



ModERFoRest: A new software for assessing the environmental performance of forest species

✉ Eduardo LÓPEZ-SENESPLEDA^{1*}, ✉ Rafael ALONSO-PONCE², ✉ Ricardo RUIZ-PEINADO¹, ✉ Valentín GÓMEZ³,
✉ Rafael SERRADA⁴ and ✉ Gregorio MONTERO⁴

¹ Instituto de Ciencias Forestales (ICIFOR-INIA), CSIC, Dinámica y Gestión Forestal. Ctra. A Coruña km 7,5. 28040 Madrid, Spain. ² For Forest Technologies S.L.L. Campus Universitario Duques de Soria, Edificio (I+D+i), 42004 Soria, Spain. ³ Universidad Politécnica de Madrid, ETSI Montes, Forestal y Medio Natural. Sistemas y Recursos Forestales. C/ José Antonio Novais 10. 28040 Madrid, Spain. ⁴ Instituto de Ciencias Forestales (ICIFOR-INIA), CSIC, 28040 Madrid, Spain. Retired.

*Correspondence should be addressed to Eduardo López-Senespleda: elopez@inia.csic.es

Abstract

Aim of study: We introduce the software ModERFoRest (*Modelling Environmental Requirements for Forest Restoration*), which is a tool to estimate the environmental requirements and environmental performance of the main forest tree species growing in Spain.

Area of study: Two of their modules have been developed to be applied mainly in Spain, but the main section can be used elsewhere as long as the user provides with presence data and environmental information.

Materials and methods: ModERFoRest has been programmed in C++, also using the Armadillo library for algebraic computation. The application can be downloaded from the INIA website (<https://www.inia.es/serviciosyrecursos/recursosinformaticos/modernforest/Paginas/ModERFoRest.aspx>) where there are also more accessible resources (currently only in Spanish language).

Main results: ModERFoRest provides three basic utilities, firstly, to select the optimal species to be used for forest restoration, at local or regional scale, among the 22 most important taxa or formations in Spain, based on ecological criteria and physiographic, climatic and edaphic information. Secondly, to explore the potential distribution areas of the species using the ecological niche models and algorithms developed throughout different projects on the autecology of the species over the last 55 years. Finally, the application provides the option of comparing different areas of the species ecologically, in order to obtain the most suitable reproductive material for the forest site under study.

Research highlights: Users can also run not only recent but also future climate scenarios in order to simulate the distribution of ecological species and use the results in reforestation programmes and planning.

Additional key words: forest management; niche models; environmental resemblance; autecology; water balance.

Abbreviations used: API (Additive Potential Index); ENM (Environmental Niche Model); FPI (Factor Potential Index); FSR (Forest Stands Resemblance); GIS (Geographic Information System); RAM (Random Access Memory); SDM (Species Distribution Model); SSER (Species Suitability for Ecological Restoration).

Citation: López-Senespleda, E; Alonso-Ponce, R; Ruiz-Peinado, R; Gómez, V; Serrada, R; Montero, G (2023). ModERFoRest: A new software for assessing the environmental performance of forest species. *Forest Systems*, Volume 32, Issue 1, eRC01. <https://doi.org/10.5424/fs/2023321-19406>

Supplementary material (Tables S1-S3) accompanies the paper on Forest System's website.

Received: 16 Mar 2022. **Accepted:** 09 Feb 2023.

Copyright © 2023 CSIC. This is an open access article distributed under the terms of the Creative Commons Attribution 4.0 International (CC BY 4.0) License.

Funding agencies/institutions	Project / Grant
Spanish Ministry of Science and Innovation	RTA2010-00095-C02-00
Spanish Ministry of Agriculture, Food and Environment	“Digitisation and application of forest species autecology studies”

Competing interests: The authors have declared that no competing interests exist.

Introduction

ModERFoRest stands for *Modelling Environmental Requirements for Forest Restoration*. It is free software to assist in management decision process or in species distribution studies, even including climatic change scenarios. It predicts species distribution areas by means of environmental niche models for the main 22 tree taxa (though it includes one syntaxon, for clarity hereafter we will refer to all of them as taxon) growing in Spain (Table S1 [suppl]), using only presence data from natural and reforested stands and providing statistical validation.

An environmental niche model (ENM) is a function that defines within the ecological space the different relations among the presence of the taxon and the range of values of the different variables that explain its distribution. In short, ENMs try to replicate the niche requirements of the taxon studied (Saupe et al., 2012). These models could be used in conservation planning (Schwartz, 2012; Mateo et al., 2013; Lin et al., 2021; Blair et al., 2022); to estimate climatic and management changes on species distribution (Thuiller et al., 2005; López-Tirado et al., 2020); to predict the spread of invasive species or diseases (Townsend Peterson & Vieglais, 2001; Chalghaf et al., 2018; Streito et al., 2021); and to provide baseline information in habitat restoration projects and identify suitable areas for species reintroduction (Gastón et al., 2014).

The first studies that generated the information included in ModERFoRest date back to the 1960s (Table S2 [suppl]). They were focused on the autecology of the main conifer taxa growing in Spain, with the aim of providing information with ecological and scientific criteria to technicians working on restoration and reforestation projects (López-Senespleda et al., 2018). These autecology works

provided an exhaustive list of climatic, physiographic and edaphic data collected at each of the sites sampled. This information was used to analyse the suitability or marginality of the forest sites for the different taxa. Over time, information for other forest taxa was added, mainly broadleaved (Table S2). In addition, these studies evolved in the course of time with the inclusion of new statistical techniques. The latest projects completed the information on the 22 most important forest taxa growing in Spain (Table S1) and attempted to analyze and summarize all the information.

ModERFoRest has been designed to be as flexible and responsive to the needs of foresters and ecological researchers as other tools such as Maxent (Phillips et al., 2006), BIOMOD (Thuiller et al., 2009), ENFA (Hirzel et al., 2002) or Domain (Carpenter et al., 1993). This tool is especially valuable for its built-in niche modelling for 22 Spanish forest taxa (Table S1), including edaphic variables, and the climatic and edaphic data calculators.

Material and methods

Specifications / System description

ModERFoRest is an application mainly developed to assist in forest restoration and forest planning. The software implements two algorithms carried out for autecology studies (Rubio & Sánchez-Palomares, 2006; Alonso Ponce et al., 2010b) to estimate the environmental niche and the resulting potential expansion areas. There are also two calculators that allow the user to compute soil profile data in the appropriate format required by the software and

Table 1. List of the links to the different web contents about ModERFoRest in the INIA website.

Content	Web link
Software	https://www.inia.es/serviciosyrecursos/recursosinformaticos/modernforest/Paginas/Encuesta%20Usuario.aspx?pageD=/serviciosyrecursos/recursosinformaticos/modernforest/Documents/MODERFOREST_v.3.1.0.zip
User manual	https://www.inia.es/serviciosyrecursos/recursosinformaticos/modernforest/Documents/MANUAL_USUARIO_v1.2.2.pdf
Article about the origin of the data	https://www.inia.es/serviciosyrecursos/recursosinformaticos/modernforest/Documents/MANUAL_USUARIO_v1.2.2.pdf
Example datasets	https://www.inia.es/serviciosyrecursos/recursosinformaticos/modernforest/Documents/DATASETS_3.1.0.zip
Course (in Spanish) to use ModERFoRest (Colegio de Ingenieros Técnicos Forestales)	http://www.forestaes.net/Canales/Ficha.aspx?IdMenu=3edd8ac1-e6a9-47d6-9355-f4164ebe7b82&Cod=c7a0f895-c12e-471d-9fe5-8b2fd92631e8&Idioma=es-ES
Course (in Spanish) to use ModERFoRest (Colegio de Ingenieros de Montes)	https://www.ingenierosdemontes.org/cns/videos-curso-online-que-es-y-como-funciona-moderforest

to obtain a wide range of climatic variables, including water balance if the mandatory data are available.

The first released version of ModERFoRest (v.3.1.0) has been compiled for Microsoft Windows 64 bit and has been developed in Qt, a well-known cross-platform application framework that uses standard C++ with several extensions. The environment used has been the Qt Creator suite. ModERFoRest uses Armadillo (Sanderson & Curtin, 2016, 2020), an open-source linear algebra library for the C++ programming language used in its algorithm calculations, as well as the LAPACK (Anderson et al., 1999), BLAS (Blackford et al., 2002) and BOOST (Schäling, 2011) libraries. English and Spanish are the current languages of the interface, but the interface could be easily translated into any other language.

Other tools included

Parallely, the application contains three calculators that return their results in the format and units necessary to be used in any of the three aforementioned modules, though they can be also useful in multiple procedures outside the program. First, the Soil Calculator, allows obtaining soil variables aggregated for each profile from data obtained by horizons. Secondly, the Climate Calculator, calculates a wide range of climate variables from raw data (both from weather stations or from raster climatic models) of monthly rainfall and temperatures. Finally, the Combined Calculator allows the integration, in a single procedure, of the two previous calculators, returning a single output file which can be directly used in the SSER or FSR modules. For the main variables used in forest species autecology studies, see Table S3 [suppl].

ModERFoRest access and resources

ModERFoRest is a native application available in Windows environments that can be freely downloaded. There is also an e-mail address (moderforest@inia.csic.es) through which users can send their comments or incidents to the authors, as well as additional material on the website to allow a better use of the software (all the links are listed in Table 1).

ModERFoRest conditions of use

Once the user downloads the software is requested to fulfil a registration form to complete the software transfer. The aim of the users' list is for statistical purposes and to focus outreach by user groups (foresters, technicians, scientists, students, teachers, etc.)

The software has been conceived to be used with taxon occurrence data. Data can arise from any origin, not only

from Spain, and it could be used with many data sources such as plant species inventories, animal occurrence data or disease data. The only restriction to the scope of species distribution in Spain is when it is intended to make use of the included niche models. These niche models, which indicate the environmental variables to be used, were developed on the basis of the autecology studies in Spain. In short, ModERFoRest is a decision management tool that needs the knowledge of an expert to be correctly interpreted.

Results and discussion

The user can choose between three available modules: (i) Species Distribution Model (SDM), (ii) Species Suitability for Ecosystem Restoration (SSER); and (iii) Forest Stands Resemblance (FSR).

SDM module

The SDM module was designed to perform predictions about the potential expansion areas of the target taxon. The SDM submenu has three sections: (i) Input options (Fig. 1a), (ii) Modelling options (Fig. 1b) and (iii) Output options (Fig. 1c).

The Input options section comprises the input data environment. It uses data of the presence of the taxon to be studied and, as covariates, environmental data such as physiographic, climatic or edaphic data, in raster format (ASCII file .asc) with projected coordinates. A key issue in species distribution modeling is the appropriate selection of these environmental covariates (e.g. Austin, 2002; Araújo & Guisan, 2006). A good practice is not to saturate the model with many covariates and try not to use highly correlated variables.

The Modelling options section allows the user to choose the algorithm to be utilised (Additive Potential Index, API, or Factor Potential Index, FPI), to change the subsample ratio and the number of iterations used in the validation procedure. Projections can also be done on a different area or climatic scenario, which is interesting when working with invasive taxa or climatic change analysis, respectively. Details about the two available algorithms are well explained in the literature (Rubio & Sánchez-Palomares, 2006; Alonso Ponce et al., 2010a, 2010b).

Validation was performed using bootstrapping techniques and the Boyce-Hirzel curve (Boyce et al., 2002; Hirzel et al., 2006). The Boyce-Hirzel curve (Fig. 1d) plots the ratio of the predicted probability of presence values divided by the expected probability of presence values by chance against the suitability index values. This curve was calculated using a sliding window of fixed width. Sliding distance and window width can be modified by the user. In addition, if more than one rep-

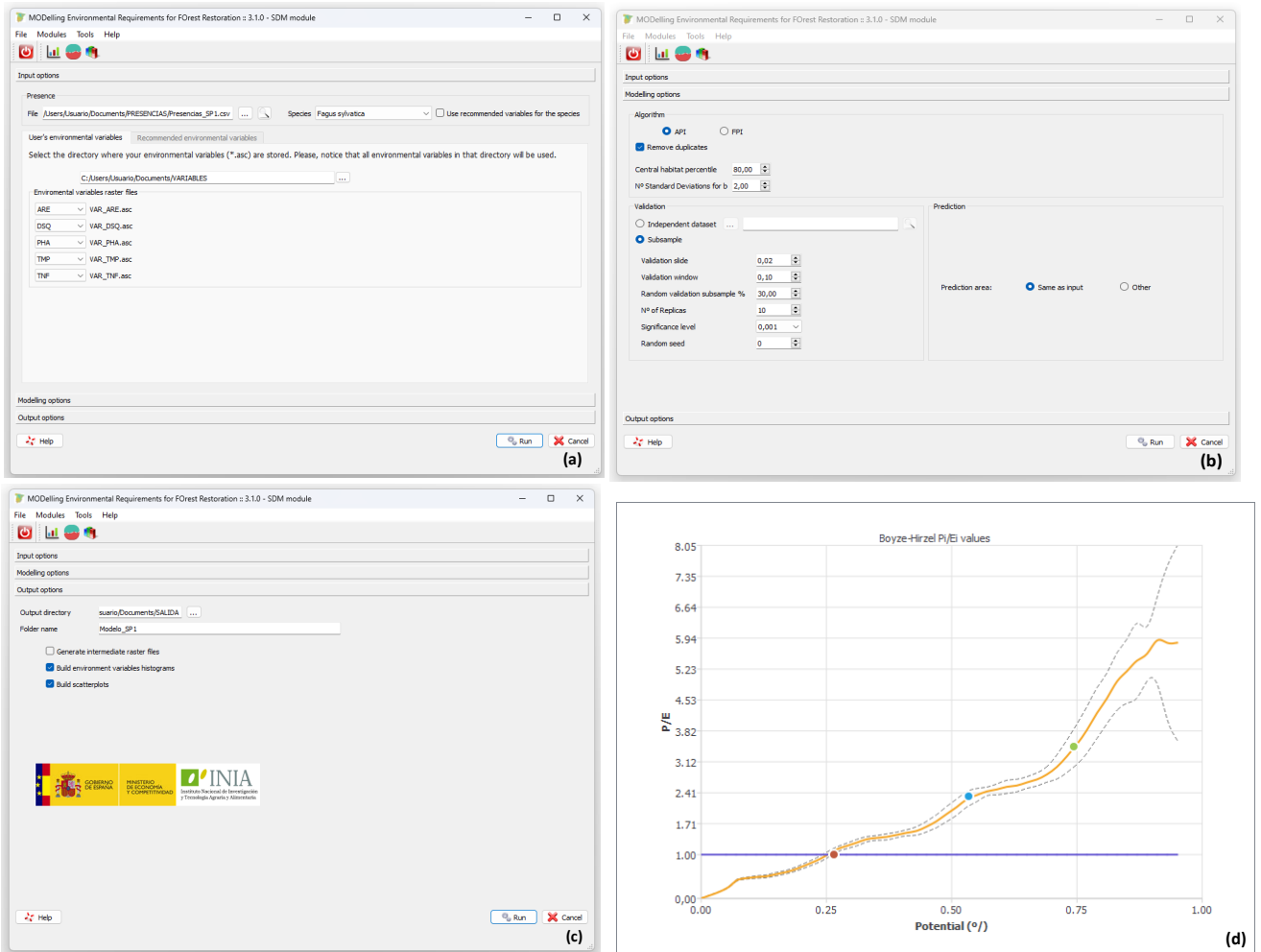


Figure 1. SDM module: Input (a), Modeling (b) and Output (c) options. Graph (d) is an example of the Boyce-Hirzel validation curve; the continuum orange line shows the P/E (predicted/expected) ratio; the dashed line shows the confidence interval (95%) for the P/E ratio; API: Additive Potential Index algorithm (presence probability).

licate has been requested, a confidence interval for the curve is displayed. If the confidence interval is above the ordinate = 1, the model is considered to be significantly better than a random model. A full explanation of the validation process can be found in Alonso Ponce et al. (2011) and López-Senespleda (2015).

Finally, the Output options section allows the user to select the output directory and to include additional results. The default outputs are the raster layers of the mean probability of presence, its standard deviation, coefficient of variation, maximum and minimum, the Boyce-Hirzel curve and the Kolmogorov-Smirnoff test for the two empirical distributions (calibration and validation datasets). The raster layers can be displayed with any GIS software.

The application has proven to perform large computations efficiently: a species distribution model built with the API algorithm (much more processor intensive than the FPI algorithm) using a presence dataset of 3876 records (with 90% of the samples reserved for validation) and five environmental rasters (1 km² of resolution) for the whole Iberian Peninsula and the Balearic Islands (around 600000

km²) took 5 minutes for each replica, running on an Intel Core i7-4712MQ at 2,30GHz with 16,0 GB of RAM.

SSER Module

The SSER module classifies the taxa available in the database (Table S1) according to their ecological suitability for a particular forest station in a similar way to the PINARES software (Gandullo & Sánchez-Palomares, 1994), but using the two algorithms available in the SDM module. The input data comprise the required/available variables for each site under evaluation. These variables can be easily computed with the calculators included in the *Tools menu* of the application (see below). A maximum of 15 variables can be used simultaneously. Moreover, ModER-FoRest suggests a set of variables to be used, both in the case of climatic-only analysis or (highly recommended) if it includes edaphic factors.

For every site of interest, the outputs contain information on the level of compatibility of each taxon and the degree of marginality with respect to each of the environ-

mental variables used (Gómez-Sanz, 2019). Moreover, for 10 out of the taxa included in the dataset that have information available on-site quality (Table S1), this module computes a prediction of the site quality based on the ecological variables, whenever they are provided by the user.

FSR Module

The FSR module selects the most suitable source of forest reproductive material for a given site, based on ecological similarity, evaluated through the Mahalanobis distance. The input data file is similar to that used in the SSER module, but in this case the election of the target taxon is required. Soil information is mandatory in this module when recommended variables are used.

The application outputs a file containing the distances (in ascending order) of each site of interest to every record included in the database filtered for the target taxon. Furthermore, four of these taxa (see Table S1, taxa identified with “*”) possess environmental data for selected seed sources (Gómez-Sanz et al., 2014) in the database, hence an extra file with the distances to these seed sources is provided whenever one of those four taxa is chosen.

Conclusions

We present a summary of the main features of ModER-FoRest software, an easy-to-use application to perform analysis in the fields of species distribution modelling, ecological resemblance and forest planning both at the local and regional scales, among others. This software is particularly devoted to assisting reforestation projects and diagnosing the stability of existing forests under current and future environmental conditions, e.g. by simulating optimal areas for taxa existence using climate change scenarios. Furthermore, the application utilises a huge amount of very valuable environmental information, chiefly edaphic, so far scattered over a large number of publications and data sources.

As in any other modelling procedure, both quality data and output interpretation must be carefully considered by practitioners. For instance, though the application permits the exclusive use of climatic data in all its modules, it is extremely recommended to incorporate edaphic variables to the analysis, principally in the SSER and FSR, i.e., in evaluations at the smaller scales.

This software cannot automatically decide on the collection of variables but guide the user to make the choice by (i) recommending a set of ecological features (based on the autecological studies that feed the software) and (ii) providing algorithms (such as API, Fig. 1), whose mathematical design was specifically conceived to deal with variables highly correlated. Next, the resolution of the environmental rasters must be defined based on the extent of the area under assessment: for regional or larger scales, a cell size of 0.5-1.0 km should be sufficient to obtain operational

results, whenever the zone is not extremely mountainous. Lastly, the number of records in the presence dataset should be above some dozens (i.e. 30-50), and depending on the environmental variability of the current distribution of the target taxon, it does not need to be particularly high (some hundreds at the most). If a larger dataset is available, we recommend, along with activating the “remove duplicates” options in the modelling options, to retain a large proportion of the records for the validation stage.

Future improvements of the program will include: (i) support rasters in other formats than .asc; (ii) support geographical coordinate systems; (iii) support datasets in excel format; (iv) new environmental variables and taxa; (v) new selected seed sources to the environmental database; (vi) a Mahalanobis distance calculator; (vii) allow user to save analysis parameters for further analysis; and (viii) translation to other languages.

Acknowledgements

The authors would thank Otilio Sánchez-Palomares for his suggestions and contributions to software improvement.

Authors' contributions

Conceptualization: E. López Senespleda, R. Alonso Ponce.

Data curation: E. López Senespleda, R. Alonso Ponce.

Formal analysis: Not applicable

Funding acquisition: G. Montero, R. Serrada.

Investigation: E. López-Senespleda, R. Alonso Ponce, R. Ruiz-Peinado, V. Gómez, R. Serrada, G. Montero.

Methodology: E. López Senespleda, R. Alonso Ponce.

Project administration: G. Montero.

Resources: Not applicable.

Software: E. López Senespleda, R. Alonso Ponce.

Supervision: R. Alonso Ponce.

Validation: R. Alonso Ponce, E. López Senespleda, R. Ruiz-Peinado.

Visualization: E. López-Senespleda, R. Alonso Ponce, R. Ruiz-Peinado.

Writing – original draft: E. López-Senespleda, R. Alonso Ponce, R. Ruiz-Peinado.

Writing – review & editing: E. López-Senespleda, R. Alonso Ponce, R. Ruiz-Peinado, V. Gómez, R. Serrada, G. Montero.

References

- Alonso Ponce R, Águeda B, Ágreda T, Modrego MP, Aldea J, Fernández-Toirán LM, Martínez-Peña F, 2011. Rockroses and *Boletus edulis* ectomycorrhizal association: realized niche and climatic suitability in Spain. *Fungal Ecol* 4(3): 224-232. <https://doi.org/10.1016/j.funeco.2010.10.002>

- Alonso Ponce R, Águeda B, Ágreda T, Modrego MP, Aldea J, Martínez-Peña F, 2010a. Un modelo de potencialidad climática para la trufa negra (*Tuber melanosporum*) en Teruel (España). *Forest Syst* 19(2): 208-220. <https://doi.org/10.5424/fs/2010192-01315>
- Alonso Ponce R, López-Senespleda E, Sánchez-Palomares O, 2010b. A novel application of the ecological field theory to the definition of physiographic and climatic potential areas of forest species. *Eur J For Res* 129(1): 119-131. <https://doi.org/10.1007/s10342-008-0254-2>
- Anderson E, Bai Z, Bischof C, Blackford S, Demmel J, Dongarra J, et al., 1999. LAPACK user's guide (3rd). Society for Industrial and Applied Mathematics, Philadelphia, PA, USA. <https://doi.org/10.1137/1.9780898719604>
- Araújo MB, Guisan A, 2006. Five (or so) challenges for species distribution modelling. *J Biogeogr* 33(10): 1677-1688. <https://doi.org/10.1111/j.1365-2699.2006.01584.x>
- Austin MP, 2002. Spatial prediction of species distribution: an interface between ecological theory and statistical modelling. *Ecol Model* 157(2-3): 101-118. [https://doi.org/10.1016/S0304-3800\(02\)00205-3](https://doi.org/10.1016/S0304-3800(02)00205-3)
- Blackford LS, Petitet A, Pozo R, Remington K, Whaley RC, Demmel J, et al., 2002. An updated set of basic linear algebra subprograms (BLAS). *ACM T Math Softw* 28(2): 135-151. <https://doi.org/10.1145/567806.567807>
- Blair ME, Le MD, Xu M, 2022. Species distribution modeling to inform transboundary species conservation and management under climate change: promise and pitfalls. *Front Biogeogr* 14(1): e54662. <https://doi.org/10.21425/F5FBG54662>
- Boyce MS, Vernier PR, Nielsen SE, Schmiegelow FKA, 2002. Evaluating resource selection functions. *Ecol Model* 157: 281-300. [https://doi.org/10.1016/S0304-3800\(02\)00200-4](https://doi.org/10.1016/S0304-3800(02)00200-4)
- Carpenter G, Gillinson AN, Winter J, 1993. DOMAIN: a flexible modeling procedure for mapping potential distributions of plants, animals. *Biodivers Conserv* 2: 667-680. <https://doi.org/10.1007/BF00051966>
- Chalghaf B, Chemkhi J, Mayala B, Harrabi M, Benie GB, Michael E, Salah AB, 2018. Ecological niche modeling predicting the potential distribution of *Leishmania* vectors in the Mediterranean basin: impact of climate change. *Parasites Vectors* 11: 461. <https://doi.org/10.1186/s13071-018-3019-x>
- Gandullo JM, Sánchez-Palomares O, 1994. Estaciones ecológicas de los pinares españoles. MAPA-ICONA, Madrid. 188 pp.
- Gastón A, García-Viñas JJ, López-Leiva C, Oliet JA, Roig S, Serrada R, 2014. Species distribution models applied to plant species selection in forest restoration: are model predictions comparable to expert opinion? *New Forests* 45: 641-653. <https://doi.org/10.1007/s11056-014-9427-7>
- Gómez-Sanz V, 2019. Site-scale ecological marginality: Evaluation model and application to a case study. *Ecol Model* 408: 108739. <https://doi.org/10.1016/j.ecolmodel.2019.108739>
- Gómez-Sanz V, Serrada Hierro R, Elena Rosselló R, Fernández Yuste JA, García Viñas JJ, López Leiva C, 2014. Medio físico de rodales selectos de especies de forestales: *Abies alba* Mill. ECOGESFOR-UPM. Madrid. <https://doi.org/10.13140/RG.2.1.1259.0244>
- Hirzel AH, Hausser J, Chessel D, Perrin N, 2002. Ecological-niche factor analysis: How to compute habitat-suitability maps without absence data? *Ecology* 83: 2027-2036. [https://doi.org/10.1890/0012-9658\(2002\)083\[2027:ENFAHT\]2.0.CO;2](https://doi.org/10.1890/0012-9658(2002)083[2027:ENFAHT]2.0.CO;2)
- Hirzel AH, Le Lay G, Helfer V, Randin CF, Guisan A, 2006. Evaluating the ability of habitat suitability models to predict species presences. *Ecol Model* 199: 142-152. <https://doi.org/10.1016/j.ecolmodel.2006.05.017>
- Lin L, He J, Lyu R, Luo Y, Yao M, Xie L, Cui G, 2021. Targeted conservation management of white pines in China: Integrating phylogeographic structure, niche modeling, and conservation gap analyses. *For Ecol Manage* 492: 119211. <https://doi.org/10.1016/j.foreco.2021.119211>
- López-Senespleda E, 2015. Autoecología paramétrica de los quejigares españoles. Doctoral thesis. Universidad de Valladolid, Palencia, Spain.
- López-Senespleda E, Montero G, Ruiz-Peinado R, Alonso Ponce R, Serrada R, Sánchez-Palomares O, 2018. Cincuenta años de autoecología forestal paramétrica en España. *Foresta* 70: 40-47.
- López-Tirado J, Vessella F, Stephan J, Ayan S, Schirone B, Hidalgo PJ, 2020. Effect of climate change on potential distribution of *Cedrus libani* A. Rich in the twenty-first century: an ecological niche modeling assessment. *New Forests* 52: 363-376. <https://doi.org/10.1007/s11056-020-09798-y>
- Mateo RG, de la Estrella M, Felicísimo AM, Muñoz J, Guisan A, 2013. A new spin on a compositionalist predictive modelling framework for conservation planning: A tropical case study in Ecuador. *Biol Conserv* 160: 150-161. <https://doi.org/10.1016/j.biocon.2013.01.014>
- Phillips SJ, Anderson RP, Schapire RE, 2006. Maximum entropy modeling of species geographic distributions. *Ecol Model* 190: 231-259. <https://doi.org/10.1016/j.ecolmodel.2005.03.026>
- Rubio A, Sánchez-Palomares O, 2006. Physiographic and climatic potential areas for *Fagus sylvatica* L. based on habitat suitability indicator models. *Forestry* 79: 439-451. <https://doi.org/10.1093/forestry/cpl025>
- Sanderson C, Curtin R, 2016. Armadillo: a template-based C++ library for linear algebra. *J Open Source Softw* 1: 26. <https://doi.org/10.21105/joss.00026>
- Sanderson C, Curtin R, 2020. An adaptive solver for systems of linear equations. *Int Conf on Signal Processing and Communication Systems*, pp. 1-6. <https://doi.org/10.1109/ICSPSC50536.2020.9309998>
- Saupe EE, Barve V, Myers CE, Soberón J, Barve N, Hensz CM, et al., 2012. Variation in niche and distribution model performance: The need for a priori assessment of key causal factors. *Ecol Model* 237-238: 11-22. <https://doi.org/10.1016/j.ecolmodel.2012.04.001>

- Schäling B, 2011. The Boost C++ Libraries. XML Press. 570 pp.
- Schwartz NW, 2012. Using niche models with climate projections to inform conservation management decisions. *Biol Conserv* 155: 149-156. <https://doi.org/10.1016/j.biocon.2012.06.011>
- Streito JC, Chartois M, Pierre E, Dusoulier F, Armand JM, Gaudin J, Rossi JP, 2021. Citizen science and niche modeling to track and forecast the expansion of the brown marmorated stinkbug *Halyomorpha halys* (Stål, 1855). *Sci Rep* 11: 11421. <https://doi.org/10.1038/s41598-021-90378-1>
- Thuiller W, Lavorel S, Araújo MB, Sykes MT, Prentice IC, 2005. Climate change threats to plant diversity in Europe. *Proc Natl Acad Sci USA* 103(23): 8245-8250. <https://doi.org/10.1073/pnas.0409902102>
- Thuiller W, Lafourcade B, Engler R, Araújo MB, 2009. BIOMOD - A platform for ensemble forecasting of species distributions. *Ecography (Cop.)* 32: 369-373. <https://doi.org/10.1111/j.1600-0587.2008.05742.x>
- Townsend Peterson A, Vieglais D, 2001. Predicting species invasions using ecological niche modelling: new approaches from bioinformatics attack a pressing problem. *BioScience* 51(5): 363-371. [https://doi.org/10.1641/0006-3568\(2001\)051\[0363:PSIUEN\]2.0.CO;2](https://doi.org/10.1641/0006-3568(2001)051[0363:PSIUEN]2.0.CO;2)