Evaluating the effects of an altered ignition catchment on important biodiversity in the Cape Peninsula of South Africa.

Using species distribution models to predict changes in *Leucadendron argenteum*, *Leucadendron salignum* and *Podocarpus latifolius* with spatiotemporal ignition catchment data.

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28/10/2021

Abstract

The CFR is globally renowned for its species richness and biodiversity. Much of the flora here are endemics, an attribute highlighting their vulnerability in a changing environment. Much of the vegetation in the CFR (fynbos) are intimately related to fire - a characteristic natural disturbance of this landscape, that varies spatially and temporally in frequency, severity, extent etc. - and flora in the CFR occur in different alternative stable states according to these fire-related properties. There has been increasing evidence that anthropogenic land use and transformation has altered the historical ignition catchment (and hence the fire regime) of the Cape Peninsula, and this has consequently raised many concerns about important biodiversity, as well as the appropriate conservation management plans thereof. While there have been many studies investigating the effects of a changing environment on important biodiversity in the CFR, not all have utilized fire-related data in their approaches, and those that have, typically do so alongside other covariates such as climate data, edaphic properties, etc. Here, I investigate the standalone effects of a changing fire regime on important biodiversity in the CFR. A total of six SDMs were constructed, two for each species, of which only differed in their fire-related environmental predictors. Species occurrence data for the two Proteaceae members were obtained via the Protea Atlas Project, while occurrence data for the forest species was obtained from the Global Biodiversity Information Facility. I selected four terrain-related predictors that would be included alongside one of two contrasting burn probability predictors (historical or transformed). One-way Analysis Of Variance (ANOVA) models were used to assess how the current distribution of each species, on average, differs from one another for each of the environmental predictors. The group-wise ANOVA comparisons revealed that, on average, there were substantial differences between both historical burn probability and transformed burn probability values associated with the three species. This was also the case all but one of the terrain-related predictors used (elevation). All SDMs, with one exception, achieved moderate to good accuracy. I have found evidence for fynbos encroachment in the Cape Peninsula due to the implicit effects of an altered ignition catchment by anthropogenic land use, although this has come without evidence of forest expansion. This framework confirms the importance of fire as a determinant of fynbos plant species distributions, and illustrates how fire could be an important determinant of species distributions from alternative stable states that are related to fynbos vegetation. This work also highlights the roles that terrain-related variables play in modelling the patterns of species distributions with a focus on fire-related changes over time. Important biodiversity in the fynbos are losing their historical habitat range as a result of the rapid urbanization that has taken place since historical conditions. Further conservation management strategies are essential in ensuring the persistence of *L*. argenteum.

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1 Introduction

The Cape Floristic Region (CFR), in the Western Cape of South Africa, is globally renowned for its species richness and diversity, often referred to as a biodiversity hotspot. Much of the flora in the CFR are endemics, occurring nowhere else in the world - an attribute that makes them particularly vulnerable and sensitive to changes in their environment. A predominant constituent of the flora that occur in the CFR, is of course, the fynbos – a term used to describe this vegetation type rather than an exclusive taxon.

Much vegetation in the CFR are intimately related to fire and are adapted in various different ways to cope with regular burning throughout the landscape – serotiny being a well-known example of such adaptations, whereby seeds are stored in the plant canopy to be released only under certain conditions (occurrence of fire in this context). Such mechanisms have evolved over extended periods of time, predating the arrival of humans in the Cape, and have essentially become an integral part of persistence in a fire-prone environment. Most depend on the occurrence of fire for generational succession, and their morphological coping mechanisms vary depending on the intrinsic characteristics of a given environment – for example, some environments experience fires more frequently than others, and the vegetation in these environments have different life history traits depending on the period of time between fires. Some fynbos, such as *Leucadendron argenteum*, require a longer post-fire regeneration period after burning to allow their offspring to mature and produce the next generation of seeds. Thus, they are typically distributed along the fynbos-forest transition margin which is associated with a larger fire return interval. In contrast, *Leucadendron salignum* is widespread, and is associated with a variety of habitats throughout the entire CFR. It is low growing compared to *L. argenteum*, and has traditionally been associated with areas that burn more frequently than the latter. Where *L. salignum* is considered abundant, *L. argenteum* has in recent years become increasingly threatened by the pressures of anthropogenic land use, and confined distribution that resides predominantly in the Cape Peninsula (Heelemann *et al.*, 2013; Bergh *et al.*, 2014).

Many areas in the CFR, with only a few exceptions, are areas of bioclimatic suitability for Afrotemperate Forests, however, it is predominantly the landscape's susceptibility to fire that separates forests from fynbos in a given region. This allows the fynbos to dominate the landscape, with forest trees being excluded on the basis of their slow growth rates in nutrient-deprived soils, and intolerance to somewhat low fire-return intervals.

Forest-like vegetation in the CFR is hence typically confined to specific areas – such as the Afromontane forests near UCT. *Podocarpus latifolius*, is not a member of the Proteaceae family, where instead it typically occurs in parts of the CFR least likely to burn (i.e., Afrotemperate forest patches). This species' distribution represents a non-flammable, fire-sensitive ecosystem that contrasts that of many Proteaceae.

Species Distribution Models (SDMs) have become a fundamental tool in many biological streams, such as ecology, biodiversity conservation and natural resource management (Guisan *et al.*, 2013; as cited in Guillera-Arroita *et al.*, 2015). Such models take a spatial correlative perspective, and typically relate geo-referenced species occurrence data with the associated environmental attributes (or environmental covariates) at a given location to estimate the species' preferable habitat and/or to predict their distribution. SDMs are thus highly informative from numerous perspectives (biogeographically, ecologically, etc.), but particularly in the way of conservation management and decision making. Guillera-Arroita *et al.* (2015) augment this in their brief review of the most common SDM applications, which revealed a predominant amount of research that aimed to identify and/or mitigate threats on important biodiversity.

While there have been countless studies investigating the effects of a changing environment on important biodiversity in the CFR, not all have utilized fire-related data in their approaches (i.e., Hoveka *et al.*, 2019). Those that have used fire-related covariates in their research (i.e. Magadzire *et al.*, 2019) have typically, however, done so alongside other key covariates such as climate data, edaphic properties, etc., and there have been fewer investigations into the standalone effects of a changing fire regime on important biodiversity. Although fire is a well-acknowledged natural disturbance that acts as a driver of species distributions and community composition in many ecosystems (Magadzire *et al.*, 2019), reduced fire being a major driver of fynbos encroachment (with forest expansion) has not been explicitly tested (Slingsby *et al.*, 2019), which sparks some motivation for this investigation.

Here, I use ignition catchment data based on both historic, and recent scenarios of anthropogenic land use in the Cape Peninsula to model the species distributions of three prominent flora. I do this in the absence of climate covariates, but rather with topographic features that I assume not to have changed between historical and recent times - and this may demonstrate the extent to which an altered fire regime has effected the respective species distributions I have chosen for this research. I make use of SDMs to explore the implicit

effects of anthropogenic land transformation on three indigenous species in the Cape Peninsula – *Leucadendron salignum*, *Leucadendron argenteum* and *Podocarpus latifolius* – which represent different alternative stable state ecosystems: Fynbos, Forest-margin transition Fynbos and Afrotemperate Forest, respectively. This may inform us about how their species distributions have changed, and will continue to change in context of a human-facilitated altered ignition catchment.

My hypotheses for this research are threefold: Firstly, that I expect to see a dramatic reduction in the suitability range associated with *L. argenteum* on the theoretical grounds that this species has historically been confined to a small mountain range within the Cape Peninsula, and with the implicit effects of land transformation on the fire regime, the already limited habitats are encroaching. Secondly, that we would observe a growth in the suitability range of *P. latifolius* within the Cape peninsula as a result of the abovementioned changes to Cape Peninsulas ignition catchment. Thirdly, that the abundant (unthreatened) distribution of *Leucadendron salignum* would provide an overall status of fynbos in a deteriorating fire regime.

2   Methods

2.1   Study area

The Cape Peninsula, a sub-region of the "City Cape Town" municipal district (Western Cape, South Africa), is a $470km^2$ landscape of rugged scenery and varied climate located at the southwestern extremity of the Cape Floristic Region (Cowling *et al.*, 1996). In accordance to the CFR, this area experiences a Mediterranean-type climate with hot, dry summers and cold, wet winters. Periodic fires occur with summer drought and strong south-easterly winds often reaching gale force (*Sensu* Cowling *et al.*, 1996; as cited in Slingsby *et al.*, 2019).

The Cape Peninsula has been regarded as having the highest topographical diversity compared to other smaller sized areas in southern Africa (Cowling *et al.*, 1996). It is characterized by a spine of sandstone-dominated ridges that run from the north to the south - causing a strong interaction between wind and topography - having an altitudinal peak of $1113m$ on Table Mountain (Cowling *et al.*, 1996; Slingsby *et al.*, 2019).

Urban development in the Cape first started to expand rapidly in the 1940's, and this land transformation and fragmentation of natural ecosystems has since been associated with a major loss in biodiversity (*Sensu* Rebelo,

Holmes, Dorse, & Wood, 2011; as cited in Slingsby *et al.*, 2019). Much of the remaining natural vegetation falls within the Table Mountain National Park, comprising a compilation of reserves throughout the Cape Peninsula, of which currently considered protected by law.

2.2   Input data

2.2.1   Species occurrence data

Species occurrence data for the two Proteaceae members; *L. argenteum* and *L. salignum*, were obtained via the Protea Atlas Project - a proprietary data source that documents the occurrence of Proteaceae varieties in southern Africa. The Protea Atlas project is widely used on account of its data quality compared to alternative "citizen science" sources. These occurrence data may be obtained through alternative sources, however, may require a substantial amount of quality control and have fewer samples over a smaller extent of a given landscape. I was not able to obtain *P. latifolius* species occurrence data from the Prota Atlas Project, and hence resorted to a free alternative source - the Global Biodiversity Information Facility (GBIF).

I have acknowledged the well-documented setbacks associated with the use of occurrence data from sources which operate primarily on a "citizen science" basis. Species distribution modelling requires knowledge on an ecological front, and this in turn allows a researcher to filter data by considering the species' fundamental niche – the area of environmental suitability for occurrence of a species. Although my two occurrence data sources may differ in quality, both sources rely on data collection by amateurs, and hence it is important to maintain a healthy level of skepticism when using such data for research. All three sets of species occurrence data were initially analysed and filtered in QGIS (version 3.16.11). Occurrence data for the two Proteaceae species were obtained from a source generally considered to be more quality controlled (The Protea Atlas) than that of the *P. latifolius* data, however, all three sets consist of records that should be excluded subjectively in an ecological context considering the research goals.

For the purpose of this investigation, I removed all occurrence locations on urban development (i.e. housing) under the assumption that these observations were either incorrectly recorded, or horticulture-related, and would not supply any biological insight. All three datasets were also checked for spatial sampling bias in QGIS - a common limitation associated with presence-only data whereby some areas of the land-

scape are sampled more intensively than others and may cause misinterpretation of their respective species distributions (Phillips *et al.*, 2009; as cited in Magadzire *et al.*, 2019). Both the *L. argenteum* and *P. latifolius* occurrence datasets were somewhat localized to specific parts of the study area, however, these respective distributions are typical and have been highlighted previously (Heelemann *et al.*, 2013; Bergh *et al.*, 2014) - hence, no spatial sample bias adjustments were made for these datasets. The *L. salignum* occurrence dataset, in contrast, was substantially larger than the others, with no general localization, and many small clumps of observations distributed evenly across the study area. I took a random sample of these data such that any spatial sampling bias was limited to the random population sample, and for the sake of having similar population size across the three species occurrence datasets. Furthermore, occurrence data with absent environmental predictor information (i.e., NA values) were removed from each set of species occurrence data. This was done in R (version 4.1.1)(Table 1).

2.2.2 Environmental data

The selection of environmental variables was largely based on the two fire-related variables being investigated, namely; historical and transformed burn probability in the study area. Specifically, I selected four terrain-related predictors that would be included alongside a burn probability predictor (historical or transformed) in SDMs for each species. These predictors were chosen from a larger set with some collinear groups (Pearson's $r = 0.7$ threshold), whereby only one variable from a collinear group was chosen in context of its biological relevance to all three species distributions. Hence, for a given SDM, there were five predictor variables: Burn probability (historical or transformed); elevation; aspect; slope and topographic position index (Table 2).

These variables were each represented by a raster layer ($90m$ resolution) that covered the extent of the study area, and were grouped into one of two raster stacks representing either the "Historical predictor" or "Transformed predictor" - only differing in their respective burn probability layers.

2.3 Models and analyses

2.3.1 Group-wise comparisons

One-way Analysis Of Variance (ANOVA) models were used to assess how the distribution of each species, on average, differs from one another for each of the environmental predictors by extracting the respective values associated with species occurrence locations on a given 90m pixel. The ANOVA model assumptions were via the "Shapiro-Wilk test", and diagnostic plots. Although one-way ANOVA is typically considered to be fairly robust against violations of the normality assumption given the sample size is sufficiently large, this should still be checked explicitly. These tests should generally be examined together with diagnostic plots (i.e., a Quantile-Quantile plot). I performed a non-parametric equivalent group-wise comparison for each model (the "Kruskal-Wallis test"), which doesn't require the assumption of normality, and compared these results with the ANOVA results.

2.3.2 Species Distribution Models

MaxEnt was used to model the species distributions of *L. argenteum*, *L. salignum* and *P. latifolius* under both the historical and transformed context of burn probability in the Cape Peninsula, and to measure the relative contribution of each variable in each predicted species distribution. There were a total of six SDMs, two per species. These SDMs were then compared by constructing an additional raster (per species), that depicts the relative change in habitat suitability (probability of occurrence) since historical times, and was done by subtracting the historical predictions from transformed predictions.

The MaxEnt (Maximum Entropy) software package (Phillips, Anderson and Schapire, 2006) is one of the most popular tools used in species distribution and environmental niche modelling. This algorithm typically outperforms other methods based on predictive accuracy, while also being somewhat "user friendly" in the growing field of quantitative approaches to understanding complex biological systems (Merow *et al.*, 2013).

In essence, MaxEnt models species distributions using inputs of presence-only, species occurrence data, as well as a set of environmental predictors over a defined study area. The program computes a species distribution by contrasting background location samples with the presence locations, where presence is unknown at the background locations. The theoretical framework rides on a basis of "Maximum entropy" as suggested by its name, where initially all locations are equally likely to be associated with a presence location, and the model then selects suitable habitat ranges based on comparisons between presence and pseudo-absence locations.

2.3.3 MaxEnt configuration and model output

I fitted six different models, each with five environmental predictors (i.e., four terrain-related predictors, one fire-related predictor). Two models were fit for each species, where each model differed in the burn probability predictor used (i.e., historical burn probability or transformed burn probability). In each model, species occurrence records were randomly split such that 70% were used to train the model, while 30% were used as test data. Background points were set to the default MaxEnt setting (10000). All feature types were selected for the model predictions (default feature settings), allowing for any complex interactions between variables that may influence the model result. Some research highlights the fact that using only simple models and avoiding complex interactions between variables may be more suitable in determining the relative importance of environmental predictors (Merow *et al.*, 2013; as cited in Magadzire *et al.*, 2019). I consider my respective species occurrence datasets to be generally small, and other research has noted the parameter tuning process to be unreliable when using small or biased datasets (Phillips and Dudík, 2008), where instead the default regularization and feature settings may be better. Hence I have left both the regularization coefficient and feature settings as default.

2.3.4 Environmental predictor importance

MaxEnt's "jackknife" analysis of the area under the receiver operating characteristic curve (AUC), and permutation importance were used to evaluate model performance and relative contribution of each variable to the predicted species distributions. These indicators reflect the model precision and accuracy, as well as the extent to which each variable contributes to the model outcome (Magadzire *et al.*, 2019).

3 Results

3.1 Group-wise comparisons and Post-Hoc analyses

The group-wise ANOVA comparisons revealed that, on average, there were substantial differences between both "historical burn probability" and "transformed burn probability" values associated with the three species ($p < 0.0001$). This was also true for "aspect" ($p < 0.0001$), "slope" ($p < 0.05$), "TPI" ($p < 0.0001$), but was not true for "elevation" ($p = 0.193$)(Table 4).

Violations to the assumption normal data were identified by the Shapiro-Wilk test in each environmental predictor (Table 3). Interestingly, the Kruskwil-Wallace test for each of the species-wise comparisons returned the same general results as ANOVA (Table 5).

Tukey's Honestly Significant Differences (HSD) procedure was performed on each of the respective ANOVA models, and these results are incorporated to the side-by-side boxplots that compare each environmental predictor across the species groups (Figures 1 and 2). All three species differed substantially from one another in the historical burn probability values associated with their respective occurrence data. Specifically, *L. argenteum* occurrences were associated with the largest burn probabilities, while *L. salignum* occurrences were associated with the lowest burn probabilities (Figure 1a). The result was different under the transformed burn probability, where only *L. salignum* differed substantially from the other two species, of which did not statistically differ from one another. Specifically, *L. salignum* occurrences were associated with the largest burn probabilities, while both *L. argenteum* and *P. latifolius* were associated with the lowest burn probabilities (Figure 1b). The elevation values associated with each of the species' occurrence data were all indifferent as suggested by the ANOVA results, and this is evident in the post-hoc analyses (Figure 2a). Each of the species occurrence datasets had noteworthy differences for the other terrain-related variables. On average, *L. argenteum* occurred in locations with lower aspect values than *L. salignum*, while *P. latifolius* occurred in locations with aspect values indifferent from both *Leucadendron* species; *L. argenteum* occurred in locations with higher slope values than *P. latifolius*, however, *L. salignum* occurred on slopes indifferent from the prior two species; Lastly, *L. argenteum* and *L. salignum* occurred in locations with indifferent TPI values from one another, but these were substantially higher values than locations *P. latifolius* occurred.

3.2 Species Distribution Models

QGIS constructions illustrating the relative changes in habitat suitability since historical times show depict different patterns for each of the species predicted distributions (Figure 3). *L. argenteum* has seen a decrease from its historical habitat on the northern mountain margins of the Cape Peninsula. Moreover, they predict that there are patches of habitat suitability extending southwards in the Cape Peninsula. *L. salignum* has seen a broad decrease in habitat suitability across the Cape Peninsula since historical times (particularly in the southern and western areas), and there is a band of habitat suitability increase surrounding the

northeastern-facing lower slopes of the Cape Peninsula, close to where *L. argenteum* has lost much of its habitat suitability range. Interestingly, My models predict, for the most part, a loss in habitat suitability ranges for *P. latifolius* since historical times, particularly on and around the main mountains that run from north to south. There are some small isolated areas of habitat suitability in the eastern and western directions of these mountains, however habitat suitability increases most in the south, towards the southern extremity of the study area.

3.2.1 Model performance

All models, with one exception, achieved moderate to good accuracy (AUC > 0.75), in determining the species distributions under the scenarios of historical or transformed burn probability (Table 6). The noteworthy exception is the model predicting the *L. salignum* distribution under the transformed burn probability data (AUC = 0.631). Additionally, the model predicting the *L. argenteum* distribution under the historical burn probability suggested slight model over-fitting ($AUC_{training} < AUC_{test}$).

3.2.2 Environmental predictor importance

In all but one model, elevation was the environmental predictor with the highest value of permutation importance in predicting the species distributions. One exception to this is the model predicting the *P. latifolius* distribution under transformed burn probability, where instead this model had TPI as the most important predictor. Burn probability was consistently either the second or third most important predictor used (Table 7).

4   Discussion

My group-wise comparisons between species occurrence data provide information about the species-specific environmental characteristics that have been used in the above modelling exercise, and represent the current status of each respective species' environments. Since I have not used historic species occurrence records, it is important to think about whether a given species' current distribution is more representative of current conditions, or historical conditions. For example, *L. salignum's* life history traits are associated with more frequent burning than *L. argenteum*, hence its fundamental niche would be in areas more likely to burn - the current *L. salignum* distribution is thus likely a vague

representation of the historical distribution. Assuming this logic, the current *L. argenteum* distribution would likely be more representative of the historical distribution, and this may also be true for the current *P. latifolius* distribution. These species-wise comparisons have revealed that historically, *L. argenteum* was associated with the highest burn probability, while *L. salignum* was associated with the lowest. This contrasts the species-wise comparisons under an altered ignition catchment, where *L. salignum* is associated with the highest burn probability. Where *L. salignum* is abundant throughout the landscape, with faster generational succession, *L. argenteum* may be considered static due to its confined distribution and relatively slow generational succession. It seems plausible that *L. salignum* communities have "shifted" with the changing fire regime over time in order to remain in areas of suitable burn probability, whereas *L. argenteum* could not.

The relative change maps since historical times somewhat support the idea of a decrease in habitat suitability for the two *Leucadendron* species. Specifically, the red bands (habitat suitability loss) surrounding mountains in the northern areas close to the Peninsula Afromontane forest patches hint at the idea of fynbos encroachment due to forest expansion with a deteriorating fire regime. These losses in suitability range come with gains elsewhere, and specifically in the case of *L. argenteum*, my models suggest that assisted dispersal to southern areas of the Cape Peninsula may be a reasonable conservation management strategy, especially with the confined distribution and threatened status of this species. The forest representative species that I have chosen to use in this study depicts a large loss of its habitat suitability in this region over time, and I cannot attribute the above-mentioned fynbos encroachment to forest expansion explicitly. Replication of this research using different (or additional) forest species may be more appropriate.

Output from my models confirm the importance of fire as a determinant of fynbos plant species distributions, and also illustrates how fire could potentially be important in determining the distributions of species from alternative stable states that are related to fynbos vegetation (i.e., Afromontane Forest species). My models highlight the roles that terrain-related variables play in modelling the patterns of species distributions with a focus on fire-related changes over time. As to be expected, fire was more important in predicting the current and historical distributions of the two fynbos species, while seemingly failing to capture the distribution dynamics of my forest species. Terrain-related variables were consistently important in predicting each of the species distributions, however, I have chosen not to focus on the complex relationships that are certainly

present between the Cape Peninsula's terrain and ignition catchment - instead, I simply used these environmental attributes to give my models additional information that would not skew the results due to changes in this fire regime over time.

It is worthwhile noting that the occurrence data have likely influenced my model results, and this could be due to a many reasons. For one, *P. latifolius* occurrence data were obtained through a less reliable source than the occurrence data for the two *Leucadendron* species. Although these data were filtered, they may have been a poor representation of the current species distribution, and hence models will fail to capture their habitat characters, ultimately leading to poor model predictability. Moreover, the *P. latifolius* occurrence data had far fewer records than the other two species occurrence datasets. Species distribution models also rely on the extent of a chosen study area, which leads me to the next limitation of this study. The *L. salignum* occurrence data was distinctly large, and although one may think that this should benefit the SDM, it may not. If the extent of a study area does not capture the entire distribution of a given species, it will fail to relate occurrences to environmental attributes - resulting in a model that is unable to precisely predict the species' distribution. I believe that this is indeed the case for my investigation. Even after randomly removing a large proportion of the *L. salignum* occurrence data, there were still no distinct localized clumps of occurrences. The poor AUC scores observed for *L. salignum*'s SDM are likely due to this limitation.

I must admit that my hypotheses for this research may have been high expectations, and evidently, SDMs require a "golden standard" of both data quality and biological understanding. It is important that we continue to appreciate the information they are able to provide on ecological dynamics over large spatial scales. This research has shown that *L. argenteum* are losing their historical habitat range as a result of the rapid urbanization that has taken place since historical conditions. Further conservation management strategies, such as assisted dispersal, are essential in ensuring their future survival as a species. Furthermore, this investigation suggests that *L. salignum* has lost a large range of habitat suitability since historical conditions, and although this result may be questionable, it provides some insight to the general status of fynbos in the Cape Peninsula that depend on frequent fires to persist. Although these results are promising and provide evidence for fynbos encroachment due to an altered ignition catchment in the Cape Peninsula, I have not found evidence for forest expansion, and hence am unable to accept my initial hypotheses.

The framework of this research is flexible, and allows for further research on the exclusive effects of an altered fire regime on important biodiversity in the Cape Peninsula. Although I have limited the number of species investigated here, these models and comparisons could easily be extended to larger groups of species that may represent alternative stable states more precisely, especially since this would also provide larger occurrence datasets.

5 Conclusion

I have found evidence for fynbos encroachment in the Cape Peninsula due to the implicit effects of an altered ignition catchment by anthropogenic land use. Although this has come without evidence of forest expansion, I would recommend replication of this research using better representative species of the fire-sensitive, non-flammable alternative stable states in the Cape Peninsula. This framework confirms the importance of fire as a determinant of fynbos plant species distributions, and illustrates how fire could be an important determinant of species distributions from alternative stable states that are related to fynbos vegetation. This research highlights the roles that terrain-related variables play in modelling the patterns of species distributions with a focus on fire-related changes over time.

6 Acknowledgements

6.1 Species occurrence data

6.2 Environmental predictor data

7 References

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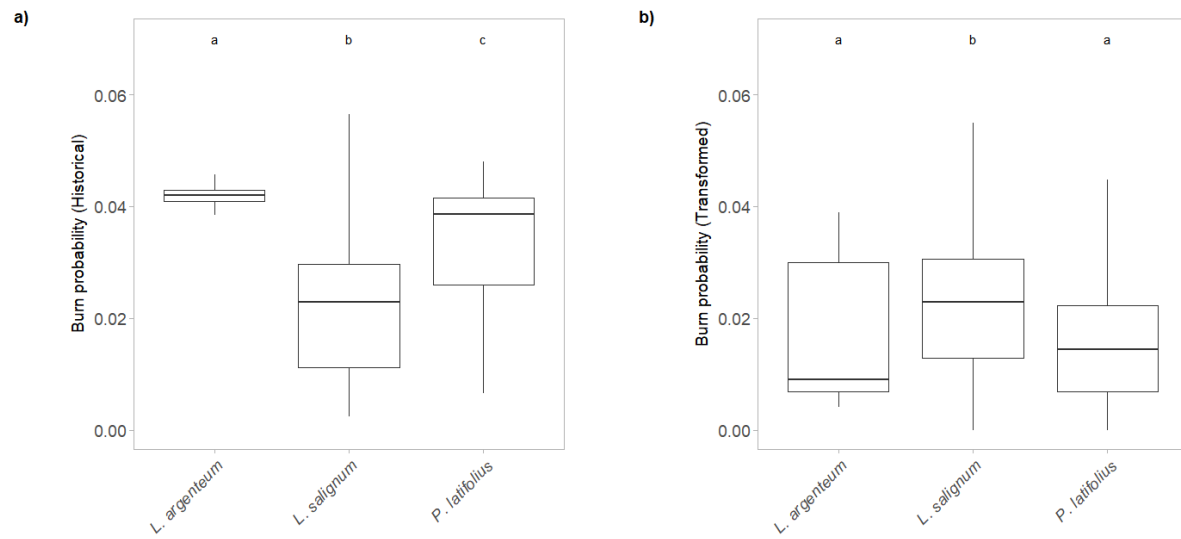
8 Appendix

Figure 1: Comparative boxplots illustrating; a) The historical burn probability values, and b) The transformed burn probability values associated with occurrence data for each species. Species with the same letter are not significantly different (Tukey's HSD).
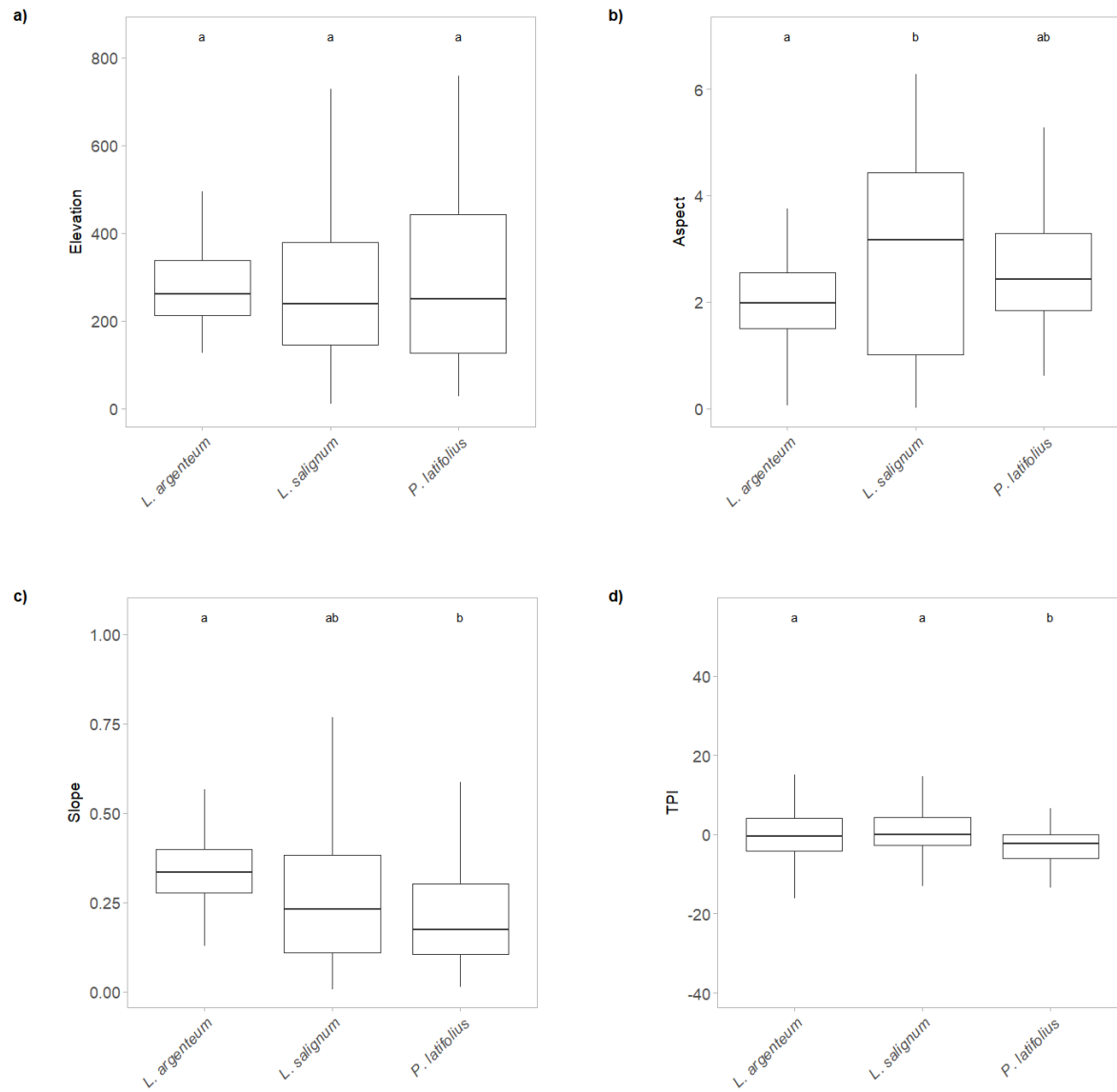
a)

b)

c)

d)

Figure 2: Comparative boxplots illustrating the mean values of four non-fire predictor variables associated with occurrence data for each species. Species with the same letter are not significantly different (Tukey's HSD). a) Elevation, b) Aspect, c) Slope, d) TPI.
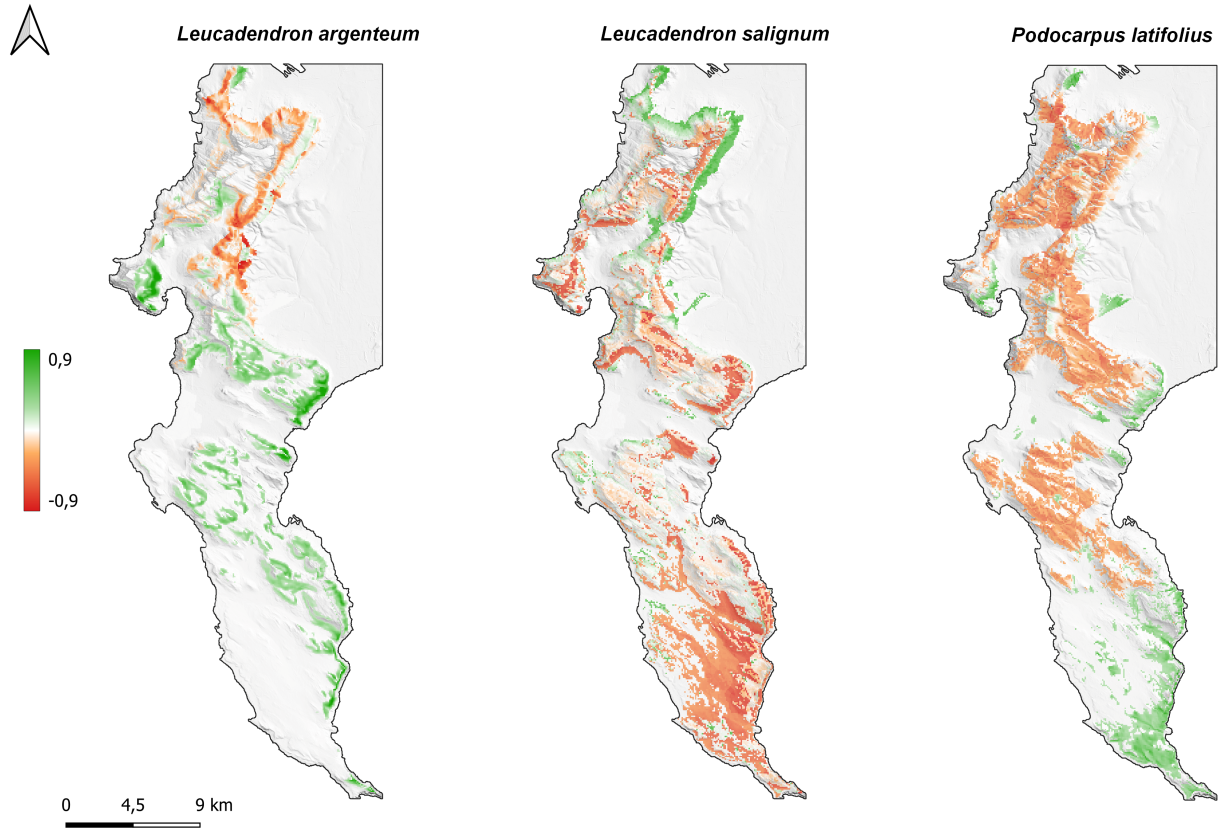
Figure 3: Change in the probability of occurrence (suitability range) as determined by the SDMs for each species. These show the relative changes between current and historical ignition catchments in the Cape Peninsula, all other covariates being the same (i.e., Transformed burn probability SDM - Historical burn probability SDM). Negative values indicate a decrease in the probability of occurrence while positive values indicate increase.

Table 1: Number of occurrences for each species before and after points were removed in data filtering

Species	Raw	Filtered	Removed
Leucadendron argenteum	140	118	22
Leucadendron salignum	2305	534	1771
Podocarpus latifolius	90	54	36

Table 2: Environmental predictors used for each model, with a brief description and source.

Predictors	Description	Source
Burn probability	Spatial classifications of the burn probability at a given point in study area (Historical: Prior to urban development, Transformed: Circa 2009)	Jasper Slingsby
Digital Elevation Model (DEM)	Digital model depicting the elevation of the geographical surface (Bare Earth Model) of the Cape Town municipal area.	City of Cape Town Open Data Portal
Aspect	The compass direction that a terrain surface faces.	Calculated from DEM in R using the "terrain" package
Slope	The rise or fall in terrain elevation over a defined terrain distance	Calculated from DEM in R using the "terrain" package
Topographic Position Index (TPI)	A method of terrain classification describing the altitude at one point relative to surrounding points.	Calculated from DEM in R using the "terrain" package

Table 3: Shapiro-Wilk test results for each of the environmental predictors used in SDMs. The null hypothesis of each test states that the data are normal.

Model	W	p
Historical burn probability	0.95261	1.471e-14
Transformed burn probability	0.95463	6.166e-14
Elevation	0.93824	$< 2.2e\text{-}16$
Aspect	0.94865	3.173e-15
Slope	0.94545	9.756e-16
TPI	0.89762	$< 2.2e\text{-}16$

Table 4: Species-wise ANOVA results comparing differences in environmental predictor values at occurrence locations. The null hypothesis in each case states that species group means are equal.

Model	Df	MS	F-Value	p
Historical burn probability	2	0.019951	148.5	<2e-16
	726	0.000134		
Transformed burn probability	2	0.0020280	15.89	1.78e-7
	703	0.0001276		
Elevation	2	49326	1.65	0.193
	726	29894		
Aspect	2	29.022	9.305	0.000102
	726	3.119		
Slope	2	0.3438	9.552	8.04e-5
	726	0.0360		
TPI	2	975.8	10.7	2.64e-5
	726	91.2		

Table 5: Species-wise Kruskwill-wallace results for each of the environmental predictors. The null hypothesis in each case states that mean ranks on some outcome variable are equal across groups.

Model	Chi-squared	Df	p
Historical burn probability	210.62	2	< 2.2e-16
Transformed burn probability	31.78	2	1.256e-7
Elevation	4.4622	2	0.1074
Aspect	13.233	2	0.001338
Slope	36.557	2	1.153e-8
TPI	15.522	2	0.000426

Table 6: AUC scores for each MaxEnt model.

Model	Training data	Test data
Leucadendron argenteum		
Historical model	0.940	0.957
Transformed model	0.869	0.810
Leucadendron salignum		
Historical model	0.820	0.786
Transformed model	0.700	0.631
Podocarpus latifolius		
Historical model	0.844	0.788
Transformed model	0.875	0.772

Table 7: Permutation contribution of environmental predictors for each model

Environmental Predictor	Historical model	Transformed model
Leucadendron argenteum		
Burn probability	33.5	21.5
Elevation	43.8	35.2
Aspect	6.7	27.1
Slope	15.6	16.2
TPI	0.3	0
Leucadendron salignum		
Burn probability	28.6	31.9
Elevation	56.1	35.4
Aspect	3.1	13.8
Slope	12.1	9.9
TPI	0.2	13.8
Podocarpus latifolius		
Burn probability	20.7	16.8
Elevation	44.9	7.2
Aspect	18.3	12.7
Slope	5.9	18.5
TPI	10.3	44.7