Impact of the Future Changing Climate on the Southern Africa Biomes, and the Importance of Geology

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Abstract

The Southern African biomes are complex biotic communities, with its distinctive plant and animal species, and are maintained under the suitable climatic conditions of the region. It includes the Fynbos Biome and the Succulent Karoo Biome, which forms the smallest of the world's six Floristic Kingdoms, and they are of conservation concern. The other six biomes are Albany Thicket, Desert, Grassland, Indian Ocean Coastal belt, Nama-Karoo, Savanna. The biomes are not only threatened by agricultural expansion, overgrazing, and mining; but also by future climate changes and droughts. This study investigates the how to best model the possible vulnerable biome areas, under future climate changes, and how Southern African geology plays a huge role in the restriction of the biome shifts. It provides evidence regarding the importance of the study to understanding the climate change impacts and the geological variables on the Southern African biomes, in terms of possible future biome habitat loss.

Keywords

Climate Change, Biomes, Geology, Southern Africa, Albany Thicket, Desert, Fynbos, Grassland, Indian Ocean Coastal Belt, Nama-Karoo, Savanna, Succulent Karoo

1. Introduction

A Biome can be described as a complex biotic community, and it is characterized by distinctive plant and animal species, and is maintained under suitable climatic conditions of the region [1]. Hence, the definition of a biome is complex as it extends beyond individual species to represent entire ecosystems under suitable

climatic conditions and geological conditions. The Southern Africa biomes include the Fynbos Biome and the Succulent Karoo Biome, which together form the smallest of the world's six Floristic Kingdoms [2]. These are unique and are of conservation concern. The other six biomes considered in this paper are Albany Thicket, Desert, Grassland, Indian Ocean Coastal belt, Nama-Karoo and Savanna.

Climate change including local climate variabilities, has been identified as a serious risk to the Southern African region [3]. Local climate variabilities are still tolerable, but extreme climatic events and pro-longed climate change would prove to be serious in terms of the impact on natural biomes and ecosystems, and good political structures and policies are needed to deal with these issues. In Southern Africa, there are conservation and management difficulties in maintaining the biomes in the face of the future climate change with prolonged droughts, but there are also other impacts such as overgrazing, land transformation and deforestation. Under the semi-arid climatic conditions, even a few degrees increase in temperature and a few millimeters decrease in rainfall could cause a decline in the biodiversity of plants and animals [4] [5].

In **Figure 1**, the present or current status and distribution of the eight Southern African biomes are shown [6], however azonal lakes and Waterbodies, and forests are excluded for modelling purposes because of their relatively small size. The eight major biomes are: Albany Thicket, Desert, Fynbos, Grassland, Indian Ocean Coastal belt, Nama-Karoo, Savanna, and Succulent Karoo. These biomes consist of plants, trees, vegetation, insects, animals, and other organisms. As complex ecosystems, biomes do not shift or move easily as a consequence of unsuitable climate such as droughts, although some animal and plant species may relocate into other biome areas.

2. Climate Data and Methods

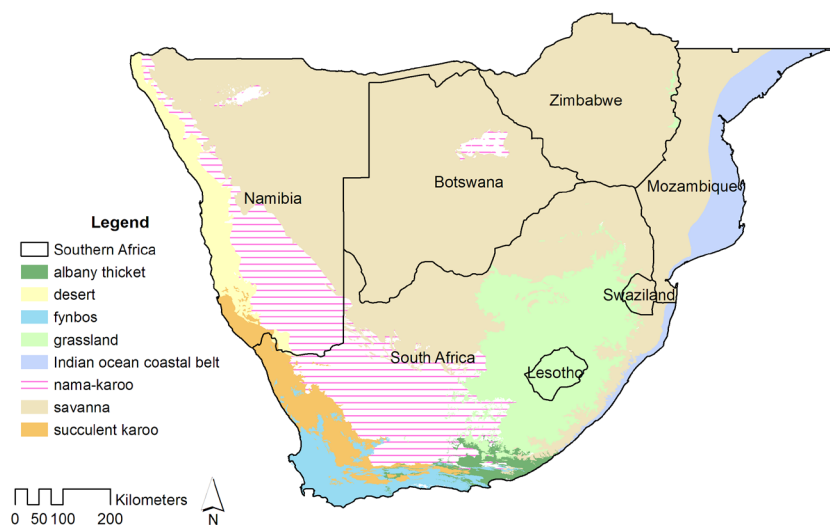The MPI-ESM-MR model from the Max Planck Institute for Meteorology was

Figure 1. Current biomes in Southern Africa [6].

used in this study, because it has proved to be a good Global Climate Model by comparison to others [7]. The MPI-ESM is a comprehensive Earth-System Model, and it consists of component models for the ocean, the atmosphere, and the land surface [8]. It is a fairly conservative model and as such was seen to be well suited for predictions of Southern African climate, with its inherent regions of dryness and wetness.

In this study we used the RCP8.5 as the future scenario, for future time period 2061-2080 [9]. Representative Concentration Pathways (RCPs) are greenhouse gas concentration trajectories adopted by the Intergovernmental Panel on Climate Change for its fifth Assessment Report in 2014 [10].The RCP are named after a possible range of radiative forcing values in the year 2100 relative to pre-industrial values, +8.5 W/m^2. RCP 8.5 assumes global annual emissions measured in CO_2-equivalents, and continues to rise throughout the 21st century [10]. RCP8.5 is a realistic future scenario based on the present human activity.

In order to examine the distribution and relationship between the biomes and the climatic variables, the distributions are modelled to show the climatic niche of the biomes. Species distribution models are used to estimate the relationship between the records at sample sites and the environmental and spatial characteristics of those sample sites [11], which in this case are the climatic variables. The species distribution model used in this study is MaxEnt [12]. MaxEnt applies Bayesian methods to estimate the potential geographic distribution of species by finding the probability distribution of maximum entropy and is an effective method for modelling species distributions from presence-only data [12] [13] [14].

The conventional Bayesian risk criterion is based on the quadratic loss function and use of a conjugate family [15], and the Maximum Entropy modelling is an important Bayesian inference, which is established by different risk criterion. MaxEnt is a Bayesian approach by which the species probability distribution is statistically estimated by searching the family of probability distributions under the maximum entropy criterion subject to environmental constraints [4].

Gibbs sampling is a statistical algorithm used by Bayesian inference, which is used in MaxEnt. The Gibbs family $\{q_\lambda(x), \lambda \in \mathrm{L}\}$, where

$$q_\lambda(x) = \frac{1}{Z_\lambda(x)} \exp\left(\sum_{i=1}^{m} \lambda_i f_i(x)\right) \tag{1}$$

with $\lambda_i = (\lambda_1, \lambda_2,..., \lambda_m)$ as the weight vector, and λ_i being the weight parameters, L being the m-dimensional space, and $f_i(x)$ representing species i's probability distribution, $Z_\lambda(x)$ being the normalized constant. Note that each element x is a pixel of the investigated area. These probabilities $f_i(x)$ represent relative suitability of the environmental conditions in each pixel [12] [13] [14].

The climate variables used in the modelling are the nineteen bioclimatic variables of BIOCLIM. BIOCLIM is a bioclimatic prediction system which uses bioclimatic parameters, derived from mean monthly climate estimates, to approximate the energy and water balances, at a given location [16] [17]. The climate variables are: BIO1 = Annual Mean Temperature, BIO2 = Mean Diurnal

Range, BIO3 = Isothermality, BIO4 = Temperature Seasonality, BIO5 = Maximum Temperature of Warmest Month, BIO6 = Minimum Temperature of Coldest Month, BIO7 = Temperature Annual Range, BIO8 = Mean Temperature of Wettest Quarter, BIO9 = Mean Temperature of Driest Quarter, BIO10 = Mean Temperature of Warmest Quarter, BIO11 = Mean Temperature of Coldest Quarter, BIO12 = Annual Precipitation, BIO13 = Precipitation of Wettest Month, BIO14 = Precipitation of Driest Month, BIO15 = Precipitation Seasonality, BIO16 = Precipitation of Wettest Quarter, BIO17 = Precipitation of Driest Quarter, BIO18 = Precipitation of Warmest Quarter, BIO19 = Precipitation of Coldest Quarter. The environmental layers are altitude, geology (lithology, rocks), and soil.

3. Projected Changes and Geology as Limiting Variables

In modelling the biomes, initially, only climate variables are used to examine the changes in the biomes in the projected future climate, as shown in **Figure 2**. As one could see, without constraints of environmental factors, the biomes are projected to expand to wherever the climates are suitable. There is major competition between the Savanna and the Nama-Karoo over the same regions. However, biomes are not just individual plants, and they are such a complex ecosystem that they cannot just move and expand due to a changing climate.

In **Figure 3**, the geology layers and soil layers are added as environmental limiting factors on the biomes. This map shows expansion and shrinkage of the biomes, but clearly the Savanna and Nama-Karoo are in competition, but less so than in the map without geology. While on the coastal side, the Indian Ocean Coastal Belt is clearly shrinking due to unsuitable climate. Just having the geology and soil layer added makes a huge difference in the projections. The white gaps are areas that are no longer climatically suitable in the future for any of the current existing biomes, and are could be vulnerable to other ecosystems moving in, or for invasive species.
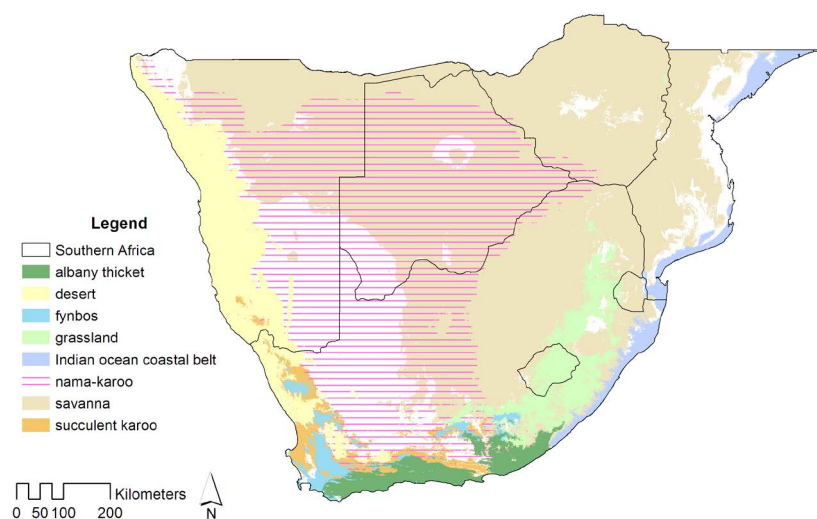

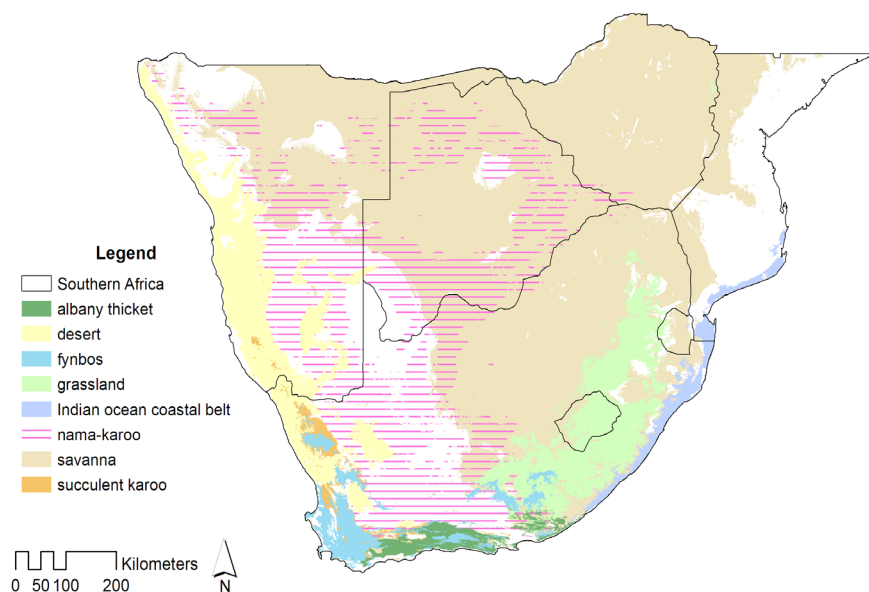**Figure 2.** Projected future (2070s) biomes based on climate only.

Figure 3. Projected future (2070s) biomes with geology (lithology and rocks) variables.

Table 1 examines the climate and environmental variable percentage contributions to the MaxEnt model. As one can conclude from the table, precipitation and temperature variables are shown to have the highest percentage contributions to the model. However, in other tests such as the Jacknife, geology is shown to have a much more significant result on the predicted biomes, which makes sense, due to the difference in future projections, just in having added geology and soil layers.

In the example used in **Figure 4**, the Jacknife Test estimates of which variables are most important in the model for the Fynbos Biome, and the environmental variable with highest gain when used in isolation is Precipitation of Coldest Quarter, which therefore appears to have the most useful information by itself. However, geology is also shown to be important to the model as well, and affects the Fynbos modelling. It is important to note, that in Southern Africa, geology is much more important and plays a much bigger role in biomes than just climate changes.

4. Interpretation and Conclusion

Finally we need to take an overall look at the future biomes. Due to geological barriers and also human activities such as urbanization, farming and mining, which all play a critical role in how the biomes react to climate changes, the biomes doesn't often "shift" to a different region. Biomes with their plants, insects, birds, and animals are constrained by soil conditions, and these are all are part of the ecosystem. Such a complex ecosystem does not expand and move easily, but shrinkage of the biomes is easy, due to loss of key organisms, as a result of climate change, prolonged drought, overgrazing, deforestation, land transformation. Therefore, for a more complete assessment of the future biomes, zero migration is assumed for **Figure 5**, in which biome expansion is prevented,

Table 1. Variable Percentage contributions to MaxEnt model.

Variable	Biomes							
	Albany Thicket	Desert	Fynbos	Grassland	Indian Ocean Coastal Belt	Nama Karoo	Savanna	Succulent Karoo
Annual Mean Temp.	0.008	0.273	0.303	6.645	0.484	3.259	1.769	0.294
Mean Diurnal Range	0.000	0.106	0.142	0.564	0.131	1.342	1.524	0.688
Isothermality	0.385	0.387	0.407	0.344	0.205	5.994	1.409	0.009
Temp. Seasonality	0.365	2.630	0.813	0.164	13.364	0.197	1.390	0.666
Max Temp. of Warmest Month	0.139	0.162	0.535	0.307	0.350	0.472	9.380	0.006
Min Temp. of Coldest Month	0.006	0.160	0.022	0.686	30.450	0.480	3.210	0.999
Temp. Annual Range	4.643	1.655	0.340	0.033	0.659	0.219	5.486	5.582
Mean Temp. of Wettest Quarter	1.748	2.908	14.816	3.392	0.509	5.907	5.985	2.753
Mean Temp. of Driest Quarter	0.642	0.165	0.466	3.800	0.454	0.296	0.095	0.297
Mean Temp. of Warmest Quarter	1.012	0.115	0.284	24.039	1.923	1.199	0.160	0.018
Mean Temp. of Coldest Quarter	0.537	0.148	0.850	0.826	0.176	1.859	16.602	0.008
Annual Precip.	0.025	88.812	0.323	0.874	1.383	6.706	2.921	0.061
Precip. of Wettest Month	0.140	0.151	0.294	0.382	1.087	2.114	4.265	1.677
Precip.of Driest Month	0.000	0.057	0.064	0.048	0.022	1.936	0.408	0.010
Precip. Seasonality	68.694	0.332	1.129	3.738	1.505	4.352	4.889	31.941
Precip. of Wettest Quarter	4.127	1.306	0.103	0.018	0.658	8.566	6.174	0.030
Precip. of Driest Quarter	16.278	0.061	0.154	36.172	7.527	0.128	3.732	0.044
Precip. of Warmest Quarter	0.231	0.084	15.061	12.195	2.165	33.482	20.260	51.343
Precip. of Coldest Quarter	0.093	0.024	62.997	2.459	1.313	0.526	1.435	1.597
Altitude	0.123	0.070	0.647	0.941	32.639	2.460	4.247	0.258
Lithology	0.118	0.242	0.181	0.749	2.141	0.632	0.917	0.973
Rock Types	0.630	0.123	0.014	0.227	0.569	0.246	0.592	0.001
Soil Types	0.053	0.032	0.056	1.398	0.285	17.631	3.150	0.748

showing only the biome as they are in the future but without any expansion into other regions.

The biomes in **Figure 5** map show significant shrinkage in area, and more white gaps are shown to be areas of vulnerability, where biomes lose habitats. The white gaps in the maps are areas that are not climatically suitable anymore in the future for the current biomes, and are vulnerable to other organisms moving in, including invasive species. Various species from different biomes may continue to exist and compete in the white gap areas, however not in the biomes as we know them at present with their entire ecosystem with all the plants and animals and insects. While all the biomes are shrinking in size, the
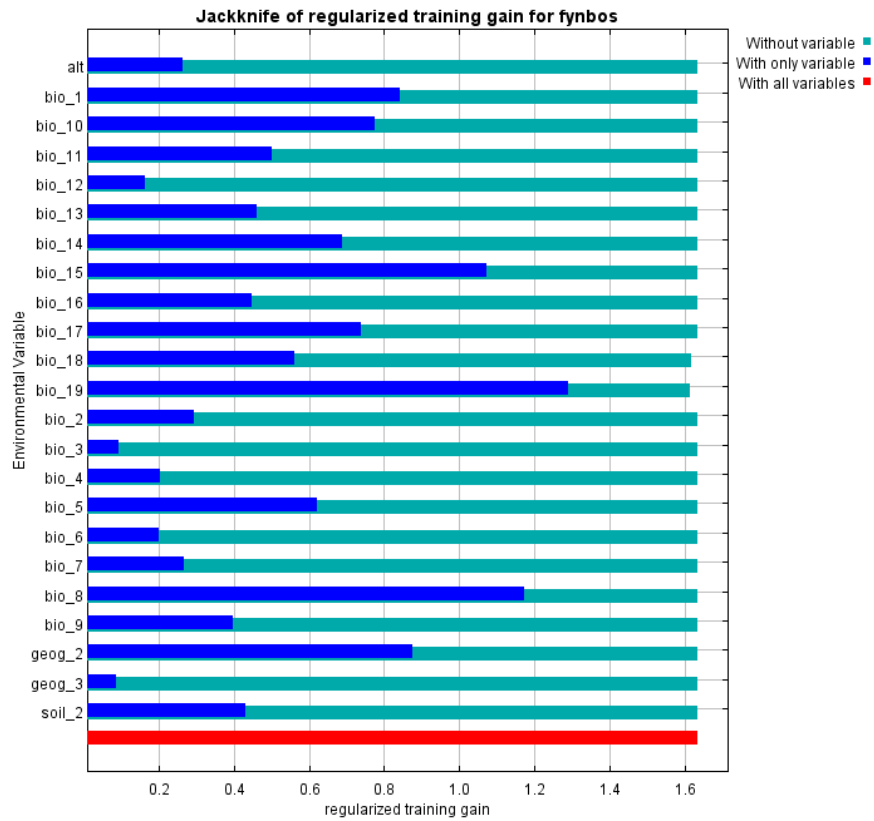
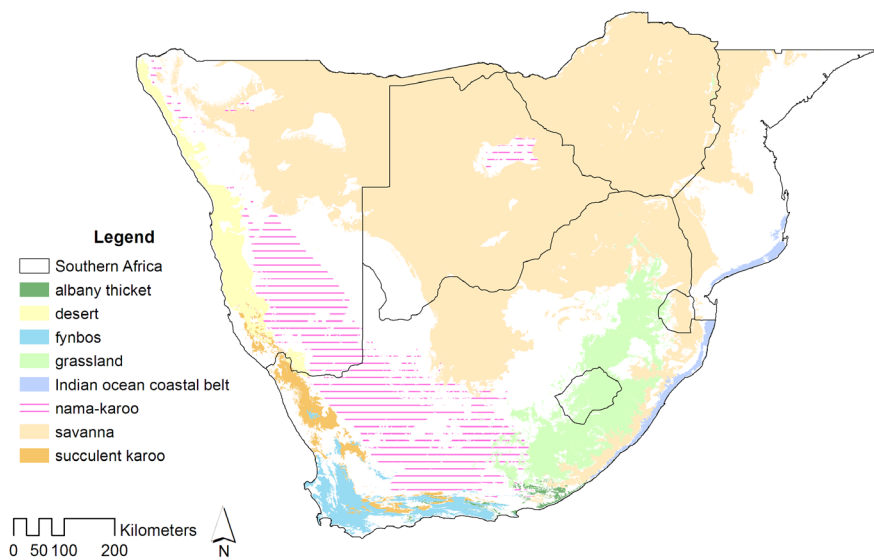**Figure 4.** Jacknife test of varables for the Fynbos Biome.

Figure 5. Projected future (2070s) biomes with zero migration.

Indian Ocean Coastal Belt and the Albany Thicket are affected the most in terms of loss of habitat. The Fynbos Biome is maintained well in spite of changing climate, but the Succulent Karoo biome faces major loss of habitat. In terms of conservation, the white gaps that indicate biome loss need to be monitored since they are potentially the most vulnerable areas.

As this study has shown that the Southern African biomes are very likely to be sensitive to temperature and precipitation, and to future climate change, and are particularly strongly affected by geological and soil constraints to their ecosystems expansion. This study provides evidence for the importance of understanding the climate change impacts on the biomes and its geographical response to the climate change [18] [19]. The biomes themselves are maintained by the current climate conditions, and therefore changes in climate would result in changes in the biome ecosystem. This study shows how the future climate change, and geology in Southern Africa play a huge role in the restriction of the biome shifts, and provides an indication of possible future biome habitat losses.

Recent climate change research has indicated that many species will become extinct by the year 2100 as a result of rapid changes in climatic conditions [19], and since species all make up the biomes, it is important for drawing up conservation and government policies, to know where the vulnerable areas are for purposes of observation and protection.

Acknowledgements

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