Peer review history for:

Kraaij T, Visser V, Pretorius GCP. The distribution and status of rooibos (*Aspalathus linearis*) and its ecotypes in the wild. S Afr J Sci. 2025;121(11/12), Art. #20627. https://doi.org/10.17159/sajs.2025/20627

HOW TO CITE:
The distribution and status of rooibos (*Aspalathus linearis*) and its ecotypes in the wild [peer review history]. S Afr J Sci. 2025;121(11/12), Art. #20627. https://doi.org/10.17159/sajs.2025/20627/peerreview

The original manuscript for review is appended below.

Reviewer 1: Round 1

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Reviewer 2: Round 1
Date completed: 20 May 2025
Conflicts of interest: None

Recommendation: Accept / Revisions required / Resubmit for review / Resubmit elsewhere / Decline / See comments
REVIEWER: Revisions required
Does the manuscript fall within the scope of SAJS? Yes/No
REVIEWER: Yes
Is the manuscript written in a style suitable for a non-specialist and is it of wider interest than to specialists alone? Yes/No
REVIEWER: No
Does the manuscript contain sufficient novel and significant information to justify publication? Yes/No
REVIEWER: Yes
Do the Title and Abstract clearly and accurately reflect the content of the manuscript? Yes/No
REVIEWER: Yes
Is the research problem significant and concisely stated? Yes/No
REVIEWER: Yes
Are the methods described comprehensively? Yes/No
REVIEWER: Yes
Is the statistical treatment appropriate? Yes/No/Not applicable/Not qualified to judge
REVIEWER: Yes
Are the interpretations and conclusions justified by the research results? Yes/Partly/No
REVIEWER: Yes
Please rate the manuscript on overall contribution to the field

Excellent/Good/Average/Below average/Poor

REVIEWER: Good

Please rate the manuscript on language, grammar and tone
Excellent/Good/Average/Below average/Poor

REVIEWER: Excellent

Is the manuscript succinct and free of repetition and redundancies?
Yes/No

REVIEWER: Yes

The number of tables in the manuscript is
Too few/Adequate/Too many/Not applicable

REVIEWER: Adequate

The number of figures in the manuscript is
Too few/Adequate/Too many/Not applicable

REVIEWER: Adequate

Are the results and discussion confined to relevance to the objective(s)?
Yes/No

REVIEWER: Yes

Is the supplementary material relevant and separated appropriately from the main document?
Yes/No/Not applicable

REVIEWER: Yes

Please rate the manuscript on overall quality
Excellent/Good/Average/Below average/Poor

REVIEWER: Good

Is appropriate and adequate reference made to other work in the field?
Yes/No

REVIEWER: Yes

Is it stated that ethical approval was granted by an institutional ethics committee for studies involving human subjects and non-human vertebrates?
Yes/No/Not applicable

REVIEWER: Not applicable

If accepted, would you recommend that the article receives priority publication?
Yes/No

REVIEWER: No

Are you willing to review a revision of this manuscript?
Yes/No

REVIEWER: Yes

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Yes/No

REVIEWER: Yes

Comments to the Author:
This manuscript describes the current status and distribution of the various wild rooibos ecotypes found in South Africa, which is limited to the Western and North-West regions of the country. The authors consulted all current publications on the topic and included a general survey of the occurrence of the different ecotypes in the areas where they have been reported. Through the use of a spatial distribution model, the authors were able to predict the occurrence and potential population size of the different wild rooibos ecotypes, highlighting the current conservation status of wild rooibos in relation to harvesting, overgrazing, fire regimes, and invasive plant species.

Here are specific comments/queries for the authors to address:

1. Keywords: I would suggest adding 'Aspalathus linearis' and/or 'rooibos' to the keywords. 'Wild

rooibos ecotypes' may also be an alternative.

2. Methods: The authors have indicated that ecotypes were recognised based on expertise/previous publications. For non-experts in the field, it would be of great value to include images of the different wild rooibos ecotypes. It would also ensure that if the publications referenced are not accessible, the readers would still be able to see what the different ecotypes are and how they can be identified.
3. Line 317: Here, the authors mention that the minimum winter temperature was found to be the most important environmental correlate. Even though it can be seen from the data presented, the authors need to indicate whether it is positively or negatively correlated.
4. Line 339: 'clinal variation' - should this be 'clonal variation'?
5. Conclusions: In this section, the authors mention the development of tracking programmes to monitor the status of the species. It would be of great value if the authors could expand on this (e.g., the potential use of aerial surveys - positives and negatives of such an approach, etc.), and whether the authors feel if AI could potentially play a role in the rapid identification of the ecotypes, should an aerial survey/digital survey be conducted. In addition, how do the outcomes of the study speak to national conservation efforts/working groups focused on indigenous biological resources? Was this study part of such an initiative?

Author response to Reviewer 2: Round 1

1. Keywords: I would suggest adding 'Aspalathus linearis' and/or 'rooibos' to the keywords. 'Wild rooibos ecotypes' may also be an alternative.

AUTHOR: The journal limits keywords to five, and usually one should not repeat words that occur in the ms title (‘rooibos’ and ‘Aspalathus linearis’ occur in the title). Based on the suggestion, we replaced ‘threats’ with ‘wild rooibos ecotypes’ (L65-66).

2. Methods: The authors have indicated that ecotypes were recognised based on expertise/previous publications. For non-experts in the field, it would be of great value to include images of the different wild rooibos ecotypes. It would also ensure that if the publications referenced are not accessible, the readers would still be able to see what the different ecotypes are and how they can be identified.

AUTHOR: Thank you for the suggestion. We now provide exemplary images of the different ecoyptes in Supplementary S1 and cite the Supplementary in L157, 160, 175.

3. Line 317: Here, the authors mention that the minimum winter temperature was found to be the most important environmental correlate. Even though it can be seen from the data presented, the authors need to indicate whether it is positively or negatively correlated.

AUTHOR: One cannot simply state whether the correlation is positive or negative seeing that the relationships are not linear (see Supplementary S7A,B,C). However, we do state (L317) that “highest suitability [is] at or below freezing temperatures” (citing the Supplementary figure).

4. Line 339: 'clinal variation' - should this be 'clonal variation'?

AUTHOR: Clinal variation is the correct term – it refers to a gradual change in a trait or characteristic across a geographical range. It is also the term that was used by the source (Brooks et al. 2021) that is cited here (L433).

5. Conclusions: In this section, the authors mention the development of tracking programmes to monitor the status of the species. It would be of great value if the authors could expand on this (e.g., the potential use of aerial surveys - positives and negatives of such an approach, etc.), and whether the authors feel if AI could potentially play a role in the rapid identification of the ecotypes, should an aerial survey/digital survey be conducted.

AUTHOR: Thanks for this query. The sparse and varied growth forms (including ground-sprawling under other vegetation) and foliage (and even flower) colours that the wild ecotypes of rooibos assume, greatly challenge attempts at identifying rooibos by means of aerial imagery and/or AI. Opportunities for using aerial imagery (such as drone imagery) and machine learning has been investigated to assist with obtaining yield estimates for commercially cultivated rooibos, but that has not proved feasible due to challenges with discerning the cultivated plants among weeds (G. Pretorius pers. comm. with remote imagery application specialist, Prof. Adriaan van Niekerk, Stellenbosch University). If with the resolution available from current

technology it isn't possible to discern cultivated plants that planted in fields, which have a much more uniform growth form and denser foliage than the array of wild ecotypes, it certainly will not work for the latter at this stage. We added a statement at the end of the Conclusions to this effect (L487-490).

In addition, how do the outcomes of the study speak to national conservation efforts/working groups focused on indigenous biological resources? Was this study part of such an initiative?

AUTHOR: We now expanded in the Introduction (L94-96) on the context of this study, rooted in a resource assessment that was commissioned by the South African government with the aim to inform potential trade regulation, and conservation assessment of the species. We also explicitly stated at the end of the Introduction (L126-128) and in the Conclusions (L485-487) that this resource assessment, which is partly reported in the current study, set a baseline for future monitoring.

Reviewer 2: Round 2
Date completed: 22 July 2025
Conflicts of interest: None

Recommendation:
Accept / Revisions required / Resubmit for review / Resubmit elsewhere / Decline / See comments

REVIEWER: Accept

Does the manuscript fall within the scope of SAJS?
Yes/No

REVIEWER: Yes

Is the manuscript written in a style suitable for a non-specialist and is it of wider interest than to specialists alone?
Yes/No

REVIEWER: Yes

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Yes/No

REVIEWER: Yes

Do the Title and Abstract clearly and accurately reflect the content of the manuscript?
Yes/No

REVIEWER: Yes

Is the research problem significant and concisely stated?
Yes/No

REVIEWER: Yes

Are the methods described comprehensively?
Yes/No

REVIEWER: Yes

Is the statistical treatment appropriate?
Yes/No/Not applicable/Not qualified to judge

REVIEWER: Yes

Are the interpretations and conclusions justified by the research results?
Yes/Partly/No

REVIEWER: Yes

Please rate the manuscript on overall contribution to the field
Excellent/Good/Average/Below average/Poor

REVIEWER: Excellent

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Yes/No

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REVIEWER: Not applicable

If accepted, would you recommend that the article receives priority publication?
Yes/No

REVIEWER: Yes

Are you willing to review a revision of this manuscript?
Yes/No

REVIEWER: Yes

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Yes/No

REVIEWER: Yes

Comments to the Author:
Thank you for addressing the comments/queries/suggestions raised during the review process.

The distribution and status of rooibos (*A spalathus linearis*) and its ecotypes in the wild

Abstract

Aspalathus linearis ('rooibos') is a polymorphic perennial shrub native to the Fynbos Biome (South Africa), which is commercially cultivated and harvested from the wild to produce rooibos tea, a herbal health drink. Ongoing utilisation of the species necessitates knowledge of the status of the species in the wild to facilitate sustainable management of the resource. Here we assessed for wild rooibos and its ecotypes, respectively, their current occurrence, potential distribution, population size, and threats to their persistence. We confirmed previous accounts of the distribution range of wild rooibos, although it was absent from historically recorded locations south of Malmesbury. The predicted distribution range of the species is almost 600 000 ha, with relatively little overlap in the predicted ranges of the respective ecotypes (120 000–250 000 ha each). Based on the predicted distribution ranges in conjunction with field-observed population densities, the total population of wild rooibos is estimated to be at least 15 million plants and each ecotype at least 3 million. More than a quarter of the species' predicted range (20–40% of each ecotype's range) occurs in proclaimed protected areas. Our evaluation of threats suggests that wild rooibos is not significantly threatened by harvesting, invasive alien plants, overgrazing, or inappropriate fire regimes. Potential genetic contamination with cultivated varieties, and further large-scale agricultural transformation are unlikely, while climate change arguably constitutes the largest threat. These findings are promising for securing the wild resource in future and valuable to inform conservation status and sustainability assessments, resource management and monitoring.

Keywords

biotrade resource; conservation status; population size; species distribution modelling; threats

Significance

- The study presents a national assessment of the status of a biotrade resource, rooibos (*Aspalathus linearis*), in the wild.
- The species' estimated population is at least 15 million plants and its predicted distribution 600 000 ha of which >25% occurs in proclaimed protected areas.
- Climate change arguably constitutes the largest threat to wild rooibos, more than harvesting, inappropriate fire regimes, genetic contamination, and further habitat transformation.
- These findings are promising for securing the wild resource in future and valuable to inform conservation status (e.g. IUCN Red List) and sustainability (e.g. CITES Non-Detriment Finding) assessments and monitoring.

Please see figures, tables and supplementary material at the end of the document.

Introduction

Aspalathus linearis (Burm.f.) Dahlg., or 'rooibos', is a highly polymorphic perennial shrub endemic to drier areas of the truly winter-rainfall, northwestern part of the Fynbos Biome[1,2] within the hyperdiverse Cape Floristic Region[3] of South Africa. Rooibos is commercially cultivated on a large scale to produce rooibos tea, a traditional herbal health drink, marketed internationally.[4] Rooibos tea is a well-established and organized industry with relatively stable production mass annually. Presently, only a very small portion of the produce (0.001% of approx. 20 000 metric tons annually) comes from wild harvested populations ([anonymised], unpubl. data), but prior to the 20th century, rooibos tea was exclusively collected in the wild[5]. With the ongoing utilisation of wild populations of the species, knowledge of its distribution, abundance, ecology, and potential threats to its persistence is vital for the sustainable management of the resource. Such foundational knowledge is also required to inform conservation status assessments (e.g., using IUCN Red List criteria)[6] and potential trade regulation (e.g., following the Non-Detriment Finding process used by CITES)[7].

Accordingly, a resource status assessment[8] was recently undertaken for rooibos in the wild with aspects related to its population ecology and effects of harvesting presented by [anonymised][9]. The current paper addresses additional aspects focussed on the distribution and abundance of, and threats to, the species and its respective ecotypes. Existing information on the distribution of rooibos is outdated or patchy, comprising parts of studies focussed on the species' taxonomy, morphology[1,2,5,10], phenolic and phytopharmaceutical properties[11-13], and genetic variation[14-16]. The current distribution of the species has not been field-verified comprehensively, and the distributions of the ecotypes have not been adequately distinguished. Lötter and Le Maitre[17] modelled the potential distribution of rooibos in cultivation and in the wild, and implications of climate change for the utilisation of the species but have not considered the ecotypes separately. The current paper, therefore, assesses for rooibos in the wild and for its ecotypes respectively: (i) their current occurrence, (ii) their potential distribution, (iii) their population size, and (iv) threats to their persistence. With this information and by drawing on a related study[9], we provide a coherent assessment of the species' status in the wild.

Study species

Rooibos occurs in the winter rainfall area from Vanrhynsdorp in the north to the Cape Peninsula and the Betty's Bay area in the south, while unconfirmed records exist as far east as Riviersonderend and Bredasdorp.[1,17] Rooibos' range is characterised by cold wet winters and hot dry summers with 300–900 mm of rain per annum with no known occurrence records in the bimodal or summer rainfall regions of South Africa.[1,17] The species occurs at elevations of 450–900 metres above sea level and is adapted to deep, well-drained, oligotrophic and acidic sands.[18] Malgas et al.[5] mapped the potential distribution of wild rooibos based on bioclimatic suitability for the species but have not clearly quantified the bioclimatic parameters that are deemed suitable for

the species' occurrence. They recommended consideration of soil factors in attempts at modelling the potential distribution of the species, in addition to investigation of bioclimatic correlates of the ecotypes separately. Lötter and Le Maitre[17] also performed bioclimatic modelling to estimate the realized niche of wild rooibos and the range suitable for cultivation under the contemporary climate and a future climate change scenario.

The ecology and harvesting of rooibos are detailed by [anonymised] (submitted). Rooibos is an extremely variable species complex displaying distinct ecotypes or geographical forms.[1,2,14] Additionally, some other closely related species, like *A. pendula* Dahlg. and *A. lebeckioides* Dahlg, may be difficult to distinguish from wild rooibos.[11] These taxonomic and identification issues complicate attempts to verify historical location records and to map the distribution of *A. linearis*. Moreover, differentiation among the ecotypes of wild rooibos, with the view to delineate and compare their distributions, is equally challenging, with several categorisations in existence that show overlap and differences.[5,10,11,15]

The ecotypes differ in habit, fire-survival strategy, vegetative and reproductive morphology, biochemistry, and genetics.[11,14,15] Local land users identified four main growth forms, namely an 'Erect' or 'Upright' form, a 'Prostrate form', a 'Bush' or 'Shrub' form, and a 'Tree' form, although Malgas et al.[5] included the Tree form with the Erect form. Both the Bush and Prostrate forms are wider than they are tall and possess more stems closer to the ground than the Erect form.[5] Hawkins et al.[10] later additionally identified the 'Salignus' type, a tall (2–3 m), lanky, willow-like, form with a sparse canopy. Prostrate and Shrub forms resprout after fire while the Erect, Tree, and Salignus forms regenerate from seed only. The cultivated 'Nortier' form of the species originates from the upright and densely-branched Erect form[11], resembling in habit the Bush and Erect types[10]. The Erect and cultivated forms possess the highest harvestable biomass.[5]

Distribution and habitat preferences are evident between the ecotypes where the Bush, Prostrate and Tree types occur towards the northern part of the species' range, and the Prostrate, Erect and Salignus types toward the south.[10] Prostrate and Erect ecotypes occur at higher elevations (>400–600 masl), the Bush type at lower rainfall sites (<200 mm p.a.) and the Salignus type at higher rainfall sites (>500 mm p.a.) at lower elevation. Ecotypes co-occur at the regional scale, e.g. Erect and Prostrate, or Bush and Prostrate occurring in the same region, whereas co-occurrence at the local scale (e.g. Prostrate and Erect occurring interspersed) is possible but uncommon.[10] For the purposes of this resource assessment, we differentiated four ecotypes, i.e.: (i) Bush (including Bush and Shrub forms), (ii) Prostrate, (iii) Erect (including Erect, Upright and Tree forms), and (iv) Salignus (after [anonymised][9]).

Methods

Current occurrence

All obtainable geo-referenced data on historically recorded wild rooibos were collated in a GIS shapefile. These data were sourced from GBIF (https://www.gbif.org/) and CapeNature databases, published research[5,10,11,14,17], and author (anonymous) and expert knowledge of wild populations. Historically recorded locations were revisited in the field as far as possible to establish the species' presence or absence at these locations. En route to these locations and to sites where population surveys were undertaken by [authors][9], additional observations were made along roadsides of the species' presence or absence. Georeferenced pictures were taken of rooibos plants present at these locations and the specific ecotype determined from the pictures. All verified and new occurrence locations of wild rooibos and its respective ecotypes were collated in a GIS database.

Species distribution modelling

We used maximum entropy (MaxEnt) modelling in R[19] using the package *dismo* to predict the distribution of wild rooibos (detailed methods in Supplementary S1). The field-verified location records (*n*=146) of the species and ecotypes were used as input data for the SDM (Supplementary S2). After removal of duplicate occurrences within individual pixels of ~1 km resolution of the environmental predictor rasters, 100 occurrences were used for modelling potential distributions. This included 12 records for the Bush type, 42 for Prostrate, 33 for Erect, and 13 for Salignus. Predictor variables used were precipitation of warmest quarter, precipitation of coldest quarter, maximum temperature of warmest month, minimum temperature of coldest month, topographical slope, soil electrical conductivity, soil K, Na, P, C, N, and pH, and percentage sand. Models were evaluated using the area under the receiver operating characteristic curve (AUC). We used the *cloglog* output of MaxEnt to predict the distribution of rooibos, both as an entire species and for individual ecotypes. This output serves as an indicator of relative environmental suitability.[20] To capture model uncertainty, we generated weighted mean suitability maps for the species and ecotypes based on an ensemble of 100 model runs with varied model choices and parameter settings.[21] For easier interpretation, we converted these weighted mean suitability maps into binary presence/absence maps by applying a threshold. To assess environmental factors that potentially affect the distribution of rooibos and its ecotypes, we produced response curves illustrating the relationship between each environmental predictor and the predicted relative suitability.

Population size and extent of protection

Crude estimates of the total population size of *A. linearis* and of the ecotypes, respectively, were calculated as a basic multiplication of the range of plant densities at which the species occurred (obtained from population surveys of [anonymised][9]) with the sizes of the predicted distribution ranges obtained from our species distribution modelling. The estimates of plant density derived from the population surveys included 14 estimates for the Bush type, 13 for Erect, 10 for Prostrate, and 5 for the Salignus type. The areas predicted to be occupied by the species and the ecotypes,

respectively, were based on the binary presence/absence predictions from the distribution modelling. The mean, minimum and maximum density of plants for the species and for each ecotype were then multiplied with the area of the predicted distribution range to provide three estimates of the population size for the species and ecotypes, respectively (i.e., population size estimates based on mean, minimum and maximum density). These estimates were interpreted with knowledge of the spatial distribution of populations in the landscape[9]. To determine the proportion of the species' and ecotypes' ranges that occur inside of proclaimed protected areas, we overlaid the predicted distribution ranges of the species and ecotypes, respectively, with a spatial layer of proclaimed protected areas (https://portal.environment.gov.za/PortalDownloads/PACA_Gazettes/ PA) in GIS.

Threats

Information on potential threats to wild rooibos was obtained from (i) the literature, (ii) discussions with land managers or harvesters, and (iii) observations or data collected during field work undertaken for the current study and the population surveys of [anonymised][9]. We furthermore assessed in GIS the occurrence of fields of cultivated rooibos within the predicted distribution range of wild rooibos and calculated the distances from cultivated rooibos to our field-verified locations of wild rooibos and to the population survey sites.

Results & Discussion

Current occurrence

A total of 235 historical location records were assimilated which informed field verification of the species' current occurrence. The species was absent at 30, and present at 47 of these locations, and recorded at 99 new locations (Figure 1). The easternmost confirmed population was at De Doorns, while rooibos was not found at an outlier north of Nieuwoudtville and one east of Vanrhynsdorp, and some locations around Citrusdal. Notably, wild rooibos was not found at any of the historical locations south of Malmesbury, at Franschoek, on the Cape Peninsula, or the Gordons Bay and Bettys Bay areas[11]. It is unclear whether the absence of *A. linearis* south of Malmesbury indicates a change in the species' distribution, inaccurate historical records, or misidentifications. More comprehensive verification of data associated with herbarium specimens is required to solve this. In many cases where rooibos was absent from historically recorded locations, the habitat at these locations were clearly unsuitable for rooibos, i.e., very steep slopes, clay soils, or wetlands, and lacking the plant assemblages commonly associated with wild rooibos populations. While it is possible that the species occurs in some of these outlying areas, it seems clear from field-verification that the species mainly occurs in the area between Nieuwoudtville in the north, Groot Winterhoek in the south, Wupperthal and the Tra-Tra mountains in the east, and just southeast of Graafwater in the west.

Predicted distributions

MaxEnt models for rooibos and its ecotypes all exhibited high accuracy (AUC values of 0.95–0.98) which lends confidence to the predicted distributions. For the species as a whole, the predicted distribution stretches from Nieuwoudtville in the north to just southeast of Ceres, with the bulk of its distribution around Clanwilliam and Citrusdal (Figure 2; Supplementary S3). This largely matches descriptive accounts of the species' distribution[1], although our predicted distribution extends beyond Vanrhynsdorp to Nieuwoudtville, but not southward beyond Ceres to the Cape Peninsula and Bettys Bay. The latter is owing to our input data not including confirmed presences of the species in the south (Figure 1; Supplementary S2). Compared to the suitability map predicted by Lötter and Le Maitre[17] under contemporary climate, our predicted distribution range has a similar boundary, but with a larger area of suitability predicted within. The area predicted by the species distribution model to be occupied by wild *A. linearis* is almost 600 000 ha in extent while the areas predicted to be occupied by the respective ecotypes ranged between approx. 120 000 and 250 000 ha (Table 2). The Salignus ecotype had the largest predicted area occupied, followed by the Prostrate type, Bush type and lastly, the Erect type.

The ecotypes exhibited distinct but somewhat overlapping predicted distributions (Figure 2). Only at the core of the entire species distribution was there substantial overlap of the ecotypes (Supplementary S4). Note that the predicted distribution for the entire species does not equal the sum of the predicted distributions of the respective ecotypes (minus duplication due to overlaps). This is because the predicted distribution for each entity (species or ecotype) is based on its own model determining suitability for that entity, and compared to the entire species, the ecotypes seem to have higher suitability at the extremes of their ranges (Supplementary S3, S4) and higher thresholds for defining presence or absence. The Bush and Prostrate (both resprouter) ecotypes had fairly similar predicted distributions, largely to the east and south of Clanwilliam and Citrusdal (Figure 2). The Erect and Salignus (both reseeder) ecotypes also had similar distributions but differed from the other two ecotypes in that their distributions extended to the west and north of Clanwilliam and Citrusdal. The Salignus ecotype was the only ecotype predicted to have a distribution extending further south to around Ceres and west beyond Piketbeg with predicted occurrences in these areas larger in extent than a few insubstantial dots. These predictions of ecotype distributions only partially match the descriptions of ecotype distribution by Hawkins et al.[10] gleaned from field observations. These authors stated that the Bush and Tree types occur towards the northern part of the species' range, the Erect and Salignus types towards the south, and the Prostrate type across the range from north to south. Our predictions show more of a distinction in distribution of the resprouter forms (Bush and Prostrate) vs reseeder forms (Erect and Salignus) between northeast and southwest, with the Salignus type's distribution being the most encompassing.

Environmental correlates of distribution

Ecotypes exhibited unique patterns in terms of the importance of variables as correlates of distribution with little overlap of variable importance ranking (Table 1). The minimum temperature of the coldest month came out as the most important correlate of distributions for rooibos and for the Bush and Prostrate resprouter ecotypes (Importance values from 45% to 52%), and exhibited highest suitability at or below freezing temperatures (Supplementary S5A,B,C). Precipitation of the warmest quarter was the second most important variable for the species and the same two ecotypes (14% to 33%), and exhibited highest suitability for low precipitation in summer (Supplementary S5A,B,C). Potassium (K) was the most important correlate for the Erect and Salignus reseeder ecotypes (41% and 70%, respectively), with suitability being highest at very low values of K (Supplementary S5D,E). Soil electrical conductivity was furthermore important for the Erect type with high suitability at very low conductivity (Supplementary SD). Carbon (C) was moderately important for the Erect and Prostrate types with high suitability at low levels of C (Supplementary S5C,D). Comparing our results with Lötter and Le Maitre[17], both studies found low minimum winter temperatures and low summer precipitation as important variables, but the other study found winter precipitation to be the most important variable and slopes of 3–10° to be moderately important, whereas precipitation in the coldest quarter and slope showed zero or near zero importance in our study.

Population size

Note that the population size estimates, due to being based on the predicted distributions derived from distinct models, for the species do not equal the sum of those of the respective ecotypes (Table 2). The total population size estimated for *A. linearis*, based on the area of the predicted distribution range in conjunction with population densities recorded by [anonymised][9], ranged between approximately 15 million and 17 billion plants (Table 2). The population sizes estimated for the respective ecotypes ranged between approximately 3 million and 5 billion plants. The Prostrate ecotype was most numerous, followed by the Bush type or the Salignus type, depending on the field density measurement considered (mean, minimum or maximum). The Erect ecotype thus had the smallest predicted range and the smallest estimated population size.

These estimates, though, need to be interpreted with circumspection, as the characteristics of the species' distribution and abundance in the landscape significantly challenged attempts at estimating total population size. Some ecotypes, such as the Salignus type, was discernible amongst other vegetation due to its upright and tall growth form, making visual assessment of the distribution and abundance of plants reasonably achievable. With the Prostrate type, this was much more difficult. Throughout its range, wild rooibos exhibits a highly irregular, clumped distribution of populations scattered across the landscape, with populations typically occupying only a small part of seemingly suitable, homogenous swathes of habitat ([anonymised], pers. obs.).

Moreover, there was very large variation in the size of populations (a few to tens of thousands of plants) and the density of individuals within populations (25 to almost 30 000 plants per hectare).[9] Extrapolating such a vast range in densities across large areas is a crude exercise which may lead to substantial compilation of error. The population density surveys were furthermore typically done in areas where plants were sufficiently dense for the population to be recognised from a moving vehicle, and sufficiently dense to enable recording of 50 individuals with reasonable survey effort. These constraints compelled surveys to be focussed on the higher end of the population density spectrum, which would have led to overestimation of population densities and subsequently of population sizes. Population densities, furthermore, not only vary in space but also in time, such as with fire frequency and post-fire vegetation age.[9] The derived population size estimates thus apply to a particular point in time, but it should be assumed that the total population size of rooibos will vary in time in relation to the extent of different post-fire vegetation ages in its distribution range.

Considering the abovementioned complexities and extensive extrapolation inherent to the estimation of the population sizes of *A. linearis* and its ecotypes, realistically, population sizes are likely closer to the bottom end of the estimated ranges. Owing to the inherent characteristics of the species' occurrence, more rigorous population size estimates would require systematic surveys of the species presence/absence in grid cells to determine variation in the density of populations across the landscape, in addition to widely replicated assessments of plant density within grid cells (within populations).

Extent of protection

More than a quarter (27%) of the predicted distribution range of *A. linearis* occurs within proclaimed protected areas on state or private land (Supplementary S6). When considering the ecotypes separately, 28% of the Bush type's predicted range occurs within proclaimed protected areas, 38% of the Prostrate type's range, 20% of the Erect type's range, and 33% of the Salignus type's range. A third to more than a half (entire species 37%, Bush type 45%, Prostrate type 36%, Erect type 57%, Salignus type 39%) of these areas are represented by protected areas on state land. The species as a whole, and all the ecotypes, are thus well conserved.

Threats

At 40% of the population survey sites of [anonymised][9] no obvious threats to the study species were noted. Overharvesting or illegal harvesting was deemed a threat at 13% of the sites, but generally, overharvesting and illegal harvesting were not found to be major threats to the wild resource.[9] Land transformation was considered a threat at 28% of sites but the terrain in many of these areas was unsuitable for rooibos cultivation, while legal regulations applicable to vegetation clearing may also deter further large-scale transformation. Overgrazing was deemed a threat at 4% of sites but no direct evidence was found that overgrazing has led to severe degradation of habitat

where wild rooibos occurs, or that it has caused mortality of wild rooibos plants. Invasive alien plants were considered a threat at 15% of the sites, virtually exclusively due to the presence of *Cuscuta campestris* ('Dodder'), a parasitic climber. Although *Acacia saligna* and *Acacia cyclops* both commonly invade cultivated rooibos fields, the latter occurred at a single site, while no other woody invasive species were noted, suggesting that invasive alien plants do not pose a substantial threat to wild rooibos populations. Changing fire regimes, and in particular, too frequent and too severe fires, threaten the persistence of biodiversity in the Fynbos Biome generally[22], but [anonymised][9] argued that inappropriate or changing fire regimes are unlikely to threaten wild rooibos, on account of long fire return periods recorded in its range and the species' ecological resilience to fire.

Climate change is predicted to severely affect the truly winter-rainfall, northwestern part of the Fynbos Biome[23,24] which coincides with the distribution range of wild rooibos. Given that minimum winter temperatures proved to be the most important environmental correlate of *A. linearis*' present distribution (Table 1), climate warming may be expected to have severe impacts on rooibos. During the population surveys, at least two wild rooibos populations appeared to have been negatively affected (widespread mortality) by unusually high rainfall during the preceding summer, which is consistent with the result that the species exhibits preference for low precipitation in summer (Table 1). It is known that rooibos, also in cultivation, requires well-drained soil and is susceptible to mortality if subjected to water-logged soils. If climate change results in more frequent episodes of extreme rainfall, as is expected, this phenomenon may threaten the wellbeing of the species. Lötter and Le Maitre[17] modelled a potential range shift of wild *A. linearis* (without consideration of the respective ecotypes) under a scenario of climate change and accordingly predicted a southeastward and upslope shift for the species but, more encouragingly, showed that most of the areas where range expansion was indicated occur in existing conservation areas or include conservation-worthy vegetation. We did not repeat this type of assessment as these findings seem sufficiently current and informative to guide conservation efforts aimed at buffering potential effects of climate change on the species. However, distinctive modelling of potential climate change effects on each of the ecotypes would be instructive.

Hybridisation seems unlikely in wild rooibos as morphological differences between ecotypes are evidently maintained even where such types occur in close proximity.[11] Isolation by distance, and geographical barriers such as mountains and deep river valleys, may play a role in gene flow in rooibos, limiting both pollination between sub-populations and seed dispersal by ants.[16] Wild rooibos displays low to moderate genetic diversity, with populations becoming less diverse south of the Suid Bokkeveld toward the Cederberg, possibly indicative of clinal variation.[16] Reseeding and resprouting populations evidently differ genetically.[14,15] The distinctness of ecotypes suggests that seed dispersal is slow and that sub-populations are worthy of conservation.[5,10,16]

We found that the predicted distribution range of wild rooibos encompasses 4181 fields of cultivated rooibos (out of a total of >9000 fields in South Africa) although all these fields do not necessarily always have standing crops. Fifty-five of our 146 verified current locations of wild rooibos (Figure 1) occur within 1 km of cultivated rooibos, while 17 of the 45 population survey sites[9] occur within 1 km of cultivated rooibos (Supplementary S7). These are very crude approximations, but they suggest that, if hybridisation is genetically feasible, less than half of the populations of wild rooibos may be at some risk of hybridisation by virtue of occurring relatively close to cultivated plants. Conversely, wild populations also occur at sites remote from cultivation, as cultivation in the vicinity is impractical. At none of the population survey sites were cultivated plants observed interspersed with wild plants. It furthermore appeared that cultivated plants do not persist very well, or reseed naturally, on old fields after cultivation has ceased. In the absence of a satisfactory infraspecific classification of the species[11], it is not known to what extent the ecotypes can or do hybridise, but it may be fair to assume that hybridisation between resprouter and reseeder types is less likely than within resprouter or reseeder types. Accordingly, some specimens were observed during the current study that seemed intermediate between the Erect and Salignus type, as well as specimens intermediate between the Shrub and Prostrate types. Given that cultivated rooibos originates exclusively from the Erect ecotype,[11] the risk of genetic contamination is likely to be the highest for reseeder types and the Erect ecotype in particular. Overall, these pieces of ad hoc evidence imply that genetic contamination with cultivated forms is unlikely to pose a substantial threat to wild rooibos. On the other hand, considering that wild Cederberg reseeding populations are genetically distinct from the wild Northern Cape resprouting populations, appropriate management of wild resources and the establishment of a genetic conservation strategy for wild ecotypes is a priority.[16]

Conclusions

This assessment showed that, at a national scale, the distribution range of wild *A. linearis* is restricted and fragmented (totalling approx. 600 000 ha), but that the species is common within this range with a total population estimated at a minimum of 15 million plants. Furthermore, a large part (27%) of the species' predicted distribution range, and of the respective ecotypes' predicted ranges, occur within proclaimed protected areas suggesting that more than a quarter of the range (and total population, assuming even distribution throughout the range) of the species, and 20–40% of the ranges of the ecotypes are managed for conservation, often on state land. Among the ecotypes, the Salignus and Prostrate types seem most secure, having the largest predicted distribution ranges and the largest portions of their ranges (33% and 38%, respectively) within proclaimed protected areas. The Erect type is least conserved (albeit still in a good state), having 20% of its range within proclaimed protected areas. Our evaluation of threats suggests that the long-term persistence of *A. linearis* in the wild is not significantly threatened by overharvesting or

illegal harvesting, invasive alien plants, overgrazing, or inappropriate fire regimes. Potential genetic contamination of wild rooibos with cultivated varieties is also unlikely to pose a threat to all but perhaps the Erect ecotype, unless the cultivation footprint expands considerably. The extent to which land clearing for rooibos cultivation and potato farming is ongoing within the wild rooibos range has not been directly investigated here, but informal observations suggest that there are relatively few places where habitat transformation is likely to threaten wild rooibos populations at a considerable scale. Climate change probably constitutes the largest threat to wild *A. linearis*, with substantial range contractions predicted for the species, and limited options available for mitigation. Overall, our findings of the state of wild rooibos are promising for securing this biotrade resource in future, and furthermore of value to inform sustainable management, potential conservation status evaluations, sustainability assessments[25], and to develop monitoring programmes for tracking the condition of the resource in future[26].

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475 **Table 1.** Importance of variables as correlates of ecotype distributions. Variable importance is a
476 mean of all 100 model runs and derived from the variable permutation importance calculated in
477 MaxEnt (measured as a percentage), where shades of red indicate high importance and blue, low
478 importance.

Variable	Species	Bush resprouter	Erect reseeder	Prostrate resprouter	Salignus reseeder
Max Temp Warmest Month	5	0	5	0	1
Min Temp Coldest Month	51	45	4	52	1
Precipitation Warmest Quarter	14	33	9	24	9
Precipitation Coldest Quarter	0	0	0	0	0
Soil electrical conductivity	4	4	22	4	7
K	8	0	41	3	70
Na	0	1	0	0	0
P	0	1	0	0	0
C	2	7	12	16	7
N	1	0	2	0	0
pH	5	0	4	0	3
Sand	8	1	0	1	0
Slope	1	7	1	0	1

479

Table 2. Population estimates for rooibos as a species and its ecotypes based on the predicted distribution ranges and field-derived densities (from [anonymised], submitted) for each ecotype. Because densities were variable across sites, population estimates were provided based on the mean, minimum and maximum plant density per ecotype.

Ecotype	Area occupied (ha)	Density: mean (plants/ha)	Density: minimum (plants/ha)	Density: maximum (plants/ha)	Population based on mean density	Population based on min density	Population based on max density
Species	589,700	3,019	25	28,889	1,780,264,533	14,742,496	17,035,838,961
Bush	121,085	2,686	109	11,087	325,173,829	13,198,268	1,342,469,650
Erect	119,884	1,578	25	6,951	189,139,788	2,997,096	833,312,465
Prostrate	161,161	5,355	27	28,889	863,000,201	4,351,343	4,655,775,610
Salignus	254,576	1,533	564	2,476	390,315,282	143,580,628	630,329,140

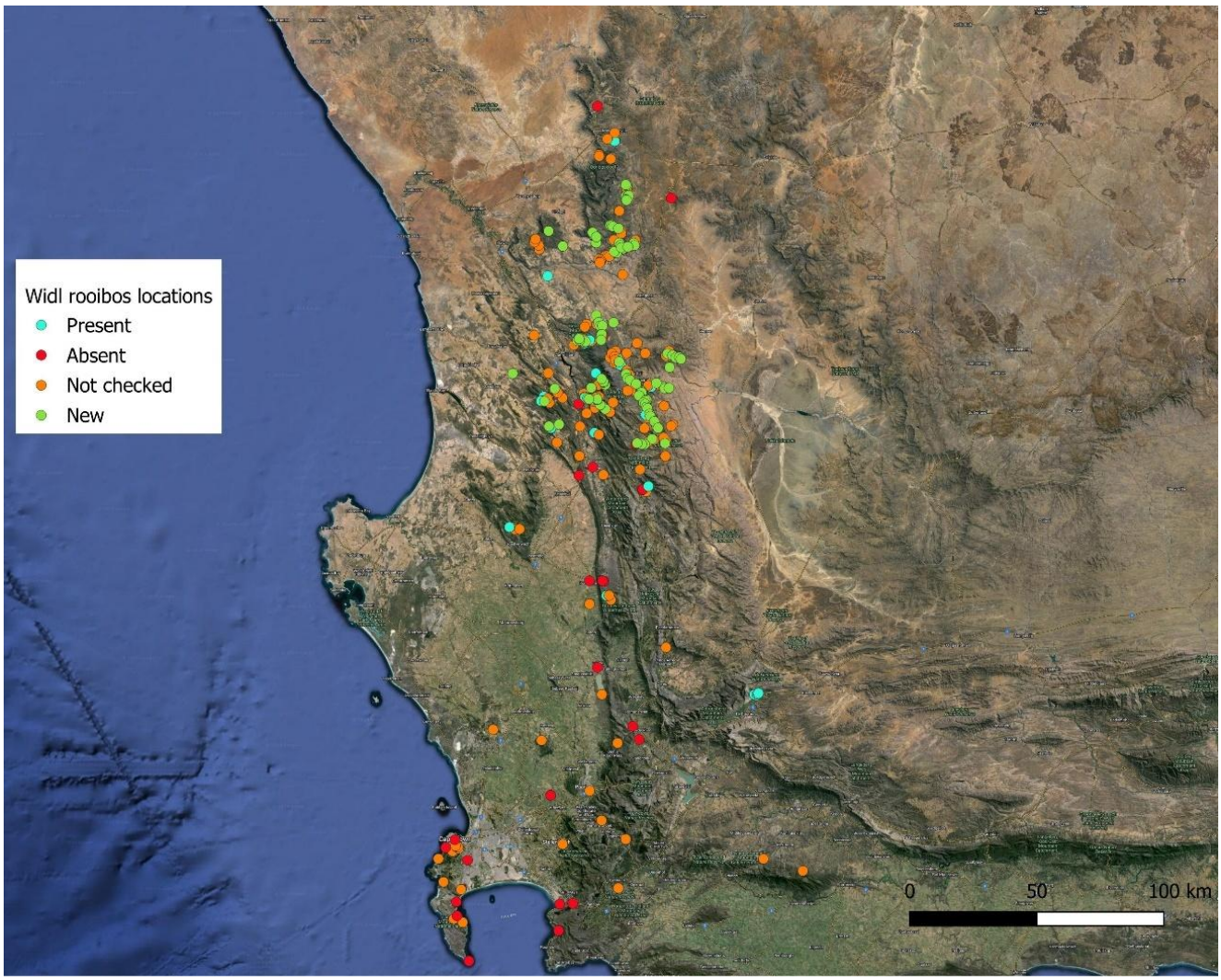

Figure 1. Results of field verification of historical location records of wild rooibos, showing where rooibos was present, absent, or not verified, as well as new location records.

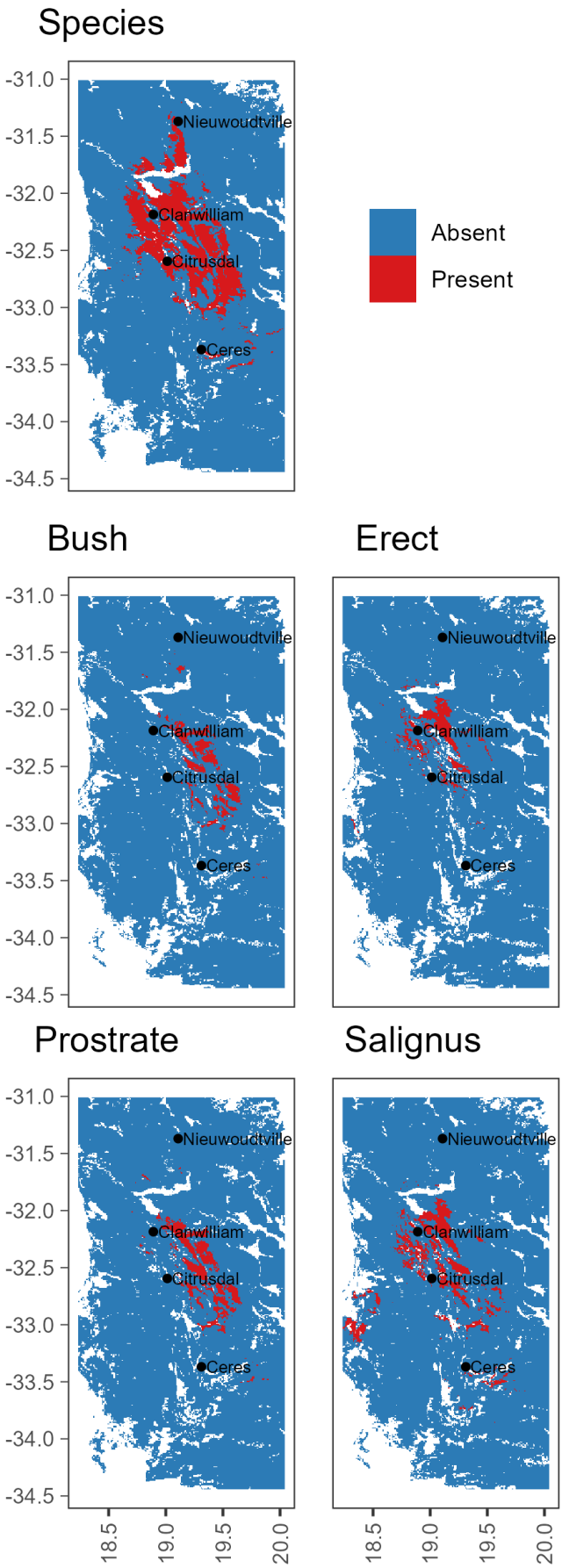

Figure 2. Predicted distributions of wild *Aspalathus linearis* for the species as a whole (Species) and for each of the four ecotypes. Red indicates predicted presence and blue predicted absence.

Supplementary material

Supplementary S1. Detailed description of methods used in species distribution modelling of *Aspalathus linearis*.

Modelling approach

MaxEnt is a machine learning algorithm used for modelling species distributions. It predicts the relative suitability (0 to 1) for a species' occurrence across a landscape based on environmental predictor variables (Guillera-Arroita et al., 2014). MaxEnt works by finding the probability distribution of maximum entropy (i.e., the most spread out or least constrained distribution) that matches the constraints imposed by the environmental variables and known species occurrences (Elith et al., 2011). MaxEnt is among the best performing species distribution modelling methods and has been widely used in ecology, conservation biology, and biogeography to predict species distributions and habitat suitability under current and future environmental conditions (Philips & Dudík, 2008; Ahmadi et al., 2023).

Although MaxEnt generally performs well for modelling species distributions, a few model choices and parameter settings can affect model outputs (Merow et al., 2013). We therefore used an ensemble modelling approach to capture model uncertainty (Araújo et al., 2019) in which 100 models were run for each ecotype (including the species as a whole), with settings determined by a Sobol sampling process that allowed for uniform sample values or options from across the full range of model settings (explained below; see Convertino et al., 2014 for a similar approach). The MaxEnt settings of interest that were sampled, as described above, were as follows: (i) the number of pseudo-absences selected within the study area, ranging from twice the number of occurrences to 20 000 (Liu et al., 2019); (ii) the MaxEnt regularisation parameter, which we allowed to vary from 1 to 5 (Merow et al., 2013); (iii) MaxEnt features - linear (L), quadratic (Q), and product (P), with a choice allowed from the combinations, LQ, LP, QP or LQP (Merow et al., 2013). To conduct the Sobol sampling across the continuum of parameter specifications described above, we used the parameterSets function from the R package *sensitivity* to generate 100 different model setting combinations.

Occurrences

The data collected to determine the current occurrence of the species and ecotypes were used as input data for the models. These data comprised a total of 126 field-verified location records for wild rooibos, representing the four different ecotypes (Figure 1). After removing duplicate occurrences within individual pixels of the ~1 km resolution environmental predictor rasters (see section below), we were left with 100 occurrences. For modelling potential distributions, we used all 100 occurrences to model rooibos as a species in its entirety, including 12 occurrences for the Bush ecotype, 42 for the Prostrate ecotype, 33 for the Erect type, and 13 for the Salignus type (Supplementary S2).

Environmental predictors

We based our selection of potential predictor variables for the distribution of rooibos and its ecotypes on Lötter and Le Maitre (2014), who investigated the potential distribution of rooibos under contemporary and future climate conditions. Climate variables, including total summer and winter rainfall, and maximum summer and minimum winter temperatures were argued to be the main factors affecting the distribution of this species (Lötter & Le Maitre 2014). From the CHELSA high resolution (30 arcsec, ~1 km) dataset (https://chelsa-climate.org/), we used four bioclimatic variables: Precipitation of Warmest Quarter (BIO18), Precipitation of Coldest Quarter (BIO19), Maximum Temperature of Warmest Month (BIO5), and Minimum Temperature of Coldest Month. Topographical and soil factors are other potentially important factors affecting rooibos distribution (Malgas et al., 2010; Lötter & Le Maitre 2014). We derived topographical slope for the study region using the ~30 m NASADEM digital elevation model and aggregated this to the same ~1 km resolution

as the climate data. We used seven soil chemical layers from a dataset developed specifically for the Cape Floristic region which included: soil electrical conductivity, K, Na, P, C, N, and pH (Cramer et al., 2019). Three layers representing soil structural properties, clay, silt and sand percentages, were obtained from the 250 m resolution global ISRIC SoilGrids dataset (https://soilgrids.org/). We calculated the percentage clay, silt and sand for the top 15 cm of the soil profile from the top two soil layers available from SoilGrids, i.e., 0–5 cm and 5–15 cm. From these 15 potential environmental predictors, we selected 13 that were not strongly correlated with one another ($r < |0.8|$), dropping percentage clay and silt.

Model evaluation

All models were evaluated using the mean area under the receiver operating characteristic curve (AUC). For the species as a whole (all ecotypes together), model evaluation was done using five environmentally separated folds using the R package *blockCV,* i.e., 80% of the data were used for model training and 20% for testing, with each fold being used for testing (Valavi et al., 2019). For rooibos ecotypes, models were evaluated using a jackknife approach, i.e., each occurrence was used in turn for testing a model trained using all remaining other occurrences. A jackknife approach was used in these instances because ecotypes generally had relatively low numbers of occurrences (all <42) (Pearson et al., 2007; Shcheglovitova & Anderson, 2013).

Predicted distributions

For each model, we predicted the distribution of rooibos as a species in its entirety or of individual ecotypes using the *cloglog* output of MaxEnt, which can be interpreted as a measure of relative environmental suitability (Guillera-Arroita et al., 2014). Using the 100 model outputs for each ecotype, we created a weighted predicted suitability map by multiplying each model run predicted distribution by its respective AUC value, and thereafter calculating a weighted mean suitability. To enable simpler comparison of model outputs, we transformed the relative suitability maps to binary presence/absence predictions using a threshold value equivalent to the maximum sum of sensitivity and specificity (Liu et al., 2013). Both the suitability and binary predictions were masked by multivariate environmental similarity surface (MESS) values less than zero – these are areas where the models are extrapolating into novel environmental space (Elith et al., 2011).

Environmental correlates of distribution

To investigate environmental factors that potentially affect the distribution of rooibos and its ecotypes, we produced response curves illustrating the relationship between each environmental predictor and the predicted relative suitability. Outputs from each of the 100 model runs were plotted, as well as a weighted mean response which was calculated by multiplying suitability values by the respective AUC value for each model run. The output from the model with the best (highest) AUC value was also highlighted on these plots.

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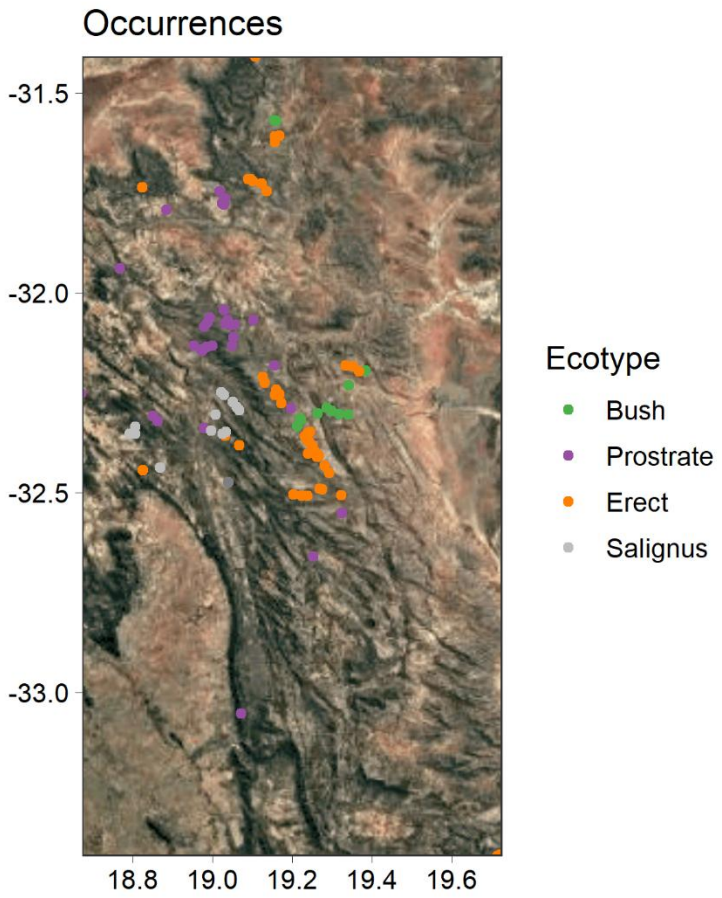
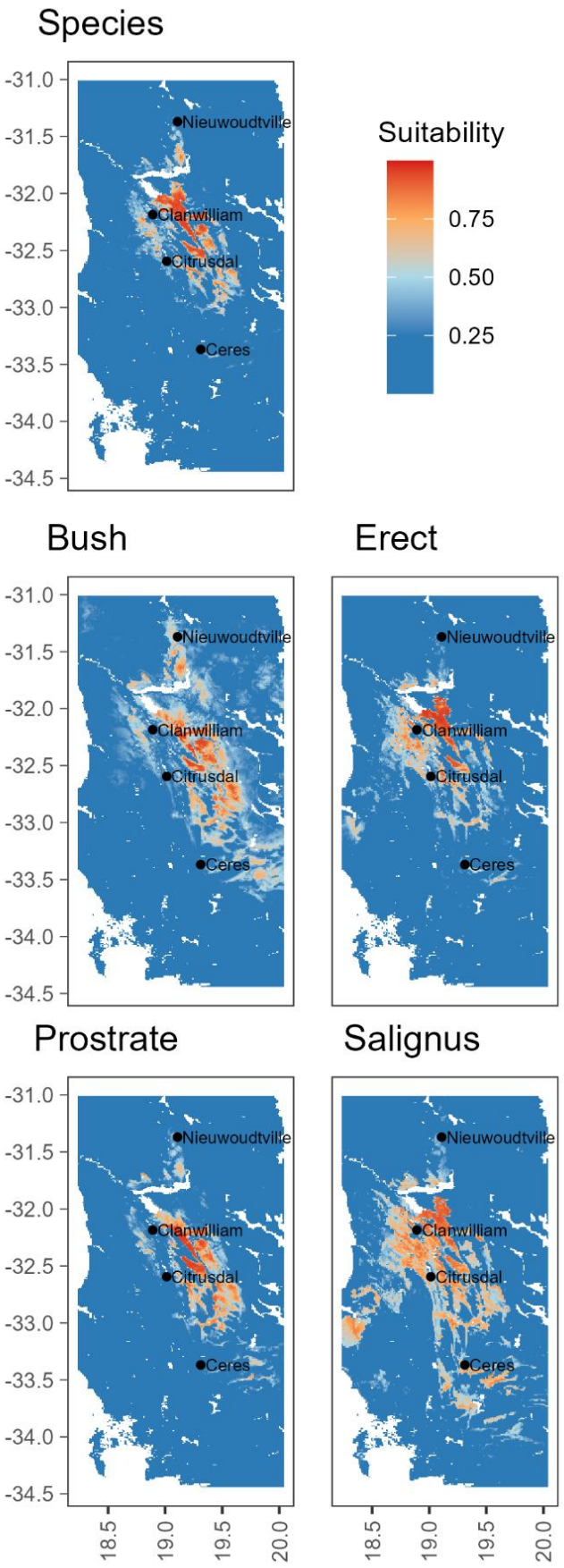
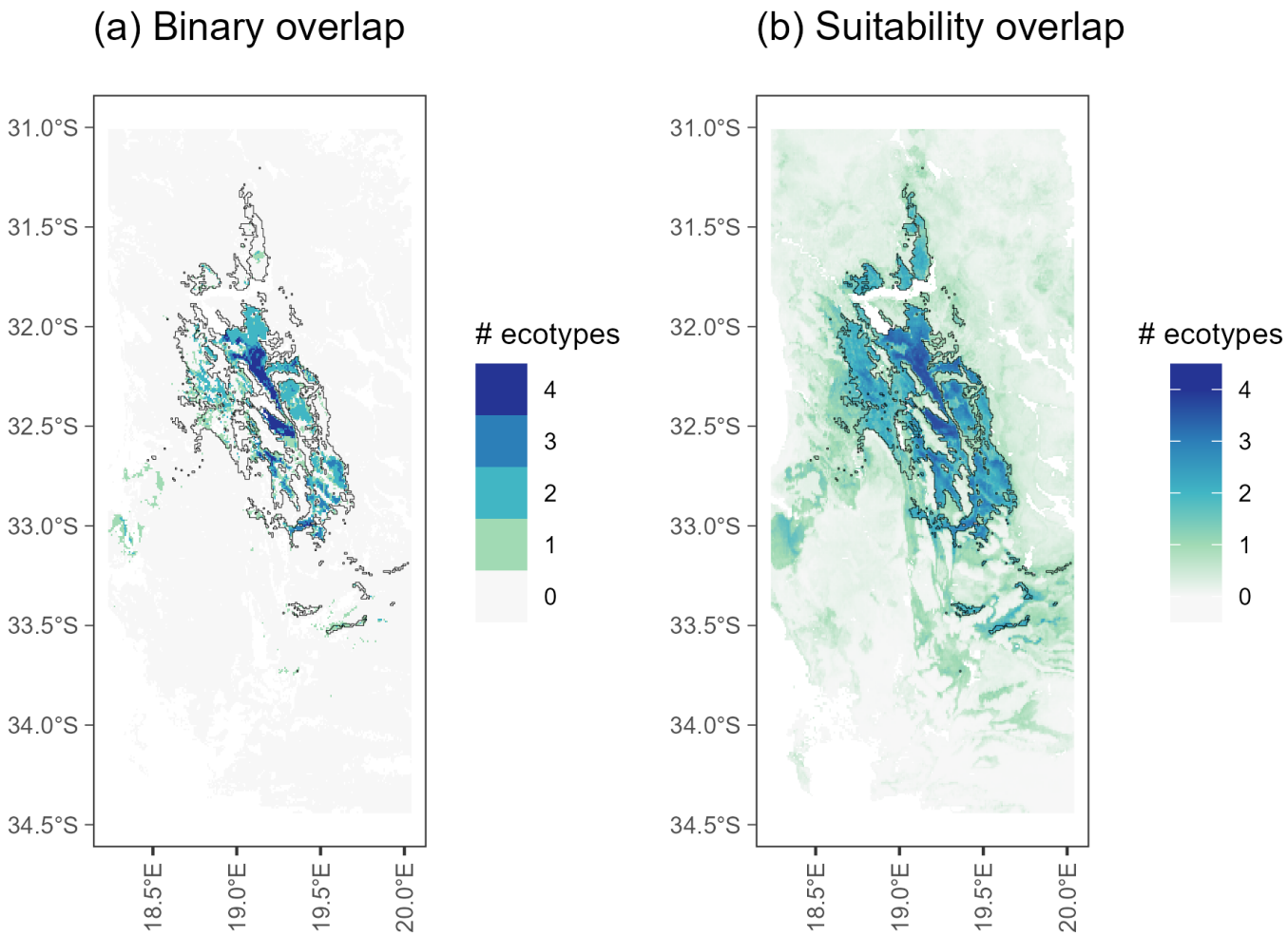
Supplementary S2. Field-verified location records of the four wild rooibos ecotypes used for MaxEnt modelling.



Supplementary S3. Predicted distributions of wild *Aspalathus linearis* for the species as a whole (Species) and for each of the four ecotypes (Bush, Erect, Prostrate, Salignus). Distributions are based on predicted suitability values, with red indicating high suitability and blue indicating low suitability.

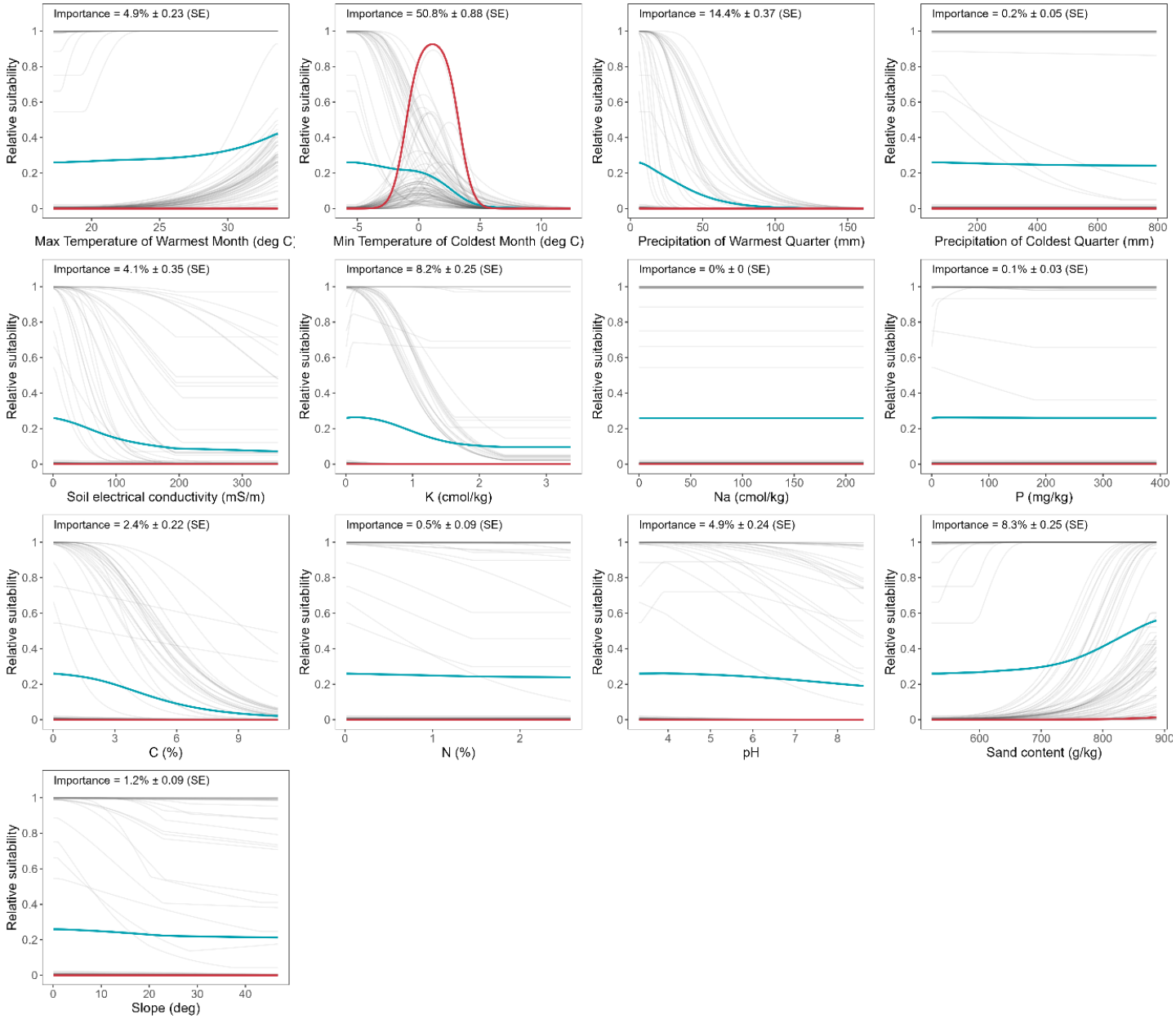


Supplementary S4. Overlap of predicted rooibos ecotype distributions expressed as the sum of the number of ecotypes predicted to occur in any given pixel (max = 4 in blue). (a) The sum of binary (presence/absence) predictions; (b) The sum of suitability values. The predicted distribution of the species as a whole is indicated by the area within the grey polygons. This highlights the generally distinct distributions of each ecotype except for the core of the species as a whole.

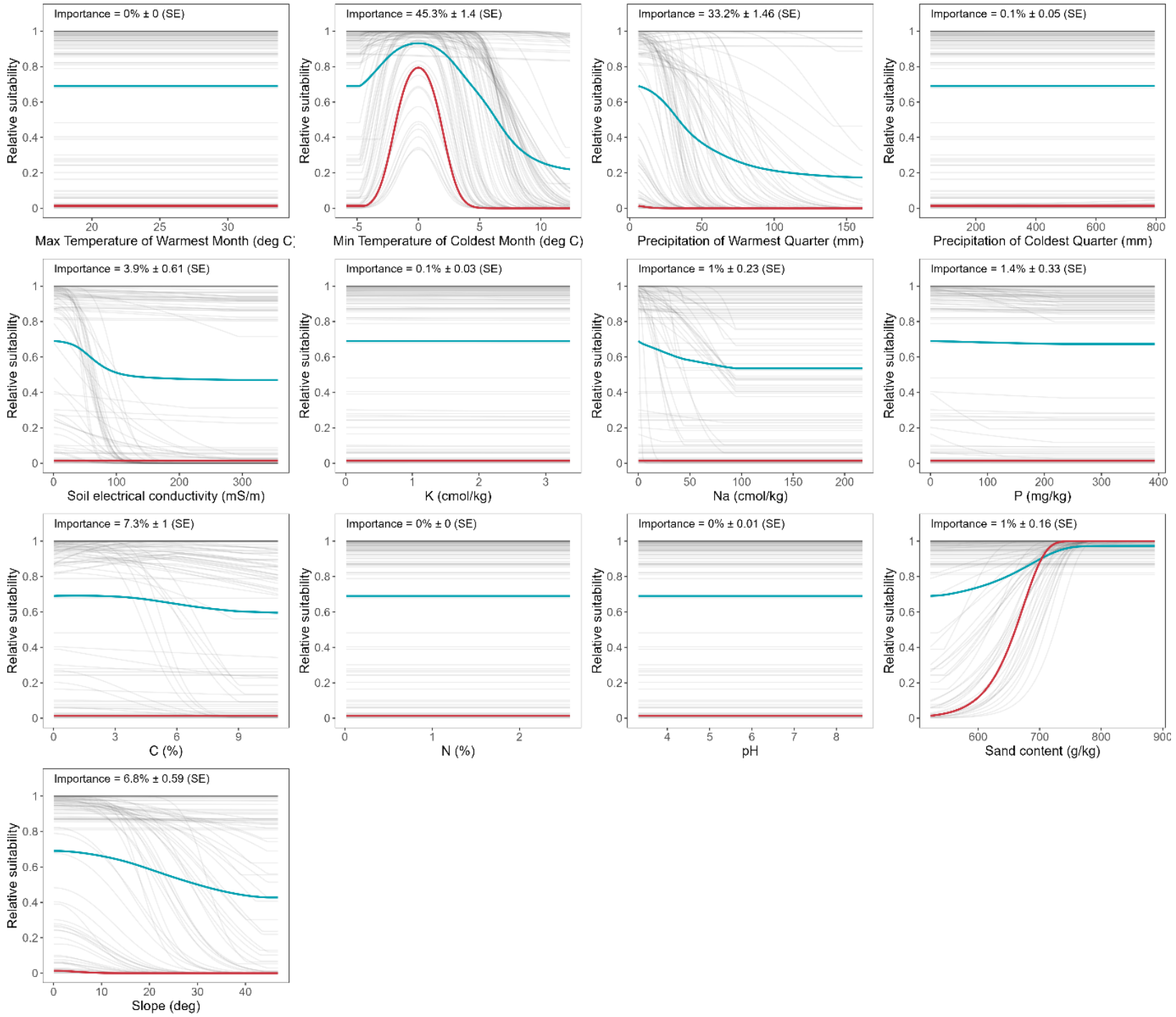


Supplementary S5. Response curves showing the relationship between predicted suitability for **(A) rooibos** as a species, and the respective ecotypes **(B) Bush**, **(C) Prostrate**, **(D) Erect**, and **(E) Salignus** and each of the 13 environmental variables used as model predictors. Grey lines represent individual model runs, the blue line the weighted mean of all 100 model runs and the red line is the best model (highest AUC value). Mean variable importance (and standard error) is shown above each variable.

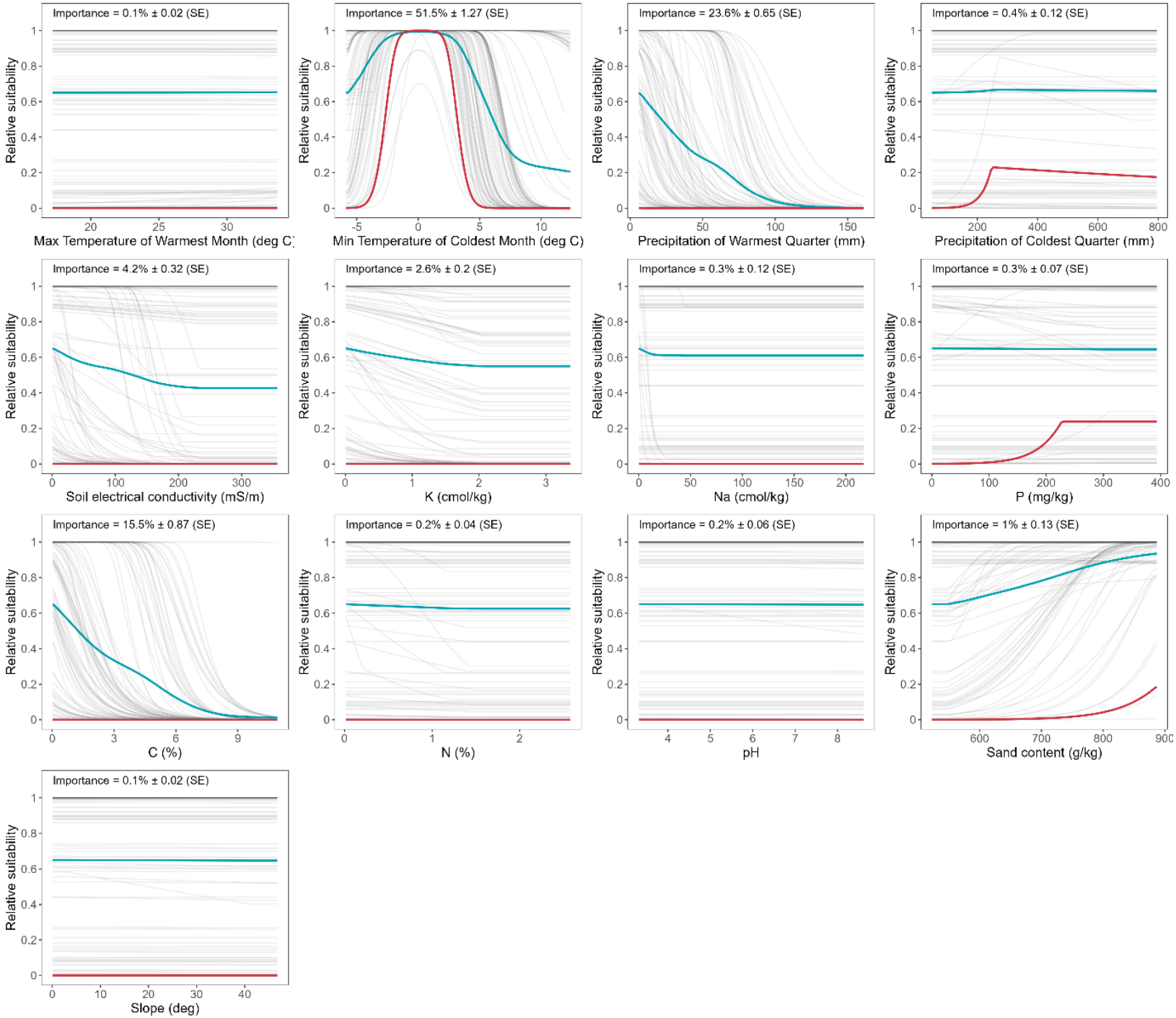
(A)


Importance = 4.9% ± 0.23 (SE)
Max Temperature of Warmest Month (deg C)
Importance = 50.8% ± 0.88 (SE)
Min Temperature of Coldest Month (deg C)
Importance = 14.4% ± 0.37 (SE)
Precipitation of Warmest Quarter (mm)
Importance = 0.2% ± 0.05 (SE)
Precipitation of Coldest Quarter (mm)
Importance = 4.1% ± 0.35 (SE)
Soil electrical conductivity (mS/m)
Importance = 8.2% ± 0.25 (SE)
K (cmol/kg)
Importance = 0% ± 0 (SE)
Na (cmol/kg)
Importance = 0.1% ± 0.03 (SE)
P (mg/kg)
Importance = 2.4% ± 0.22 (SE)
C (%)
Importance = 0.5% ± 0.09 (SE)
N (%)
Importance = 4.9% ± 0.24 (SE)
pH
Importance = 8.3% ± 0.25 (SE)
Sand content (g/kg)
Importance = 1.2% ± 0.09 (SE)
Slope (deg)
Relative suitability

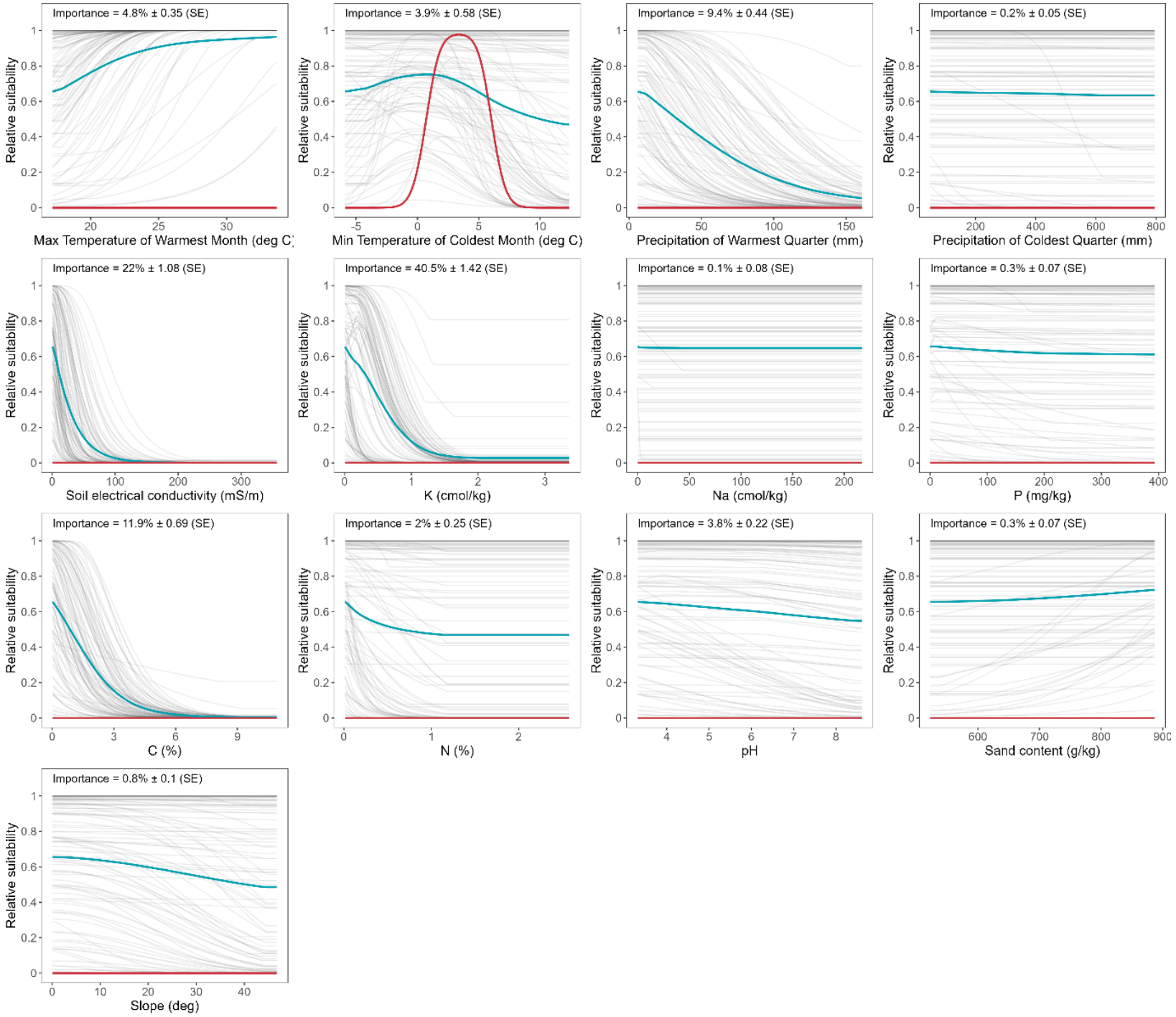
(B)


Importance = 0% ± 0 (SE)
Importance = 45.3% ± 1.4 (SE)
Importance = 33.2% ± 1.46 (SE)
Importance = 0.1% ± 0.05 (SE)
Importance = 3.9% ± 0.61 (SE)
Importance = 0.1% ± 0.03 (SE)
Importance = 1% ± 0.23 (SE)
Importance = 1.4% ± 0.33 (SE)
Importance = 7.3% ± 1 (SE)
Importance = 0% ± 0 (SE)
Importance = 0% ± 0.01 (SE)
Importance = 1% ± 0.16 (SE)
Importance = 6.8% ± 0.59 (SE)
Relative suitability
Max Temperature of Warmest Month (deg C)
Min Temperature of Coldest Month (deg C)
Precipitation of Warmest Quarter (mm)
Precipitation of Coldest Quarter (mm)
Soil electrical conductivity (mS/m)
K (cmol/kg)
Na (cmol/kg)
P (mg/kg)
C (%)
N (%)
pH
Sand content (g/kg)
Slope (deg)

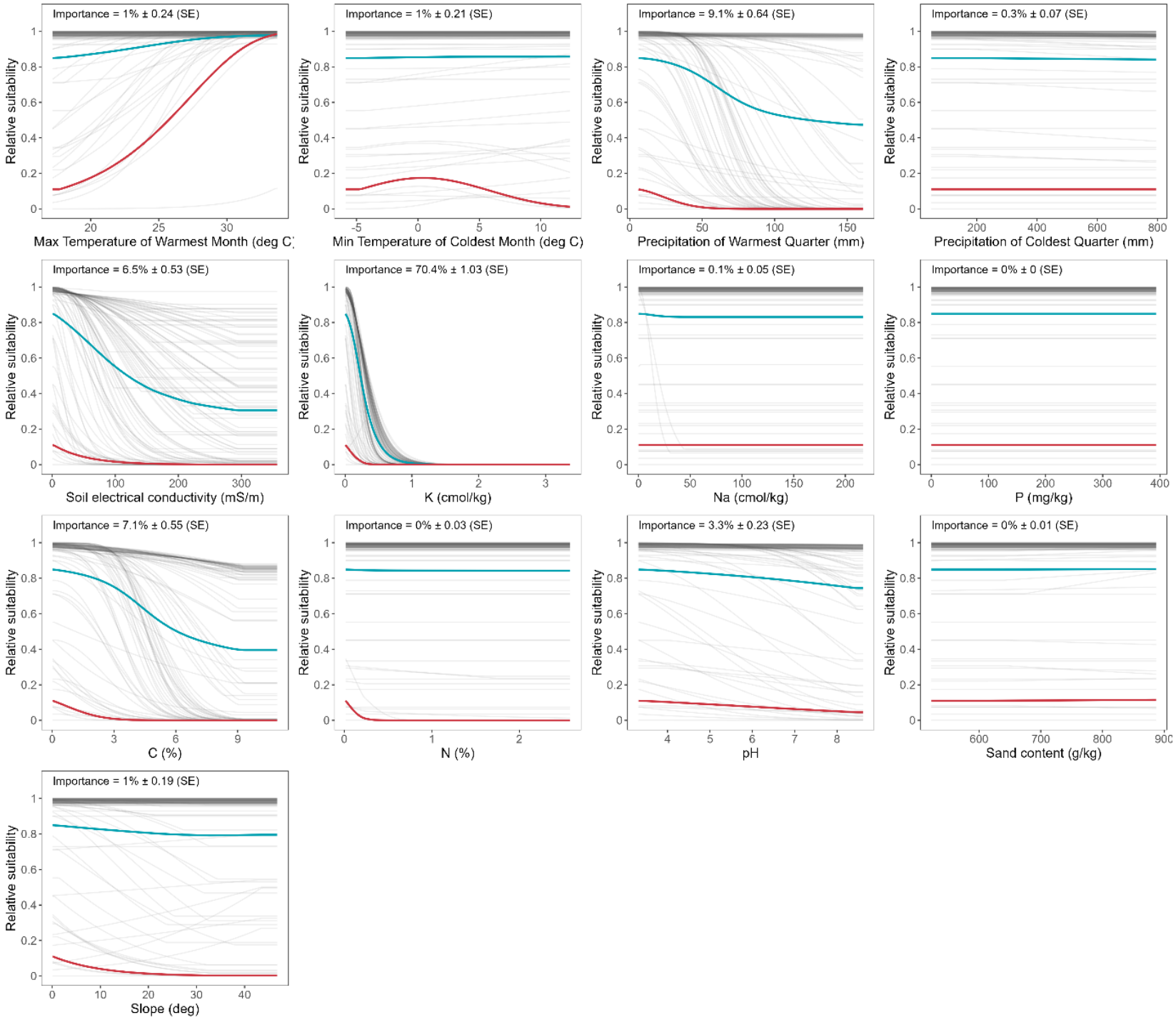
(C)


Importance = 0.1% ± 0.02 (SE)
Relative suitability
Max Temperature of Warmest Month (deg C)
Importance = 51.5% ± 1.27 (SE)
Min Temperature of Coldest Month (deg C)
Importance = 23.6% ± 0.65 (SE)
Precipitation of Warmest Quarter (mm)
Importance = 0.4% ± 0.12 (SE)
Precipitation of Coldest Quarter (mm)
Importance = 4.2% ± 0.32 (SE)
Soil electrical conductivity (mS/m)
Importance = 2.6% ± 0.2 (SE)
K (cmol/kg)
Importance = 0.3% ± 0.12 (SE)
Na (cmol/kg)
Importance = 0.3% ± 0.07 (SE)
P (mg/kg)
Importance = 15.5% ± 0.87 (SE)
C (%)
Importance = 0.2% ± 0.04 (SE)
N (%)
Importance = 0.2% ± 0.06 (SE)
pH
Importance = 1% ± 0.13 (SE)
Sand content (g/kg)
Importance = 0.1% ± 0.02 (SE)
Slope (deg)

(D)


Importance = 4.8% ± 0.35 (SE)
Max Temperature of Warmest Month (deg C)
Importance = 3.9% ± 0.58 (SE)
Min Temperature of Coldest Month (deg C)
Importance = 9.4% ± 0.44 (SE)
Precipitation of Warmest Quarter (mm)
Importance = 0.2% ± 0.05 (SE)
Precipitation of Coldest Quarter (mm)
Importance = 22% ± 1.08 (SE)
Soil electrical conductivity (mS/m)
Importance = 40.5% ± 1.42 (SE)
K (cmol/kg)
Importance = 0.1% ± 0.08 (SE)
Na (cmol/kg)
Importance = 0.3% ± 0.07 (SE)
P (mg/kg)
Importance = 11.9% ± 0.69 (SE)
C (%)
Importance = 2% ± 0.25 (SE)
N (%)
Importance = 3.8% ± 0.22 (SE)
pH
Importance = 0.3% ± 0.07 (SE)
Sand content (g/kg)
Importance = 0.8% ± 0.1 (SE)
Slope (deg)
Relative suitability

(E)


Importance = 1% ± 0.24 (SE)
Max Temperature of Warmest Month (deg C)
Importance = 1% ± 0.21 (SE)
Min Temperature of Coldest Month (deg C)
Importance = 9.1% ± 0.64 (SE)
Precipitation of Warmest Quarter (mm)
Importance = 0.3% ± 0.07 (SE)
Precipitation of Coldest Quarter (mm)
Importance = 6.5% ± 0.53 (SE)
Soil electrical conductivity (mS/m)
Importance = 70.4% ± 1.03 (SE)
K (cmol/kg)
Importance = 0.1% ± 0.05 (SE)
Na (cmol/kg)
Importance = 0% ± 0 (SE)
P (mg/kg)
Importance = 7.1% ± 0.55 (SE)
C (%)
Importance = 0% ± 0.03 (SE)
N (%)
Importance = 3.3% ± 0.23 (SE)
pH
Importance = 0% ± 0.01 (SE)
Sand content (g/kg)
Importance = 1% ± 0.19 (SE)
Slope (deg)
Relative suitability

Supplementary S6. Proclaimed protected areas on state (S) or private (P) land which partially occur within the predicted distribution range (Figure 2) of A*spalathus linearis* and its ecotypes (respectively). WHS=World Heritage Site. Protected areas source: https://portal.environment.gov.za/PortalDownloads/PACA_Gazettes/PA

Entire species / ecotype	Protected area name	Designation	State / private	Entire PA size (ha)	Area (ha) of PA in range
A. linearis	Sederberg Mountain Catchment Area	Mountain Catchment Area	P	59,414	33,095
A. linearis	Sederberg Wilderness Area	Forest Wilderness Area, WHS	S	62,794	32,360
A. linearis	Koue Bokkeveld Mountain Catchment Area	Mountain Catchment Area	P	96,857	17,371
A. linearis	Groenfontein Private Nature Reserve	Nature Reserve	P	14,014	13,752
A. linearis	Matjies Rivier Provincial Nature Reserve	Nature Reserve, WHS	S	18,754	10,485
A. linearis	Winterhoek Mountain Catchment Area	Mountain Catchment Area	S	51,325	8,123
A. linearis	Matroosberg Mountain Catchment Area	Mountain Catchment Area	P	82,531	5,694
A. linearis	Dwarsrivier Nature Reserve	Nature Reserve	P	5,808	5,235
A. linearis	Wagenboom Nature Reserve	Nature Reserve	P	6,467	4,629
A. linearis	Cederberg Private Nature Reserve	Nature Reserve	S	4,062	3,397
A. linearis	Oorlogskloof Nature Reserve	Nature Reserve	S	6,170	3,272
A. linearis	Mooiberg Nature Reserve	Nature Reserve	P	3,186	3,186
A. linearis	Kromrivierkloof Nature Reserve	Nature Reserve	P	3,904	2,288
A. linearis	Bakkrans Nature Reserve	Nature Reserve	P	2,288	2,204
A. linearis	Taaiboschkraal Nature Reserve	Nature Reserve	P	4,625	1,720
A. linearis	Ben Etive Nature Reserve	Nature Reserve	P	5,085	1,522
A. linearis	Alsfontein Nature Reserve	Nature Reserve	P	1,325	1,325
A. linearis	Skimmelberg Nature Reserve	Nature Reserve	P	1,353	1,299
A. linearis	Grootwinterhoek Protected Environment	Protected Environment	P	4,351	1,138
A. linearis	Vogelfontein Nature Reserve	Nature Reserve	P	1,488	1,096
A. linearis	Klein Cederberg Private Nature Reserve	Nature Reserve	P	990	990
A. linearis	Hooggelegen Nature Reserve	Nature Reserve	P	825	724
A. linearis	Nieuwe Gift Nature Reserve	Nature Reserve	P	564	552
A. linearis	Op de Berg Private Nature Reserve	Nature Reserve	P	423	423
A. linearis	Ceres Bergfynbos Reserve	Nature Reserve	P	7,000	389
A. linearis	Bergwater Private Nature Reserve	Nature Reserve	P	304	272
A. linearis	Tweekuilen Nature Reserve	Nature Reserve	P	1,335	140
A. linearis	Kruis Nature Reserve	Nature Reserve	P	323	87
A. linearis	Mountshoek Protected Environment	Protected Environment	P	7,181	72
A. linearis	Hawequas Mountain Catchment Area	Mountain Catchment Area	P	51,604	71
A. linearis	Vogelfontein 319 Nature Reserve	Nature Reserve	P	57	57
A. linearis	Banghoek Private Nature Reserve	Nature Reserve	P	1,035	20
A. linearis	Rondeberg Oord Private Nature Reserve	Nature Reserve	P	266	18
Bush	Sederberg Wilderness Area	Forest Wilderness Area, WHS	S	62,794	7,308
Bush	Groenfontein Private Nature Reserve	Nature Reserve	P	14,014	5,060
Bush	Matjies Rivier Provincial Nature Reserve	Nature Reserve, WHS	S	18,754	4,376
Bush	Dwarsrivier Nature Reserve	Nature Reserve	P	5,808	4,346
Bush	Cederberg Private Nature Reserve	Nature Reserve	P	4,062	3,272
Bush	Koue Bokkeveld Mountain Catchment Area	Mountain Catchment Area	P	96,857	1,847
Bush	Mooiberg Nature Reserve	Nature Reserve	P	3,186	1,741
Bush	Kromrivierkloof Nature Reserve	Nature Reserve	P	3,904	1,440
Bush	Bakkrans Nature Reserve	Nature Reserve	P	2,288	1,344
Bush	Wagenboom Nature Reserve	Nature Reserve	P	6,467	1,096
Bush	Klein Cederberg Private Nature Reserve	Nature Reserve	P	990	722
Bush	Alsfontein Nature Reserve	Nature Reserve	P	1,325	324
Bush	Vogelfontein Nature Reserve	Nature Reserve	P	1,488	255
Bush	Op de Berg Private Nature Reserve	Nature Reserve	P	423	170
Bush	Oorlogskloof Nature Reserve	Nature Reserve	S	6,170	146
Bush	Sederberg Mountain Catchment Area	Mountain Catchment Area	S	59,414	127
Bush	Matroosberg Mountain Catchment Area	Mountain Catchment Area	P	82,531	42
Bush	Bergwater Private Nature Reserve	Nature Reserve	P	304	25
Prostrate	Sederberg Wilderness Area	Forest Wilderness Area, WHS	S	62,794	13,547
Prostrate	Sederberg Mountain Catchment Area	Mountain Catchment Area	P	59,414	7,661
Prostrate	Groenfontein Private Nature Reserve	Nature Reserve	P	14,014	6,843
Prostrate	Koue Bokkeveld Mountain Catchment Area	Mountain Catchment Area	P	96,857	6,323

Entire species / ecotype	Protected area name	Designation	State / private	Entire PA size (ha)	Area (ha) of PA in range
Prostrate	Matjies Rivier Provincial Nature Reserve	Nature Reserve, WHS	S	18,754	5,734
Prostrate	Dwarsrivier Nature Reserve	Nature Reserve	P	5,808	4,984
Prostrate	Cederberg Private Nature Reserve	Nature Reserve	P	4,062	2,590
Prostrate	Mooiberg Nature Reserve	Nature Reserve	P	3,186	2,241
Prostrate	Bakkrans Nature Reserve	Nature Reserve	P	2,288	2,110
Prostrate	Kromrivierkloof Nature Reserve	Nature Reserve	P	3,904	1,860
Prostrate	Matroosberg Mountain Catchment Area	Mountain Catchment Area	P	82,531	1,612
Prostrate	Alsfontein Nature Reserve	Nature Reserve	P	1,325	1,325
Prostrate	Wagenboom Nature Reserve	Nature Reserve	P	6,467	1,186
Prostrate	Vogelfontein Nature Reserve	Nature Reserve	P	1,488	905
Prostrate	Klein Cederberg Private Nature Reserve	Nature Reserve	P	990	678
Prostrate	Skimmelberg Nature Reserve	Nature Reserve	P	1,353	606
Prostrate	Op de Berg Private Nature Reserve	Nature Reserve	P	423	402
Prostrate	Bergwater Private Nature Reserve	Nature Reserve	P	304	200
Prostrate	Nieuwe Gift Nature Reserve	Nature Reserve	P	564	185
Prostrate	Taaiboschkraal Nature Reserve	Nature Reserve	P	4,625	82
Prostrate	Winterhoek Mountain Catchment Area	Mountain Catchment Area	P	51,325	72
Prostrate	Vogelfontein 319 Nature Reserve	Nature Reserve	P	57	57
Prostrate	Hooggelegen Nature Reserve	Nature Reserve	P	825	28
Erect	Sederberg Wilderness Area	Forest Wilderness Area, WHS	S	62,794	11,832
Erect	Dwarsrivier Nature Reserve	Nature Reserve	P	5,808	4,075
Erect	Sederberg Mountain Catchment Area	Mountain Catchment Area	P	59,414	3,375
Erect	Matjies Rivier Provincial Nature Reserve	Nature Reserve, WHS	S	18,754	1,549
Erect	Koue Bokkeveld Mountain Catchment Area	Mountain Catchment Area	P	96,857	1,125
Erect	Kromrivierkloof Nature Reserve	Nature Reserve	P	3,904	982
Erect	West Coast National Park	National Park	S	36,566	236
Erect	Skimmelberg Nature Reserve	Nature Reserve	P	1,353	229
Erect	Vogelfontein Nature Reserve	Nature Reserve	P	1,488	159
Erect	Alsfontein Nature Reserve	Nature Reserve	P	1,325	158
Erect	Bergwater Private Nature Reserve	Nature Reserve	P	304	146
Erect	Winterhoek Mountain Catchment Area	Mountain Catchment Area	P	51,325	100
Erect	Rondeberg Oord Private Nature Reserve	Nature Reserve	P	266	82
Erect	Matroosberg Mountain Catchment Area	Mountain Catchment Area	P	82,531	39
Erect	Vogelfontein 319 Nature Reserve	Nature Reserve	P	57	34
Erect	Wagenboom Nature Reserve	Nature Reserve	P	6,467	7
Salignus	Sederberg Wilderness Area	Forest Wilderness Area, WHS		62,794	25,337
Salignus	Sederberg Mountain Catchment Area	Mountain Catchment Area	P	59,414	11,955
Salignus	Koue Bokkeveld Mountain Catchment Area	Mountain Catchment Area	P	96,857	8,516
Salignus	Matroosberg Mountain Catchment Area	Mountain Catchment Area	P	82,531	8,290
Salignus	Dwarsrivier Nature Reserve	Nature Reserve	P	5,808	4,857
Salignus	Winterhoek Mountain Catchment Area	Mountain Catchment Area	P	51,325	3,664
Salignus	Hawequas Mountain Catchment Area	Mountain Catchment Area	P	51,604	3,264
Salignus	Groenfontein Private Nature Reserve	Nature Reserve	P	14,014	3,150
Salignus	Grootwinterhoek Protected Environment	Protected Environment	P	4,351	2,384
Salignus	Wagenboom Nature Reserve	Nature Reserve	P	6,467	2,144
Salignus	Matjies Rivier Provincial Nature Reserve	Nature Reserve, WHS	S	18,754	2,021
Salignus	Kromrivierkloof Nature Reserve	Nature Reserve	P	3,904	2,012
Salignus	West Coast National Park	National Park	S	36,566	1,170
Salignus	Skimmelberg Nature Reserve	Nature Reserve	P	1,353	1,132
Salignus	Ben Etive Nature Reserve	Nature Reserve	P	5,085	913
Salignus	Ceres Bergfynbos Reserve	Nature Reserve	P	7,000	900
Salignus	Hopefield Private Nature Reserve	Nature Reserve	P	1,706	358
Salignus	Klein Cederberg Private Nature Reserve	Nature Reserve	P	990	259
Salignus	Groot-Winterhoek Wilderness Area	Forest Wilderness Area, WHS	S	24,311	216
Salignus	Bergwater Private Nature Reserve	Nature Reserve	P	304	200
Salignus	Alsfontein Nature Reserve	Nature Reserve	P	1,325	183
Salignus	Vogelfontein Nature Reserve	Nature Reserve	P	1,488	151
Salignus	Jakkalsfontein Private Nature Reserve	Nature Reserve	P	1,783	140
Salignus	Langeberg-Wes Mountain Catchment Area	Mountain Catchment Area	P	63,585	119

Entire species / ecotype	Protected area name	Designation	State / private	Entire PA size (ha)	Area (ha) of PA in range
Salignus	Rondeberg Oord Private Nature Reserve	Nature Reserve	P	266	82

Supplementary S7. Distribution of cultivated rooibos fields in relation to the predicted (modelled) distribution of wild rooibos and the locations of population survey sites ([anonymised], submitted).