**Assessing species richness, diversity and assemblage of forest patches within a grassland matrix in the Afrotemperate ecosystems**

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**Abstract**

Changes in species diversity have been widely used in environmental monitoring and global change studies as an indicator of vegetation change over time. High mountain ecosystems such as the Golden Gate Highlands National Park (GGHNP) host a relatively high number of plant species due to less human disturbances compared to the surrounding lowland areas. This study investigated the species richness and diversity in the Afrotemperate forest and woodland communities of the GGHNP.

For vegetation classification, the TWINSPAN algorithm was firstly used to do a floristic analysis of thirty-two sampling plots and refined further using the Braun-Blanquet procedures and JUICE programmes. The Detrended Correspondence Analysis (DCA) and the phytosociological analysis of the vegetation data resulted in five plant communities and one sub-community across various topographic gradient. The *Olinia emarginata–Podocarpus*

*latifolius* forest was found to be the most diverse forest whereas the *Kiggelaria africana* forest showed relatively lower species diversity. Species richness was also relatively high in the *Olinia emarginata–Podocarpus latifolius* forest plots, compared to the *Leucosidea sericea–Buddleja salviifolia* woodland, and the *Euclea* crispa–*Protea caffra–roupelliae* savannas. Data on plant assemblages and classification provide invaluable information for studies focussing on climate change studies, species distribution models and the associated bioclimatic variables. Understanding the importance and complexities of high mountains and forest ecosystems is therefore essential for developing effective conservation strategies.

Key words: Diversity, richness, afrotemperate, forests, ordination, classification

**Introduction**

High mountain ecosystems are renowned for their exceptional biodiversity, hosting a wide array of plant species that have adapted to extreme climatic conditions, making them a crucial subject of study and conservation effort (Myers et al 2000, Pauli et al. 2003, Carlson et al. 2013, Winkler et al. 2016). Mountains are characterised by their high topographical heterogeneity and cooler climate, with the temperature decreasing by about 0.5 to 0.6 degrees Celsius for every 100 meters rise in altitude compared to the surrounding lowlands (Noguesbravo 2008). In addition, mountains experience less human disturbance than the lowlands and could function as refuges for both flora and fauna (Pauli et al. 2003, Noguesbravo 2008, Carlson et al. 2013). However, Afrotemperate forests tend to occur in areas of high human population density and are under intense threat from agricultural practices, fire, and grazing (Chapman et al. 2004, Cordeiro et al. 2007).

The climate variation experienced in the different mountain ranges in southern Africa has profound effects on the ecosystem and species that inhabits these environments due to differences in longitude, topography, size, elevation, and aspect (Brown & du Preez 2019). As altitudes increases, the temperature decreases, resulting in distinct temperature gradient across different elevation, thereby influencing vegetation patterns, species distribution, and overall biodiversity in mountain ecosystems (Brown & du Preez 2019). Additionally, extreme climate variation and fires in mountains can also impact critical ecosystem services, leading to variation in water availability and influencing the composition and structure of forest and woodland communities within a grassland matrix (Meadows & Linder 1993, Lézine et al. 2019). Afrotemperate forests are characteristically small and fragmented, typically occurring within a grassland matrix and commonly host a diversity of endemic species, which are unable to migrate to other appropriate habitats as the climate gets warmer (Chapman et al. 2004, Cordeiro et al. 2007).

Forest ecosystems change constantly, sometimes through periodic catastrophic disturbance that completely changes the structure of the ecosystem, and which can indeed create a new ecosystem, with a new set of species (Linder 2014). Severe alterations in plant diversity have been observed based on short-term and on long-term vegetation analysis in global change studies (Erschbamer et al. 2009, Calabrese et al. 2018). Shrubs expansion, local herbaceous species extinctions, and consistent changes in the ecology and structure of high mountain communities are important in the description of the plant communities (Calabrese et al. 2018). However, other forest ecosystems remain stable for many decades under natural conditions, with changes occurring on a much smaller scale (Andie et al. 2017). In the Drakensberg Mountains of South Africa, there are still ongoing investigations looking into the spatial distribution of the Afrotemperate forest and the environmental impacts affecting these islands of forest within a grassland matrix (Meadows & Linder 1993, Linder 2014, Andie et al. 2017, Lézine et al. 2019, Daemane et al. 2021).

This study investigated the species diversity in the Afrotemperate forest and woodland communities of the GGHNP. The isolated forest and woodland patches are of significant importance as seed banks for the surrounding gorges, which occur in the rugged foothills of the Drakensberg where genetic and floristic diversity can be maintained. Species richness and diversity are therefore important in conservation management as they are frequently used in global change studies and biodiversity monitoring as indicators of functional ecological systems.

**Sampling Methods**

Study Area

This study was undertaken in the GGHNP in the Orange Free State Province in South Africa within the foothills of the Maluti Mountains. To the south, the park borders the northern part of Lesotho (Figure 1). The current extent of the park is 32,758.35 ha. The park extends between the towns of Clarens (20 km) and Phuthaditjhaba (40 km) on the R712 provincial road that meanders through the middle of the park. It lies in the foothills of the Maloti Mountains in the Rooiberg range. The park is south-east of Bethlehem and south-west of Harrismith, 360 km from Johannesburg.
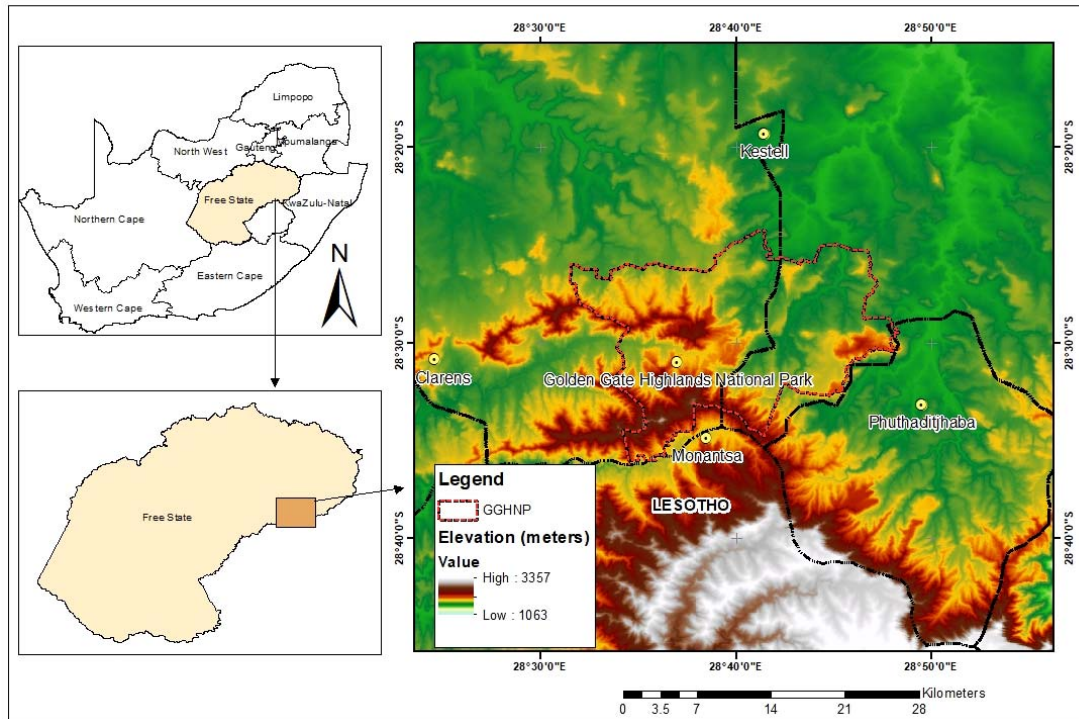
Figure 1. Topographical map showing the location of Golden Gate Highlands National Park in the context of the rest of South Africa and the Provinces.

The park is underlain by rock formations representing the upper Karoo Sequence which is intruded by dolerite dykes and sills. The park forms part of the Maloti Drakensberg Catchment Complex which produces about 50% of the total water supply in South Africa. The area falls under the summer rainfall region where the rainy season stretches from September to April with a mean annual rainfall of 780 mm. The winters are very cold and dry with the temperature dropping below freezing point. The vegetation of the park is predominantly grassland, with a small percentage of woodland and forest communities along the rivers and in sheltered places that are protected from fire. Mucina and Rutherford (2006) identified five dominant vegetation units associated with the study area, namely Eastern Free State Sandy Grassland (Gm4), Basotho Montane Shrubland (Gm 5), Northern Drakensberg Highland Grassland (Gd 5), Drakensberg–Amathole Afromontane Fynbos (Gd6) and Lesotho Highland Basalt Grassland (Gd 8).

Delineation of forest and woodland polygons

The forest and woodland polygons were delineated using high-resolution images within Google Earth, from Maxar technologies responsible for WorldView 1–3, and GeoEye with less than 1m resolution from 2015 to 2020 (Daemane et al. 2021). Thirty–two woodland polygons

were identified and converted from Google Earth files to shapefile and topologically corrected in ArcGIS version 10.5.1.

Vegetation sampling

A total of 32 sample plots were located within the forest and woodland polygons to ensure that all variations in the vegetation were considered and sampled. Global positioning system (GPS) locations of all sample plots were collected. Plot sizes were fixed at approximately 900 m² according to Brown et al. (2013). In each plot, the Braun–Blanquet cover scale of each species was estimated visually. The cover-abundance data collected using the Braun–Blanquet surveys were transformed to a numerical scale ($r$ = 0.5; + = 1; 1 = 2; 2a = 8.5; 2b = 17.5; 3 = 35; 4 = 70; 5 = 140) to calculate species diversity described by Van der Maarel (2007).

Data Analysis

Floristic Data Analysis and Ordination

The floristic data was captured using the BBPC-program (Bezuidenhout et al. 1996). The data was exported to JUICE (Tichý, 2002) from where a first approximation of the plant communities was derived using the modified TWINSPAN (Two-way Indicator Species Analysis) classification algorithm proposed by Roleček et al. (2009). The phi coefficient of association in Juice Programme (Chytrý et al. 2002) was used to determine the fidelity of each community. The lower threshold values were set at 65, 70, and 45 for fidelity, frequency, and cover respectively, and the upper thresholds at 80, 80, and 60. The different plant communities are described according to their diagnostic, constant, and dominant plant species as determined from the synoptic table analysis. Dominant species are those that are most conspicuous in a plant community and are high in one or more of the importance values (Barkman et al. 1964), in this case, fidelity, cover, and frequency.

The Detrended Correspondence Analysis (DCA) was also applied to the data set to confirm the existence of the different plant communities and to determine whether the gradients in the plant communities along different ordination axes could be explained by gradients in specific environmental characteristics (ter Braak 1986, Chahouki 2013). The Shannon–Wiener index of diversity ($H$) and the Rich–Gini–Simpson index of diversity ($RGS$) (Shannon & Weaver 1949, Guiasu & Guiasu 2010) were calculated for each of the major plant communities using PAST 4.3 programme (Hammer et al. 2006).

$$Shannon - Weiner\ Index\ (H) = -\sum_{s=1}^{S} p_i ln p_i \qquad \text{Equation 1}$$

$$Rich - Gini - Simpson\ (RGS) = n - \sum_i p_i (1 - p_i) \qquad \text{Equation 2}$$

Where $p_i$ = (number of individuals of one species)/(total number of all individuals)

Entropies such as the Shannon Wiener and Gini/Simpson indices are not considered true diversities and therefore conversion of these to effective number of species is the key to a unified and intuitive interpretation of diversity (Jost 2006). The diversity results from the Shannon Wiener were converted to effective numbers as described by Jost (2006) to reflect common behaviours and properties that allow for appropriate comparisons between plant communities.

$$Effective\ number = \exp(-\textstyle\sum_{i=1}^{S} p_i ln p_i)$$     *Equation 3*

**Results**

Vegetation Classification

The phytosociological analysis of the vegetation data resulted in the identification of five major plant communities and one sub-community. The detailed descriptions of the plant communities are provided below and reference to species groupings is found in the phytosociological table (Suppl. 1).

Vegetation Description

1. *Euclea crispa–Protea roupelliae* savannas

This community is found in Species Group A, with *Protea roupelliae* as the diagnostic species and both *Euclea undulata* and *Protea roupelliae* as the dominant species. Proteas occur mostly on the southern slopes and their densities depend mostly on the fire intensities, even though they are fire resistant. The *Euclea crispa–Protea roupelliae* savannas are mostly found in rocky outcrops and relatively lower altitudes as compared to the *Euclea crispa–Protea caffra* savannas. *Euclea undulata* species are protected from fire and found between large boulder sandstone screes and embedded within the Basotho Montane Shrubland vegetation unit (Mucina & Rutherford 2006). The herbaceous layer is dominated by grasses such as *Eragrostis lehmanniana*, *Aristida congesta*, *Eragrostis chloromelas*, *Eragrostis obtusa*, *Themeda triandra*, and *Heteropogon contortus* (Species G) .

2. *Euclea crispa–Protea caffra* savannas

This community is found in Species Group B, with the *Protea caffra* as the diagnostic species and both *Euclea undulata* and *Protea caffra* as the dominant species. Like the *Euclea crispa–Protea roupelliae* savannas, this is not a true woodland vegetation unit, but widely scattered trees in the grassland. The *Euclea crispa–Protea cafrra* community is found in open grassland with high herbaceous cover, and therefore fire tolerant. The *Protea caffra* is found in relatively

higher altitude compared to the *Protea roupelliae*. Shrubs such as *Diospyros austro–africana*, *Calpurnia intrusa*, and *Cussonia paniculata* subsp. *paniculata* (Species Group E) also occur in this community. The herbaceous layer is dominated by species such as *Eragrostis lehmanniana*, *Aristida congesta*, *Eragrostis chloromelas*, *Eragrostis obtusa*, *Themeda triandra*, and *Heteropogon contortus* (Species G) .

3. *Buddleja salviifolia–Leucosidea sericea* woodland

This community is found in Species Group C, with *Leucosidea sericea* as the diagnostic species and *Acacia dealbata* (Species Group G), *Buddleja salviifolia*, *Leucosidea sericea*, *Myrsine africana*, *Passerina montana* and *Rhamnus prinoides* (Species Group C) as the dominant species. Other shrubs found in this community include *Euclea crispa* (Species Group A), *Euclea undulata*, *Artemisia afra*, *Cussonia paniculata* subsp. *paniculata*, *Gymnosporia heterophylla*, *Searsia pyroides* and *Diospyros austro–africana* (Species Group E). The herbaceous layer is dominated by grasses such as *Eragrostis lehmanniana*, *Aristida congesta*, *Digitaria eriantha*, *Cymbopogon plurinoides*, *Themeda triandra*, and the reed *Miscanthus capensis* (Species Group G). The invasive plant species, *Poplus canescens* and *Acacia dealbata* have a high cover and associated with the drainage lines in this community.

4. *Kiggelaria africana* forest

This community is found in Species Group D, with *Kiggelaria africana as* the diagnostic and the dominant species. Other abundant species associated with the *Kiggelaria africana* forest include *Leucosidea sericea*, *Rhamnus prinoides*, *Myrsine africana* (Species Group C), *Olinia emarginata*, *Gymnosporia heterophylla*, *Searsia pyroides* (Species Group E). There is also a strong presence of weeds such as *Cyathula cylindrica* and *Solanum nigrum*, along with the other herbs such as *Galium rotudifolia*, and *Plectranthus grallatus* (Species Group G). These are comparatively the smallest forest patch type associated with the rocky outcrops. The herbaceous layer is poor, the forest floor consists of ferns such as *Blechnum inflexum*, *Cheilanthes quadripinnata* and *Cheilanthes eckloniana* (Species Group E).

5. *Podocarpus latifolius–Olinia emarginata* forest

This community is found in Species Group E, with *Olinia emarginata* and *Podocarpus latifolius* as the diagnostic and *Euclea undulata* as the dominant species. The *Podocarpus latifolius–Olinia emarginata* forest is found between sandstone boulders, rocky outcrops and along riverbanks and in protected kloofs. Other abundant woody species associated with this forest community include *Euclea undulata*, *Pittosporum viridiflorum*, *Ilex mitis* var. *mitis*, *Scolopia mundii*, *Maytenus penduncularis*, *Cussonia panicula* subsp. *paniculata*, *Gymnosporia heterophylla*, and *Diospyros austro–africana* (Species Group E). This is the largest

Afrotemperate forest type occurring in the park. The *Podocarpus latifolius–Olinia emarginata* forest host a variety of fern species such as *Cheilanthes eckloniana*, *Cheilanthes viridis var virids*, *Cheilanthes quadripinnata*, *Asplenium aethiopicum* (Species Group E), *Adiantum capillus–veneris*, *Polystichum dracomontanum* (Species Group F) *and Pteris cretica* (Species Group G). The grass layer is poorly developed, and the forest are protected from fires.

5.1. *Celtis africana–Olinia emarginata* forest

This sub-community is found in the *Podocarpus latifolius–Olinia emarginata* forest, on rocky outcrops and along riverbanks and in kloofs. It is represented by Species Group F. *Celtis africana* is the diagnostic species whereas *Podocarpus latifolius* and *Olinia emarginata* are the dominant species. Other abundant species found in the *Celtis africana–Olinia emarginata* forest include *Clutia natalensis* and *Greyia sutherlandii* (Species Group F), *Kiggelaria africana*, *Maytenus undata*, *Myrsine africana*, *Leucosidea sericea*, *Buddlea salvifolia* (Species Group C), and *Euclea crispa* (Species Group A).

Detrended Correspondence Analysis

Ordination algorithm was applied to the data set to determine whether the gradients in plant communities along different ordination axes could be explained by specific environmental characteristics (ter Braak 1986, Chahouki 2013). The scatter diagram in Figure 2 shows a DCA gradient along ordination axis 1 (E = 0.65) and axis 2 (E = 0.43). The gradient along ordination axis 2 (E = 0.43) could be explained by plant communities occurring in deep valleys sheltered from fire, and with deep soils and relatively high clay content with high water retention capacity and high organic content. These are *Kiggelaria africana*, *Podocarpus latifolius–Olinia emarginata* and *Celtis africana–Olinia emarginata* forests.

The *Leucosidea sericea* woodland communities occur mostly in the drainage lines, though they do intersect with the forest species in protected gorges and encroaching the midslopes in the open grassland (Daemane et al. 2021). The outlier plot in the top middle of the scatter diagram is dominated by the invasive species such as *Populus canescens* and *Acacia dealbata*. Almost no species are shared at the opposite ends of the gradient, the forest and *Protea* savannas (i.e., there is a high beta diversity). The first axis is associated with the dryland woodland communities dominated by *Protea roupelliae* in the lower footslopes, interfacing with *Euclea crispa* in open rocky grassland. *Protea caffra* is dominating in the midslopes and associated with shallow soils, poor water retention and relatively low organic content (Daemane et al. 2021).
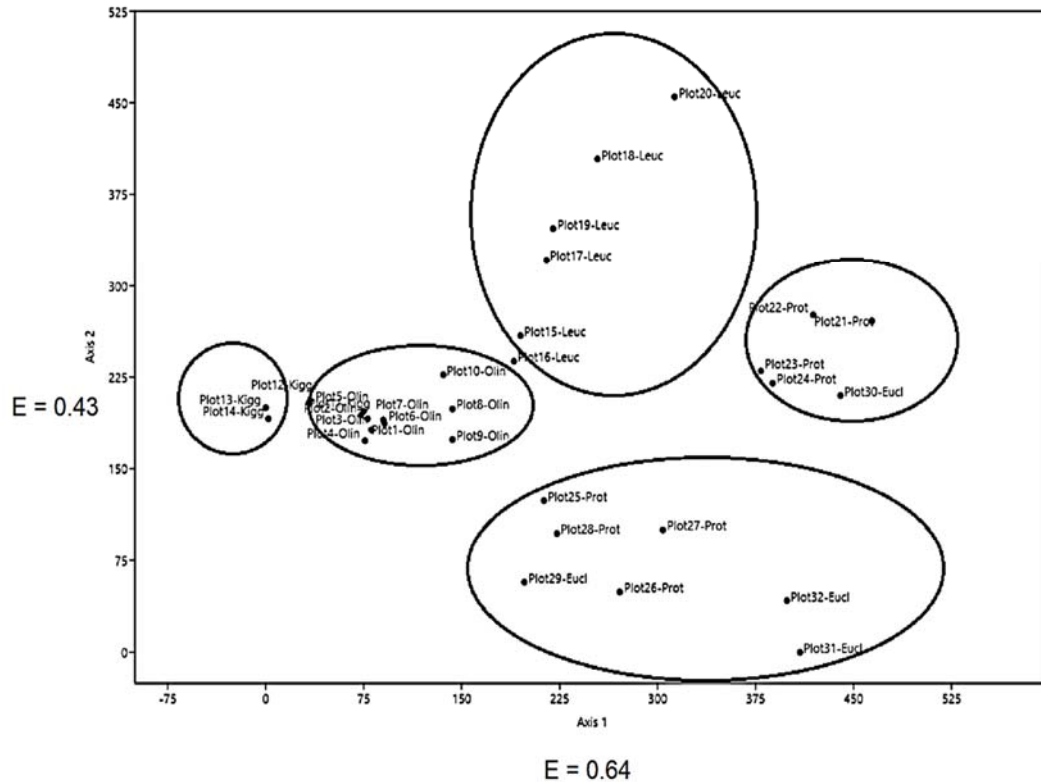
Figure 2. Detrended Correspondence Analysis ordination with 32 plots showing different woodland and Afrotemperate forest communities in the Golden Gate Highlands National Park. Species Diversity

*Podocarpus latifolius–Olinia emarginata* community had the highest diversity and species richness compared to the *Kiggelaria africana* forest and the rest of the woodland communities (Figure 3). Species diversity per 900 m$^2$ within the forest plots (plot 1 to 10) varied from 23 to 54. The biggest forest in the park, Donkerkloof (Plot 1 and 2) had the highest diversity and species richness (Figure 3). Species diversity within *Leucosidea sericea–Buddleja salviifolia* woodland varied from 5 to 21. The biggest *Leucosidea sericea* sites in the Snowhill area (Plot 15 & 16) had the highest diversity compared to other *Leucosidea sericea* sites. The inclusion of many ecotonal species in *Leucosidea sericea–Buddleja salviifolia* woodland plots caused variation in terms of diversity and richness due to encroachment of these species outside the riverine habitats. Species diversity within *Protea* woodlands varied from 9 to 18, with high herbaceous species composition. The *Euclea* woodland plots (plot 29 to 32) had the lowest species diversity, varying from 5 to 9 compared to all the woodland communities (Figure 3).
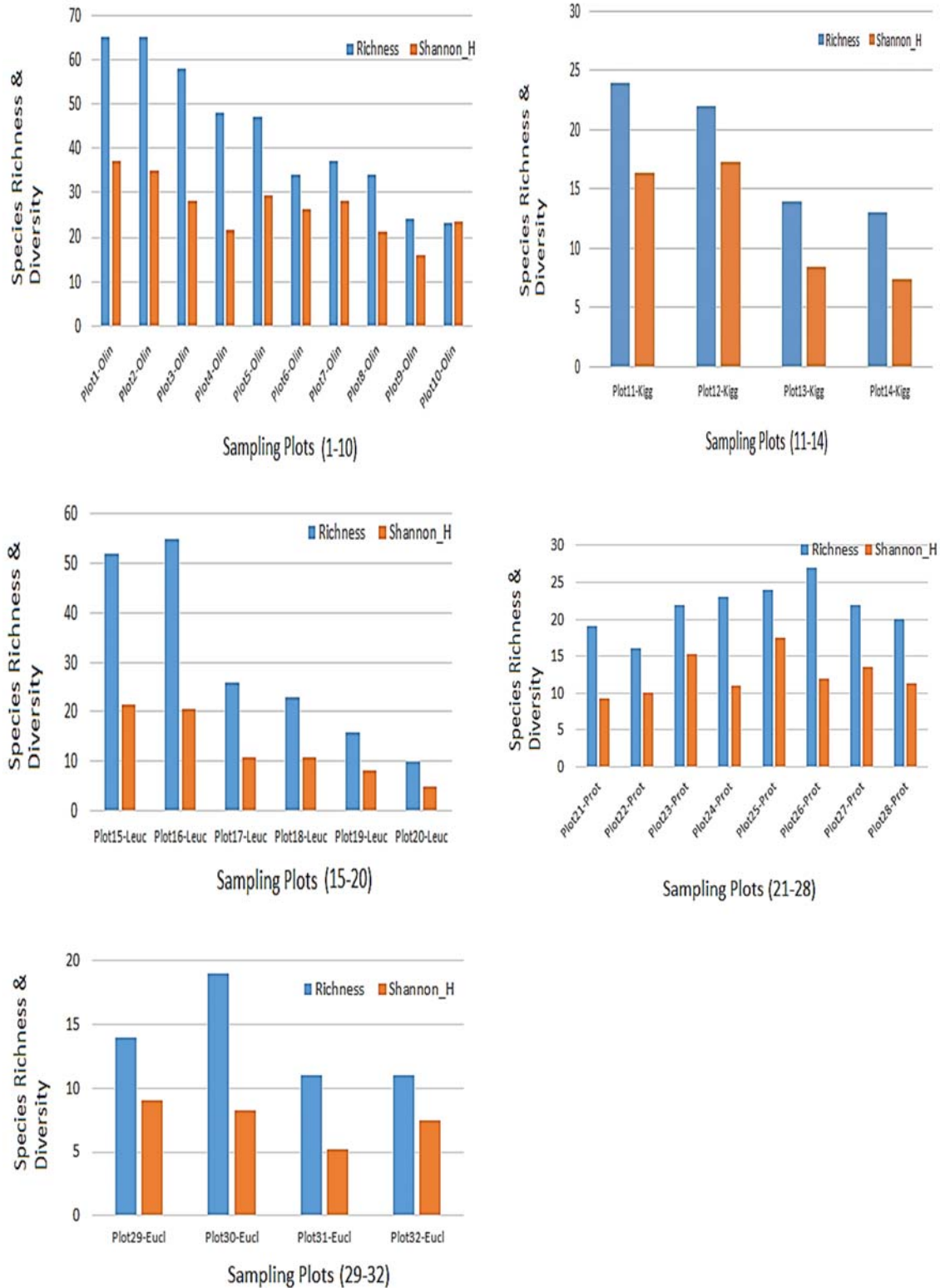
Figure 3. Species richness and diversity for the thirty-two sampling sites representing Afrotemperate and woodland plant communities in the Golden Gate Highlands National Park.

**7.5. Discussion**

The Afrotemperate forests in GGHNP contained proportionally high species richness and diversity compared to the other woodland communities. The diagnostic species in the Afrotemperate forests are *Olinia emarginata*, *Podocarpus latifolius*, and *Kiggelaria africana*. These forests are found as small-sized patches in fire refugia such as the narrow gorges, lower scarps, and slopes, and below the sandstone cliffs. In a study undertaken by Manfred (1990) in the GGHNP, species diversity per square meter within circular plots varied from 34 to 54 species (average of forty-four species). Similar pattern in species richness and diversity was also observed in the current study where species diversity varied from 23 to 54 per 900 m$^2$ . The biggest Afrotemperate forest in the park, Donkerkloof had the highest diversities and richness with the average number of species between 36 and 65 respectively.

Species such as *Halleria lucida*, *Ilex mitis*, *Podocarpus latifolius*, *Rapanea melanophloeos* and *Diospyros whyteana* were previously used to define the  Afrotemperate forests in the region (White 1978). Although these Afrotemperate forests should fall under Killick's (1963) classification of a *Podocarpus* climax forest, it can however be seen that these are *Olinea emarginata* climax forest. The study by Manfred (1990) also confirmed this with higher cover values for *Olinea emarginata* than for *Podocarpus latifolius*. The herbaceous layer of these forests has a low species diversity mostly dominated by Pteridophytes.

The *Podocarpus latifolius–Olinia emarginata* forests of the GGHNP have floristic affinities to those described by Du Preez *et al.* (1991) in the eastern Free State Province. They fall under his class *Scolopietii mundii* of the order *Podocarpetalia latifolii*. They fit well under Du Preez *et al.* (1991) first association, *Clauseno-Podocarpeztum latifolii* because many of them occur in sandy soil of the Clarens Sandstone. These Afrotemperate forests also have remarkably similar diagnostic species, including a high presence of *Olinia emarginata*. However, the Afrotemperate forest types may still differ in terms of their structure, species composition, and species richness (Cooper 1985, Mucina & Rutherford 2006).

The *Kiggelaria africana* forest have floristic affinities to those described by Fuls (1993) and Killick (1963). The *Kiggelaria africana* forest have floristic affinities to the *Artemisia afra–Kiggelaria africana* low thicket community previously described in the area due to the high presence of diagnostic species such as *Kiggelaria africana* and *Leucosidea sericea*, and shrub layer of species such as *Myrsine africana* and *Clutia pulchella* (Killick 1963, Fuls *et al.* 1993). According to Killick (1963), *Kiggelaria* forests are not true Afrotemperate forests but a dominant forest type and may function as precursor type vegetation which invades *Leucosidea–Buddleja* woodland. However, the *Kiggelaria africana* forest may eventually

become *Podocarpus latifolius–Olinia emarginata* forest, depending on fire and the dispersal of Afrotemperate elements into them (Manfred 1990).

The *Leucosidea sericea* woodland is sometimes referred to as the scrub forest, and mostly found in various habitats. It forms riparian thickets along the Drakensberg rivers, but also form natural shrublands on protected slopes (from heavy grazing or fire) at high elevations and can also secondarily invade heavily disturbed pastures. The *Leucosidea sericea–Buddleja salviifolia* woodland creates a suitable habitat for forest species such as *Diospyros whyteana*, *Diospyros autro-africana*, *Kiggelaria africana*, *Maytenus undata*, *Myrsine africana*, *Buddleja salviifolia*, *Rhamnus prinoides*, *Searsia* species, *Olinia emarginata* and *Euclea* species.

Proteas form open 'woodlands' though they were ecologically never mapped as a vegetation unit before but only considered to be part of the respective grasslands in which they occur (Mucina & Rutherford 2006). This is because  Proteas are widely scattered and although their occurrence in these grasslands is natural, their presence does not create a quantitative new ecological status to be considered as a woodland community.

## 7.6. Conclusion

The Afrotemperate forests provide a suitable habitat for many forest species, thereby contributing substantially to the overall biodiversity of the GGHNP. They are also a source of floristic diversity and a home for certain endemic tree species of South Africa, such as *Olinea emarginata* and *Scolopia mundii*. A Detrended Correspondence Analysis (DCA) ordination algorithm and the phytosociological analysis confirmed the existence of the different forest community assemblages and how the gradients along different ordination axes are associated with specific environmental variables.

These forests, as small as they may be, are important biogeographical links between larger forest areas in the wider Drakensberg region in South Africa and their spatial distribution may be affected by climate change in future. The Afrotemperate forest were found to have relatively high species diversity and richness compared to the other woodland communities. The GGHNP forests are therefore in need of special conservation measures because they occupy only a small fraction of the total park area of which the *Podocarpus latifolius–Olinia emarginata* forest are the largest.

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