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ORIGINAL RESEARCH

Pre-assessments of plant conservation status in islands: the case of French Overseas Territories

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Abstract
Assessment methods have been developed to estimate a preliminary conservation status for species and subsequently to facilitate the building of Red Lists. Such pre-assessment methods could be particularly useful in the French Overseas Territories (FOTs) where Red Lists tend to be out-dated or absent and where a high number of endemic species face detrimental anthropogenic pressures. We first aimed to conduct a preliminary assessment (hereafter, pre-assessment) of the conservation status of endemic plants from Guadeloupe, Martinique, Réunion, Mayotte, French sub-Antarctic islands, New Caledonia, and Scattered Islands. We then compared the various methods used in conducting the pre-assessment and discussed ways to adapt these methods to small territories. We compiled occurrence data of endemic species identified thanks to a previous taxonomic work and pre-assessed their conservation status under Red List criteria A and B and the use of a Random Forest algorithm. We then measured the accuracy, specificity, and sensitivity of each method based on existing Red Lists. The Random Forest algorithm and a method based on range-size performed best at correctly attributing conservation status. Using these pre-assessment methods, we estimated that up to 60% of the endemic flora of the FOTs is potentially threatened. Range restriction but also anthropogenic pressures were key factors that explained these risks. Pre-assessment methods are useful tools to get a first measure of species conservation status. These methods should be adapted to the territories considered and their conservation issues in order to reach a good performance.

Keywords Red List · Pre-assessments · Islands · Tracheophytes · French overseas territories · Endemics

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Introduction

Plants are the dominant kingdom in terms of Earth biomass, representing around 82% (c.a. 450Gt), and represent around 370,000 species (Bar-On et al. 2018; Roskov et al. 2019; Freiberg et al. 2020). Plants are essential to the functioning of ecosystems and provide invaluable services to humanity. Yet, almost 22% of vascular plants may be threatened with extinction, although only 14% of them have had their conservation status assessed at the global scale (Brummitt et al. 2015; IUCN Red List version 2022-2 2022). The conservation status of species is essential for the prioritization of conservation actions and one of the tools designed for this purpose is the Red List of threatened species of the International Union for Conservation of Nature (IUCN) (Mace et al. 2008). The IUCN Red List is the world's most commonly used system for gauging the extinction risk faced by species. It is based on criteria and data to assess for each species: i. a population decline (criterion A); ii. a reduced range (criterion B); iii. a small population and decline (criterion C); iv. a very small population (criterion D); and/or v. a quantitative analysis of the risk of extinction (criterion E) (IUCN 2012). These criteria are used to assign a threat category to each species. The Red List allows to consistently document the conservation status of species, to identify areas in need of special protection, to support conservation actions and policies, and to monitor the changing state of biodiversity on Earth (Rodrigues et al. 2006).

Assessing the conservation status of a species is a time-consuming and costly process that requires extensive studies on the taxonomy and chorology of species, monitoring the changes of populations and threats in a territory, mobilizing and training a large number of experts, conducting dedicated workshops, processing data and publishing results, among other tasks (UICN France 2018). It therefore proves impractical to assess and regularly update the status of every plant species on the planet, especially as new species are described every day (on average 2400 annually in the last 10 years [IPNI 2021]). In addition, existing plant assessments have not accumulated on the Red List in a systematic way due to different types of biases. For example, more attention is paid to plant species expected to be threatened, so that species that may be secure are under-evaluated (Bachman et al. 2019). To overcome these difficulties, methods and tools for preliminary conservation assessments (hereafter, pre-assessments) have been developed to support and speed up the evaluation of the conservation status of species while following standards close to those used in the Red List framework (e.g. Stévart et al. 2019; Bachman et al. 2020). Although an assessment following Red List standards is necessary to know the genuine conservation status of a species as defined by the IUCN, such pre-assessment methods have been used for comprehensive analyses of potential extinction risks of the flora of Puerto Rico (Miller et al. 2012), Hawaii (Krupnick et al. 2009), the Lesser Antilles (Carrington et al. 2017), and Greece (Kougioumoutzis et al. 2021). Automatic pre-assessment methods have therefore a high potential to assist Red List assessments (Cazalis et al. 2022).

In this study we focus on selected French overseas territories (FOTs) and aim to pre-assess the conservation status of their endemic flora. According to existing regional Red Lists (New Caledonia, French Polynesia, Guadeloupe, Martinique, Réunion, Mayotte), more than half of the seed plants endemic to the FOTs could be threatened with extinction, of which nearly 1/3 have been assessed as critically endangered (Véron et al. 2021). This figure remains high in ferns and lycophytes since 37% of endemic species are threatened with extinction (Véron et al. 2021). However, there is still a large number of species whose conservation status is unknown or out-of-date and no longer corresponds to the current conservation status of the taxon. The stakes are high since nearly 4000 species of tracheophytes are endemic to the FOTs (Véron et al. 2021), of which 10 are part of biodiversity hotspots (Myers et al. 2000). In these territories, plant taxa face a vast array of threats, such as deforestation, invasive species, changes in land use, fires, tourism, mining activities or climate change (e.g. UICN France et al. 2014, Meyer et al. 2021). With the exception of French Guiana and Adélie Land, FOTs are islands, and species found in insular territories are likely more vulnerable to anthropogenic pressures than continental species (Russell and Kueffer 2019). Thus, the proportion of threatened endemic plants is higher in the FOTs than in metropolitan France and even higher than on a global scale (Nic Lughadha et al. 2020; Véron et al. 2021).

The application of pre-assessment methods to the endemic flora of the FOTs is an important contribution to conservation actions in these territories. These pre-assessments compile baseline data for future actions and these new data could support future Red Lists. The numerous botanical field collecting campaigns carried out for several centuries in the overseas territories, the study of herbaria specimens and their digitization, the existence of national and regional taxonomic repositories, recent inventories and participatory sciences are all assets allowing for the analysis of these pre-evaluations. The detailed knowledge of the flora of certain, but not all, territories and the existence of recent Red Lists (e.g. New Caledonia) make it possible to test the performance of these methods and their bias in order to improve upon them. Knowledge of island characteristics, biogeography, environmental pressures, collecting efforts, conservation issues and available floristic data in the overseas territories means that factors that have not yet been taken into account can be tested to analyze the performance of pre-assessments methods globally. The objectives of this study are therefore to:

(1) Pre-assess the conservation status of the endemic flora of selected FOTs, in particular for Not Evaluated species;
(2) Compare the performance of four assessment methods to correctly predict IUCN Red List conservation status while considering factors absent from previous studies;

Method

Compiling and cleaning data

The first step of this study was to compile occurrence data of strict endemic and regional endemic plant species (see definition in Supplementary Information 1) of Réunion, Mayotte, Guadeloupe, Martinique, Scattered Islands, French sub-Antarctic Islands and New Caledonia. We focused on these FOTs due to conservation issues for endemic plants and data availability (Supplementary Information 1). To select endemic species we used the French national taxonomic repository TAXREF (Gargominy et al. 2021) and a recent checklist of the FOTs endemic plants (Véron et al. 2021). Only species records within the geographic boundary of the FOTs were used in the analysis. The main data sources included local inventory datasets (e.g. https://mascarine.cbnm.org/; Carrington et al. 2018), the National inventory of natural heritage – the official data source of French National Red Lists—(INPN; MNHN and OFB 2021), the Global Biodiversity Information Facility (GBIF), the collections of the Paris herbarium (P) along with the ones of the FOTs herbaria (e.g., GUAD, MTK, REU, MAO, NOU) and other international herbaria (e.g., K, MO, G) (all data sources are in Table 1). In total we compiled occurrence records for 3545

Table 1 Data used for each territory

	Main sources of species records	Number of occurrence records compiled	Median age of records	Pre-assessed endemic species	Anthropogenic pressures (criterion A)	Criterion B parameters
New Caledonia	Endemia and RLA Flore NC 2019; ERMINES project (for ultramafic substrates); Herbaria P and NOU; Other international herbaria; INPN; GBIF	126,329 records including 121,657 georeferenced	1978	2591 (out of 2758 endemic species)	Urban and agricultural environments (Gouvernement de la Nouvelle-Calédonie 2014); Loss of forest cover (Hansen et al. 2013); Fires (OEIL 2021); Active mines (Gouvernement de la Nouvelle-Calédonie 2014)	AOO, EOO according to recommendations of (IUCN 2012) Number of locations = 10 km*10 km square grid
Réunion	Mascarine; Herbarium REU; Herbarium P; INPN; GBIF	102,406 records including 102,208 georeferenced	2010	413 (out of 489 endemic species)	Urban and agricultural environments (Bossard et al. 2000); Land use change 2012–2018 (Bossard et al. 2000); loss of forest cover (Hansen et al. 2013); invasive species (Fenouillas et al. 2021)	AOO, EOO (IUCN 2012) Number of locations = 10 km*10 km square grid
Mayotte	Mascarine; Herbarium MAO; Herbarium P; INPN; GBIF	7178 records including 7088 georeferenced	2012	117 (out of 124 endemic species)	Urban and agricultural environments (Bossard et al. 2000); Land use change 2012–2018 (Bossard et al. 2000); loss of forest cover (Hansen et al. 2013)	AOO [EOO not considered] (IUCN 2012) Number of locations = 5 km*5 km square grid

Table 1 (continued)

	Main sources of species records	Number of occurrence records compiled	Median age of records	Pre-assessed endemic species	Anthropogenic pressures (criterion A)	Criterion B parameters
Martinique	CBN Martinique; Herbarium MTK; Herbarium P; Dataset in Carrington et al. (2017); INPN; GBIF	4514 records including 3640 georeferenced	1945	183 (out of 221 endemic species)	Urban and agricultural environments (Bossard et al. 2000); Land use change 2012–2018 (Bossard et al. 2000); loss of forest cover (Hansen et al. 2013)	AOO, EOO (IUCN 2012) Number of locations = 10 km*10 km square grid
Guadeloupe	Gwada Botanica (https://www.gwadabotanica.fr/); Herbarium GUAD; Herbarium P; Dataset in Carrington et al. (2017); INPN; GBIF	8551 records including 7985 georeferenced	1981	187 (out of 206 endemic species)	Urban and agricultural environments (Bossard et al. 2000); Land use change 2012–2018 (Bossard et al. 2000); loss of forest cover (Hansen et al. 2013)	AOO, EOO (IUCN 2012) Number of locations = 5 km*5 km square grid
French sub-Antarctic islands (Kerguelen, Crozet, Saint-Paul, Amsterdam)	National Nature Reserve of the French sub-Antarctic Islands; Project IPEV 136 Subanteco; GBIF; Herbarium P	12,652 records of which 12,372 geolocated	2017	16 (out of 15 endemic species + 2 patrimonial species)	Not assessed	Kerguelen: AOO, EOO (IUCN 2012) Number of locations = 10 km*10 km square grid Saint Paul, Amsterdam, Crozet AOO, 100 m*100 m square grid, Number of locations = 100 m*100 m square grid CR = ≤0.5% of grid cells; EN = ≤3.5%; VU = ≤7.5%

Table 1 (continued)

	Main sources of species records	Number of occurrence records compiled	Median age of records	Pre-assessed endemic species	Anthropogenic pressures (criterion A)	Criterion B parameters
Scattered Islands (Europa, Glorioso, Juan de Nova, Tromelin)	Conservatoire Botanique National Mascarin (Hivert et al. 2018)	Hivert et al. (2018)	Hivert et al. (2018)	38 (out of 38 endemic species)	Not assessed	AOO, 100 m*100 m square grid. CR = ≤0,35 to 0,96% of grid cells; EN = ≤2,88 to 3,5%; VU = ≤6,73 to 7,48% Besides, different thresholds are used to estimate extinction risks at local and regional scales (see Hivert et al. 2018) Number of locations = number of islands

Criterion B parameters vary between territories in order to reach the best performance possible for this pre-assessment method. *CLC* Corinne Land Cover (Bossard et al. 2000)

*Occurrence records include preserved specimens, living specimens, observations, photographs, and material samples taxa, i.e. 89% of endemic tracheophytes in the FOTs (Véron et al. 2021). Some studies proposed to use only data freely available on the web (GBIF, BIEN etc.), yet this would lead to inaccurate results for the FOTs because they are incomplete and/or not precise enough (all specimen data are not in GBIF, many sensitive data have had their coordinates approximated etc.).

Within these compiled datasets (one for each territory), a comparison was made between the names of the species and the French national taxonomic repository TAXREF (Gargominy et al. 2021). The spelling of the names of the taxa present in these datasets was compared to the names present in TAXREF and corrected when necessary. Only taxa considered endemic or subendemic in TAXREF and in the Endemia repository for New-Caledonia were kept. The names in the datasets that are considered synonyms in TAXREF were changed to their accepted names. We kept occurrences at the species and infra-specific levels because: (i) data often allow the identification of taxa below the species level, (ii) Red Lists can accommodate infra-specific taxa, (iii) many taxa are endemic at the infra-specific but not the specific level (see Supplementary Information 2 for results of a complementary analysis at the specific level). It was also necessary to filter the data by removing duplicate occurrences, and by removing or correcting erroneous coordinates (especially occurrences in the sea or at the center of the territory).

Many occurrences had locality information but were not georeferenced. However, pre-assessments of IUCN status mostly require spatial coordinates for each collected specimen. When necessary, we therefore created locality indexes (i.e. we attributed spatial coordinates to locality names found on herbarium labels) mainly with the help of botanical experts of the FOTs who have a comprehensive knowledge of these islands and their botanical collections. This made it possible to post-facto assign longitude, latitude, and uncertainties on the coordinates for places in Martinique, Guadeloupe, Réunion, New Caledonia, and the French sub-Antarctic Islands. Walker et al. (2022) showed that minimal data-cleaning performed well in the context of automated assessments and that excluding uncertain data would considerably reduce the coverage of automatic assessments. Thus, we preferred to keep most of uncertain data, although we excluded the ones that mentioned a locality that was too vague (e.g. “Guadeloupe”). Moreover, we estimated whether coordinate uncertainty was higher or lower than 2 km, which is the size of the grid cell recommended to estimate species Area of Occupancy (IUCN 2012). We then ran an analysis on the influence of uncertain coordinates on our results (see Section “Method performance and potential changes in conservation status (objective 2)” and Supplementary Information 2). However, we acknowledge that coordinates and uncertainties estimations were often subjective. In total we compiled ca. 255,000 georeferenced occurrences of FOTs endemic taxa. Regarding the Scattered Islands we directly extracted range distribution data from Hivert et al. (2018) who estimated species conservation status based on criteria that were adapted from the Red List criteria due to the very small size of the territory and conservation management purposes.

Preliminary conservation assessments (objective 1)

Pre-assessments are conducted with available data and aim to overcome the difficulty (or impossibility) to exactly reproduce the IUCN approach and standards automatically. To allow approaching the potential threats status of species, these methods sometimes deviate from IUCN criteria and sub-criteria, but instead use variables related to extinction risks which make them highly performant (e.g. Stévart et al. 2019, see also Discussion).

Here, we used four successful methods developed in the literature to assign pre-assessment conservation statuses to endemic tracheophytes of the FOTs (Fig. 1). We adapted these methods to each territory according to its geographic characteristics and data availability (Table 1).

Criterion B, considering jointly criteria B1a, B2a, B1b, B2b

Criteria B1a and B2a This method calculates the area of occupancy (AOO), extent of occurrence (EOO) and the number of locations for each species based on georeferenced data (IUCN 2012). The EOO provides information on the overall geographical distribution while the AOO provides information on the area occupied by a species (see detailed definition in IUCN 2012). A location is "a particular area from the ecological and geographical point of view in which a single threatening event can rapidly affect all individuals of the taxon present". AOO, EOO and number of locations allows pre-assessment using criteria B1a and B2a according to Dauby et al. (2017). We used the R package "ConR" and the default options of the "IUCN.eval" function, although sometimes adapted to the geographical characteristics of the territory (Table 1). Thus, the AOO was calculated using a 2 km × 2 km grid whose origin varies over a given number of iterations and we retained the minimum value of the AOO over all iterations (see other methods in Moat et al. (2018)). For a trade-off between efficiency and speed, we chose to vary the grid origin 20 times. For the identification of locations, and due to the difficulty of complying with the definition stated above using automatic methods, a location was defined as a 10 km × 10 km or 5 km × 5 km grid cell encompassing the largest possible number of occurrences (Table 1). Nevertheless, we performed a sensitivity analysis to estimate the influence of grid size on our results (Supplementary Information 2). We did not assess fragmentation as no methods exist to automatically do so. The thresholds of EOO, AOO and number of locations used to pre-assess the category of a taxon were generally those defined by the IUCN (IUCN 2012), except for very small islands. Indeed, IUCN thresholds to assess extinction risk assessments do not always

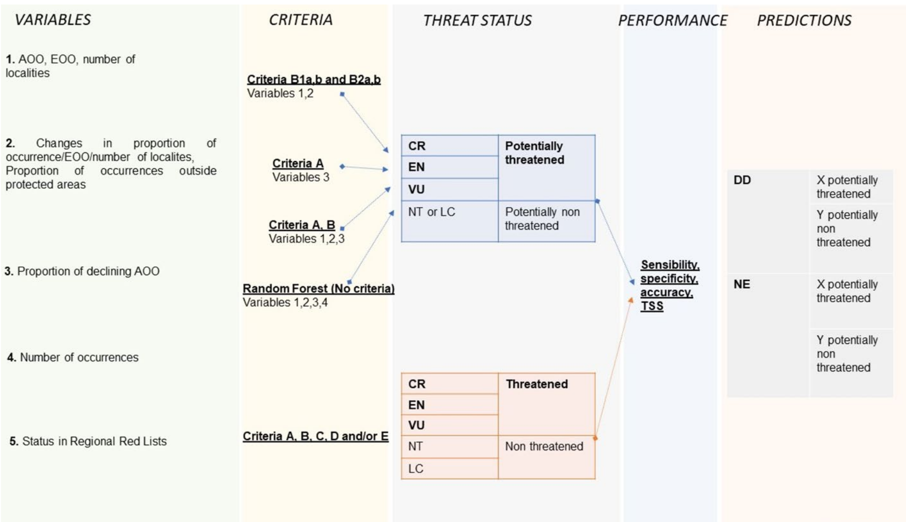

Fig. 1 Methodological summary of the study

comply with management objectives in very small territories and it is therefore not recommended to use the IUCN standards there. New thresholds were therefore defined for the Scattered islands, Crozet, Saint-Paul and Amsterdam (islands of the French sub-Antarctic islands) at both local/single island and regional scales following Hivert et al. (2018) (Supplementary Information 3). These adaptations do not allow measuring a genuine IUCN conservation status but they are useful for conservation management issues in small territories.

Criteria B1b and B2b This method is adapted from Carrington et al. (2017) and aims to pre-assess a continuing population decline, i.e. criteria B1b and B2b. It is used to estimate a decline in one of the following elements relative to a reference year:

- the AOO of a taxon estimated using the ConR package (Dauby et al. 2017);
- habitat quality by assessing the proportion of occurrence of a taxon outside any protected areas (as defined in protectedplanet.net and assuming that protected areas prevent population declines). A potential decline is estimated for this criterion when half of the occurrences are outside the protected areas;
- the number of locations (Dauby et al. 2017);
- the proportion of yearly observations for a taxon. We chose to estimate the changes of the proportion of individuals rather than the number of individuals in order to roughly take into account sampling differences between years.

However, we acknowledge the difficulty of estimating a continuous decline using automatic methods, the often 'opportunistic' data available, and the differences in sampling in time and space (see below how this limitation was taken into account in the analysis of method performance). We chose 2010 as the reference year assuming that this conforms to the IUCN recommendations to estimate a continuous decline (IUCN 2012) and that a 10 year period should ideally be used to estimate the state of a species (UICN France 2018). Yet, as the IUCN guidelines do not recommend a specific threshold to estimate a continuous decline, we also conducted additional analyses by choosing the reference year as the median year of collection for each territory (Supplementary Information 2). Finally, the reference year does not influence the binary classification of species as "threatened" or "non-threatened" (see below).

The joint analysis of the pre-assessments of sub-criteria B1a, B2a, B1b, B2b, i.e. based on AOO, EOO, number of locations and population decline, makes it possible to estimate criterion B following the IUCN analysis grid (see IUCN 2012) and attribute a status critically endangered (CR), endangered (EN), vulnerable (VU) or near-threatened or least-concern (NT or LC) to species. The expertise of experienced botanists is indispensable to estimate sub-criterion c) [extreme fluctuations] and, to our knowledge, it is not assessable using automatic methods, so it was not considered in this study.

Criterion A

The purpose of this method is to estimate the decline of a population based on the proportion of the AOO of each species that intersects a degraded area (Stévart et al. 2019). Indeed, the decline of a population can be inferred from habitat losses according to the IUCN (IUCN 2012). We identified degraded areas based on land cover data (e.g. Bossard et al. 2000), evolution of land cover (Bossard et al. 2000) and on pressure maps specific to each territory (e.g. loss of forest cover, fire frequency, invasive species) (Table 1). A raster map combining all these degraded areas was built for each territory and was used to calculate a potential decline in the AOO as defined by Stévart et al. (2019). Following Stévart et al. (2019) method, a species is pre-assessed CR, EN or VU if more than 80%, 70% or 50% of its AOO intersects degraded areas, respectively.

Criteria A, B

This third methodological approach attributes a conservation status corresponding to the most threatened status between criterion A and criterion B. Used jointly, criteria A and B are similar to the PACA method of Stévart et al. (2019), with the difference that the potential decline of a population (criteria B1b and B2b) is estimated differently: by the presence in a degraded habitat according to Stévart et al. (2019), by the comparison to a reference year in our study. Yet, the former option was tested in Supplementary Information 2. In addition, when we did not observe any decline for a taxon but the ConR algorithm (criterion B1a and B2a) classified the species in a threat category based on the EOO, the AOO and the number of locations, we followed the method of Stévart et al. (2019) and defined the categories "likely rare" (CR or EN according to ConR but without observed decline) and "potentially rare" (VU according to ConR but without observed decline). The classification “likely rare” is analogous to the VU category under criterion D2 (i.e. restricted area of occupancy or number of locations with a plausible future threat that could drive the taxon to CR or EX in a very short time). Conversely, a taxon pre-assessed LC or NT based on its AOO or EOO but facing a decline was classified as “LC or NT, potential decline”.

Random forest (Breiman 2001)—no defined criteria Random Forest is a machine learning method particularly suitable for pre-assessments of extinction risks (Bland et al. 2015; Pelletier et al. 2018; Walker et al. 2022). Here we used the "Random Forest" algorithm to classify endemic plants in a conservation status category, the predictors being the variables used for criteria B (AOO, EOO, number of locations, decline in one of the variables indicated in point *i.*, proportion of occurrence within a protected area) and A (proportion of the AOO degraded for each pressure taken individually and for all pressure layers combined). We also estimated the importance of these variables on IUCN Red List statuses by calculating the Importance of Gini according to the Random Forest algorithm (Supplementary Information 4; Breiman 2001). The model parameters for each territory were adjusted to achieve the best possible performance. The model was trained and evaluated across the entire dataset of taxa having an IUCN status (excluding Data Deficient [DD] and Not Evaluated [NE] taxa), as recommended by Walker et al. (2022) whose results “favor using all assessed species” for training, “even when well-designed sub-samples are available”. We then used the classification trees generated in order to estimate a pre-status for DD and NE taxa.

We also explored another machine learning method, the neural network approach from (Zizka et al. 2020), using similar predictors (Supplementary Information 2).

Pre-assessments were performed with the R software (R Core Team 2020) and scripts are available online at https://github.com/arthur-b-1303/Projet_Fentom

Method performance and potential changes in conservation status (objective 2)

Following the pre-assessment of conservation statuses, we aimed to test the effectiveness and limitations of each method (Fig. 1).

For each method we compared existing IUCN statuses to the pre-assessed ones. We assessed each status independently (Supplementary Information 5 and 6) and then classified the species as potentially threatened (CR, EN, VU) or non-threatened (LC or NT). In addition, we adopted a precautionary approach and considered 'likely rare' and 'potentially rare' species as threatened because of the similarity of these categories to the VU status under criterion D2. We then analyzed the proportion of species that 1) remained threatened after pre-assessments (sensitivity) and 2) remained non-threatened (specificity) following pre-assessments. Therefore, DD and NE species were excluded from the calculation of sensitivity and specificity indices. A high sensitivity indicated that there was a high proportion of species classified as threatened by the IUCN that were pre-assessed potentially threatened. A high specificity method indicated that there was a high proportion of species classified as non-threatened (LC or NT) by the IUCN that were pre-assessed non-threatened.

We estimated the accuracy of the pre-assessments, i.e. the proportion of species correctly assessed, and the True Skill Statistic (TSS) which is equal to "sensitivity + specificity—1". TSS scores range from 1 to − 1, with 1 indicating a perfect pre-assessment model, while a value of 0 or lower indicates that pre-assessments are no better than if status had been pre-assessed randomly. Because of our choice to consider "likely rare" and "potentially rare" species as threatened, the identification of a decline or not does not influence the performance of a method.

Results

Pre-assessment methods using criterion B and Random Forest performed best

The pre-assessment method with the best TSS and accuracy was the Random Forest method for Réunion, Mayotte, and it also had a good performance in New Caledonia (Fig. 2). It gave a sensitivity of 75–96% for these territories and a specificity between 79 and 87% (Fig. 2). In contrast, the use of Random Forest for the endemic flora of Guadeloupe had a low sensitivity (38.3%) but a high specificity (78.9%). Due to the absence of Red Lists in the French sub-Antarctic islands, the low number of endemic species with a conservation status in Martinique, and the absence of pressure maps in the Scattered Islands, the Random Forest method was not applied for these 3 territories. The other machine learning method we tested (Zizka et al. 2020) also performed well but with lower accuracy than Random Forests (Supplementary Information 2). Pre-assessment of status using criteria A and B together provided the best sensitivity for New Caledonia and Réunion, but the specificity of this method was low. As for criterion B used alone, it had the best accuracy and TSS for Guadeloupe and New-Caledonia and a relatively high specificity and sensitivity in the Scattered Islands (local and regional scales). The high TSS in Guadeloupe was due to high sensitivity whereas specificity was very low for this territory, i.e. criterion B assigned greater extinction risks to Guadeloupe's endemic tracheophytes than the assessments in the 2019 Red List (UICN Comité français et al. 2019). On the other hand, criterion B assigned lower risks to Réunion endemic taxa compared to the 2013 Red List (UICN France et al. 2013). In order to improve the performance of methods and take into account the differences in surface area between territories, different grid cell sizes and thresholds were used for the calculation of the AOO and the number of locations in Mayotte, the French sub-Antarctic Islands, Guadeloupe, Martinique and the Scattered Islands

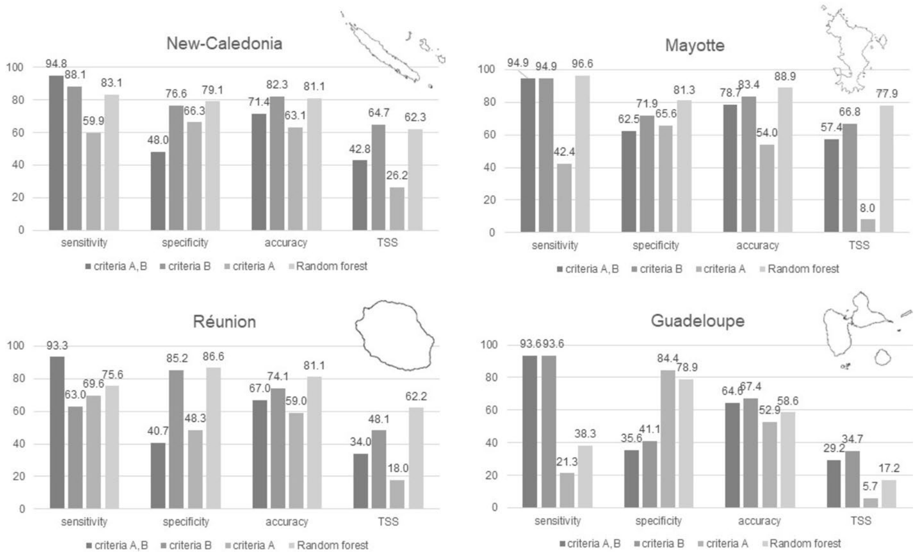

Fig. 2 Accuracy, TSS, sensitivity and specificity of the four pre-assessment methods for four FOTs: Guadeloupe, Mayotte, Réunion, and New Caledonia. Methods are represented from dark to light grey: criteria A, B; criteria B; criteria A; Random Forest. For graphical reason the TSS score was multiplied by 100. Performance analysis could not be applied to territories where no or few endemic taxa were assessed with a IUCN conservation status

(Table 1, Supplementary Information 2). The use of criterion A alone, obtained with different pressure layers (Table 1), gave the lowest TSS and accuracy for all the territories.

Finally, the number of specimens significantly distinguished LC species, which had a large number of observations, from threatened categories (CR, EN, VU) which had a low number of observations, in all territories.

Based on the best performing methods, up to sixty percent of endemic species are potentially threatened

We used each method in each territory but chose to present results only for the best performing ones (all results are in Supplementary Information 5). Using the most appropriate pre-assessment method for each territory, 2135 taxa (60.0%) were found to be threatened (Table 2; Supplementary Information 5 and 6). In Réunion and Mayotte, the method with the best precision and TSS, i.e. the Random Forest algorithm, indicated that in total 262 taxa endemic to these territories would be potentially threatened and 273 would be non-threatened (Table 2). Adding the criterion B results obtained in territories where it performed the best (New-Caledonia, Guadeloupe), or where the Random Forest algorithm could not be applied (Martinique, Scattered islands, French sub-Antarctic islands), we pre-assessed an additional 1873 as potentially threatened and 1147 as non-threatened. However, the number of threatened taxa estimated with criterion B is probably a high estimate due to the low specificity of this method in Guadeloupe (i.e. many NT or LC species have been pre-assessed as threatened) but also to the lower specificity of Criterion B in New Caledonia compared to the Random Forest method. When the Random Forest method,

Table 2 Number of species pre-assessed as potentially threatened using the "Random Forest" (Réunion, Mayotte), criterion B (New Caledonia, Martinique, Guadeloupe, Kerguelen), criteria A + B (Martinique) or criterion B based on Hivert et al. (2018) (Supplementary Information 3: Scattered Islands, Crozet and Amsterdam-Saint-Paul)

	Pre-assessment method	Spermatophytes		Pteridophytes		All taxa
		Strict endemics	Regional endemics	Strict endemics	Regional endemics	
New-Caledonia	Criterion B	1495 (60.1%)	0	53 (51.9%)	0	1548 (59.7%)
Réunion	Random Forest	119 (49.5%)	45 (35.1%)	5 (26.3%)	12 (46.1%)	181 (43.8%)
Mayotte	Random Forest	41 (75.5%)	38 (62.2%)	1 (100%)	1 (100%)	81 (69.2%)
Guadeloupe	Criterion B	18 (90%)	99 (71.2%)	1 (100%)	24 (88.8%)	142 (75.9%)
Martinique	Criterion B	25 (86.2%)	121 (81.3%)	0	17 (100%)	163 (89.1%)
Scattered Islands	Criterion B, adapted as in [Hivert et al. 2018], local scale)	2 (25%)	15 (39.4%)	0	0	17 (36.9%)
French sub-Antarctic islands	Kerguelen: Criterion B, Crozet; Amsterdam-St Paul: Criterion B adapted as in Hivert et al. (2018), local scale)	1 (11.1%)	1*(20%)	0	1 (50%)	3 (16.6%)
Total		1701 (59.6%)	319 (62.3%)	60 (48.3%)	55 (73.9%)	2135 (60.0%**)

Percentages of the total taxa in these categories are given in parentheses. **Colobanthus kerguelensis* is potentially VU in Crozet but LC in Kerguelen. **A few endemic taxa of the Scattered islands and French sub-Antarctic islands were counted several times as they have a conservation status in several islands of these territories which obtains good precision and TSS in all territories, is used in New Caledonia and Guadeloupe, the total proportion of threatened endemic taxa is 56.4%.

Discussion

How many endemic species are potentially threatened and why?

Using pre-assessment methods with the highest performance for each territory we estimated that up to 2135 endemic taxa are potentially threatened and 1420 are potentially non-threatened for seven FOTs. The proportion of potentially threatened endemic tracheophytes is thus 60.0%, which is higher than recent estimates based on published Red Lists (51% for spermatophytes and 37% for pteridophytes; Véron et al. 2021). Of these, 91 of the 138 previously categorized DD taxa and 1160 of the 1745 previously categorized NE taxa are potentially threatened. This shows that a high proportion of DD species may be potentially threatened as found in mammals (Bland et al. 2015), reptiles (Bland and Böhm 2016) or sharks and rays (Walls and Dulvy 2020). However, many taxa have few records, e.g. 443 taxa have three or fewer records, and further studies, local expertise or inventories would be necessary to understand whether this represents a genuine extinction risk or a lack of knowledge. Moreover, it must be considered that not all factors leading to the DD classification of a taxon can be taken into account by the pre-assessment methods, e.g. uncertain occurrences, taxonomy, misidentification, nomenclature (e.g. lost or uncertain type specimen), unknown provenance (Hochkirch et al. 2021). For these reasons we did not define a DD pre-status category in this study and suggest that further knowledge is necessary for some taxa assessed as DD in a Red List to evaluate their conservation status. Therefore, identifying the causes of data-deficiency will facilitate the use of pre-assessment methods to predict the extinction risk of these species, include them in biodiversity indices and species conservation status analyses, and avoid unnoticed extinctions (Bland et al. 2017). Besides, we acknowledge that in New-Caledonia and Guadeloupe the number of potentially threatened taxa may have been over-estimated (the method with the highest accuracy had a relatively low specificity in these territories, see Section "Performance by criteria, limitations and improvements"), and using a method with a higher specificity in these territories reduced the proportion of threatened taxa in the FOTs to 56.4%.

Based on the methods with the highest accuracy and TSS, Martinique has the highest proportion of potentially threatened taxa but method performance could not be assessed in this case and there is a lack of occurrence data for many taxa (pers. comm. G.Viscardi). Guadeloupe also has a high proportion of potentially threatened endemic tracheophytes, however risks may have been overestimated in this territory as the specificity of the method is low. This is likely due to the lack of comprehensive occurrence data for taxa previously classified as non-threatened and to their natural range-restriction. Excluding Guadeloupe and Martinique, Mayotte is the territory with the highest proportion of potentially threatened endemic species due to the narrow range of endemic species there and high levels of threats, especially agriculture and deforestation. In Réunion, plants occurring in areas with high alien plant invasion pressure are expected to be at risk (Fenouillas et al. 2021). Pressure from invasive species is likely a main threat to endemic plants in all FOTs due to competition for resources (alien plants) and grazing by introduced animals (e.g. cattle, rabbits) (Soubeyran et al. 2015, but see Caujapé-Castells et al. 2010). Thereby, endemic plants from the Scattered islands are threatened by invasions (plants, goats), cyclones (for woody species) and the small size of their populations make them highly vulnerable to extreme climatic events and/or sea level rise. Yet, reduced human activity, flora monitoring and conservation actions explain why the proportion of threatened endemic plant species is lower in these islands compared to other FOTs. In New-Caledonia other important pressures on plant diversity are fires and mining activities (Meyer et al. 2021). Moreover, it is important to consider the interactions between these threats, which are expected to have a greater impact than taken individually (Krupnick 2013; Leclerc et al. 2018; Rojas-Sandoval et al. 2020). For example, in the French sub-Antarctic islands, recent climatic changes, the drop in precipitation, combined with warmer temperatures, have led to the decline of certain native species, leaving bare soil, which has benefited the most dispersive invasive species and changed the structure of communities (Chapuis et al. 2004; Robin et al. 2011).

What are the implications of pre-assessments for biodiversity conservation?

Pre-assessments are not intended to replace Red Lists, as it is essential to follow the methodology developed by the IUCN to assess the genuine conservation status of species in a standardized and reproducible way. In particular, we acknowledge that the variables used do not rigorously match the criteria of the IUCN Red List, although they try to conform to the criteria as much as possible and are all related to extinction risks (see 4.3.2). Yet our aim was to automatically pre-assess the potential extinction risks of species, and many criteria and sub-criteria are difficult (if not impossible) to evaluate without the knowledge of experts. We see several benefits of the pre-assessment methods used in this study to assist Red Lists. First, these methods can help to prioritize first-time assessments (e.g., many taxa in Martinique, Kerguelen) and re-assessments (e.g., Réunion, Mayotte). Especially, automated methods can be used during the pre-evaluation step of the IUCN Red List process. They give an indication of which taxa are most likely to be threatened and which should attract closer attention during IUCN assessment workshops when resources and time are limited. They also allow the identification of species which are likely not threatened (Bachman et al. 2020), especially by using pre-assessment methods with high accuracy, and which need less data compared to threatened species to be published on the Red List (IUCN 2013). This allows the reduction of resources spent on predicted-to-be non-threatened taxa. Second, the variables used in automatic pre-assessments can contribute to evaluate the Red List criteria, for example calculating the proportion of the range size of a taxon that intersects newly degraded areas can help to estimate a decline in species habitat quality. Third, pre-assessments can help prioritize data collection, for example by identifying data-deficient species that are likely to be threatened and may require further knowledge to validate their conservation status (Cazalis et al. 2022). From the uses presented above, pre-assessment methods can support the development of Red Lists by facilitating the evaluation of the conservation status of more taxa, allowing one to cover more taxonomic groups, geographical regions and more up to date assessments. Furthermore, this will support the use of Red Lists as a powerful tool to evaluate the state of biodiversity, to prioritize species in conservation planning, to support conservation policies such as the Convention on Biological Diversity and to raise awareness of biodiversity loss. We therefore agree with Cazalis et al. (2022) who advocated that pre-assessment methods should be better used in IUCN Red Lists. Yet, as stated above, it is essential to follow the methodology developed by the IUCN to assess the genuine conservation status of species and it is not recommended to use pre-assessment methods alone to implement conservation actions. We therefore believe that the main aim of the pre-assessment methods is to facilitate the development of Red

Lists which will further contribute to conservation actions and policies. Finally, researchers in biodiversity conservation often need information on conservation status that are not available yet for many taxonomic groups and geographic places. Therefore, using automatic methods can help to approach species conservation statuses with a high confidence and include the results in research studies.

Quality and shortcomings of pre-assessment methods and the necessity to adapt them to the studied territory

Data quality

This pre-assessment of the conservation status of the flora of the FOTs benefited from a first study on the taxonomy and endemic status of tracheophytes and bryophytes, a necessary step for this new study (Véron et al. 2021). In addition, recent field collections have allowed us to precisely geolocate endemic species in the FOTs. Yet, there are still taxa with imprecise coordinates, especially in Mayotte and Guadeloupe, which may require further inventories by botanical experts. We also compiled herbarium data that can be used to determine the change of a species' range over time, to guide new collections, to revise taxonomy, to discover new species or to document extinctions. Information on the rarity or commonness of the taxa is also sometimes directly written on the herbarium sheet. More importantly, herbarium specimens allow reproducibility (the base of the scientific method) as only these permanent collections allow for the reassessment of the identification of taxa at any time from the initial observation in the field. Herbarium data thus provide a historical context of the floristic diversity of a territory and its evolution. For example, in Réunion, the use of herbarium data alone informs us that many collections have been made in places that are now degraded. Many studies have thus recommended using herbarium data for conservation purposes (Rivers et al. 2010, 2011; Nic Lughadha et al. 2019; Albani Rocchetti et al. 2021).

Performance by criteria, limitations and improvements

Criterion B based on AOO, EOO, number of locations, is relatively easy to automatically measure for pre-assessing IUCN conservation status (e.g. Dauby et al. 2017; Moat 2017). The size of a species' range is strongly correlated with its extinction status (Bland et al. 2015), and we have shown the importance of range and population structure variables on the classification of species into one of the Red List threat categories (Supplementary Information 4). We acknowledge that rarity and conservation status are two different concepts, as a narrow-range species may have stable populations and be secure while a widespread species could be threatened on a high proportion of its range and at risk of extinction. Yet, narrow range-size is an important indication of extinction risk. In the "largest and statistically better supported review of the relation between traits and extinction risk to date", Chichorro et al. (2019) showed that species with small range and narrow habitat breadth were the most vulnerable to extinctions. Previous pre-assessments also showed that species pre-assessed with Criterion B-based methods had a high probability of matching their IUCN Red List status (Nic Lughadha et al. 2019; Zizka et al. 2020). In line with these results, we found that for the majority of territories the simplified use of criterion B had a high accuracy and TSS, especially in New Caledonia. The high performance of criterion B and its tight relationship with extinction risk means that species pre-assessed as potentially threatened require specific attention during IUCN workshops and that only few of them are expected to be secure in these territories. On the contrary, criterion B specificity was low in Guadeloupe while sensitivity was high, meaning that pre-assessed conservation statuses have likely been overestimated. This indicates that it is important to look at all performance measures to fully assess the reliability of pre-assessment methods. Interestingly, criterion B was not the most frequently used criterion in existing Red Lists (with the exception of New Caledonia) which have often used criterion D and sometimes criteria C and A (Supplementary Information 1). This shows that a simplified version of criterion B assessment can perform well to assess whether a taxon is potentially threatened or not, even if it was classified in a Red List based on another criterion. This could be explained by the expected positive relationship between AOO and the number of individuals (criterion C) and of the use of AOO in criterion D2. However, Walker et al. (2022) showed that a simplified criterion B method may not perform as well in pre-assessing the conservation status of species previously classified in a Red List based on criterion A.

A limitation of this range criterion is, however, that the threshold values of EOO and AOO defined by the IUCN (2012) are not always adapted to the small size of some territories, leading to an overestimation of the extinction risk (Martín 2009). The IUCN therefore does not recommend using the Red List criteria in very small territories. Consequently, for the Scattered Islands and French sub-Antarctic islands (except Kerguelen), where assessing conservation status is an important conservation challenge to respond to management objectives (Hivert et al. 2018, see also Molloy et al. 2002; Martín 2009), it was necessary to adapt the size of the grids used to calculate the AOO, but also the conservation status thresholds defined by the IUCN. Such adaptations are not recommended in the IUCN Red List but in the context of pre-assessments they improve the performance of methods using criterion B for small territories.

Estimations of population decline (here comprising decline in EOO or number of individuals) are of moderate importance in classifying taxa as threatened. Nevertheless, the observation of a decrease in the number of occurrences or the range of a species or a low degree of protection may indicate that special attention should be paid to the conservation status of the species. Indeed, biodiversity losses cannot only be assessed in terms of extinction, and population decline is another indicator to analyze the impact of anthropogenic activities (e.g. Bissessur et al. 2017). This is particularly the case for strict island endemics where there are no populations outside the territory to replenish the island population. Furthermore, in the case of regional endemics, this reinforcement may be made difficult by the need to cross the ocean, which acts as a barrier to dispersal for many species. There are also species for which there is no estimated decline following the method of Carrington et al. (2017) but for which the area of occurrence or number of occurrences is very low. These species have been classified as ’likely rare’ or “potentially rare” which can also correspond to a VU status under criterion D2. These species are not currently endangered but future pressures could strongly impact them and quickly move them to EX, CR or EN. Due to these limitations in estimating the number of locations and a continuous decline, we acknowledge that some of the species pre-assessed as potentially threatened under criterion B may not be at risk. However, as this method has a high accuracy we expect that such species are few and that the criterion B method remains useful to identify species potentially at risk. Improving on the automatic measure of the number of locations and population decline is a future challenge in the development of pre-assessment methods.

The criterion A pre-assessment method makes it possible to estimate the proportion of a species’ distribution area affected by anthropogenic pressures. Yet, it assumes that threats are uniform across the species range and are fixed in time and space. The strength of the criterion A assessment according to Stévart et al. (2019) is that it greatly increases the sensitivity of pre-assessments when combined with criterion B. The joint use of criteria A and B therefore helps to identify species that are potentially at risk because they are range-restricted and/or found in a degraded area. In addition, habitat degradation variables are relatively important in the classification of a taxon in one of the Red List threat categories. The available pressure maps allow a first assessment of the severity of the threat (Fenouillas et al. 2021), whereas criterion B focuses on geographical criteria. However, the severity of anthropogenic pressures could vary greatly depending on the taxa. For example, some species can be found in urban environments—such as *Clusia major* in Guadeloupe or *Aloe mayottensis* in Mayotte—or in areas where fires occur (depending on fire intensity). On the contrary, some taxa could also be threatened despite their expected resilience to the anthropization of habitats (Bissessur et al. 2017) or when they are on the periphery of a degraded area. Here we considered that a taxon must have been observed within a currently degraded area for it to be potentially impacted, therefore the conservation status of taxa found close to degraded areas may have been underestimated. In Mayotte, for example, many occurrences are found close to deforested areas but have not been considered as impacted, which underestimates the risk they face.

The Random Forest algorithm provides the best accuracy, specificity and TSS in Réunion and Mayotte and also performs well in New-Caledonia. With the exception of Guadeloupe, this method also has a good sensitivity, and is therefore particularly well adapted to the pre-assessment of NE species. We also tested different parameters of the algorithm in order to make the method as reliable as possible. One of the difficulties in using classification trees is the complexity of interpreting the results and the choice of model parameters, although recent publications have improved our understanding and use of these models in the context of pre-assessments (Walker et al. 2022). The application of these models also requires that a conservation assessment has taken place in the past and that enough data are available to train the model. In addition, we used range, degraded habitat, and protected area variables, but considering other factors such as climate, habitat, could improve these methods (Walker et al. 2022; but see Bland et al. 2015). In particular, the impact of climate change has not been considered: while many studies focus on changes in phenology or range, the impacts of climate change on population survival are still poorly known (Albani Rocchetti et al. 2021). In small territories, such as the Scattered Islands, sea level rise due to climate change could lead endemic species to extinction. Besides, future climate modeling can greatly help us understand how species ranges, and their future conservation statuses, are expected to change (Dubos et al. 2021).

Conclusion

In this study we showed the value of pre-assessment methods to estimate potential conservation statuses and support Red Lists. Especially, Random Forest and criterion B pre-assessments methods were generally successful in classifying species as threatened or non-threatened, with up to 88% accuracy. Therefore, we support the idea that automatic pre-assessment methods can support IUCN Red Lists to fasten and prioritize assessments by identifying predicted-to-be threatened taxa. We suggest that the choice of the pre-assessment method and its parameters should be adapted to the characteristics of each territory and especially its size in order to fully consider conservation goals and achieve the best possible performance. For example, changes in pre conservation status thresholds in very small territories as in the Scattered Islands or some of the French sub-Antarctic islands could help to better tackle conservation challenges. Based on the best performing pre-assessment method for each FOT we estimated that up to 60% of tracheophytes endemic to the FOTs could be threatened. The future assessments using the standardized IUCN Red List methodology could focus first on the species pre-assessed as threatened in this study. Once the species confirmed as threatened are identified we recommend that conservation measures be put in place as soon as possible to protect these threatened species.

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Author contributions SV, AB, CR-V, EL, SM, VI, GR, OG, SL, MP, ST and GG contributed to the study conception and design. Material preparation and data collection were performed by all authors. Analyses were performed by SV, AB and EL. The first draft of the manuscript was written by SV, AB and EL and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Data availability The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Competing interests The authors have no competing interests to declare that are relevant to the content of this article.

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