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BioClimSol: a decision support system integrating future climate and ground conditions

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Summary

Decision support systems inform modern forest management in European countries. With climate change, measures to enhance forest resilience, such as tree species diversification and adaptive silvicultural practices, might benefit from management practices in other countries. The present article provides a review of the French BioClimSol decision support system for forest managers. The tool projects the risk of dieback for 13 tree species, considering a stand to be dying when at least 20% of co-dominant or dominant trees have had at least 50% branch or twig mortality. The article explains the methodology, indexes, and usage of BioClimSol and provides insights into forests and climate change in France to ease lesson-learning for practitioners in other countries.

Introduction

Decision support systems inform modern forest management in European countries. They can help balancing ecological, economic, and social objectives while addressing challenges like climate change, biodiversity loss, and sustainable resource utilization. Finding effective solutions for forest adaption to climate change is a major topic in forest science and practice. How forests respond to changing temperatures, precipitation patterns, and extreme weather events has become more difficult to predict while measures to enhance forest resilience, such as tree species diversification and adaptive silvicultural practices, might benefit from management practices in other countries. Researchers at the Bavarian State Institute of Forestry (LWF), for instance, have calculated climate analogues for temperate European forests in so-called "twin regions", i.e., regions where the current climate is comparable to the expected future climate at a site of interest (Mette et al., 2021). Such twin regions for forests of Northern Bavaria are located in the south of France (Vallée du Rhone), Northern Italy and Balkan countries (Brandl et al., 2023).

The Bavarian decision support system for forest management (BayWis) provides comprehensive geo and factual information for planning and analyses, including growth projections and risk assessments for 21 tree species. The present article seeks to inform further development of decision support systems for Bavaria and other countries with evidence from France. It explains the decision support system integrating future climate and ground conditions BioClimSol by looking at its methodology, indexes, and usage. To sketch the context for BioClimSol, the article starts with a chapter on forests and climate change in France.

Forests and climate change in France

Forests in mainland France and Corsica cover 17.5 million hectare (ha), or 32% of the territory. For almost two centuries, forest area has been increasing. In 1908, for instance, the forest covered almost 10 million ha. Since 1985, the stock of living wood has risen from 1.8 to 2.8 billion cubic meters. Today, hardwoods account for 65% and conifers for 35%. Oaks (sessile, pedunculate, pubescent and holm) are the hardwood species most represented in the territory (44% of hardwood volume). Norway spruce and silver fir together account for 40% of conifer volume. In recent years, however, the volume of coniferous trees tended to decline, due to lower biological production, as well as increased mortality and harvesting (IGN, 2024).

Three quarters of the forests (13.1 million hectares) are privately owned (IGN, 2024), with more than 3 million forest owners. Of these, 2.2 million (67%) have less than one ha. Almost 380.000 (11%) of these own more than 4 ha, accounting for 76% of private forest area. There are 50.000 owners of more than 25 ha (45% of private forest area), accounting for the majority of wood sales from private forests. Very few owners own more than 100 ha. Approximately 36% of private forests have a sustainable management document (CNPF-IDF, 2021).

Public forests account for a quarter of all forests, including state-owned forests (1.55 million hectares) and other public forests (owned by communes, other local authorities, and public establishments) (2.8 million hectares) (IGN, 2024).

As on a global scale, trends in average annual temperatures in mainland France show a clear warming trend since 1900. The rate of warming has varied, with a particularly marked increase since the 1980s. In 2019, the average annual temperature of 13.7°C was 1.8°C above normal (1961-1990), making 2019 the third hottest year since the beginning of the 20th century, behind 2018 (+ 2.1°C) and 2014 (+ 1.9°C) (MTECT-SDES, 2021). Rising temperatures have lengthened the growing season by several days per decade, with earlier budburst and later leaf senescence. This has boosted production in temperate forests.

Table 1: Share of main tree species in France, © IGN 2024

Species	Area (in thousands of ha) where the species can be found		
	Where the species can be found Presence of at least one recordable tree of the species on the plot	Where the species is dominant Recordable trees of the species with the highest relative canopy cover of the plot	Where the species is pure Recordable trees of the species form more than 75% of the plot's relative free canopy of the plot
Pedunculate oak	5.652 ± 94	2.210 ± 67	734 ± 41
Sessile oak	4.151 ± 81	1.843 ± 58	777 ± 39
Pubescent oak	3.254 ± 85	1 413 ± 62	1.413 ± 62
Beech	6.050 ± 92	1.500 ± 59	592 ± 39
Chestnut	3.440 ± 84	686 ± 42	266 ± 27
Ash	5.560 ± 104	622 ± 41	137 ± 19
Hornbeam	4.666 ± 78	622 ± 36	71 ± 13
Holm oak	1.884 ± 66	801 ± 51	456 ± 41
Maritime pine	1.540 ± 54	1.027 ± 44	786 ± 40
Scots pine	2.438 ± 76	893 ± 49	481 ± 38
Silver fir	2.501 ± 69	563 ± 36	237 ± 24
Norway spruce	1.846 ± 60	494 ± 34	241 ± 24
Douglas fir	1.157 ± 49	443 ± 32	296 ± 26

However, this also increases water requirements and hence water stress on the southern margins of species. In the longer term, mild winters are likely to disrupt bud and seed dormancy. Competitions between species, as well as the cycles of pathogenic fungi and insect pests, are also modified, with knock-on consequences for the vulnerability of species and the composition and functioning of forest ecosystems.

Decision support for managing with tree species in climate change

The heating climate decreased the predictability of existing forest growth models. Determinants affecting the decline or progression of tree species, incl. CO_2 levels, competition, parasitism as well as the more frequent catastrophic events, are not sufficiently addressed. Dieback and mortality rates show a strong impact of the latest climatic anomalies. They have increased by 50% in the last decade. This is particularly true of Scots pine, where the health of populations has deteriorated sharply in the Southern Alps and Central France. The overall trends, however, are clear. Rising temperatures enable tree species to settle further north, inland or higher altitudes. For example, the Holm oak, currently confined to the Mediterranean area and a thin Atlantic fringe, is expanding in Nouvelle Aquitaine and other areas in the West thanks to sufficiently mild climates, while declining on the southern or lower margin of its distribution range because of growing water deficits.

The French National Center for Private Forest Ownership (CNPF) has developed the BioClimSol tool for helping foresters to take the right decisions in adapting forests to climate change. The tool provides an assessment of the risk of dieback for 13 tree species, considering a stand to be dying when at least 20% of co-dominant or dominant trees have had at least 50% branch or twig mortality. A so-called vigilance level (BioClimSol Index – IBS) for different tree species is calculated based on:

- organic factors for the consideration of living things, in this case a species, or a stand (Bio)
- current climatic conditions in the plot and future conditions under different scenarios (Clim)
- the soil conditions in the plot (Sol), which can compensate for or catalyze the effects of stresses of all kinds (climatic, biotic, topographic, silvicultural factors)

The tree species include in BioClimSol are: pedunculate oak, sessile oak, pubescent oak, holm oak, cork oak, common chestnut in oceanic plains, common chestnut in continental and mountain climates, beech, Douglas fir, common spruce, Norway spruce, Scots pine, Atlas cedar, common ash. The inclusion of additional species is foreseen.

CNPF started developing the BioClimSol in 2010. The tool was born out of the “Atlantic oak groves” project conducted jointly by the Regional Forest Ownership Centers (CRPF) of the Atlantic seaboard and the Institute for Forestry Development (IDF). In 2008, the CRPFs were faced with a growing number of requests for sanitary cuttings in oak groves (mainly pedunculate oak), particularly in Poitou-Charentes and Pays de la Loire. Studies had demonstrated the impact of repeated years of high water deficit on the loss of vitality of oak stands, particularly pedunculate oak. The existing predictive maps for tree species dieback had serious limitations. The ability to draw up climatic vigilance maps was an innovation of the BioClimSol tool. The tool supports the field expertise of the given practitioners, which remains central for making precise assessments of the risk of dieback for the selected tree species.

BioClimSol was built with the participation of scientific partners and research organizations: Département Santé des Forêts (Forest Health Department), Météo France, INRAE, AgroParisTech and IGN. The Operational Group SPNA – Precision sylviculture in Nouvelle-Aquitaine – was the «case study» to test the deployment of the tool through a training session specifically organized in chestnut stands.[1] User feedback and comments have helped improving the application.

The BioClimSol methodology

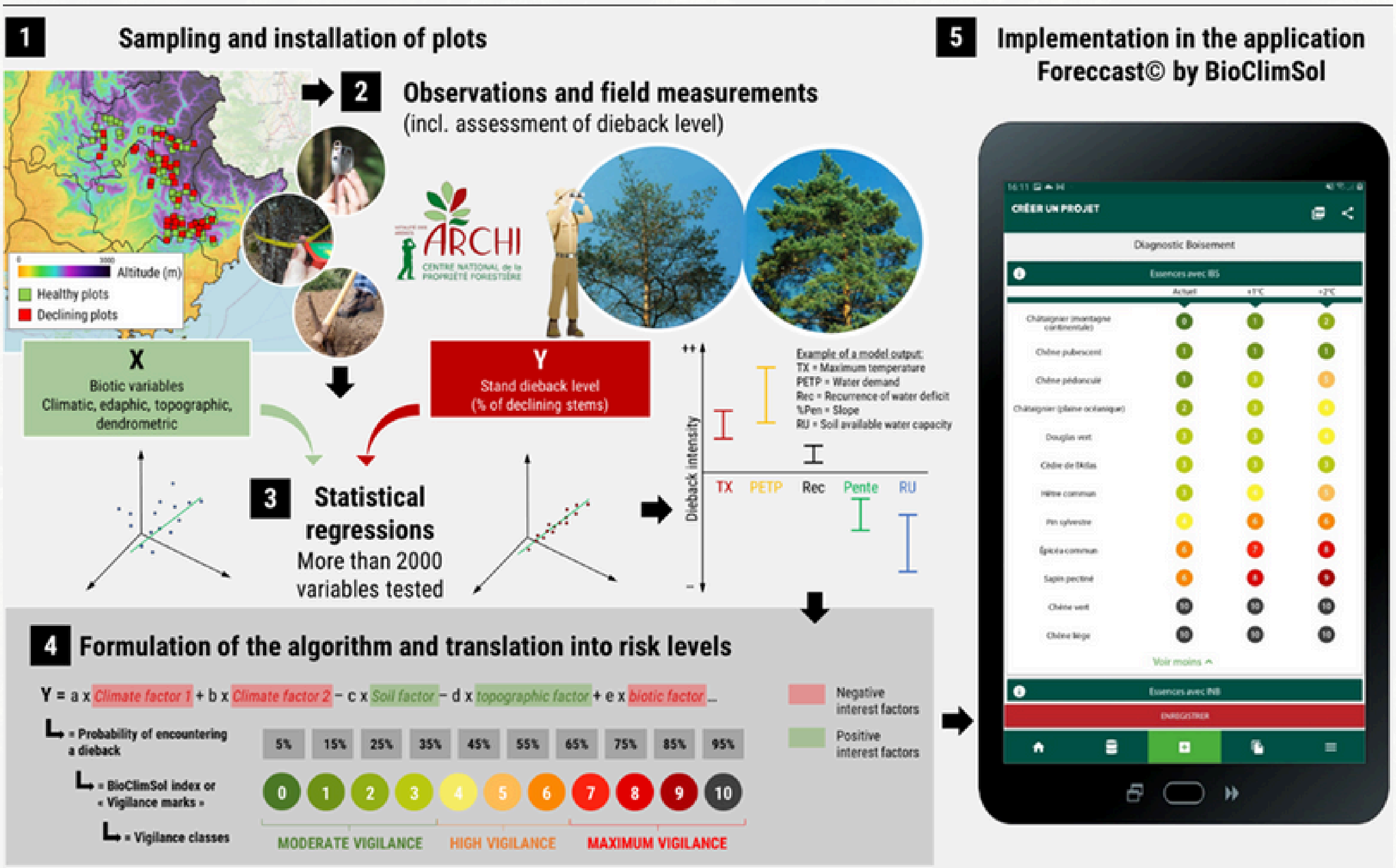
In a first step, the climatic limits of the species are defined on the basis of its world distribution range and data from the CHELSA model,[2] Météo France (AURELHY, SAFRAN), AgroParisTech (DIGITALIS) and IGN (DTM - digital terrain model). Obtained for certain variables by downscaling, the resolutions used are very fine (from 25 m. to 75 m.) and seek the best precision for reliable expertise at plot level. Future climate scenarios are expressed in terms of degrees of temperature increase relative to the climate normal for 1981-2010, and parameterized according to the trends of the DRIAS model from MétéoFrance. For example, in the case of pedunculate oak, a climatic transect is defined with respect to the climatic water balance (from most favourable to most unfavourable), and within this transect, measurement plots are randomly selected in the field.

In a second step, different data for the plots is collected (soil, hydromorphic characteristics, usable reservoir, pH, dendrometry characteristics, age, health status, etc.).

An elaborate statistical method is applied to identify and assign weights to the explanatory factors of dieback, and to measure their interaction effects. The model results in the formulation of an equation for assessing the probability of encountering a decline phenomenon. According to this method, a dieback model is produced from a minimum of a hundred field plots and characterizes an observed phenomenon, specific to the species and the context studied (including time).

Since 2019, 36 studies, involving nearly 5.000 measurement plots and 100.000 trees measured using the same protocol, have been used to calibrate the vigilance level. The data collection protocol is standardized. For example, for pedunculate oak in 2019, 310 plots were used to establish the model and three studies were carried out with measurements for more than 100 criteria, and statistical analysis at 5% (see Lemaire et al., 2022 for Scots pine). There are three vigilance levels:

Figure 1: BioClimSol dieback index (IBS)



[1] Katso: https://www.cnpf.fr/nos-actions-nos-outils/outils-et-techniques/bioclimsol (last access: 06.12.2024)

[2] CHELSA (Climatologies at high resolution for the earth's land surface areas). Katso: 222 (last access: 06.12.2024)

- Moderate vigilance (from 1 to 3 out of 10) with a low risk of dieback (25% chance of encountering dieback according to previous thresholds)
- High vigilance (4 to 7 out of 10) with 25 to 60% risk
- Maximum vigilance (7 to 10) with 60 to 90% risk

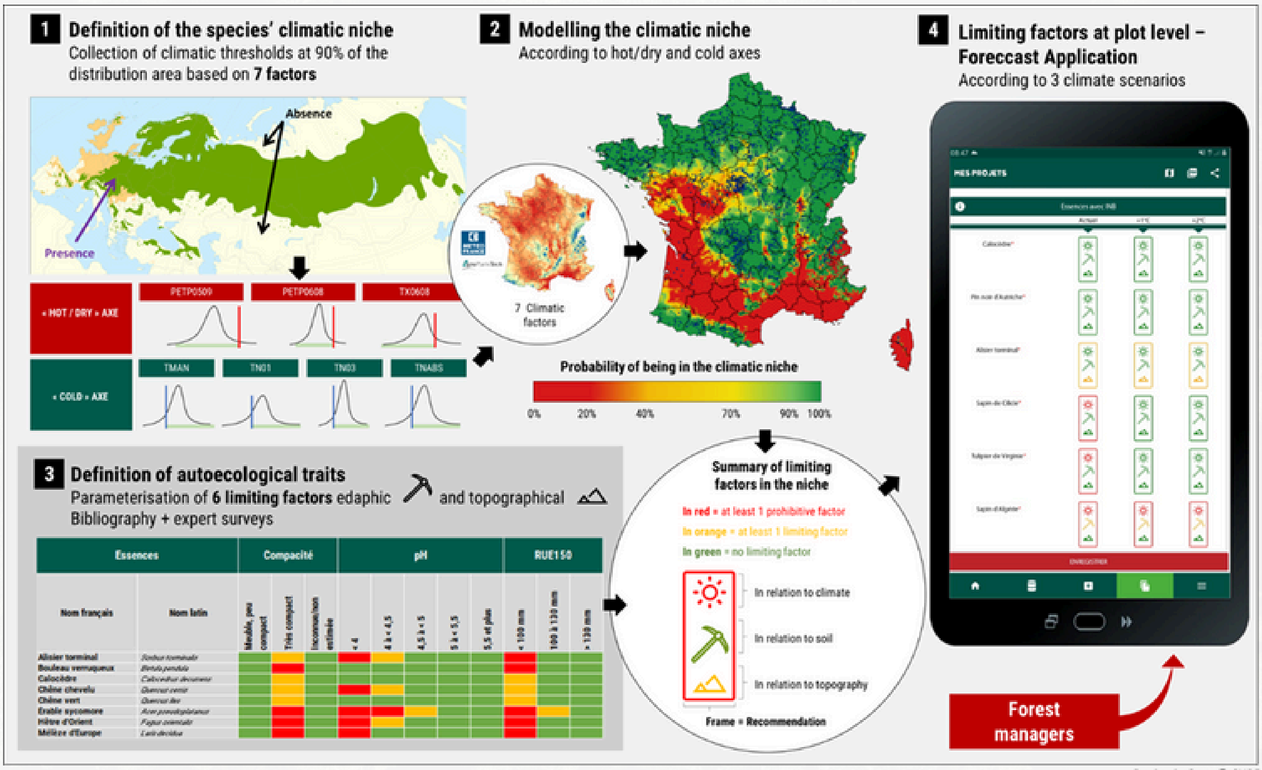
The model works with a constant climate, and a climate at +1°C and +2°C average temperature increase. It could also work at +3°C, +4°C and higher temperature increases.

Modeling niches for alternative tree species

In the frame of BioClimSol, a niche index (INB) was added to identify alternative species for reforestation purposes. The projections for the niche index of tree species are based on three data sources: climatic, topographical, and edaphic. The thresholds for 7 climatic parameters are extracted from the CHELSA global climate model (90% quantile of the range of the included species). These thresholds are then projected onto the climatic gradients of France (current and future climate scenarios). The result is displayed as a pictogram according to three probability classes (<30%, 30 to 70%, >70%). Limiting factors linked to topography and soil are also expressed by pictograms based on a matrix (categorical) of species' self-ecological requirements, itself parameterized by bibliographic work and expert surveys.

In late 2024, an IBN for 34 species is available in the tool. 20 new INBs will be integrated in 2025-2026.

Figure 2: BioClimSol niche index (INB)



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Use of BioClimSol applications

BioClimSol maps are available for specific uses (forestry policies, research work, etc.) and are subject to strict contractual conditions (agreement, user charter, etc.). In addition, they are systematically accompanied by interpretation keys that detail the data sources, reading conventions, and the limits of interpretation and use. A BioClimSol mobile application is available for Android. It represents the data acquisition interface for a user in the field, enabling users to:

- record general diagnostic information (location, project name),

- characterize the site context (topography, local conditions),
- record stand characteristics (species diagnosed, dendrometric characteristics),
- describe the soil ("usable" water reservoir, pH, hydromorphy),
- indicate the presence of health problems (frequency and intensity of the main problems),
- note the stand's level of dieback (ARCHI and/or DEPERIS protocols).

Three modules are available for consulting the tool's expertise: visualization of climatic data on the plot, stand diagnosis, and renewal solutions diagnosis. Dieback (IBS) and niche (INB) models are embedded in the mobile application in the form of algorithms. At the end of the calculations, BioClimSol provides its expertise in the form of risk assessments for a range of tree species in different climatic scenarios, also referred to as vigilance levels. These calculated risk assessments of tree species' dieback and niches for alternative tree species can then be used to draw up management recommendations. These recommendations appear as general management advice for the adaptive management of forests in the context of climate change, which can be adapted to the local context by means of a more in-depth technical reflection. When a level of vigilance is alerted, it is necessary to clearly identify the factors involved in the risk assessment, in particular by looking at the parameters that have the greatest influence on the decline of the species studied.

When diagnoses are recorded on the application, the field data (including the level of dieback of the stands diagnosed, as well as all the stationary and silvicultural variables recorded) are stored on the tool's servers and regularly updated by ongoing research and development (R&D) work. The mobile BioClimSol application thus supports a continuous learning and model performance improvement.

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Further information

Further information on BioClimSol

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