strict forest reserves protect less than 1% of European forests[141].

In addition, the majority of these protective measures concern unproductive forests (poor soils), mountain forests (steep slopes) or other forests that are inaccessible while forests in plain regions (or on rich soil) are largely under-represented (especially coastal formations, Mediterranean and hygrophites). In Europe, protected forests are very dispersed (37,800 zones) and small (95% of them



Proportion of forests of a few European countries that are protected as forest reserves and strict forest reserves[141] *(for France, not all information about nature reserves has been included).*

have less than 10 ha). Of the 50 largest forest reserves, 36 are in Russia, 6 in Fenno-Scandinavia and only 4 are in Southern Europe.

Protected forests are rarer in Europe than in Canada or in many tropical countries, even though their economy is greatly dependent on wood as a resource. Classifying all old-growth forests as "strict forest reserves" would not form an insurmountable economic sacrifice in Western Europe where they are few in number and small in size. The area freed by the abandonment of agricultural lands has already made it possible to increase the total area of production forests. There could also be compensation for the classification of new strict forest reserves, especially in state forests (see § 4.3).

A regional example: protection of old-growth forests in the Vosges

In the Vosges, scientists and naturalists have for decades been interested in old-growth forests[59]. Although the majority of these forests are small, their protection is already well under way. A recent inventory of these sites and their protection status[35] makes it possible to evaluate the quality of the network and to identify its deficiencies:

• 42 old-growth forests identified (from 5 to 400 ha),

• 2500 ha concerned (60 ha on average per site; 9 sites greater than 100 ha),

• 60% fir-beech stands (Natura 2000 codes 9110 & 9130),
25% subalpine beech groves (Natura 2000 code 9140),
11% Maple forest with Lunaria (Natura 2000 code 9180).

• 1358 ha classified as strict forest reserve:
700 ha (5 sites) classified as strict forest reserve in nature reserves (RN),
360 ha (5 sites) classified as strict biological reserve (RBI),
280 ha (5 sites) classified under strict protection in forest management plans,
18 ha (1 site) as strict forest reserve by the Prefect Order for Biotopes (APB).

Findings:

• less than 1% of the forests of the Vosges massif are old-growth,

• only mountain and subalpine storeys still have old-growth forests,

• only 38% of the sites (54% of the total area) are protected by strict forest reserves,

• these protective measures (RN, RBI, APB) are only permanent for 26% of the sites (43% of the area).

Additional safeguards:

• the protected status of existing old-growth forests is only satisfactory for a quarter of the sites and therefore has to be improved in the future (creation of new nature reserves and strict biological reserves),

• the area of strict forest reserves is generally less than 50 ha (except for nature reserves) and should be increased in the future by the classification of peripheral zones,

• numerous types of forest habitats no longer exist as old-growth forests (notably at the lower montane and upland levels) and managed forests thus need to complete the network of strict forest reserves,

• connectivity between existing old-growth forests is only sufficient on the secondary ridge of the southern Vosges and should therefore be improved elsewhere by the complementary classification of managed forests.

Many forest reserves (and the majority of strict forest reserves) have been introduced in unproductive or hardly accessible zones such as in the Ravin de Valbois Nature Reserve (Photo: Marie-Christine Langlois). *The network should be completed in the future by plain and upland level forests.*

France is ranked eighth out of 20 in Europe by the WWF[72] *for its performance in terms of forest protection. It receives the maximum score for its "management plans", but the worst score for the quality of its "management effectiveness"!*

2.3.3 High places

To the north, the Taïga occupies the largest land area. From the south of Norway to Lapland, a relatively intact forest belt contours Scandinavia's mountains. This forest joins Russia via the north of Finland as far as the Urals. To the south, a few fragments of old-growth forests once again come in contact with each other in places and notably along the Finno-Russian border in Karelia. Having been closed for very long, this zone today harbours the finest European brown bear populations.

Further south, fine fragments of temperate forest still remain in the Ukraine, Belorussia, Poland and other East European countries. The forest of Bialowieza, with its European bison population, is the most well known.

Alluvial forests are the rarest type of forest, because they are limited to the beds of large rivers. As the majority of European rivers have been canalised and their flood zones drained, alluvial forests have often been clearcut and then converted into poplar plantations. There are still some fine examples along the Danube, the Tisza and the Sava rivers, as well as some more moderate-sized fragments along the Rhine and the Rhône in France.

Alluvial forest undergrowth in the Ile de la Platière Nature Reserve, young Mediterranean forest (non-managed green oak plantation) in the Gorges de l'Ardèche Nature Reserve and peatland mountain forests in the Frankenthal Nature Reserve (Photos: Bernard Boisson).

Old-growth forests are also very scarce in the Mediterranean region. There are fine chestnut formations in Bulgaria, Macedonia and Greece, and Zelkova formations in Crete; fine riparian forests in Spain, Portugal and Turkey; and interesting coniferous forests, often endemic (*Pinus, Abies, Juniperus, Tetraclinis*), in Macedonia, Bosnia, Albania, Italy, Greece, Sicily, Spain, Cyprus, Crimea, Turkey, Corsica, Crete and Malta.

Old-growth mountain forests are found in Spain, in the Alps, the Tatras, the Balkans and further east in the Caucasus and the Urals. Smaller cores remain in France in the Vosges, the Jura, the Pyrenees and the Massif Central. They are very important because of their size and number of endemic species.

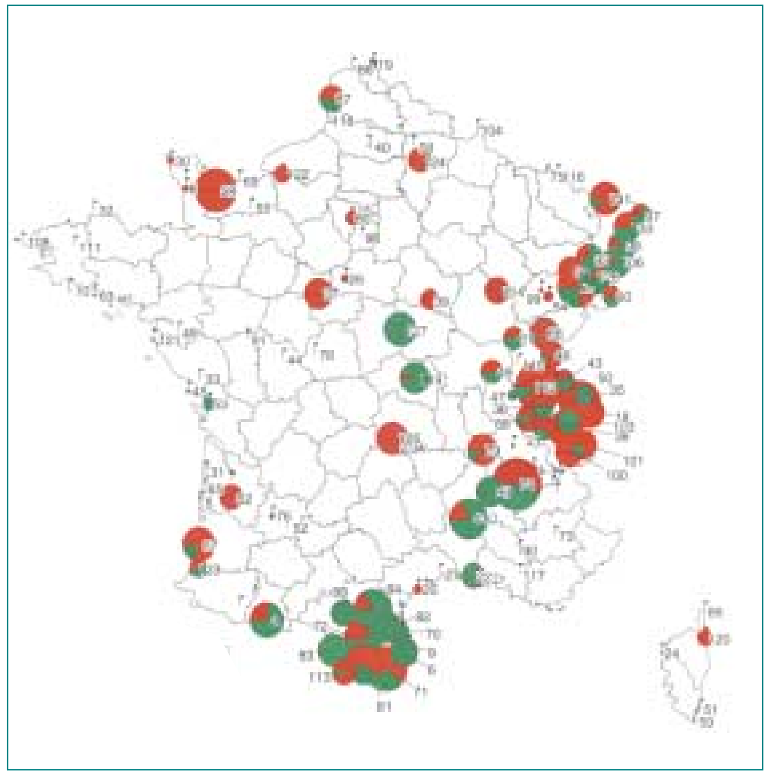
2.3.4 The old-growth forests and nature reserves of France[69]

Of the 144 nature reserves (NR) in France in 1999, a hundred harbour forests and sixty support old-growth forests (mostly public forests). The first of these reserves was established in 1961 but it has only been since 1973 that the rate of establishing nature reserves has accelerated.

More than a third (13,310 ha) of the forests protected by nature reserves in Metropolitan France are old-growth forests (200,000 ha of old-growth forests have also been inventoried in France's overseas nature reserves and more than 2000 ha in regional nature reserves). Almost half of these protected old-growth forests are larger than 50 ha, and those that are less than 50 ha only comprise 4% of the wooded area of the network of reserves. In more than 80% of all cases, France's natural forest reserves have a wooded peripheral zone.

Twenty-two of these old-growth forests have a strict regulatory status but these sites only comprise 10% of the total area of nature reserve old-growth forests. Non-governmental organisations are the most common managers (65% of the forested nature reserves; 37% of the forested area in nature reserves) but the

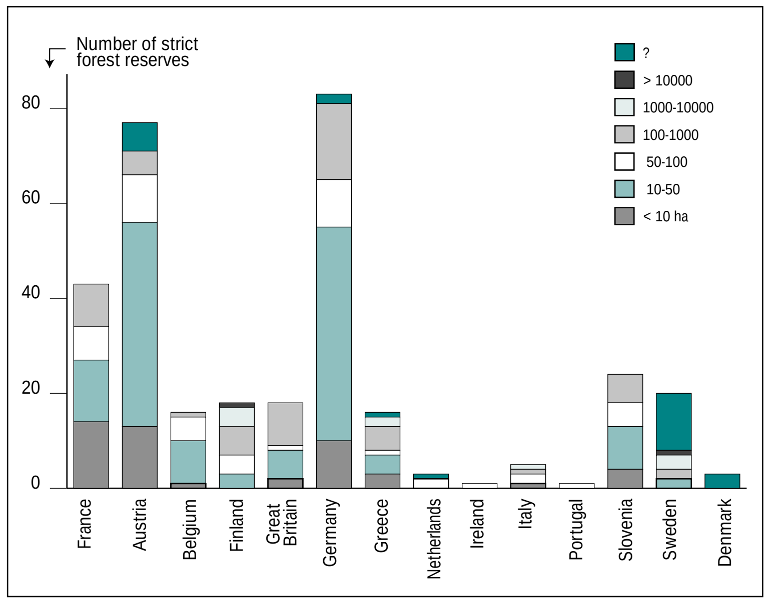
Silvicultural activities are strictly prohibited in the majority of Rhineland nature reserves (Photo: Bernard Boisson).



Location and size of forested nature reserves in Metropolitan France
The symbols are proportional to the size of the reserves. Old-growth forests in green and managed parts in red; RNF codes according to the chronological establishment of the reserves.

More than half of French forested nature reserves are found at less than 250m altitude. Absent from the upland level, these forest reserves are most often alluvial forests in the plain and beech groves or coniferous forests in the mountains.

The dominant species of French nature reserves are Pinus uncinita (in 32% of old-growth forests), beech (20%) and green oak (12%) but almost all French forest habitats are represented (see Table § 4.3.4).



Size and number of strict forest reserves inventoried in Europe (1999).

national and regional parks manage the largest nature reserves (only 11% of the sites but 39% of the forested area).

In 1999 (year of the last European inventory) France had 13% of Europe's strict forest reserves and an equal proportion of strict forest reserves larger than 50 ha. The number of French sites with old-growth forests is in reality much higher but only the forest reserves (some nature reserves and strict biological reserves) where logging is clearly prohibited (in their bylaws) were taken into account in this evaluation. France has fewer strict forest reserves than Germany and Austria. And unlike Finland, Greece, Italy and Sweden, France does not have a strict forest reserve larger than 1000 ha (15 exist in Europe).

2.3.5 Endangered species

Since forests formerly covered the greater part of the European continent, it is not surprising to note that the majority of European animal and plant species (several tens of thousands) have an affinity for this environment. Even if some of these species can seem banal, a number of them can only be found in Europe, and their conservation is therefore one of the primary missions of forest reserve managers.

Tarpans (wild horses) and aurochs (wild ox) have long since become extinct (in the 17^{th} and 18^{th} centuries). "Small species", a number of which are now on the brink of extinction, are unable to attract attention and gain the support of public opinion. This is the reason why bears, lynx, European bison, capercaillie, black stork and other vertebrates are today the standard-bearers of forest protection in Europe. Although these symbolic species are often indicators of a rich and protected nature, the real stakes in terms of biodiversity are greater. Depending on the country, 20-50% of mammals and 15-40% of forest birds are endangered today in Europe, and the same is true for a higher or equal percentage of mosses, lichens, flowering plants and invertebrates.

The capercaillie is one of the symbolic species of French forests
(Photo: Grand Ventron Nature Reserve).

The old-growth forest of Bialowieza hosts more than 60 species of mammals, 200 birds, 1000 vascular plants and 10,000 insects[72]
(Photo: Bernard Boisson).

Naturalness: ecological utopia or panacea

"Naturalness" is a neologism used by an increasing number of managers of natural areas. This term conveys the impact of humans on the environment: a primary forest has a high degree of naturalness, while a managed forest has a lower degree of naturalness. The fact that it is so favoured today by managers is evidence that this concept has proven to be particularly practical:

- **it makes it possible to measure the degree of preservation (or of disturbance) of a natural environment along a gradient (degree of naturalness);**
- **high naturalness is in many cases (e.g., for saproxylic* species) synonymous with a high biodiversity and the presence of noteworthy species.**

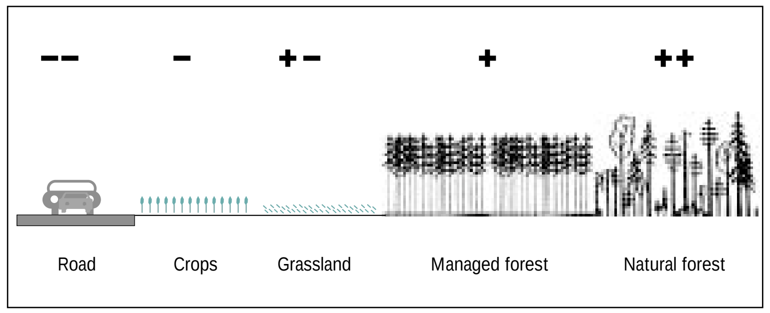
3.1. Naturalness or the impact of humans on forests

The concept of naturalness stems from a simple but too often implicit idea in the publications that refer to it. The growing interest of protected-forest-area managers in the concept of naturalness warrants that it be defined more clearly. The misunderstandings between the different forest actors slow down the implementation of management measures that aim to increase naturalness, measures that do not necessarily mean the halting of all logging.

In dictionaries, "natural" characterizes that which is "relative to the universe, to its laws", that is "produced by the physical world, without human intervention", "that is not artificial" (artificial being "produced by man, his work, his techniques"). "Naturalness" thus refers to the natural or artificial character of an object, a species, an ecosystem, a way of functioning, etc.

Naturalness should be perceived as a gradient from less natural to more natural (and vice versa) and not as a "binary" concept where natural is opposed to artificial. That is the main source of misunderstanding between "conservationists" and "silviculturists", the latter criticizing the former for wanting to restore a pristine

The old-growth forests of Europe do not have the biodiversity of tropical primary forests (here in Costa Rica) but are nevertheless, in their own biogeographical context, just as remarkable
(Photo: Olivier Gilg).



The degree of naturalness is a gradient nature from which humans would be excluded, a utopian vision par excellence[109]. There are, in fact, no more forests that are completely artificial than forests that are completely natural. All have a degree of naturalness, for example, between 0 and 1: a plantation of exotic trees would have a value close to 0 and an old-growth forest a value close to 1.

To evaluate forest naturalness thus means measuring the degree of artificialization of a forest, in other words the difference between its current naturalness and its maximum potential naturalness.

Peterken[144] suggests several variants to define this maximum potential naturalness:

- a state that existed in the Mesolithic* period before Man's impact became significant (can sometimes be specified by paleoecology*) ;
- a state that would develop if man's activities ceased today (can be assessed with the help of models);
- a state that would prevail today if modern ("post-Mesolithic") humans had not had an impact on forests.

This last definition is the most interesting for managers. It can be measured directly in the field in certain reference forests. In fact, some unmanaged (since they are often inaccessible) forest fragments have a naturalness approaching this state if large-scale anthropogenic* disturbances are disregarded (§ 2.1).

The degree of naturalness of a forest can be assessed by comparing its current naturalness with its maximum potential naturalness measured in a reference forest (unmanaged) of the same type.

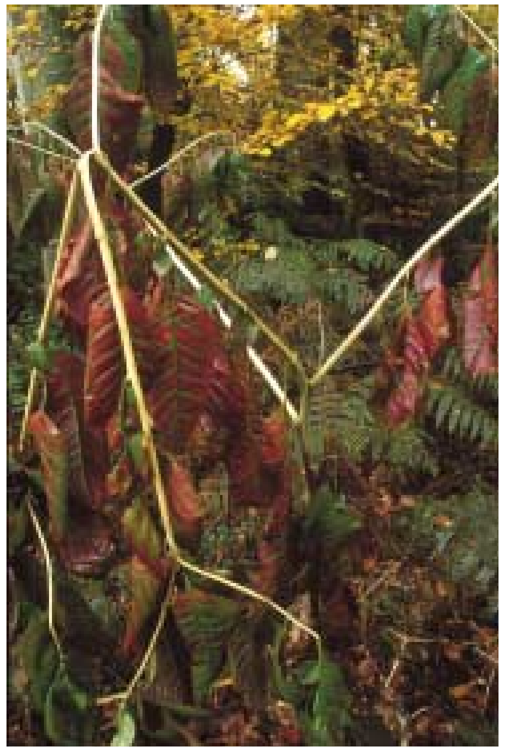
Of course, it would be utopistic to want to restore a maximum degree of naturalness everywhere. The hand of Man has done and will continue to do its work. The advantage of evaluating the degree of naturalness of a forest is simply to indicate to managers the degree of artificialization or human impact of their forests. It is up to them and the decision-makers to set the naturalness targets to preserve or restore the ecosystems and species in their care (§ 6.3).

3.2. Active or passive management? From theory to practice…

If naturalness is a relatively recent concept in Europe, it is on the contrary deeply anchored in North American culture. The national parks established across the Atlantic at the end of the 19th century already had the aim of protecting pristine zones, free from all human impact. This policy was meant to guarantee the American people the conservation of natural wonders that rival the beauty of cathedrals and other monuments from the Old World. It also made it possible to conserve evidence of pristine landscapes encountered by the pioneers during their conquest of the West, landscapes symbolizing the real "roots" of a people with a recent history[19].

Even though species and habitat protection were not the main objectives of this policy, the establishment of national parks permitted the preservation of ecosystems with a high degree of naturalness over vast areas. The 1964 passage of the "Wilderness Act" marked a turning point in taking naturalness into account that became an explicit motive to protect natural areas.

Several species of invasive exotic plants have made their appearance in protected old-growth forests: Himalayan balsam and Japanese knotweed in alluvial forests or, as shown here, Phytolacca from the U.S.A. in the biological reserve at Fontainebleau (Photo: Bernard Boisson).



A wilderness area is defined in this Act as a zone that is "protected and managed so as to preserve its primeval character", "where the earth and its living communities are untrammeled by man" (non-managed, unmodified zones[196]), "where man is but a passing visitor".

This definition corresponds fairly well to the prevailing idea of the concept of naturalness. Nevertheless, it introduces two distinct and sometimes contradictory sub-concepts: anthropogenic* naturalness (which is maximal without human disturbances and thus promoted by passive management) and biological naturalness (which is maximal when biological equilibria are intact, whatever the type of management).

Managers who desire to increase the naturalness of their site (anthropogenic naturalness and biological naturalness) often have to choose between:

- passive management that aims to increase anthropogenic naturalness by means of non-intervention: to limit the impact of humans and allow natural dynamics according to new equilibria,
- or active management that aims to increase biological naturalness but that is often done to the detriment of anthropogenic naturalness: works to restore historical equilibrium conditions between the environment and species. Note that passive management also permits (but usually in the longer term) the increase of biological naturalness when natural dynamics is not hindered by certain obstacles (modified edaphic* conditions, presence of invasive species, etc.)

What can be done about invasive exotic species?
Fight them relentlessly to the detriment of the site's anthropogenic naturalness (§ 3.2)? Should they be allowed to follow their own natural progression, and thus accept the loss of other species? Most forests are concerned but alluvial forests particularly so, as water courses are excellent migration routes for these species. Numerous research programmes have been launched in Europe. Let us hope they will focus as much attention on ethical aspects (should active management be chosen (§3.2) in environments with a high naturalness?) as on practical solutions, for the most part bound to fail. How can one hope to be able to eradicate all the diaspores* of these species at the continent level? Our action will at best slow down the progression of these species locally (to avoid, for example, the disappearance of certain sites of rare taxa) , but only new ecological equilibria will be capable of combatting the colonization of these "green pests" in the long term. In the Foret de la Massane Nature Reserve, the managers have noticed that after several years of uninterrupted progression, the Cape groundsel (originating from South Africa) had finally become the prey of a small aphid, a butterfly, a fly and a parasitic fungi.

This choice is sometimes difficult:

Should invasive species (introduced or simply outside their natural range such as beech in a Rhineland forest) be eliminated, if necessary with the use of herbicides, to restore the native plant associations of French fluvial forests?

Should artificial gaps be created to enable capercaillies to survive? (see § 4.1.2)

Should beavers be reintroduced in French riparian reserves, lynxes and bears in French mountain forests?

To answer these types of questions, managers first have to assess the impact of these management measures (active or passive) in terms of biological and anthropogenic naturalness:

A. An excessive increase in the densities of certain species (for example, cervids by silvicultural or hunting arrangements, or of certain birds by the placement of nesting boxes) reduce both anthropogenic naturalness (by including various works) and biological naturalness (by the modification of natural equilibria). Such actions should therefore be rejected if the aim is to increase the naturalness of a forest.

B. At the same time, the planting of exotic taxa* on a site results in a combined lowering of biological and anthropogenic naturalness.

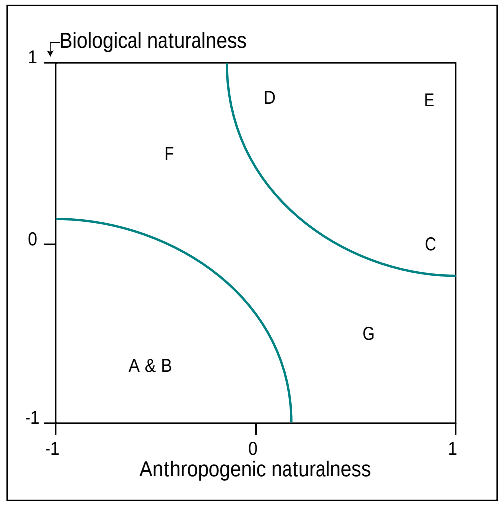
C. Closing a forest trail in itself has no immediate impact on biological naturalness but the operation is immediately justified by the increase of anthropogenic naturalness (reduction of disturbances for sensitive fauna).

D. Restoring the original emplacement of a forest trail would, on the contrary, permit an increase in biological naturalness (for example, by returning a stream to its natural bed, which had been previously deviated by ruts) without significantly altering anthropogenic naturalness (a trail already being a highly man-made environment and restoration works only being ephemeral). The operation in this case is therefore once again justified in terms of naturalness.

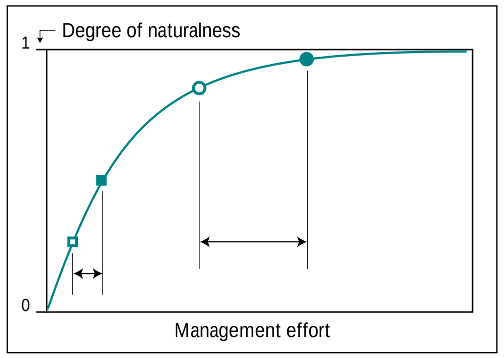
E. Prohibiting the gathering of saproxylic* species (for example, *Fomes formentarius*) is a measure that is easier to assess because it enables one to simultaneously increase biological naturalness (better redistribution of mineral elements in the soil) and anthropogenic naturalness (less attendance and disturbances).

F. Restoring forest undergrowth by the mechanical destruction of an exotic, invasive species will contribute to an increase of biological naturalness to the detriment of anthropogenic naturalness.

G. Non-intervention in the case of spontaneous regeneration of exotic species on a site (spruce in the mountains) would, on the contrary, result in an increase in anthropogenic* naturalness to the detriment of biological naturalness.



Impact of a few management operations on biological and anthropogenic naturalness
Above to the right, the operation is justified in terms of the increase in total naturalness. Below to the left, it has to be avoided. In the median of the graph, the benefits in terms of naturalness are debatable and the question needs to be examined in more detail.



The required effort to increase forest naturalness depends on the sort of change but also on the initial naturalness of the stand. It is simpler to double the naturalness of a plantation of exotic species (squares) than to increase the naturalness of an old-growth forest (circles) by 10%.

TO SUM UP, THE QUEST FOR A HIGHER DEGREE OF FOREST NATURALNESS HAS TO BE ORGANIZED IN 4 STAGES:

It is advisable, first of all, to define the maximum potential naturalness of the site (see § 3.1).

By comparing this state to the current state of the forest, it is then possible to draft the list of factors that contribute (or have contributed) to decrease the naturalness of this forest: abiotic factors (climate change, soil modification), biotic* (extinction or introduction of species, new biological equilibria) or directly anthropogenic* (logging, attendance).*

It is then advisable to define the conceivable means of action (operations; feasibility and scientific relevance) to reduce or eliminate the impact of these factors. During this stage, dilemmas between active and passive management will appear.

The last stage is more "political". It consists of selecting the operations that will be retained to reduce the gap between the current naturalness of a forest and its maximum potential naturalness. Naturalness can be increased in all forests. Whether they are managed intensively or have been classified as strict forest reserves for a long time, there are always factors that change their naturalness (whether they act within, in the immediate periphery, or at a great distance from the reserve). As a general rule, the lower the degree of naturalness of a forest, the easier (technically and economically) to increase it (see fig. p.30 below). Leaving a dead tree in a poplar plantation is a simple and inexpensive operation. On the other hand, to combat the wilting of a forest with a high degree of naturalness might be beyond the reach of managers; rather the mandate of international anti-pollution programs. These stages are close to those of the management plans of nature reserves[151]. The evaluation of management measures should also be introduced at regular intervals (10 years being sufficient for forest ecosystems).

In the first five cases (A-E), the impact of management operations in terms of naturalness is easy to assess. In the last two cases (F-G), managers are faced with a dilemma: should anthropogenic* or biological naturalness be favoured?

There is no perfect answer to this question. It is not possible to make a comparative evaluation of (and thus classify objectively) two such different approaches. When such dilemmas arise and to avoid making unfortunate choices, managers should ask themselves more general questions before opting for one or the other solution[105]:

- Is the site's naturalness on the whole compromised due to the intended action?
- Is technical knowledge sufficient to "manipulate" the naturalness of the site ?
- What are the consequences and risks generated by the action of the manager compared with those of non-action?
- Does the public have sufficient confidence in the manager to give them unconditional authority?
- Is the desire to restore an ecosystem closer to its original functioning (high degree of biological naturalness) more important than that of preserving an environment without human impact (high degree of anthropogenic* naturalness)?
- How many anthropogenic* disturbances (active management) are tolerable in an environment with a high degree of naturalness?
- Can a target be defined for the future degree of naturalness to be attained? Etc.

3.3. Naturalness and biodiversity: contradictory or complementary concepts?

Certain forest actors have already integrated the concept of naturalness in their management policy. Several obstacles nonetheless limit the generalization of these initiatives:

- Adopting a still little known concept, managers can be faced with the lack of understanding of their interlocutors (the public, decision-makers, other managers) who prefer to base their conservation policies on the concept of biodiversity;
- When the manager aims to simultaneously increase both naturalness and biodiversity, certain management measures can seem contradictory.

Overcoming the first obstacle requires training those involved about the concept of naturalness (one of the objectives of this technical report). Choosing between two divergent management measures seems more difficult, although in the majority of cases, antinomy only raises an incorrect or partial use of the concept of biodiversity. It is necessary here to re-examine the definition of biodiversity.

Biodiversity (or biological diversity) is but one of the concepts at our disposal to qualitatively evaluate a natural environment. Up until the Rio Earth Summit (1992), conservation programs were especially oriented towards rare or endangered species. By the end of the Summit, "biodiversity" became "THE" fashionable term. Today it is the spearhead of conservation policies.

Global biodiversity or local specific richness?

Various methods have been used to measure biodiversity: specific richness; specific, taxonomic* or functional diversity (trophic* levels, key species, guilds*), etc. Unfortunately these methods only measure a part of the concept of biodiversity, and therefore only consider known species (15% of the living organisms on our planet).

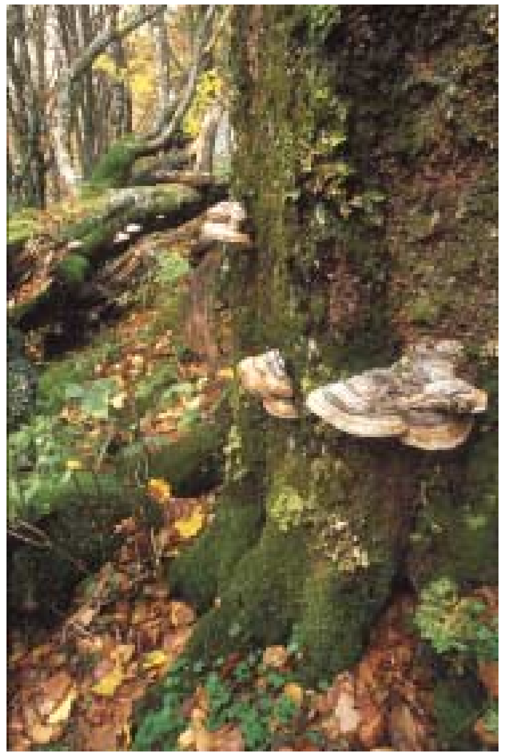
The other factor that limits these methods is linked to spatio-temporal variations of biodiversity. How does one compare biogeographic zones, ecosystems, communities and other assemblages without considering their respective scale of study, spatial mosaics and physical environments? How does one assess the diversity of a population or a community without considering its dynamics?

The United Nations' report on assessing biodiversity (written by 1500 scientists) emphasizes these difficulties and warns against the use of inappropriate methods[82]. Lists of species are often "sold" for biodiversity, but in reality these lists only measure specific diversity or richness. One aggravating factor is that, in most cases, these lists are limited to flowering plants and vertebrates. An open environment would thus seem "richer" than a forest, a clearcut would sometimes be "richer" than an old-growth forest. Yet the results thus obtained would only reflect the specific richness of the chosen habitat and the choice of the taxonomic group studied[9]. They are hardly relevant to assess biodiversity. Forest management based on such results will have something in common with gardening for the benefit of one or the other taxonomic group and regardless of how the environment functions. The caricatured optimum of such a form of management, focused solely on specific richness, would be a zoological or botanical garden!

Fragmentation (§ 4.3) also helps illustrate this confusion between specific diversity and global biodiversity. Fragmentation, whether it results from urban, agricultural or industrial development, helps to increase the heterogeneity of the environment and in certain cases the specific richness of certain taxa* at the local level. Despite this, today no-one any longer disputes the harmful effects of fragmentation on global biodiversity; certain people even see it as "the greatest threat to forest biological diversity"[131].

The main idea behind the concept of "biodiversity" is the conservation of global biological diversity at the ecosystem level (ecological diversity), as well as the species (specific diversity) and individual level (genetic diversity)[32]. Certain authors[54] also speak of structural diversity that, in forests, is characterized by the size and shape of the trees, the mosaic of gaps, the different storeys, the organic soil horizons, the standing dead trees, the necromass on the ground, etc.

Naturalness: ecological utopia or panacea



Forests with a high degree of naturalness also have a high degree of biodiversity (Photo: Bernard Boisson)

Adherents of naturalness, by their "laisser faire" politics, place more confidence in natural dynamics and equilibria. Faced with the extraordinary complexity of living beings and our countless past mistakes, they adopt a certain "precautionary principle" by supporting the hypothesis according to which (and subject to it being possible to restore functional ecosystems) global biodiversity would be better preserved by the conservation of ecosystems with a high degree of naturalness and functionality than by specific interventions intended to preserve or increase the number of taxa (many of which remain unknown) of a given region.

Biodiversity versus naturalness

The concept of biodiversity acknowledges that the main quality of the natural global environment lies in its diversity (at all levels of organization). Naturalness, for its part, highlights an intact (non man-made) character of the environment. Are these two perspectives very different?

For both concepts, human activity is a preponderant factor. It is responsible for nearly all species extinctions (that reduce global diversity) and, by definition (§ 3.1), is what impairs naturalness.

Faced with such a fact, the adherents of "naturalness" suggest preserving or restoring biological equilibria (better functionality) by limiting or "repairing" (restoration) the impact of Man. Those who promote the importance of "biodiversity" attempt to safeguard global biological diversity by a range of very substantial actions (including ex-situ conservation).

In theory, promoting "naturalness" also means attaining the objectives of conserving "biodiversity" since, except for rare anthropophile taxa* from recent evolution, all species that are known today already existed and thus had a place (ecological niche*) in the reference ecosystems of the beginning of the Neolithic (5000 years ago). To restore habitats today that are free from human intervention, with a high degree of naturalness, would thus make it possible to safeguard them all. However, it is impossible in practice to regain maximum naturalness everywhere (this would require us to go back and live as Neanderthals!). In certain environments that are small and disturbed for a long time by Man, such a return is, moreover, impossible (certain extinctions or disturbances having irreversible effects). While it appears for some as an ecological panacea, naturalness will not in itself allow us to safeguard our planet's biodiversity. Increasing naturalness often means conserving a large number of species (including some very rare ones), which also helps conserve biodiversity, but this is not always a sufficient measure.

"Biodiversity", more Cartesian (measured according to the number of taxa*), seems easier to implement in the eyes of the public. It is also appealing due to its modernity: there is no concern for the past, the emphasis is on safeguarding what exists today (it makes us feel less "guilty" than naturalness). Biodiversity management, which is more interventionist, has the merit of being able to rely on proven conservation methods (management, restoration). It thus brings solutions to problems for which naturalness has no solution (for example, species conservation ex-situ in zoos and botanical gardens following the destruction of their habitat). Since the restoration of functional environments likely to be recolonized naturally by these species often takes too long, these actions help take care of the "interim" period. Unfortunately, these measures do not always guarantee the long-term protection

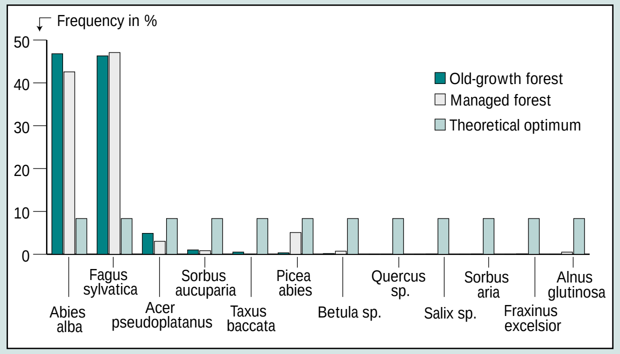
What indices should be used to measure biodiversity?

The most commonly used indices to measure diversity (and wrongly biodiversity) are those of Shannon-Weaver. According to these indices, the more species there are and the closer their respective abundances, the higher the diversity. These indices are totally inappropriate to measure biodiversity because:

• They do not consider the potentialities of an environment (maximum number of species able to live in this environment). The comparison of two sites therefore has to be restricted to similar environments;

• They highlight respective species abundance. A site on which all species have the same abundance will have maximum diversity. A site on which 9 species out of 10 are very rare (usually the most important to preserve biodiversity) will have a lower score. In addition, a functional site (all trophic* levels present) could have a lower score than a disturbed site since the higher trophic* levels (predators, for example) are naturally comprised of less numerous species.

The figure below illustrates this problem for the concrete case of Grand Ventron Nature Reserve. Old-growth forests (FCN) and managed forests harbour the same species and at similar frequencies (which indicates a high degree of naturalness in managed forests in terms of their composition). Yet the value of the Shannon index of specific diversity is twice as high in the theoretical optimum (identical frequency for all species), which is true ecological nonsense.



The use of unsuitable indicators to measure biodiversity is the cause of numerous misunderstandings. When silviculturalists increase the diversity of birds, butterflies or flowering plants by creating a gap in the stand, they only rarely contribute to preserving global biodiversity. They provide non-forest species with a substitute habitat and thus increases the specific richness of their territory, but it is rare when such measures help increase biodiversity by safeguarding a genetic heritage, a species or ecosystem threatened at the biogeographic level. By fragmenting forest areas, such measures, to the contrary, benefit ubiquitous species and can even lead to the extinction of populations of forest species. Even in the rare cases where these measures are justified (for example: forest conservation of species whose survival is compromised elsewhere due to the destruction of their habitat), they reflect above all our inability to safeguard these species in their original environments. Should forests serve as repositories for species threatened in other habitats? Would it not be better to restore the original environments for these species?

To overcome the problems of these indices, some recommend the use of "umbrella" species (whose presence indicates the presence of a large number of species) or of an adapted Shannon index taking into account (by weighting) the value of ecosystems and species[195]. Biodiversity, just as naturalness, nevertheless remains a general concept that would be utopistic to want to measure by a simple mathematical equation.

of these taxa*. What will happen to species preserved ex-situ if their natural habitat is not restored, recovered? Naturalness, in promoting the conservation or restoration of habitats with a high degree of naturalness (maintaining itself without human intervention), will enable the long-term conservation of these species (and at less expense; the final objective being non-intervention).

The fact that less than only 15% of the taxa inhabiting the biosphere are actually known is another obstacle to implementing a policy solely based on biodiversity (by definition, a concept encompassing all species). As a result, in regions that are poorly known but with a high biodiversity (tropical forests, for example), biodiversity conservation is translated as a policy to maintain naturalness (for example, large strict nature reserves in French Guyana). Preserving biodiversity by preserving naturalness is a wise principle since, once all taxa are known, their coexistence, which depends on countless interactions (between species or between species and their habitats), cannot be compensated for with a multitude of specific conservation measures.

With different approaches, the two concepts are thus very often complementary. When dilemmas appear between biodiversity and naturalness, the manager should show common sense and evaluate the relevance of the various options in terms of global biodiversity. Here is an example: should a rare heliophyte* species on a particular site be favoured by "opening" the forest? If the populations of these species are not threatened at the regional level (often the level used for plants), the justification of such operations is poor, as they will help decrease the naturalness of the site without even increasing global biodiversity (caution: a rare species is not necessarily endangered). If, on the contrary, it is a matter of an original taxon, for example, of an endemic genotype whose conservation depends on these works (its original habitat having been destroyed or being too fragmented to host a viable metapopulation), the operation would seem justified in terms of global biodiversity. The choice between biodiversity and naturalness will, nevertheless, always remain difficult since the operations may be harmful to other endangered species whose existence or ecology is unknown.

In conclusion, we can say that forest management that aims to increase site diversity will only rarely lead to an increase in biodiversity at the regional level. Since there is no universal level to grasp the concept of biodiversity (besides the global level), the best thing to do for the manager in the case of a dilemma is therefore to assess the regional impact of their local management. If local action does not bring benefits at the higher (regional) level, it would be better to opt for a policy to increase naturalness.

"BIODIVERSITY: WRONG SPECIES, WRONG SCALE, WRONG CONCLUSIONS»[39]

The real question managers of natural areas should ask is "which species (and habitats) should be protected", not "how many". The evaluation of biodiversity should be qualitative, oriented towards threatened species (specialists, endemics, rare, indigenous) and show less interest in species that are generalists, opportunists and exotics, which often prosper independently of the use of the area. Six categories of threatened species can be distinguished:

• Species having low densities and large territories, particularly vulnerable to fragmentation (this is the case of some large predators such as the brown bear in the Pyrenees);

• Species whose dispersal and colonizing ability are limited (such as the capercaillie in mid-mountain forests) ;

• Endemic species;

• Species with specific requirements in terms of habitat (specialized) such as the numerous saproxylics;*

• Migratory species requiring favourable habitats at their breeding and wintering sites, and all along their migratory routes;

• Rare species.

3.4. How can one measure naturalness?

Just as for biodiversity, the evaluation of naturalness can affect different levels of organization:

• intra-specific level: pine forests in the Landes region derived from foreign genotypes have a lower "genetic naturalness" than indigenous pine forests;

• specific level : in France, a forest of robinia or Douglas fir will

have a lower naturalness than a forest of indigenous species;
- ecosystem level: a forest mosaic comprised of different spontaneous communities will have a greater degree of naturalness than a fragmented forest where woods, prairies and crops are alternated;
- structural level: the naturalness of a forest can also be understood by the spatial organization of storeys (vertical structure) and of silvigenetic phases (horizontal structure), the spatio-temporal dynamics of these phases, the abundance of dead wood, etc.

As previously mentioned (§ 3.1), the degree of naturalness of a forest must be evaluated by measuring the gap (or the differences) between its current naturalness and its maximum potential naturalness.

The approaches will be different depending on whether one uses data from the past, present or projections into the future to estimate the maximum potential naturalness. To put it more simply, paleoecology helps determine the maximum potential naturalness relative to a past state, synchronic and diachronic approaches, and the catalogues of forest stands relative to the current state of the reference sites, modelling according to a simulated future state (§ 3.1).

3.4.1 Paleoecology

Various sciences aim to describe our past environments. They enable us, in particular, to retrace the evolution of landscapes during the Holocene (since the end of the last glaciation) and to determine what were the most important stages of this evolution, whether it was a matter of climatic, biological (species colonization) or anthropogenic* events (initial clearings, introduction of species, etc.).

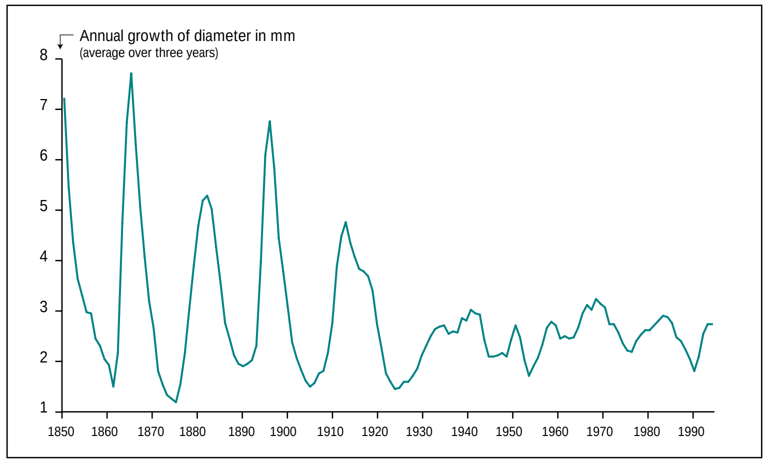
PALYNOLOGY (study of pollens) is undoubtedly the most well-known of these disciplines: one of the oldest and most precise (both at the species level described and of the period covered). It is unfortunately limited to plant species and its spatial accuracy depends on the species (certain pollens are transported over long distances, while those that are too heavy hardly migrate at all).

THE STUDY OF MACRO-REMAINS, often associated with palynology, makes up for certain of its shortcomings. By studying fragments of leaves, needles, seeds or even animals, it completes the spectrum of species studied and gives a more accurate picture of local conditions (macro-remains are rarely transported over long distances).

PEDO-ANTHRACOLOGY is the study of wood charcoal. Whether fires are natural (lightning) or anthropogenic* (clearings, charcoal burner's clearings), fires produce charcoal that is very resistant to oxidation (plus very easy to date) and can be preserved in most

soils. Their study helps retrace the presence of woody species on a site through time, as well as the natural altitudinal limit of forests[29-31]. Soil charcoal stratification (mixed by invertebrates) is, unfortunately, not chronological, and it is therefore necessary to date a large number of fragments to obtain a precise idea of the forest dynamics (an expensive method).

DENDROCHRONOLOGY is the study of the annual growth rings of trees. It is especially used by climatologists to retrace climatic variations of the past (by analysing the variations in the growth rings). This technique also enables to reconstitute certain variables of the immediate environment of a tree.



Growth in diameter of an ash tree in the Valbois Nature Reserve[106]. With each new cut of the coppice (every 15 years on average), the ash is exposed to light and its annual growth increases dramatically. It can be concluded that this forest was managed as coppice with standard (ash being part of high forests) from the mid 19th century to the beginning of the 20th century. Logging of this forest ceased in 1910.

ARCHEOLOGY also provides precious information. Besides data about the environment of our ancestors (charcoal and bone fragments indicate the presence of certain species), excavations help date the transition phase of the hunter–gatherer civilization to a more sedentary one of farmers. It is this transition that marks the beginning of anthropogenic* disturbances, of the "domestication" of nature.

WRITTEN DOCUMENTS should not be neglected in evaluating the recent evolution (since the Middle Ages) of a forest. Acorns, branches, fungi, berries, then provided significant revenues and their exploitation was regulated and recorded. Historical studies[62] are therefore very interesting to understand recent evolution and thus the naturalness of a site.

Whatever the discipline used, it is the study of "recent" evolution (several centuries to several millennia) of plant cover that provides the manager with the most valuable information to assess the naturalness of their forest. It is certainly interesting to know the forest types that have succeeded the tundra of the Late Glacial but in the long term, as these changes have nothing to do with the human actions (and therefore with naturalness); they only inform us about climatic changes or the successive arrival of different species. The study of the recent history of our forests permits us, on the contrary, to discover and date the impact of large anthropogenic* disturbances of our forests: clearings, plantations, introductions or selection of certain species, etc.

3.4.2 Synchronic approaches

Unlike paleoecology (comparison of an ancient state with the current state), the synchronic approach involves comparing the current state of two distinct sites; one of the two being unmanaged (for a long time or always), forming the reference in terms of naturalness (§ 3.1). Having such a reference forest is the most favourable case for managers. In effect, information from the past (incomplete) or future predictions (uncertain) are no longer necessary; it is enough to compare the two sites, and this comparison (quantitative or qualitative) can be done at all organizational levels (§ 3.4). It is possible in this case, for example, to assess naturalness by comparing:

- the richness of indigenous forest taxa*;
- the abundance of certain taxa ;
- the structural diversity (vertical structure for storeys, horizontal for phases, but also the abundance of dead wood; § 5.2.2) ;
- forest fragmentation, infrastructures, attendance, etc.

(see examples of synchronic approaches in § 5)

Protection of the last remaining old-growth forests, even though smaller in size, is a major conservation stake, not only to protect the taxa and original structures they harbour (§ 4), but also to be able to avail of reference sites that enable one to evaluate the naturalness of other forests by using a synchronic approach* (Photo: B. Boisson).

3.4.3 Catalogues of forest stands

These catalogues, which today cover most French regions, can be used to determine the naturalness of forest species. They form an inventory of potential stands of a region (in equilibrium with the environment without anthropogenic* disturbances) for all types of soils, orientations and altitudes. It is encouraging to note that these catalogues are today often taken into account when establishing management plans of managed forests (public and private). These managers thus acknowledge that a stand in equilibrium with its environment has better silvicultural potential (yield) than a stand of exotic species (less naturalness). For a long time, it was the short-term (one or two cutting cycles) yield that dictated the choice of species. This choice, which favours fast-growing species, has often proven to be an ecological and economic catastrophe (less resistance to allochthonous* species, storms, soil degradation, etc.). By favouring stands in equilibrium today, "sustainable" forest management (long-term yield) is encouraged.

3.4.4 Predictive models

Forest models help simulate the maximum potential naturalness of a forest (§ 3.1). Taking into account site characteristics, the species present, as well as their biology and ecology (model "parameters"), it is in fact possible to predict the evolution of a forest over a given period (respective abundance of species, duration of cycles, growth rate, biomass and necromass values, spatio-temporal dynamics of the sylvatic mosaic, etc.[98]). Unlike the catalogues of forest stands (§ 3.4.3), these parametric models have a dynamic aspect: they can take into account and thus test the impact (at different time scales) of the presence of introduced species, different types of silvicultural management, etc. They can also integrate the predictions of other models (for example, climatic change).

Of course, these predictions remain theoretical. As they are difficult to test (silvigenetic processes occur very long *in situ*), they are not always accepted unanimously, and managers hesitate before deciding to use them. Moreover, these models only concern woody species and therefore do not allow an assessment of the naturalness of other forest components.

In addition to these "forest" models, there are many specific models that, based on the ecological requirements of a species, enable one to predict the evolution of its populations[115]. If it is a matter of an indicator species dependent on old-growth forests, these models make it possible, for example, to calculate the degree of naturalness of a site relative to this species.

3.4.5 Empirical approaches

In numerous cases, the lack of both knowledge and means limits the implementation of studies such as those shown in the preceding sections. Certain people therefore prefer to measure forest naturalness by using other, more empirical approaches[184].

Empirical calculation of an indicator of forest naturalness

(rough draft from the Alsace Nature Federation, 1996)

I. Indicators of naturalness at the biogeographic region level

1 Floral composition
• native species in proportions close to natural proportions (score=5)
• native species but introduced genotypes or proportions far from natural values (4)
• 0-20% exotic species or native species in proportions very far from natural proportions (3)
• 20-70% exotic species (2)
• more than 70% exotic species (1)

2 Partitioning and areas (for a region with a forest at the climax stage)
• no fragmentation of forest cover (5)
• afforestation rate greater than 80% (4)
• afforestation rate is 40-80% (3)
• afforestation rate is 15-40% (2)
• afforestation rate less than 15% (1)

3 Functionality
• natural disturbances still occurring (5)
• natural disturbances modified by humans (3)
• natural disturbances alleviated by humans (1)

II. Indicators of naturalness at the parcel level

5 Floral composition
• native species in proportions close to natural proportions (5)
• native species but introduced genotypes or proportions far from natural values (4)
• 0-20% of exotic species or native species in proportions very far from natural proportions (3)
• 20-70% of exotic species (2)
• more than 70% exotic species (1)

6 Structural composition (it is desirable to add a variable that factors the quality and quantity of dead wood)
• natural structure (natural disturbances) with dead and living trees of all diameters (5)
• irregular horizontal and vertical structure; permanent regeneration without a defined age of exploitability; with some phases of ageing (trees with diameter > 50 cm) (4)
• regular structure; regeneration spread over 15-50% of the average age of exploitability (3)
• regular structure; regeneration spread over 5-15% of the average age of exploitability (2)
• even-aged stands divided into areas of more than 10 ha (1)

7 Quality of the peripheral zone
• parcel located in a big massif (> 10,000 ha) with a structure and composition close to the natural state (5)
• parcel located in a big massif with a structure and composition moderately different from the natural state or parcel located in a small massif of good quality (score >3 for variables II 1 and II 2) (4)
• parcel located in a large forest massif of poor quality (3)
• parcel located in a small forest massif of poor quality (2)
• parcel isolated from all forest contexts (1)

8 Functionality
• natural disturbances still occurring (5)
• natural disturbances modified by humans (3)
• natural disturbances alleviated by humans (1)

In total: the sum of the eight scores equals the naturalness index.

3

Protecting old-growth forests

“Natural and semi-natural forests are an essential part of European heritage because of their aesthetic, cultural, educational and scientific value” (Council of Europe, 1987).

4.1. Multi-functional forests

4.1.1 Outdoor laboratories

Protection of the last remaining old-growth forests is a major conservation stake to protect the structures and taxa* that they harbour (§ 2 & 5) but also to avail of reference sites allowing to assess the degree of naturalness of managed forests (§ 3.4).

“When silvicultural techniques resemble spontaneous development, efforts to achieve a good result are limited; on the other hand, when silvicultural techniques are very different from spontaneous development, much effort is required to achieve the objective”[99].

Silviculturists take an interest in old-growth forests for other reasons. One of their objectives is to avail themselves of management methods to lower the costs of production while increasing woody production[99]. By having a better understanding of natural processes (regeneration, competition, dynamics, etc.), the silviculturist could increase the yield of their forest by imitating nature[154]. Of equal interest to foresters[58] is the better resistance of old-growth forests to parasitic attacks[80] and natural disturbances (for example, storms)[12,182], and their great diversity in terms of genetic resources[176].

Of course, the scientific interest of old-growth forests is not limited to conservation or production. Spared of the main anthropogenic* disturbances and corresponding to climax* stages of our ecosystems, these forests also become the subject of fundamental research. The close relationship between the forest and its environment, having been studied for a long time in France[104], will be even more studied in the future in the context of programmes to combat climate change, since forests are both producers and absorbers of carbon dioxide[8] (§ 4.1.3).

The average volume of dead wood in Europe’s managed forests today is only a few m³/ha, while it is often more than 50-100 m³/ha in old-growth forests. The volume of dead wood has thus suffered a decrease estimated at more than 90% at the landscape level. It is estimated (based on island theory; § 4.3) that 25 to 50% of saproxylic species have already disappeared as a result of this decrease[164].

4.1.2 Noah’s arks to preserve biodiversity

There are numerous works that have underlined the interest of old-growth forests for the conservation of species and habitats (§ 5.4).

Old-growth forests harbour rare species and habitats, some of which have disappeared completely from managed forests. Logs and large dead trees are the favourite habitats of an extremely varied entomofauna. The abundance of these insects benefits many birds, often cavity nesting birds such as woodpeckers (the most rare of which, the three-toed woodpecker and white-backed woodpecker live almost exclusively in old-growth forests). These species, by boring holes in old dead or decayed wood, provide nesting sites for other species too, such as certain owls.

4

In addition to the presence of ancient trees and a significant necromass, the great vertical structural diversity (multi-storeyed forests) and horizontal (sylvatic mosaic) of old-growth forests is what explains their larger specific richness[64] and the greater stability of their animal communities in the long term[183].

The presence of relict and symbolic species such as the capercaillie has also often been associated with the presence of old-growth forests. This species seeks multi-storeyed forests and small herbaceous openings to raise its young[108,179].

Specific richness of two protected sites with old-growth forests

	Bialowieza (1250 km²)[57]	La Massane (336 ha)[185]
Insectes	env. 8500	2902
dont : Hymenoptera	*3000*	*270*
Coleoptera :	*2000*	*1453*
Lepidoptera :	*1000*	*364*
Diptera :	*800*	*429*
Birds	228	60
Mammals	62	33
Fishes	24	2
Amphibians and reptiles	19	20
Vascular plants	990	694
include : Phanerogams	*953*	*676*
Cryptogams	*37*	*18*
Fungi	>2000	362
Lichens	334	281
Bryophytes	254	196
Total :	**>12,500**	**>5,000**

4.1.3 Carbon sinks

The concentration of carbon in the atmosphere has increased by 40% since 1800 and has led to a rise in mean global temperature. Ecosystems are capable of storing large quantities of carbon, but the quantities released by the use of fossil energy sources today exceeds their ability to self-regulate, and so the rise in temperature is likely to continue[114].

Forests, being carbon sinks, play an important role in combating global warming. Their contribution can be increased even further:

- by conserving large areas of non-managed forests, ecosystems with the greatest capacity for temporary carbon storage are favoured;
- by increasing total forest area, a portion of carbon released by the combustion of fossil fuels is recovered (stored again);
- the use of wood as a source of energy permits the partial replacement of fossil fuel sources;
- it is also advisable to favour, as much as possible, the "neutralization" of carbon by the transformation of wood into stable products (construction materials, furniture, etc.).

Reforestation would also permit an increase in the wood supply (the risk of having old-growth forests exploited would be

In nearly all the French regions where it nests, the capercaillie is in decline and among the condemned species (see "extinction debt" § 4.3.3). Today this species is at the centre of a scientific debate opposing those who wish to save it by active management (artificial creation of gaps beneficial to the species) and those who advocate passive management (spontaneous creation of gaps that favour natural dynamics and disturbances; see § 3.2). In this example, active management can limit the decline of the capercaillie in the short term, but passive management of vast forests with a high degree of naturalness is probably a better conservation strategy in the long term.

Forêt de la Massane Nature Reserve, Eastern Pyrenees (Photo: B. Boisson).

Every year, 6 billion tons (b.t.) of carbon are released by the combustion of fossil fuels and 2 b.t. by deforestation. Only half of these quantities is recycled in ecosystems and 4 b.t. are therefore added each year to the 750 b.t. already present in the atmosphere.

Reforestation helps neutralize a portion of greenhouse gases arising from the combustion of fossil fuels. The area available is, unfortunately, reduced and this reforestation sometimes produces opposite effects. The use of certain fertilizers releases greenhouse gases that are more harmful than carbon. In boreal regions, reforestation cancels the positive cooling effect of open landscapes where snow cover reflects a large portion of solar radiation[114].

Fontainebleau Forest (Photo: B. Boisson).

decreased) and a reduction in the impact of fragmentation by partially restoring connectivity between massifs.

4.1.4 Vehicles of development

The protection of old-growth forests should not lessen the importance of their socio-economic role. Without the public's approval, protection will only be "tolerated" by the population and its effectiveness (and longevity) will be limited. It is thus important to highlight the benefits of this protection for the population. The scientific and ecological interests of these safeguards are only understood and defended by a part of the population: scientists, naturalists and certain foresters. There are, however, other objective reasons for society to protect old-growth forests.

From an educational perspective, old-growth forests "help show the extraordinary vitality, dynamics, diversity, complexity and beauty of forests developing in accordance with only the forces of nature"[27] and that long ago covered nearly the entire European continent. They thus offer a fantastic educational medium for the life sciences, earth sciences, history, physics and chemistry (biochemical cycles), etc. They also allow us to understand the climate change issue from a more positive vantage point than by the simple "pollution" approach.

The cultural interest of these forests is equally important. The reasons for their presence greatly interests historians because it allows them to retrace the spatio-temporal evolution of human activity, or to define more precisely the contact points between different zones of political influence[62]. The appearance, aestheticism and ambiance unique to old-growth forests have appealed to many artists for several centuries. The forest of Fontainebleau, represented ever since the 18th century by the painter Jean-Baptiste Oudry, is the perfect illustration as it "hosted" a true community of painters (Barbizon School) in the 19th century. Many artists found the source of their inspiration there[18,33]. It is due to their initiative that certain parcels of land were classified ("artistic series") and withdrawn from silvicultural operations as of 1853.

For many (particularly the wood industry), the economic interest of old-growth forests is a priority:

- Although it is difficult to quantify, the main economic benefit of these forests comes from the improvement of silvicultural techniques inspired by their functioning (§ 4.1.1). Management that is closer to natural processes can lead to a lowering of management costs and/or an increase in productivity. Silvicultural practices that are different from natural functioning (for example, exotic species or regular high forest) often appear very cost-effective for several rotations but sometimes have harmful long-term consequences (soil destabilization and impoverishment);

- The protection of certain infrastructures ensured by old-growth forests also needs to be mentioned. Difficult to exploit and producing wood of average quality, many unexploited hillside forests protect villages and roads from the risks of landslides or avalanches. The logging of these forests (often subsidized or showing a loss) sometimes needs to be followed by very costly structures (avalanche barriers, for example). It would therefore be better to leave these forests so they can protect us at no cost.
- When the classification by decree of a strict forest reserve results in a loss of revenues (even potential ones), the owner can claim financial compensation (Article L.332-5 of French Environmental Code). This compensation can be calculated as a lump sum (based on the value of the trees) or annually (based on average profitability).
- Protection of old-growth forests sometimes bring significant revenues to local populations. In the Bavarian Forest National Park where more than 50% of the forests are strict forest reserves, tourist numbers have risen from 200,000 to 1.5 million in 16 years and today constitute 20% of the region's annual turnover. Important measures of reconversion and compensation have accompanied this protection[27,36]. At a very different (small) scale, the setting up of forested nature reserves in the small French communes with old-growth forests can still result in benefits from the passage (interns, seminars, training courses, outings) or settling in (permanent staff of the reserve) of people who participate in the local economy and development.

Recreational interest. Exploring a nearly virgin forest has a definite attraction for a population craving new discoveries. The fragility and often small size of old-growth forests does not lend itself to the mass eco-tourism developed in certain natural forests (Bavarian Forest National Park, for example). Individual exploration, authorized but not promoted, seems to be the most appropriate recreational option for French sites.

4.1.5 Coming in contact with our "roots"

One of the leitmotifs to justify the conservation of natural forests in North America (§ 3.1) is to preserve, for the benefit of humans, zones that are "primeval, pristine, remote", even "worrying" for some, where one can "feel at peace with nature by facing one's ancestral fears"[181]. These would be zones where our senses and deepest emotions could be revitalized. Such a realization can, in effect, be considered essential to gain public support and to the success of (French) conservation policies. To envisage such a plan, old-growth forests will also need to remain free of infrastructure (including paths, signs, etc.) and… open to the public, despite their possible status as "strict forest reserve".

In the Grand Ventron Nature Reserve, the dead trees overhanging a secondary road have been kept despite the opinion of road safety experts: the risk that they would fall onto the road was ultimately considered negligible compared to the risk of rockfalls that would have been created by removing these trees, which would have then required the setting up of an artificial protection of the roadway[66].
In this same reserve, the communes receive an annual compensation from the State of 22.87 € per ha for parcels classified as "strict forest reserve".
In the neighbouring Frankenthal reserve, a lump sum compensation has been calculated according to the value of the existing trees and logging costs (deducted from this value).
In strict forest reserves of certain Rhineland nature reserves, the territorial communities are the ones who compensate the losses in revenue (from wood and hunting) to the local land-owning municipalities.

"When a society no longer finds its ideal, it is left to humans to seek what is primordial. They look for it in pristine nature before finding it again in themselves"[18].

4.2. Multiple threats

If today it is advisable to protect old-growth forests, it is because they are seriously threatened. They are threatened with extinction in the most severe cases, and threatened with "denaturing" when their degree of naturalness is altered.

A distinctive feature of these forests is that the destruction of their natural character only takes a few hours (logging). Their restoration, however, when such is conceivable (certain actions, such as a break in continuity, are irreparable), can require several centuries.

Protection of old-growth forests should therefore be devised and implemented in a preventive, sustained and long-term manner. In a recent report on forest protection in Europe, the WWF identifies 8 main threats[72].

- The first is administrative and social. If local populations and authorities are not involved in protection, it will be poorly accepted and little respected.
- Even when it is outlawed, illegal or camouflaged logging (for security or health reasons) remains a threat.
- Hunting today sometimes limits itself to shooting the most prominent animals, which alters equilibria between silviculture and hunting when the density of herbivores is too high. To make matters worse, large predators have often been extirpated, and when feeding is provided by hunters for large herbivores, it increases their survival rate (§ 2.2.4). The overabundance of large herbivores thus leads certain silviculturists to justify artificial regeneration.
- Construction of infrastructure (destruction or fragmentation (§ 4.3.2) of old-growth forests). What is a forest ecosystem worth compared to a highway project or a high speed rail line deemed of "public utility"?
- Certain exotic species, more dynamic than the native ones, colonize many environments (§ 3.2).
- Mining exploitation, a threat in certain countries, is negligible in France.
- "Green" tourism, to the contrary, is in full expansion. Attendance at these forests is therefore expected to increase and their ability to withstand the effects of visitors will quickly be exceeded. This attendance must be "controlled" but not prohibited because it certainly benefits humans and indirectly the conservation of environments181 (§ 4.1.5). A proper balance remains to be found.
- Fires, natural disturbances in certain regions, are a major threat to Mediterranean forests where they are encouraged by human activities. Note, however, that most fires (often arson) that affect the south of France every year most often concern pine forests that have been planted or are in the stage of recolonization and not old-growth forests.

SCIENTISTS' APPEAL

In France, more than 200 scientists in 2001 initiated an appeal to the government authorities for the protection of France's forests. They asked, among other things, for:
1. Implementation of a representative and functional network of protected forests:
• assess the strengths and shortcomings of current protection;
• identify criteria and indicators for a periodic evaluation of protection;
• define a project to consolidate the protected forests network, with priorities;
• establish political and financial conditions likely to improve protection;
• modernize forest management in protected areas.
2. Strict protection of large forest areas:
• create a coherent sub-network of strict forest reserves (major deficiency in France);
• establish several strict forest reserves larger than 100 km² in Metropolitan France.

The last threat to be mentioned here is the most discreet and insidious, that which slowly but inexorably alters our environment: pollution. Nearly invisible and originating outside forests, it is easy to neglect it. Yet it is omnipresent and contaminates at all levels, especially in the trophic networks.

4.3. Conservation strategies

4.3.1 What are the objectives?

In general terms, forest protection policy aims to[72]:

1. Establish a network of protected forests that are ecologically representative, socially beneficial and efficiently managed.
2. Achieve an appropriate form of management from an environmental, social and economic point of view in non-protected forests.
3. Develop and implement appropriate programs, from an environmental and social perspective, to restore degraded landscapes and forests.
4. Protect forests from pollution and climatic change by reducing emissions and by adapting management.
5. Ensure that political and commercial decisions safeguard forest resources and lead to a fair distribution of the associated costs and benefits.

More specifically, to "guarantee the protection of the last remaining natural forests and other high-value forests for conservation," the WWF recommends the following directives[72]:

1. In Eastern and Northern Europe (regions that still have vast pristine forests): "the largest natural forest areas (>50,000 ha) should be protected, thus safeguarding their development without human disturbance of long-term processes".
2. In regions with only small zones of old-growth forests:
- old-growth forests and other forests of high ecological value should be protected, enlarged and connected (preservation of corridors) ;
- the elements of natural forests that are lacking in Western Europe should be restored.
3. For a responsible wood trade, the WWF requests that:
- companies have a clear policy and take active measures to avoid the use of wood from virgin or remarkable forests;
- companies use FSC-certified wood (§ 6.4).

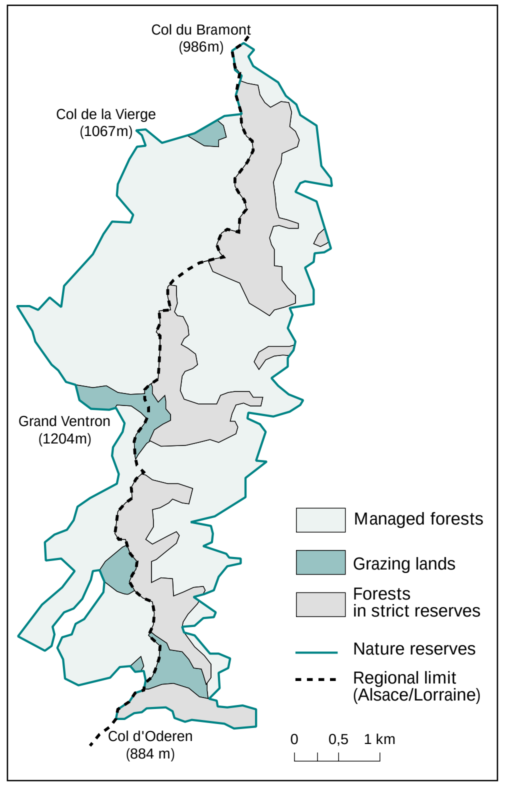
The French National forest Office expresses the following objectives for its strict biological reserves[134]: "free expression of natural evolutionary processes, no silvicultural intervention, no exploitation whatsoever."

The conservation of old-growth forests is based around three strategic axes:

• Protect the last remaining old-growth forests;

• For habitats no longer existing in their natural form: protect managed forests where a high degree of naturalness will be restored for the long term (objective: construct a representative network);

• Adopt management modes similar to natural processes in the managed forests outside old- growth forests (and between sites for the sake of connectivity).



Since strict forest reserves are often small in France, the creation of peripheral buffer zones is a complementary protection measure. For strict biological reserves, forest improvements could present specific recommendations for peripheral forests: plantations, treatments, fertilization and limited or prohibited clearcuts. For the integral parts of nature reserves, the reserve itself can act as a buffer zone. This is the case of the Grand Ventron Nature Reserve (1650 ha) where the 400 ha of strict forest reserve (old-growth forests) are located in the central zone.

In fragmented forests, a certain number of changes occur. The smallness and isolation of the sites reduce the exchange of individuals between sites. Certain accidental events can lead to the disappearance of species. Under natural conditions, such catastrophes would be healed quickly by the migration of new individuals from adjacent zones, etc. In isolated sites, opportunities for internal migration are limited or non-existent. As a result, these sites gradually lose certain species and those that survive reach unusual values of relative abundance (Curtis, 1956[40]).

In these strict forest reserves, "all direct human intervention liable to modify the composition or structure of natural habitats is prohibited". These reserves:

- should form a network of habitats representative of the ecological diversity of French forests; and by ending logging should enable the preservation or restoration of a sample of "natural" forest environments throughout the country;
- are intended for fundamental research on the functioning of forests;
- contribute to the protection of species linked to advanced stages of forest maturity;
- are capable of fulfilling the yearnings of a society in search of the "natural" and have an educational role;
- Lastly, one of the more important objectives (§ 5): "strict forest reserves can eventually form reference areas to assess forest environments that are more affected by man-made disturbances".

4.3.2 Fragmentation: from island theory …

Natural or artificial isolation (fragmentation) of habitats results in an impoverishment of biodiversity. This ancient observation[40], clarified by the "theory of island biogeography" in the 1960s[116], is one of the most important principles of conservation[162]. Fragmentation induces loss of habitat for species and the isolation of their populations. The original equilibrium between species and their habitat is thus upset. The smaller a habitat is, the greater the risk of extinction for certain species increases (rare species in separated areas or for whom the size of a viable population has to be high). The more a habitat is isolated, the more the number of new species liable to colonize it decreases.

Numerous models have been proposed based on these theories to estimate the number, size and type of reserves required to ensure the long-term survival of species. In France, the protection of old-growth forests is more often an emergency measure than a conservation strategy. Conversely, in the United States, the effects of fragmentation are explicitly taken into account for certain taxa* since forests must "permit viable populations of indigenous vertebrates to survive"[86].

The principles of island theory today govern most conservation strategies of natural environments.

Fragmentation, naturalness and biodiversity

Forest fragmentation, by increasing landscape homogeneity, sometimes leads to the appearance of new species. Skylarks, for example, which nest in open environments (such as clearcuts), can contribute locally to an increase in "species richness". Some would use this as an argument to refute the concept of naturalness for the benefit of biodiversity (§ 3.3). The effects of fragmentation on biodiversity should, nonetheless, be measured at the biogeographic level. Consider a well-known group such as birds, for example. Between 1850 and 1986, 11 species disappeared from Alsace while 7 new ones appeared[47]. But the species that disappeared are threatened at the national/international level (great bittern, black swan, osprey, little tern, lesser grey shrike), while the newly arrived species are common (great crested grebe, tufted duck, laughing gull, collared dove, fieldfare, rook). Habitat fragmentation, even if it contributes locally to increase species richness, inevitably leads to a decrease in both global naturalness and biodiversity (§ 3.3).

4.3.3 …to that of metapopulations

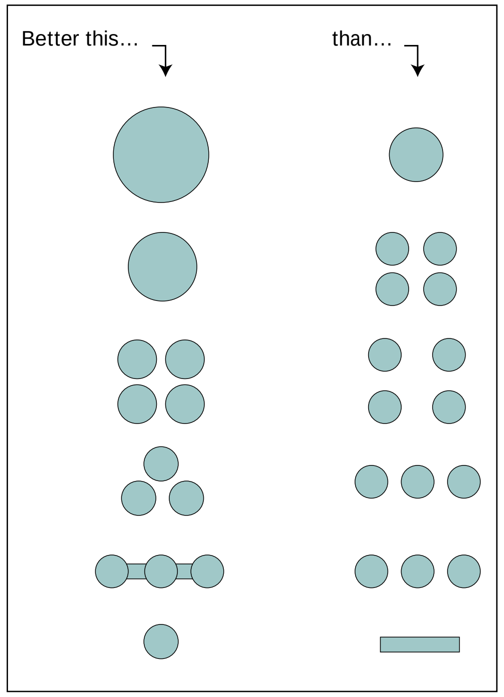
Biologists have long considered species populations as groups where all individuals interact in the same way with their congeners. This simplification hides the effect of age, size, spatial distribution and the migration of individuals on population dynamics. The study of metapopulations[74] fills these gaps by integrating the impact of relationships between individuals on the dynamics of the entire population. In fact, it is a matter of a specific case of island theory in which only one species is considered. Instead of studying the rates of colonization and extinction of an island by different species, these rates are studied for different sub-populations of the same species (each "patch" of habitat being occupied by a distinct sub-population).

A metapopulation is thus composed of several local populations (sub-population). A fragmented forest massif would include, for example, as many local populations as forest fragments. But the scale of the study will also depend on the sort of species studied. In the case of saproxylic* species with limited mobility, it is sometimes thought that dead trees (in which several generations can develop) harbour local populations. Certain Coleoptera (*Bolitophagus reticulatus* living in the fructifications of *Fomes formentarius*; *Osmoderma eremita* living in the humus of large cavities) seem to correspond to this model.

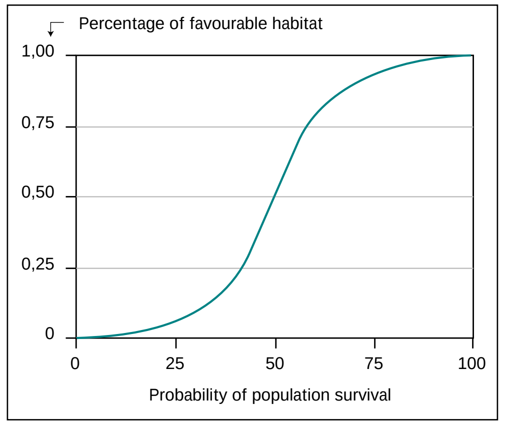
The advantage of this approach is that it allows modelling of the dynamics of local populations.

Main lessons of the theory of metapopulations[74] :
- the size or density of a population is affected by the migration of individuals,
- the density of a population is affected by the size of its habitat and its isolation,
- for a metapopulation to be able to persist, the dynamics of local populations must be asynchronous* (otherwise there is a risk of a simultaneous extinction of all local populations),

"Fragmentation is the greatest threat to biological diversity[131]."



Simplified planning principles for the creation of reserves according to the "island theory"[45].



Impact of habitat destruction on a population's chances of survival.

- local extinctions and colonizations characterize the dynamics of metapopulations,
- the existence of favourable but non-occupied habitats is not abnormal,
- each local population being at risk of extinction, the long-term survival of a species is only possible at the level of metapopulation,
- the risk of extinction of a local population depends on the size of its habitat,
- the colonization rate of a habitat depends on its degree of isolation,
- the occupation of a habitat by a species thus depends on its size and its degree of isolation,
- modelling the spatial dynamics of metapopulations can be used to predict the dynamics of a metapopulation in a fragmented landscape,
- two or more competing species whose simultaneous survival is impossible locally yet can coexist as metapopulations,
- likewise, a predator can coexist with its prey at the metapopulation level while it fluctuates locally towards extinction.

This approach has also made it possible to show that the probability of survival of a population is not correlated linearly to the fraction of habitat still favourable for the species. Maintaining two dead trees per hectare in a forest where their natural density is 20 would make one believe that by conserving 10% of the habitat favourable to saproxylic* species, 10% of these species (or populations of species) would be able to survive, but this value is greatly inferior.

Another lesson of these studies concerns the inertia of ecosystems in terms of species extinction[48]. Once a forest habitat is no longer fit for a species, this species does not necessarily disappear in the short term. Because of its numerous local populations, the species can survive several years before dying out. The presence of a species is therefore not always an indicator that the quality of the habitat is good. This property of metapopulations thus provides a second opportunity to managers of natural areas, who in this case could restore the habitat and correct the errors of the past before the species disappears completely (see box).

Extinction debt and species credit: the Finnish example[75]
Boreal forests comprise 50% of the forests on earth. In Finland, half of the 45,000 species of fungi, plants and animals are forest species and 6% of them are endangered (25 to 73% of forest species have already become extinct in the south!).
In the south of Finland, where 2000 species are inextricably

Protecting old-growth forests

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linked to the presence of old-growth forests (1% of wooded areas), the "extinction debt" (number of species condemned whose extinction is likely in the medium or long term) is estimated at 1000 species. Setting up a more ecological sort of forest management and the restoration of old-growth forests over greater areas could limit these extinctions taking into account "species credit" (species that could benefit from these new management and conservation measures: (1) species already extinct but which could recolonize the region starting from neighbouring populations and (2) species on the verge of extinction being part of the "extinction debt" but which, thanks to these measures, would manage to survive).
Different management and conservation measures have been evaluated. It appears clearly that to save those species that are actually threatened with extinction: (1) it is better to concentrate management and conservation efforts in certain zones rather than to spread the same efforts in a diffuse way over the entire territory, (2) better results are obtained if restored forests are located close to still existing old-growth forests, which would facilitate the return of threatened species.

4.3.4 Establishing a network of protected old-growth forests

To plan the establishment of a network of protected old-growth forests is not an easy task[167]. Such a network must first of all be acceptable from a social and economic point of view. For it to be relevant from an ecological point of view, it must fulfil certain scientific criteria, some of which were discussed in the preceding chapter. These two points of view are sometimes very different, hence it is not possible in this report to present a global "protection plan for old-growth forests". It is possible, nevertheless, to present the catalytic idea that should be the basis of thinking for setting up such a plan.

Representativity: the network of old-growth forests should include all types of habitats. In France, only mountain forests and alluvial forests are well represented. Hillside, (non-alluvial) plain and Mediterranean forests are under-represented. In the current state of forest reserves (table p.52), nature reserves cover larger areas and a greater number of forest habitats than biological reserves, although the latter are more numerous. This discrepancy should, nevertheless, lessen in the future when the objectives of the 1998 memo on strict forest reserves will have been achieved. It should also be noted that the central zones of national parks contain nearly 100,000 ha of forest habitats in which silvicultural activities are often reduced (with the well-known exception of Cévennes National Park, which in itself has 60% of this area but where the

Thuripherous juniper formations (Alpes, Pyrenees, Corsica) are rare and under-represented habitats in the French network of protected areas
(Photo: Bernard Pont).

forests, originating from reforestation projects, hardly have any "natural characteristics")[190].

Permanence: in order to be reliable and sustainable, the network must rely on strong protection measures (§ 6.2): nature reserve (NR) or strict biological reserve (RBI). Regional nature reserves and forest management plans (with limited timeframes) do not make it possible to guarantee the permanence of a network of protected old-growth forests.

Connectivity: matters of network connectivity are more complex because they depend on the (variable) ecology of forest species. Connectivity between two sites will, for example, be understood differently depending on whether it is a matter of ensuring the survival of a large mammal that is highly mobile or that of an invertebrate with reduced mobility. One of the options often adopted consists of simultaneously promoting:

- the connectivity between massifs by conserving or restoring forested "corridors";
- the naturalness of managed forest massifs by applying management methods that are closer to natural conditions, by preserving old trees, dead trees and/or by introducing ageing islands (see § 4.3.6);
- the establishment or enlargement of strict forest reserves, true "cores" of the network. For species that are strictly saproxylic* and have limited mobility, the impact of the first two measures is limited. For these species, the connectivity of micro-habitats within the same core (for example, between dead trees) is what should be considered important.

Functionality: establishing the conditions of a functional network is a delicate matter. The general functionality of the network is guaranteed by the connectivity of the habitats (see above). The functionality of the sites and habitats of this network is, to the contrary, determined by their size and quality (type of management). The more a habitat is spread out and has a dynamic close to natural conditions, the more it will be functional. Just as for naturalness, functionality is measured along a gradient. The choice will therefore often be political, but certain scientific thinking can, nevertheless, help make it more objective (§ 4.3.5).

4

Forest habitats found in French nature reserves (RN) and biological reserves (RB)

FCN = old-growth forests - RBI = strict (“integral”) biological reserves

	Nature reserves				Biological Reserves				Site Natura 2000
Code "Corine"	Nb of RN	Total area	Nb FCN	**Area FCN**	Nb of RB	Total area	Nb of RBI	**Area RBI (1)**	State november 2001 Total surface area (4)
Deciduous forests									
41.1 Beech forests	15	7 766	12	**893**	46	2 081	9	**400**	121 950
41.2 Oak-Hornbeam forests	4	404			19	150	2	**60**	27 664
41.3 Ash forests	4	64	1	**2**					11 871
41.4 Mixed forests of slopes and ravines	9	438	8	**135**	15	186	4	**103**	14 978
41.5 Acidophilous oak woods	3	50	3	**65**	9	73	1	**54**	14 807
41.6 Pyrenees oak forests									
41.7 Thermophilous and supra-Medit. oak forests	7	473	4	**240**	19	311	1	**40**	
41.8 Hop-, Oriental and thermophilous hornbeam forests									
41.9 Chestnut woods	3	105							14 096
41A Hornbeam woodlands (pure or nearly p. form.)	1	1							
41B Birch woodlands (on non-marshy terrain)	2	725							
41C Alder forests (non riparian and not marshy)	1	2	1	**2**					
41D Aspen woods	2	6	2	**25**					
41E Service tree (Sorbus) woodlands	1	3	2	**8**					
41F Elm woodlands (non riparian and non ravine)	4	63	2	**2**					
41G Lime woods (non riparian and non ravine)	1	5	1	**6**					
41H Other deciduous woodlands	4	284	3	**245**					
Coniferous forests									
42.1 Balsam fir forests	10	2 435	6	**270**	20	517	2	**6**	
42.2 Spruce forests (excluding plantations)	4	4 349	2	**155**	18	427	4	**117**	19 442
42.3 Larch and Swiss stone pine (P. cembra) forests	1	5			2	?			9 294
42.4 Bog pine (P. uncinata) forests	8	5 816	7	**4 267**	8	426	1	**2**	31 775
42.5 Scotch pine forests	4	629	4	**587**					0
42.6 Austrian pine (Salzmann & Corsican laricio) forests	2	412	1	**384**	5	397	2	**150**	12 476
42.8 Mediterranean pine forests	2	33	1	**6**	5	24	1	**?**	32 017
42.A Cypress, juniper and yew dominated forests					4	15			3 432
Riparian forests									
44.1 Willow riparian formations	8	337	8	**313**					7 063
44.2 White alder riparian gallery forests	2	11	2	**10**					
44.3 Ash-Alder woods of rivers	13	396	11	**388**	20	66	5	**20**	49 958
44.4 Mixed oak-elm-ash forests of rivers	6	415	5	**332**	4	387	3	**82**	19 258
44.5 Southern riparian forests of alder and birch	1	4	1	**4**					
44.6 Mediterranean forests of poplars, elms and ash	4	265	4	**244**					
44.8 Southern riparian galleries and thickets									2 277
44.9 Alder swamp woodlands	5	19	5	**31**	26	50			
44.A Birch-Conifer swamp forests	2	2	2	**21**	33	97	2	**?**	7 141
Evergreen hardwood forests									
45.1 Olive-carob tree forests					1	0			600
45.2 Cork oak forests					3	?			13 311
45.3 Meso- and supra-Mediterranean green oak forests	4	994	4	**819**	14	967	3	**11**	58 429
45.8 Holly woodlands					1	3			1 089
Wooded dunes	**1**	**62**	**1**	**62**	**2**	**85**			
Total metropolitan France (2)	**>100**	**>37 500**	**>60**	**>13 311**	**168**	**>6 900**	**26**	**<1 355**	**472 928**
Total overseas departments (3)	**6**	**207 616**	**6**	**207 609**	**8**	**<124 179**	**6**	**<118 164**	

1 - the values are different from those in table 123 from the natural heritage observatory of biological reserves that counts forests with the RBD status for 4 sites
2 - the totals are different from the sum of values shown in the list, because for certain sites only the forest area is known, and not details per habitat.
Except for the RBI (1355 ha = total of sectors listed including non-forest habitats), the totals represent minimum values since forest areas are not known for all the sites and the NR listed after March 1999 have not been included
3 - for biological reserves overseas, the totals concern the total area of the RB and RBI, and thus include non-forest habitats (for example, volcanic)
4 - (the area of “Natura 2000” is shown as a reminder since it is not certain that in the future it will be concerned with management tools devoted to safeguard old-growth forests).

Protecting old-growth forests

4.3.5 What should be the minimum size of forest reserves?

Recommendations for the minimum size of sites vary greatly. Certain scientists and organizations[72,155] recommend areas of 1000 to more than 50,000 ha. The French National Forests Office recommends a minimum of 50 ha in plain regions and 100 ha in mountain regions[134] (§ 4.3.5).

The idea that scientists have of the minimal size for a forest reserve varies:

- a few hectares sometimes being sufficient in our temperate climate to allow all silvigenetic phases to be present; it is this threshold that according to certain people guarantees the functionality of a forest;
- several tens of hectares of old-growth forests are necessary to ensure the maintenance of a sylvatic mosaic and the survival of certain metapopulations, it is this area that is considered by others as the minimum threshold;
- several hundreds, even several thousands of hectares are required for other species (with big territories) whose viable populations have to number several hundred individuals[162]. The size of a functional massif for an entire animal community can therefore attain several hundreds of km[2];

For ecologists, a forest reserve has to be big enough to permit the long-term survival, without genetic impoverishment[144], of all forest species. The risks encountered by these species in undersized reserves are numerous[144]:

- the number of micro-habitats at their disposal can be limited (most species use several micro-habitats);
- their vital territories can be larger than the reserve;
- the seasonal movements of species can exceed the limits of the reserve;
- the size of certain populations can be less than their minimum viable population size;
- the size of the reserve can be too small to allow all the silvigenetic phases (and to their specific species) to be present simultaneously;
- the ratio between the perimeter (edges) and the area of a reserve can be too high to allow “interior” species (who avoid edges) to survive;
- certain populations will be too small to ensure the maintenance of their genetic diversity. As a result, their variability and ability to adapt will diminish.

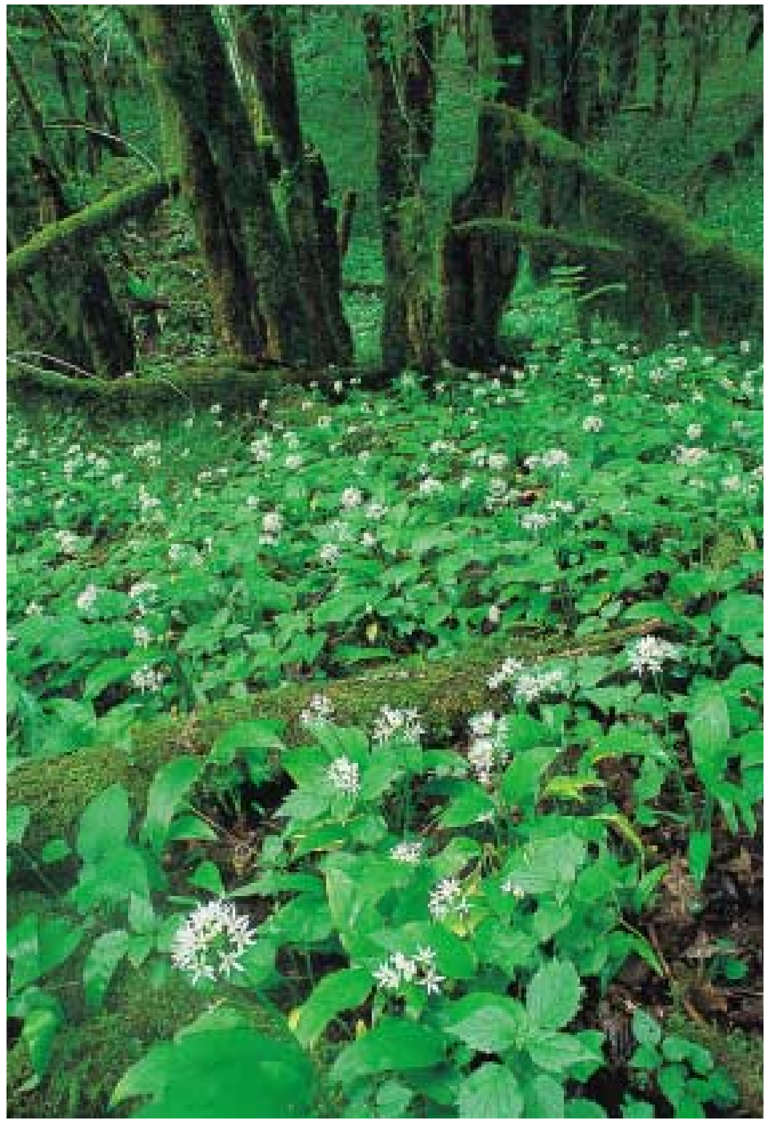
Estimating the minimum size of a reserve means estimating[144]:

- the required size so local fluctuations can be cancelled by others at the reserve level (which is, for example, the case of a sylvatic mosaic in which the respective proportion of each silvigenetic phase is more or less constant): “minimum equilibrium size”;
- or the size of a reserve in which all the sources of internal recolonization are maintained (which limits the risks of extinction): “minimum dynamic size”[70].

Each species having its own unique requirements of regeneration (its own dynamics), the minimum size of a reserve should, in effect, be equal to the minimum area that permits all species to regenerate themselves. This minimal size varies in forests according to the dominant disturbance regime. In forests with "patch dynamics" (§ 2.2.5), the minimum dynamic area of many species is less than 100 ha and reserves of a few hundred hectares will therefore enable these species to survive. In forests with "large-scale dynamics", on the contrary, reserves of several tens of thousands of hectares could still be smaller than the minimum size required by certain species[144]. Certain models make it possible to estimate the minimum size of forest reserves according to the intensity and frequency of disturbances[89].

These concepts can help determine the minimum size of a reserve, but keep well in mind that no reserve, even a very big one, will ever make it possible to safeguard all elements of biodiversity. According to its size, a reserve will help safeguard functional ecosystems, viable populations or, when it becomes too small, just individuals.

With its 6 ha in high water (4 ha of which are wooded), the Ile de St Pryve St Mesmin Nature Reserve is one of the smallest French reserves. Even though it is rich in species (271 vertebrates, 505 plant species) and of international importance for migratory birds, this reserve is much too small to enable the conservation of a sylvatic mosaic of alluvial afforestation. On the other hand, the nature reserves of the Hauts Plateaux du Vercors (16661 ha) and Haute Chaîne du Jura (10781 ha), more than 50% covered with forests, are vast enough to maintain viable populations of a large number of forest species.



Ravin de Valbois Nature Reserve, Doubs (Photo: B. Boisson).

4.3.6 Ageing islands: archipelago of naturalness or floating islands?

For several years there has been a notion circulating in foresters' circles called "ageing islands" ("îlots de vieillissement" in French). It is difficult to find its exact origin, but since the 1980s some people have taken an interest in the question[103,192,193]. Conservationists and silviculturists agree that: first, it would be good to have parcels of old forests with natural dynamics in managed big massifs; and then obtain a dense network of old forest islands that can only be done with the aid of existing legal protection tools.

From an ecological perspective, the appeal of such a network is apparent on looking at metapopulation ecology (§ 4.3.3) since it could permit the maintenance of characteristic species of old-growth forests within the managed massifs. These species are notably the ones that are incapable of surviving in a completely managed forest (absence of their particular habitat), and those unable to survive in

Establishment of a network of ageing islands:

Founding ideas from the 1980s[103,192,193]:

- islands of 1 to 5 ha or including 50 to 100 old trees with a diameter of ≥ 45cm,
- distance between two islands less than 1 km,
- total area of islands: 2 to 3% of the total area of the massif,
- larger areas (≥ 25 ha) have to be present in the massif,
- the islands are maintained during the entire duration of the silvigenetic cycle (phases of ageing and decay included) and are not managed.

Recommendations from the 1997 Manuel of Forest Management[49] and the regional memorandum of the ONF Alsacee of 7 May 2001:

- islands placed in forests with an area > 20 ha,
- islands between 0.5 and 5 ha in size, and comprised of big or old trees,
- all species, habitats and sites concerned,
- choice of zones at low risk of windfall,
- total area of islands: approx. 3% (even 5% in certain cases) of the forest area,
- 5 to 10% of the area to regenerate will be recruited as a complement to or replacement of islands that are dead or decaying during revisions of forest management plans,
- the islands are not strict forest reserves; they are subject to improvement cutting, they produce quality wood and the trees are harvested while healthy,
- age of renewal is understood between the axis of maximum economic exploitability and twice the age of optimum exploitability,
- island cartography is prepared for each forest,
- these regional instructions are applied in State forests and are provided to owners of community forests.

The main weaknesses of these recommendations relate to the ecology of metapopulation and the requirements of saproxylic species:

- if these measures are only applied to large massifs (> 20 ha), forest continuity will not be restored because this continuity is weakest in highly fragmented forest landscapes, where massifs are less than 20 ha;
- the distribution of islands (for example, less than 1 km between islands[103]) should be specified to avoid them all being located in a limited sector of the massif;
- the proposal of "hard cores"[103] (for example, 2% of the total area of the massif for a single large ageing island and 3% for several smaller islands) should be retained;
- if they continue to be managed, these islands will only permit the return of the optimum phase in managed forests, not the phases of ageing and decay (§ 2.2);
- if the location of the islands changes incessantly with the new forest management plans, neither the spatial or temporal continuity of the network can be guaranteed, and yet these characteristics are essential to maintaining numerous species (§ 5.4).

Setting up a network of ageing islands aims, in particular, for the safeguard of certain species characteristic of old-growth forests within managed massifs (Photo: Bernard Boisson).

4

too small an old-growth forest (stochastic* risk of long-term local extinction) and isolated (no possibility to recolonize from a site so close-by). For conservationists, the prospect of a network of ageing islands was therefore that of an archipelago of small old-growth forests within an ocean of managed forests.

Silviculturists' vision of this network is not necessarily the same. As it was presented locally (ONF note, 7 May 2001; Alsace regional department) this network is quite different from the notion of conservationists and scientists. For the latter two, the idea of ageing involves the conservation of islands until the trees die and decompose. For silviculturists, ageing is considered relative to the usual age at which trees are cut, but these trees are cut while still in good health. Comprised of islands whose spatial distribution will be constantly revised (when the islands are managed and new islands are designated elsewhere), the network will thus be formed of "floating islands" of large trees in the midst of an ocean of younger trees. Such a network will certainly benefit some species of birds that only nest in the cavities of big trees (black woodpecker, stock dove, Tengmalm's owl, etc.)[192], habitats[142] that are more and more rare in managed forests (in France, more than 90% of the trees are less than 55 cm in diameter[7]). But the benefit of simply extending the cutting age of stands is very likely to be limited, particularly for saproxylic* species[122].

If one disregards the size of the islands and the proportion of the massif that will be devoted to these islands (two variables that will no doubt continue to be the source of much discussion), the future French "network" of ageing islands (as shown in Alsace) already suffers from two main deficiencies:
- absence of ageing and decay phases, essential to the conservation of saproxylic* species (taxa* that are most threatened by forest exploitation; § 2.2, 5.3, 5.4)
- absence of spatial and temporal continuity of the network since the geographic location of the islands will change constantly.

Studying old-growth forests

Sections 5.1 and 5.2 describe the main principles that managers need to keep in mind to initiate their research. Sections 5.3 and 5.4 show the advantage of studying the different functional (dynamics, structure, specific habitats) and taxonomic* components of old-growth forests with the aid of examples chosen in France or elsewhere.
The aim of this chapter, however, is not to present an exhaustive inventory of research and monitoring methods used in nature reserves (see[189]).

5

5.1. Choosing and evaluating management methods

The study of old-growth forests can have a fundamental or applied aim. In theory, the works directed by a forest manager should above all be applied (specify the most relevant management methods), as their role is to manage a space to attain management plan objectives, not to advance science. These studies should therefore provide tools to "aid decision-making" and for "monitoring".

In practice, since scientific knowledge is often insufficient, managers are at times led to research answers to questions that are relevant to fundamental research.

5.2. Descriptive and comparative studies

Descriptive studies are only of interest to managers if they can be compared (thus becoming comparative!) to reference studies (lists of endangered taxa, indicators, etc.), to similar studies carried out at other sites or if they help measure differences within the same site:*
- *a sampling of several plots will help measure differences in the area; for example, the impact of different management methods in the same massif;*
- *monitoring over time (diachronic monitoring) will help evaluate the impact of a given form of management in the long term.*

It is also important to distinguish between descriptive and comparative studies. The advantage of descriptive studies of taxonomic groups or of the silvigenetic processes of a forest is often limited for the manager.

As described in § 2, by comparing the structural characteristics of a forest at different stages it is possible to understand its silvigenesis. In § 3, it was explained how the comparison between the maximum potential naturalness of a forest and its current naturalness makes it possible to assess its degree of naturalness.

In all cases, it is the "confrontation" of several series of data that allow the manager to glean the most meaningful lessons.

Since every manager must answer their own questions, it is up to them to define (with the help of other specialists) what studies are most relevant to find the answers they seek. In any case, managers should also be as clear and precise as possible in formulating their questions (hypotheses) since no method will help them find a relevant answer to a poorly phrased question.

5.3. The forest

5.3.1 Stand structure and forest dynamics

To study forest dynamics is to study the changes that occur in a forest and their causes.

Forest dynamics can be studied by comparing the structure of stands at different stages of their silvigenetic cycle (synchronic approach) or by observing the structure of a stand at different periods of its evolution (diachronic approach).

A standardized method for designing surveys has recently been proposed for European strict forest reserves by the participants of a European program on scientific and technical cooperation (COST E4). This initiative does not impose the use of the same analytical tools but, by promoting a common method, provides interesting perspectives on comparative structural studies. The only impediment is that the method is difficult to set up and thus too expensive for its use to become widespread.

COST E4 methodology to monitor the dynamics of old-growth forests (protocol already applied in France in certain strict forest reserves[150]):

Sampling:
- a primary plot of 500 m^2 per ha (every 100 m along the transects)
- 4 sub-plots of 2m radius to be installed at the 4 cardinal points (for description of sub-storeys, regeneration and herbaceous vegetation);

Site variables:
- orientation;
- slope;
- topography;
- type of humus;
- type of site;

Dendrometric variables:
(for trees > 5 cm in diameter):
- species;
- diameter;
- height, total and of first branch;
- volume;
- traces of bark stripping or rubbing;
- cavities;
- state of decomposition of dead trees;
- type of dead wood on the ground: stumps, volis, logs;
- diameter of stumps;

Low layers of the sub-plots
- species;
- density;
- damage;

Herbaceous layers of the sub-plots
- list of vascular species present;
- coverage.

"STRONG INFERENCE" APPROACH

The "strong inference"[146] approach answers our scientific interrogations in four steps: (1) devise different hypotheses to explain the problem, (2) select the method likely to exclude one or more of these hypotheses, (3) implement research according to the method adopted and (4) use the same procedure from the start by formulating new sub-hypotheses to test in order to obtain a more and more precise answer to the original question. This approach thus looks like a tree diagram: at each branch, a new hypothesis (question) is presented. This approach is at the origin of the tremendous scientific advances of the 20th century in physics, chemistry, molecular biology. Ecology, with its great level of detail and complexity is a domain of "high-level information" where decades of research can easily be lost if the most relevant hypotheses to be tested are not defined precisely and in advance[146]. The strong inference approach can be easily applied to the study of old-growth forests, by simply taking care to study the easiest system to answer our questions (since the more a system is complex, the more difficult it will be to isolate the exact cause of a phenomenon) and not only testing hypotheses that can be validated, but also refuted (since "a theory can only live if it can be mortally threatened"[146]).

Pollard willows, Alsace (Photo: Bernard Boisson).

MONITORING SPONTANEOUS DYNAMICS OF ALLUVIAL FORESTS IN 6 NATURE RESERVES[34]

- *on 5 rivers: Rhine (2 sites), Rhône, Drôme, Doubs and Loire ;*
- *1185 ha of nature reserves, of which 734 ha are wooded and 416 ha in strict forest reserves;*
- *329 plots (600 m^2 on average) surveyed in 1994 (surveys planned every 10 years).*

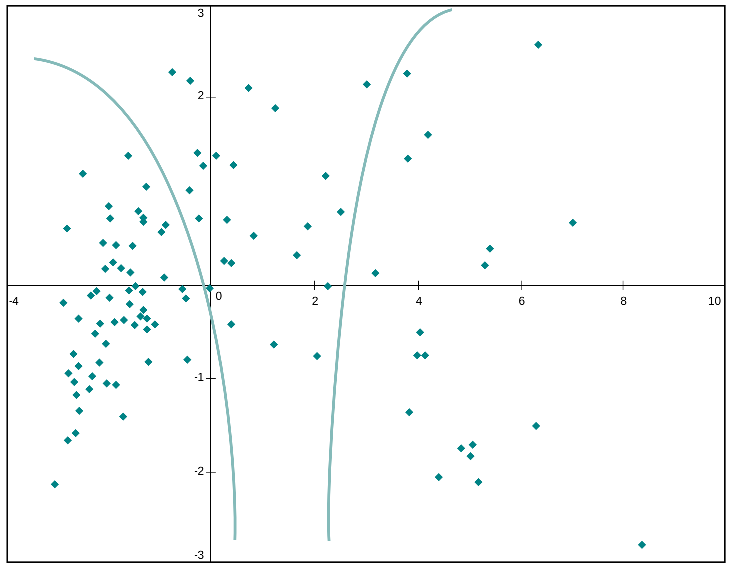
For each plot:
- *dendrometric inventory of each tree > 7.5 cm in diameter: location, species, size, diameter, social status, health condition, presence of lianas;*
- *abundance-dominance indicator of each shrub species (diameter < 7.5cm);*
- *regeneration level of each arborescent species (3 classes: > 0.5, 2 and 4m).*

In total:
- *9417 living trees surveyed and 12099 stems measured;*
- *20 tree species on average per nature reserve;*
- *500 to 600 trees/ha on average.*

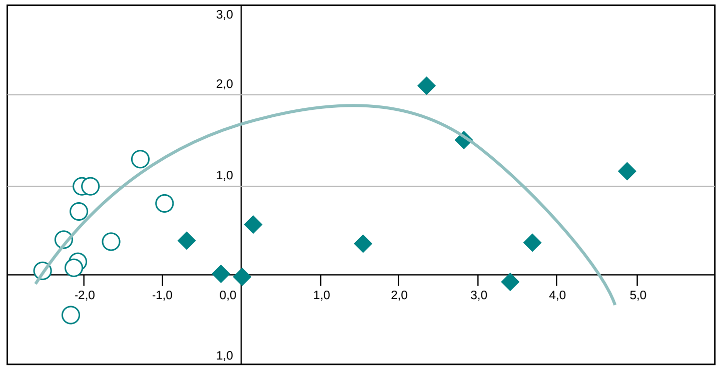
Considering the awkwardness of this type of method, the use of structural indicators (of complexity, connectivity, heterogeneity, etc.) is sometimes prefered[113].

Here are a few examples of methods and indicators used to assess the structure of a forest stand:
- It is possible to organize woody species according to the average density, frequency (number of occupied plots) and relative dominance (basal area*) of each species (in %)[1]. This avoids having too great a contribution of abundant species with small specimens or too small a contribution of dominant species of low density. This gives an initial idea of the structure of a stand without considering its vertical stratification.
- Certain methods developed for animal communities can also be used. Vertical stratification of the forest can thus be measured by the (adapted) Shannon-Weaver diversity index that then becomes an indicator of structural heterogeneity[64,108].
- Factorial analyses are also used to identify the variables that best explain the structure of the stands[16,173]: species, site conditions, management modes, etc. The factorial discriminant analysis is therefore interesting because it makes it possible, when the degree of naturalness of different plots is known, to calculate an indicator of naturalness (fig. p.60).
- The abundance of big dead trees is characteristic of old-growth forests and it is often possible to compare the structure of different stands by a simple graphic representation of this variable[165,174]. National inventories can thus help locate and assess forests with a high degree of naturalness at a country level[110]. At a site level, the representation of biomass and necromass also allow one to evaluate the structural differences according to the type of management[65].

Factorial discriminant analyses and forest structures



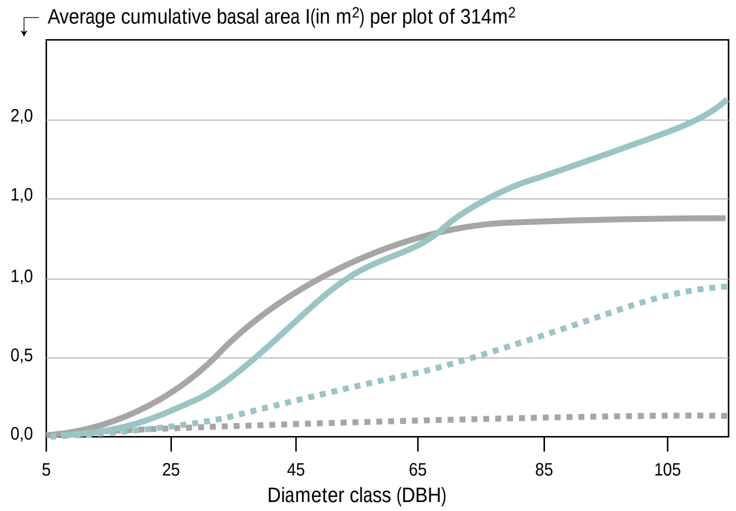
Based on 104 surveys from the Grand Ventron Nature Reserve, this analysis integrates 3 variables for living trees and 3 for dead trees (number of stems, total basal area*, basal area* of the largest tree). This analysis provides an indicator of structural naturalness to correctly classify 96% of the plots in one of the three categories of naturalness (managed forests on the left, old-growth forest on the right, and occasionally and intensively managed forests in the centre)[65].
Old-growth forests are characterized by their high basal area* of dead wood, while the managed plots are distinguished by their high number of living and dead trees (the latter being small in diameter).



The discriminating power of the variables used in the Grand Ventron Nature Reserve is confirmed by the application of this naturalness index to beech plantations of the Forêt de la Massane Nature Reserve (fig. above; very different site conditions). Diamonds: 10 plots of old-growth beech plantations in strict forest reserves; circles: 11 managed plots in adjoining state forests (Gilg, O., Garrigue, J. & Magdalou, J.A., unpublished).

Grand Ventron Nature Reserve
(Photo: Bernard Boisson).

Cumulative basal area and biomass



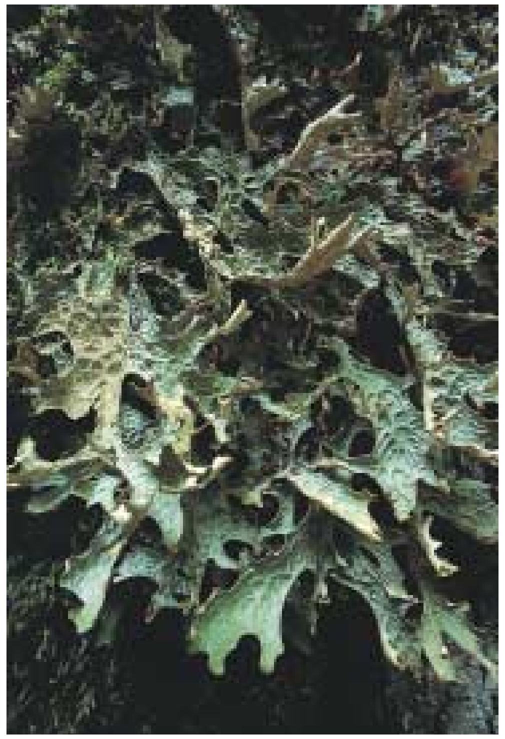
Total cumulative basal area (solid lines) and dead trees (dotted lines) of old-growth forests (green line) and managed forests (grey line) of the Grand Ventron Nature Reserve[65]. The difference between these two forest types is obvious for large living trees and for necromass (8 times greater in old-growth forests) which in managed forests includes only young trees.

5.3.2 Dead wood

More than 20% of forest species depend on dead wood[164]. The absence of ageing and decay phases, rich in dead wood, is therefore one of the main ecological deficiencies of managed forests (§ 2.2).

As of the 1960s, the benefits of dead wood were highlighted by scientists[53,143]. However, it would have to wait until the 1980s for the publication of the first monographs devoted to this particular habitat[78] and its inhabitants[172], as well as a real inclusion of this forest component in the thinking of conservationists and managers.

Subject to exhaustive inventories (including invertebrates, fungi, mosses, lichens and not just vertebrates), the specific richness of forest species (including saproxylics*) and the presence of rare species are more important in old-growth forests than in managed forests. These differences can be explained by the particular dynamics, more stable conditions, and by a greater abundance and diversity (species, diameters, stages of decomposition) of dead wood in old-growth forests (as many as 200 species in a single snag*). This observation naturally makes managers want to increase the absorption capacity of their managed forests for saproxylic* species. What are the volumes, diameters, distributions or states of decomposition of dead wood permitting a species to survive on a site ? By studying old-growth forests where these

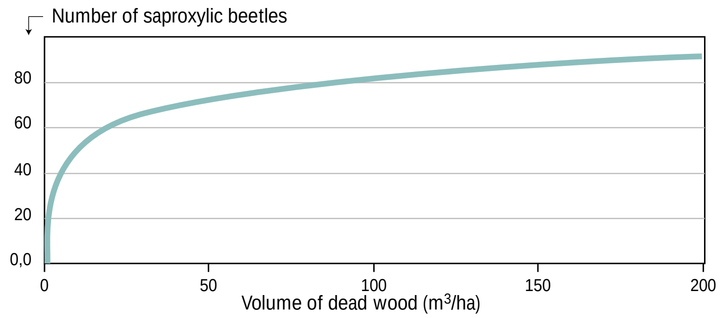


Lobaria pulmonaria, lichen (Photo: Bernard Boisson).

Peltigera sp., lichen (Photo: Bernard Boisson).

species still have viable populations, it will be possible to define recommendations of conservation management for these species in managed forests.

Number of saproxylic Coleoptera and quantity of dead wood[122]:



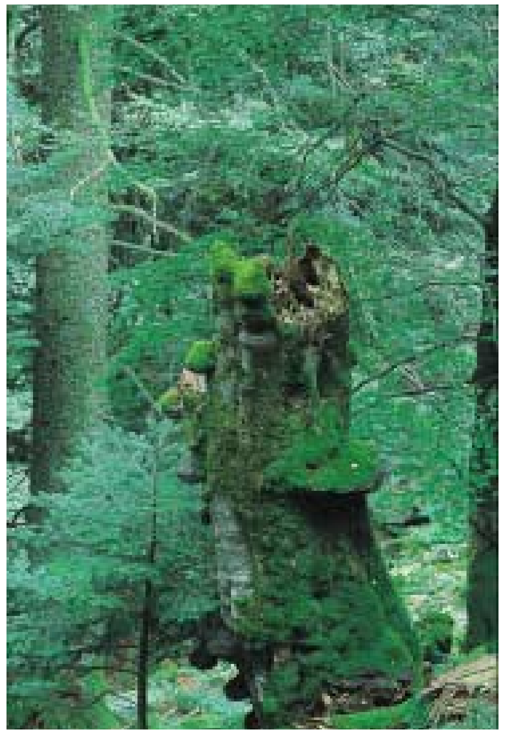
Dead trees with a large diameter and at an intermediate stage of decomposition are the richest in saproxylic species. This figure illustrates the increase in species that can be reached in a managed forest by maintaining dead wood. The non-linearity of this relation explains: (1) the increase, even limited (<30 m^3/ha), of dead wood has a very positive effect on specific richness and (2) that all additional increases of dead wood permit new species to survive (non-threshold value).

Dead wood is an extremely varied habitat (several dozen different micro-habitats; § 2.2.7) and the variables that determine the presence of a species are numerous (box p.63).

Of the 13 studies that compared old-growth forests and mature managed forests, the specific richness of saproxylic species was, on average, 50% greater in the former[164].
The poor quality of old managed forests compared to old-growth forests can be explained by: (1) the absence of certain micro-habitats, (2) a lower abundance and diversity of dead wood and (3) the interruption of the spatio-temporal continuity of micro-habitats[164].

Decomposition of wood, Ile de Rhinau Nature Reserve (Photo: Bernard Boisson).

Studying old-growth forests



Grand Ventron Nature Reserve (Photo: Bernard Boisson).

Variables used to characterize dead wood:
- Species
- Growth habit (snag, log, stump, branches)
- Diameter (measured or divided in classes: small, average, large)
- Age of tree at its death (from core samples) and the date of its death (dendrochronology)
- Presence of cavities, wounds, fungi, bark beetles…
- Bark condition (adhesive, peels off in layers, lacking)
- State of decomposition SUMMARY[139]:
  1. Healthy or nearly healthy wood (entire trees recently colonized by saproxylics*)
  2. Wood in early stage of decomposition (pith still solid)
  3. Wood in advanced stage of decomposition (spongy wood, shreds of bark)
  4. Rotten wood

  DETAILED[170]:
  1. Dead 1-2 years, bark and phloem* still fresh
  2. Wood still hard, bark still present, but no longer any fresh phloem*
  3. Wood partially decomposed, part or majority of bark is peeling on conifers
  4. Majority of the wood completely soft, no bark left on conifers
  5. Almost entirely decomposed, mosses and lichens covering the trunk

  VERY DETAILED[11,38]:
  1. Whole trunk; bark, branches and branchlets intact
  2. Healthy trunk, hardwood, lacking small branches, more than 50% of the bark still present
  3. Wood is soft in places, a few branches still present, more than 50% of the bark missing
  4. Little or no bark left, no more branches, wood is soft with small crevasses, parts missing
  5. Large pieces of wood missing, contour of trunk deformed, start of colonization by vascular plants
  6. Majority of the wood is already thoroughly decomposed, trunk colonized by different herbaceous plants, shrubs and trees
  7. Humification close to 100%, trunk difficult to distinguish, no more traces of hard wood

  OR A MORE ORIGINAL MEANS OF CHARACTERIZATION[102]:
  1. Hard wood that a knife cannot penetrate except for a few mm
  2. Wood still fairly compact; a knife can penetrate 1-3 cm
  3. Soft wood that a knife can penetrate over half the tree's radius
  4. Wood completely decomposed that a knife pierces right through
- Site conditions, etc.

Studying old-growth forests

The state of decomposition of dead wood is particularly important for the study of saproxylic* species. Every stage of decomposition harbours a specific community, and as numerous studies have shown, particularly in the Forêt de la Massane Nature Reserve[41-43,185], it is possible to observe true successions of species throughout this decomposition.

Four main stages of decomposition can thus be distinguished (with certain variations depending on whether it is a standing or downed dead tree, conifer, broad-leaved tree, etc.)[164]:

1. Onset of Coleoptera (Scolytidae, Curculionidae and Cerambycidae). Begin at death of the tree and lasts 1-2 years. By colonizing dying wood, scolytids bring other saproxylic* species with them (140 for *Ips typographus*). The cambial* zone is rapidly colonized owing to the galleries excavated by these Coleoptera.
2. Begin during the second year following the death of the tree and can last 5 to 10 years. This concerns species that will feed on phloem* remains and species associated with the development of fungi under the bark and in the surface wood. First fructifications of polypores*.
3. Phloem* has been consumed and the subcortical habitat disappears as the bark falls off. Stage characterized by mycophagous* species, their parasites and their predators. Every species of polypore* harbours a specific community and sometimes even specific species.
4. Begin when the majority of sapwood* is consumed and the duramen* starts to decompose. Saproxylic species are becoming rarer (pith provides little nourishment) and are replaced by litter invertebrates that use the trunk for shelter (molluscs), to estivate (ground beetles), hunt or nest (ants).

These last 15 years, the study of dead wood has focused on three themes: (1) explaining the availability of dead wood according to disturbances, silvigenesis and forestry, (2) the role of dead wood in the dynamics of nutritive elements and carbon and (3) its importance for the many saproxylic* species.

Perforations made by woodpeckers, Ile de Rhinau Nature Reserve (Photo: Bernard Boisson).

METHODS TO EVALUATE RATES OF DEAD WOOD DECOMPOSITION

(see also Fig. § 2.2.8 & Tab. § 6.3.3):

- *diachronic method: monitoring the decreasing density of a piece of dead wood over time;*
- *synchronic method: comparison of different densities of dead wood (of the same species and site), dead at different times;*
- *mixed method: simultaneous use of both methods to measure the decreasing density of dead wood (for example, over 10 years) on different trees whose death date is known.*

INVENTORIZATION METHODS FOR DEAD WOOD[175]:

Tree volume:

- *Standardized functions: for the majority of species and regions there are graphs that make it possible to estimate the volume of a tree according to its diameter and its height.*
- *Sections: more difficult yet more precise, this method consists of measuring sections of the trunk at different heights. The volume of the cylinders of each section are then summed.*

…/…

Total volume (or basal area):

- *Plots: the volume of all dead tree and branches present is added on a plot of a given area. Systematic sampling will thus make it possible to estimate the average necromass* of a massif.*
- *Strip transect: same principle but the plots are replaced by strips (equal to rectangular plots) of a given size.*
- *Line transect: with this method, only dead wood situated on the line is surveyed, not the snags. This method, particularly interesting when dead wood is plentiful or irregularly shaped, permits a quick and precise assessment of necromass* on the ground. The volume of dead wood on the ground (V) in m^3/ha is calculated by the equation $V = \pi^2 \sum d^2/8L$, where L is the length of the transect (in m) and $\sum d^2$ the sum of the squares of the diameters measured (in cm).*
- *Other methods that are more complicated or take more time to implement are sometimes used (aggregative methods, exhaustive inventories, etc.)*

The choice of a sampling method and plan will depend on the time available and the results expected. When necromass is compared among other surveys (species, structures…), plots will often be preferred. When the objective is to estimate the volume of dead wood, the transect and strip could be preferred. It is also possible to use several methods simultaneously by, for example, surveying the volume of dead wood on the ground by a line transect (quick and precise) and the volume of standing dead wood by a strip transect (centre delimited by the line transect).*

These research programs now need to be continued around eight axes[91]:

- Decomposition rates of dead wood, essential variables to study dead wood dynamics. They are only known for a few species (§ 2.2) and the impact of site conditions, state of decomposition, silvicultural practices and the disappearance of certain saproxylic* species on these rates is poorly known.
- Modelling of forest dynamics makes it possible to assess the volumes and types of dead wood present throughout the silvigenetic cycle. This will give the volumes of dead wood produced in natural forests and what volumes need to be restored in managed forests to allow the survival of certain species.
- The dispersal ability of species determines their survival (§ 4.3). Increased knowledge of these abilities is needed to plan the ecological corridors between different population cores or, if fragmentation is too great, to extend favourable habitat around existing cores[112].
- The critical thresholds of the viability of saproxylic* populations are little known. By comparing the dispersal and colonizing ability of species with the dynamics of dead wood, it should be possible to predict their long-term viability.
- The loss of genetic variability of an isolated population can decrease its chances of survival. The number of studies devoted to this subject should be increased.
- The development of standardized methods to assess the diversity of certain organisms is also desirable. Ex.: only certain saproxylic* fungi produce fructifications, which distort the inventories.
- The study of disturbances and youth phases of old-growth forests is less widespread than for old-age phases. It is advisable to improve our knowledge of these stages in order to better assess the impact of silvicultural practices.
- The development of ecological management methods (allowing the conservation of dead trees) with small economic implications is also a challenge of the future.

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5.4. Species and communities

5.4.1 Vascular flora and the description of forest habitats

The herbaceous layer reflects above all the site conditions of the forest. Its composition thus helps determine, with the aid of catalogues of forest stands, the type of “climax*” forest stand of a site. The existing stand, by its similarity or its divergence with this potential climax stand, could thus serve as a basis for an initial assessment of a forest’s degree of naturalness (§ 3.1).

The vascular flora also reflects the diversity of forest micro-habitats. Every gap, rocky protrusion, stream, log, reveals particular site conditions. Forest exploitation can locally increase the specific richness of a forest by favouring the development of heliophyte* species. These species, certain of which are found in old-growth forests, are thus common in managed forests. Yet these changes do not lead to an increase in biodiversity at the regional level (§ 3.3).

The number of vascular plants unique to old-growth forests is low [126,144] and little research has been devoted to them[189]. Moreover, the ecology of these species (shade-tolerant species, geophytes*, hemicryptophytes*) is often different from one region to another[81]. *Sorbus torminalis* and *Mercurialis perennis* indicate, for example, the presence of old forests in certain regions[144,185] but are abundant elsewhere in managed forests. The relative abundance of certain species may be indicators of naturalness at the site level. Thus, in the Grand Ventron Nature Reserve, European mountain ash (*Sorbus aucuparia*) is much more frequent in old-growth forests and bramble in managed forests. As a general rule, the limited ability of these old-growth forest species to colonize new sites are linked to their limited dispersal ability, small production of diaspores* and lower competitiveness.

In certain cases, the presence of a particular species can indicate the historical absence of humans and, in fact, the presence of old-growth forests. Certain species (such as yew) have been systematically exploited (cabinet-making) or removed to avoid that domestic animals eat them[159]. Others (*Ribes uva-crispa, Vinca minor*), on the other hand, are associated in certain regions with ancient human occupation[50].

The analysis of a forest’s seed bank (seeds waiting in the soil to germinate) is equally instructive. Among the tens of species (per m^2) present in an old-growth forest[107], certain have completely disappeared from managed forests. The restoration of plant communities of a natural stand starting from the seed bank is therefore not always possible[10]. To be complete, this restoration should in certain cases be “active” (§ 3.2), for example, by reintroducing species (§ 6.3.4).

Rowan (Sorbus aucuparia), Vallée de Chaudefour Nature Reserve (Photo: Bernard Boisson).

Clearcutting and replantation of forests result in the disappearance of more than 97% of Trillium ovatum (North American wood lily) and the survivors practically no longer reproduce. Even in non-managed forests, specimens located at less than 65 m from fellings stop reproducing[93]. This example shows to what extent certain species are affected by silvicultural operations and fragmentation of forest massifs (§ 4.3.2-3).

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In the Ravin de Valbois Nature Reserve, inventories made of only 0.5 ha of non-managed forests have made it possible to identify >200 species of fungi and several tens of bryophyte species[106]. In the Forêt de la Massane Nature Reserve, more than 300 species of fungi (partial inventory), 200 species of lichens and as many bryophytes[185] have been inventoried.
① Armillaria mellea (common on the stumps of dead or dying trees), ② Ganoderma sp. (polypore),*
③ Mycena renati (a genus that includes several tens of species) and ④ Pholiota aurivella (edible; on dying trees) (Photos: Forêt de la Massane Nature Reserve)

5.4.2 Bryophytes, lichens, fungi and forest continuity

The study of “lower” plants (non vascular) is particularly interesting in old-growth forests. Sometimes spectacular (fructifications of certain polypores* >1m in diameter[144]), these plants have an important role in the functioning of forests. Certain species of the genus *Lobaria*, a slow-growing corticolous* lichen typical of old-growth forests, can fix up to 10 kg of atmospheric nitrogen per ha and per year. Fungi, for their part, in their mycelial networks fix a large part of the mineral elements released during the decomposition of dead wood and thus help redistribute these elements, essential to the growth of young trees, in a radius of several meters[17]. Soil mycorrhizae also play an essential role in the functioning of forests. The composition and diversity of these species are greatly disturbed by intensive logging[25]. Mosses, many species of which characterize the advanced stages of dead tree decomposition[38], ensure, among other things, maintenance of high humidity at the surface of trees and the soil, humidity that is essential to the development of numerous species, including tree species themselves.

Rare forest lichens often occupy the trunks of large living trees whereas polypores* colonize dead or dying trees[169], particularly the largest ones[132]. The presence of large trees and the abundance of dead wood explain the greater richness of assemblages of lower plants in unmanaged forests[133] (a third of the 600 bryophytes in Sweden can be found in only 20 ha of old-growth forests[135]; in the Forêt de la Massane Nature Reserve, 34% of the 238 fungi inventoried are saproxylics[185]). Managed forests often harbour less than half of the saproxylic* fungi found in old-growth forests[169]. Saproxylic species are increasingly rare in Europe, and a number of

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these species are today on the Red Lists of endangered species (1/3 of polypores* are endangered in Sweden[171]). Since lower plants harbour many specialized insects (§ 5.4.3), which in turn are food for vertebrate insectivores[145], their bio-indicator value has often been stressed.

Numerous studies show the bio-indicator qualities of lower plants and notably that of forest lichens. The majority of these works concern pollutants and, more recently, climate change. Ecological continuity (forest cover, fires, area stability) can also be assessed with the aid of lichens[82]. In Europe, *Lobaria pulmonaria* has often been used to evaluate the temporal continuity of old-growth forests. The thallus* of an individual can maintain itself several decades on the same tree. Since sexual reproduction is rare, the dissemination of sori (masses of cells produced at the surface of the thallus) ensures the survival of the species[71]. Heavier than spores, the majority fall vertically and their dispersal is limited to a few meters. If the continuous presence of large trees is ruptured, this species will not be able to survive. There are about thirty similar lichens in the oak plantations of Western Europe. Lichens have been used particularly in the United Kingdom[152] and United States[160] to establish "indicators of ecological continuity".

Polypores*, for their part, provide interesting study perspectives of spatial continuity. Unlike *Lobaria pulmonaria*, these fungi are able to colonize habitats (dead or dying trees) that are ephemeral, scattered and appear at random. Although some of their spores (several thousands produced per hour and per cm^2) can be transported over long distances (several hundreds of km)[177], most fall in the immediate proximity of fungi (furthermore, two spores have to land on the same spot so the colonization of the fungus can begin). If the density and the renewal rate of large dead trees are too low, the spatial continuity of the "large dead tree" habitat will be ruptured and these species will become extinct. This phenomena is particularly obvious in certain French beech forests inside strict forest reserves where *Fomes formentarius* colonizes in great numbers and with great speed all the dead or dying trees while in neighbouring managed parcels and with identical site conditions, their colonization is only occasional even when a large-diameter dead beech is left in place. Certain saproxylic* fungi are also excellent indicators of temporal continuity. In Finland, for example, several species (including *Fomitopsis rosea*) are typical of natural forests but absent from managed forests, even mature ones[168]. Lastly, it should be noted that certain species are susceptible to edge effects that give rise to unfavourable microclimatic conditions[171].

Lobaria pulmonaria is a slowly colonizing lichen whose presence is associated with that of large trees. Because of this, it is an indicator of forest continuity
(Photo: Bernard Boisson)

The regeneration of a regular high forest after a storm (natural disturbance) makes it possible to maintain a greater number of lichens than regeneration after a clearcut [148].

Species that are slow colonizers (a few meters per year at most) are all potentially bio-indicators of temporal forest continuity.

The study of lower plants, which is difficult (many species, uncertain identification), has the advantage of a greater sampling flexibility compared to insects. Unlike insects, these species are immobile and sometimes have a very long lifespan, and surveys are not distorted by the activity of the species (blooming periods, rain, etc.). Nevertheless:
• the absence of a species characteristic of old-growth forests does not necessarily indicate that the habitat is unfavourable (§ 4.3). It is therefore recommended to study a large number of sites or several taxonomic groups (for example, lichens and Coleoptera) to qualitatively evaluate a forest habitat[129];
• the presence of these species is not sufficient to give the habitat a "good score". Certain polypores* can, for example, survive despite the fragmentation of a massif but at densities that no longer permit their associated fauna (mycophagists, for example) to survive[97]. Moreover, in the case of logging, certain typical species of old-growth forests will be able to survive awhile on the "worthless" dead wood left in place[169] (cf. "species credit": § 4.3.3).

5.4.3 Saproxylic* insects and diversity of micro-habitats

The study of forest insects provides much information but is difficult to implement: specialists are few and greatly in demand, reference books are rare, forest insect ecology is not well known, the method of capture (death of the animal) contradicts forest regulations, etc. Managers therefore often focus on the best known family: Coleoptera.

In addition to being well known (for example, long-horned beetles), Coleoptera have the advantage of being numerous (as species and individuals) and well represented in forest environments where half of the 10,000 French species can be found[48].

Some are ubiquitous and are found in all forests, others (certain carabid beetles) need big rotting stumps and are therefore more localized. The most remarkable and typical of old-growth forests are undeniably saproxylic beetles[22], which contribute for wood decomposition.

Their high diversity is combined with a high degree of specialization. Every ecological niche (peeling bark, sap flow, decayed cavities, woody humus, fungi, dead wood, dying wood, decomposing wood, etc.) has its own community of saproxylic beetles belonging to different trophic levels (detritivores, xylophages, mycophagists or predators).

French old-growth forests harbour several thousands of species of saproxylic beetles. As each has a particular ecology, their diversity depends on that of the micro-habitats (§ 2.2.7).

① *Rosalia alpina (adults on freshly cut trunks and dead beeches; larvae in trunks of various broad-leaved trees),* ② *Prionus coriarius (larvae in decomposed stumps of certain broad-leaved trees),* ③ *Aegosoma scabricorne (larvae in old trunks of standing dead trees),* ④ *Anthaxia midas (larvae in maple trunks and branches),* ⑤ *Trichodes cf leucopsideus (larvae and adults prey on xylophagous insects)*[48], ⑥ *Lucanus cervus (adult consumes the sap of wounded oaks; larvae in stumps and trunks).*
(Photos: Forêt de la Massane Nature Reserve)

It is estimated that 20% of the invertebrates of the original European forests are saproxylic (37% of Coleoptera inventoried in the Forêt de la Massane Nature Reserve[185]). Logging and especially the growing scarcity of dead wood have already led to the disappearance of a large number of these species[96]. Certain ones, associated with small pieces of dead wood or the initial stages of wood decomposition (pioneer xylophages) have survived in managed forests. But many have become scarce and are no longer present today except in old-growth forests in the form of relict and isolated populations[144]. This is the case with species for which one part of their cycle (for example, the larval stage) takes place in large pieces of dead wood in an advanced stage of rotting, habitats that have disappeared from managed forests.

When they survive, these species are evidence of both a natural functioning of forests (presence of ageing and decay phases, continuity of dead wood) and of a satisfactory continuity of naturalness[92] (§ 5.4.2).

Monitoring saproxylics* over time (diachronic monitoring) or a comparative study of sites managed differently (synchronic monitoring) can help identify the conditions necessary to maintain them and assess the quality of the environment in terms of naturalness.

However, considering their great specialization, one must respect some rules when doing comparative inventories:
• use the same protocols and, if possible, permanent traps (several

In Germany, 100 of the 375 saproxylic Coleoptera inventoried in six old-growth forests in the south of the country are endangered[23] *(idem for 19% of the 800 Finnish species).*

In Finland, Pytho kolwensis, a Coleoptera, is only found in wet spruce forests (in peat bogs) that have remained intact for 170-300 years, are rich in dead wood (73-111 m^3/ha) and in which the density of large dead trees on the ground has been constant since at least 100 years[166]*.*
Of the 553 saproxylic Coleoptera found in some of these spruce forests, 232 are associated with dead wood and 78% are more abundant in old-growth forests.

In Sweden, natural spruce forests harbour 5 times more insect species than the adjacent managed forests. This richness is correlated to the abundance of lichens (habitat of many insects) and also probably explains the largest abundance of forest passerines[145]*.*

The impact of fragmentation on a complete group of saproxylic species has been brilliantly highlighted in boreal forests[97] *where a system with three trophic levels (lignicolous fungus, mycophagous butterfly, parasitic fly) was studied in old-growth forests that had been isolated for a fairly long time. Three fourths of non-fragmented sites (of a massif of 1300 ha) harbour all these levels. To the contrary, only 25% of forests fragmented for 2-7 years still have these 3 levels, and 30% of forests isolated for 12-32 years have no level whatsoever (the others having only fungi). This example also illustrates concepts of "credit species" and "depth of extinction"*[77] *(§ 4.3.3).*

weeks) in order to avoid the distortions associated with hatching periods or different activities;
• for diachronic studies: reuse the same trapping sites;
• for synchronic studies: formulate clear hypotheses and select appropriate sites. If one desires to study the effect of fragmentation: choose sites that only differ by the size of the massifs, the distance between massifs or the duration of isolation of the massifs. If the objective is to highlight the impact of a particular management mode, the sites being studied should only differ for this variable and have a substantial site similarity;
• carefully document site conditions and the current and past management modes of the sites studied;
• choose a qualitative approach (families and species) rather than a quantitative approach (individuals), which is more difficult and sensitive to the frequent numerical fluctuations of insects.

In protected old-growth forests, managers often concentrate their research and communication efforts on certain prominent species. The Cerisy Forest Nature Reserve is internationally known for a rare variety of *Carabus auronitens*, the Grand Ventron Nature Reserve has produced a CD ROM in which it presents *Sinodendron cylindricum* (a characteristic beetle of old-growth forests), the Forêt de la Massane Nature Reserve is doing its utmost to inventory all the woody humus filled cavities of large trees harbouring a rare "priority species" (known in this forest since 1875) according to the European Habitat Directive: *Osmoderma eremita*[63]. A dense network of cavities at the site level is essential to the survival of this species[149] that, as many other cavity insects, has very limited dispersal ability (several hundred meters). Only 15% of the adults studied left the tree of their birth. Every favourable tree thus harbours a population distinct from a larger metapopulation (see § 4.3.3).

5.4.4 Birds and forest stand structure

Before the current craze for "small organisms" (invertebrates, lower plants), birds were the primary subjects of forest research (aside from woody vegetation). The close relationship between avifauna and forest structure has been thoroughly described in most regions[61,128]. It is known today that each phase of silvigenesis corresponds (for given site conditions) to a specific community. The same communities are sometimes found in managed forests and old-growth forests[64]: regular old high forests have, for example, a physiognomy that is comparable to that of the optimum stage of old-growth forests. Most bird species have a ubiquitous behaviour in terms of forest naturalness and are unsuitable to indicate the natural character of a forest.

The ornithological interest of old-growth forests can be measured by the presence or abundance of particular species. Those nesting in cavities (17% of species in the Forêt de la Massane Nature

Reserve[185], 34% of nesting birds of the Grand Ventron Nature Reserve[64]) are more abundant in old-growth forests. The tree creeper and nuthatch are the species whose densities are best correlated with the degree of forest naturalness in the Grand Ventron Nature Reserve. For these species that prefer old forests (abundant food on the trunks and in the bark of the big trees), the lack of favourable cavities (size, tree species, depth, exposure, height, density) is one of the limiting factors. It has thus been possible to multiply the density of tree creepers by 13 in certain managed forests after the placement of nest boxes[37]. Some of these cavity nesting birds (black woodpecker, but also the stock dove and Tengmalm's owl, which are dependent on the cavities made by the former) are only able to nest in large cavities. The presence of large-diameter trees is an additional requirement in terms of habitat, a requirement that the future networks of ageing islands (§ 4.3.6) may be able to fulfil.

If certain cavity nesting birds still find nesting sites in managed forests, those species that feed on saproxylic* insects are much rarer and are often excellent indicators of naturalness. The white-backed woodpecker, which currently only remains in a few European old-growth forests, is an example. Its presence is linked to that of dead wood and its specialization for saproxylic* insects is such that in certain regions its presence has been used to identify the richest zones of threatened Coleoptera[119]. The three-toed woodpecker has a fairly similar ecology[88] but prefers coniferous forests. Spruce mortality owing to forest decay and the outbreaks of bark beetles (one of its main prey) that followed (§ 6.1) seem to have been favourable to this woodpecker species, which is currently recolonizing certain regions (Prealps of Vaud, Black Forest in Germany)[44].

Lastly, it should be mentioned that old-growth forests harbour much more stable communities (in specific richness and in abundance) than managed forests[183] and they provide better wintering conditions for sedentary species (by having the greatest diversity of forest micro-habitats)[145].

In the coniferous forests of North America's Pacific coast, numerous vertebrates depend on old-growth forests. In certain of these forests, more than half of the species use dead wood as food or to reproduce: certain salamanders (look for dead trees in an advanced stage of decomposition), white-tailed eagles (nest in trees that are on average more than 400 years old), red tree voles (live in the canopy of old Douglas fir forests), Northern flying squirrels (seek cavities), spotted owls (feed mainly on the latter two species)[144].
The spotted owl, which depends up to 90% on old-growth forests and whose densities are very low (1 couple for 800 to 1600 ha of old-growth forest) is a spearhead of North American forest conservationists. To save it, modelling based on the theory of metapopulations recommends minimum conservation of 15 to 30% of original old-growth forests in zones spaced 20 km apart on average and each able to harbour 15-25 couples[74].

Logs in Ravin de Valbois Nature Reserve
(Photo: Bernard Boisson)

Bialowieza Forest, Poland (Photo: Bernard Boisson)

The many ornithological works devoted to the harmful effects of forest fragmentation on bird reproduction and survival[6,87,194] are not mentioned here but see § 4.3 and 5.4.5.

5.4.5 Mammals and the fragmentation of forest massifs

With the exception of the flying squirrel, European mammals are not strictly dependent on old-growth forests. The abundance of several small mammals is, nevertheless, highly correlated to that of dead wood[52] and many mammals rest, reproduce and feed in tree cavities, in fact having larger and more stable populations in old-growth forests. In the Forêt de la Massane Nature Reserve, 26% of the mammals use cavities as their main home[185]. Tree cavities are sometimes the only conducive habitats for bat reproduction. Likewise, large dead trees (> 1 m in diameter) and large stumps torn by the wind are the only hibernation sites for bears in certain regions.

The history of large mammals is closely linked to that of forests. Killed for their flesh (ungulates) or their fur (carnivores), they were the first to suffer the influence of humans in the forest. Solitary (except for wolves), having large territories and not reproducing every year, large carnivores have naturally low densities. It is hunting, excessive attendance and fragmentation, more than the alteration of forest structures that, in the majority of cases, has caused the decline or disappearance of these predators. Their vital territories, for example, are from several hundred to several tens of thousands of hectares[57,144,153] and the majority no longer find the necessary conditions in Europe (due to highly fragmented forests) to maintain viable populations. The only means today of reconciling their presence with human activities is the maintenance or restoration of large interconnected wooded areas of several thousands of hectares.

Even in Bialowieza National Park (Poland), the protected area (47 km^2) is not capable in itself of maintaining lynxes and wolves (average individual territory, respectively: 71 and 217 km^2). The area of the entire forest massif (1250 km^2) is also considered insufficient for the reintroduction of wolverines (individual territory estimated for the region: 1000 km^2 [57]). The theory of "metapopulations" was also applied in this massif to propose a development plan compatible with the reintroduction of wolverines and bears[57]. By combining the protection of several big national parks that are interconnected and surrounded by buffer zones, Poland will perhaps one day recover its predator guild* while continuing to devote the majority of its territory to production activities.

Remember that without these large carnivores, even a forest protected as a strict nature reserve will always show a lack of naturalness. These mammals are actually the only ones to respond in a dynamic way to the densities of their prey (functional and numerical, "density-dependant" responses) and thus able to restore a global equilibrium "forest – herbivores – predators"[14]. In their absence, the herbivore populations will have a tendency to grow disproportionally until they attain or exceed the carrying capacity of their environment, and cause forest damage and disturbances to the silvigenesis. Hunting, even when part of a rigorous management (adherence to hunting management plans), cannot completely substitute for predators to maintain this fragile dynamic equilibrium (unlike predators who respond immediately to variations in the abundance of their prey, hunting is a delayed response). Indeed, a time lag of several months for a predator (or hunter) to regulate the population of its prey has a tendency rather to destabilize the system[67,76]. Providing fodder, sometimes recommended to limit forest damage done by game animals, is not an appropriate solution either because maintaining abnormally high densities only defers the damage that will then sometimes be even more pronounced.

5.4.6 Other examples…

MOLLUSCS

Snails and slugs are good candidates to study the temporal and spatial continuity of old-growth forests[21,130]. Fragmentation and loss of habitats, notably forest habitats, have already caused the disappearance of many molluscs: close to 40% of animal extinctions documented since the 17th century[20]. As a result of their extremely limited mobility, it seems more advisable to study them than *Lobaria* lichens (§ 5.4.2) which, although rare, sexual reproduction occasionally allows to colonize new distant sites. The use of molluscs as indicators of naturalness is nevertheless limited by: (1) the reduced number of widely-distributed species (many are endemic to small geographic zones), (2) the poorly known ecology of the species and, in particular, their preferences for different forest micro-habitats and (3) significant variations in the composition and abundance of malacostracan communities according to soil pH, variations that make comparisons between sites difficult.

MOLECULAR BIOLOGY

The study of DNA today offers new perspectives by allowing the identification of individual organisms (particularly interesting in studying the population dynamics of saproxylic species). It allows one to better understand the evolution and distribution of species, to evaluate the impact of fragmentation on the risk of extinction for local populations, to determine the origin of certain species, etc. The study of a threatened saproxylic* fungi (*Fomitopsis rosea*) has, for example, made it possible to show the genetic impoverishment of small and isolated populations[85,177]. Fragmentation is also undoubtedly the cause of the genetic drift observed of certain isolated populations of mycophagous* beetles[92,164].

MODELLING OF PREDATOR-PREY INTERACTIONS

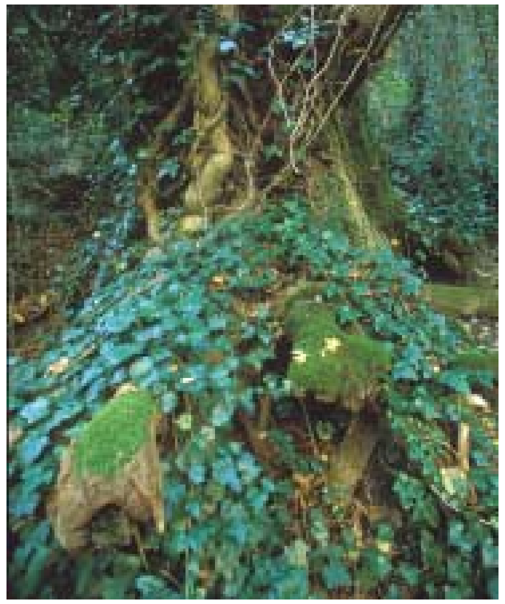
Just as for dead wood (§ 6.3), modelling the dynamics of herbivore populations and their predators is very instructive for managers. By adapting traditional "predator-prey" models13,123, it is possible, for example, to estimate the "equilibrium densities" of herbivores and their predators (densities towards which the system tends to return to after a disturbance/fluctuation[51]). These densities help:

- *evaluate the "naturalness" of herbivore and carnivore populations: the further their densities are from the equilibrium values (and of natural fluctuations), the more they are disturbed;*
- *determine if these populations are experiencing growth or decline;*
- *and without their natural predators, determine the "natural" densities of herbivores (in equilibrium with the environment) that hunters should set as a target, the other alternative being to favour the return of native predators (§ 6.3).*

Other perspectives for managers

In the preceding chapters, I have given a detailed description of conservation measures, management and scientific monitoring that should be implemented to ensure the maintenance of a satisfactory network of old-growth forests. Unfortunately, these measures are not sufficient to ensure their long-term conservation and this chapter presents a few accompanying measures that are equally important.

6.1. Destroy the myths



Lianas, clematis in alluvial forests or ivy as here in the Gorges de l'Ardèche Nature Reserve, are often destroyed in managed forests under the pretext that they "choke" and cause the death of the trees that serve as their support (Photo: B. Boisson).

Stinging and thorny species, unpopular, are often cited as examples to caricaturise the "abandoned" forest. Yet nettles and bramble are ruderal species whose presence is above all associated with human activities: the former, nitrophiles, proliferate on enriched soil; the latter characterize zones where the soil has been turned several times. In the Massif du Grand Ventron Nature Reserve, bramble is, moreover, one of the plant species that discriminates the most clearly between managed forests and old-growth forests where it is very rare.

6.1.1 Is forestry compulsory?

The most widespread and harmful myth for strict forest protection programs is that forests could not maintain and develop themselves without human intervention. It is true that certain plantations of species exogenous to the site (spruce in plain, American oak, etc.) would be quickly replaced by more competitive indigenous species if the silviculturist stopped maintaining and regenerating them. Old-growth forests, to the contrary, replenish and maintain themselves perfectly without human intervention. To believe and insinuate that the forest would be replaced by a "mess of scrub" if humans ceased to maintain it is just pure nonsense. Forests existed long before Man domesticated them and they will undoubtedly outlive him.

6.1.2 Insect pests

The farmer and silviculturist have always had to combat destructive insects whose rapid proliferation can ruin their work.

Dead wood has for a long time been eliminated under the pretext that it harboured such fauna. Our better understanding of the ecology of these pests now allows us to take a more measured approach.

Among the thousands of forest species (more than 10,000 surveyed in Fontainebleau Forest), less than fifty are true insect "pests". Most, such as the well-known scolytids, are only secondary pests. They usually colonize the trunks of dying or recently dead trees and not the trunks of healthy trees. The problem linked to scolytids is that in the case of a severe outbreak (when there are simultaneously many dead or dying trees allowing many scolytids to reproduce), those scolytids that attack healthy trees (behaving from then on as primary pests) will have a sufficient impact to cause the death of healthy trees. The winter storm of 1999, by knocking down several tens of millions of cubic meters of wood, generated favourable conditions for such outbreaks, and it is estimated that a million cubic meters of softwoods were weakened by these attacks in 2001.

Should dead trees be removed under the pretext that they form potential breeding grounds for outbreaks of scolytids? Note, first of all, which forest species are concerned. Damage (by primary pests) caused to pine trees was observed in France for the first time in 2001 following the storm of 1999. Such damage is therefore exceptional. On fir trees, damage intensity is linked to the trees' state of health (hydrous stress in case of drought). The lack of substantial damage on fir trees in 2001 (humid Spring) despite the large quantities of dead wood on the ground indicates, therefore, that it is not necessary to remove dead fir trees to combat its scolytids. The use of species and ecotypes adapted to site conditions is a more timely measure. Spruce forests are more affected by scolytids than any other forest type. In serious cases, several thousands of hectares can be affected. But although certain scolytids can disperse themselves about 5 km around their reproductive zone, damage caused to living trees are rarely observed at more than a few hundred meters from the epicentres of outbreaks. Keeping dead spruces in strict forest reserves does not create any sanitary problem whatsoever if no managed spruce forest is within close proximity. In the opposite case, it would be advisable to define a buffer zone in which scolytids would be fought or the spruces replaced (at the time of the next forest management plan).

Note that wood storage zones can form much more dangerous sources of outbreaks than dead trees scattered in the forest. Finally, let us also not forget that if old-growth forests are often blamed for the risks they incur to production forests, the opposite is also true. Following storm damage in spruce plantations, the outbreaks of scolytids have sometimes also spread from these production forests to adjoining strict forest reserves.

It is therefore advisable to remain objective when considering the real outbreak risks of insect pests from strict forest reserves. Those scolytids that can be primary pests often represent less than one percent of the total number of scolytids[121], and in the absence of a severe disturbance (such as the exceptional storm of 1999 or chronic stand weakening by acid rain), their impact on production forests is almost nil. Since their favourite habitat is dying or recently dead trees (before the phloem* dries), it is only in the case of massive tree deaths that scolytids will be able to pullulate, but the quantity of dead wood in an old-growth forest is not a risk factor[120]. Because this wood has accumulated over long periods and is constantly renewed, the proportion of "recent" dead wood (less than 2 years) is usually relatively low. Certain scolytids (living in stumps and other logging residues) are more abundant in managed forests than in old-growth forests[120].

6.1.3 Hazardous trees

Another recurring problem is that of the risk associated with falling dead trees or branches.

Three-toed woodpecker (Photo: Arnaud Hurstel).

THE PROBLEM OF SCOLYTIDS IN THE BAVARIAN FOREST NATIONAL PARK (GERMANY).

More than half of the 24,250 ha of this park are classified as strict forest reserve and a large portion of spruces, weakened in particular by acid rain, are attacked by scolytids. Since the mission of this national parks is to restore a large old-growth forest (see § 4.1), dead and dying trees are left in place and serve, in particular, as habitat for the three-toed woodpecker, rare and symbolic species of European natural forests that reaches very high densities there. The fight against scolytids only takes place in the perimeter (a band of 500 m or more) outside the National Park (over an area of 3,500 ha in 1998) in order to limit their damage in the surrounding managed forests.

Strict forest reserve in Bavarian Forest National Park (Photo: Arnaud Hurstel).

Although accidents are extremely rare, it is considered, and with good reason, that the falling of dead wood is liable to cause serious accidents. Consequently, to limit their responsibility, landowners and forest managers tend to want to eliminate all trees "at risk" (dead, sick, hollow or disfigured) here and there from forest paths and tracks over an area equal to the height of the stand. If the impact of these measures is negligible in the large, fairly inaccessible forest massifs, this is not the case in suburban forests. In certain forests of the city of Strasbourg, for example, the aim of the forest manager is to restore the forests to a high degree of naturalness, but the network of paths, tracks and exercise trails is so dense that the proportion of the forest where "at risk" trees are eliminated is greater than 50% in some places. In such situations, it is advisable to leave the downed trees (during security cuts) in place, which will at least increase the necromass on the ground surface. In the opposite case, there is a great risk of seeing felling for economic reasons using the security argument as an alibi.

To this day, the security argument suffers from the lack of evaluations of the real potential risk. What is the probability that a dead tree will fall on someone walking in the forest? There is no doubt that the risks we run in our daily life (especially on the roads) are infinitely higher. The real question is therefore not “what is the risk?” but “who is responsible?” If owners and managers had to be held responsible for all the potential risks in natural environments, we would soon have campaigns to eradicate vipers and hornets, etc. Failing to accept these natural risks and following the example of motorists, perhaps we should just take out “dead wood” insurance against this risk rather than removing them, because there will never be “zero risk”.

Finally, note that for some silviculturists, keeping dead trees is a deliberate management choice that aims to increase the functionality and thus productivity of the forest. In this case, dead trees can be incorporated as a production tool. To ask these silviculturists to remove dead trees would be the equivalent of asking a horticulturist to stop using natural compost.

6.2. Protecting old-growth forests

Based on the small area in question (< 1% of forests in France), the strict protection of all old-growth forests would not have any significant economic consequences in France, especially since it mostly concerns unexploitable or not very profitable forests.

The complex nature of the procedures and the historical opposition of silviculturists explain in part the current shortcomings of the network of protected old-growth forests. Since a few years, we are nevertheless witnessing a change in mentality and the current development of strict biological reserves should permit an increase of protected areas.

From this perspective, the role of the State is the determining factor since it is:
- the State that makes ministerial decrees to classify strict forest reserves (nature reserve or biological reserve);
- the State (and not the National Forests Office) that owns national forests where a large portion of the old-growth forests inventoried are found.

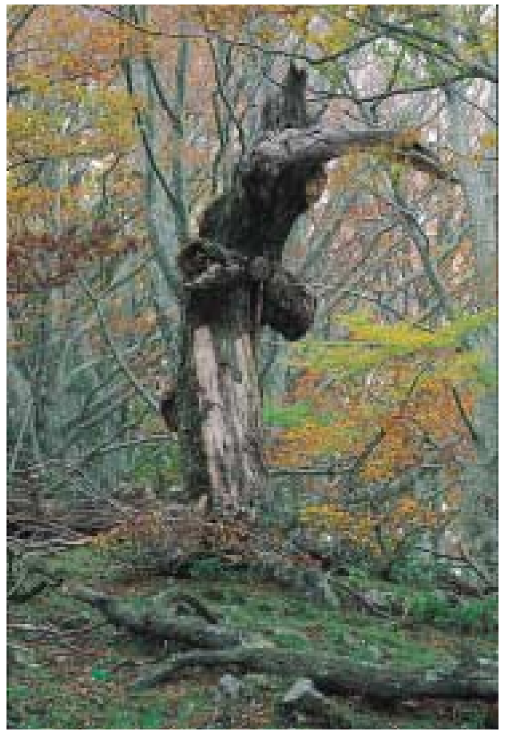
LEGAL STATUS ENABLING TO PROTECT OLD-GROWTH FORESTS IN FRANCE:

- *the national nature reserve, whose creation decree can provide for the establishment of a strict forest reserve. This is undoubtedly the most effective measure of protection, even though quite difficult to set up (applies to the public and private domain);*
- *the directed or strict biological reserve (state or local), for relevant forests of the forest system;*
- *the regional nature reserve, which is very simple to establish;*
- *Prefect Order for Biotope Protection provides a multitude of possibilities and deserves to be used more often, especially in emergency situations;*
- *the strict forest reserve of national parks, provided for by the Rural Code since 1960 but only implemented once (Lac de Lauvitel: Ecrins National Park)[26];*
- *sites that are acquired, rented or under agreement with regional conservancies for natural areas which, in certain regions (Alsace in particular[68]), have a genuine policy of old-growth forest conservation.*
- *the series of forest management protection measures that can ban logging for the duration of a “forest management plan” (can be interesting as a transitional measure).*

6

Other perspectives for managers

6.3. Restoring the naturalness of our forests



Forêt de la Massane Nature Reserve
(Photo: Bernard Boisson).

If strict protection of the last European old-growth forests is vital and urgent, increasing the naturalness of managed forests is equally essential. As described in § 3.1, naturalness is measured along a gradient. Whatever the factors in the past that have led to a lowering of naturalness, it is always possible to restore it in part by adopting appropriate management measures.

Two types of restoration can be considered:
- prohibit logging from forests to convert them into an old-growth forests;
- increase the degree of naturalness of forests while continuing to exploit them.

The first case refers to “conversion management”. This conversion, begun in many nature reserves, will enable, in the long term, to make the network of French old-growth forests denser. The current network actually only covers small areas and is extremely uneven (more than 50% of coniferous mountain forests)[69,72].

In the second case, forest exploitation will be organized so as to simultaneously increase the degree of naturalness of the forest. Structural naturalness is usually the aim of restoration operations: reconstitution of a sylvatic mosaic composed of different aged and sized units, restoration of a substantial store of dead wood, etc. The “naturalist” silviculture of some managers (for example, ProSylva) partly satisfies this concern. Certification of forest products (§ 6.4) should also help increase the naturalness of certain forests into the future.

6.3.1 Conversion management

To convert a managed forest into an old-growth (non-managed) forest, managers can choose between an active management that favours biological naturalness and a passive management favouring anthropogenic* naturalness (§ 3.2).

Passive management has the advantage of being quite inexpensive (nature itself will take care of the restoration) and generally helps obtain good results. The dynamic equilibria of an old-growth forest are, moreover, so complex and so fragile that no active management could restore it better than nature itself. Unfortunately, restoration is long (several centuries to restore naturalness approaching maximum potential naturalness) and can be slowed or even blocked in places. A spruce or larch forest (exotic to the site) can sometimes regenerate itself naturally and prevent the spontaneous return of native species.

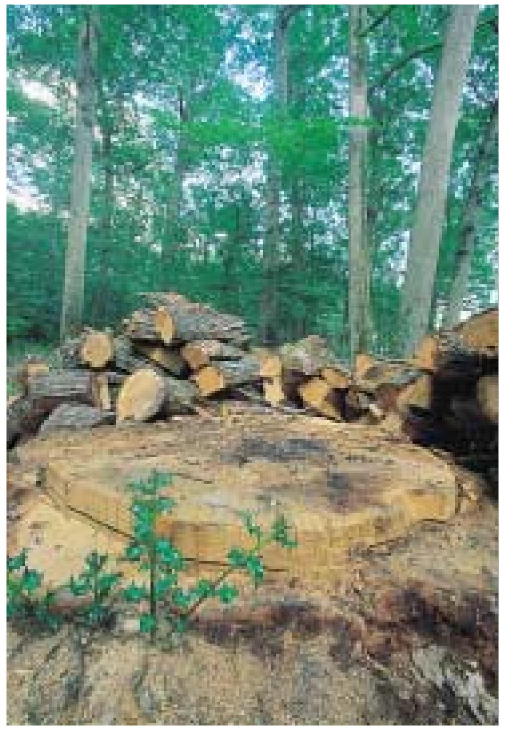
6

Active management can accelerate the conversion, notably by removing these blockages. It is, on the other hand, much more expensive, undermines anthropogenic* naturalness and is highly dependent on our level of knowledge: the theoretical optimum to reach (maximum naturalness; § 3.1) not being defined in the same way according to managers. To avoid active management being diverted to commercial ends, it is imperative that downed trees, in the context of conversion operations, be left in situ (see § 6.1.3).

In nature reserves, passive management is favoured. Only those parcels where the conditions are unfavourable to a spontaneous and rapid return of an old-growth forest are sometimes subjected to active management.

When conversion concerns plantation forests[100], active management can be justified. Creating gaps of varying sizes is usually the most effective operation. The number and size of the gaps are chosen according to their observed values in old-growth forests of the same sort. In temperate Europe, the majority of gaps have a diameter of 0.5 to 2 times the height of adult trees and these gaps cover 10-15% of the forest area (new gaps should be created every 10 to 15 years to preserve this proportion). It is recommended to continue creating gaps until 50% of the initial forest area is converted, the remaining 50% meanwhile having arrived at a sufficiently advanced age and stage of fragmentation for its conversion to occur naturally. It is also important to distribute these gaps in a random way over the entirety of the site.

In the Netherlands, where the majority of forests have been planted, numerous studies have been devoted to "active" methods of conversion, the evaluation of which is sometimes achieved thanks to simulation models of forest dynamics[98] (§ 3.4.4). The main conclusions of these evaluations are[100]:
- too much thinning of a forest results in an overly substantial regeneration on the entirety of the site, and instead of ending up with a mosaic of different aged units (close to a natural mosaic), the forest will remain relatively even-aged*. At the beginning of the conversion, the canopy must therefore remain as closed as possible and the creation of gaps limited to small-sized units;
- the creation of gaps of varying sizes is the best means to accelerate the development of a sylvatic mosaic close to the natural mosaic;
- gaps that are too small (less than half the height of the trees) are quickly closed by the crown extension of neighbouring trees, and are therefore of little interest for regeneration;
- considering the seed bank present on a site, the elimination of exotic species that regenerate naturally is impossible if the conversion operation is limited to creating gaps. The trees of these exotic species should be cut (or ring-barked at the base to produce standing dead trees) before creating gaps. The interval between these two operations will depend on the longevity of the seeds in the soil;
- the rapid establishment of dominant herbaceous species (bracken, nettle, bramble) slows the regeneration and development of a mosaic of different aged units;
- browsing can also slow gap regeneration. This browsing is more severe when the number of gaps is too small.



Timber harvest in Tronçais Forest
(Photo: Bernard Boisson).

6.3.2 "Renaturing" managed forests

In forests where logging continues, naturalness could also be increased (to a lesser extent).

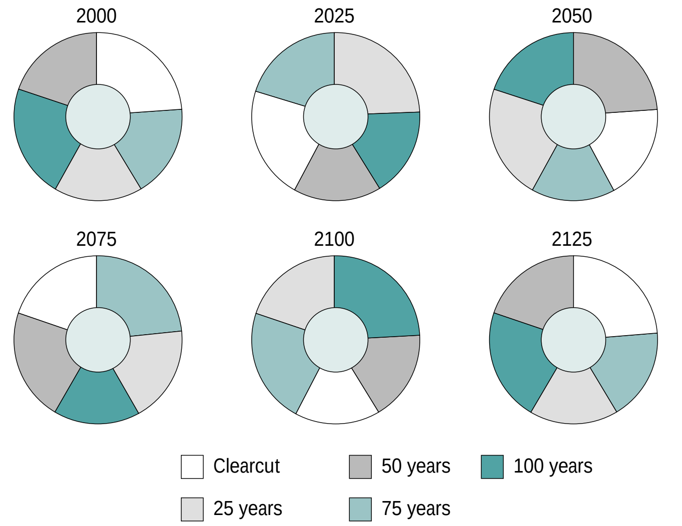
Restoration of irregular stands from regular stands can be done based on the active conversion operations described in § 6.3.1. These measures make it possible to obtain a sylvatic mosaic closer to the natural conditions of temperate regions (patch dynamics; § 2.2.5) while continuing the commercialisation of downed trees during the creation of gaps. In forestry jargon, the manager will have simply "converted" his regular high forest into an irregular high forest. In practice, high irregular forests are often more interesting than regular high forests because they require less silvicultural work (thinning), are less sensitive to disturbances (storms, parasitic attacks), and are more functional, and thus sometimes more productive. On the other hand, they require greater technical know-how and more frequent felling (because they cover smaller areas).

Restoring the sylvatic mosaic means restoring a silvigenesis close to the natural functioning of the forest (§ 2.2). The species whose presence is dependent on this dynamic will benefit, but others, solely linked to very old (absent) phases, will not. For the latter species, restoration should be accompanied by the setting up of unmanaged plots until their decay and/or by maintaining significant quantities of dead wood, particularly of large diameter (§ 6.3.3).

In the past, only old-growth forests enabled these species to maintain themselves locally. In the future, the creation of a denser network of "ageing islands" and "senescence islands" (§ 4.3.6) should allow some of these species to once again spread their range of distribution. Since many saproxylic* species have limited mobility, the indispensable condition for the success of such a policy is that these islands are large enough to allow all silvigenetic phases to be present simultaneously. In the opposite case, those species whose survival depends on a particular phase of the silvigenetic cycle will be forced to migrate from one island to another to maintain themselves as metapopulations (their survival will thus depend, among other things, on the distance between islands and their migratory capability; § 4.3.3).

The advantage of these ageing islands or of an old-growth forest in general can be increased by providing a “buffer” zone. This zone can be permanent (perimeter of a given size in which a certain structure, a certain density of dead trees, etc. are preserved) or be part of a rotation (fig. below).

Forest rotation with central refuge zone



To reduce the impact of fragmentation and of the reduction of old-growth forest areas, Harris[79] proposes a rotation. The forest would be managed around a non-managed central core (serving as a refuge zone for old-growth forest species) so forests of all ages are in contact with this core. Whatever the species' requirements for its young or old stages, it will thus always benefit from another favourable zone in addition to the central refuge zone. The area occupied by a given species will thus be enlarged, as will its possibilities to migrate from one refuge zone to another under the assumption that this plan would be reproduced on a large scale (§ 4.3).

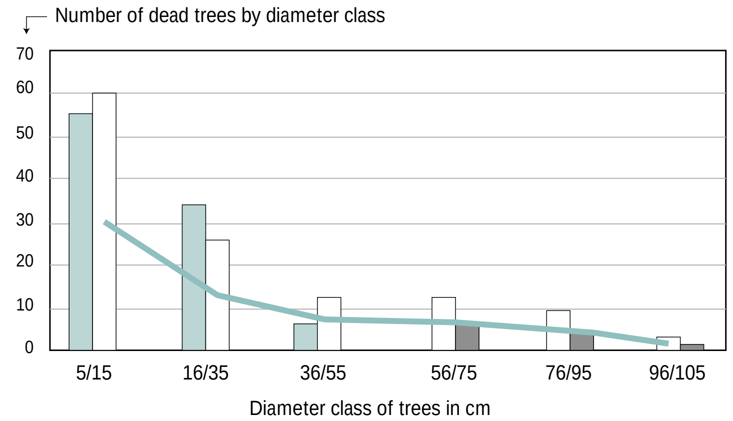
6.3.3 Conserving dead trees

Another means of partly restoring the naturalness of a forest is to increase its volume of dead wood, important habitat for forest species (§ 5.3) and functionality. Three distinct approaches can be suggested:

Increase the number of dead trees[125]

- Establish intended objectives:
  This first phase is undoubtedly the most difficult. When it is a matter of increasing biodiversity, the procedure consists of identifying the species associated with dead wood and cavities; studying the size of their territory, the (tree) diameters they require (and their state: standing dead wood, down, firm, worm-eaten, etc.) then to deduce the number and types of dead trees required to maintain these species. It is obvious that such an approach, conceivable for a few well-known species (birds, for example) will never permit evaluation of the needs of the smallest creatures, which contribute the most to biodiversity. This approach should therefore be reserved for the most threatened species.
  In a more arbitrary way, managers can simply establish a level of “naturalness – dead wood” to restore. According to the optimal number and type of dead trees (reference forest) and of the observed values on their sites, they can determine their own conservation objectives for dead trees (fig. below). The choice of level of “naturalness – dead wood” will depend, of course, on the sacrifice of logging they will be prepared to concede. It is important that this level be the same for all diameter classes in order to ensure that the necromass is not solely restored by trees with small diameters.
- Estimate the number of dead trees present:
  This phase of the inventory will permit the manager to assess (pre-restoration) the level of naturalness already existing in the forest in terms of dead trees.
- Estimate the renewal rate of dead wood:

“Dead trees” objective:



Evaluation of restoration needed to recover a level of naturalness in dead wood of 50% (arbitrary example) for an managed beech plantations in the Eastern Pyrenees. The white bars indicate the density of dead trees per hectare in a strict forest reserve of La Massane NR, the green bars indicate the density measured in the periphery of a managed national forest (method[65]), the black bars show the deficiency of dead trees per hectare calculated based on a restoration target of 50% (green line). This restoration would entail, in this example, the conservation of dead trees with a diameter greater than 55 cm (Gilg, O., Garrigue, J. & Magdalou, J.A., unpublished). On this site, as in many other managed forests, large-diameter dead trees are the most sorely lacking. The absolute number of dead trees is not an indicator value of the naturalness of a forest if it does not refer to their diameter. Small-diameter dead trees are sometimes even more numerous in managed forests(especially during the growth phase) than in unmanaged forests[65].

  This third phase (if there is sufficient knowledge) will make it possible to plan the restoration effort according to age and type of forest. It is, for example, impossible in the short-term to find large-diameter dead trees in a regular high forest in its growth phase. Knowing the renewal rate of dead wood will help anticipate this problem by preserving big trees during logging.
- Manage the recruitment of dead trees:
  The last, or operational phase consists of “producing” dead trees. The simplest and most economical is to avoid felling dying trees or logs. It is also possible to keep hollow or disfigured trees, and allow them to develop until their natural death rather than cut them during maintenance and thinning operations.

Grand Ventron Nature Reserve
(Photo: Bernard Boisson).

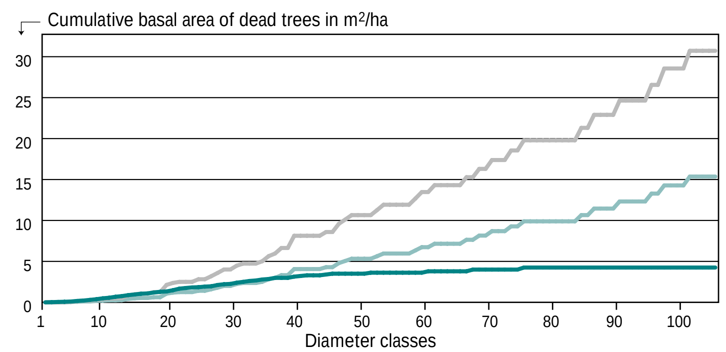
Dead wood dynamics is monitored in several reserves: as here in the Forêt de la Massane Nature Reserve (Photo: Olivier Gilg).

Increase total necromass*

A more global method to evaluate the quantity of dead wood to restore in an managed forest is to compare the total volume (or basal area*) of dead wood between the old-growth reference forest and the managed forest. It is no longer necessary here to consider the diameter of dead trees because these trees have such small diameters that they make a negligible contribution in terms of necromass* (the basal area* of 100 trees with a diameter of 5 cm equals that of a single tree of 50 cm). Dead trees with a large diameter should therefore receive priority in being preserved. This approach is more practical than the preceding one because it allows more flexibility in the choice of trees to preserve, since there is not always a wide range of diameters in a managed forest.

Even in regular high forests, the conservation of dead trees during clearcuts can be beneficial to certain species. This is particularly true in regions of severe disturbances where the original habitat of certain threatened species (snags that are isolated and in very sunny places in large regeneration units) is comparable to dead trees left standing during a clearcut[94].

Necromass objective



Cumulative basal area of dead trees in old-growth beech-fir stands (grey line) and managed (dark green line) of the Grand Ventron Nature Reserve[65]. The total necromass is 7 to 8 times greater in old-growth forests and it will therefore be necessary to increase this value by 3 to 4 times in managed forests to attain the theoretical objective of 50% (light green line).*

Increase the recruitment rate of dead wood

When the aim is to attain a certain volume of dead wood and not to restore a fraction of the reference necromass (two previous approaches), it is possible to estimate the recommended volume of dead wood to preserve in situ annually according to the decomposition rates of species and of the site (Table p.85). It is therefore simply a matter of a variation of the first figure of § 2.2.8

In France, it would be possible to multiply by 10, on average, the volume of dead wood in managed forests by devoting only 10% of annual growth to dead wood dynamics (this would mean a sacrifice of harvesting of less than 10% since only 60% of the volume produced is economically exploited).
As the increase in the amount of carbon dioxide in the atmosphere (§ 4.1.3) would also lead to an increase in forest productivity, the conservation of such a volume of dead wood in managed forests would therefore not result in a lowering of production relative to the historical volumes of production.

where the volume of dead wood to preserve each year (R) is: $R = (Y_g \times k) / 100$; Y_g being the average volume of dead wood (in m^3) that the manager wishes to attain and k, the annual decomposition rate in %.

Knowing k for their species and site, the manager can thus easily calculate the average annual volume of dead wood that should be left in place to attain their targets. For a target of 15 m^3 of dead wood per ha[188], the average volume of dead wood that will have to be left in place annually will thus be 0.45 m^3/ha when k=3% or 0.30 m^3/ha for k=2% (for the sake of comparison, 40-50 tons of dead wood per ha are recommended to preserve the diversity of vertebrates of Australian alluvial forests whose natural necromass* is approx. 100 tonnes/ha[117]). By basing this on the decomposition rate of dead wood (§ 2.2), it is possible to increase the volume of dead wood by 10 times in France's managed forests (a volume of 15 m^3/ha[7]) by "sacrificing" less than 10% of productivity (>5 m^3/ha/year[7]).

Dead wood recruitment (in m^3/ha/year) to ensure in managed forests according to the objective of restoration and the species' decomposition rate (k).

Average volume of dead wood/ha aimed to be restored	Annual decomposition rates of dead wood (in %)					
	1,5	2	2,5	3	3,5	4
10	0,15	0,2	0,25	0,3	0,35	0,4
15	0,225	0,3	0,375	0,45	0,525	0,6
20	0,3	0,4	0,5	0,6	0,7	0,8
25	0,375	0,5	0,625	0,75	0,875	1
30	0,45	0,6	0,75	0,9	1,05	1,2
40	0,6	0,8	1	1,2	1,4	1,6
50	0,75	1	1,25	1,5	1,75	2
60	0,9	1,2	1,5	1,8	2,1	2,4
70	1,05	1,4	1,75	2,1	2,45	2,8
80	1,2	1,6	2	2,4	2,8	3,2
90	1,35	1,8	2,25	2,7	3,15	3,6
100	1,5	2	2,5	3	3,5	4
150	2,25	3	3,75	4,5	5,25	6
200	3	4	5	6	7	8
300	4,5	6	7,5	9	10,5	12

Fontainebleau Forest (Photo: Bernard Boisson).

6.3.4 Reintroducing saproxylic species?

Whatever the success of restoration programs, certain characteristic species of natural forests will not be able to recolonize restored forests on their own. Some will have disappeared from the region. Others, barely mobile, will be unable to colonize the site from their nearest populations. Even the colonization of lignicolous fungi, whose spores are dispersed over great distances, is unlikely beyond several hundred meters[177] (their germination requires the simultaneous presence of two spores).

Therefore, certain species should be chosen for reintroduction in restored forests. I have already cited an example of inoculation of fungi spores[140], initially done for other purposes (to create cavities), but whose realization is also conceivable in a context of restoration. The reintroduction of saproxylic* invertebrates also deserves to be studied. The effectiveness of transferring adults or tree trunks containing larvae could be evaluated on a few pilot sites. To increase the chances of success and not "rob" natural forests of their dead wood, it is very easy to imagine the transport of "colonizable" dead wood (of a favourable age for the target species) towards an old-growth forest at a favourable time (period of activity and egg-laying), then return it during the following winter in the to-be-restored forest[172]. The transfer of epiphytic lichens attached to pieces of bark has, to the contrary, already been conducted with success in certain forests[144] and is foreseeable for rare and common species (*Lobaria spp.*) of natural forests with a high degree of continuity[71,83,84].

By definition, reintroduction is only foreseeable for species whose historical presence has been recorded. This constraint, unfortunately, limits the generalization of such actions for small species (invertebrates, bryophytes, fungi, lichens) whose former, often suspected presence is rarely documented.

6.4. Certification of sustainably managed forests

Public opinion is not insensitive to the negative effects of logging in natural forests around the world. For the last ten years or so, consumers have been looking for food and materials that are produced according to a certain ethic. Consequently, there are certification procedures being established today to enable them to identify wood products from forests in which "social, economic, ecological and spiritual aspects are taken into account for both present and future generations".

Faced with the proliferation of different types of certifications, several non-governmental organizations have recently evaluated the four main certifications from the following bodies (www.fern.org): Forest Stewardship Council (FSC), Pan-European Forest Certification (PEFC), Canadian Standards Association (CSA) and Sustainable Forestry Initiative (SFI). This evaluation, validated and supported by the main conservation organizations throughout the world (including the WWF, Greenpeace and French Nature Reserves), only acknowledges one independent and credible certification, which is that of the FSC. According to them this is the

Polypore, Fontainebleau Forest
(Photo: Bernard Boisson).

AMONG THE 10 MAIN FSC PRINCIPLES, HERE ARE A FEW:

- *To conserve biological diversity and its associated values (water resources, soils, and unique and fragile ecosystems and landscapes) in order to maintain ecological functions and forest integrity: do an impact study, ensure the protection of rare and threatened species and of their habitats, maintain or improve ecological functions, protect representative samples of ecosystems in their natural state, prepare guidelines to minimize forest damage (erosion, forest tracks, hydrographic network), limit the use of chemical products and prohibit their storage onsite, control the use of biological control agents, prohibit the use of genetically modified organisms, and control and monitor the use of exotic species;*
- *Develop and implement a management plan that specifies management objectives, describes the forest resources to be managed and limits exploitation (environmental and social), […] specifies environmental safeguards based on assessments, plans for the identification and protection of rare, threatened and endangered species, etc.*
- *Consider high conservation value zones to maintain or enhance their value*
- *Make plantations as close as possible to natural conditions*

only system that can be applied to all the world's forests, whatever their area and land tenure. Unlike other institutions, the FSC is also the only one to be granted decision-making power equal to the different interest groups (economic, social and ecological)[15].

At the end of 2001, 22 million hectares around the world were already certified by the FSC. With less than 0.1% (roughly 14,000 ha) of its national forest area certified by the FSC, France is lagging far behind other European countries (52% in Estonia, 42% in Sweden, 38% in the United Kingdom, 14% in Croatia, 5% in Switzerland and 2.2% in Germany). FSC certification is, moreover, very irregular in France: more than 10,000 ha are certified in the northeast, 5000 ha being from private forests in the Vosges du Nord Regional Natural Park (7% of the total forest area of this park), and more than 3000 ha in Aquitaine[190].

6.5. Evolving our way of thinking

For old-growth forests to one day attain a significant level (coherent and functional network) and become permanent, their protection has to gain public support.

Conservationists today should broaden their message. The advantage of old-growth forests far surpasses the context of "small creatures" that many are unaware of and will continue to be so. Some of our fellow citizens are receptive to scientific arguments, others to economic analyses or to philosophical and artistic considerations. All reasons to protect these forests (§ 4.1) should therefore be highlighted and promoted. The number of times that articles, books, conferences, exhibitions, radio or TV programs have mentioned the issue of old-growth forests in France can be counted on the fingers of one hand. This technical report, the numerous publications of the WWF and other projects in progress (books, exhibitions, etc.) aim in part to fill this gap.

At the same time, for the arguments presented here to be accepted by decision-makers, they have to be supported by solid scientific evidence and not just by lists of species. That is exactly what is at stake by including scientific studies. Ask good questions and test good hypotheses, to draw out the most relevant naturalist knowledge often available about these sites. Managers often have an encyclopedic knowledge of their site, but in order to best reach their management objectives and be capable of supporting them scientifically, they cannot shy away from a rapprochement with other naturalists, managers and scientists.

6.6. Exchange experiences

Whatever strategies have been implemented to preserve old-growth forests (§ 4.3), the exchange of experiences between managers is an extra asset to help achieve conservation objectives.

These exchanges, which should be developed on a permanent basis, already exist within several national and international networks:

- "forest" groups and "fluvial reserves" within the scientific commission of the French Nature Reserves (RNF); particularly concerned by the conservation and management of old-growth forests;
- exchanges between the main networks of nature protection organizations: RNF, WWF, FNE (France Nature Environment), LPO (League for the Protection of Birds), ENF (Natural Areas of France: regional conservation offices), Greenpeace, etc. (e.g., joint stance: "partnership charter for the restoration of forests after storms")
- close relationship (especially locally) between the managers of French nature reserves and the National Forests Office. Their staff also meet regularly as part of the advisory board for the management of nature reserves or at technical and scientific seminars. It would, nevertheless, be desirable for the initiatives and experiences of the two networks to be able to be exchanged regularly in the future within a "technical forum";
- At the European level, several networks also facilitate the exchange and bring together the experiences of managers of protected forests. Some, such as "Eurosite" are open to all managers; exchanges occur at meetings or via an internet forum. Others, more institutional in nature, such as the COST programs, only bring together designated representatives from member countries. After an initial multi-annual action program (COST E4 : "Forest Reserves Research Network in Europe" 1995/1999) that resulted in the creation of a shared database for the European forest reserves (www.efi.fi) and the definition of a common research protocol for these reserves, a second program (COST E27) has recently begun. Its aim is to describe, analyse and harmonize the main categories of protected forests in Europe with the tools of protection available at the international level. French Nature Reserves (RNF) is one of the two French representatives for this program.

6.7. What forests do we want for the future?

The future that a society holds in store for its forests depends on a large number of parameters of which culture and economic level are probably the most important.

In Western Europe, whose landscapes are forever scarred by intensive agriculture and widespread industrial and urban infrastructure, ecological awareness dates to the 1960s[46]. For more than 30 years, under the pressure of public opinion, the French legislature has created protection tools that different actors have gradually put to use. The number of protected areas has since increased, but at the same time "ordinary nature" (non-protected) has not stopped losing ground. The evaluation of these years is therefore mitigated since our natural environments appear inescapably condemned to being either protected or degraded (and since degradation occurs more quickly than protection, the prospect of such an evolution is hardly glowing).

Faced with this observation and the arrival of conservation biology, conservation policies have broadened their scope in the last ten years. With the introduction of concepts such as biodiversity and sustainable development, restoration and ecological management of "ordinary nature" (essential to maintain biological equilibria) are today the axes of complementary conservation that public opinion is currently assimilating.

More than ever, the conservation of old-growth forests should be organized in the future around 4 axes:

- awareness-raising about the importance of protecting these unique environments;
- substantial and rapid protection (strict forest reserves) of remaining old-growth forests;
- complementary protection of certain managed forests in order to improve the representativeness of the network;
- increasing the naturalness of managed forests by using a silvicultural management that is closer to the natural dynamics and by the restoration of a functional network of forest habitats with a high degree of naturalness.

Long ago the trees
we didn't know where they came from
Long ago the trees
were people like us
But sturdier, happier
possibly more loving, wiser…
Jacques Prévert, Trees

Forêt de la Massane Nature Reserve
(Photo : Bernard Boisson).

Glossary

Primarily based on S. Parent's Dictionnaire des sciences de l'environnement. Hatier Rageot, 1991.

Abiotic: that which does not depend on living beings.

Allochtonous: not originally from the region where it lives (opposite of native or Autochtonous).

Anthropogenic: describes phenomena (for example, anthropogenic disturbances) that are caused or maintained by the conscious or unconscious actions of humans.

Asynchronous: (movements, dynamic, etc.) not occurring at the same time.

Autotroph: living beings capable of using minerals as a source of nourishment. Green plants are autotrophs with carbon.

Basal area: area of the section of a tree trunk, measured at human height (1.30 m).

Biotic: pertaining to living beings.

Cambial: from *cambium*: type of wood where the growth of a tree originates.

Climax (stage): state of a plant community that has attained a stage of sustainable equilibrium with the climatic and edaphic* factors of the environment, in the absence of human intervention.

Clone: unit of lineage, by asexual division, of a cell or an individual. Clones are genetically identical to each other and the shared ancestor from which they are derived.

Corticolous: (animal or plant species) living on, under or in bark.

Diaspore (or disseminule): unit of plant dispersal (seed, spore, cluster of cells, etc.).

Duramen ("heartwood"): old and dense wood at the heart of the trunk.

Ecological optimum: range of environmental factors that are the most favourable to the development of an organism or a population.

Edaphic: concerns physical and chemical properties of the soil that affect vegetation.

Even-aged: a stand or a forest comprised of trees of the same age.

Geophyte: a perennial plant whose survival from one year to the next relies on buds located in the soil (ex. bulb plants).

Guild: group of related species that belong to the same trophic* level and utilize the same kinds of resources.

Heliophyte: a plant that seeks the light of the sun.

Hemicryptophyte: a perennial plant whose persistent parts are close to the ground in winter (rosettes of leaves, buds).

Heterotroph: an organism that has to ingest a substance in an organic form to be able to use it for the synthesis of its own substance. All animals are heterotrophic for carbon and nitrogen, unlike green plants (autotrophs*).

Mesolithic: intermediary period between the Paleolithic (Stone Age) and the Neolithic (beginning of agriculture and domestication) that began 5000 years BC.

Mycophagist: organism that eats fungi.

Necromass: biomass of dead organisms.

Niche (as in "ecological niche"): position occupied by a species in an ecosystem, defined by its living requirements and its relationships with other species.

Paleoecology: science devoted to the study of the ecology of organisms and biocenoses that are no longer present today.

Phloem (syn. liber): "living" part of bark that transports (in both directions) carbohydrates manufactured in leaves.

Polypores: Basidiomycetes (fungi) generally living on trees. Polypores are characterized by a hymenium (superficial layer covered with spores) made of parallel tubes that form a perforated surface.

Resilience: property of an ecosystem to remain in a state of equilibrium despite the various ecological disturbances it faces.

Saproxylic: any species dependent, during at least a part of its lifecycle, on dead or dying wood, fungi living in wood, or other saproxylic species (predators or parasites)[172]

Sapwood: soft and light-coloured wood located at the periphery of the trunk, beneath the cambium that produces it.

Snag: part of a log (uprooted or broken tree) that remains standing.

Stochastic: produced by chance (or at random).

Taxon: any group organized in a classification of living beings, of whatever rank.

Thallus: simple, vegetative body undifferentiated into stem, leaves or roots of a plant form devoid of wood.

Trophic level: within the food chain or a trophic network (several chains), stage in the course of matter and energy cycles, starting with producers and ending with tertiary consumers.

Vascular (flora): that possesses vessels or tracheids (for example, flowering plants in contrast to lichens, mosses, fungi).

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Old growth forests

CHARACTERISTICS, CONSERVATION AND MONITORING

Among the varied functions of a forest, that of production has always been privileged at the expense of ecological functions. Forest managers now wish to combine different objectives in "multi-functional" areas. This is the case in suburban forests, where the social role is predominant. It is also the trend in protected areas where ecological functions are highlighted. Although lacking a large "primary" forest that represents the ecological optimum for scientists, certain measures of protection and management can be adopted to increase forest "naturalness".

This technical report has the following objectives:

- to describe the functioning of old-growth forests and to clarify the concept of naturalness;
- to present the reasons that encourage us to protect forests, as well as the different means available to those who manage natural areas to help study and preserve them.

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