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ORIGINAL ARTICLE

Identifying Mozambique's most critical areas for plant conservation: An evaluation of protected areas and Important Plant Areas

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Abstract

Successful protected area networks must represent biodiversity across taxonomic groups. However, too often plant species are overlooked in conservation planning, and the resulting protected areas may, as a result, fail to encompass the most important sites for plant diversity. The Mozambique Tropical Important Plant Areas project sought to promote the conservation of Mozambique's flora through the identification of Important Plant Areas (IPAs). Here, we use the Weighted Endemism including Global Endangerment (WEGE) index to identify the richest areas for rare and endemic plants in Mozambique and subsequently evaluate how well represented these hotspots are within the current protected area and IPA networks. We also examine the congruence between IPA and protected areas to identify opportunities for strengthening the conservation of plants in Mozambique. We found that high WEGE scores, representing areas rich in endemic/near-endemic and threatened species, predict the presence of IPAs in Mozambique, but do not predict the presence of protected areas. We also find that there is limited overlap between IPAs and protected areas in Mozambique. We demonstrate how IPAs could be an important tool for ensuring priority sites for plant diversity are included within protected area network expansions, particularly following the adoption of the "30 by 30" target agreed within the post-2020 Convention on Biological Diversity framework, with great potential for this method to be replicated elsewhere in the global tropics.

KEYWORDS
biodiversity, botanical richness, conservation planning, convention on biological diversity, IPAs, IUCN red list, protected areas, WEGE

1 | INTRODUCTION

An estimated two in five plants are threatened with extinction; however, plants are frequently underrepresented in conservation prioritization schemes (Nic Lughadha et al., 2020). This underrepresentation is often associated with a lack of available data, for example extinction risk assessments, or data that are not readily available in policy-useful formats (Nic Lughadha et al., 2020; Plantlife, 2018). For instance, the trigger species for Key Biodiversity Areas globally are overwhelmingly dominated by vertebrates: 68% of trigger species are vertebrates while plants represent only 25.2% trigger species (KBA, 2023); this is despite the number of described plant species being several times larger than the number of described vertebrates (IUCN, 2022a).

This underrepresentation of plant taxa is of great concern as priority sites for plant diversity do not always correlate with other taxa. For instance, only 53% of Important Plant Areas (IPAs), defined as "the most important places in the world for wild plant and fungal diversity that can be protected and managed as specific sites" (Plantlife, 2018), overlap with Important Bird Areas in Europe and the Mediterranean (Darbyshire et al., 2017). Furthermore, overlap between IPAs and protected areas can be as low as 25% in some European countries (Melovski et al., 2012). In an African context, although there are 12 countries with IPAs identified or in the process of being identified (Plantlife, 2023), there have been no attempts as yet to quantify the overlap between IPAs and the protected area network on a national level. One African nation where IPAs have been identified is Mozambique.

Spanning nearly 16.5° in latitude, and with a coastline of over 2700 km^2, Mozambique hosts a wide range of botanical diversity influenced by variable geology, climate, and altitude (Darbyshire et al., 2019; Izidine & Bandieria, 2002; Odorico et al., 2022). Over 7000 different plant taxa (species and infraspecific taxa) are known from Mozambique, including over 270 strict-endemic taxa and around 390 near-endemic plant taxa (Darbyshire et al., 2019; Odorico et al., 2022).

However, this rich flora faces significant threats. Much of the Mozambican population is dependent on small-holder agriculture, with increasing outputs in recent decades achieved through increasing the area farmed, rather than increased productivity (World Bank, 2022). In addition, extraction of wood for charcoal production is the primary source of fuel for most people (Massuque et al., 2021). As a result of these and other threats, Mozambique has experienced extensive habitat loss, with 13% of tree cover (of over 30% canopy) lost between 2001 and 2021 (World Resources Institute, 2022). Habitat loss, in turn, is a major threat to Mozambique's flora (IUCN, 2022b). Endemic and near-endemic plants are most at risk: 55% of endemic and near-endemic plants assessed for the IUCN Red List of Threatened Species (hereafter "Red List") are threatened with extinction, compared to 19% of all native Mozambican plants (Darbyshire et al., 2023).

As primary custodians for plants found wholly or mostly within its borders, Mozambique has a particular responsibility toward conserving these species and, as a signatory of the Convention on Biological Diversity, is legally obliged to fulfill this commitment. Moreover, 90% of the Mozambican population is dependent, directly or indirectly, on biodiversity for their livelihoods, including provision of food, fuel, medicines, and materials (MITADER, 2015). Conservation of plant species in Mozambique is therefore of great importance and should be recognized as both a national and international priority.

To this end, the Mozambique Tropical Important Plant Areas (TIPAs) project was established to influence and inform conservation actions and ensure effective protection of Mozambique's priority areas for plant conservation through the identification of 57 IPAs (Figure 1; Darbyshire et al., 2019, 2023). The project also generated large amounts of data on the wild plant diversity of Mozambique, including the first comprehensive assessment of the country's endemic flora, alongside the collation of an accompanying georeferenced dataset of taxon occurrence records, novel data generated through targeted botanical field surveys, and a revised IUCN Red List for the threatened plants of Mozambique (Darbyshire et al., 2023). Further information on the identification of IPAs in Mozambique is available in Table S1 and the volume "*The Important Plant Areas of Mozambique*" (Darbyshire et al., 2023).

In this paper, we investigate whether plant diversity hotspots (based upon endemism and extinction risk of species) predict the presence of protected areas, to establish whether the development of the protected area network has been influenced by and is reflective of these hotspots. We use the Weighted Endemism including Global Endangerment index (WEGE) to quantify these plant biodiversity hotpots. We also evaluate the distribution of IPAs against the distribution of WEGE values to allow comparison with the protected area network and to better understand which IPAs are of highest conservation value. Finally, we compare the distribution of IPAs and PAs, identifying opportunities for expansion of the protected area network to better encompass plant diversity, with particular focus on those IPAs identified as priorities within the WEGE analysis.

Following the Convention on Biodiversity post-2020 framework, countries around the world will be expanding their protected area networks to meet the "30 by 30" target aiming for at least 30 per cent of land and sea areas globally to be within protected areas by 2030. Uninformed protected area expansion, however, risks excluding the most important sites for plant diversity. Using the results of our analyses, we recommend which sites might make good candidates for inclusion within any protected area network expansion in Mozambique, with insights that may inform protected area expansion elsewhere in the global tropics.

2 | METHODS

GIS analyses were undertaken in ArcGIS Pro version 2.9.0 (ESRI, 2021) and R version 4.1.3 (R Core Team, 2022).

We produced a raster layer of the WEGE scores using the spat_ras function in the WEGE R package (Farooq, Azevodo, et al., 2020).

Cell size within this raster is 25×25 km and the extent encompassed the entirety of Mozambique. WEGE is calculated using the following formula:

$$\text{WEGE} = \sum_{i=1}^{SR} \sqrt{\text{WE}_i} \times \text{ER}_i$$

WEGE value for each cell represents the sum of the square root of the partial weighted endemism value (WE_i) multiplied by the probability of extinction (ER_i) for each species recorded within a given cell. Further details of this calculation are outlined by Farooq, Azevedo, et al. (2020). Weighted endemism here is inversely proportional to the number of grid cells in which a species occurs within. For extinction risk, the IUCN50 transformation from Davis et al. (2018) was used with the following probabilities: LC=0.0009, NT=0.0071, VU=0.0513, EN=0.4276, and CR=0.9688. Davis et al. (2018) used projected extinction probabilities based on the Red List Criterion E (IUCN, 2012) which they subsequently transformed, assuming exponential decay of a species, to reflect extinction risk over 50 years. Extinction risk values for Near Threatened and Least Concern species were calculated by extrapolating from the decay constants of threatened species. For DD species, the probability of VU was used (0.0513) following Bland et al. (2015).

The species occurrence data used to calculate WEGE index were derived from a georeferenced dataset of 4591 records from 446 plant taxa, of which 206 were endemic and 240 were near-endemic (including infraspecies; taxa following Darbyshire et al. (2019, 2023)) curated as part of the Mozambique TIPAs project. Inputting plant taxa into the WEGE calculation where there is not complete and accurate occurrence data for these taxa across their ranges could

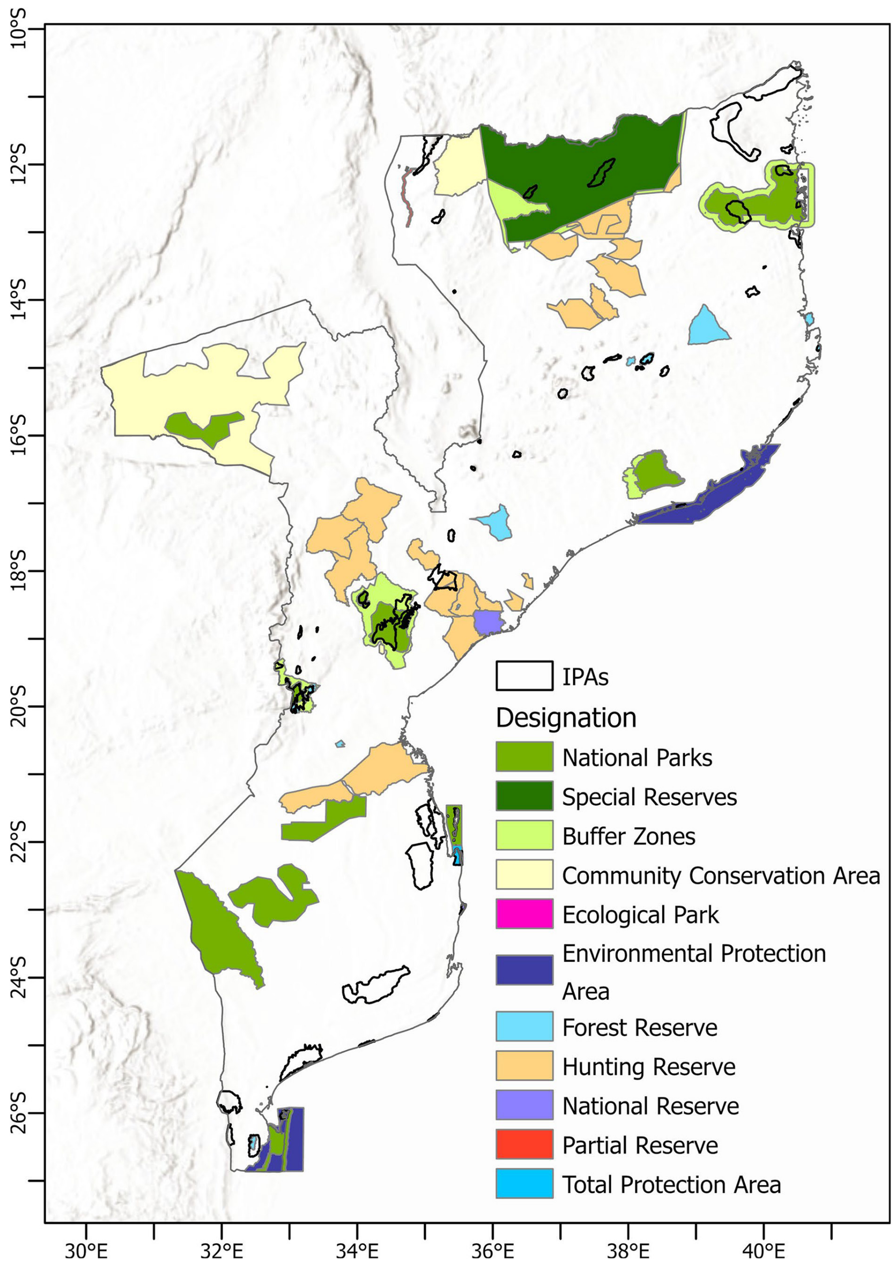

FIGURE 1 Protected areas of Mozambique, colored coded by designation, compared to IPA network.

result in inaccurate weighted endemism scores that do not truly reflect the distributions of these taxa. Therefore, the species within this dataset were limited to endemic and near-endemic plant taxa, for which we had reliable occurrence data in the dataset. Species also had to be assessed for the Red List, including assessments that are yet to be published but have been entered into the IUCN Species Information Service. The dataset also contained records from the years 1843 to 2020. Due to a lack of recent collecting effort in parts of Mozambique, we included all records so as not to underestimate the biodiversity value of these parts of the country. Where there is no occurrence data within a cell, the WEGE value cannot be calculated.

For near-endemics, occurrence points from outside of Mozambique were included to calculate WEGE scores. However, the WEGE raster was subsequently clipped to include only cells that fall fully or partially within the borders of Mozambique.

For comparison with the distribution of WEGE scores, IPAs (shapefiles available on the TIPAs Explorer, https://tipas.kew.org) and the protected area network of Mozambique (Biofund, 2022; UNEP-WCMC & IUCN, 2022) were mapped alongside each other. Forest Reserves are included within the protected area data, although it should be noted that they are not managed within the protected area system of Mozambique at present.

To investigate whether WEGE score predicts the presence of IPAs and protected areas, we applied generalized linear models (GLMs) with binomial error distributions using the stats package Version 3.6.2 in R (R Core Team, 2022). Across all models, WEGE value of each cell was used as the predictor while one used presence of a protected area as the response variable and another the presence of IPAs as the response, following the formula:

$$\text{glm}\left(\text{presence of protected area or IPA} \% \text{WEGE, family} = \text{"binomial"}\right)$$

Presence or absence of a protected area or IPA was scored for each cell of the WEGE raster. Presence refers to any overlap between a protected area or IPA and each cell of the WEGE raster. The "estimate" values reported for each model represent the average change in the logarithmic odds of a cell being within an IPA or protected area, respectively, if WEGE score was to increase by one. The *p*-value of each co-efficient, representing the statistical significance of WEGE scores in predicting the distribution of either IPAs or protected areas, is also reported. We also provide the results of an additional GLM modeling only protected areas managed by the National Administration of Conservation Areas (ANAC), namely National Parks, National Reserves and Special Reserves, against WEGE value. These sites are, theoretically, in receipt of more effective conservation management than other designations and, therefore, understanding whether the distribution of these ANAC-managed sites can be predicted by high WEGE values may further inform conservation planning in Mozambique.

Congruence between IPAs and the protected area network was analyzed through calculating the spatial overlap. To avoid misrepresentation of protected area overlap with IPAs where two separate protected areas are designated at the same location (for instance, there are three separate forest reserves, Moribane, Maronga, and Zomba, that fall within Chimanimani National Park), protected area polygons were dissolved so all protected area boundaries that fall within other protected areas were merged into the encompassing polygon.

Alongside this measure of the total overlap between the protected area network and IPAs, the overlap between protected areas and IPAs was also calculated for each protected area designation. Protected area designation type follows Biofund (2022) (see Figure 1).

3 | RESULTS

3.1 | Analysis of WEGE values in relation to protected areas and IPAs

Across Mozambique, mean WEGE score is 0.018575, with values ranging from 0.000036 to 0.359628. Table 1 details the top five highest value cells for WEGE score. A total of 781 out of 1221 (64%) cells across Mozambique had a no WEGE score, representing no records of endemic/near-endemic or threatened species within the dataset. Cells with no records of endemic/near-endemic or threatened species within the dataset represent 22% of cells where IPAs are present (Figure 2) and 71% of cells where protected areas are present (Figure 3).

The GLM used to model WEGE score as a predictor of presence of a protected area indicates that WEGE values do not predict the presence of protected areas (estimate = 2.8793 ± 2.7309, $p = 0.292$). Similar results were obtained when only ANAC-managed sites were modeled (Figure S1). Contrastingly, the GLM (Figure 4) used to model WEGE score as a predictor of presence of an IPA demonstrates a strong positive relationship between WEGE score and the presence of an IPA (estimate = 27. 2140 ± 4.9616, $p = 4.14\text{e-}8$).

Where WEGE scores are higher, IPAs are more likely to occur, with an average WEGE score within IPAs of 0.033528 compared to an average of 0.010763 for cells that do not overlap with IPAs (Figures 2 and 4). Contrastingly, there is little difference between the average WEGE score of cells within protected areas, 0.020772, compared to cells outside the protected area network, 0.017416 (Figures 3 and 4) while there is also little difference in mean WEGE value when only protected area managed by ANAC are considered (Figure S4). Forty-seven out of 57 IPAs have a maximum WEGE score, according to the cell with the highest WEGE value within the boundaries of a particular IPA, above the national average WEGE score (Table S2). In comparison, only 26 of the 60 protected areas of Mozambique (including buffer zones as separate entities) have maximum WEGE scores above the national average and several of those that are above the national average overlap spatially, for example the forest reserves within Chimanimani National Park, or are neighboring and so share the same cells within the WEGE analysis (Table S3).

3.2 | IPAs and the protected area network

A total of 25.39% (5819.55 km^2) of Mozambique's IPA network area falls within a protected area (Figure 1). The large majority of overlap between IPAs and the protected area network occurs within national parks (14.07% of the IPA network area). Buffer zones account for the second largest overlap with the IPA network (11.17% of the IPA network area), with the Chimanimani National Park Buffer Zone and Gorongosa National Park Buffer Zone contributing significantly. However, overlap as a proportion of the total area of national parks/buffer zones in Mozambique as a whole, as shown in Table 2, is not notably higher than for other protected area designations. Community conservation areas and ecological parks are the only designations that do not intersect with any IPAs. Forest reserves cover just 2.38% of the IPA network.

Of the 60 different protected areas of Mozambique, 23 (37.70%) overlap at least in part with the IPA network. The levels of overlap between IPAs and protected areas vary regionally, with good IPA coverage in the protected areas of central Mozambique, moderate coverage in northern Mozambique and limited coverage in the south. Significant gaps include several IPAs in coastal, southern Mozambique, the “Sky Island” mountains across Nampula and Zambezia provinces and the coastal and escarpment IPAs in Cabo Delgado Province.

4 | DISCUSSION

4.1 | Plant diversity hotspots of Mozambique

The distribution of WEGE scores throughout Mozambique is highly uneven. There are a number of outliers, with WEGE values several times higher than the national average, which represent biodiversity hotspots for the Mozambique's most rare and threatened plants. Across Mozambique, the distribution of cells with high WEGE values appear to be largely congruent with the centers of plant endemism as proposed by Darbyshire et al. (2019). Such an association with WEGE is to be expected as these areas are rich in range-restricted endemics, many of which are known to be at greater risk of extinction in Mozambique (Darbyshire, 2023).

Higher WEGE values have been shown to predict the presence of IPAs indicating that, based on the species data available, the distribution of the IPA network is strongly influenced by the highest priority sites for the rarest and most threatened plant species across Mozambique. Two of the criteria most frequently applied to identify IPAs in Mozambique were IPA sub-criterion A(i), triggered by the presence of threatened species, and sub-criterion B(ii), triggered by the presence of a significant proportion of the national list of endemic and range-restricted species within a site (Darbyshire et al., 2023). By identifying the highest priority sites that meet these criteria, the IPA network reflects areas of high WEGE value, including the majority of the highest scoring cells nationally (Figure 4). Calculating WEGE score for each IPA (Table S2) also informs which sites may be of higher priority for conservation action, which could be of great use for informing targeted conservation actions when resources are limited.

Despite the congruence between IPAs and WEGE, 9% of cells outside of the IPA network have WEGE scores that exceed the national average. While this proportion is low, some of these cells are particularly high scoring: Angoche for example, ranks tenth highest nationally (0.116208) while the Raraga River Estuary area northeast of Quelimane ranks eleventh (0.116136). These areas have been excluded as potential IPAs as they have been heavily degraded, and their high scores reflect the inclusion of historical records. Further investigation would be required to confirm the continued presence of priority species at such sites, but it is highly likely that at least some important species have been locally extirpated and, as such, true WEGE score for these sites would be much lower.

There are also several IPAs in areas with low WEGE scores. Some IPAs have been designated because of the presence of a single species, often where it is endemic to the site, or where habitats are particularly worth conserving. In Niassa Province for instance, there are a number of IPAs with maximum WEGE scores below the

TABLE 1 Top five ranking WEGE cells and their localities, including overlap with any protected areas or IPAs.

WEGE ranking	25 × 25 km cell origin	Locality	Protected area	Important Plant Area	WEGE score
1	(−11.83°, 40.19°)	Quiterajo (Namacubi Forest)	N/A	(4) Quiterajo	0.359628
2	(−15.58°, 36.94°)	Mount Namuli	N/A	(25) Mount Namuli	0.238540
3	(−20.08°, 32.94°)	Chimanimani Mountains	Chimanimani National Park and Buffer Zone; Maronga Forest Reserve	(41) Chimanimani Mountains; (42) Chimanimani Lowlands	0.226236
4	(−15.08°, 38.19°)	Serra Ribáuè- Serra M'paluwe	M'paluwe Forest Reserve; Ribáuè Forest Reserve	(23) Ribáuè-M'paluwe	0.225596
5	(−10.83°, 40.19°)	Lower Rovuma (northeast)	N/A	(1) Lower Rovuma Escarpment	0.217192

Note: WEGE score rounded to 6 decimal places. IPAs numbered according to Figure 2.

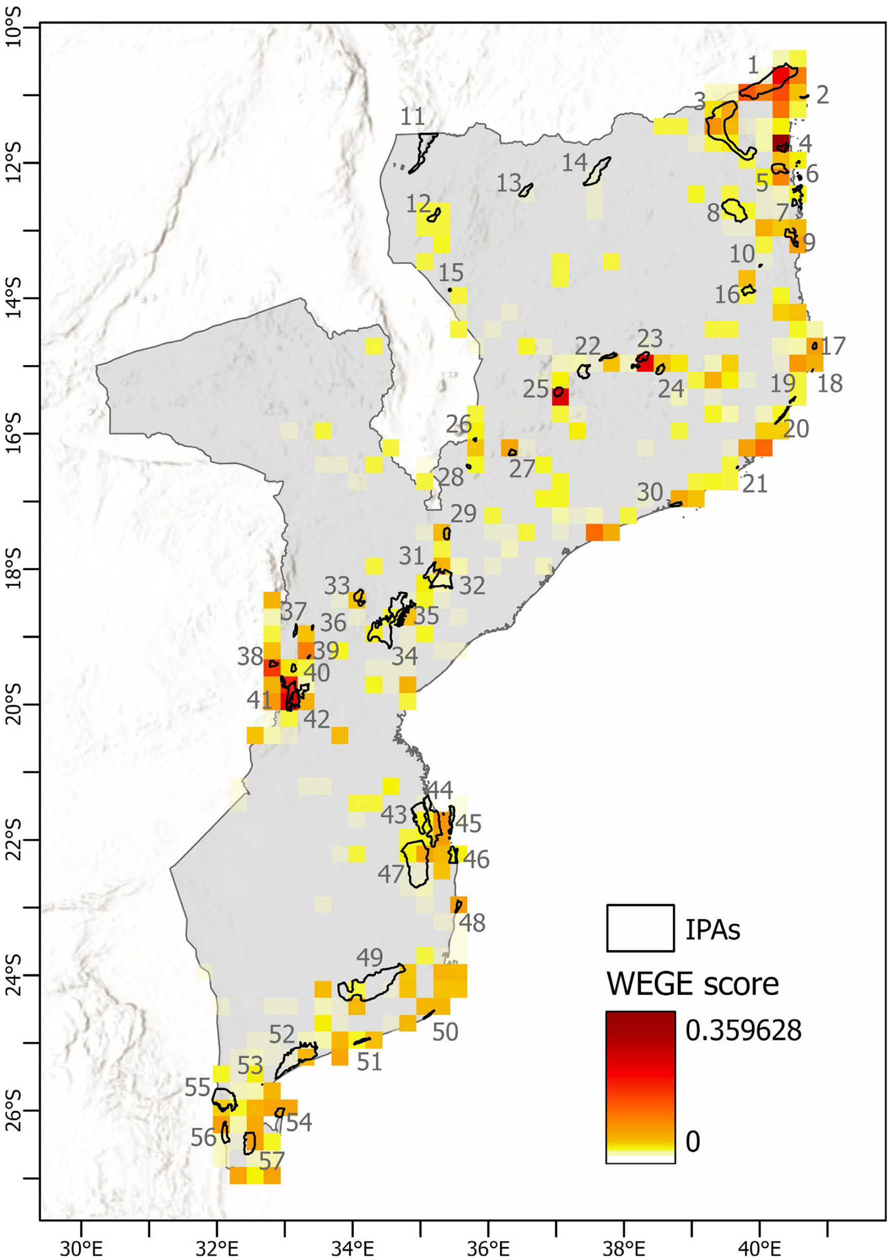

FIGURE 2 WEGE score for plants across Mozambique compared with the IPA network. IPA numbers correspond to "Map Number" in Table S1.

national average, while the Txitonga Mountains IPA has no WEGE score, due to an absence of occurrence data within the dataset used for analysis. The site, like many in Niassa, has received limited survey effort to-date, although the IPA trigger species, *Hartliella txitongensis*, was collected and described as new to science following fieldwork for the Mozambique TIPAs project and is known only from this IPA globally (Osborne et al., 2022). *H. txitongensis* has not yet been assessed for the Red List and so was not included within our dataset, although this species is provisionally assessed by Osborne et al. (2022) as Critically Endangered and so would likely score highly. In addition to *H. txitongensis*, there are two other species potentially new to science collected within the same site survey. The Txitonga Mountains' unique habitats, including significant areas of montane grassland—a restricted and nationally threatened habitat type, and suspected metal-rich soils which may well have given rise to rare species adapted to this particular ecology (Osborne et al., 2022). The Txitonga Mountains were therefore recognized as an IPA on this basis.

The WEGE metric is a conservation priority metric at the species level and although threatened, endemic/near-endemic plant species should be important considerations within conservation planning, other features such as habitats of conservation importance, like the rare habitats of Txitonga, or ecosystem service provision have also been considered in the designation of IPAs (Darbyshire et al., 2023) and should also be accounted for in conservation actions.

4.2 | Data limitations

Most cells across Mozambique have no WEGE value due to an absence of occurrences for endemic/near-endemic and threatened species within our dataset. As noted previously, in areas such as the

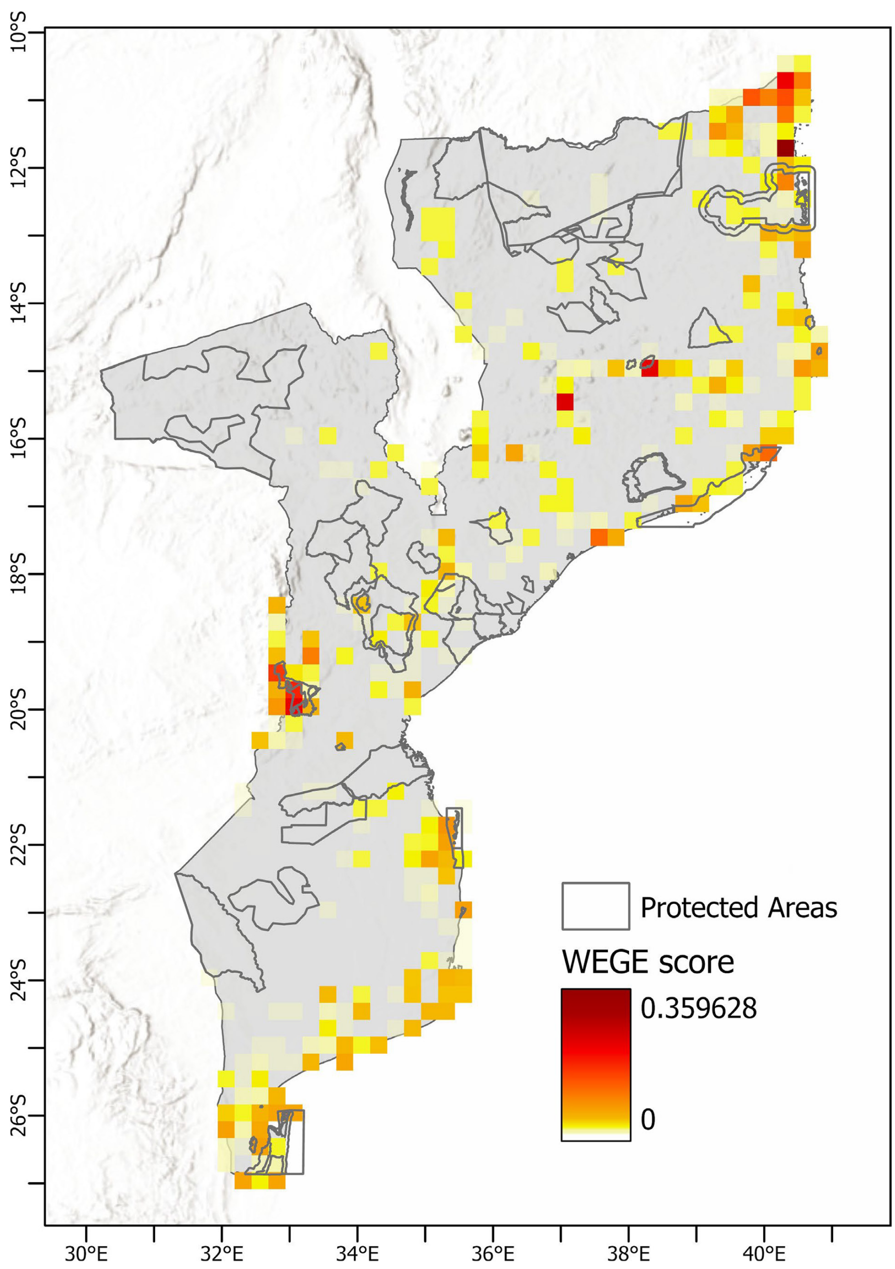

FIGURE 3 Overlap of WEGE scores for plants across Mozambique compared with the protected area network.

Txitonga Mountains, more data are needed to fully quantify WEGE. The data were also limited to included only endemic/near-endemic and threatened species. This limitation would not meaningfully impact the distribution of priority areas for WEGE, based on current knowledge, as the species that would trigger these high scores (those with high endemism and extinction risk) are those included within the dataset.

This largely accounts for the skew in IPA distribution toward cells with occurrence data—22% of cells that intersect with IPAs have no occurrence data compared to 64% of cells nationwide. While IPAs are less likely to occur in poorly studied areas, as evidence of trigger species is required to designate an IPA, it is also to be expected that IPAs are more likely to coincide with areas where the priority species, which the dataset used is based entirely upon, are known to occur.

Conversely, areas known to be low in diversity, particularly the extensive expanses of mopane woodland and some types of dry miombo woodland (Timberlake & Chidumayo, 2011), skew toward having no WEGE value. Dominated by widespread, Least Concern taxa, including several *Brachystegia* species, *Julbernardia globiflora*, and *Colophospermum mopane*, many of these cells would score close to zero values if included within the WEGE analysis, although further research is recommended to confirm these low scores.

In addition, while this analysis primarily highlights the sites with the most geographically restricted and threatened species without directly accounting for species complementarity across different sites, it implies a level of complementarity through the WEGE metric. Weighted endemism is inversely proportional to species range, while those species with the highest extinction risk in our dataset tend to be range restricted too as they have often been assessed

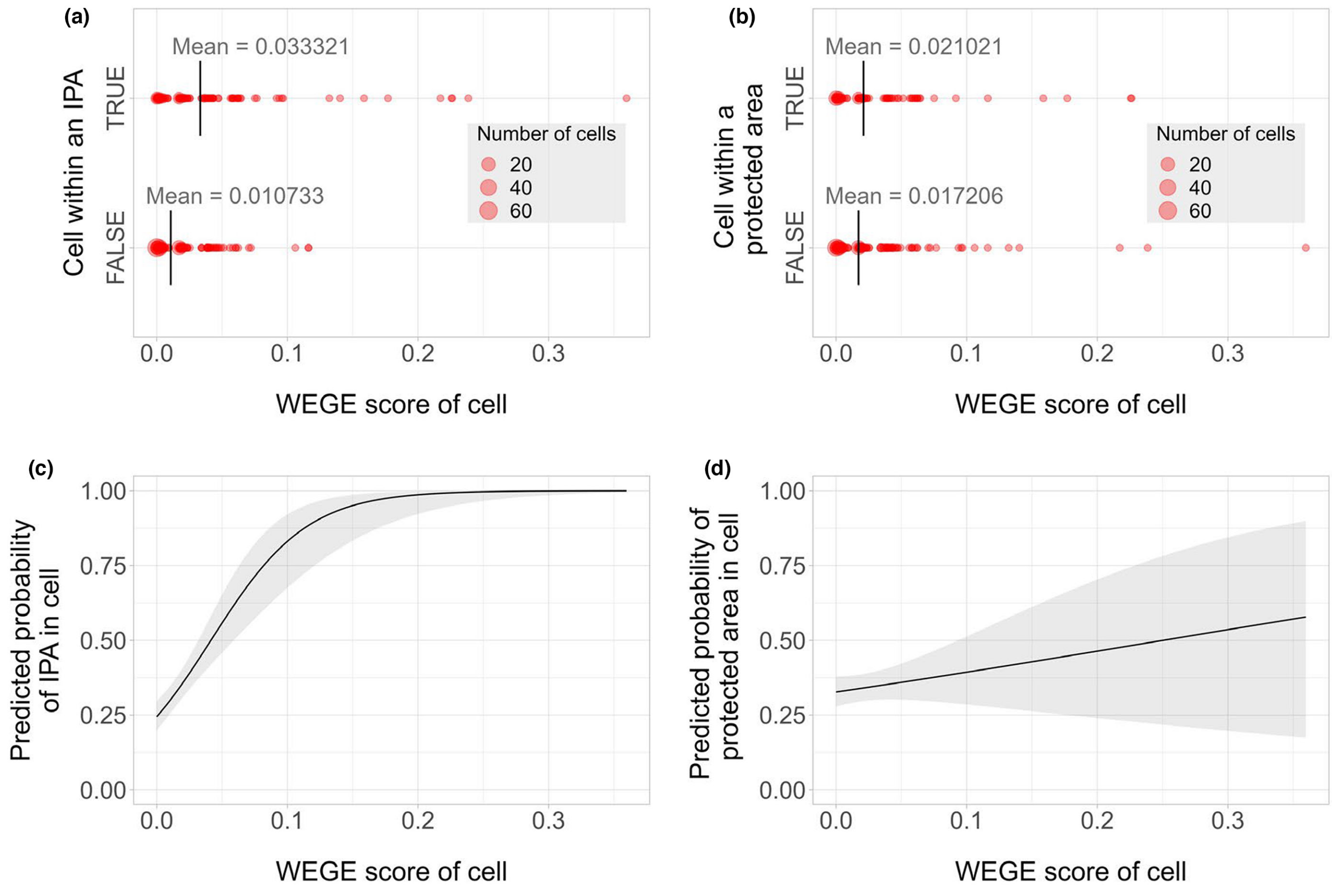

FIGURE 4 (a, b) Plots showing the observed relationship between WEGE score of a grid cell and the presence or absence of IPAs (a) and protected areas (b) in each cell. Point size is proportional, with a square root transformation, to number of cells. While there is a difference in mean WEGE score between cells where an IPA is present compared to where it is absent, with WEGE score higher on average in cells that intersect with IPAs, there is not a clear difference in WEGE score between cells where protected areas are present or absent. (c, d) Predicted probability of a cell falling within an IPA (c) or a protected area (d) generated by the corresponding generalized linear model. 95% confidence intervals shown in gray. The narrow confidence interval surrounding predicted probabilities of the presence of an IPA in a cell suggests that WEGE score is statistically significant in predicting the presence of IPAs, with high WEGE scores predicting a higher likelihood of an IPA present within that cell. Contrastingly, the large confidence interval surrounding the predicted probability of a protected area within a cell demonstrates how WEGE score cannot confidently predict the presence or absence of a protected area within a given cell.

using Red List criterion B or D2. Therefore, high ranking sites, characterized by unique species rarely found elsewhere, are expected to demonstrate a degree of implicit complementarity.

4.3 | Protected areas and plant diversity hotspots

IPAs have been demonstrated here to have a strong relationship with the distribution of endemic and threatened species, while also considering other valuable aspects of biodiversity such as rare habitats. Therefore, the limited representation of IPAs within the protected area network is of great concern for plant conservation in Mozambique.

The WEGE analysis also demonstrates that many of the richest sites for threatened and endemic/near-endemic plant taxa fall outside Mozambique's protected area network. According to our analysis, richness in threatened and rare species does not predict the presence of a protected area, suggesting that plant conservation priorities have not had a significant influence on the establishment of protected areas in Mozambique.

In northeast coastal Mozambique, for instance there are significant aggregations of high scoring WEGE cells outside the protected area network. One concerning example is Quiterajo, which has the highest WEGE score nationally, and as such has been recognized as an IPA, but is not currently within a protected area. There is no other formal conservation management of this site and rare species, including four that are globally endemic to this site, are imminently threatened by habitat clearance for agriculture, wood resources, and settlements (Darbyshire, 2023; Darbyshire et al., 2020; Timberlake et al., 2011). Without any site-based protection, there is a high risk of extinction for the unique plant taxa of Quiterajo.

Another significant area of incongruence between priority sites and the protected area network is the Mount Namuli IPA. Namuli is the richest site for nationally endemic plants, with 19 known only from this mountain (Darbyshire & Timberlake, 2023),

TABLE 2 Overlap between Important Plant Areas and protected area network including a breakdown by each protected area designation type.

Designation	Areal overlap (km^2)	Overlap as a proportion of the total IPA network area	Overlap as a proportion of the total area of each designation
National Park	3223.46	14.07%	7.29%
Buffer Zone	2560.81	11.17%	5.35%
Special Reserve	806.02	3.52%	2.11%
Hunting Reserve	603.03	2.63%	1.15%
Forest Reserve	544.83	2.38%	10.48%
Total Protection Area	225.92	0.99%	51.53%
Environmental Protection Area	204.10	0.89%	1.48%
National Reserve	50.51	0.22%	3.14%
Ecological Park	0	0.00%	0.00%
Community Conservation Area	0	0.00%	0.00%
Partial Reserve	0	0.00%	0.00%
TOTAL OVERLAP	5819.55	25.39%	3.90%

Note: "Total overlap" refers to overlap between IPAs and any protected area, this total is less than the total for each designation as some protected areas of different designations overlap.

triggering the second highest WEGE value nationally. Compared to Quiterajo, fewer species at this site have been found to be threatened with extinction, resulting in a slightly lower WEGE value. However, this site is still in urgent need of protection from threats including forest clearance for farming of potatoes and other crops and associated increases in uncontrolled burning (Timberlake et al., 2009). Comparisons of satellite images available between September 2013 and November 2015 indicate an estimated forest loss of 10%–30% over this short period (Darbyshire & Timberlake, 2023). These losses are ongoing (Timberlake, 2021) and, without interventions, much of this critical habitat at this site may be lost in the near future.

Few areas outside of the protected area network of Mozambique are free of threats to biodiversity, with some areas severely threatened (Darbyshire et al., 2023). Greater consideration for plant diversity is needed to ensure that the richest IPAs nationally for the rarest and most threatened species, such as Quiterajo and Mount Namuli, are conserved and the extinction of the unique plant diversity they host is prevented. IPAs could serve as a vehicle for addressing the major gaps, such as these, in the protected area network.

Countrywide, protected area distribution has been shown not to be influenced by areas of high plant endemism and extinction risk. There are, however, some examples of good congruence between IPAs and protected areas within some of the flagship national parks of Mozambique, notably the Chimanimani, Gorongosa and Quirimbas National Parks, each with multiple IPAs falling within their boundaries. Chimanimani National Park and Buffer Zone, for instance, was established, in part, to conserve areas of unique plant diversity (Sitefane, 2020) and is a particular success in this respect. This national park is the richest area in the Mozambique for range-restricted plants nationally many of which are endemic to this cross-border mountain range (Osborne & Darbyshire, 2023).

However, the overall distribution of sites managed by the ANAC for conservation purposes, including national parks, does not show a strong relationship with areas of high WEGE value. Across the protected area network as a whole, there has been equally limited consideration for plant diversity. This likely reflects the conservation priorities when many protected areas were established in the 1960s and 1970s—motivated by the presence of wildlife, particularly the utilization of species for trading, food and sport (Soto, 2008). As a result, some areas of particular importance for plant diversity, such as Quiterajo and Mount Namuli, are overlooked within the protected area network.

Through the National Strategy and Action Plan of Biological Diversity of Mozambique 2015–2035 (NSAPBD), developed as part of Mozambique's responsibilities under the CBD, the Mozambican government committed to "have at least 30% of habitats of endemic and/or threatened flora and fauna species with strategies and action plans for their conservation in place" by 2025 and will "identify and describe the Areas of Plant Importance" to achieve this target (MITADER, 2015). The Mozambique TIPAs program has directly delivered on the latter action, but our analysis has identified significant gaps in site-based conservation for these areas critical for endemic and threatened plants in Mozambique. Through conservation of the IPAs identified, whether in protected areas or otherwise, Mozambique could address the current shortfall in protection of these sites and meet their NSAPBD commitment.

However, designation of protected areas alone is insufficient if it is not followed by conservation action. National parks, for example, offer the greatest protection of a site in terms of legal designation but, in practice, the plant diversity within these sites is often still at risk. Quirimbas National Park has lacked funding since its inception and has been adversely affected by agricultural encroachment, deforestation, and extraction of wood for fuel and timber, losing nearly 3020 km^2 of natural vegetation cover between 1999 and 2017 (Mucova et al., 2018). Elsewhere, knowledge gaps prevent the effective management needed to conserve important plant species within protected areas (Darbyshire et al., 2023). The identification of IPAs within the boundaries of national parks and other protected areas highlights the need for and can inform more effective management of plant species within these sites.

In the case of forest reserves, which are not currently managed within the protected area network of Mozambique, an absence of conservation management within those identified as IPAs puts rare and threatened species and habitats at risk. Ribáuè and Mupalue Forest Reserves, for instance, fall within the fourth highest cell for WEGE value nationally but, without conservation management, there are currently no controls on agricultural expansion within reserve boundaries. Forest loss on the two massifs encompassed by each reserve was estimated to be between 35 and 50% in the years 2000–2020 (Montford, 2019). While the biodiversity value of Forest Reserves has been increasingly recognized in recent decades (Müller et al., 2005), it would be highly desirable for those identified as IPAs to be managed for conservation purposes, alongside other protected area designations, by the ANAC. This would create, at the very least, an obligation toward protecting the biodiversity of these sites.

Alongside greater consideration for plant species within conservation management of existing protected areas, the establishment of new protected areas based on IPAs may also be considered. While site-based conservation of plant diversity may not be feasible in some cases, for instance in parts of Cabo Delgado Province where violent insurgencies have resulted in security and humanitarian concerns, there are several sites in Mozambique where the designation of protected areas would be highly appropriate. For example, Mount Namuli IPA, as one of the richest sites nationally for plant diversity, is a prime example of a site that should gain legal protection. Mount Namuli is also important for other taxa and has been recognized as a Key Biodiversity Area with important populations of several rare and threatened amphibian, bird, butterfly, mammal, and reptile species (WCS et al., 2021). The NGO Nitidae and local partners around Namuli established a community-led conservation initiative and aim to legally secure this site as a Community Conservation Area (Darbyshire & Timberlake, 2023). The identification of IPAs and the WEGE index, which highlights high priority IPAs such as this (Table S2), are important resources for informing and motivating the expansion of the protected area network to encompass critical sites for plant conservation.

The "30 by 30" target, adopted at the Convention on Biological Diversity (CBD) COP15, requires Mozambique and countries around the world to conserve 30% of land and seas within protected areas by 2030. Mozambique will have to increase the 23% (Biofund, 2022; UNEP-WCMC & IUCN, 2022) of its land area currently within protected areas to meet this target in under a decade. However, it is important that any expansion is evidence-based to make genuine conservation gains for species and habitats. The relatively small and highly targeted areas identified as IPAs—in total representing only 3% of Mozambique's terrestrial land area (Darbyshire et al., 2023)—would make a great contribution toward the "30 by 30" target and begin to address the omission of critical sites for plant conservation in the protected area network. Using the WEGE scores of each of these IPAs calculated here (Table S1) would also help prioritize sites most in need of conservation—a necessary step where conservation resources are limited.

Throughout the global tropics, biodiversity levels often far exceed resources available to conserve (Adenle et al., 2015). The benefits of the approach taken here, the identification of IPAs and additional prioritization of each of these sites, could be applied elsewhere in the tropics to ensure that plants are not overlooked in conservation actions, without employing "land-hungry" solutions, while also meeting international commitments such as those toward the CBD.

AUTHOR CONTRIBUTIONS

Sophie L. Richards, Harith Farooq, Iain Darbyshire, and Hermenegildo Matimele contributed to the study conceptualization. Data curation was performed by Saba Rokni, Jo Osborne, Iain Darbyshire, Castigo Datizua, Clayton Langa, and Hermenegildo Matimele. Formal analysis was performed by Saba Rokni and Harith Farooq. Data visualization was performed by Saba Rokni. The first draft of the manuscript was written by Saba Rokni and all authors commented on previous versions of the manuscript. All authors read and approved the near-final manuscript.

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CONFLICT OF INTEREST STATEMENT

The authors have no relevant financial or non-financial interests to disclose.

DATA AVAILABILITY STATEMENT

A significant proportion of occurrence data used in this study is available in on GBIF at https://doi.org/10.15468/8enzjm. As occurrence data from third parties have been used in the analysis, we do not have permission to publish the entire occurrence dataset. However, we will deposit the calculated WEGE value data that have been derived the occurrence data. IUCN Red List category for each species was derived from the IUCN Red List of Threatened Species https://www.iucnredlist.org/.

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SUPPORTING INFORMATION

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