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Climate Change Impacts on Hydrological Niches of Restionaceae Species in Jonkershoek, South Africa

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***Abstract*-The Restionaceae species of the Fynbos biome is part of the Cape Floristic Kingdom is threatened by urbanization, agricultural expansion, groundwater extraction, and climate change. Therefore, it is necessary to assess and monitor the Restionaceae species under the impact of climate change. South Africa is a semi-arid environment, and hydrological factors are the main variables in the determination of species niches. This study investigates the microclimate at Jonkershoek, and examines the impact of climate change to the plant species distribution, thus creating shifts in the hydrological niche. This study generates its own unique microclimate hydrological datasets for modelling species niche. The Restionaceae species and their hydrological niche at the Jonkershoek study area are assessed under future climate change scenario, at a microclimatic level. It provided evidence regarding the importance of the study to understanding the climate change impacts on hydrological niche and on species richness.**

Keywords- Climate Change; Hydrological Niche; Restionaceae; Fynbos Biome; Microclimate; Jonkershoek; South Africa

I. INTRODUCTION AND BACKGROUND

Examining the recent debates on climate change over the Anthropocene hypothesis, which indicates we as humans may have changed the planet Earth and its ecosystem, and our human activities have an impact on the Earth's atmosphere and geological processes [1]. This makes conservation and management of our ecosystem more difficult as not only we face prolonged droughts in Africa; we also have problems of land transformation and deforestation. The Restionaceae are a family of perennial evergreen wind-pollinated flowering plants, which varies from 10 cm to 3 m in height, and based on the evidence from fossil pollens, it originated from more than 65 million years ago [2, 3]. Regarding conservation, the Restionaceae is threatened by urbanization, agricultural expansion, groundwater extraction, and as well as climate change. Therefore it is essential to discover the influence of hydrological variables on the Restionaceae at a local microclimate level, under the effect of climate change. Hydrological factors are the significant environmental variables which contributes to the determination of species niche, because of the semi-arid environment of South Africa. A niche defines the way in which a species fits into an ecosystem and ecological community, and it is modelled by the environmental variables [4]. In this study, we examine the hydrological niche which models the Restionaceae habitat through hydrological variables, under the impact of climate change and therefore hydrological changes.

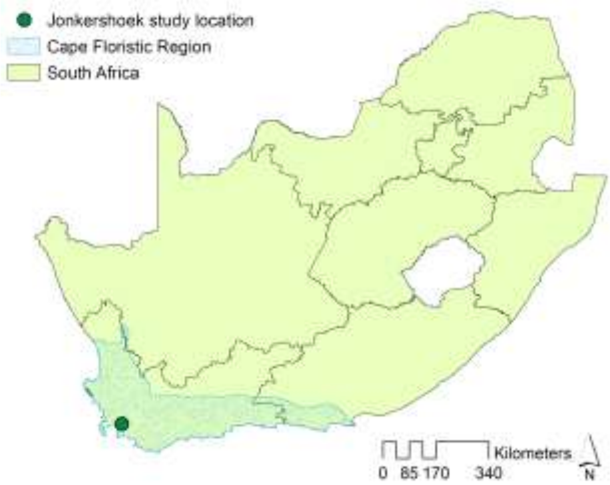

Fig. 1 Jonkershoek study location in South Africa

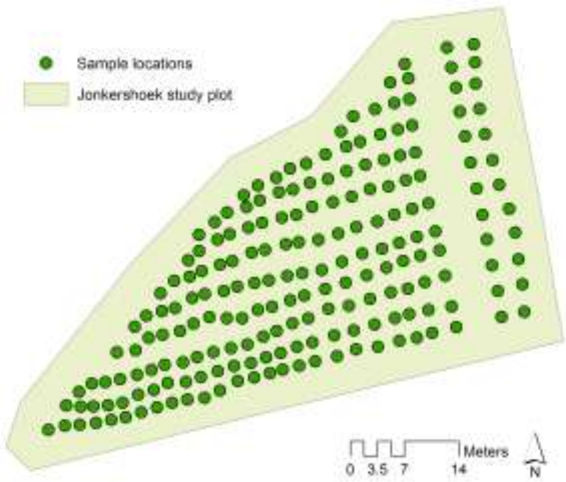

Fig. 2 Jonkershoek study area plot and sample locations

The study area is at Jonkershoek within the Cape Floristic Region, as shown in Fig. 1, in South Africa. Due to the land topography of the study area, the precise plot area size can vary. Fig. 2 shows a plot of the 50m by 50m study area, with 200 sample locations, placed on a grid 3-5 m apart. Samples measurements were taken for the following variables: elevation, water

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table depth, and recordings for the presence or absence of Restionaceae species at each sample point [5]. Previous studies of species niche have focused on macroclimate level and on climate variables rather than local microclimate level and hydrological variables, and primarily the previous studies of species niche and climate change have used mostly countrywide macroclimate datasets.

Since hydrological factors are the significant environmental variables which contribute to the determination of species niche, because of the semi-arid environment, the water-table depth becomes the main hydrological variable in this study. The soil water regime of hydrological variable used in the study is based on the hydrological models from previous research [6]. The water-table depth was monitored by the use of tube wells, and supported by automatic logging pressure transducers. The tube wells were read manually every two weeks, and subsample data was recorded every four hours for at least twelve months. Using the hydrological data from the tube wells, the water-table depth for each sample location was obtained [5, 7, 8].

This research has generated its own unique microclimate hydrological datasets for modelling species niche at a local level. It focuses on the microclimate level, and examines the influence of the hydrological variable on plant species distribution, creating a hydrological niche for the individual plant species. The primary objective of this study is to assess the microclimate at Jonkershoek, and to model the impact of future climate change to the plant species distribution and hydrological niche, and to provide evidence of the importance of the study to understanding the climate change impacts on hydrological niche and on species richness.

II. RESTIONACEAE AND HYDROLOGICAL VARIABLE

To explore the hydrological niche of plant species, the hydrological variable needs to be first evaluated, which is the water table depth. This study generated its own microclimate hydrological datasets for modelling species niche based on the elevation and water table depth, and samples were taken at each sample point to determine the presence or absence of Restionaceae species [5]. The seven Restionaceae plant species found at the Jonkershoek study area are: Elegia asperiflora, Elegia juncea, Hypodiscus albo-aristatus, Hypodiscus aristatus, Restio filiformis, Restio triticeus, Staberoha cernua.

Ordinary kriging was performed on the data in order to produce the microclimate environmental layers, which was then used to calculate the hydrological niche of the Restionaceae species. Kriging is an interpolation procedure that uses collected observations and a semivariogram, in order to determine the values of non-sampled locations, and the procedures involved in kriging does incorporate measures of error and uncertainty when determining the estimations. Ordinary kriging is a form of kriging which uses a location-dependent weighted average, of the observed data values, collected from the given locations, where the weights depend on the spatial correlation structure of the data itself [3, 9, 10, 11].

Ordinary kriging is a linear predictor [3, 9, 10, 11]:

$$\hat{Z}(s_0)=\sum_{i=1}^{N}\lambda_i Z(s_i) \tag{1}$$

where s_i is a location with observation $Z(s_i)$, and coefficient λ_i satisfies the ordinary kriging linear equation system:

$$\begin{cases}\sum_{j=1}^{N}\lambda_j\gamma\left(\varepsilon(s_i)-\varepsilon(s_j)\right)-\psi=-\gamma\left(\varepsilon(s_i)-\varepsilon(s_0)\right),\ i=1,2,\cdots,N\\ \sum_{j=1}^{N}\lambda_j=1\end{cases} \tag{2}$$

The ordinary kriging system is produced under the assumption of an additive spatial model:

$$Z(s)=\mu(s)+\varepsilon(s) \tag{3}$$

where $\mu(s)$ is the basic (expected) spatial trend, and $\varepsilon(s)$ is an error term.

$$\mathrm{E}\left[\varepsilon(s)\right]=0,\mathrm{V}\left[\varepsilon(s)\right]=\sigma^2(s) \tag{4}$$

Accordingly, the variogram 2γ of the random error function ε is defined as follows:

$$2\gamma(h)=\mathrm{E}\left[\left(\varepsilon(s+h)-s(h)\right)^2\right] \tag{5}$$

where h is the separate vector between two the spatial points $s+h$ and s [3, 9, 10, 11]. The semivariogram model used in this study is as follows:

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$$\gamma(\mathrm{h};\theta)=\theta_s\left[1-\exp\left(-3\left(\frac{\|\mathrm{h}\|}{\theta_r}\right)^{\theta_e}\right)\right] \tag{6}$$

for all h, where $\theta_s \geq 0$ and $0 \leq \theta_e \leq 2$ [12]. Finally, the microclimate variables of elevation and water table depth are generated.

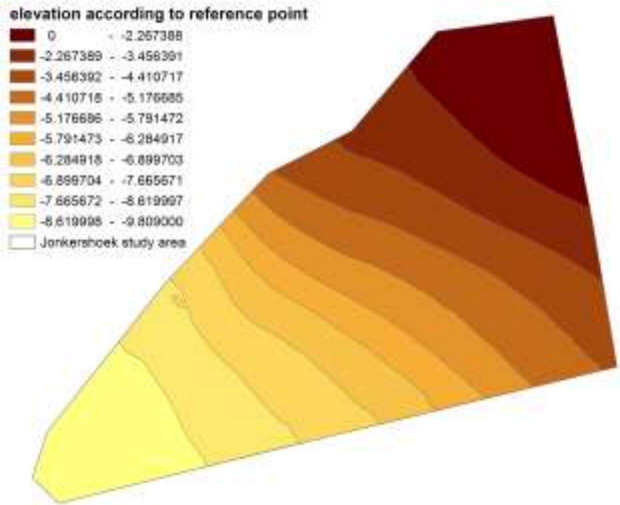

Fig. 3 Relative elevation according to reference point, longitude 18.9529, latitude -33.99333 at 350 meters

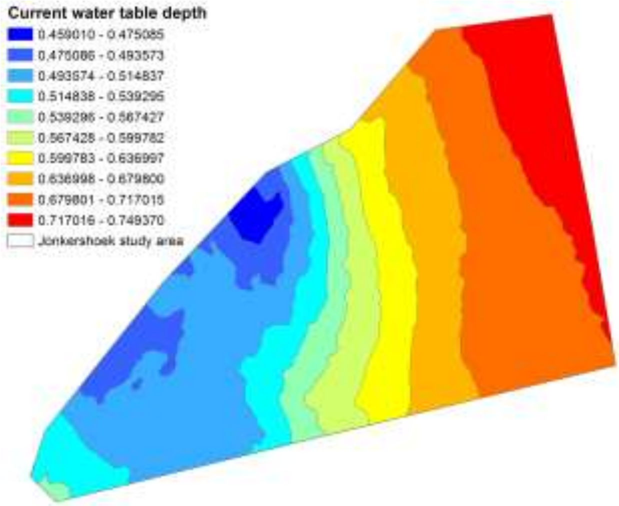

Fig. 4 Current Water table depth (WTD) at Jonkershoek

Fig. 3 shows the relative elevation. These values were recorded in relation to a reference point near the plot: longitude 18.9529, latitude -33.99333 at 350 meters. The reference point at the Jonkershoek location was at a higher elevation than the plot, so all points on the plot appeared negative; the darker colours indicate higher relative elevations. In Fig. 4, the water table depth (WTD), sometimes referred to as depth to water (DTW), is shown. Higher WTD values signify deep or lower water tables, which are related to drier conditions [5].

III. CLIMATE CHANGE MODELLING

In order explore the possible changes in the hydrological niche between the present and future climate, new microclimate data are produced for the future scenarios. Present current water table depth is used in determining the hydrological niche of the seven Restionaceae species. As for the future, since no microclimatic variables are available, our own modelled results are used. MPI-ESM-MR model from the Max Planck Institute for Meteorology was selected based on it proved to be a good Global Climate Model by comparison to others [13]. The MPI-ESM is a comprehensive Earth-System Model, and it consists of component models for the ocean, the atmosphere, and the land surface [14]. It is a fairly conservative model and as such was seen to be well suited for predictions of Southern Africa climate, with its inherent regions of dryness and wetness [14].

In this study we used RCP2.6 and RCP8.5 as comparative future scenarios. Representative Concentration Pathways (RCPs) are greenhouse gas concentration trajectories adopted by the Intergovernmental Panel on Climate Change for its fifth Assessment Report in 2014 [15]. The RCP are named after a possible range of radiative forcing values in the year 2100 relative to pre-industrial values, +2.6 and +8.5 W/m2, respectively. RCP 2.6 assumes that global annual emissions measured in CO2-equivalents peak between 2010-2020 with emissions declining after, and RCP 8.5 assumes emissions continues to rise throughout the 21st century [15]. Obviously, RCP2.6 is a good but unlikely future scenario, and RCP8.5 is a more realistic future scenario based on the present human activity.

To interpret macroclimate data into microclimate data:

$$\text{Future WTD} = (C/F)*\text{WTD} \tag{7}$$

In which WTD is water table depth, and F is future total precipitation for Jonkershoek, and C is current total precipitation for Jonkershoek, and therefore (C/F) represent the ratio. For RCP2.6 the WTD is not too different from the present WTD with a slight loss of water, while in RCP8.5 WTD is much higher in value due to more loss in water. In this way, the two future WTD for RCP2.6 and RCP8.5 are generated on the microclimate level, and the hydrological niche for the seven Restionaceae can also be generated for present and the two possible future scenarios.

IV. CHANGES IN HYDROLOGICAL NICHE

To explore future climate impacts, the new microclimate data are used to model the changes in hydrological niche of the

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seven Restionaceae species. Restionaceae species occupy a wide range of environmental conditions, and inhabit both moist and dry environmental conditions [5]. Therefore, the seven species used in the study have different hydrological preferences; some are distributed in wetter environment and some are distributed in drier environment, and some has no preferences. A species distribution model is used to estimate the relationship between Restionaceae species records at sites, as well as the spatial and hydrological characteristics of the sites [16]. The species distribution model used in this case is MaxEnt [17].

The conventional Bayesian risk criterion is based on the use of a conjugate family, and the quadratic loss function [18], and Maximum Entropy modelling (MaxEnt) is basically a Bayesian inference, and it is established by using different risk criterions. Therefore, MaxEnt has a Bayesian approach by which the species probability distribution, subject to environmental constraints, are statistically estimated by searching the family of probability distributions, under the maximum entropy criterions [3].

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

$$q_\lambda(x) = \frac{1}{Z_\lambda(x)} \exp\left(\sum_{i=1}^{m} \lambda_i f_i(x)\right) \quad (8)$$

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. Each element x is a pixel of the investigated area. The probabilities $f_i(x)$ represents relative suitability of the environmental variable in each pixel [17, 19, 20].

Fig. 5 and 6 depicts the hydrological niche of the Elegia asperiflora species, modelled using present and future hydrological variable water table depth. Clearly, under the RCP8.5 scenario, there is a greater loss of niche, but it also shows niche expansion to the left of the study area.

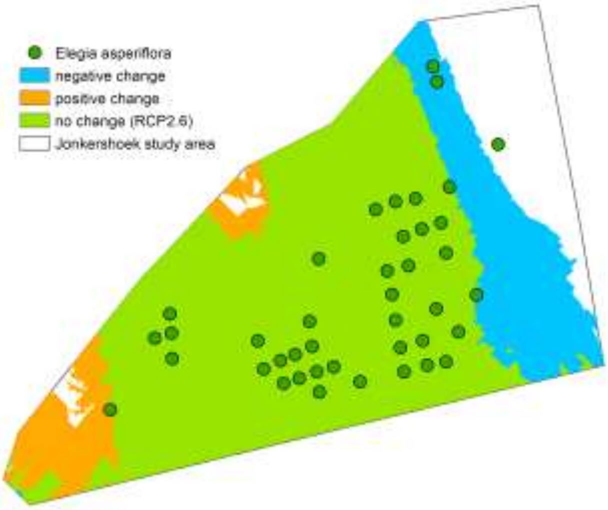

Fig. 5 Change in hydrological niche of Elegia asperiflora under RCP2.6

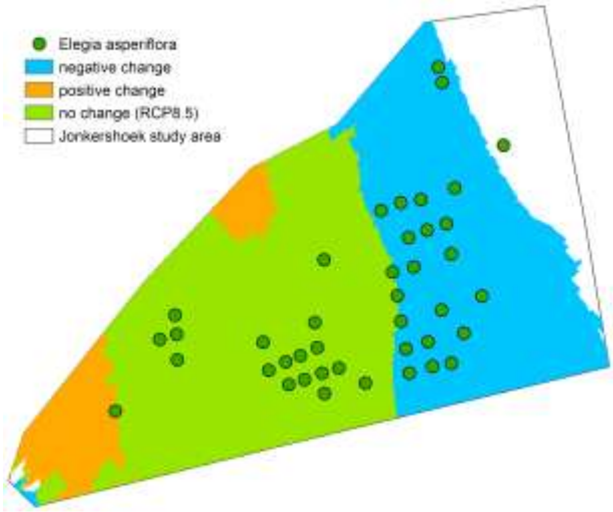

Fig. 6 Change in hydrological niche of Elegia asperiflora under RCP8.5

Fig. 7 and 8 depicts the hydrological niche of the Elegia juncea species, modelled using modelled using present and future hydrological variable water table depth. Under the RCP2.6 scenario, not much changes, with loss and gain of the niche area. But under the RCP8.5 scenario, there is a significant loss of niche.

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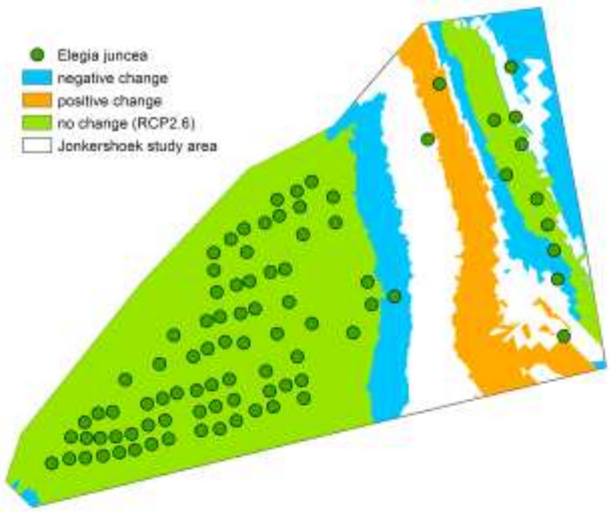

Fig. 7 Change in hydrological niche of Elegia juncea under RCP2.6

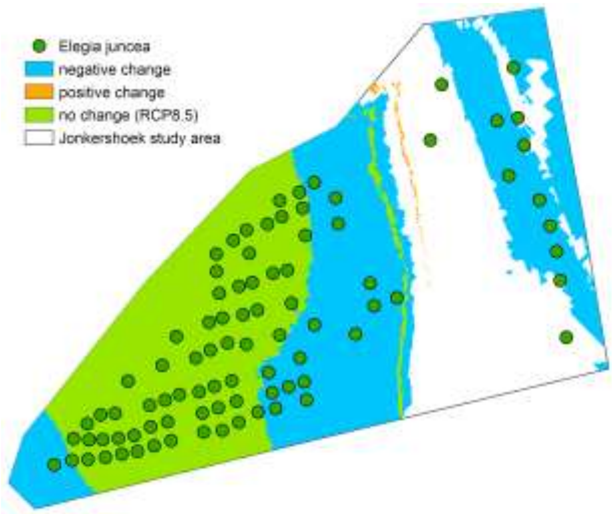

Fig. 8 Change in hydrological niche of Elegia juncea under RCP8.5

Fig. 9 and 10 depicts the hydrological niche of the Hypodiscus albo-aristatus species, modelled using modelled using present and future hydrological variable water table depth. Under both future scenarios, the species loses habitat, but under RCP2.6, most of the original niche area is maintained.

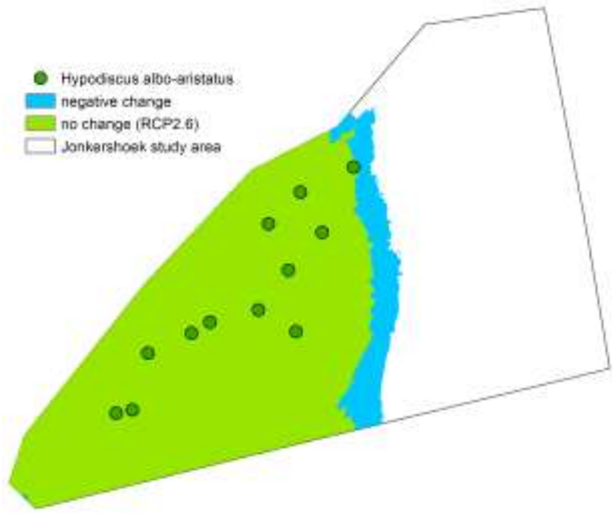

Fig. 9 Change in hydrological niche of Hypodiscus albo-aristatus under RCP2.6

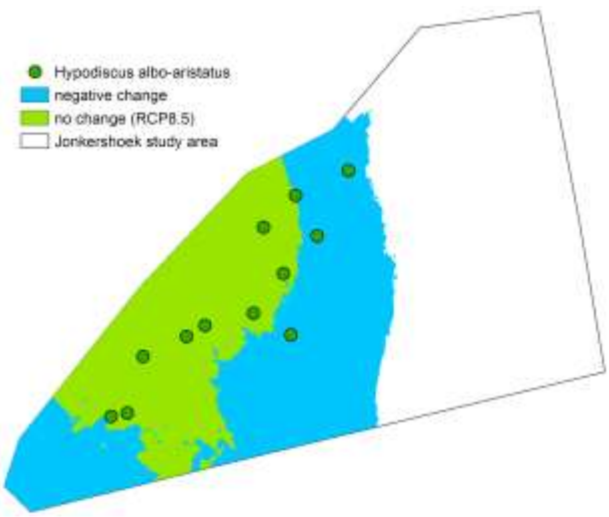

Fig. 10 Change in hydrological niche of Hypodiscus albo-aristatus under RCP8.5

Fig. 11 and 12 depicts the hydrological niche of the Hypodiscus aristatus species, modelled using modelled using present and future hydrological variable water table depth. Under RCP2.6, there is no area loss, but it shows a niche expansion. However in RCP8.5, there is a loss of niche area.

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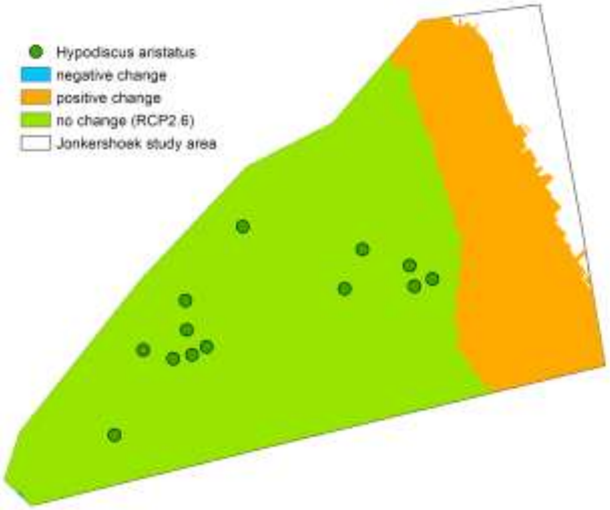

Fig. 11 Change in hydrological niche of Hypodiscus aristatus under RCP2.6

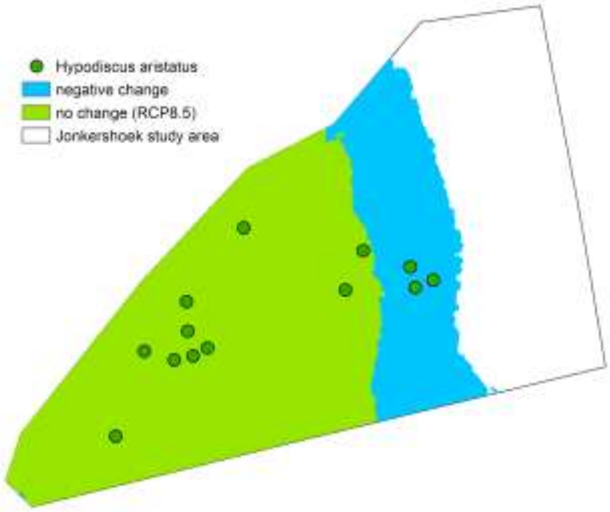

Fig. 12 Change in hydrological niche of Hypodiscus aristatus under RCP8.5

Fig. 13 and 14 depicts the hydrological niche of the Restio filiformis species, modelled using modelled using present and future hydrological variable water table depth. In this case, both scenarios are losing hydrological niche areas.

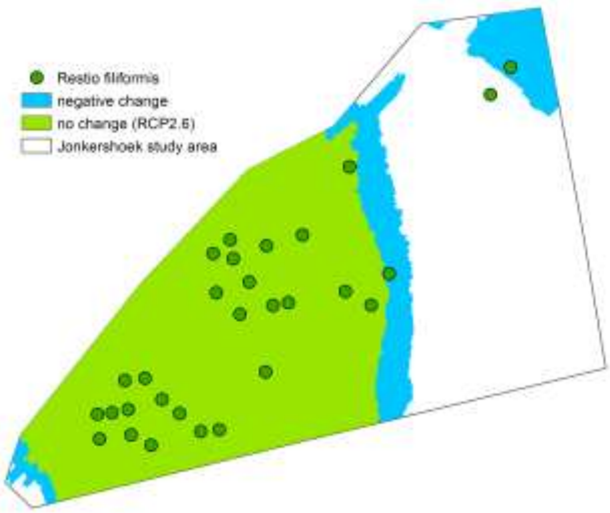

Fig. 13 Change in hydrological niche of Restio filiformis under RCP2.6

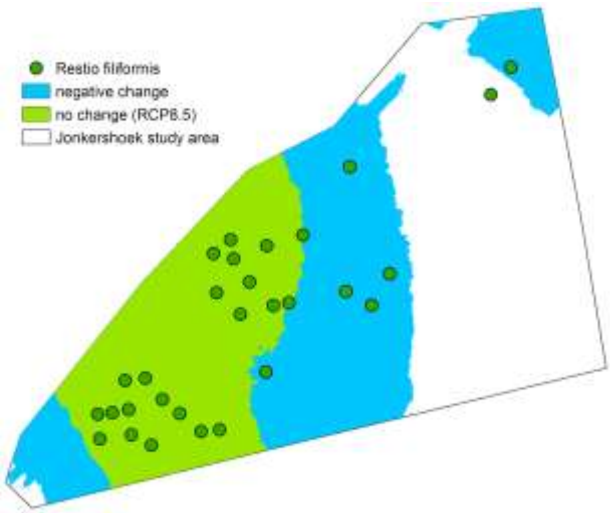

Fig. 14 Change in hydrological niche of Restio filiformis under RCP8.5

Fig. 15 and 16 depicts the hydrological niche of the Restio triticeus species, modelled using modelled using present and future hydrological variable water table depth. This species is more widespread and maintains are greater part of its niche under different conditions.

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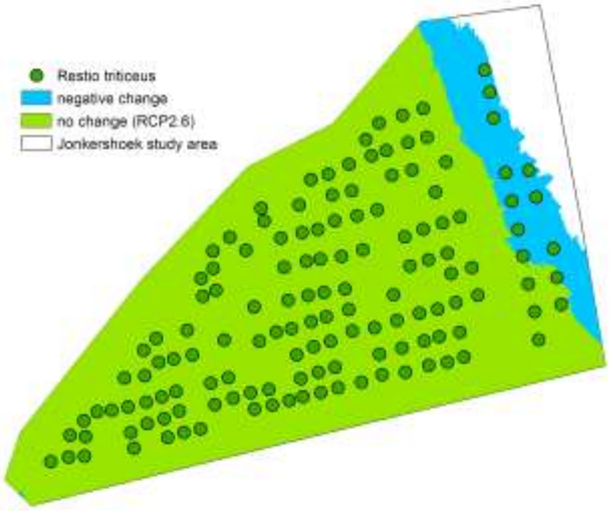

Fig. 15 Change in hydrological niche of Restio triticeus under RCP2.6

Fig. 16 Change in hydrological niche of Restio triticeus under RCP8.5

Fig. 17 and 18 depicts the hydrological niche of the Staberoha cernua species, modelled using modelled using present and future hydrological variable water table depth. The RCP8.5 scenario shows much greater of loss of habitat area.

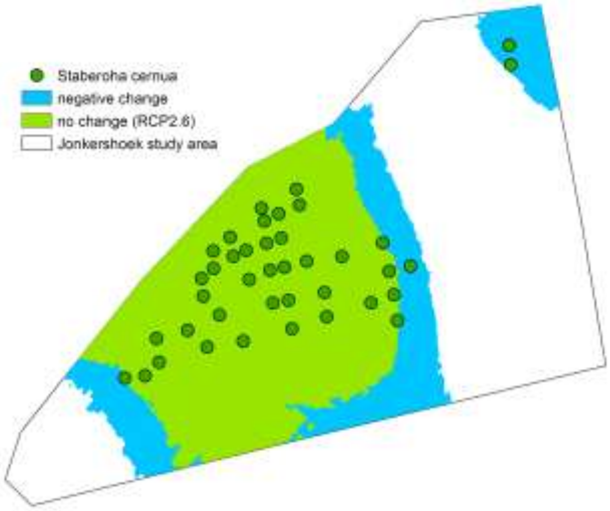

Fig. 17 Change in hydrological niche of Staberoha cernua under RCP2.6

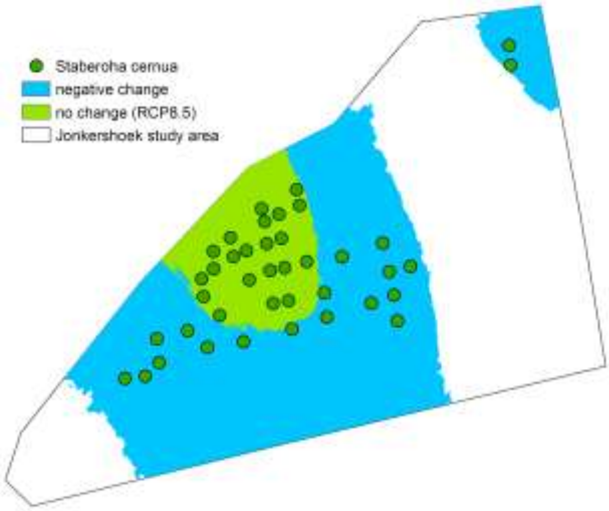

Fig. 18 Change in hydrological niche of Staberoha cernua under RCP8.5

As shown in Fig. 5-18, some Restionaceae species prefer wetter conditions and some prefer drier conditions, and each individual species has its own hydrological niche with their own niche requirements, but they also coexist with other species within the same ecological niche, and thus compete for the same hydrological resources. Under changes in climate and in competition for water resources, the species would change their niche areas accordingly.

V. SPECIES RICHNESS INDEX

Fig. 19 shows the present species richness index of the Restionaceae species at Jonkershoek. The species are concentrated on the lower half of the plot area, where the WTD is lower, with more availability of water resources.

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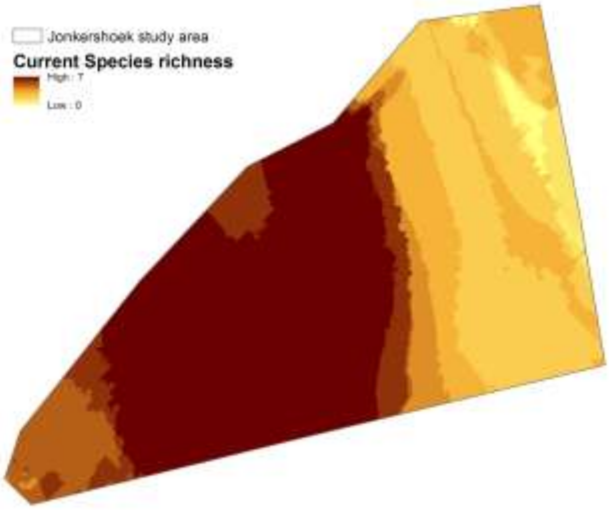

Fig. 19 Present species richness in Jonkershoek

Fig. 20 and 21 shows the future species richness of the Restionaceae species at Jonkershoek. Under RCP2.6, the species richness index is very similar to the present species richness index, and in RCP8.5, the high species richness areas are reduced to the plot area with the lowest WTD. There is a definite loss of species richness in the RCP8.5 scenario, due to a loss of water in the future scenarios.

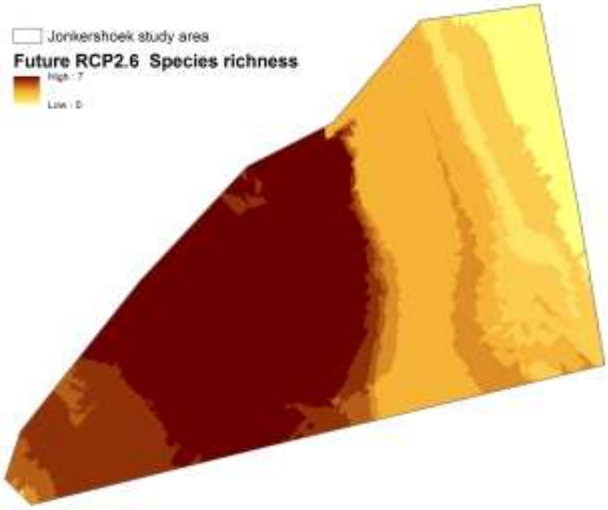

Fig. 20 Future RCP2.6 species richness index in Jonkershoek

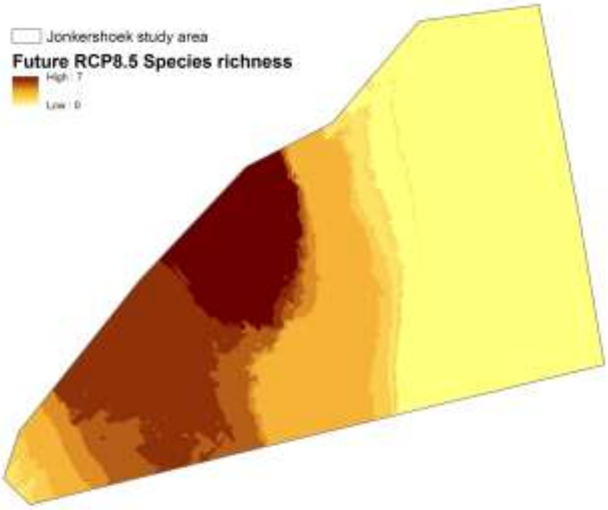

Fig. 21 Future RCP8.5 species richness index in Jonkershoek

These study results suggest a direct climate impact on the conservation of species richness, linked to hydrological variable changes. Should there be any climate change (in this case, less rainfall) resulting in a higher water table depth, it could result in a reduction of species richness, as some species might not survive with the changed conditions. Accounting for South Africa's semi-arid environment, groundwater extraction and the creation of more boreholes will ultimately cause a change in hydrology and therefore impact the Restionaceae species niche [21, 22].

VI. CONCLUSIONS

In this study, we employed microclimate modelling techniques to generate hydrological layers, in order to explore the hydrological niche of the Restionaceae species, in the present and the future. In the Jonkershoek study area, the water table depth was identified as the main contributing hydrological variable. The seven Restionaceae plant species Elegia asperiflora, Elegia juncea, Hypodiscus albo-aristatus, Hypodiscus aristatus, Restio filiformis, Restio triticeus, Staberoha cernua; all have their own hydrological niche, which indicates the different hydrological requirements of each individual species, all of which yet coexist and share the same hydrological niche area in Jonkershoek.

The study assessed and modelled the effectiveness of using hydrological variables to determine hydrological niches at a microclimate level in a semi-arid environment. The study has also provided evidence that any climate changes will cause changes in the hydrological variables, which will cause changes in the hydrological niche of the individual species and a subsequent change in the species richness index. The results of this study are invaluable to the assessment and monitoring of

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plant species due to hydrological changes.

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