Selecting priority areas for the conservation of endemic trees species and their ecosystems in Madagascar considering both conservation value and vulnerability to human pressure

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ABSTRACT

Madagascar is one of the most biodiverse countries in Africa, due to its level of endemism and species diversity. However, the pressure of human activities threatens the last patches of natural vegetation in the country and conservation decisions are undertaken with limited data availability. In this study, we use free online datasets to generate distribution models of 1,539 endemic trees and prioritise for conservation and restoration considering threat, alongside conservation value and cost. Threats considered include illegal logging, forest degradation and agriculture or slash and burns activities. We found that the areas with the highest potential concentration of species are along the north and south-east of the country where more than 400 tree species can be found. Most scenarios identify a common conservation and restoration priority area along the north east of the country. Our findings guide managers, conservation organizations or governments in decisions about where to invest their limited conservation resources.

KEYWORDS: systematic conservation planning, trees, Marxan, MaxEnt, species distribution modelling, GBIF, Marxan with probabilities.

INTRODUCTION

The global biodiversity crisis has led to an increasing interest in planning and prioritisation strategies to ensure that resources for conservation are allocated to areas which provide the highest conservation gains (Consiglio et al. 2006). As a result, scientists around the world have developed several methods for selecting priority conservation areas (Olson & Dinerstein 1998; Myers et al. 2000; Brooks et al. 2006; Langhammer 2007); Marxan (Ball, Possingham & Watts 2009)) and Zonation (Moilanen 2009) are the main softwares used for prioritization and protected areas design. While the foundations of conservation planning highlight the importance of considering threatening processes during prioritisation (Margules & Pressey 2000; McCarthy et al. 2012; Allan 2013) and software is available to do this (Game et al. 2008), much of the prioritisation literature to date has focused on cost-effective design only (Ferraro 2002; Naidoo 2006).

As well as a surge in the methods for prioritisation, there has been a rapid increase in the availability of free online information on human pressures on the environment (Alkemade et al. 2009; Watch 2012; Wood et al. 2015) and on the location of different species. Recent studies have developed global maps on anthropogenic threats to biodiversity (e.g. Venter et al. 2016) providing the information needed to incorporate threats in conservation prioritisation. Additionally, free online datasets of species ocurrences records from the Global Biodiversity Information Facility (GBIF) support advances on the study of species distributions around the world (Qin et al. 2017). Such compilations of datasets allow scientists and managers to increase the knowledge of lesser-known species that human populations depend on, for their livelihood and wellbeing, in areas with limited data availbility (Brown et al. 2013). One of these species the Grandidier's baobab (*Adansonia grandieri*), defined as "cultural keystone species" by Garibaldi and Turner (2004), is one of the most iconic symbols of Madagascar's wildlife, playing an important role due to its economical and traditional significance in Malagasy culture (Metcalfe et al. 2007; Marie et al. 2009).

We focus on Madagascar (587,000 km^2), one of the highest priority areas for biodiversity conservation in the world (Mittermeier et al. 1998; Myers et al. 2000). The island is the home to several flagship conservation species, such as lemurs (50 species) and baobabs (7 species) (WWF 2017). Its unique geographical conditions, diversity, and the island's variable microclimate have resulted in high levels of species diversity and endemism (Goodman & Benstead 2003; Phillipson et al. 2006; Dewar & Richard 2007), and a great diversity of primary vegetation types (Moat & Smith 2007). Increasing human pressures threatens Madagascar's biodiversity, with forest cover declining by 70,000 km^2 from 1950´s to 2000 (Harper et al. 2007), so that only 10% of original Madagascan forest remains (Mittermeier et al. 2005). Madagascar´s endemic trees form a critical part of many ecosystems on the island, providing useful resources to local people and providing economic benefit for impoverished Malagasy communities (Bennett 2011).

Human activities such as illegal logging, agricultural pressure, illegal fires and habitat fragmentation compromise the survival and recruitment of endemic trees (Seddon et al. 2000; Mittermeier et al. 2005), sometimes reducing their distribution to small areas with just a few individuals (Kremen et al. 2008). Although Madagascar´s government has carried out significant efforts to increase the number of protected areas (Gardner et al. 2018), the data available to inform tree restoration and conservation decisions remains limited, many taxa remain unprotected (Kremen et al. 2008), especially many of Madagascar´s endemic tree species (Callmander et al. 2007; Vieilledent et al. 2013; Rakotoarinivo et al. 2014) which are rarely included in management planning. To preserve the island's charismatic flora and fauna, further conservation and restoration actions must be implemented urgently (Rakotoarinivo et al. 2014).

In this study, we present a methodology to prioritise tree-focussed conservation and restoration actions for data-limited regions like Madagascar based on: 1) distribution areas of Madagascar´s known endemic tree species and 2) considering indices of threats related to human pressure (specifically illegal logging, human footprint, and agriculture) in parallel to data on conservation value and cost. We use free on-line global biodiversity datasets on the locations of individual trees to undertake species distribution modelling (Phillips, Anderson & Schapire 2006) and prioritize for conservation and restoration using the software Marxan with Probability (Ball, Possingham & Watts 2009). The map of priority areas we produced can help guide managers, conservation organizations and governments to plan and implement future conservation and restoration actions in Madagascar (Seddon et al. 2000), and researchers improve the endemic tree distribution maps.

METHODS

Species occurrence and environmental data

Species occurrence records for vascular plants in Madagascar were downloaded from the GBIF (http://www.gbif.org/), a free online database, whose primary data source cames from Missouri Botanical Gardens (http://www.tropicos.org/Project/Madagascar) database. As we are working with poorly known species, some of many had few observations and within geographically restricted local areas. In order to gather as much data as were possible to define potential distribution areas of tree species for conservation or restoration actions, we used a long time period and so included data collected between 1833 to 2016. We decided to include information spanning the historical distribution of the trees because we want to identify areas where trees can be restored as well as conserved. Our original GBIF plant database included about 335,575 occurrences. We classified our trees as endemic based on the database GlobalTreeSearch (http://www.bgci.org/globaltree_search.php) of endemic tree species from Botanical Gardens Conservation International (BGCI: https://www.bgci.org/) that store 2,991 Madagascar endemic trees species records collected from Missouri Botanical Garden database (Beech et al. 2017), this approach reduced the database to 94,488 occurrences. Duplicate records of tree species with the same coordinates sampled in the same year were deleted form the database. Records of the same tree species falling within the same 1 km^2 planning unit, were recorded as one occurrence. Occurrence data was also filtered to only include occurrences inside Madagascar. All species that had more than 10 occurrences in our final database were used to model species distributions, the same criteria used by the key biodiversity areas protocol (IUCN 2016), The clean database included 56,287 ocurrences. To identify the number of endemic tree species within our database, we joined it to the Madagascar trees IUCN Red List (IUCN 2017; Fig 3).

Our final database included 1,539 Madagascar endemic tree species; 106 of these species were considered threatened by the IUCN Red List. This comprises of 51% of known Madagascar endemic tree species from a total number of 2,991 cataloged in by BGCI, and the 45 % of the 232 Madagascar´s tree species included in the IUCN Red list. Previous projects developed in Madagascar based on global datasets focussed in endemic tree species were able to model distribution maps for 753 and 735 species respectively (Kremen et al. 2008; Brown et al. 2015), so we developed the most comprehensive species distribution mapping of endemic trees in Madagascar to date.

Bioclimatic and environmental data are needed to inform models of habitat suitability (Phillips et al. 2009; Elith et al. 2011). To develop our habitat suitability models we downloaded 19 bioclimatic and 7 environmental variables from Madaclim (https://madaclim.cirad.fr/ see S3) with a 30 arc-second resolution grid (i.e. 1 km^2 resolution), these were used as predictors in our distribution models. Without a general scientific consensus about the best method to determine relevant predictors for target species (Elith & Leathwick, 2009), we performed a Principal Component Analysis (PCA) (Legendre & Legendre, 1998) using SPSS statistical software to determine the influence of the non-correlated bioclimatic variables (Vieilledent et al. 2013).

The use of environmental variables rarely affects species distributions, but in some cases, they can improve the model accuracy (Elith & Leathwick 2009). Previous studies (Anderson &

Martinez-Meyer 2004) demonstrated that modern land-cover classifications should not be used for museum herbarium datasets, and that soil-type and elevation data generalize better when they are correlated with bioclimatic variables (Phillips et al. 2009). Based to these findings we included altitude, slope, and geology as continuous and categorical environmental variables in our model (Du Puy & Moat 1996; Vieilledent et al. 2013).

Species distribution modeling

Franklin (2010) defines a Species Distribution Model as a model that relates species distribution data with information on the environmental and spatial characteristics of those locations (Elith et al. 2011; Qin et al. 2017). Among all the approaches that produce species distribution models, we selected MaxEnt, a model based on the principle of maximum entropy (Phillips, Anderson & Schapire 2006), to predict the Madagascar tree distributions. We selected MaxEnt because it can work with presence and presence-absence data (Elith et al. 2011), continuous and categorical variables (Baldwin 2009), and has been found to perform well in comparison with the other approaches (Anderson et al. 2006). We ran MaxEnt with command line function so that worked with a minimum of 10 occurrences of each species (Pearson et al. 2007; Elith et al. 2011). Five-fold cross-validation was selected to calibrate the models using a random selection of training and testing sets of predictions (Radosavljevic & Anderson 2014). ESRI GIS software was used for analysis and mapping.

We evaluated the accuracy of the models in two ways: 1) Using threshold-independent measures by defining Area Under the Curve (AUC) values of the Receiving Operator Curve (ROC), and 2) using threshold-dependent measures to define threshold presence-absence values (Phillips, Anderson & Schapire 2006; Radosavljevic & Anderson 2014). AUC values determine the ability of models to discriminate between sites where species are present or absent, comparing locations where the species is known to be present with a random selection of sites across the study region (training and testing predictions) (Phillips, Anderson & Schapire 2006; Radosavljevic & Anderson 2014). Higher AUC values suggest better models, thus we ranked the AUC value for each tree species model (AUC < 0.7 was considered “uninformative”; 0.7 ≥ AUC < 09 was considered “good”; 0.9 ≥ AUC < 1 was considered “very good”) (Swets 1988; Baldwin 2009).

Threshold-dependent values provide us information about the likelihood, between 0 and 1, of each pixel predicting suitable habitat for our tree species (Phillips, Anderson & Schapire 2006). We applied the 0.5 threshold to generate presence-absence maps of potential species distribution (Jimenez-Valverde & Lobo 2007), therefore values among 0 – 0.49 were considered as potential absences and values 0.5 - 1 were considered as potential presences. We generated presence-absence distribution maps for each Madagascar endemic tree species with AUC > 0.7 in our database.

Prioritization

We identified priority restoration and conservation areas for Madagascar’s endemic trees using information on tree distribution, threat and cost. We used an extension of Marxan software called Marxan with Probability (MarProb) to include the main threats detected for endemic tree species conservation into the prioritization exercise (Game et al. 2008; Tulloch et al. 2013). The final output is a selection of planning units that met the defined conservation targets, for the lowest cost, which targeted areas with lowest chance of being destroyed by a threatening process.

We targeted 10% of the distribution of each endemic tree modeled, based on the national biodiversity action plan 2015 – 2025 from the Madagascar government. Madagascar was divided into 24,465 planning units (2,500 ha each). We defined our planning units as a 5 x 5 km grid to limit the total number of planning units because of MarProbs’ current processing limitations (Ball, Possingham & Watts 2009). Our focal conservation features were the endemic tree species in Madagascar, represented by our species distribution models, so species distribution models were resampled to the 5 x 5 km planning units. Due to the difficulty of generalising costs for the local and specfic management actions required for heterogeneous species at a national scale in Madgascar, we defined the cost associated to each planning unit as the total area occupied by the threats within it (Klein et al. 2013). We assume undertaking conservation interventions in areas which have a greater human pressure will be associated to a greater opportunity cost and cost of implementation (e.g. restoration becomes more expensive in degraded areas).

We defined four scenarios for our MarProb analysis based on the different threats to the trees in Madagascar. These were 1) roads representing illegal logging, 2) human footprint representing forest degradation, 3) agriculture representing slash-and-burn activities and 4) all the threats combined, hereafter the human pressure index (Rogers et al. 2010). These threat indicators and the human pressure index were included as threat probabilities into the MarProb analysis – areas with higher threat had higher probabilities.

We extracted threats indicator variables from free online GIS datasets including: Global Roads Open Access Data Set (gROADS), FAO land cover (Kalogirou 2012) and human footprint raster file (Venter et al. 2016). The human footprint layer (Venter et al. 2016) was ranked from 1 to 10, representing the lowest to highest level of human activities respectiviely. This raster file was resampled to same resolution to our planning units. The area impacted by roads was estimated by creating a 2 km buffer zone on both sides of the roads, these areas were considered to be the most likely to be impacted by illegal logging events (McConnell 2002). Agricultural areas were identified by aggregating the land categories “artificial surfaces”, “mosaic cropland vegetation”, “mosaic forest cropland”, and “mosaic vegetation cropland”. Threat resulting from roads and agriculture were defined as percentage of land affected by that threat per planning unit.

$$Roads = ha\ affected\ i\ /\ total\ ha\ i \qquad (i = number\ of\ planning\ unit).$$

$$Agriculture = ha\ affected\ i\ /\ total\ ha\ i \quad (i = number\ of\ planning\ unit).$$

The final human pressure index value in each planning unit was calculated by multiplying each threat indicator.

$$Human\ pressure\ index = Roads * Agriculture * Human\ population$$

We ran two versions of the prioritization, a protected areas scenario where protected areas were locked into the final solution, and no protected areas scenario where they were not considered. We ran MarProb 100 times for each scenario.

Priority areas for conservation actions were based on the planning units' irreplaceability representing how important each planning unit is to achieve the set conservation targets. As an indicator of irreplaceability, we assessed the MarProb summed solution that shows the number of times each planning unit is selected over 100 software runs.

RESULTS

Species distribution models

After removing correlated variables (Suppoting Information Fig 3), we identified the following bioclimatic variables for species distribution modelling using the PCA analysis results (Suppoting Information Fig 4): Isothermality, annual mean temperature, annual precipitation, precipitation in the wettest month, precipitation in the driest month, mean temperature in the driest quarter (3 months of the calendar year), mean temperature in the coldest quarter and the mean temperature warmest quarter.

In general, the 1,539 tree species distribution models developed performed well, showing a general AUC value acceptable for the 1,539 trees species (mean AUC = 0.8968; mean (SD) = 6.93 %). Of those, 1,517 species performed with AUC values > 0.7 and 22 species had AUC value < 0.7, the latter models were removed from further analysis. The predictors that contributed most to the models were precipitation in the driest month, geology, and precipitation in the wettest month (Table 1).

Table 1: Predictors contribution to Maxent model's assessment in percentages. AUC value for the total number of tree species N = 1,539 modelled. Values between 0.5 > AUC < 0.7 = uninformative (22 species); 0.7 ≥ AUC < 09 = good (676 species); 0.9 ≥ AUC < 1 = very good (841 species).

Predictor	% Contribution of each predictor to Maxent distribution models
Precipitation Driest Month	30.540
Geology	22.700
Precipitation Wettest Month	11.740
Isothermality	9.440
Mean Temperature Warmest Quarter	5.460
Mean Temperature Coldest Quarter	4.500
Altitude	4.370
Slope	4.190
Mean Temperature Driest Quarter	3.790
Annual Precipitation	2.380
Annual Mean Temperature	0.890

In accordance with the 0.5 threshold criteria, we generated individual presence maps with the potential distribution for 1,517 Madagascar endemic tree species, including 104 trees species in the IUCN Red List (an example in supporting information Fig 5). The sum of our distribution models shows potential trees endemic distribution areas at a 1 x 1 km resolution (Rakotoarinivo et al. 2014) (Figure 1 and Supporting Information Fig 6). The areas with the highest species richness values are along the east coast, the areas with the highest concentration of species are along the north and south-east of the country where more than 400 species are found (Figure 1). This may be influenced by biases in data collection towards protected areas, cities, the east coast, and along main roads.

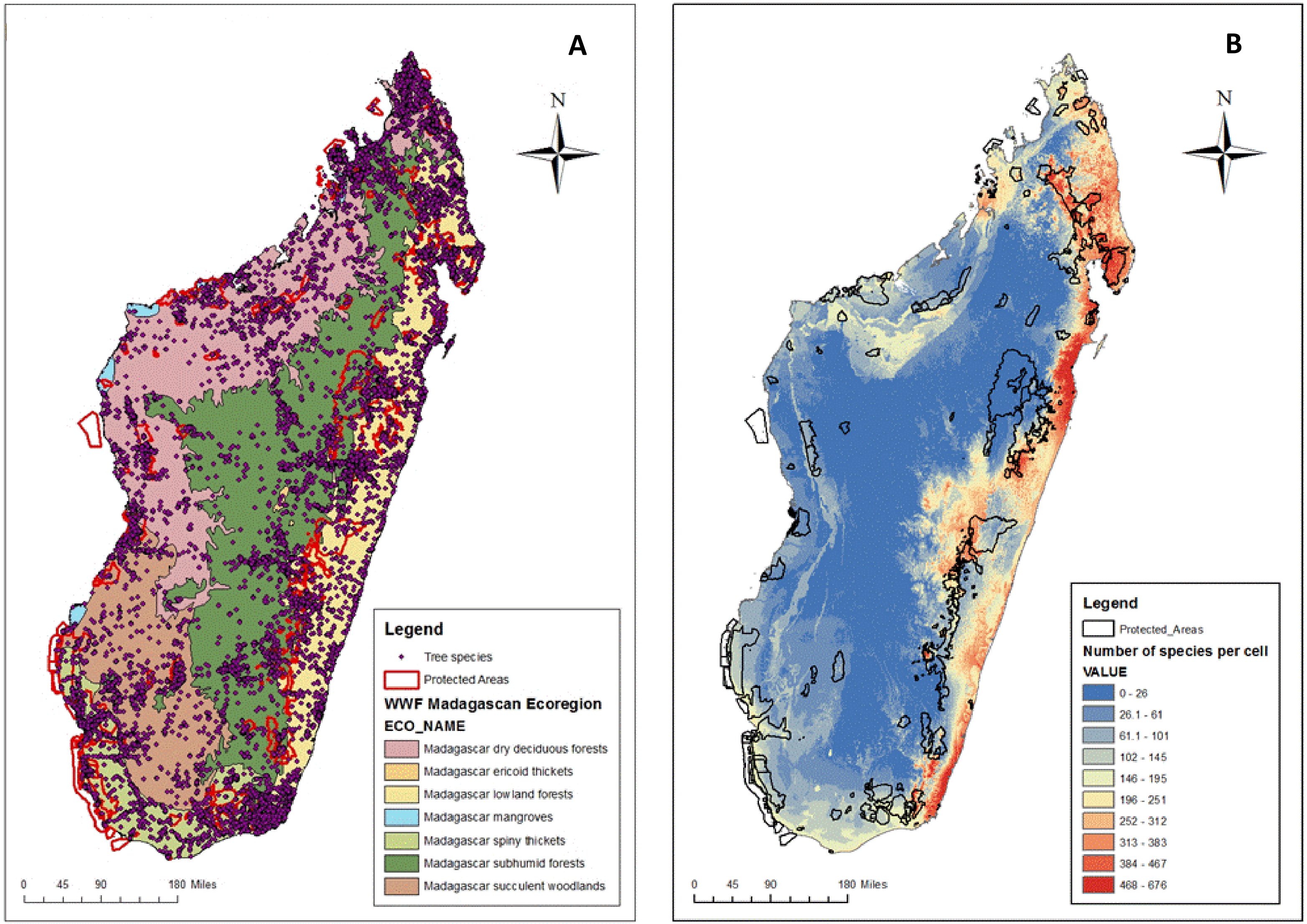

Fig 1: Representation of (A) known locations and (B) the sum of the potential distribution models of the 1,517 endemic trees in Madagascar within our database. B illustrates the sum of MaxEnt presence-absence models. Protected areas data is from WDPA (2016). Grid resolution 1x1.

Prioritization

Differences in the location of priority areas for tree restoration or conservation actions were found across the country depending on the threat scenario (Figure 2 and Supporting Information Fig 7). One region along the north east of the country was identified as a common priority area across two scenarios (selected from 70-100 times; Figure 2). Small areas of high conservation value were also found along the south-western coastline in all scenarios. In contrast, priority areas within the center of the country vary significantly when considering the different threat indicators, suggesting these are more sensitive to the data used and require more investigation. Planning units with a high selection frequency (selected 70 – 100 times. Figure 2) are our best estimate of the high priority areas for restoration or conservation actions in Madagascar, considering information on all the different existing threats, cost and conservation value (Klein et al. 2013; Tulloch et al. 2017).

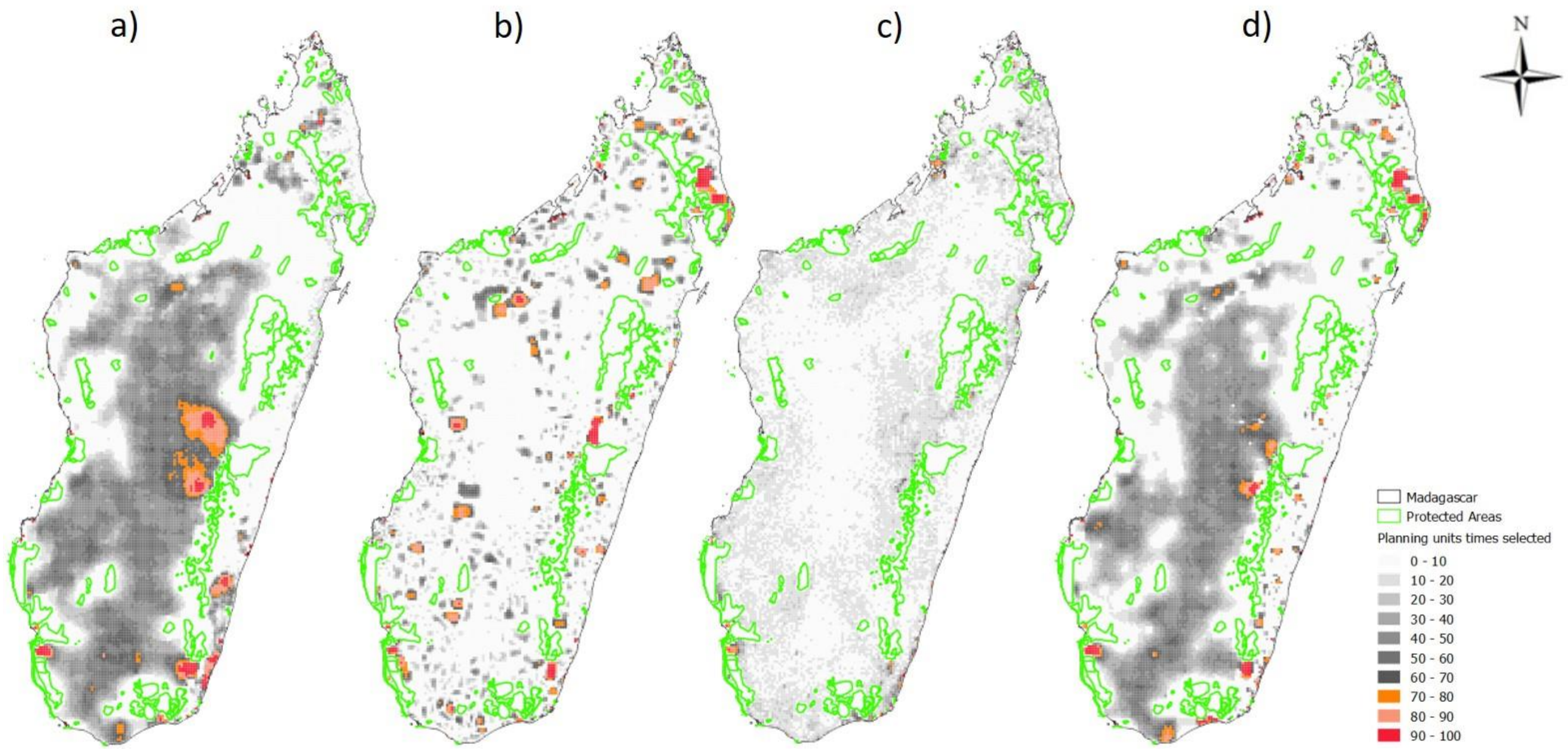

Fig 2: Priority areas for the conservation and restoration of endemic trees in Madagascar outside existing protected areas. The different scenarios represent priority areas of habitat according to the following threats: a) agriculture, b) roads, c) population density, and d) all the threats combined, represented by the human pressure index. The protected areas data is from WDPA (2016). Grid resolution (5 x5 km).

DISCUSSION

Madagascar is a global biodiversity hotspot, yet critical conservation decisions are often made with limited information. We developed the largest spatial database on the distribution of endemic trees to date (including 51% of Madagascar´s known endemic tree species) and used it to identify priority areas for endemic tree conservation and restoration efforts. In selecting priority areas for tree species management, we incorporated information on different threats and costs, taking advantage of MarProb, a new prioritization tool (Tulloch et al. 2013) to identify the areas where conservation and restoration actions would be both cheapest and at the least risk from existing threats. This study complements previous studies that modelled species distributions and undertook conservation prioritization involving diverse taxa in Madagascar (Kremen et al. 2008; Rogers et al. 2010), by increasing the number of species with modelled distributions (Vieilledent et al. 2013; Rakotoarinivo et al. 2014; Brown et al. 2015) and considering the level of threat alongside data on conservation value and costs. As well as the conservation and restoration of Madagascar's endemic species being important in their own right, these trees create forestry habitat for other threatened arboreal species like lemurs (Malabet & Mario 2017) and can improve the local livelihood in agriculture by preserving associated ecosystem services (Barrios et al. 2018).

Land managers working in low- and middle-income countries, like Madagascar, often have low data availability or low-quality information to guide conservation decisions. During the exploration phase in this study, we found only 232 assessed all tree species listed on the IUCN Red List, and of these just 102 had distribution maps (IUCN 2017). In contrast, recent botanical studies have identified at least 2,991 endemic tree species in the island (Beech et al. 2017). Thus, Madagascar continues to be an area under exploration by botanists and other ecologists. We found littoral forests in Madagascar have the highest tree species richness (Figure 1), complementing previous work by Consiglio et al. (2006). However, every year important taxonomic studies are published, outdating assessments of species distributions and prioritizations. To avoid this, we developed our speciels modelling and conservation prioritization methodology so that it can be rapidly replicated when information on endemic tree species are updated. Practitioners and decision-makers should use the most updated information available to make decisions, as waiting for more information before implementing conservation actions can be costly (Grantham et al, 2009).

Online databases such as the GBIF, GlobalTreeSearch or Tropicos database, that collate occurrences, distributions and taxonomic information from botanic gardens, museums, academia, NGOs, forestry organizations, and agricultural institutions on known tree locations around the world were critical in this study and should be consistently used and updated. They provide an invaluable source of information for scientists and managers (García-Roselló et al. 2015; Beech et al. 2017) working in data limited region by reducing the replication of expensive data collection efforts (Mateo et al. 2018). Citizen science can help to increase the quantity of valuable information, increasing the efficiency and accuracy of conservation prioritizations. Collaboration between governments, public and private institutions is needed to manage and update the information compiled and ensure restoration and conservation decisions are based on the best information available.

Areas of northern, southwestern, and central Madagascar were selected as priority areas for restoration and conservation actions in this study (Figure 2), complementing previous studies focussed on a smaller number but larger variety of species (Kremen et al 2008). These similarities could be the result of similar threats acting on the different groups of species or the dependency of many species assessed by Kremen (2008) on trees. The northern and northeaster region of Madagascar are the last wilderness areas of the country, with the highest aggregation of natural resources and forestry richness (Mittermeier et al, 2005). We identify the Ankalampona region, Majorejy Natural Reserve and Makira Natural Park as conservation and restoration priorities, due to its high potential species richness and low human pressure. In central, northeast and east regions of Madagascar, littoral forest present high values for human threats so, although endemic species aggregation is high, conservation actions could be costly too, thus the areas selected as conservation and restoration priorities are patchy but include the Fandrina Vondrozo Paysage Harmonieux Protégé and south of Midongy Befotaka National Park. Finally, the southern and eastern litoral forest from the south and southwest region of the island have unique endemic tree (e.g. *Alluaudiposis* and *Salvadoropsis* genera) and low levels of threat (Aronson et al, 2018). Conservation and restoration priority areas within these regions include Ambovombe, Betanty, south of Amoron'i Onilahy Paysage Harmonieux Protégé, north of Tsimanampesotse National Park, Antongo, Ambararata, north of Besalampy, Besakoa littoral coast, and Analalava region. Madagascar Central Plateau presents low agriculture, roads, and human pressures values; however, our models show lower aggregation of the potential distribution of endemic tree species, due to the limited tree species information in remote or inaccessible locations. This situation makes that our conservation prioritization assessment can exclude like priority for conservation or restoration actions those areas with lower selection rates (from 50 % to 70 %). Regardless, conservation practitioners should remember that, given the uncertainty in the data used for this conservation prioritization, the results are merely a guide and should be reevaluated at a local scale where information on the value, costs, and threats associated to conservation and restoration actions can be refined (Pressey et al, 2013).

Our priority areas were defined considering some of the dominant human threats for endemic tree species on a national scale: agriculture representing slash-and-burn activities, roads representing illegal logging and human footprint representing forest degradation. Rivers, however, also play a specific role in driving illegal logging activities in Madagascar’s humid regions (Allnutt et al, 2013), where they are used to move logs from the interior to the coast. Future prioritization assessments that focus on local or regional scopes of illegal logging could build on our analysis by including spatial information on rivers. Other considerations, which could build on our prioritization for the conservation and restoration of endemic trees, would be considering taxonomic distinctiveness or threat status of the different species of endemic trees.

Conservation researchers and practicioners or Madagascar national authorities can use our maps for different purposes. We used species occurrence data from studies across a wide range of years indicating potential instead of existing tree distributions, so some tree species could have already disappeared from the areas where they were previously detected. Thus, in areas where the forest is degraded or removed our prioritization should guide the implementation of forest restoration actions (Rodrigues et al. 2009) to promote the survival of Madagascar's key habitats for endemic tree species (Cowlin et al, 2003). On the other hand, where forest is still standing and in good condition, these maps can guide the implementation of conservation actions or the production of management plans for focused on priority tree species in areas which are already protected (Figure 2 and Supplementary Figure 5S). Although Madagascar has increased the number of protected areas recently, many of them still require management plans (Gardner et al. 2018) and very few contain actions for threatened flora. Additionally, researchers can also use known and potential tree distribution maps, derived from this data, to evaluate the existing and past effect of human pressure on a wide range of species that are impacted by the same threats (Cardillo et al. 2004). Finally, the tree distribution models resulting from this compiled data can serve as a guide for researchers wanting to refine the information on the distribution of Malagasy trees (Mateo et al 2018).

In conclusion, this study represents a first step in prioritizing conservation planning actions in Madagascar considering species richness, threat and cost, and is one of the few examples of the use of Marxan with Probabilities in the scientific literature. We identify that the northern east, northern west and south-eastern Madagascar littoral forest should be prioritized for conservation and restoration action. These areas can be further refined with better information on the cost of conservation or restoration actions in Madagascar. We also produced the largest database on the past and present distribution of endemic Malagasy trees. While many of these maps relied on limited information, they are invaluable to guide further researcher on endemic tree distribution and forest inventories.

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SUPPORTING INFORMATION

PCA results (Appendix Fig 3 and Fig 4). Representation of presence-absence models by Maxent compared with Areas of occupancy (AOO) maps on the IUCN Red List (Appendix Fig 5). Representation of known locations and sum of potential distribution presence-absence MaXent models of threatened Red List endemic tree species in Madagascar of our database (Appendix Fig 6). Priority areas for the conservation and restoration of endemic trees in Madagascar, considering the current distribution of protected areas (Appendix Fig 7).

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PCA results bioclimatic variables analysis for MaxEnt models.

Fig 3: Correlation matrix to detect correlations between bioclimatic variables. Those variables most correlated were excluded for MaXent modelation assessments.

Correlation Matrix[a]

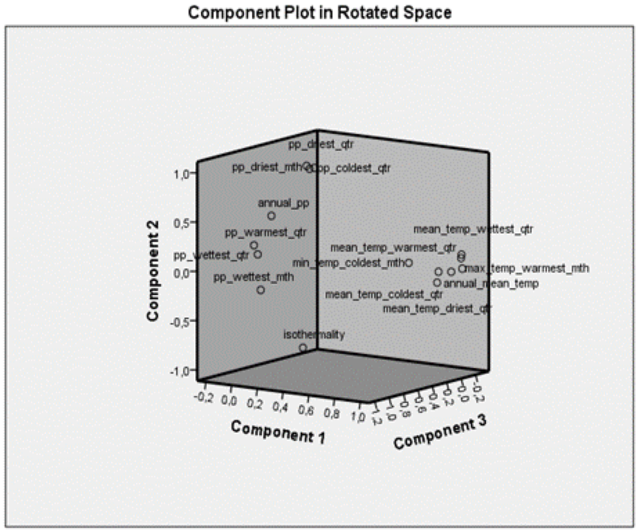
		Mean temp coldest qtr	isothermality	Max temp warmest mth	Min temp coldest mth	Mean temp wettest qtr	Mean temp driest qtr	Pp warmest qtr	Pp coldest qtr	Annual pp	Annual mean temp	Mean temp warmest qtr	Pp driest mth	Pp wettest mth	Pp wettest qtr	Pp driest qtr
Correlation	Mean temp coldest qtr	1.000	0.131	0.830	0.915	0.928	0.989	0.087	0.030	0.094	0.983	0.939	-0.045	0.272	0.161	0.007
	isothermality	0.131	1.000	0.018	-0.005	-0.099	0.042	-0.289	-0.689	-0.427	0.035	-0.074	-0.661	0.010	-0.232	-0.661
	Max temp warmest mth	0.830	0.018	1.000	0.584	0.937	0.822	-0.219	-0.166	-0.232	0.904	0.939	-0.243	-0.080	-0.180	-0.197
	Min temp coldest mth	0.915	-0.005	0.584	1.000	0.798	0.925	0.331	0.329	0.392	0.865	0.805	0.266	0.420	0.394	0.315
	Mean temp wettest qtr	0.928	-0.099	0.937	0.798	1.000	0.938	-0.028	0.087	0.014	0.978	0.998	0.010	0.062	0.017	0.059
	Mean temp driest qtr	0.989	0.042	0.822	0.925	0.938	1.000	0.136	0.128	0.159	0.979	0.945	0.046	0.271	0.201	0.101
	Pp warmest qtr	0.087	-0.289	-0.219	0.331	-0.028	0.136	1.000	0.658	0.932	0.016	-0.037	0.614	0.867	0.983	0.661
	Pp coldest qtr	0.030	-0.689	-0.166	0.329	0.087	0.128	0.658	1.000	0.856	0.032	0.064	0.976	0.331	0.615	0.993
	Annual pp	0.094	-0.427	-0.232	0.392	0.014	0.159	0.932	0.856	1.000	0.036	0.001	0.832	0.749	0.923	0.860
	Annual mean temp	0.983	0.035	0.904	0.865	0.978	0.979	0.016	0.032	0.036	1.000	0.985	-0.045	0.172	0.080	0.005
	Mean temp warmest qtr	0.939	-0.074	0.939	0.805	0.998	0.945	-0.037	0.064	0.001	0.985	1.000	-0.014	0.073	0.014	0.035
	Pp driest mth	-0.045	-0.661	-0.243	0.266	0.010	0.046	0.614	0.976	0.832	-0.045	-0.014	1.000	0.297	0.570	0.987
	Pp wettest mth	0.272	0.010	-0.080	0.420	0.062	0.271	0.867	0.331	0.749	0.172	0.073	0.297	1.000	0.919	0.338
	Pp wettest qtr	0.161	-0.232	-0.180	0.394	0.017	0.201	0.983	0.615	0.923	0.080	0.014	0.570	0.919	1.000	0.616
	Pp driest qtr	0.007	-0.661	-0.197	0.315	0.059	0.101	0.661	0.993	0.860	0.005	0.035	0.987	0.338	0.616	1.000

Fig 4: Component matrix that indicate the predictors for target species that explain most of the tress species distribution ocurrences (A). KMO and Bartlett´s test to assess the accuracy and sinicativity of PCA assessment (B). Component assessment that explain the number of data explained for three statistical significative predictors in the Component matrix (C).

B

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.825
Bartlett's Test of Sphericity	Approx. Chi-Square	2876445.062
	df	105
	Sig.	0.000

Component Correlation Matrix			
Component	1	2	3
1	1,000	,003	,086
2	,003	1,000	,354
3	,086	,354	1,000
Extraction Method: Principal Component Analysis.			
Rotation Method: Oblimin with Kaiser Normalization.			



A

Component Matrix[a]			
	Component		
	1	2	3
mean_temp_coldest_qtr	,877	-,449	
isothermality		-,498	,674
max_temp_warmest_mth	,662	-,667	
min_temp_coldest_mth	,929		
mean_temp_wettest_qtr	,850	-,482	
mean_temp_driest_qtr	,913		
pp_warmest_qtr	,463	,771	
pp_coldest_qtr	,474	,777	
annual_pp	,519	,840	
annual_mean_temp	,869	-,493	
mean_temp_warmest_qtr	,848	-,499	
pp_driest_mth		,797	
pp_wettest_mth	,484	,497	,678
pp_wettest_qtr	,507	,721	,446
pp_driest_qtr	,452	,793	
Extraction Method: Principal Component Analysis.			
a. 3 components extracted.			

C

Component	**Initial Eigenvalues**			**Extraction Sums of Squared Loadings**			**Rotation Sums of Squared Loadings**
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total
1	6.714	44.759	44.759	6.714	44.759	44.759	6.478
2	5.712	38.081	82.840	5.712	38.081	82.840	4.645
3	1.815	12.098	94.938	1.815	12.098	94.938	4.673

Fig 5: Representation of presence-absence models by Maxent (figure black and white) compared with Areas of occupancy (AOO) maps on the IUCN Red List (imagen in color). a) Dypsis rivularis (EN); b) Adansonia grandidieri (EN); presence: black and orange areas.

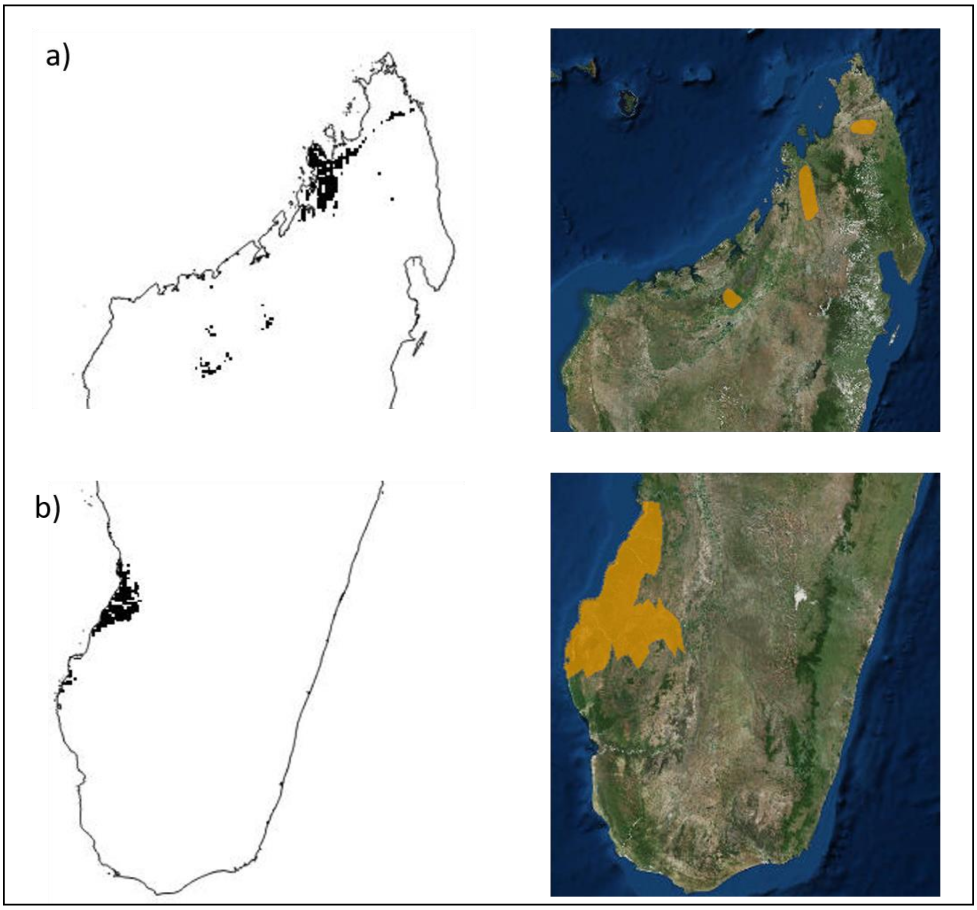


Fig 6: Representation of known locations (A) and sum of potential distribution presence-absence MaXent models (B) of threatened Red List endemic tree species in Madagascar of our database, 104 in total. Protected areas data is from WDPA (2016). Grid resolution 1x1 km.

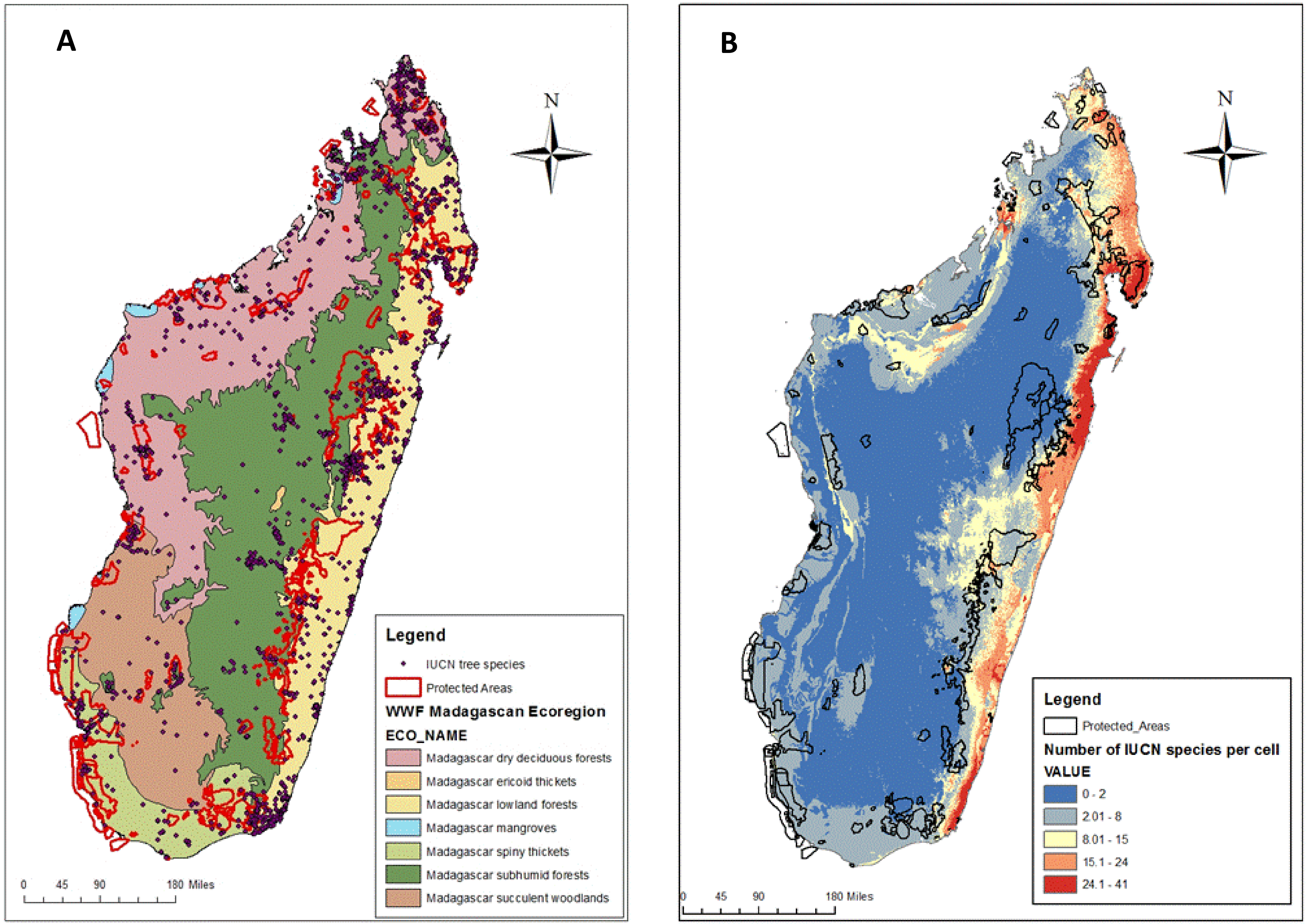


Fig 7: Priority areas for the conservation and restoration of endemic trees in Madagascar, considering the current distribution of protected areas. The different scenarios consider different types of thrats including a) Agriculture, b) Roads, c) Population, and d) a combined human pressure index. Protected areas data is from WDPA (2016). Grid resolution (5 x5 km).