ATLAS CEDAR AND CLIMATE CHANGE IN FRANCE: ASSESSMENT AND RECOMMENDATIONS

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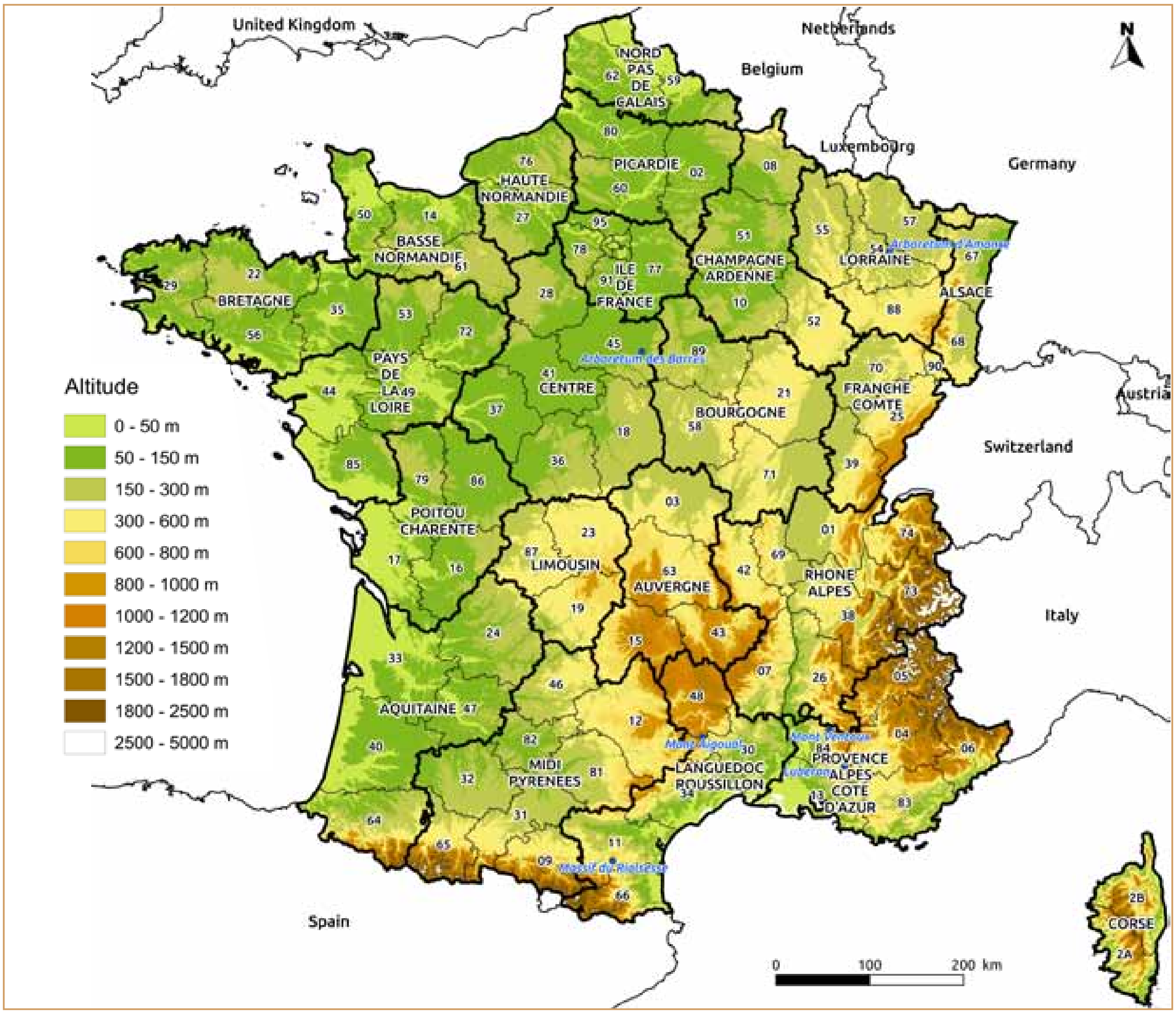

N°	DEPARTMENT	REGION	N°	DEPARTMENT	REGION	N°	DEPARTMENT	REGION
01	Ain	RHONE-ALPES	32	Gers	MIDI-PYRENEES	64	Pyrénées-Atlantiques	AQUITAINE
02	Aisne	PICARDIE	33	Gironde	AQUITAINE	65	Hautes-Pyrénées	MIDI-PYRENEES
03	Allier	AUVERGNE	34	Hérault	LANGUEDOC-ROUSSILLON	66	Pyrénées-Orientales	LANGUEDOC-ROUSSILLON
04	Alpes-de-Haute-Provence	PROVENCE-ALPES-COTE-D'AZUR	35	Ille-et-Vilaine	BRETAGNE	67	Bas-Rhin	ALSACE
05	Hautes-Alpes	PROVENCE-ALPES-COTE-D'AZUR	36	Indre	CENTRE	68	Haut-Rhin	ALSACE
06	Alpes-Maritimes	PROVENCE-ALPES-COTE-D'AZUR	37	Indre-et-Loire	CENTRE	69	Rhône	RHONE-ALPES
07	Ardèche	RHONE-ALPES	38	Isère	RHONE-ALPES	70	Haute-Saône	FRANCHE-COMTE
08	Ardennes	CHAMPAGNE-ARDENNE	39	Jura	FRANCHE-COMTE	71	Saône-et-Loire	BOURGOGNE
09	Ariège	MIDI-PYRENEES	40	Landes	AQUITAINE	72	Sarthe	PAYS-DE-LA-LOIRE
10	Aube	CHAMPAGNE-ARDENNE	41	Loir-et-Cher	CENTRE	73	Savoie	RHONE-ALPES
11	Aude	LANGUEDOC-ROUSSILLON	42	Loire	RHONE-ALPES	74	Haute-Savoie	RHONE-ALPES
12	Aveyron	MIDI-PYRENEES	43	Haute-Loire	AUVERGNE	75	Paris	ILE-DE-FRANCE
13	Bouches-du-Rhône	PROVENCE-ALPES-COTE-D'AZUR	44	Loire-Atlantique	PAYS-DE-LA-LOIRE	76	Seine-Maritime	HAUTE-NORMANDIE
14	Calvados	BASSE-NORMANDIE	45	Loiret	CENTRE	77	Seine-et-Marne	ILE-DE-FRANCE
15	Cantal	AUVERGNE	46	Lot	MIDI-PYRENEES	78	Yvelines	ILE-DE-FRANCE
16	Charente	POITOU-CHARENTE	47	Lot-et-Garonne	AQUITAINE	79	Deux-Sèvres	POITOU-CHARENTE
17	Charente-Maritime	POITOU-CHARENTE	48	Lozère	LANGUEDOC-ROUSSILLON	80	Somme	PICARDIE
18	Cher	CENTRE	49	Maine-et-Loire	PAYS-DE-LA-LOIRE	81	Tarn	MIDI-PYRENEES
19	Corrèze	LIMOUSIN	50	Manche	BASSE-NORMANDIE	82	Tarn-et-Garonne	MIDI-PYRENEES
21	Côte-d'Or	BOURGOGNE	51	Marne	CHAMPAGNE-ARDENNE	83	Var	PROVENCE-ALPES-COTE-D'AZUR
22	Côtes-d'Armor	BRETAGNE	52	Haute-Marne	CHAMPAGNE-ARDENNE	84	Vaucluse	PROVENCE-ALPES-COTE-D'AZUR
23	Creuse	LIMOUSIN	53	Mayenne	PAYS-DE-LA-LOIRE	85	Vendée	PAYS-DE-LA-LOIRE
24	Dordogne	AQUITAINE	54	Meurthe-et-Moselle	LORRAINE	86	Vienne	POITOU-CHARENTE
25	Doubs	FRANCHE-COMTE	55	Meuse	LORRAINE	87	Haute-Vienne	LIMOUSIN
26	Drôme	RHONE-ALPES	56	Morbihan	BRETAGNE	88	Vosges	LORRAINE
27	Eure	HAUTE-NORMANDIE	57	Moselle	LORRAINE	89	Yonne	BOURGOGNE
28	Eure-et-Loir	CENTRE	58	Nièvre	BOURGOGNE	90	Territoire-de-Belfort	FRANCHE-COMTE
29	Finistère	BRETAGNE	59	Nord	NORD-PAS-DE-CALAIS	91	Essonne	ILE-DE-FRANCE
2A	Corse-du-Sud	CORSE	60	Oise	PICARDIE	92	Hauts-de-Seine	ILE-DE-FRANCE
2B	Haute-Corse	CORSE	61	Orne	BASSE-NORMANDIE	93	Seine-Saint-Denis	ILE-DE-FRANCE
30	Gard	LANGUEDOC-ROUSSILLON	62	Pas-de-Calais	NORD-PAS-DE-CALAIS	94	Val-de-Marne	ILE-DE-FRANCE
31	Haute-Garonne	MIDI-PYRENEES	63	Puy-de-Dôme	AUVERGNE	95	Val-d'Oise	ILE-DE-FRANCE

Map and list of the French departments, regions and sites marked in the text with an asterisk (*).

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1. Atlas cedars at "Mont Ventoux*" (Vaucluse imation.

* The Vaucluse is a French department. The departments and the regions are marked in the text with an asterisk and are located on the map on p. 2.

Atlas cedars at "Mont Ventoux*"

WHY CEDAR?

2. After recent droughts in the Tarn*, some species such as Norway spruce (on the left) and Douglas fir (on the right) face dieback issues.

Recent climate change has revealed the limits of species so far adapted to their environment. Among conifers, Norway spruce, Scots pine and Douglas fir sometimes exhibit worrying symptoms of decline. Climate change models predict an increase in the mean temperature of 2-5°C from now until the end of the century and a higher frequency in extreme weather events, such as droughts and storms. Forest populations will face an important change and evolution in the ecological conditions that influence their growth and survival.

To cope with this situation, foresters must adapt their management strategies and consider using tree species that are less drought-sensitive. Atlas cedar is one such species. Since its introduction in 1862, Atlas cedar has been widely planted in forests in south-eastern France and has adapted to the Mediterranean part of France whose climate may in the future cover a larger part of the French territory. Despite harsh environmental conditions, Atlas cedar can be very productive, providing well-shaped individual trees and a sustainable and valuable timber. Cedars are also much appreciated for landscape purposes and are currently free of serious health issues.

However, what do we know about the adaptive capacity of cedar to climates and soils from temperate zones? Recent problems of forest dieback, which was observed in several arboretums after the drought in 2003, remind us that, **to be successful, cedar reforestation must comply with strict recommendations regarding environment, plant material type, establishment techniques and population management.**

To help forest managers and planners decide whether to use cedar, this brochure gathers useful knowledge, from the literature reviews[1] and from recent studies. In addition, a specific nationwide survey from 2011 reviews previous experiences in growing cedar stands.

A NATIONWIDE SURVEY

Designed for gathering information regarding existing references about cedars throughout France, a survey was launched in 2011 with technical teams from INRA[2], IRSTEA[3], ONF[4] and CNPF[5] (CRPF[6] and IDF[7]). A form for completion containing the plot location, environmental description, forest population and history was circulated. An analysis of the causes that might have triggered success or failure was conducted via an open-ended question. Altogether, 196 responses, of which 90 were from the Mediterranean zone, were received from 42 departments. Sixty-two percent of the plots were located in private forests (see map 11, p. 10). Information that could be fully analysed was available for nearly 100 of these responses.

1 Numbers between squared brackets refer to grouped references on p. 28 and p. 29.
2 INRA: National Institute for Agricultural Research; see http://institut.inra.fr/en
3 IRSTEA: National Research Institute of Science and Technology for Environment and Agriculture, the former Cemagref; see http://www.irstea.fr/en/accueil
4 ONF: National Forest Agency, which manages French public forests
5 CNPF: National Centre for forest ownership; see http://www.cnpf.fr/forest-development-organisations-461599.html
6 CRPF: Regional Forest Owners Centre
7 IDF: Institute for Forest Development

WHICH CEDAR FOR FRENCH FORESTS?

The genus *Cedrus* includes 4 species, some of which are not adapted to French climates.

ATLAS CEDAR *(CEDRUS ATLANTICA)*

Atlas cedar comes from North African mountains (Morocco and Algeria).

In France, Atlas cedar was introduced to forests in the middle of the 19th century at "Mont Ventoux*" (Vaucluse*), at "Luberon*" (Vaucluse*) and in "les Corbières" ("massif du Rialsesse*" in the Aude*). Some populations from that time still survive and regenerate. Cedar is one of the best examples of successful acclimation in France. Reforestations have progressively spread onto the low- and mid-elevation mountains in the Southeast and, more recently, to diverse regions and departments (Midi-Pyrénnées*, Lot-et-Garonne*, Dordogne*, Poitou-Charentes*, Rhônes-Alpes* and even Basse-Normandie*, Haute-Normandie* and southern Bretagne*. See map 11 on p.10).

Atlas cedar is the largest contributor to the forest cover in more than 20,000 ha of the forest in France[8]. At best, dominant heights can reach 30 to 40 metres. Through reforestation, which is mainly established using artificial French provenances, the limits of use and strategies for managing these populations from establishment to thinning have been determined.

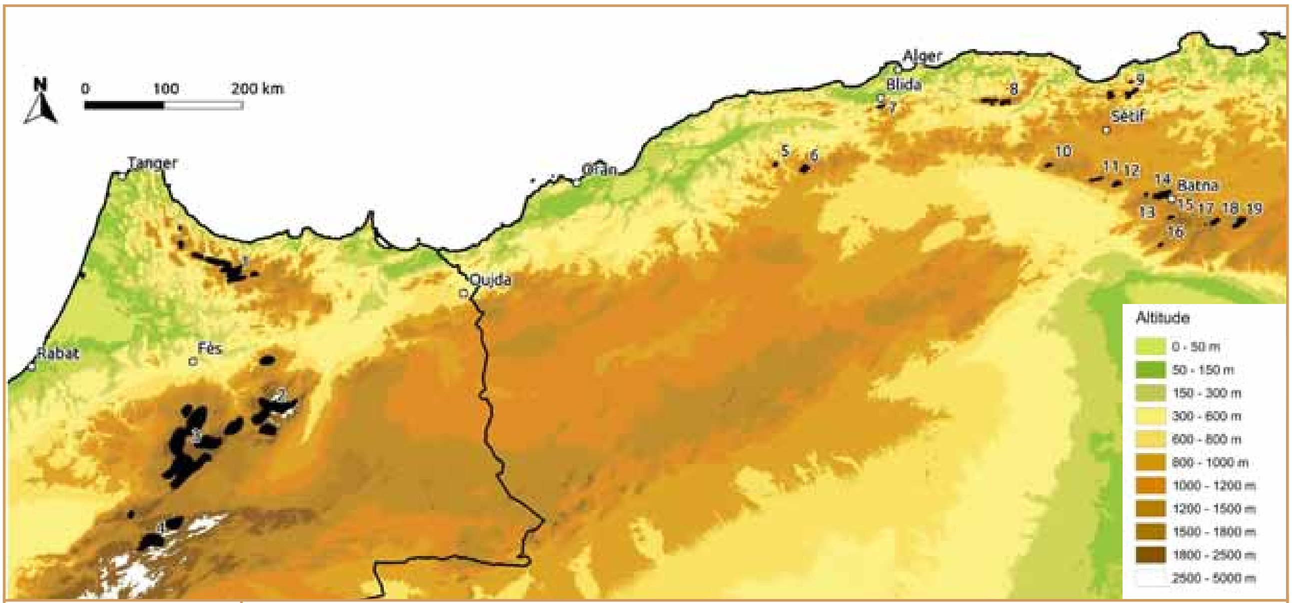
3. Cedar groves in "Chelia", Algeria.

4. Atlas cedar cones and foliage.

5. Cedars at Morocco Middle Atlas.

6. Cedars at "Mont Ventoux"* (Vaucluse*).

[8] Productive woods that were inventoried by the IGN (National Institute for Geographic and Forest Information) from 1991 to 2003 depending on the departments.



MOROCCO	ALGERIA			
1: Rif	5: Ouarsenis	9 : Babors	13 : Refaa	17 : Ichemoul
2: Eastern Middle Atlas	6 : Theniet-el-Had	10 : Djebel Maadid	14 : Belezma	18 : Chelia
3: Central Middle Atlas	7 : Chrea	11 : Boutaleb	15 : Sgag	19 : Ouled Yacoub
4: Eastern High Atlas	8 : Djurdjura	12 : Guethian	16 : Djebel Lazreg	

7. Natural range of the Atlas cedar (in black).

OTHER CEDARS

LEBANON CEDAR *(CEDRUS LIBANI)*

This cedar from the Middle East is abundant in Turkey and is also present in Lebanon and in Syria. In France, Lebanon cedar is mainly found in parks as an ornamental tree and is adapted to limestone lands [13]. Atlas cedar and Lebanon cedar are not easily distinguished.

Currently, there is no selected provenance for Lebanon cedar. Several comparative plantations that were established in southern France, showed the following characteristics [12, 13]:

- **a high late-spring frost sensitivity** for these Lebanon provenances, which should be avoided;
- **for dry soils on limestone, some Turkish varieties** from eastern "Taurus", which can sometimes be found in nurseries, may be preferable.

However, tests must be still conducted before launching the introduction of this cedar.

CYPRUS CEDAR (*CEDRUS BREVIFOLIA*)

This cedar from Cyprus has no potential for introduction in France for productive timber purposes. Indeed, Cyprus cedar is highly late-spring frost sensitive and exhibits low growth rates [13].

DEODAR CEDAR (*CEDRUS DEODARA*)

Originally from the western Himalaya, this cedar shows good growth but is more drought-sensitive [12] and late-spring frost-sensitive than is Atlas cedar. Deodar cedar is only seen as an ornamental tree in parks.

THE FOLLOWING INFORMATION ONLY CONCERNS ATLAS CEDAR, WHICH CONSTITUTES THE MAJORITY OF CEDAR GROVES IN FRANCE.

ATLAS CEDAR, UNDER WHICH CLIMATE CONDITIONS?

Mediterranean mid-elevation climate, which characterises the natural range of Atlas cedar, has rather harsh and often snowy winters. The annual total rainfall varies with latitude and elevation but the intra-annual distribution includes 2 to 4 dry months[9]. This climate is also characterised by a large number of clear days and a dry atmosphere for a large part of the year.
The prospect of extending the range of cedar must take into account the ability of the species to acclimate to the climate of other French regions.

ATLAS CEDAR TOLERATES A WIDE RANGE OF TEMPERATURES

In its natural range, Atlas cedar is exposed to annual mean temperatures varying from 7.5°C to 15°C, with average minimum temperatures for the coldest month between -1°C and -8°C and average maximum temperatures for the warmest month that can reach more than + 32°C [3].

Atlas cedar can resist temperatures up to + 41°C but cannot survive winter temperatures below -25°C[10].

FROSTS MUST BE MONITORED

Atlas cedar is **late-spring frost sensitive**; though it is not affected in its natural range and in the Mediterranean zone, several frost-damaging events have been recorded in the colder and more continental regions of the Jura* and Ardennes*. **Some southern sources**, within experimental plots, can sprout 2 to 3 weeks earlier, making these sources **more vulnerable**. Sheltered plantations could reduce this risk for young seedlings.

After a harsh winter, cedars can be subjected to physiological desiccation damage that is caused by sudden milder weather, triggering increased evapotranspiration demands that the soil, which is still frozen, cannot satisfy.

One must also appreciate the necessity and beneficial action of freeze-thaw cycles in helping cones to shed scales and release seeds, thereby aiding in natural regeneration.

DROUGHT TOLERANT DESPITE HIGH WATER REQUIREMENTS

Stands where Atlas cedar is well suited to the site conditions receive **annual rainfall of between 800 and 1500 mm** on average in the natural range of Atlas cedar and in France. Exceptionally, Atlas cedar can prove successful with less rainfall if there is an edaphic compensation (see example [38]).

Cedars differ from pines in that cedars do not save water; **the stomatal regulation of their transpiration is rather average**. Indeed, cedars continue to photosynthesise and grow under quite high levels of drought [26], which may explain the observation of dried tree-tops and, in some cases, the sudden death of vigorous individuals in the absence of any other responsible biotic agents (see picture 8). **Cedars' tolerance to drought mainly lies in their ability to draw deep water** via their deep root system[11]. Atlas cedar can react to drought by interrupting its lengthwise growth [40][12] or by diminishing its needle size and therefore its evapotranspiration loss (see picture 9). As in some other species (Scots pine and Norway spruce), drought can trigger cambial necrosis, which produces resin flows along the trunk (see picture 10) and can later heal.

Atlas cedar is not a maritime climate species and uncertainties remain concerning its adaptation to high atmospheric moisture. **Outside of the Mediterranean zone, Atlas cedar is susceptible to the pathogenic fungi *Armillaria mellea* and *Heterobasidion annosum*** (see picture 19 and pp. 26-27).

[9] H. Gaussen defines a month as dry if rainfall P in mm and average temperature T in °C follow this rule: P < 2T

[10] Climate and mortality data from February 1956 at "Mont Aigoual*" [17] and at the arboretum of Amance* in Lorraine*.

[11] Under controlled conditions, it has been demonstrated that cedars develop more roots than any other aerial parts in case of drought. Other studies suggest that cedars under regular and moderate water stress are more resistant to severe and occasional droughts that are well-watered cedars, as the former have developed a deeper root system [20, 25, 28].

[12] During summer droughts, cedars make up for the loss of growth in height the following year, if rainfall is normal [29]. This observation may be explained by storage, as cedars continue to photosynthesize under drought conditions.

8. Vigorous cedar suddenly killed because of water deficit.

9. Cedar branch under water stress, developing shorter needles (microphyllia).

10. Droughts can trigger cambial necrosis, which is responsible for resin leaking.

WIND AND HEAVY-SNOW SENSITIVE, BUT RELATIVELY INSENTITIVE TO FIRE

Its brittle wood makes cedar susceptible to wind or heavy snow damage (**treetop and branch breaking**). When deeply rooted, Atlas cedar is less prone to windthrow.

Cold or dry winds can also exacerbate the effects of frost and drought.

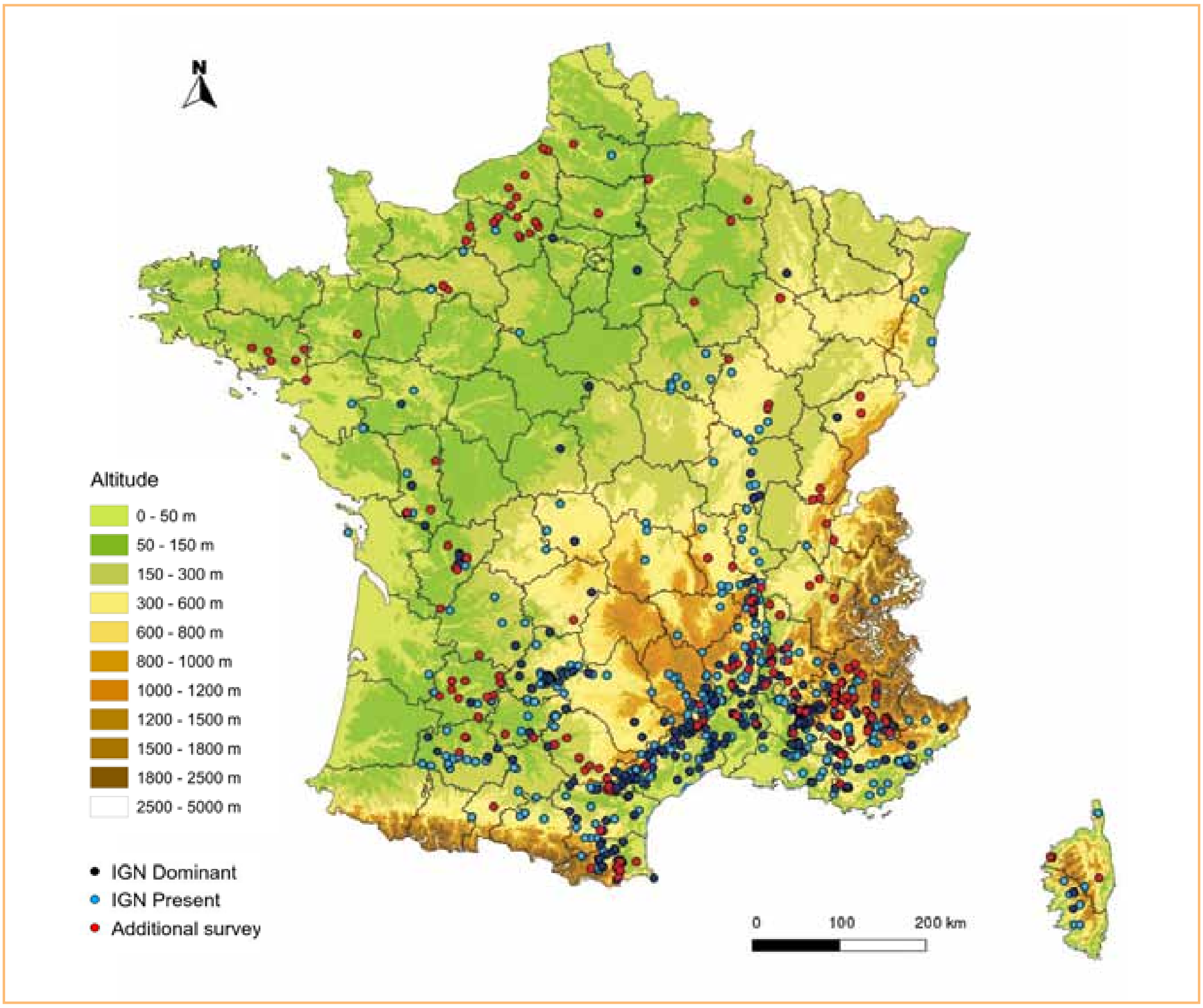
Because of climate change, fire risk will increase and spread into regions that were formerly at a lower risk. However, cedar litter, which consists of short needles, is compact and somewhat less flammable than is the litter of pines [44]. Cedar stands, especially if they are closed, are less flammable and efficiently limit the spread of forest fire.

DISTRIBUTION AND POTENTIAL FOR EXPANSION

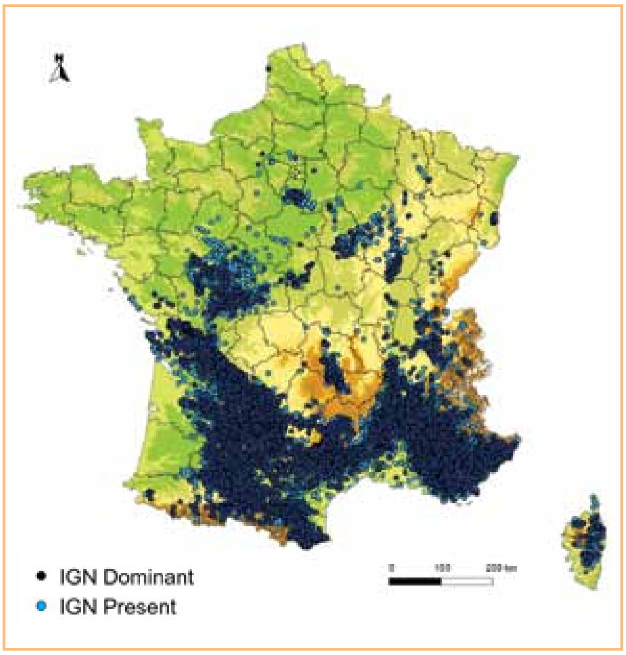
The importance and the distribution of cedars in France are the results of the adaptation of cedars to environmental conditions, as well as their reforestation history (subsidies policy and emulation of successful neighbouring introductions). Map 11 on p. 10 locates plots from successive inventories from the IGN (National Institute for Geographic and Forest Information), indicating the presence of cedars. Local dot density in the map is correlated with the local proportion of land area that is actually occupied by cedar. The map shows that **cedar is present in regions under a southern climate influence**: the Rhône corridor, the South-west, the southern and western borders of Massif Central up to Poitou-Charentes*. The nationwide survey plots (see p. 5) are also shown in the map; these plots are not statistically representative but show that plantations also exist in Bretagne*, Basse-Normandie* and Haute-Normandie*. However, it is difficult to use evidence from young plantations to draw firm conclusions about cedars' adaptation and acclimation to local climates.

The projected global warming and the increase in the intensity and frequency of summer droughts should increase the lower altitudinal and latitudinal limits of cedars, causing their exclusion from a large area of the Mediterranean zone. In mountains, the appropriate climate conditions for Atlas cedar should move uphill, and this species may progressively spread into south-western zones, where its introduction is already possible, then into western areas and further into central and north-eastern zones.

The resistance of cedar to drought has been noted but it has limits. Diebacks have been observed among the most southern populations of its natural range in Morocco and Algeria (see picture 13). After the 2003 drought, losses also occurred in France among populations that were located close to their climatic boundaries, i.e., too-low altitudes in the Mediterranean region or on inappropriate soils in temperate zones. In general, older mature trees and stands are at greater risk than are younger stands, suggesting that shorter rotations may be preferable on sensitive sites. Therefore, **the effective establishment and the good growth of young stands do not ensure that they will remain adapted to site conditions in the longer term.**



11. Locations of IGN sample plots and of field surveys from the additional nationwide survey, 2011 (see pp. 5 and 9).



12. Location of IGN plots including pubescent oaks. In the Mediterranean area, pubescent oak's bioclimatic zone is recommended for planting cedars. Therefore, if this principle can be validated by observations in other regions, the presence of pubescent oak is suggestive of a favourable site for Atlas cedar acclimation.

13. Dead cedars in "Belzema", Algeria (see map 7, p. 7).

INFLUENCE OF LOCAL ECOLOGICAL FACTORS

Soil characteristics are as important as climatic factors in determining potential suitability for cedar. Cedar autecology is well-known in the Mediterranean, where cedar has often been reforested since its introduction in 1862. Even if this knowledge can be useful for temperate zones, it is not sufficient to propose a precise identification key for favourable sites. The nationwide population survey has nonetheless confirmed the influence of ecological factors that can determine the potential for the expansion of cedar into temperate zones, where it presents on average improved productivity compared to that of Mediterranean zones[13].

ALTITUDE, ASPECT, AND TOPOGRAPHY

Altitude and, to a lesser extent, aspect are important factors influencing growing conditions through their effect on temperature and rainfall. The upper altitudinal limit for cedars should increase with global warming. Topographic position is also associated with water availability and soil thickness; moreover, the steeper the slope and the larger the difference in elevation, the larger the variation in water availability and soil thickness.

Recommended altitudes in the Mediterranean region	
Favourable	> 600 m for north facing slopes > 700 m for adret slopes
+/- Favourable	400 to 600 m for north facing slopes 500 to 700 m for adret slopes
Not recommended, except in case of strong topographic-edaphic compensation	< 400 m for north facing slopes < 500 m for adret slopes

IN MEDITERRANEAN ZONES

In Mediterranean zones, the best altitudinal zone seems to be aligned with the range of the pubescent oak (*Quercus pubescens*). **Under 400 m, cedar disappears** unless there are strong topographic-edaphic compensations.

Altitudes **between 600 m and 1000 m on north slopes and between 700 m and 1200 m on south slopes** provide the optimal rainfall and temperature conditions.

Topography determines the lateral water flow on the surface or in superficial layers. Convex sites or stands that are located upslope therefore have an unfavourable water balance compared to that of concave sites or low-lying sites where increased soil water is available. In addition, soil material redistribution through superficial erosion or colluviation/slope-wash causes **soil thickness to often be correlated with land forms**, which accentuates the links between local topography and water balance: well-watered deep soils are generally found downhill in valleys and plains, whereas unfavourable soils are found uphill on summits and hilltops. Middle slope situations are intermediate, and the potential for forestry can be very diverse [35].

IN TEMPERATE ZONES

We can provide few recommendations for these parameters without examining the climatic characteristics at a detailed scale, even if shifting to a temperate zone means decreasing the altitudinal limits. The introduction of cedar may be possible in **plains and mid-mountains** up to altitudes as high as **1000-1200 m in the Southern Alps** depending on the aspect; to **1000 m in the northern Alps, Pyrenees and Massif Central; and to 700 m in the Jura and in the Vosges Mountains[14].**

[13] Populations in temperate zones are very often less than 40 years old. Good growth response among young trees does not mean that cedars' future is secured, as a limiting factor can occur later. For example, as water demands peak during development, any unsuitable soil conditions might become limiting during severe droughts.

[14] These altitudinal limits were based on observations made inland in the Mediterranean zone and were transposed to other massifs on the basis of an increment of 1°C every 200 km north or 150 m in elevation. These limits will evolve with climate change.

SOURCE ROCKS AND MATERIAL

The results from cedar introductions are highly variable according to soil substrates. Some edaphic requirements are particularly important throughout the natural and introduced range of Atlas cedar. The nature of the source rocks or upper layers often determines the growth potential and survival of this species, even if other factors might alleviate or mask their influence. In addition, it is in some cases important to understand certain aspects of the substrate.

Higher growth is observed on siliceous rocks, particularly on schist and micaschist. Good results are also found on sandstone, gneiss, basalt and dolerite. On granite rock which weathers in granitic coarse-grained sands where the water storage capacity is low, growth is variable and strongly depends on the soil depth.

Cedars tolerate limestone well and show an average growth on calcareous soils.

Substrates that are too rich in magnesium (dolomites) [34], leading to rather unaerated (marls) or excessively poor (quartzite) soils, must be avoided.

On shallow soils, especially in the Mediterranean zone, three substrate characteristics must be considered along with the rock type in order to evaluate the possibilities of deep rooting:

- **the origin of the material:** alluvium, colluvium and boulders are often earthy and soft and are therefore more favourable for cedar growth than soils from altered materials;
- **rock cracking and the inclination of geological layers** opposed to the superficial slope are also favourable factors (see picture 14);
- **the presence of an indurated layer or indurated materials,** which cannot be penetrated by roots, is a highly unfavourable factor (see picture 15).

	Rock sources	Cracks and fractures (if shallow soil)	Dip (if shallow soil)	Material	Indurated layer
Favourable	non-granitic siliceous material, recent alluvial deposits	numerous	perpendicular to the slope	alluvial deposits, agricultural soils	absent
+/- Favourable	limestone, dolomite limestone, alternatively limestone/marl, old alluvial deposits	present	slanting	colluvial deposits, screes	deep under the surface
Unfavourable	granite, calcareous-clay substrate	absent	downslope	alterite, open-air lapiaz	intermediate depth
Not recommended	marl, argillite, dolomite	-	-	-	upper layers

14. Despite a superficial soil, this cedar was able to root in cracked limestone.

15. A material that cannot be penetrated by roots (light stratified scree) is a fatal flaw if located in superficial layers. The dark colluvial layer overlaying the scree is well exploited by the root systems of cedars.

SOIL

The tolerance of cedar to drought can be explained by the trees' capacity to draw deep water. Any diagnosis based on site inspection must take into account the soil depth that can be exploited by the root system. Cedar is able to penetrate into cracks in rocks but can be blocked by indurated layers (iron pan and lime re-precipitation) or by clayey, compact, water-logged or simply hydromorphic layers. Observations in temperate zones follow the same patterns in terms of growth and health as identified in Mediterranean zones.

Soil thickness is the best factor to explain growth in height. Thus, in the Mediterranean zone, a proportion of rock outcrops greater than 10%, reflecting a shallow soil, is an unfavourable factor.

Cedar is **very sensitive to soil aeration and favours rocky soils more than does any other tree species**, so long as such soils do not constitute an impenetrable barrier. The proportion of rocks or sandy soils, especially fine sands, is not a handicap if the depth is sufficient to ensure a suitable water storage capacity. **Shallow sandy soils that developed on granitic coarse-grained sands must be avoided. Sandy-loamy soils are the most favourable, and cedar is not suited to clay soils**. For the same reasons, **soils without structure or that are compact or massive are unfavourable.**

Cedar does not root in hydromorphic soils. No cedar groves have been recorded on very hydromorphic soils that are permanently or temporarily water-logged. Hydromorphic features, even if slightly present in the first 50 cm, are often associated with disease problems, including Armillaria root disease and dieback. If the hydromorphic marks are deep, the growth of young trees can be deceptive, because older trees will become drought sensitive as the stand develops and its water needs increase (see picture 27, p. 16).

Cedar **tolerates a wide range of soil pH values**. However, very acidic soils (podzolic) should be avoided such as heathland and moorland soils in "Landes*". On very alkaline soils with free calcium carbonate causing a high level of active lime in fine soil, the growth of cedar will be reduced. The fertility of the soil has a strong positive influence on cedar growth and in some cases compensates for limited soil thickness. On infertile soils, the establishment and growth of cedar is very poor. Any positive reaction to fertilisation, in particular to the addition of phosphorus, demonstrates the importance of the fertility and availability of base cations.

	Soil depth	Rocky outcrops	Coarse components	Texture	Structure and compactness	pH value	Hydromorphic features
Favourable	> 60 cm	none	< 30 %	balanced, sandy loams, fine loamy sands	aerated (aggregates)	4 to 6.5 Not very acid to neutral	absent
+/- Favourable	30 to 60 cm	rare	30 to 60 %	other cases	soft, particle structure not very compact	7 Decarbonized soil (null or low reaction to HCL)	some hydromorphic features below 50 cm depth
Unfavourable	< 30 cm	> 10 %	> 60 %	dominated by coarse sands if soil depth < 60 cm	rather compact	> 7 Fine carbonised soil (high reaction to HCL)	hydromorphic traces above 50cm depth
Not recommended	-	-	-	clayey	massive, compact or without structure	< 4 Poor soils, such as podzolitic soils	waterlogging. Permanent or temporary water table

UNDERSTANDING AND RECOGNISING BORON DEFICIENCY

On some siliceous rock sources and water-limited sites (e.g., during the establishment stage of dry-filtering soils) cedar can display specific symptoms that are linked to boron deficiency. After planting, terminal shoots (principal stem and branches) dry out, followed by lateral shoots, etc. Cedars then adopt **a bushy form called a "ball shape"**. This phenomenon was observed especially on granite in Hérault*, in Ardèche* and in Corrèze* (the risk is higher on infertile granite, such as leucogranite); on gneiss soils in Haute-Loire*; on basaltic soils and more rarely on schist soils. Symptoms disappear in certain cases when trees have developed an extended root system or when boron has been added (see picture 16) [30, 31, 32].

16. – Apical dominance is re-established after the addition of boron to a previously "ball shaped" cedar

THE EFFECT OF COMBINED ECOLOGICAL FACTORS: SOME TYPICAL EXAMPLES

Analysing the site conditions and the set of factors, including their combined effect for possible compensations and limiting factors is important. The following examples taken from the nationwide survey, illustrate different situations in temperate and Mediterranean zones, combining soil, climatic and topographic factors, among others. Data for vigour and health, which are not always correlated, are also presented. Some effects of unfavourable factors can appear late in the rotation, which demonstrates that conclusions on environmental and site adaptation can not be based on the establishment and growth of very young stands. The purpose here is not to establish a site guide but, rather, to help foresters in analysing environmental and site factors and their influence.

STANDS ON LIMESTONE

Picture number	Department	Altitude (m)	Topography	Aspect	Tm [15] (°C)	Tx [15] (°C)	Annual rainfall (mm)	Rainfall in June-July-August (mm)	Substrate	Soil depth (cm)	Dominant structure and compactness	Dominant texture	Coarse elements	Hydromorphic features	Top height (m)	Age (year)	Growth	Health condition
17	84	1010	mid -slope	SW	9.3	23.8	1084	186	cracked limestone	45	rather soft, particle structure	loamy clay	45 %	no	20	77	+	++
18	52	367	plateau	-	9.5	23.4	922	209	cracked limestone	20	rather soft, particle structure	loamy clay	30 %	no	15	36	+	+
19	16	106	plateau	-	11.8	25.6	858	156	limestone	120	rather compact, particle structure	loamy sand then clay	0 %	locally water logged	17	23	++	-

Favourable | +/- Favourable | Unfavourable | Not recommanded

17. Typical cedar grove on cracked limestone (inland Mediterranean zone). Despite shallow soil (rendzina) and a high proportion of coarse elements, growth is good as a result of adequate rainfall and cracks that are penetrated by roots (Vaucluse*).

18. Growth is limited in shallow soils and clays but is still possible because cracks are present in the soil parent material. Cedar values this type of soil, whereas other tree species do not (Haute-Marne*).

19. Very heterogeneous stand. Growth is very good across the stand, but a patchy clay layer that is 30 cm deep causes temporary water-logging and triggers occasional dieback along with the presence of the fungus Armillaria. (Charente*).

[15] Tm: annual mean temperature; Tx: maximal mean temperature for the warmest month.

STANDS ON ACID ROCKS

Picture number	Department	Altitude (m)	Topography	Aspect	Tm 16 (°C)	Tx 16 (°C)	Annual rainfall (mm)	Rainfall in June-July-August (mm)	Substrate	Soil depth (cm)	Dominant structure and compactness	Dominant texture	Coarse elements	Hydromorphic features	Top height (m)	Age (year)	Growth	Health condition
20	11	740	uphill	N	11.5	26.6	940	134	schist	100	soft	clay loams	20 %	no	34,7	113	++	++
21	35	70	plateau	-	11.3	23.9	730	136	schist	40	rather soft, particle structure	loam	5 %	no	20,6	45	+	+
22	42	550	mid -slope	SW	10.4	26.5	572	182	granit	40	rather soft, particle structure	clay sands	55 %	no	18	75	-	+
23	56	70	plateau	-	11.5	23.9	817	129	granit	80	soft, aggregate	sandy loams	20 %	no	13,7	21	+	+

20. Climate is favourable, water storage is good and there are no limiting factors. The growth and health of the stand are very satisfying (Aude*).

21. Even on shallow soils, schist is a good substrate. The oceanic climate rainfall compensates for the small water storage capacity. High fertility due to previous agriculture is also a favourable factor (Ille-et-Vilaine*).

22. Soil has numerous limiting factors: a high level of coarse elements, coarse sands, poor soil and relatively little water storage that is not compensated for by the climate. Growth is poor (Loire*).

23. A deep soil and a low level of coarse elements compensate for a filtering texture. The soil remains infertile, but the results are better than in 21. A light P-K19-19 fertilisation was applied at the foot of each tree in this former moorland/heathland site (Morbihan*).

16 Tm: annual mean temperature; Tx: maximal mean temperature for the warmest month.

STANDS ON MARL, CLAY OR DOLOMITE

Picture number	Department	Altitude (m)	Topography	Aspect	Tm [17] (°C)	Tx [17] (°C)	Annual rainfall (mm)	Rainfall in June-July-August (mm)	Substrate	Soil depth (cm)	Dominant structure and compactness	Dominant texture	Coarse elements	Hydromorphic features	Top height (m)	Age (year)	Growth	Health condition
24	05	1030	mid -slope	S	8.9	25.7	950	175	colluvial deposits on marl	80	aggregate	clay loams	5 %	no	18,9	52	+	+
25	12	820	plateau	-	9.4	23.8	884	183	dolomite	30	rather soft, particle structure	loamy sand	40 %	no	2	14	- -	- -
26	04	650	uphill	SE	12.3	29.9	710	151	marl / limestone	20	rather compact	clay loams	30 %	no	3	20	- -	-
27	45	145	plain	-	10.8	25	634	162	clay-with-flints	60	soft then compact	loamy sand then clay	20 %	60 cm deep	25,3	66	++	-

24. Despite the marl soil, the stand is healthy as a result of topography that prevents water stagnation. On marl soils, one must distinguish alterite (to be avoided) from colluvial soils, which can lead to effective results (Hautes-Alpes*).

25. This stand is suffering from yellowing and dieback. The shallow soil and dolomite are unfavourable (Aveyron*).

26. Twenty-year-old cedars 1 m tall. This site has too unfavourable factors: a shallow soil and a limestone-marl substrate (Alpes-de-Haute-Provence*).

27. This stand was established on clays with flints; the root system has not penetrated the clay layer (60 cm deep – note the hydromorphic features). The drought in 2003, which was aggravated by a bark beetle attack, was fatal to several vigorous 80-year-old cedars (Arboretum des Barres* in the Loiret*).

[17] Tm: annual mean temperature; Tx: maximal mean temperature for the warmest month.

RECOMMENDATIONS FOR CEDAR ESTABLISHMENT

Adapted plant material and techniques favouring establishment and rapid root system growth must be used to successfully plant cedars.

SUCCEEDING WITH YOUR PLANTATION

Choosing appropriate plants and establishment techniques is crucial to prevent failures.

CHOOSING THE BEST PLANT MATERIALS

Compared to natural range provenances, French provenances show a good genetic diversity and good adaptation, which guarantee the performance of these genetic materials[18]. Careful growth conditions in nurseries are necessary to obtain quality plants and to ensure a low transplant-related mortality rate.

In the Mediterranean region, the use of plants belonging to the tested categories (blue label) **CAT-PP-001 (Ménerbes), CAT-PP-002 (Mont Ventoux) and CAT-PP-003 (Saumon) is preferred**. These plants have demonstrated superiority with respect to two properties: plasticity to respond to diverse environmental conditions and height growth.

Outside of the Mediterranean region, the different origins and provenances have not been evaluated by research; we will therefore use those from the provenance region "CAT900-France" (selected category – green label), which groups 43 populations into 6 French regions and covers 574 ha [14].

Cedars develop an important central root system very quickly. To avoid damage during transplanting, saplings grown in **tall "anti-bun" buckets with a minimum capacity of 400 cm3** (see picture 28) are strictly recommended, even for planting outside of the Mediterranean zone. In addition, **vigorous plants must be chosen (11 cm-tall and 3 mm in diameter minimum at the collar), that are aged between a few months and a year old (1-0 G)** in order to avoid any root deformation. Cedars also have **to be grown in a peat-bark mix**. When following these recommendations, a significant reduction in the mortality was noted in experimental plantations [19].

Some tree nurseries propose mycorrhizal-innoculated plants. In reforestation, the advantage of these plants is variable due to the widespread occurrence of mycorrhiza in soils.

Artificial seedling trials were not convincing and very seed wasting. This option thus remains very expensive.

28. Cedar saplings in 400 cm3 "anti-bun" buckets: type WM (left) and square grooved (right).

[18] Some southern provenances from the natural range might sprout slightly too early and could be better adapted in the future given climate changes. The establishment of comparative experiments under various climatic conditions would be most particularly important.

PREPARING SOIL AND CAREFULLY PLANTING

These operations are strongly linked to plantation success. Rapid access of young saplings' roots to anchorage and water nutrition layers must be facilitated through soil preparation and careful planting.

Sub-soiling is efficient in the Mediterranean zone on shallow limestone soils or when the rock source is not naturally cracked. This operation is also recommended when there are obstacles to root system development (coarse element rate or compacted layers – see pictures 29). Sub-soiling at a minimum depth of 60 to 80 cm is recommended.

In other cases, deep ploughing and other tillage reduce competition from grasses and herbs. On steep slopes, a hydraulic excavator should be used (see picture 30). Plants should be **planted in loosened soil.**

The **root ball must be constantly moist** until planting and firmed to remove gaps between the roots and the soil.

Outside of the Mediterranean region, cedars might be attacked by "**Fomes**" (*Heterobasidion annosum*) especially after planting on formerly infected conifer sites. Young trees are killed by the fungus without any warning sign (no sporophores and no heart rot), unlike older trees.

29. Subsoiling on rocky soils greatly improves establishment success and plantation start-up by accelerating root development. This operation is performed with 1 (left), 2 or 3 (right) teeth, depending on soil resistance and can be followed by a levelling operation.

30. The mechanical "spider" digger, which digs planting holes in appropriate sites, enables foresters to plant saplings with covered roots under harsh conditions. This tool can reach steep slopes up to 60 %.

31. Plantation quality, here on agricultural soils, determines population success. Frequent tillage might effectively reduce herbaceous competition.

MONITORING COMPETITION AND SANITARY RISKS FROM EARLY STAGES

This half-shade species can bear lateral light shelters during its first years (see picture 32), after which cedar requires full light to grow well.

As cedars are **very sensitive to herbicides**[19], their use should be restricted to ground preparation before plantation. Further applications should be manual or by mechanical grinding. When used after plantation, herbicides should be applied with a cache. **Mulching** when planting is a possible alternative.

Cedars are **sensitive to animal damage**, including from rabbits, deer (scraping, see picture 33) and stags (debarking). Individual protection must be considered, or if the risk turns out to be high, then fencing should be used.

The plants may be attacked by **hylobius** (*Hylobius abietis*), especially after felling which leaves fresh stumps. We recommend a fallow period of 1 to 3 years between clear-felling conifer and planting cedar and a carefully monitoring of the sites.

32. Lateral shelter, here broom, can benefit cedar if carefully controlled.

WHICH CONDITIONS ARE OPTIMAL FOR NATURAL REGENERATION?

Natural regeneration would be even more successful if seed years were anticipated, environmental conditions for seed reception sites improved and competition controlled.

On fertile sites, cones can occur as early as 15 to 20 years, but **fructification becomes sufficient for regeneration only after 40 years of age**. Cone production is generally abundant every 3 - 5 years and only concerns a variable fraction of the stand. The development of cones takes 2 years; therefore seed dispersal can be anticipated a year in advance [39]. A freeze-thaw action is beneficial and even necessary for cone scale shedding and seed dispersal. Seeds can abundantly disperse over 30 to 60 m from seed trees and in some cases over greater distances as a result of strong wind and/or steep slopes.

On heterogeneous limestone soil, an abundant regeneration can benefit from favourable micro-site conditions (cracks). Before sowing, **picking, burning the logging residues or prescribed burning of the underbrush performed by a specialised team** will facilitate contacts between the seeds and the mineral layers (see picture 34). Deeper tillage would also be necessary if soils are not cracked or fissured enough to ensure a rapid establishment of the root system.

33. Deer browsing and scraping. Protection is recommended in sites with high deer numbers.

[19] Legislation on the use of herbicides is quickly evolving, making it difficult to provide up to date recommendations on this issue (go to http://e-phy.agriculture.gouv.fr).

34. Abundant regeneration next to seed sources, favoured by burning the logging residues (Luberon* in Vaucluse*).

On the limestone area of "Provence", the regeneration of cedars is much easier than that on acid soils because of reduced vegetation competition. The observed situations mainly concerned canopy closure between isolated cedars and extension. Thus, as a result of strong northernly wind called "mistral", cedars invade pubescent oaks coppice clearings (see picture 35). Coppice facilitates cedar regeneration by providing a shelter that is regularly removed, thereby satisfying satisfying the need for light and allowing cedar succession.

As with saplings, **seedlings are extremely sensitive to weed competition and to drought** during establishment.

35. Oak coppice colonization by cedars in "Luberon*" (Vaucluse*).

MEGASTIGMUS SP. : A CEDAR'S SEED PARASITE

36. *Megastigmus schimitscheki* (left) and *Megastigmus pinsapinis* (right) on a cedar cone.

This little wasp lays eggs in cones (see picture 36). Larvae feed on growing seeds. Damage can occur to 80 % of the seeds. For the moment, there is no particular threat from the resident species Megastigmus pinsapinis to natural regeneration. Megastigmus schimitscheki, a species that recently arrived from the Middle East to cedar groves at "Mont Ventoux*" might be more threatening. Current studies are following the presence of these two parasites to assess risks for selected populations and for potential seed orchards.

CHARACTERISTICS AND USES OF CEDAR TIMBER

Cedars produce a quality timber that is stable, sustainable, and adapted to the majority of uses. This timber is nonetheless brittle and often knotty.

The **natural sustainability of cedar heartwood**, which is rich in natural essential oils[20], is the main asset of cedar (see picture 37). Cedar timber is well adapted to **outdoor use** without any soil contact and without the use of any treatment such as exterior joinery, claddings (see picture 38), panes, urban furniture, etc. Cedar wood has a strong smell that keeps moths away but prevents its use in food packaging.

Well known for its **brittleness**, cedar timber has a low modulus of elasticity and low modulus of rupture. However, this timber can be used for wood frames if the carpentry is oversized (see picture 39).

Low-density forests or non-pruned trees have **large branches** (see picture 43 p. 23) that produce timber of lesser quality that is much more **knotty** and heterogeneous[21] (see picture 40).

Compared to other tree species, cedar wood has a **high density** and shows **high stability** and **low shrinkage** [45] (see figure 42). The distortion of cedar wood is limited as a result of drying. The ring width is not a factor that affects wood density in a prohibitive manner. The growth rate thus slightly influences the timber quality.

Cedar has many uses, from the most common (paper, pallet, form work, etc.) to the noblest uses for old trees from its natural range (fine woodworking, sculpture and slicing/ veneer). Cedar has an agreeable smell and colour making it an appreciated timber.

37. Heartwood, which is darker, is the most sustainable part of the timber, its proportion increases with age. (First-generation cedars, 130 years old, introduced at "Mont Ventoux*" in Vaucluse*).

38. Cedars are particularly adapted to outdoor uses (here: paneling boards).

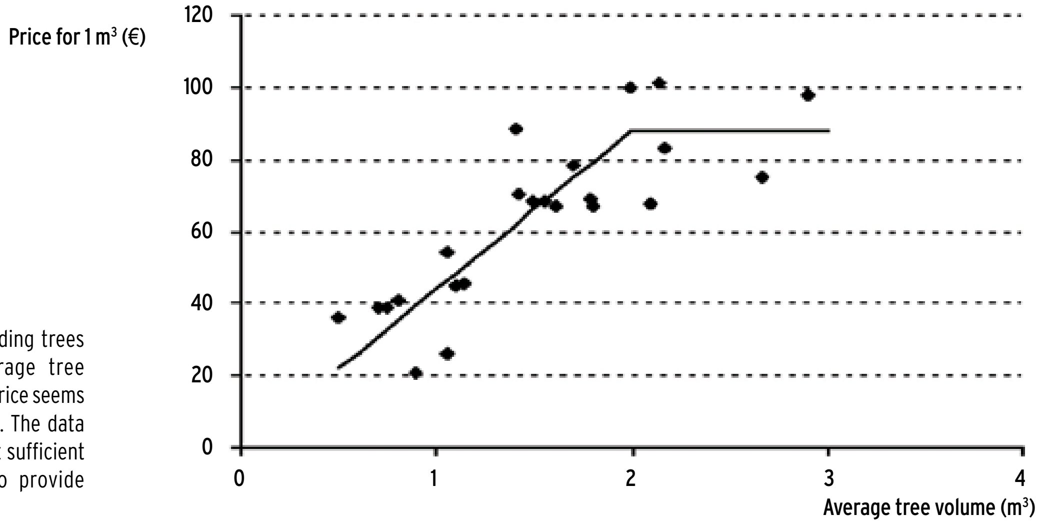
39. Cedar wood frame from "Mont Ventoux*" in Vaucluse*

40. The absence of pruning leaves knots that decrease the timber quality (here: a branch that created a non-adherent knot in the most external planks).

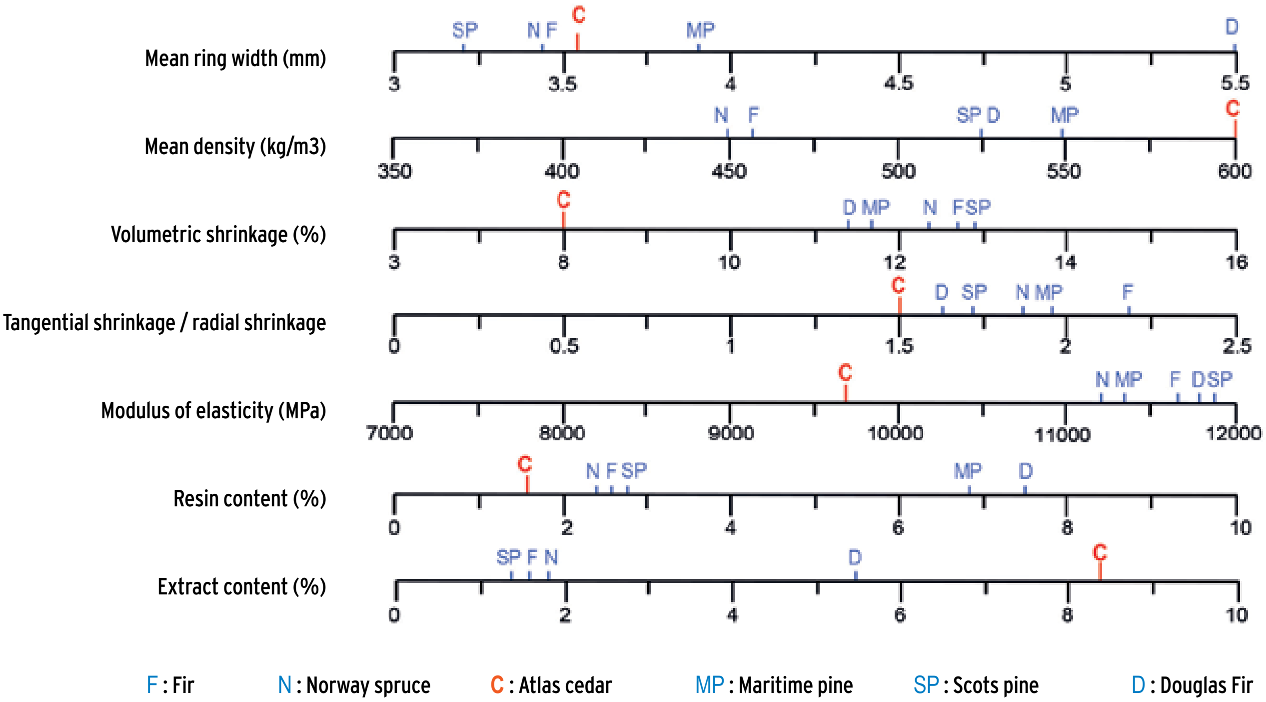
[20] In cedar wood, resinous channels only appear after a trauma such as a wound, bark beetle attacks or cambial necrosis.

[21] A survey dated 2009 in south-eastern France sawmills specified that the major defect is the frequency of large knots, which discourage the use of cedar for woodworking or wood frames [46].

Sale prices for Atlas cedar are nearly the same as those of Douglas fir (see graph 41).



41. Sales prices for standing trees according to the average tree volume (ONF, 2007). The price seems to stabilise beyond 2 m³. The data here are nonetheless not sufficient in terms of number to provide definite conclusions.



42. Cedar wood technological properties compared to those of the most-used conifers in France [45].

CEDAR: A CONFUSING NAME

In English, the term "cedar" is also used for species that not only belong to the genus *Cedrus* but also to genera of the Cupressaceae family (*Chamaecyparis, Thuja, Juniperus, Calocedrus,* and *Austrocedrus*). These species have an odorous wood as do *Cedrus* species. More rarely, "cedar" may be used to refer to *Cryptomeria japonica* (Japanese cedar) or to *Pinus sibirica* (Siberian cedar).

WHICH SILVICULTURAL TREATMENTS TO ADOPT?

Cedar silvicultural practices must take into account a certain number of factors: vigourous branch growth, high population heterogeneity and high quality heartwood development. These specific characteristics have consequences for forestry, which must also take into account constraints that are linked to climate change and economics.

MAJOR CRITERIA THAT ARE CONSIDERED FOR AN ADAPTED SILVICULTURE

BRANCH GROWTH REQUIRES PRUNING

Cedar holds more branches than does pine. Cedar branches are also larger than those of pine, spruce or fir. The number and size of the knots are thus higher. These characteristics and the absence of natural pruning strongly suggest a need for artificial pruning or the maintenance of stem densities that are high enough to limit branch growth (see picture 43).

HETEROGENEOUS POPULATIONS

Tree height variation is greater than that of other species under the same conditions (see picture 44). The possible explanation is that cedar, because of its deep root system, is directly linked to micro-site conditions which vary and affect growth[22]. Cedar growth is particularly variable on limestone. This phenomenon and the observed heterogeneities suggest the following:

- a **sufficient stem density at planting** to enable selection in successive thinning;
- **selective thinning.**

HEARTWOOD SUSTAINABILITY

Cedar timber is of interest, particularly for its sustainability and durability. This quality is associated with the heartwood, which is rot proof. Managing high densities and allowing stands to over-mature will limit sapwood development and thereby favour the heartwood-sapwood ratio.

CLIMATE CHANGE

Climatic models predict a slight decrease in the water supplies for populations whose needs will increase during tree development. Recent results obtained from experimental stands showed that

43. Cedars tend to produce large branches, even more when isolated or in sparse woods. Cedars tolerate artificial pruning very well (tree on the right).

44. Cedar stands are often heterogeneous, as in this plantation on limestone soil in the Gard*, despite subsoiling.

[22] Genetic variability, or in some cases planted trees being left in polyethylene bags, which is a forbidden practice, are other hypotheses that are not mutually exclusive.

heavy and early thinning would improve the populations' tolerance to water stress, at least for two years. **Green branch pruning**, by decreasing water consumption will improve the resistance to drought, especially when pruning is associated with heavy thinning.

The predicted increase in the temperature and frequency of exceptional climatic events (droughts and storms) suggests a **shortening of rotations** in order to decrease the probability of damage in even-aged stands.

The associated increased fire risk also suggests the need for artificial pruning, which curbs fire expansion by creating a vertical discontinuity in the fuel distribution.

THE ECONOMIC CONTEXT

Due to the difficulty in selling the products of the first thinning, a choice is made to reduce plantation densities and to promote a late, heavy, mechanised and partitioned first thinning.

The existence of subsidies for pruning and precommercial thinning lowers costs and produces a better timber quality. Pruning is expensive because of the number and thick diameter of branches (in 2012, pre-tax prices by stem were 4 € to 5 € for pruning up to 6 m once or 1.2 € up to 3 m and then 2.8 € to 3 € between 3 and 6 m high).

WINDFALL RISK

In the Mediterranean zone, cedar's deep rooting, although dependent on the soil type and depth, makes it less sensitive to windthrow than other tree species. However, cedar is more sensitive to windbreak because of its brittle timber. In temperate zones, wind damage risk might be greater, particularly for tall stands. **An intensive first heavy thinning is recommended, followed by lighter thinning to favour stand stability via a "block effect".**

SUGGESTED SILVICULTURAL TRAJECTORIES

Choosing a forest plan must take into account sometimes conflicting constraints, requiring some compromise. Given the silvicultural requirements of cedar, two clear trajectories are presented for even-aged stands, both with advantages and downsides. These trajectories rely on dominant height and are independent of age. They are boundaries to the range of choices. According to the objectives, site constraints and financial and technical resources, intermediate forestry is possible as well. Forestry for uneven-aged stands with continuous tree cover or mixed stands is also an option.

PRECISION FORESTRY FOR QUALITY TIMBER:

> **Purpose:** quality timber production with a target felling diameter varying between 45 and 55 cm depending on the site fertility and rotation age.

> **Characteristics:** rather high stand density, mixed selective thinning from above and from below, two pruning interventions and late clear cutting.

Dominant height[1]	Type of intervention	Stem number before intervention[2]	Stem number after intervention[2]	Felling rate
-	**Plantation** at 2.5 m x 2.5 m preferably or 2 m x 3 m if mechanised cleaning	-	1600-1660	-
6 - 8 m	**Pruning up to 3 m high** on 150 to 200 stems/ha just before thinning. Avoid pruning stems in the lines that are expected to be cut for possible partitioning	-	-	-
	Precommercial selective thinning benefiting designated trees	1450 - 1500 [3]	950	35 %
12 - 15 m (right when the first thinning is achievable)	**Pruning up to 6m high** on 150 to 200 stems/ha to choose just before thinning among the previously pruned trees	-	-	-
	First thinning: only selective[4] or both systematic (one line out of five to create partitioning) and selective (one tree out of three between partitioning)	950	600 if only selected[4], 500 with partitioning	35 - 45 %
16 - 19 m	**2nd thinning:** selective	600 - 500	450 - 370	25 %
20 - 23 m	**3rd thinning:** selective	450 - 370	350 - 280	25 %
24 - 27 m	**4th thinning:** selective	350 - 280	260 - 210	25 %
28 - 31 m	**5th thinning:** selective	260 - 210	200 - 160	25 %
32 - 35 m	**6th thinning:** selective	200 - 160	150 - 160	0 - 25 %
35 m [5]	**Clear felling[5] (or seeding felling)**	160 - 150	0 (50-90)	100 % (40-65 %)

[1] The low value or high value according the height when the first thinning will occur.

[2] Stem numbers are indicative. Thinning tends to be heavier for low fertility rates.

[3] After a probable mortality of 10% after planting.

[4] If non-mechanised thinning. Only selective or selective between loose partitioning, in this case not taken into account for stem number.

[5] For the lower fertilities, clear felling will occur when the dominant height is less than 35 m or when the target felling diameter is reached.

INTENSIVE FORESTRY WITH LIMITED INVESTMENTS:

› **Purpose:** rapidly produce soft wood lumber and limit investments with a target felling diameter varying between 45 and 60 cm according to the site fertility and rotation age.

› **Characteristics:** low stand density, partitioning, pruning just once, early clear-felling.

Dominant height	Type of intervention	Stem number before intervention[1]	Stem number after intervention[1]	Felling rate
-	**Plantation** at 3 m x 3 m preferably or 3.5 m x 2.5 m if necessary for mechanised cleaning	-	1 110	-
12 - 15 m (right when the first thinning is achievable)	**Pruning up to 6m high** on 150 to 200 stems/ha just before thinning.Avoid pruning stems that are located in the lines that are expected to be cut for possible partitioning	-	-	-
	First thinning: both systematic (one line out of five to create partitioning) and selective (one tree out of three between partitioning)	1000[2]	500	50 %
18 m	**2nd thinning:** selective benefiting pruned trees	500	350	30 %
22 m	**3rd thinning:** selective	350	250	30 %
27 m	**4th thinning:** selective	250	170	30 %
31 m [3]	**Clear felling[3] (or seeding felling)**	170	0 (60-100)	100 % (40-65 %)

SPECIFICITIES IN CASES OF NATURAL REGENERATION

› A seeding cut will be applied. Cut intensity has to be adapted to risk of competition with grasses and shrubs.

› The final cut will occur on established regeneration (seedlings between 50 cm and 2 m tall).

› In the case of a density greater than 2500 seedlings/ha, with nearly no differentiation among seedlings, one precommercial thinning brings the density to approximately 1000 stems/ha when the dominant height is approximately 3 m. In the case of no seedlings on at least 50 % with empty zones 200 m² minimum wide, an artificial complementary regeneration can be considered.

45. Natural regeneration, shown before thinning in picture 34, and shown here after selective thinning to 1100 stems/ha, carried out when the dominant height was 6 m.

Criteria	Precision forestry	Intensive forestry	Remarks
Diameter growth rate	😐	🙂	The target felling diameter is reached earlier with lower densities.
Branch size	🙂	☹️	A higher plantation density leads to thinner branches.
Pruning efficiency	🙂	😐	Two pruning interventions lead to a higher timber quality with fewer knots.
Heartwood ratio	🙂	☹️	Higher stand density and longer rotation favour higher heartwood proportion.
Shape defects of the bole	🙂	☹️	A higher plantation density gives more choices in selecting trees meeting requirements.
Costs	☹️	🙂	Precision forestry, however, leads to better qualities and trees that can be sold at higher prices.
Probability of escaping "climatic accidents"	😐	🙂	A shorter rotation reduces the risk of experiencing a drought or storm.
Windfall and windthrow risk	😐	🙂	Intensive forestry trees will be more resistant.

[1] Stem numbers are indicative. Thinning tends to be heavier for low fertility rates.

[2] After a probable mortality of 10 % after planting.

[3] For the lower fertilities, clear felling will occur when the dominant height is less than 31 m or when the target felling diameter is reached.

NECESSITY AND PRACTISE OF PRUNING

Cedar tends to grow large branches and does not prune itself naturally. Artificial pruning is therefore necessary to obtain quality timber. Moreover, green branch pruning reduces water consumption and improves tree resistance during drought periods.

Pruning twice and at early stages (preferably at a dominant height of 12 m) is recommended in order to avoid cutting too-thick branches and to increase the proportion of knot-free timber:

> **the first pruning is up to 3 m high for trees that are at least 8 m tall, selecting 250 to 300 stems/ha**[1].

> **the second pruning is up to 6 m high during the first thinning** at a dominant height of 12 m, **for 150 to 200 stems/ha** selected preferably among already pruned trees. Thinning and pruning at the same time accelerate knots' healing and prevent thinned trees from being dominated by their neighbours.

Selected trees are the most vigorous and with the best shaped stems. Selective thinning must benefit these trees. The first pruning should concern more stems than the second to open up selection possibilities. Cedar tolerates without damage an intensive and early pruning, at least up to mid-height.

[1] Pruned trees with small diameters (10-15 cm) are more prone to debarking by deer. If deer are indeed present, protection should be put in place just after pruning.

46. Thinning in "Luberon*", reducing the density from 750 to 500 stems/ha. Dominant height: 17.6 m at 74 years old.The timber will be used as pulpwood and small saw log.

47. Cedars pruned up to 6m high 14 years earlier.

FIGHT AGAINST "FOMES"

During thinning, stump staining must be systematically performed to prevent the Fomes fungus spread.

MANAGING IRREGULAR OR MIXED POPULATION

As semi-shade species, cedars can grow in uneven-aged high stands (see picture 48) or in mixed plantations with species whose requirements are close to those of cedar, such as pubescent oak, Austrian black pine or Corsican pine. Although both mixed and uneven-aged populations are known for their resilience to global warming, and uneven-aged populations are also more resistant to storms, precise management and careful monitoring are required to maintain these populations in their state. In uneven-aged high stands, limited data are available on cedar. The basal area must be maintained between 28 and 32 m^2/ha. Felling every 6 to 12 years must remove 15 to 25 % of the basal area each time, according to the stock standing, proportion of heavy timber and selling constraints (lot size).

To reduce the lack of references, an experimental plot that was treated as an uneven-aged high forest was established in "Luberon*".

The creation of mixed populations is possible through enrichment, via spaced lines that are perpendicular to dominant winds or 2 to 3 clumps per hectare of at least ten individuals each to guarantee a minimum genetic diversity. Other tree species must be controlled to facilitate access to light for the cedar.

In a mixed pine stand, one should be wary off the **processionary caterpillar** (*Thaumetopoea pityocampa*), which preferentially attacks pine but can secondarily attack cedars. The distribution of this caterpillar will move north in response to climate change.

48. An uneven-aged population in "Luberon*"

COMPLEMENTARY HEALTH ISSUES

The major sanitary issues were successively dealt with in the domains to which they were related. This chapter discusses several complementary issues that deserve mentioning.

SOME SPECIFIC PESTS

These pests do not present major health issues.

Cedar budworm (*Epinotia cedricida*) larvae cause defoliation damage by consuming needles in autumn and winter. From December, the chenille remains in sheaths made of needles stuck together by silk and upholstered by dung (see picture 49). Defoliation can be important before burst but does not lead to the tree death.

Two species of **aphids** specifically attack cedars. Their colonies develop at the tips of branches and twigs:

> ***Cedrobium laportei*** can trigger the loss of needles. The introduction of a specific parasite (***Pauesia cedrobii***), which is well acclimated, should efficiently regulate populations.

> ***Cinara cedri*** develops in large colonies that are discernible to the naked eye (see picture 50). Producing abundant honeydew covered with a black film of sooty mould (fungus), this aphid is a source of nuisance in popular locations. As a result of numerous natural regulators, tree health is rarely threatened.

49. Old larva of *Epinotia cedricida* in its sheath.

50. Colony of *Cinara cedri*.

Parasites can also further weaken stands that are already stressed due to poor soil or climate conditions. Among these parasites are the following:

> **Armillaria** observed in France outside of the Mediterranean zone;

> **Bark beetles** that cause problems in stands in their natural range;

> The fungus ***Sphaeropsis sapinea*** which can infect the tree through young stems or more often through a wound or a necrosis from diverse origins.

In addition, **wood fungi** that are responsible for rotting at the heart of the tree are present in northern Africa, but do not currently cause problems in France.

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- Pauline Marty (CRPF Languedoc-Roussillon*)
- Jean Ladier (ONF, Research and Development Department)
- Christian Ripert (IRSTEA, Mediterranean Ecosystems and Risks Research Unit)
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- Frédéric Huard (INRA, Agroclim Unit)
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DECEMBER 2012

Tarn*

Ille-et-Vilaine*

In adapting forests to climate change, cedar is often recommended as a potential species to replace existing conifers that are sensitive to drought.

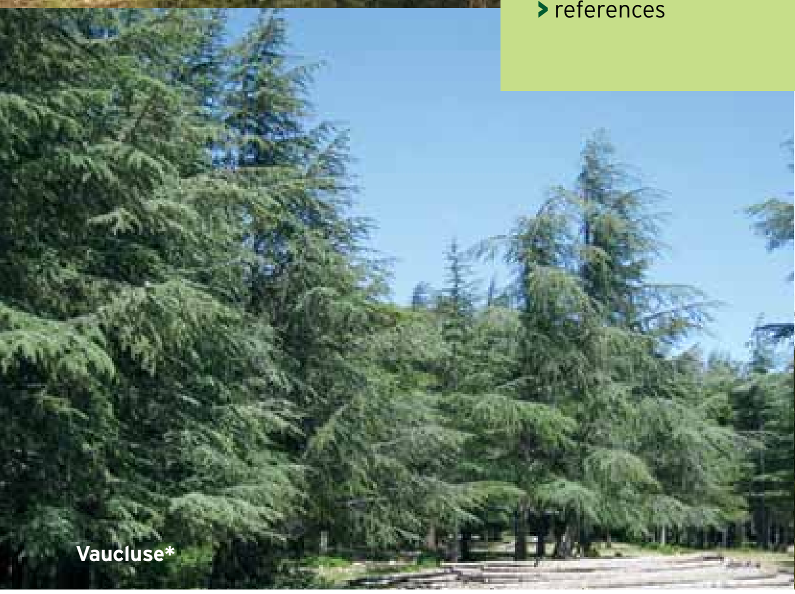
The experience in the French Mediterranean zone and the more recent tests in the temperate zone confirm this interest. Nevertheless, cedar establishment and silviculture must follow strict guidelines in order to be successful.

The state of knowledge on Atlas cedar, as synthesised in this document, is drawn from a literature review and from a nationwide survey of field trials. The information will help foresters to make informed decisions concerning the establishment and management of cedar stands, including the following aspects:

- autecology and behaviour with respect to climatic factors and soil characteristics
- technical recommendations for reafforestation and management of stands
- indications and criteria to select silvicultural treatments
- timber quality and uses
- health issues
- references

Eure-et-Loir*

Eure*



Vaucluse*

Marne*