Joint Evaluation of Storms, Forest Vulnerability and their Restoration

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

The production of this evaluation report is the result of the deliberations of a group of scientific experts set up at the instigation of INRA and Cemagref in discussion with the Rural and Forest Area Directorate, and with the help of the Research consortium on Forest Ecosystems (GIP ECOFOR). The aim was to produce a “state of the art” report on these questions using existing references and “expert knowledge” by mobilising a wide range of French and foreign scientists, and specialists concerned with forest development and management, covering all the subjects concerned.

Firstly, the evaluation covers the climatic storm hazard and factors which affect trees and forest vulnerability to wind. It demonstrates the exceptional nature of the storms at the end of December 1999, which occurred during unfavourable water-logged soil conditions. These events cannot be related to global warming at present: similar storm levels have already been observed in the past, and the consequences of global warming on storm levels are not clear, even if an increase in extreme phenomena should not be excluded. Storm hazard can be predicted in zones which are exposed regularly: the Atlantic coast, the Rhodanian ridges, Languedoc-Roussillon and the east of Corsica but this is more difficult elsewhere. In addition the changes occurring in French forests which cover larger and larger areas, and are more and more vulnerable (increased dominant height and volume per hectare) explain part of the increase in observed and forecasted damage.

Then tree and stand stability factors are examined. Wind action on the tree occurs mainly at crown level and is transmitted via the trunk to the root-soil complex. Wind resistance of a tree to those forces is related to its *form*: area developed by the crown, height of the centre of pressure, relative size of the aerial parts and the rooting system; its *structure*: permeability and branching of the rooting parts, root architecture; and *mechanical properties*: of the wood but also the soil which intervene in the absorption of swaying and its consistency which ensures greater or lesser tenacity. In spite of having greater wind resistance a squat tree is considered to be more stable.

Resistance properties of a tree depend on the species but also on all the other external factors influencing growth, development and characteristics of the tree. Pathogenic factors (especially root rot) can increase the vulnerability of their hosts to wind, even if the extent of damage due to the storms at the end of 1999 cannot be related to a poor state of health of French forests. Site influences the rooting conditions (anchorage quality) as well as growth of the aerial parts; a “good” site does not necessarily ensure better stability, especially if it encourages an imbalance between the aerial parts and the rooting system. Suitable species for a site is not questioned, as high productivity reduces economic risk due to advanced harvesting; and suitable forestry management, by regulating competition, creates trees with a good shape.

Joint Evaluation of Storms, Forest Vulnerability and their Restoration
Sébastien Drouineau, Olivier Laroussinie, Yves Birot, Daniel Terrasson, Thomas Formery and Bernard Roman-Amat

However, the effect of competition on tree growth is only one of the aspects by which a stand influences its own stability. Trees brought-up in stands certainly produce forms which are less stable, but contact with neighbouring trees contributes greatly to the absorption of the swaying motion. So together they have special structured properties (the "block effect"), but there is a limit: generalised windfall (the domino effect). The wind is also greatly reduced inside the stand. However forest edges which are dense and vertical present an obstacle to the wind, they also result in greater pressure above, responsible for turbulence which is often devastating behind. Discontinuities in the cover (e.g. heavy clearing) have similar consequences and expose trees which are not "educated" to wind even more. It is possible to treat forest-edges to reduce this mask effect by encouraging permeability (the role of deciduous trees in winter) and/or by grading the height of the forest-edges (to act as a deflector). These contradictory influences of structure and competition on stand stability make it impossible to come to a conclusion about the different treatments, and similarly for stands with mixtures in the dominant storey. Nevertheless, it has been observed that in regular stands, the block-effect has limits, high densities produce unfavourable tree form (low taper), leading to irremediable instability in the stand once it reaches a certain height.

The second part of the evaluation considers the restoration of forest stands. These are derived from the objectives assigned to the forest and initially those of the owners, who have been severely discouraged by the extent of the damage and the lack of co-operation in the industry. This lack of motivation should subside with time. Apart from the strictly legislative structure, restoration also fits into a forestry policy which encourages its multifunctional nature and is careful to integrate the forest into a wider plan for rural areas via a national approach. Under the circumstances, there are numerous stakes related to restoration which are outside the strictly forest plot framework and which concern many intervening parties. Such an approach however depends on the identification of a collective project, the existence of a discussion and organization structure, and the agreement of the owner concerned, which assumes a contract system. For certain restoration problems requiring urgent treatment, it will not be possible to proceed in this way.

Restoration should be well thought out, with diagnosis carried out at different spatial scales. The consequences of the storm on different environmental functions of the forest, the increase in fire-risk, the potential risks involving the large game species and pests (scolytid, the under bark beetle) on stands in place and regeneration , are increased at the fairly large scales, from the forest massif to sub-regional scales (for biodiversity management plans). At the forest and plot scale it is the forest equilibrium, evaluation of damage and its consequences on forest planning, and operations to be carried out in the plots, the potential natural regeneration and the stand in place, which will be the centre of interest.

Some important lines of action concerning restoration strategies emerged from this analysis:

- *The control of ungulate populations.* Their predictable increase will often make drastic control essential and thus an increase in hunting plans in co-operation with the hunters. In critical cases other legal measures will have to be set up.
- *A minimum clearance of plots to be encouraged.* At the same time this measure should maximise the value of the wood on the ground as much as possible, limit fire and pathogen risks associated with the presence of dead wood, and carbon losses, and finally make future planting or cultural operations possible.

- *Soil conservation*. Prevention of chemical (humus removal) or physical (compaction) degradation, which entails the use of machinery which is as suitable as possible, but above all used correctly. This concern is greater in view of the amount of work and investment required so precautions should be taken at any price to avoid supplementary restoration work.
- *Suitable treatment of remnants*. Creating large windrows and especially burning them poses problems in the return of elements which are fixed there, to the soil. When chipping or simple clearing is not possible, the creation of small windrows close together is preferable using suitable machinery, and which could form tracks for use by the machinery to limit compaction.
- *Encouragement of restoration methods using natural processes as much as possible*, whenever the preceding stand was satisfactory, and excluding high production silvicultural situations which require the use of highly efficient Forest Reproductive Material (MFR). This would limit the initial investment and make the prediction of any deficiencies in MFR possible, and eventually provide the production industry with a clearer idea of requirements during the coming years by using contractual demands for plants, at the end of enrichment for example. These methods are also less vulnerable to damage by game.

It is also necessary to compare silvicultural scenarios on the basis of their economic performance. Ideally, when created, these scenarios take economic risk related to different hazards, of which wind is one, into account, but this approach is limited by the lack of correctly established damage models. All the same, one must admit that investment decisions by owners are generally dictated by liquidity constraints.

Finally, having identified the weakness in crisis management, measures should be taken in preparation for future storms. The evaluation came up against a lack of knowledge and experience due to the rarity of the phenomenon, which emphasises the need for a European monitoring system to centralise data. To ensure the most efficient response, a pre-established procedure, emergency measures and the maintenance of a minimum infrastructure should be envisaged. The crisis situation has provided an opportunity to improve risk evaluation. This supposes, firstly, that risk is spread spatially, even knowing that it is difficult to map the storm and even more so, the risk at a local level. At the management unit level prevention also plays a part in this evaluation. It is influenced by the choice of silvicultural objectives and suitable techniques in relation to exposure and by an evaluation of risk in the economic calculations; finally more efficient risk cover should be considered. At present "storm" insurance is linked to damage insurance; the offer is limited, with an upper limit, and wind speed thresholds above which the forest is not insurable any more, are low. In fact only 700–900,000 ha of forest are insured. The development of private insurance requires the creation of better damage models. An indemnity system specifically for forests could be envisaged, as forest do not have access to either the National Catastrophe (Cat. Nat.) system or the Agricultural calamities system. All the same, the financial capacity of these indemnity systems has been damaged by the storms, and access to indemnity implies that one is insured, as these systems are underwritten by the insurance companies. Another possibility is a modification of the Investment Deduction (Deduction Pour Investment, DPI) allowing tax deductions on long term immobilisation, a sort of "auto-insurance".

INTRODUCTION

The storm at the end of 1999 had a profound and long lasting impact on the forest sector and some of its component parts: the ecosystems themselves, owners and managers, and some participants in forest exploitations and industry. In response to this catastrophe, which is unprecedented in the history of French forests, INRA[1] and Cemagref wished to make a contribution to clarify state decisions and especially the instigating measures, not only concentrating on the restoration of damaged or destroyed forests, but also improving the stability of unaffected or future forests, using silvicultural methods.

INRA and Cemagref have taken the initiative to set up a scientific evaluation group in collaboration with the Countryside and Forestry Department (Direction de l'Espace Rural et de la Forêt-DERF) of the Ministry of Agriculture and Fisheries, with a triple objective: i) to produce within four months a joint evaluation of the storm and forest vulnerability and to suggest ways of restoring the forest damaged – this is the aim of current discussion paper; ii) secondly, to refine the conclusions of this report, after the interpretation of the initial damage evaluation by the National Forestry Inventory in a few test zones; iii) supervision of short-term research projects, and creation of new mid-term research programmes.

The originality of this work is the construction of a genuinely joint evaluation, associating scientists and practical experts. The short delay fixed for the production of this report has allowed us only to mobilize existing knowledge, i.e. individual knowledge (the expert's voice) as well as the abundant French and foreign reference data. The evaluation group has brought together a wide range of scientists from various disciplines and belonging to very diverse organisations (Museum National d'Histoire Naturelle, CNRS, ENGREF, French, Swiss and German Universities, Météo France, Cemagref and INRA), and development specialists or forest managers (IDF, IFN, ONF private owners and forestry experts). This evaluation group consists of about 30 people and is supported by a "second circle" of about 50 experts chosen in relation to their specialities. GIP ECOFOR (research consortium on forest ecosystems) has made a major contribution to the evaluation group by providing secretarial assistance and carrying out the synthesis of this work.

The evaluation report consists of two sections. The first covers the climatic storm risk and factors affecting tree and forest vulnerability to wind. From this knowledge of course lessons can be learnt regarding restoration and a better understanding of the risk related to wind in the management of forests which were less or unaffected. The second section presents recommendations on how and why restoration could proceed.

We hope that this joint scientific evaluation, which is well within the remit of public research organisations, will contribute to the public decisions which will be made in the

1 The acronyms are clarified in a glossary at the end of the report

Joint Evaluation of Storms, Forest Vulnerability and their Restoration
Sébastien Drouineau, Olivier Laroussinie, Yves Birot, Daniel Terrasson, Thomas Formery and Bernard Roman-Amat

near future to help the restoration of French forests. We wish to thank all those who have taken part, and emphasise that this report owes much to the competence of the experts, their capacity to listen and discuss, and their commitment, so that this work should be useful to everyone.

Bertrand Hervieu, INRA President
Jean-François Carrez, Cemagref Chaiman of the Board

PART 1: CLIMATIC STORM HAZARD AND FACTORS RELATED TO THE VULNERABILITY OR RESISTANCE OF FORESTS

WIND, CLIMATE AND FRENCH FORESTS

The storm at the end of 1999: of exceptional intensity and extent

The intensity and extent of the two storms in December 1999 were very rare. The areas affected by exceptional winds covered a large part of the country. Thus within a perimeter designated by Strasbourg - Colmar - Mulhouse - Orléans - Rouen - Reims - Nancy - Strasbourg, the foot of the Pyrenees and the length of the Atlantic coast from Biscarosse to the Vendée, the mean wind speed measured during the storms was equivalent to a phenomenon not expected to return for more a century. In addition, there had been high precipitation during December 1999 which, with the exception of the southeastern quarter of the country, had resulted in high soil water saturation.

During the last fifteen years there has been no lack of "high winds" which have made an impression, however, even if the number of storms has increased during the last 30 years relative to the preceding decades, this tendency is not visible at the century level: storm activity has simply returned to the same level as that at the end of the 19th century. The high inter-decennial variability and the lack of statistical data sets do not allow us to conclude whether there is an increase in the phenomenon and even less that it is related to climatic change.

The increase in gas levels producing an atmospheric greenhouse effect will lead to climatic warming. In the absence of clear results from observations, one naturally turns to simulations to try to estimate the consequences on the violence and frequency of storms, but one comes up against poor reconstructions of extreme phenomena by numeric modelling. They have been studied indirectly using statistical criteria related to the appearance of extreme phenomena, but the results obtained by several teams are contradictory. Nevertheless one must remember that the increase in extreme phenomena is not improbable in a hypothesis of higher global warming than at present.

French forests: bigger and more vulnerable

Even if wind hazard does not seem to have changed very much throughout the century, the undeniable increase in forest damage is certainly due to changes in French forests. Since the middle of the 19th century this change has occurred in two principal directions, firstly,

Joint Evaluation of Storms, Forest Vulnerability and their Restoration
Sébastien Drouineau, Olivier Laroussinie, Yves Birot, Daniel Terrasson, Thomas Formery and Bernard Roman-Amat

an increase in forest area, and secondly, changes in management towards high forest instead of coppice and coppice with standards.

The first, which exposes a greater forest area to the wind, is a direct factor resulting in increased damage. Changes in management methods have resulted in modifications in stand structure and composition, at the same time increasing the stakes in play – higher standing volume per hectare and higher wood value – increased vulnerability – and overall an increase in top height. A comparison of the last two complete rotations of the National Forestry Inventory with mean dates of 1980 and 1992, and data from the current rotation for certain departments, confirms that these tendencies are still valid and can be used to provide more details:

- The forest area is increasing: an increase of 80,000 ha per year for the period between 1991 and 1998 (source TERUTI).
- The mean standing volume is increasing: 129 m^3/ha in 1980 to 149 m^3/ha in 1992.
- Coppice and mixtures of coppice with broad-leaved standards are decreasing (–310,000 ha and –220,000 respectively for the period 1980–1992) while high forests are increasing (+800,000 ha in 1980–1992).
- The area covered by high top height stands is increasing.
- In the special cases of coniferous stands, using the stability classes defined by the IDF (see below), the Douglas fir, common silver fir and spruce show a clear increase in the proportion of stands in the categories designated “fragile” or “unstable”.

The influence of the coniferous plantations installed with the help of the National Forestry Fund on these figures, and the evolution of coppice with standards into high forest (by conversion or ageing) is clear.

In the case of the coniferous stands mentioned the silviculture is clearly to blame. Nevertheless the situation cannot be entirely controlled nor explained by the management used (including the absence of any intervention), which is not independent from the general objectives fixed for the forest and the evolution of the rural landscape, and the timber market (for example, the absence of outlets for small-size softwood). Finally, the increase in forest productivity which has occurred during the last few decades has to be added to this (this is partly due to higher atmospheric CO_2 levels, to atmospheric nitrogen pollution and to climatic warming) which is related to an increase in the top height of the stands.

The wind: exposed zones

The Atlantic coast, to the west of a line from Bordeaux to Rouen, the Rhodanien ridges and the Languedoc -Roussillon, as well as eastern Corsica, are the most exposed regions (with a time span of less than five years for the return of a maximum wind speed of 120 km/h). Storm evaluation is more complex when smaller scale factors are considered: locally a combination of topography and wind direction play a decisive vote. Finally, at even smaller scales it is the stand itself which influences the nature of the wind, especially its aspect, speed and turbulence (see below).

TREE AND STAND STABILITY

The following discussion separates the different factors which might have an effect on tree and stand stability. This approach has the advantage of being simpler and clearer and is often sufficient to demonstrate a relationship between the observed instability and one or even two obvious causes (e.g. Windfall concentrated in oaks whose root systems have been severely attacked by collybia (root rot). Conversely, it does not allow one to foresee the possible advantages (for example, poor individual tree stability could be compensated for, to a certain extent, by the "block effect" of the stand) or the synergies between different factors. In addition, interactions between factors are not accentuated. For example, the extremely variable behaviour of species from one site or silviculture to another, complicates the analysis of species vulnerability. Douglas fir, under good soil conditions has a fairly good anchorage capacity due to its heart root system. However, as it is very sensitive to soil humidity it develops a plate root system in soils which are only slightly hydromorphic and thus become ideal subjects for windfall. For these reasons, the analysis of stand stability required a team of experts capable of combining the factors into a few relevant "synthetic variables", essentially stand dendrometry, mechanical properties of trees and anchorage quality in the soil (the latter parameter integrates site, health and species characteristics) to provide an overall diagnosis of stability.

The tree

Wind induces tree swaying which follows a simple mechanical model. The gusts themselves produce a pulsation (short gusts of a few seconds), and resonance phenomena are possible. Each part of the tree: the crown, trunk and root + soil complex, plays a role in the response of the tree to the wind effect and contributes to its resistance properties.

The wind action mainly affects the crown. A wide crown has a large wind resistance, especially when the tree is in leaf, but conversely the presence of branches lowers the centre of gravity and pressure bringing them closer to the anchor point (the soil) and so reducing the combined forces involved, (wind and weight once the tree is not perfectly vertical). In addition, branch movement contributes to a large extent to damping the swaying (this contribution has been estimated to be 40% in the case of a Sitka spruce stand.

The trunk transmits the effort to ground level and has little effect on damping the swaying. Its complex structure gives it special resistance properties, but it has heterogeneities and breaks preferentially at a level with structural faults. A tree develops these zones of weakness naturally throughout its growth (knots or wide rings for some species), but they may also be due to external factors, mainly disease or insects. Attack by *Fusarium* in poplars, *pyralis* in maritime pine, cankers due to *Nectria* in beech or *Cryphonectria* in sweet chestnut, are also preferential breakage points.

The general form of the aerial parts influences fragility. The stability of individual trees with the same height is reinforced by low taper (h/dbh ratio) and with an equivalent taper, height increases instability. Briefly, short squat trees have the best form. It has also shown theoretically that the multiplication of reiterated movement could play a part, due to the possible resonance phenomena between the tree and the principal branches, so multiplying the risk of damage and especially breakage at the fork levels.

The root system traps a large quantity of soil, mainly between the fine roots. The weight of this soil/root complex attains 6 to 8 times that of the aerial parts of the tree, and is primarily responsible for the anchorage in the soil. Anchorage quality is thus inseparable from the soil characteristics and is as good as the volume explored is large, and the material consistent (while remaining penetrable). The root architecture plays a double role. Firstly anchorage quality is related to the type of root system that a species develops depending on whether it can grow without constraint, the heart root system is considered to be the most efficient, followed by the tap root system, and finally the sinker root system. For a given wind direction it is the roots situated along the wind axis which will come into play, in tension and compression, and from this point of view a symmetrical root system has no weak spots. Finally, it has been shown that for certain associations root rot/host specie, there is a high correlation between infection level and wind vulnerability (especially for oak and Douglas fir). Data is limited, but it is probable that similar situations exist for many pairs other than those already studied.

In the reaction of a tree to wind stimuli, root rocking acts like a shock absorber. There too the soil plays a role, and particularly its state at the time of wind action. In certain cases rocking energy may transform saturated clay soils into a plastic or even liquid state. In the storms at the end of 1999, the soils were nearly all saturated with water which made uprooting easier. Conversely, a dry soil provides a better anchorage, but loses part of its shock absorbing properties: so broken tree tops occur more frequently relative to other types of damage.

The relative size of the different parts of the tree play an obvious part in the stability. An over-sized aerial structure relative to the root system is a major destabilising factor (the case of beech trees on a calcareous plateau with shallow soils, the effect of nitrogen fertiliser).

Finally, a tree is a dynamic structure which uses biological mechanisms in reaction to stimuli. The mechanism which has been studied most is the growth of reaction wood, which is known to maintain the tree in its vertical state. The role of such mechanisms in wind resistance is less well known. However, it has been observed that:

- In many cases forest edges show higher resistance, in those of wind permeable stands like poplar: often only the edges remain standing.
- Storms which blow from an unusual direction are often more devastating.

These observations suggest that the “education” of trees relative to wind action often put forward, might also be due to biological adaptation mechanisms. Some of these mechanisms are beginning to be identified, especially at the root level, like asymmetric growth of root tissues (the appearance of compression wood exclusively on the leeward side which ensures better resistance to compression in maritime pine) or root growth adaptation (e.g. faster growth on the upper side of the roots on the leeward side resisting the compression due to the wind in Sitka spruce.

Site type

The key parameter in tree stability and by extrapolation in stands, is the depth to which roots can physically penetrate. When the aerial parts of the tree develop normally, the blockage of roots at shallow depths leads irrevocably to an imbalance between the aerial and the underground parts. These barriers may be due to site characteristics, as in the case of sites with shallow soils. The calcareous plateau of Lorraine and sites with shallow soils on sandstone in the Vosges are two examples, which are unfortunately highly instructive, of vulnerable situations which were badly affected by the storms at the end of 1999. The presence of hard pan horizons (iron pan in the Landes), or permanent water-tables near the surface (pelosols pseudogley) also limit the volume of soil that roots can exploit and reinforce stand instability for the same reasons. Another possible origin of blocking barriers may be the mechanisation of forestry work: the appearance of compaction in silty or silty clay soils is a frequent phenomenon where forestry work has been carried out badly.

The role of soil consistency on the quality of anchorage has already been raised. Very stony or sandy soils are special cases where the substrate has low consistency and is permanently very poor in terms of stand stability. In most cases soil consistency depends on the soil water content and declines with an increase in humidity, which explains the instability on these soils when they are saturated with water.

Chemical content may have some influence. In particular, high nitrogen availability, whether of natural or fertilizer origin, encourage the growth of the aerial parts (in particular the leaf mass) to the detriment of the root system, which creates an imbalance. In excess, the mobile element N, is present near the surface, through which inputs occur, and percolates through the lower horizons. Fine root development is oriented towards the upper horizons thus reducing their contribution to tree anchorage.

The stand

The position of the stand from a topographic point of view exposes it to a greater or lesser extent to wind effects, due to the local relief and the dominant storm direction: (mainly from the west in France, except for the Mediterranean coast). This results in the “education” and “selection” of trees in situations most vulnerable to dominant winds. Conversely, storms blowing from an unusual direction often have surprisingly disastrous effects (the case of the 1982 storm in Auvergne).

The aerodynamic characteristics of the stand are of utmost importance. The dense forest edges create excess pressure at the front of the stand which generates turbulence behind. This masking effect can be corrected by the progressive build-up of the forest edge to act as a deflector, or by creating greater permeability at least in winter by using mixed broad-leaved trees (the role of the defoliated crown of broad-leaved trees). Foresters in the UK prefer the first method (even though it requires more space) considering that the beneficial effect of permeable forest edges is reduced by wind penetration into the stand even if it has been braked. However, it seems possible to combine the two methods of forest-edge management. Breaks in stand continuity also generate turbulence giving rise to serious damage. It is important to note that once breaks in continuity occur when the stand is already in place, the corresponding forest-edges, then called false forest-edges are made up of trees which have been exposed suddenly, without having been “educated” to wind and are thus very vulnerable.

The combined effect of height and taper of stands has been widely studied for many coniferous species and is summarised correctly by graphs of top height v. mean diameter, thus demonstrating the stability zones in a stand. This shows:

- that increasing top height for the same taper increases stand instability, and finally leads to high instability whatever the taper. Conversely, stands with low top height are always very stable.
- that increased taper ensures greater stability of stands with the same top height.

Stand stability characteristics are not only the result of the sum of the individual stability of the component trees, but also include the “block effect to different degrees, mainly as a function of stand structure. The positive effect on stability of the “block-effect” has been confirmed by experiments. The “block-effect” involves the mutual support of trees in the same strata by crown contact, which thus depends on stand density. The existence of an under-storey seems to have a beneficial effect on stability but this observation needs to be confirmed.

It is difficult to come to a conclusion on the effect of canopy structure on stand stability. A regular canopy presents less resistance to the wind and the trees benefit from the block-effect, but in general the individual trees are more elongated and thus less stable. An irregular canopy presents a rougher surface to the wind, but the trees are less elongated and thus individually more stable.

Silvicultural aspects

Stand stability is also the result of human activity, and is mainly due to management but also to installation. Working the soil is supposed, in one way or another, to improve root exploitation in a soil which exhibits rooting constraints, either by improving the structure and its penetrability, or by modifying its humidity. Even if the initial results are questionable from the stability point of view (a better root system but increased tree height growth), the positive effects seem clearer later: height increases are erased, but an improved rooting-system architecture is acquired. Tree taper is better, which leads to improved individual stability and to an early harvest (and thus large stand instability is forestalled). Working the soil can improve stability under certain working conditions, as long as the soils in question present real obstacles to root penetration, which can be partly removed by working the soil. The positive effects shown above are only observed in soils where root exploration is limited in one way or another (soils with a hard pan, gleys with a surface-water table and peaty soils). Drainage, in particular, is useful in wet soils. However, all work creating asymmetrical root systems must be avoided (ridge and furrow, work in lines, etc.), the consequences of which, in terms of stability, have been be observed for several types of work and species (Lodgepole pine, Scots pine, Sitka spruce).

In plantations, the conditions under which operations are carried out and the quality of the plants have a direct effect on the future root system. The initial root system of the plants is greatly influenced by the growing conditions. In particular, there are many examples of unstable stands derived from unsuitable container grown plants (especially maritime pine). It should be noted, however, that certain species, especially spruce and

Douglas fir, but not pines, are capable of developing an adventitious root system which can alleviate an initially deficient system. The influence of root deformations on tree stability either perturbs the development of root system or sap flux, or results in mechanical weakness. They do not generally have any visible consequences on the aerial parts.

Clearings are crucial in silviculture in relation to stand stability. They have two opposing effects on stand stability. The immediate consequence is destabilisation due to the sudden opening in the stand which destroys the “block-effect”. This instability is temporary and lasts until cover is restored (3–5 years). The taller the stand, the more marked is the effect. The delayed effect of clearing is, conversely, to increase tree diameter and thus the form factor which gives them greater stability, at least when the intervention occurs sufficiently early. In even-aged coniferous stands, the stability zones should have been defined using the top height/mean diameter graph tendencies and are very useful for adapting clearing operations to the nature of the stand. Generally, to have more stable stands, a choice has to be made between the “block-effect” strategy with minimum intervention, earlier harvests and small-sized products (the Atlantic silviculture of the British) and the “dynamic silviculture” strategy which encourages the development of good individual tree stability using management to maintain the stand in a “stable” zone.

Silvicultural treatment

Simple short rotation coppice is a typical example of silviculture adapted to wind. Risks are minimized as the stands are less vulnerable being shorter in height and economic risks are reduced due to a short rotation (low stakes). Of course, the choice of the type of treatment is not entirely determined by the analysis of wind risks and production is generally the primordial determining factor.

Observations made after several storms show that in many cases coppice with standards is particularly vulnerable to wind action. This does not seem to be the case nationally for the storms at the end of 1999, however the latter observation is not true at the regional level. The extreme variability of stand structure included in “coppice with standards” is probably responsible for the contradictions existing between different observations. Nevertheless, one can say that “old” coppice with standards (by this we mean, in relation to the normal treatment method: no reserve harvest, no choice of standards and late coppicing) show high instability levels. The reserve is ancient (age is an instability factor in broad-leaved trees) and the component individuals have modified crowns due to canopy closure and even competition with the coppice (death of low branches and increased density in the upper parts) tending towards greater instability. In addition, in oaks it has been shown that trees in a coppice tend to have higher root-rot infection rates than those of free standing trees. The tendency is toward a clear increase in this type of stand: in 12 years the area of over 40-year-old coppice has increased by 600,000 ha i.e. +72%.

High forest systems produce taller trees (vulnerable to wind) and greater volumes of valuable wood (higher economic risk).

There is insufficient objective data to compare the efficiency of regular and irregular systems and thus reach conclusions about the superiority of one type of silviculture compared with another. In fact, the irregular systems include very diverse situations which, in addition, are all poorly represented in France as well as in neighbouring countries. One can at the very most produce an assessment of the advantages and disadvantages of the two types of treatment in a tabular form. For this exercise a selected natural forest and an even-aged forest were considered, so as to limit it to simple, clear-cut cases.

Advantages in terms of stability	Even-aged forest	Selected forest
Low surface irregularity of stand	+	–
Good individual tree stability	+/–	+
Trees not very exposed to wind (except forest-edges)	+	–
Stand stabilized by the block-effect	+	–
Presence of production at the forest scale	+/–	+/–
Structure avoiding generalised wind throw by the domino effect	–	+
Economic resilience	+/–	+/–
Ecological resilience: presence of seedlings and young shoots	–	+

+ Yes (always) +/– Not always (conditional) – No (never)

Note that the comparison for an owner, will depend on the area of the property and the proportion of forest in his heritage.

Species

In addition to the interactions between species and other factors already considered (including site and silviculture) each species is generally used preferentially in a given context with a given silviculture, which makes comparisons between species more risky. (Is it possible to compare Scottish Sitka spruce with an Atlantic silvicultural management, with widely spaced poplars?). Analysis of species vulnerability requires extreme caution, but it is possible to draw some objective conclusions:

- Under conditions where the root system can develop freely, species tend to form a heart root system with better anchorage in the soil, and are less vulnerable to being uprooted (see above). On wet soils species with plate root systems are more at risk of being uprooted (e.g. Spruce).
- Due to greater crown permeability, broad-leaved trees, having lost their leaves in autumn/winter, are less vulnerable than coniferous trees (except larch) during this period (when the vast majority of storms occur).
- On deep soils (with well developed root systems) for trees of similar height, traction trials show that beech is very resistant, then oak, Douglas fir is moderately resistant, and spruce has poor resistance. Damage occurs as follows: beech and oak at trunk level, Douglas fir breaks at ground level and spruce is uprooted.

The desire to adapt species to the site from a stability point of view should be moderated as it is not necessarily positive and may result in negative effects. For example:

- Strong anchorage in the soil is certainly efficient in the prevention of windfall but when the wind is very violent there is a risk of broken tree tops. The latter results in greater economic losses (completely broken wood or timber greatly reduced in value) and more difficult reforestation by mechanical means due to the presence of tree stumps.
- In certain cases, good site adaptation, where trees find the growth and development conditions favourable, may lead to high instability (e.g. beech tends to become very tall on mesotrophic or eutrophic sites).

Although age implies greater stand instability in broad-leaved trees, it is possible that things are not as linear for conifers. The most vulnerable age band for Scots pine seems to be between 20 and 60 years, and 80–120 years old for spruce.

It has not been possible to demonstrate that mixtures have an effect on stand stability. An analysis of damage per type of stand in Bavaria in 1990, and the case of a mixture in the dominant strata, seem to show that the vulnerability of mixtures results more from the vulnerability of the species present than its pure or mixed nature. A frequent consequence of storms in mixed stands and also in the same strata, is the loss of its mixed nature by the selective removal of one species (which is more sensitive or whose individuals are slightly taller).

PART 2: WHY AND HOW TO RESTORE THE DAMAGED FOREST HERITAGE?

OBJECTIVE, FORESTRY POLICIES AND NATIONAL DEVELOPMENT

Recommendations that one could make in relation to the integration of storm risk into stand restoration are inseparable from the objectives set out for the forest. The first section of this report has shown that there is no unique silvicultural model guaranteeing the stand against violent winds and that increased vulnerability of French forests to storms was partly due to modifications of the objectives that had been fixed. The definition of the objectives is the responsibility of the owner. Nevertheless his decisions are regulated by national policies which have been adapted to regional forestry characteristics. In general the policies are defined by the national forestry strategy and projected laws of forest orientation aim to take the different functions of the forest into account (adapted to the national scale) and to improve the integration of forestry management throughout the country.

Firstly one should emphasise the fact that the different functions or services provided by the forest are not equally vulnerable to storm hazard. The production function is undeniably the most vulnerable. Regarding biodiversity, storms should be considered as a disturbance (in the ecological sense of the term)[2]. Certain experts consider that the impact of disturbance on the biodiversity is related to the frequency and intensity of the disturbance following an upward curve at first, which then declines. The storms of 1999 constitute a rarely occurring phenomenon, nevertheless its exceptional character is mainly due to the wide area concerned rather than the level of local damage recorded (plots exist in a similar state after any severe storm). Also one must consider that in terms of local levels of disturbance storms do not generally constitute an ecological catastrophe. Social functions (walking, contemplation etc.) are also affected but generally to a lesser or temporary extent, with the exception of the value given to special stands or trees. The problem often arises from denying access to stands which may be dangerous to users. Uses like hunting may be interfered with temporarily under certain conditions, but be improved afterwards (increased capacity to shelter deer).

Secondly, storms have a social impact at two levels. On one hand they have a direct effect on the motivation and attitudes of the owners and managers. This is not limited entirely to those suffering damage. As after each disaster one notices a discouragement (the desire to sell, to discontinue all investment etc.) and an appeal to national solidarity for compensation and help with restoration. Work on the evolution of behaviour in the face of disaster shows that classically these feelings die down with time. These results

2 The impact of which is not necessarily negative.

were confirmed by observing behaviour following the 1987 storm in Brittany: in fact less than 15% of the forests damaged were abandoned.

On the other hand, storms act like a crisis and thus provide an opportunity to re-open social debate. This debate is concerned partly with the sustainability of forest management and suitable techniques used. It is also concerned with the place of the forest in the country. For the second, one must emphasise particularly the questions raised by various representatives, whether the opportunity should be taken to renovate the forest in all areas where it had been destroyed. This is particularly relevant in the geographical areas where forestry levels are considered to be excessive by the local people. This is also applicable to areas considered as a priority relative to other policies.

Better integration of forests into the rest of the country, desired by the projected forest orientation law, requires demands to be taken into account before carrying out restoration projects. At the same time the time-lag between urgent restoration and the delay required for social debates makes generalisation of this action difficult. The success of such a project is limited by three factors:

- the existence of a discussion structure between participants allowing a collective country wide project to be set up (and not just one collective forestry project).
- the existence of local interest likely to stimulate negotiation.
- the support of the owners concerned.

Practically, these conditions can be met in Regional Natural Parks. The restoration should be spread over about ten years, so it is the moment to consider the means of providing adequate structures to set out a national approach.

In other respects, the achievement of such projects depends on the adoption of delegation methods which remove the administrative obstacles to all changes in land use (land clearance tax and authorisation, re-payment of any public aid or tax reductions).

Finally, the storm could be considered to be the opportunity to revise location plans of certain interests whose relevance at the national scale has increased (Natura 2000 network, communal service plans for natural and rural areas...). This opportunity should be grasped without question for public and in particular state property, notably to set up a network of unmanaged forests. Conversely, it does not seem to be opportune, except with contracted compensation, to add this hypothesis to the present worries of private forests.

DIAGNOSIS AND RESTORATION STRATEGIES

Diagnosis and restoration, as above, do not only concern the plot or the forest owner. Certain aspects are relevant to national and regional or even to local interests. The latter may be either at the land planning level or at a property demarcation level within the forest itself.

- The regional administration is the appropriate level to identify plans of action at the territorial unit level for restoration programmes and to decide on the corresponding funds required to set it up.

- It is important to encourage co-operation between the decisions taken at different scales, at the overlapping or superimposed national unit level and forest properties so as to give some overall continuity to restoration.
- At the plot or management unit scale the preliminary diagnosis is the key phase for taking decisions on restoration and for project success.

Establishment and evaluation of environmental assessment

The environmental function of the forest may have been affected by the damage caused by the storms. The indirect impacts related to the quality of restoration will be covered below in the section on silvicultural techniques.

The first consequence of the storm was a high carbon release related to the abundance of windfall in the forest as well as clearing and soil working.

The stake has here at least a national extent. Even if other factors influencing the choice of how to clear and work the soil take precedence, it is also possible that they correspond to the objective of reducing carbon release. For example, avoiding the burning of remnants and limiting soil disturbance help to maintain the carbon stocks in the forest. Certain reforestation projects may also be favourable in terms of carbon fixation, like planting rapid growth species, but in the mid-term, these measures should deal with the exploitation and use of wood in “long lasting” products.

Analysis of the consequences of changing the vegetation, on the water cycle is carried out at the catchment level. High levels of deforestation have to occur (about 30%) before major repercussions are observed. The storms should therefore have little direct effect on this, apart from locally. The impacts on the catchment dynamics are related to the percentage of the area affected and the total soil cover, and are almost impossible to separate from the exploitation after windfall, but they are not significant for a total area cleared of 20% of the catchment, and 50% in the case of scattered windfall. In the absence of any intervention, the impact on the water cycle is perceptible but does not last long (for the next 3 years). Locally, steep slopes which may suffer from erosion should be identified. In valleys, the consequences mainly have a bearing on water quality and especially its turbidity. Thus, the clearing of large areas should be avoided at the catchment area level for a long time but this precaution is not extremely limiting. Restoration should also take water acidification problems into account, which are created by reforestation with certain species when large areas with an acid substrate are concerned (e.g. spruce forestation of certain valley floors in the Vosges).

From the biodiversity point of view, the storm may affect the conservation policies adopted or being set-up, and so they should be re-evaluated. The diversification of habitats which the storm has created in places, could be used in the creation of a French network of biodiversity conservation, integrated into the Pan-European Ecological Network of the European Council. The efficiency of a network structure of this type, optimising the dispersion of species between different core areas to improve mixing, is highly dependant on the diversity of the habitats at these core areas (= knots in the network) so that a large number of species can pass or shelter there, and that they are sufficiently species rich to act as dispersion sources themselves. The storm should provide an opportunity to rethink the network structure, if possible by integrating new core areas and eventually restoring a certain number of corridors (linear structures like hedges, often blown down in Normandy for example).

The approach is very different for stands which have been affected by the storm and which are of special conservation interest (for example, nature reserve networks or *in situ* forest genetic resource conservation networks). In this case efforts will be concentrated on a damage inventory and as far as possible the restoration of stands. There too, the national plan of action should be re-assessed: identification of “new” candidates to replace damaged stands and changes in the statute to reduce the possibility of the same thing happening again. In fact it is possible to make an inventory of each aspect of the heritage value of the stands (cultural, aesthetic etc.) and to evaluate the post-storm situation, allowing measures to be set up at the relevant regional level.

Fire risks and prevention strategies

There is no doubt that fire risk will increase next summer, including regions where risk is normally marginal, due to the presence of easily inflammable material on the ground. In plots affected by windfall, the quantity of inflammable material in the lower vegetation strata will change from a few tonnes per hectare to a few tens of tonnes. The risk will be increased if there is summer drought and in the areas concerned, it will be higher than the normal risk in the Mediterranean region.

Separation of wind fall zones by re-opening existing tracks, combined with clearing the inflammable material here and there from the tracks, represent an efficient method of preventing generalised fires and make access for prevention services easier.

Controlled burning aims to reduce the quantity of inflammable material on the ground and to clear plots. In fact, burning wood with a diameter greater than 1 cm is incomplete, so clearing plots cannot be carried out using this method except in the case of previous windrowing. In addition, controlled burning has two disadvantages: the export of mineral and organic elements which is particularly crucial on poor soils; and fire control. Suitable moments meteorologically, allowing burning are limited and fire danger is always present. So one should:

- encourage the use of tie-ridges in windfall zones to avoid fire propagation.
- limit the use of controlled burning to situations where it is not possible to reduce the quantity of inflammable material on the ground by other methods, and to moments when meteorological conditions are suitable; it should however, be forbidden on poor soils.
- locally, in regions at risk, plans to encourage plot clearance should be re-enforced.

The need to control ungulate populations

Changes in ungulate population dynamics following the storms results in:

- marginal direct mortality.
- the birth-rate is sometimes disturbed in the following year: intra-uterine death, neo-natal losses, etc.

- a possible reduction in hunting pressure due to problems and even access to the forest forbidden (this is the case for the 1999 storms).
- the appearance of generally much improved feeding conditions due to the availability of material which is not normally accessible (buds, young shoots etc.) and the appearance of more appetising vegetation in the openings.

Thus a measurable increase in populations in the coming years can be expected. The population levels will eventually become a limiting factor regarding regeneration and young stands. They will also have an effect on vegetation dynamics with the risk of species disappearance. Finally the consequences outside the forest will have an effect on agriculture and even road safety (especially in forests near edge of urban areas).

The first measures necessary should be aimed at providing means of regulating ungulate populations adequately. The regulation of large game in forests is traditionally undertaken by hunters who must conform by contract to the hunting plans negotiated at a departmental level. The number of animals taken in France is low compared with levels operating in Germany for example, but that is also related to lower population levels. Everywhere that diagnosis shows that the number taken should be increased, the first stage is to renegotiate the hunting plans in co-operation with the hunters. It is also possible that the use of little used hunting techniques which are efficient in over-crowded forests, like stalking, could help to achieve a higher success rate while being psychologically more acceptable. However, experience shows that acceptance and production of increased hunting plans are often difficult, and that the mobilisation of hunters, however necessary, is likely to be insufficient in certain cases. In situations where the increase in large game reaches intolerable levels for certain forest functions and where the use of hunters alone does not produce sufficient control, other means of controlling the populations will have to be brought into play. This cannot be considered without the co-operation of all parties concerned and especially the hunters.

As a complementary measure, the ungulate problem must be taken into account by adapting the choice of restoration in relation to the no doubt inescapable increase in game.

The smallest openings only occur when clearing is abnormally high and must constitute the zones gained by large game. For this it seems reasonable to concentrate on the natural healing capacity of the stand. In the case of larger openings one must remember that in general, natural regeneration is less menaced by large game than plantations, and can thus be used preferentially where possible (beech had a large mast production in 1999 and is not very appetising). Targeted intervention could be used as a complement after a few years, using suitable methods of plant protection.

In all cases, associated vegetation must be made use of, which forms a substitute food instead of the target species.

Evaluation and control of the main pests and diseases associated with windfall

Plant health problems related to storms can be of two types: i) a threat to the stand in place and to regeneration success due to pathogens and pests or to an abrupt change in environmental conditions (e.g. burnt bark in beech) and ii) degradation of stored wood affecting its market value and even its technological quality. The second aspect is not strictly related to restoration problems and will not be covered here.

Bark beetles, capable of "explosive" outbreaks constitute an immediate and often very serious threat to stands in place. The greatest worry concerns the typograph (*Ips typographus*) in spruce whose rapid multiplication capacity is well known, as well as its aggressive nature at high population levels. Trees which are physiologically deficient and a high local concentration of windfall are factors which make the situation worse. Conversely conditions which are unfavourable for insects (e.g. climate) may slow down population development.

Fungi can also affect stands in place. Especially, damaged root systems of trees shaken by the wind provide openings for root rot, and a decline in the health of the trees concerned is possible. In the case of *Fomes*, the stumps provide an opening for the fungus, which multiplies in the stumps and is then transmitted to living trees by root contact, which makes restoration itself questionable.

Principles governing the methods of controlling insects are not very different, whatever the insect considered, it is the urgency of the measures to be taken which vary as a function of risk. It requires rapid exploitation of trees in the forest combined with clearance in zones at risk (chipping the remnants is very efficient), suitable treatment of trees felled, by spraying (in the case of oak), debarking (very efficient against bark beetles in fir, spruce and even pine), even strictly controlled insecticide treatment, wood storage in places where colonisation cannot occur (more than 10 km from the forest, and the possibility of limiting stocks, which implies that the wood industry is capable of functioning at maximum output. Pheromone traps provide useful information, if only partial, to monitor populations, but does not regulate populations efficiently in cases of generalised infestation. However, the measures recommended above are not realistic in cases of general damage over large areas. So priority must be given to the treatment of infested stands which require less work and still have high future value.

For coniferous stands (mainly spruce and pine) treatment of stumps to prevent *Fomes* could be considered. When the fungus is already present at high levels in the original stand, it may be necessary to change the species.

Diagnosis at the forest and plot level

In the field, diagnosis concentrates on the nature of damage: its intensity and distribution, and congestion in the plot. This diagnosis is coupled with an evaluation of the remaining stand: its economic value of course, but also its capacity to continue afterwards and if necessary regenerate naturally (the presence of seed production in neighbouring plots and the existence of a seed bank in the soil should also be taken into account), and the risks associated with its presence (falling trees or branches, heath risks etc.) or its absence (rising water level, increased light at the soil level).

In regular forest, it is the intermediate situations, with damage levels affecting 30 to 70% of future timber (or 1/3 to 2/3 of the surface area) which require a more detailed diagnosis. Below these levels, work is limited to an exploitation of the wind fallen trees and clearing if necessary. Above this, restoration is considered to be essential.

In situations where exploitation of windfall and/or its restoration is considered, external constraints have to be reviewed. In particular, access problems which had not perhaps been organised before the storm. Also the importance of the worksite at a national level with "peaks" at a local level, already pose problems of material, manpower and company availability which must be taken into account.

In several cases, storm related damage is great enough to question the relevance of the management objectives. Diagnosis followed by redefinition of these objectives, and translated into updated management documents (planning or PSG) is thus necessary; help to update these documents should be envisaged.

At the forest scale

In regular forest, damage evaluation results simply in the re-establishment of priorities regarding regeneration. Generally, this can be advanced, including the improvement group plots, in areas of major damage or retarded for certain regeneration group plots which have no openings and are little affected, to preserve the equilibrium of the regeneration groups; This evaluation can make use of the damage maps obtained by photo-interpretation, and are sufficient to isolate clear cases (destroyed or intact stands), completed if necessary by a field inventory which is useful for quantifying damage in the particularly badly affected stands. Access to these maps, especially by private forest managers, would be a simple measure to help diagnosis. In irregular forest, only near destruction of the stand would call the objectives fundamentally into question at the plot level (the plot will inevitably become more regular after restoration). It is possible to produce a map of the stand types after the storm, to refine the objectives, once access is possible.

An estimation of the remaining volume is based on the inventories. A statistically efficient method is to use a stratified inventory, based on types of damage so that samples are homogeneous with low internal variability, and to reduce the number of plots required for description of the associated stand types. This stratification can be made using the photo-interpretation of the stands, or using systematic exploration preferably in the field by noting simple descriptive variables of damage intensity.

Natural regeneration potential: what would happen in the absence of any intervention?

Some plots have not had any restoration following storms in the past. Two situations are possible: preliminary exploitation/extraction of wood in place or that the plots are completely abandoned. In certain cases it has been observed that a stand does not become established rapidly (it is still not established after 10–15 years) and that these phases are often associated with colonisation by weed species (bracken, *Molinia* etc.). Nevertheless it is too early to be categorical about the results of the occurrence of such "blockages" relative to current work, or to come to any conclusion about the end result. (It is possible that the forest will end up by taking over after several decades). Apparently in most cases forest tree seeds are present, therefore many situations exist where this potential regeneration cannot take place.

Under certain conditions mechanisation has a marked effect on the soils (see forestry techniques). It is hardly surprising that in the plans being studied, wood extraction using heavy machinery seems to have had an effect in certain cases, this type of work can also jeopardise the seed source itself (removal of the upper horizon) and increase light intensity which encourages invasion by sun-loving weeds (brambles, broom, bracken etc.).

Finally it must be added that the decomposition time for wood, which is not broken up and not in touch with the ground, can, depending on the species and diameter, be much longer than ten years and can constitute a real obstacle to access and circulation in a plot.

Creation of stand restoration plans

What type of regeneration?

The choice between natural regeneration and plantation is partly independent from the storm, but it is useful to reiterate the bases for choice, mainly as a reminder, but also because the post-storm context may have some bearing on the advantages and disadvantages of the two methods.

	Advantages	Disadvantages
Plantation	• Access, stand composition is fixed from the beginning → easier to direct operations • Speed of stand creation • Evaluation of genetic progress	• Installation costs (the need to mobilise investment capacity instantly) (1) • Amount of preparation work (mechanisation) (1) • Vulnerable to ungulates (1) • Low species number • Vegetation succession disappears
Natural regeneration	• Little preparation work (2) • Less vulnerable to ungulates • Initial stages of natural processes maintained.	• Regeneration uncertain (1) • Stand behaviour • Some inter-breeding if few seed trees.
Low density plantation in addition to natural regeneration	• Lower initial investment (1) • Opportunist plan: plantation investment can be reduced depending on the quality of natural regeneration • Deferred plantation → plants can be ordered in advance (availability) and their quality defined, for example by a breeding contract (1). • Natural processes partly maintained	•Individual cost of plants (including individual protection) • Plan installation difficult (impossible to mechanise part of the planting) • Difficult to find complementary plants during the future life of the stand →What is the “additional value” of the final stand?

(1) advantage/disadvantage increased following the storms.
(2) advantage/disadvantage questionable following the storms.

The post-storm situation influences the organisation and methods used in plot regeneration:

- work organisation and finance, as well as availability of suitable plant material (from the genetic point of view, related to the site, with no defects) and equipment, leads to the need to stagger plantation work.
- compared with a normal situation, the amount of work will result initially in the most economical methods being used preferentially, and thus the use of natural regeneration will be used as much as possible, including situations where plantation alone was being used before. The range of plantation densities is vast, from simple enrichment to plantation as a complement to natural regeneration and depends especially on the quality of natural regeneration and the choice and characteristics of the target species. One must bear in mind that natural regeneration is more difficult to obtain for all the species, for which natural regeneration techniques by progressive cutting are better adapted (the case for oak and beech, but for the latter, due to a good mast production in 1999, natural regeneration will hopefully provide few problems). Finally, for other species (spruce, Douglas fir or pines), natural regeneration may be difficult to obtain or may not be desirable (mainly for reasons of stand quality).

The choice between the restoration methods, by plantation, natural regeneration or mixed methods depends on the objective fixed for the forest, the species present (in this respect the situation is very different between oak forest, and an old Douglas fir or Scots pine plantation), the competence of the manager and the diagnosis made for the plot. The two latter points should limit the risk of failure associated with restoration.

Economical performance of forestry scenarios

The choice of objectives given to the forest and the diagnosis for the stands in place have been used to isolate the principal restoration options. The corresponding forestry scenarios can be tested to compare their economic efficiency.

Economic analysis of the restoration scenarios uses actualisation theories. This analysis, to be relevant, should take a production risk into account which until now, has rarely been the case (see below). Previous observations have established a number of stand instability thresholds (especially for conifers). So it is possible to integrate this parameter into economic calculations associated with growth models[3] which could provide the initial elements to help the management. However, this work has not yet begun and remains to be done. It will take the instigating measures associated with restoration into account, which may evolve with time.

Conversely, it must be remembered that at present we do not have damage models (curves of damage levels related to hazard frequency), which are indispensable for a rigorous economic evaluation of risk. This is an important field of investigation. Using the approach used by a large landowner and forest manager: for the forestry scenarios chosen,

3 At the stand level in certain simple, well examined situations, essentially regular monospecies, the use of programmes based on growth models and including if possible economic modules (Oasis or Capsis) could provide precious help in decision making.

he compares the damage observed in the forest with the length of time for the return of "severe storms". The resulting model is very simple and empirical, but may constitute the initial stage. In agreement with the "Atlantic" forestry of the UK this model tends to favour high production and short rotation conifers in preference to longer rotation broad-leaves, even if the first case is more vulnerable.

For immediate restoration, it must be emphasized that investment decisions on the part of the owners are generally governed by cash constraints rather than by logic related to economic profitability on investment. This explains the high sensitivity of their decision relative to help with plantation. In the present case, this sensitivity is increased even more by two factors. One, this liquidity constraint is at a crucial level, due to low income related to physical damage, the collapse of the timber market and the increase in the cost of reforestation. Secondly, the psychological situation, as seen above, results in a lack of motivation. The public aid plan for restoration will be a determining factor both regarding the principal of restoration itself and investment levels.

OPTIMISATION OF FORESTRY TECHNIQUES

This section is not intended to replace reforestation manuals. In fact it is only interested in the way that specific post-storm problems are treated, related particularly to the importance of fallen timber, to the original ecological data (game, risk of disease etc.) and the restoration economy. Of course it must be added that techniques favouring stability should be given priority and unfavourable techniques avoided, but the description of factors worsening the situation, given in the first part of this document gives sufficient information on this subject.

Work specific to restoration and in preparation for reconstruction

Exploitation of windfall is a reasonable preoccupation after a storm even when the results of the storm have lost all commercial value. At least partial clearing is necessary in the most affected plots to provide access and circulation. Previous storms show that circulation problems created by the presence of material on the ground last for a long time (some plots still suffer from these problems after the 1982 storm in the Auvergne). It seems to be essential to give some grant aid to provide minimal clearance in these plots. This should be a minimum with regional modifications, sometimes fairly low when it is only for the prevision of access to plots and movements within them, and sometimes higher, for example, in the case of fire risk. In most cases this operation involves forest management and depending on the case, limits plant health and fire risks.

The presence of abundant remnants complicates or makes forestry work impossible and is associated with the plant health and fire risks already mentioned. Total chipping maintains and allows the rapid availability of organic and mineral elements. However it often leaves a mulch (accumulation of organic matter on the ground) which is sometimes thick, possibly causing seed rot and a passing toxicity. This method is only useful when the quantity of remnants is not excessive.

The most classic method of resolving the problem is windrowing. This method induces a concentration of mineral and organic elements in the windrows, which once liberated into the soil, are only available to a small percentage of the stand (especially if the windrows are widely spaced). Burning the windrows transforms the temporary storage into gross exportation, without counting the fire risks possibly associated with this operation: it should thus be prohibited as much as possible. Windrowing also encourages the proliferation of certain pests and rodents. Finally, windrowing techniques often require machinery (especially bulldozers removing the humus together with remnants). This operation should thus be avoided as much as possible, and in practice it is sometimes sufficient to break up the crowns and only extract the largest branches (the only ones that really prevent work), and redistribute the smaller diameter remnants which rot after a few years on the soil. Another use of the remnants is to use them on the tie-ridges, after chipping, to limit the impact of machinery on the soil. When windrowing alone is feasible it should be carried out by suitable machines. A mechanical digger with caterpillar tracks is suitable as it does not remove the humus, allows closer windrows which disturb the soil chemistry less, and exert less pressure on the soil.

In several cases the plots are scattered with stumps which have broken at abnormal heights, and get in the way of work especially in reforestation, and require treatment when they are located in zones used by machinery (mainly tie-ridges). In some cases the presence of these tree stumps present a major pathogenic risk (see above). The ideal would be to destroy the stump on site with a digger fitted with a Becker claw. When windfall is abundant, it becomes necessary to level the ground and replace the root boles. Lastly, tree fall and clearing, or movement of machinery may cause widespread soil compaction, making restoration, notably by ploughing, indispensable before reconstruction.

The role of mechanisation in the post-storm context

The effects of mechanisation on the soils are particularly important due to the extent of the sites and the quantity of wood on the ground responsible for this exceptional activity in the forest. The soils may be subjected to chemical degradation due to the humus removal. This danger is even greater in soils which are porous, acid or have low mineral reserves. The soils are also in danger of being damaged by compaction and rutting, and even more so, as the silt content increases, or there is water logging near the surface, low stone content and high soil humidity. Other factors making the situation worse include steep slopes, lack of vegetation cover and a “severe” climate.

A few major principles regarding working methods become evident and are relative to:

- setting up tie-ridges which concentrate the impact of materials on the ground to a limited area which is not planted later.
- choice of the intervention period (to avoid working on wet soil!).
- protection of tie-ridges by spreading all or part of the remnants.
- windrows should be avoided as much as possible (concentration of organic and mineral elements).

- bare soil should not be left for long periods, to limit physical erosion and chemical modifications (loss of exchange capacity by migration of fine particles, nitrate drainage etc.).
- choice of suitable machinery (low pressure tyres, caterpillar tracks).

Setting up tie-ridges is also useful for predictable changes in forestry, which will require more mechanisation. From the beginning this ensures that future operations in the stands, begun following the storms, take place under the best conditions.

Taking everything into account, the most efficient methods of limiting damage requires machinery which is limited in number in France at least for certain models (large chippers). Even if such methods should certainly be encouraged, unsuitable methods should be prevented and material should be maintained in good working order.

Environmental measures associated with exploitation

The storms have produced large modifications in the nature and distribution of microhabitats in the plots affected. In particular, it has created new ones which it is possible to preserve with little cost or effort, when this has no effect on future work or when there is no risk of disease (dead wood). Levelling, considered above, does not exclude the possibility of leaving some root plates of windfall, and similarly for broken tree trunks and windfall (a few per ha). Abandoned dead wood will be chosen amongst those having no more economic value (due to the type of damage, its quality or species) and as often as possible another species from that projected for the future stand, to reduce contamination risks from pathogens. To limit congestion it is possible to strip the branches off the abandoned wood on the ground.

Restoration by planting: choice of plant material

The storm will increase the demand for trees during the coming years. Supply problems of trees, which may be related to the quantities available, origin, genetic quality or external quality, are predictable. After the collapse in requirements in 2000 due to the impossibility of preparing sites in time, requirements should grow enormously in 2001 and be above the annual mean for the previous period, and for several years to come. The seed-plant suppliers are however under-exploiting their production capacity. Taking the length of time for plant production into account, modification in production is above all influenced by the possibility of making viable predictions of requirements. Certain experts think that more widespread use of contract systems is desirable to improve this predictability. At the same time this depends on a public aid system being set up and decisions to encourage regeneration more or less strongly, instead of replanting.

Relative to quality, the storm may create shortages of certain species or sources over shorter or longer periods. For most of the conifers the seed stocks are sufficient. The production capacity of the state tree seed orchards is not in question, even if maritime pine orchards have suffered high levels of damage. For broad-leaved trees especially with large seeds, conservation is sometimes more limited. Cherry trees will be the most affected as shortages are already a recurring problem. The situation may also be critical for beech, depending on the size of the re-forestation programmes. A general revision of the range of classified stands will be necessary in any case, probably with greater urgency for certain sources of sessile oak. It should not be indispensable to rely to any great extent on imports or derogated harvests. Only the rare cases stated above require special examination. Vegetative reproduction of bulk lots of seedlings could also be a valid method if there are shortages of certain sources.

Taking the extent of restoration into account, it may also be necessary to be particularly careful with respect to advise in terms of choice of source and the category of plant material. Apart from the exceptions stated above, the storm does not justify any departure from the rules. Nevertheless it would be wise to take this opportunity to renew efforts of popularisation in terms of genetic quality and external forest plant material.

In the special case of conifers, it may be the moment to use plants treated against hylobie (*pine weevil)* for plantations after windfall in old coniferous stands where rapid multiplication has been observed.

Methods using natural processes

The extent of areas concerned by partial or total restoration requires the use of low intensity methods, even in situations where total plantation is usual. An interesting method from several points of view, when possible, is the initiation of natural regeneration completed by planting if necessary. This method is cheaper at first because plantation work is limited (in the strict sense). In addition, natural regeneration is generally less vulnerable to being eaten by game, which due to growing numbers, may concentrate attacks on associated vegetation. Complementary plants, being less numerous can be taller and better protected from the game. The final advantage of this system is that it rejuvenates the forest ecosystems, as the initial stages of these vegetation series are under represented or by-passed (in the case of plantation) at the forest massif level. The site catalogues are an indispensable tool in the description of predictable vegetation successions and climax stands.

Nevertheless it is wrong to believe that natural regeneration can solve all problems and in particular that it costs nothing. Preliminary clearing of plots generally remains indispensable, and a certain number of jobs are more onerous. In cases of delayed enrichment planting, like natural regeneration it is advisable to forecast tie-ridges in the culture from the first year, to allow movement within the plot later, and particularly access to future plants or shoots. Development of pioneer species (goat willow, birch, mountain ash etc.) could be used to advantage, to reconstitute the forest environment, to control low level competitive vegetation and to educate plants. Neighbouring countries (Switzerland and Germany) do not hesitate in using these accompanying species. However, they have to be controlled which entails fairly close monitoring.

Coppice seems to shoot easily from the stump even after intensive exploitation work. If it is one of the target species, it is possible to use the shoots and proceed with operations of choosing standards. If not, it can be used as an accompanying plant as well as the spontaneous pioneer vegetation.

Finally, it must be remembered that these methods are used after a diagnosis, and that if the future of these plots in the absence of plantation is still not clear, it is necessary to minimise the damage at ground level during exploitation and to ensure that the previous, and if possible the present number of seedlings is sufficient. The risk of failure is high and especially if appropriate cultivation work has not been done and this should be taken into account in all potential public aid policies.

GET READY FOR THE NEXT STORM

The modification of institutional procedures to achieve a more efficient follow-up and reaction to an incident

The lack of data is one of the limiting factors for reaching clear conclusions, whether involving favourable or worsening circumstances, or the efficiency of measures to be used. A good example is the impossibility of reaching a conclusion about the stability of even-aged and uneven-aged high forest. It would be useful initially, to make a list of the real information required after a storm, separating the short from the mid-term requirements. Then, a monitoring system should be set up to carry out an evaluation of damage, examining the prevailing conditions and organising a follow-up of the measures which could reduce this deficiency. The rarity of the phenomenon and the interest of covering the maximum number of situations makes one think that this monitoring system could be European. This demands an effort which will be useful, if not in a harmonisation of measurements and methods, at least the extrapolation from these measurements would allow comparisons to be made and allow their incorporation into the same sample.

In addition, a pre-established procedure for setting up emergency measurements in cases of severe storm damage, and the maintenance of a minimum framework specific to the exploitation of wide spread windfall, (for example storage zones, rail transport capacity) should be considered seriously in partial preparation for the consequences of future storms.

Improving risk evaluation

Risk evaluation cannot be examined independently from the definition of objectives, on which it is generally dependent. It must not be forgotten here that the definition of objectives, including economic ones, can result in not looking for the minimal vulnerability (see economy compared with forestry scenarios). In other respects, it must be emphasised that what is involved is mainly an economic risk and not essentially a public security risk. The legitimacy of state action should take this distinction into account.

Taking storm risk into account in the planning and management of forests results in the examination of three types of question:

- the localisation of the stakes in play throughout the country.
- prevention at the management unit level.
- economic risk cover.

However, storms are only one of many hazards which can cause damage in the forest. Taking risk into account is to analyse all factors, whether natural (freezing, drought, or degradation caused by pests) or man-made (pollution, market collapse...) which could alter the production value.

Localization of the stakes

It is possible to imagine a map of the storm allowing one, for example to produce public aid packages. However, one comes up against a problem of scale, the nature of the wind is influenced locally by topography or exposure. Supposing that this parameter could be examined for several regions which are particularly exposed (for example by the CRPF – Regional centre of forest ownership consulted to verify the simple management plan – P.S.G.), but practically this can only be carried out at the plot level, for example on the choice of species and plantation techniques. It must also be emphasised that the greatest vulnerability factors like length of rotations, age of clearing, etc. are overlooked by the public aid distribution process. Overall these factors suggest that creating a storm risk map, by definition including hazard, vulnerability and stakes, is not to be recommended.

In spite of this, it seems reasonable to look for a better spatial distribution of risks. This process is an organisational measure leading to the structuring of the area so as to obtain an acceptable distribution of zones with low and high vulnerability.

Prevention at the management unit level

This is an important aspect. It returns to the three questions already examined elsewhere in this report: the choice of a suitable objective relative to the degree of site exposure; the use of the least vulnerable forestry techniques (see Part 1); economic investment analysis integrating all the risks.

Economic risk cover

Classically, cover is either provided by the individual himself or by national liability, or by mutual insurance between people exposed to the same risk (insurance organisations).

In Europe there are different cultural differences between countries regarding the sharing of risks attributed to natural catastrophes. In countries like Norway or Germany this cover is entirely the responsibility of the private sector. In other places, for certain risks, insurance may be obligatory: subsidence in Great Britain. France is one of the countries where the State intervenes to a fairly great extent, sometimes in the form of indemnities, but more often in the form of help towards restoration (the case of the forest).

In France few forests are insured (~5%) and even so this insurance is only an extension of fire insurance. This situation is due to a multitude of reasons amongst which are: the poor understanding of this risk, a cultural habit of turning to the State for aid in the face of natural catastrophes, the fact that the forest is rarely a major element in household revenues, a lack of interest in this risk by insurance companies and to chain effects (few people insured, thus high tariffs, thus a dissuasive effect), etc.

It must also be emphasised that the insurance companies always recognise their limits in the face of extreme phenomena (an upper limit for refunds) so there must be a guarantee system of an even greater order (re-insurance, guarantee funds, etc.).

To develop insurance systems, at first it will probably be necessary to debate the limits of State intervention, and storms can certainly not be isolated from other natural catastrophes. It would also be possible to make insurance obligatory, which does not seem desirable as the forest is rarely a vital element for households. The two directions to follow seem to be a closer analysis of the question with the insurance sector, and concentration on an information and publicity campaign to accompany, notably the distribution of public aid.

Finally, certain experts consider that even if national policy encourages multifunctional systems, risk cannot be mutualised between all those concerned with the future of the forest. The storm represents above all, an economic risk for the investors, and mutualisation could only be considered between them. Other experts consider that its multifunctional nature should be accompanied by shared risks with the beneficiaries. In all cases, sharing the greatest part of the risk with public companies should be examined for forests which represent major stakes (notably at the social or environmental level) using contractual mechanism processes.

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GLOSSARY

AFOCEL	Association Forêt Cellulose Forest – Cellulose Association
Cemagref	Institut de recherche pour l'ingénierie de l'agriculture et de l'environnement Strategic and applied research institute in agricultural and environmental engineering
CIRAD	Centre de coopération Internationale en Recherche Agronomique pour le Développement
CNIEFEB	Compagnie Nationale des Ingénieurs et Experts Forestiers et des Experts Bois
CNRS	Centre National de la Recherche Scientifique French National Centre for Scientific Research
CRPF	Centre Régional de la Propriété Forestière Regional Centre of Forest Ownership
ENGREF	Ecole Nationale du Génie Rural des Eaux et Forêts French Institute of Forestry, Agricultural and Environmental Engineering
FVFE	Fédération de la Vulgarisation Forestière de l'Est
DERF	Direction de l'Espace Rural et de la Forêt Countryside and Forestry Department
IDF	Institut pour le Développement Forestier Institute for Forestry Development
IFN	Inventaire Forestier National National Forest Inventory
INRA	Institut National de la Recherche Agronomique National Institute for Agricultural Research
MAP	Ministère de l'Agriculture et de la Pêche Ministry of Agriculture and Fisheries
ONF	Office National des Forêts French National Forestry Board