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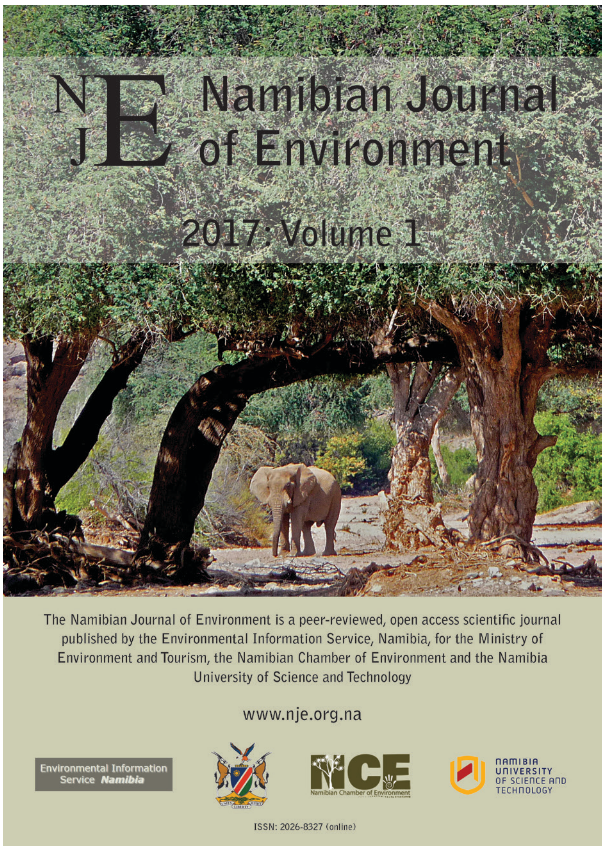

SECTION A: PEER-REVIEWED PAPERS

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Biodiversity zoning in the Greater Fish River Canyon Landscape in southern Namibia

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ABSTRACT

An objective process of biodiversity zoning is presented using the Greater Fish River Canyon Landscape in southern Namibia (partially overlapping with the Ai-Ais – Richtersveld Transfrontier Park, which stretches across both sides of the Orange River) as an example. Using satellite imagery, broad habitat units were mapped, and plant species lists were compiled for these units, based on local, national and regional distribution data, published information and targeted field work. Formal protection, red-list status, and an index of rarity based on distribution range and endemism were used to determine a rating for species of conservation importance. These ratings were summed per landscape unit, providing an overall rating for each unit. The topographically heterogeneous landscape in a transitional area between southern Africa's winter and summer rainfall regimes was delineated in 32 landscape units. A total of 835 plant species was included in this study, 265 of which were defined as having particular conservation importance. The systematic incorporation of level of endemism and an index of rarity based on range size, facilitated a fully objective process of biodiversity zoning. The resulting zoning presents a relative measure of prioritisation for conservation, sufficiently flexible to be adapted to the species richness and data range in a particular study area and is therefore site-specific. Although a large part of the study area is formally protected in state-protected areas and adjoining private nature reserves, nearly 50% of the most important area in the western Succulent Karoo section of the landscape is on private farmland and townlands of the mining town Rosh Pinah with no formal protection. Also, exploration and small-scale mining take place along the Orange River. All these factors pose a threat to some of the rarer plants.

Keywords: biodiversity, endemism, zonation, Gariep, mountain flora, rarity, range size, Succulent Karoo biome, transfrontier park, Namibia, Fish River Canyon

INTRODUCTION

Managing biodiversity in areas where inventories are incomplete, fragmented or biased towards certain groups of taxa is a challenge worldwide (Reid 1998, Cooper & du Plessis 1998, Fuller et al. 2010, Franklin et al. 2011). Where biodiversity information and data-collection time are limited, expert opinion is often used to prioritise areas of importance for biodiversity conservation (Cowling et al. 2003). While this approach has its merits in many situations (Reyers et al. 2007), it lacks objectivity, resulting in a call for more consistency in biodiversity assessments (Landi & Chiarucci 2010). This paper outlines an objective process for biodiversity zoning at landscape level, using the Greater Fish River Canyon Landscape (GFRCL) in Namibia as an example.

The GFRCL is positioned in the Gariep Centre of Endemism in southern Africa (van Wyk & Smith 2001), in a transitional area between summer and winter rainfall. On regional maps a biome boundary is depicted to run through the Huns Mountains in the centre of the GFRCL (Snijman 2013) or pockets of Succulent Karoo are delineated in a Desert- Nama Karoo matrix (Rutherford 1997). While such pockets of 'biome islands' are also found across other southern African biome boundaries (Potts et al. 2015), this transitional position is expected to result in high plant diversity in this area (Burke 2015), as predicted for ecotone areas elsewhere (Kunin 1998, Kark 2013, Potts et al. 2015).

Administratively the GFRCL contains the Namibian section of the Ai-Ais – Richtersveld Transfrontier Park, which is jointly managed by Namibia and South Africa. While a fair amount of information on biodiversity of the Richtersveld is available (e.g. Williamson 2000, Duncan et al. 2006, Hendricks et al. 2007, Young & Desmet 2016), the Namibian part of the park is poorly studied. As part of a park-neighbour initiative in Namibia, inventories of the flora were undertaken to enable biodiversity zoning and to support the development of management guidelines. The Greater Fish River Canyon Landscape was created as part of a Global Environment Facility – Namibian government initiative to address integrated land management of protected areas and their surroundings. The landscape was developed around one of Namibia's prime tourism attractions, the Fish River Canyon, and includes the Ai-Ais Hotsprings Game Park, several private nature reserves and farming areas adjoining the park (Ministry of Environment and Tourism 2011) (Figure 1). The purpose of this paper is to present the process and the results of zoning the biodiversity of the Greater Fish River Canyon Landscape. Plants are used as indicators for biodiversity because (1) they are the basis for most food chains, (2) compared to other taxa in Namibia (except for birds), information on distribution is readily available and (3) they are immobile and therefore indicate habitats at a small scale. They can therefore be considered a proxy for other biodiversity. This is in line with many conservation planning initiatives around the world where plants are often used as indicators (e.g. Brudvig et al. 2009; Egoh et al. 2009) and particularly in areas where the flora is known to be of great conservation importance, such as the Gariep Centre of endemism and the Cape region (van Wyk & Smith 2001; Rebelo et al. 2011).

METHODS

Study Area

The study area is positioned just north of the Orange River in Namibia (Figure 1) and is a varied landscape of mountains, gorges, valleys, plateaus and plains. It includes the Huns and Namus Mountains in the west, the lower Fish River, the Gamkab plains and the Orange River valley, with the Fish River Canyon as a popular tourist destination. The southern boundary is the perennial Orange River. At the interface of three major Southern African biomes, the Succulent Karoo, Nama Karoo and Desert biomes (Rutherford 1997), and floristically part of the Gariep ecogeographic unit in the Extra Cape Flora (Snijman 2013), the area is rich in biodiversity.

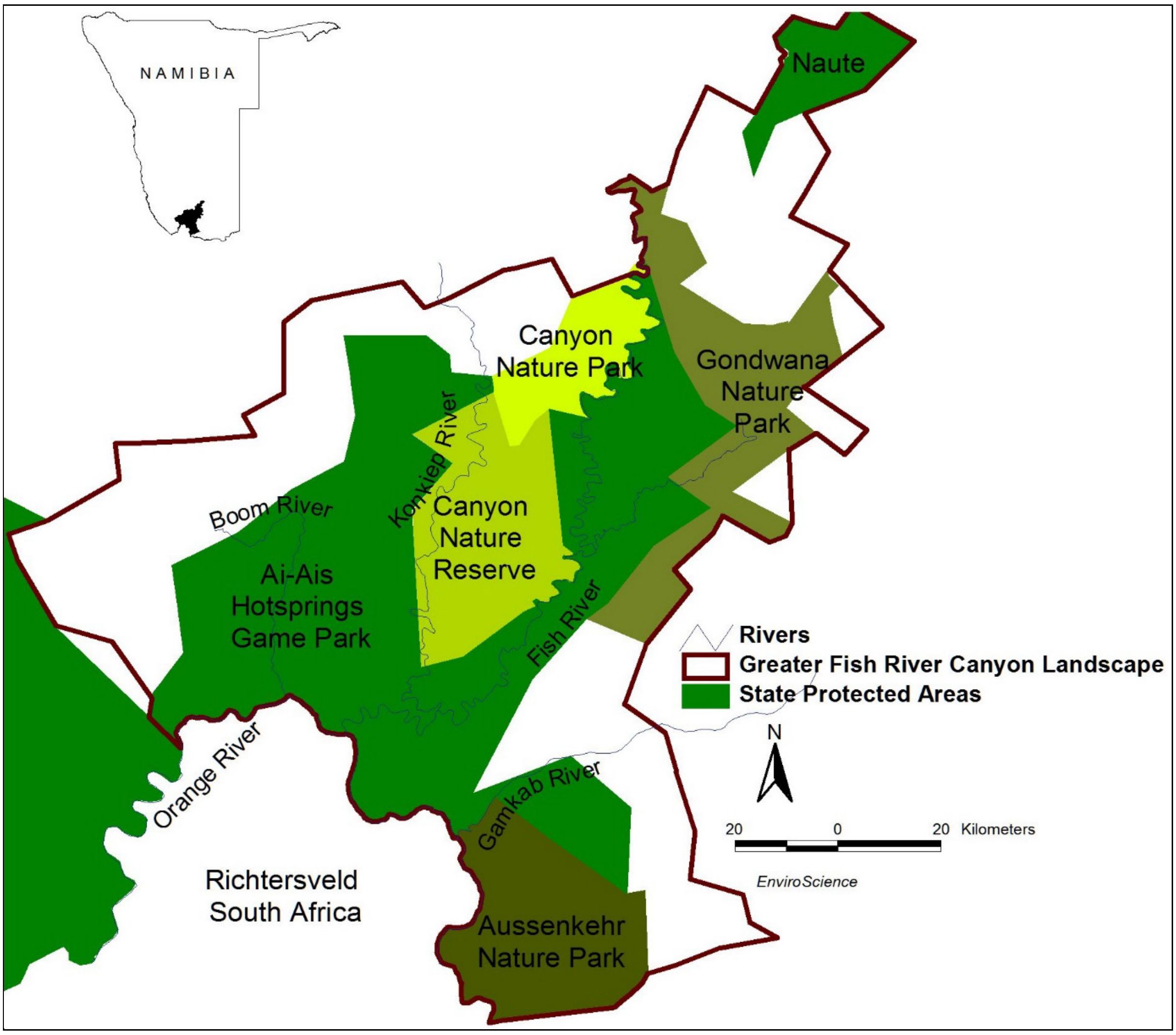

Figure 1: *Position of study area and extent of Greater Fish River Canyon Landscape (GFRCL) in Namibia. White areas in the GFRCL are commercial farmland.*

The underlying geology ranges from the oldest rocks in Namibia to recent Quaternary sediments. Some 600 to 550 million-year-old sedimentary rocks of the Nama Group are exposed in large parts of the study area. Gneisses, granites and other metasedimentary rocks of the Namaqua Metamorphic Complex (1,800-100 Ma [Million years]) and the Gariep Group (800-500 Ma) are also present, as well as sedimentary rocks and volcanic intrusions of the much younger Karoo Group (345-140 Ma) (Swart 2008). The complex geology and geomorphological forces created a rugged landscape, with altitudes ranging from less than 100 m above mean sea level at the deeply incised Orange River to 1,654 m at the Namuskluft peak. Soils are poorly developed regosols or arenosols.

The climate is arid and mean annual rainfall ranges from 50 to 100 mm, increasing along a south-west to north-east gradient. Summer and winter rains can occur. Mean annual temperatures range between 16ºC and 20ºC, increasing along a west-east gradient. The south-eastern corner borders one of the hottest areas in Namibia where temperatures over 36ºC are measured during the hottest months (Mendelsohn et al. 2002). The temperature range at the Canyon Roadhouse, for example, in the north-eastern part of the study area, was 0-38ºC during 2017. These broad bioclimatic gradients are modified locally by mountainous terrain. The higher reaches receive more rainfall and temperatures are lower here. Fog occasionally drifts east from the Atlantic Ocean along the Orange River valley and reaches the western part of the study area. In summary, this is an area of high diversity in landscapes and climatic extremes.

The vegetation is sparse and consists largely of leaf-succulent dwarf shrubs (mainly the genera *Amphibolia*, *Antimima*, *Eberlanzia*, *Lampranthus*, *Leipoldtia* and *Ruschia*, as well as *Zygophyllum*), herbs and grasses in the west and south (Figure 2). Shrubs, grasses and herbs are dominant in the east. On the eastern plains prominent shrubs are Euphorbia gregaria and *Rhigozum trichotomum* (Figure 3). Grasses, largely represented by *Stipagrostis* species, are more prominent in the north and east. Trees and tall stem-succulents e.g. *Aloidendron dichotomum*, *A. pillansii* (formerly *Aloe*) and *Pachypodium namaquanum* provide prominent landmarks, mainly in the west of the study area (Figure 2), but are widely dispersed, except along rivers. Here riparian thickets with trees such as *Acacia* (*sensu lato*) karroo, *Salix capensis*, *Searsia pendulina* and *Tamarix usneoides* grow along the permanently-flowing Orange River. Trees and patches of reeds (*Phragmites australis*) also grow along the Fish River. Mountain slopes support very diverse vegetation with many range-restricted species such as *Arctotis fruticosa*, *Antimima dolomitica*, *Caesalpinia merxmuelleri*, *Conophytum taylorianum*, *Eberlanzia clausa*, *Moraea thermarum*, *Portulacaria armiana*, *Ruschia ruschiana* and *Schwantesia loeschiana*.

The eastern and north-eastern part of the study area is covered by extensive plains and a section of the Gamkab basin (Figure 3d). The north-central part provides a mosaic of plains and rocky terrain, but unlike in the west and east, these plains are positioned at higher altitude between 1,000 and 1,400 m above mean sea level. The Fish River Canyon incises deeply into the plateau and rocky terrain in the central-eastern part of the study area, resulting in a landscape characterised by deep valleys and steep slopes flanked by plateaus at different elevations.

Approach to the study

The study built onto biodiversity zoning at landscape level for the Ai-Ais Hotsprings Game Park (Burke 2011) and was undertaken to fill data gaps in a rapid assessment and biodiversity zoning to inform management. Plants were selected as biodiversity indicators because vegetation can readily be used for landscape-level mapping, and information on plant distribution is electronically available in Namibia, although not complete and to some extent at a coarser scale than required for this study.

Available plant distribution data (at quarter degree square resolution, i.e. 15 minute intervals on a latitude-longitude grid) from Namibia's National Botanical Research Institute's (NBRI) specimen database (WIND) were used to guide the fieldwork, in order to fill evident data gaps (De Ornellas et al. 2011). Fieldtrips were undertaken in summer (19 April - 4 May 2013) in the eastern part of the study area and in winter (31 September - 9 October 2013) in the western part. A Google image was used to delineate homogenous mapping units, based largely on habitat (Cowling & Heijns 2001), and mostly at 1:100,000 scale, but high resolution Google images obtained by the Namplace project were used to clarify some mapping boundaries. Field data from the 2011-2013 surveys were combined with the specimen data from WIND, data from the Karios observatory of the BIOTA project (Jürgens et al. 2010), publications (Burke 2004), web-based databases (Craven & Kolberg 2017) and data collected for other biodiversity assessments. Plant species lists were then compiled for each landscape unit, and although not entirely complete, these species lists provide the best approximation and serve as relative indicators. The conservation importance of each plant species was rated based on the criteria endemism, red-list status according to IUCN (Loots 2005, with updates to 2013), narrow-range (as an indicator for rarity) and legal conservation status (Table 1), in this study collectively referred to as "species of conservation importance". The nomenclature follows Klaassen & Kwembeya

Figure 2: *Mountain landscape units in the Greater Fish River Canyon Landscape: (a) Granite koppies in the south-east of the Aussenkehr Nature Park support a surprising number of plant species in the driest and hottest part of the study area, (b) steep canyons dissect the limestone and shale layers of the northern Huns Mountains, here with* Pelargonium spinosum *in the foreground (c) the well-vegetated slopes of the western Namus Mountains advertise Succulent Karoo. Inset, left to right:* Aloidendron ramosissimum*,* Tylecodon paniculatus *and* Pachypodium namaquanum*.*

(2013), with updates for new species (Steiner 2006, Goldblatt & Manning 2013, Kativu & Bjora 2016).

Endemism and narrow-range were introduced as criteria additional to the IUCN red-list classification, because many endemic species with a very restricted range in Namibia are not legally protected. For the purpose if this study narrow-range (as an indicator of rarity) is based on the number of recorded distributions in quarter degree squares (1 qds = 15 minute intervals on a longitude-latitude grid). One quarter degree square (qds) is approximately 625 to 650 km^2 in Namibia (i.e. three qds amount to 1,875-2,025 km^2, which is close to the 2,000 km^2 threshold of a plant species' range considered critical by IUCN (2001) based on area of occupancy). The rating used in this assessment is based on these figures, although distribution across quarter degree squares equates more to extent of occurrence. The NBRI's specimen database, published sources (Loots 2005), web-based databases (Craven & Kolberg 2017, Raimondo et al. 2009) and own observations were used to determine the known distribution of plant species.

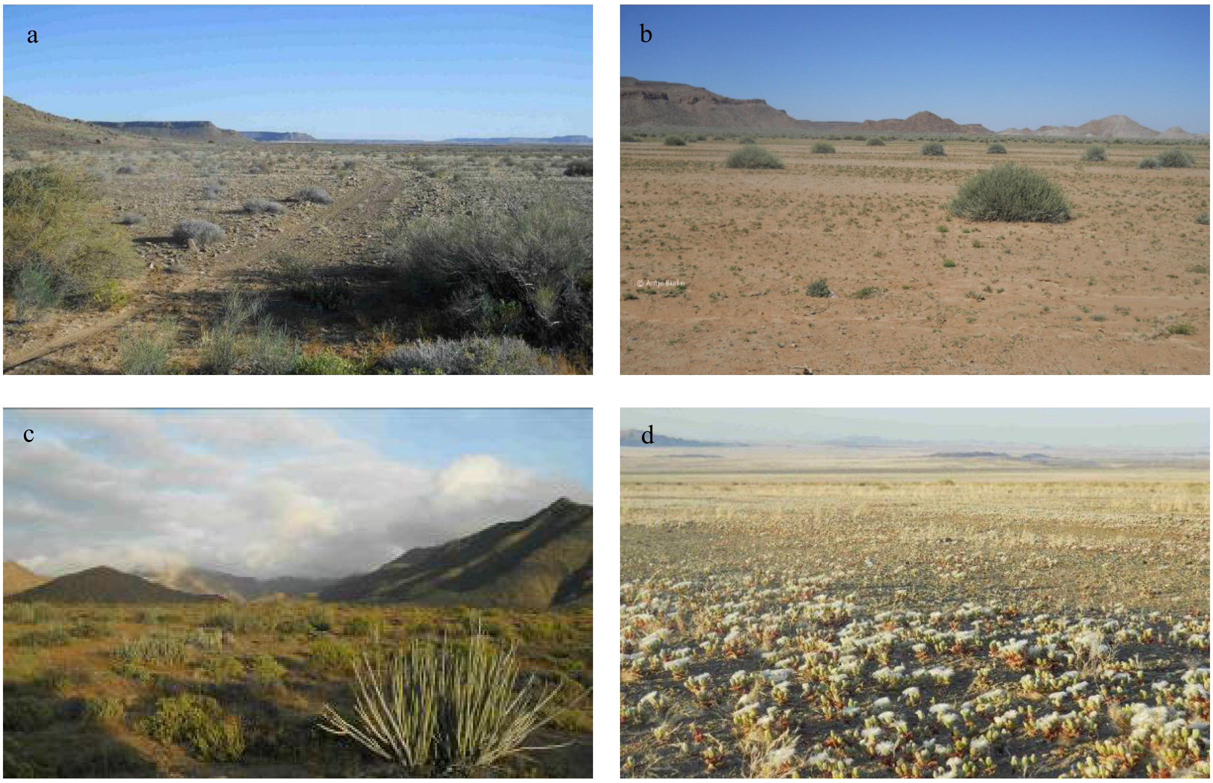

Figure 3: *Plains in the Greater Fish River Canyon Landscape: (a) fringing the northern Huns Mountains, dwarf shrubs are dominant on the Moedhou plains; (b)* Euphorbia gregaria *is the dominant plant on the Gawachab plains in the north-east of the study area; (c) the Dreigrat plains in the Succulent Karoo Biome receive occasional fog; (d) the Gamkab plains in the eastern study area are covered in carpets of succulent creepers (here* Mesembryanthemum garusianum*) and grasses (*Stipagrostis *sp.) after good rains, but are barren most other times.*

An additional rating of 1 for protected species (Nature Conservation Ordinance 4 of 1975 and 247 of 1977 and Forest regulations No. 170 of 2015) or Cites (Convention on International Trade in Endangered Species of Fauna and Flora) listed species was only added if the species had not received a score for endemic, red-listed or narrow-range, to avoid double accounting (protected and Cites species are often endemics). The ratings of plant species that received a ranking of conservation importance were added per biotope resulting in one numerical figure for each landscape unit. The mean of all values was determined and used to delimit the three class intervals (Table 2), which in this study was weighted towards higher values, as the data range was large (2-301) and dominated by one outstanding highly rated mapping unit.

Table 1: *Rating of plant species according to level of endemism, red list status, narrow-range and legal conservation status (qds = quarter degree square).*

Category	Description	Rating
Endemism	Confined to Southern Namib or southern Karas Region	3
	Confined to Namib Desert or Gariep Centre of Endemism	2
	confined to Namibia	1
Red list status	Endangered	3
	Vulnerable	2
	Near-threatened	1
Narrow-range	1-3 qds	3
	4-6 qds	2
	7-10 qds	1
	>10 qds	0
Protected	Protected under Nature Conservation Ordinance 4 of 1975 and 247 of 1977 and Forest regulations No. 170 of 2015	1
Cites		1

Data quality was rated to provide some indication of completeness of the plant species list for each landscape unit. The quality assessment took into account the coverage of the area for each biotope and the nature of the rainy season. This is subjective, but it is not included in the algorithm for determining biodiversity importance and used only to (1) better interpret the resulting zoning and (2) guide future

Table 2: *Range of values applied for biodiversity importance in the Greater Fish River Canyon Landscape.*

Class interval	**Value**	**Biodiversity importance**
Lowest value to mean	<57	Fair
Mean + mean	57-114	Medium
> mean + mean + 1	>14	High

research. "Good", "medium" and "poor" were used in this evaluation. "Poor" data quality usually means a lack of rain in these areas resulting in not being able to include short-lived species and species which are only active for a short period of time, such as such as herbs and bulbs.

To ascertain whether particular functional groups of plants were more likely to be of conservation importance, growth form distribution was compared between the overall flora and species of conservation importance. The growth form categories ferns, geophytes, grasses, herbs, shrubs and trees followed standard definitions (Ellenberg & Mueller-Dombois 1967), while succulents were classified according to von Willert et al. (1990).

RESULTS

Based on the proposed algorithm, nearly one third (265) out of a total of 835 plant species included in this study were species of conservation importance (see downloadable Appendix 1). The highest ranked species are shown in Table 3, most of which are succulents. Overall, the majority of the species are shrubs (33.5%), followed by herbs (22%) leaf-succulent dwarf shrubs (15.7%), geophytes (10.3%), grasses (7.9%) and dwarf stem-succulents (3.5%). Species of conservation importance showed a very different growth form distribution: over one third of the species of conservation importance were leaf-succulent dwarf shrubs (37%), followed by shrubs (21%) and dwarf stem succulents (11%) (Figure 6). This included many Namibian endemic leaf-succulent dwarf shrubs such as *Astridia hallii*, *Drosanthemum nordenstamii*, *Eberlanzia clausa*, *E. sedoides*, *Ruschia ruschiana* and *R. sabulicola*. Other functional groups (geophytes, grasses, herbs, trees and tall stem-succulents) each contributed less than 10% to the species of conservation importance, but this includes the charismatic stem-succulents *Aloidendron pillansii* (formerly *Aloe*, Grace et al. 2013) and *Pachypodium namaquanum*. Shrubs are represented amongst others by the range-restricted Namibian endemics *Caesalpinia merxmuellerana*, *Eriocephalus klinghardtensis*, *Euclea asperrima* and *Haematoxylum dinteri*.

The mapping delineated 32 landscape units based on landform, climatic regime and, in some instances, underlying rock types (Figure 4, Table 4). Thirteen landscape units represent plains (Figure 3), three represent rivers and 16 represent mountains and inselbergs (Figure 2). The western and southern part of the study area is mountainous with plains wedged between these mountains.

Table 3: *The highest ranked plant species of conservation importance in the Greater Fish River Canyon Landscape. * denotes succulent plants.*

Plant species	Endemism	Red-list	Narrow-range	Summed rating
Neoluederitzia sericeocarpa	3	3	2	8
*Juttadinteria albata**	2	2	3	7
*Schwantesia loeschiana**	3	2	2	7
*Aloidendron pillansii**	2	3	1	6
*Antimima dolomitica**	3	1	2	6
*Crassula numaisensis**	3		3	6
Elephantorrhiza rangei	3		3	6
Lebeckia dinteri	3		3	6
Monsonia trilobata	3		3	6
Chlorophytum boomense	3		3	6
*Ruschia sabulicola**	3		3	6

Table 4: *Landscape units, their biodiversity conservation rating and data quality in the Greater Fish River Canyon Landscape.*

Landscape unit	Biodiversity rating	Data quality*
Altdorn hills and plains	Fair	Good
Arimas plains	Fair	Poor – dry
Aussenkehr hills	Fair	Good
Canyon slopes	Medium	Good
Dreigrat plains	Medium	Good
Eastern sand plains	Fair	Good
Eastern Orange mountains	Medium	Poor – dry
Fish river and tributaries	Fair	Moderate
Gamkab inselbergs	Fair	Good
Gamkab river	Fair	Good
Gamkap plains	Fair	Good
Gawachab plains	Fair	Good
Gondwana hills	Fair	Moderate
Holoogberg	Fair	Good
Klein Karas mountains	Fair	Moderate
Konkiep plains	Fair	Moderate
Lowen river and Naute dam	Fair	Moderate
Moedhou plains	Fair	Poor – dry
North-east canyon lands	Fair	Moderate
North-west canyon lands	Fair	Moderate
NE Namus mountains	High	Moderate
W Namus mountains	High	Moderate
Naute inselbergs	Fair	Moderate
Naute plains	Fair	Moderate
Northern Huns mountains	Fair	Poor – coverage
Nudavib mountains	High	Good
Obib mountains	High	Moderate
Orange River valley	Medium	Good
SE Orange mountains	Medium	Moderate
Southern Huns mountains	Medium	Poor – coverage
Succulent Karoo sand plains	High	Good
Zebrafontein plateau	Medium	Good

** Dry: only dry season data were available;*
Coverage: the area was only partially sampled.

In the context of the GFRCL, most of the western Succulent Karoo section of the study area is classified as being of "high" conservation importance, the remainder of the winter rainfall influence area of "medium" conservation importance (Figure 5). "Medium" conservation importance also extends north-east along the Fish River and east along the Orange River. Data quality is considered good for nearly half of the landscape units and poor only for five landscape units (Table 4).

DISCUSSION

Species of conservation importance

Leaf succulent shrubs of the Aizoaceae (formerly Mesembryanthemaceae) contributed the largest group of species of conservation importance. This is not surprising in a transitional area to the Succulent Karoo Biome and therefore in close proximity to a major centre of diversity of Aizoaceae (Chesselet et al. 2000, Klak et al. 2004). Also, a substantially higher proportion of dwarf stem-succulents were amongst the species of conservation importance than represented in the overall flora, and also, more stem-succulents and trees than in the overall flora (Figure 6). The dwarf stem-succulents include, in addition to Aizoacae (e.g. *Conophytum*), many Apocynaceae (tribe Ceropegiae), a group of plants well represented in this area with the genera *Hoodia, Larryleachia, Quaqua* and *Tromotriche* (Bruyns 2014), numerous *Crassula* species, Crassulaceae, and dwarf succulent *Euphorbia*, due to a variety of niches suitable to the dwarf stem-succulent habit. The contribution of leaf-succulent dwarf shrubs with Succulent Karoo affinities is evident and congruent with growth form distribution in the Extra Cape Flora (Snijman 2013), to which the study area belongs. It is nevertheless surprising that geophytes do not contribute more to species of conservation importance than represented generally in the flora of the study area and the Cape Floristic Region nearby (Proches et al. 2006), particularly as a number of new geophytes have been discovered during the fieldwork for this study (Goldblatt & Manning 2013, Oberlander et al. 2014, Kativu & Bjora 2016, Burke, in press). There could be two reasons for this: either (1) geophytes are under-collected in this area or (2) geophytes are possibly not as range-restricted as the dwarf stem-

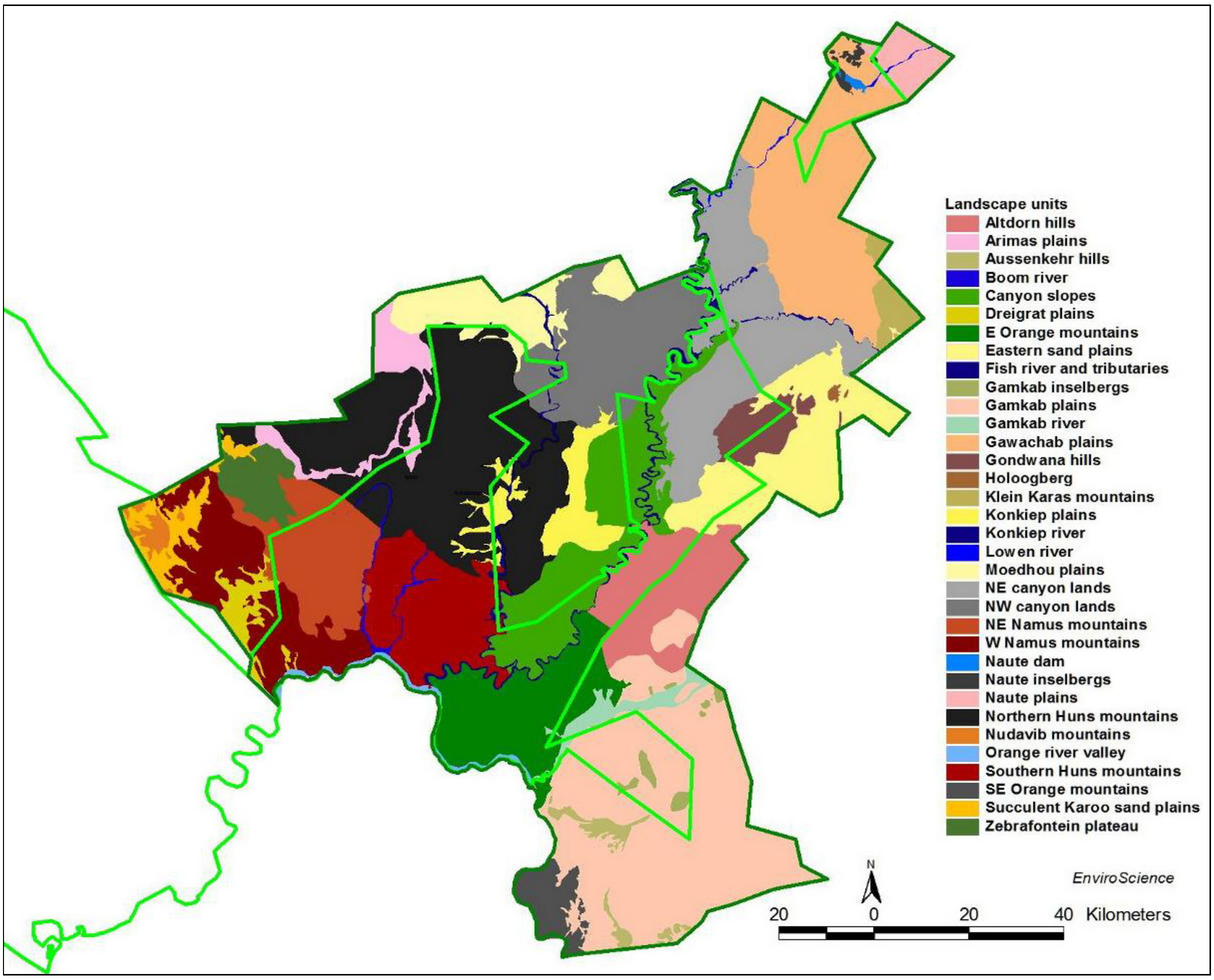

Figure 4: *Landscape units in the Greater Fish River Canyon Landscape and boundaries of state-protected areas (bright-green outline).*

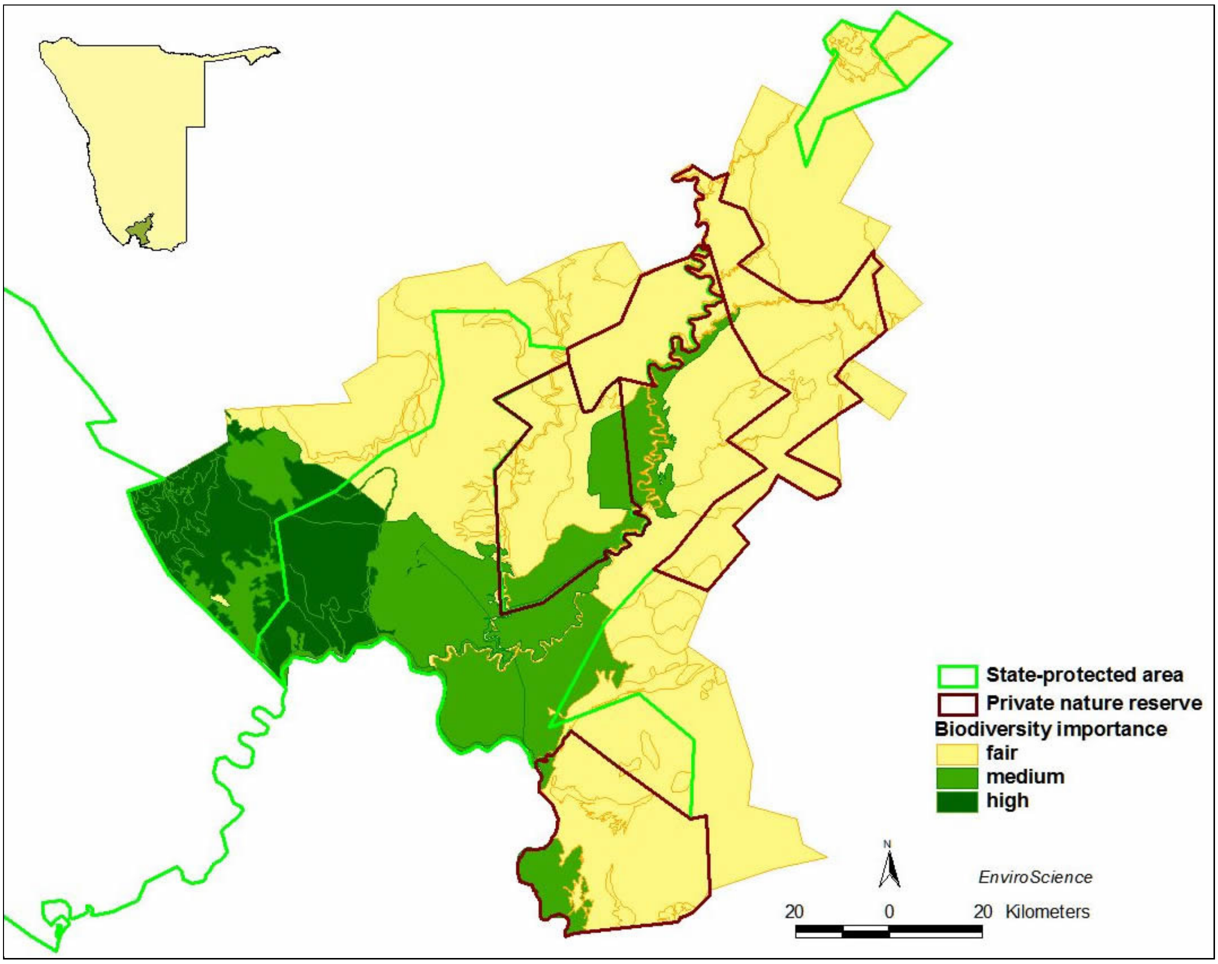

Figure 5: *Biodiversity zoning for conservation importance in the Greater Fish River Canyon Landscape in Namibia (ochre lines indicate the boundaries of broad habitat units).*

succulents. This would have to be investigated in future studies.

Biodiversity zoning

Conservation planning often incorporates expert knowledge where biodiversity inventories are incomplete or time is limited. Although this is justified in many situations (Cowling et al. 2003, Reyers et al. 2007), expert knowledge carries some bias. The approach used in this study requires a reasonably good inventory for the selected target group of taxa, but offers an objective process in determining biodiversity importance. To obtain an inventory, all available distribution data (not only data of the National Herbarium's specimen database), plus targeted field work to fill evident gaps in Namibia were used. Although the data are certainly not complete, they are a good approximation of the status of plant diversity in the study area. A recent study in South Africa (Williams & Crouch 2017) clearly supported this approach and highlighted the pitfalls of only relying on national data. This rating reflects plant diversity, endemism and a proxy for rarity, which are widely used indicators in conservation planning (Burgess et al. 2007, Knapp 2011, Pressey et al. 2003). What is new in this approach is the systematic incorporation of range sizes of species and level of endemism (Table 1). This has proved particularly important since IUCN discouraged the use of the category "rare" in red-listing (IUCN 2001, Gärdenfors 2001), and "rare" is now applied only occasionally in Namibia's red data list (Loots 2005), but not incorporated systematically. On the other hand, rarity has been stressed as an important criterion in national assessments of biodiversity (Cadotte & Davies 2010, Knapp & Salomn 2010), and using only red-listed species as indicators, which is often the focus of biodiversity assessments (Cowling & Lombard 1998), may therefore be insufficient in this area. The low number of red-listed plant species corroborates this point (Table 3). In total, only 4.5% (40 species) of plants of conservation importance included in this study were red-listed in a threatened category, a further 13 species were "rare" in Namibia's red-list, while 265 species (one third of the species included in this study) were used as indicators of conservation importance when the method introduced here was applied. This is, to some extent, a reflection of the number of species that have so far been assessed.

However, the fact that overall only 29% of the assessed species were categorised in one of the threatened (including near-threatened) categories, several of which have a narrow distribution range, highlights the possible shortcomings using only red-list species in a threatened category as indicators. Greater diversity in indicators is expected to better reflect the underlying plant and habitat diversity and concomitant species interactions (Danielson 1991, Zobel 1997, de Bello et al. 2010), and would therefore be more representative of the ecosystems in the study area.

The rating of plant species could be adapted for different purposes (Table 1). For example, this study places legally protected species at the same level as species listed on Cites. If more emphasis should be given to national legislation over international guidelines, ratings could be adopted accordingly. Also, there is, to some extent, an overlap between the categories "endemism" and "narrow-range", giving a higher weighting overall to the range sizes of species than any of the other categories, which is justified in an area with many species with restricted ranges. For other purposes, the overbearing influence of narrow range sizes may not be appropriate and the categories "endemism" and "narrow-range" could be combined in one rating.

"Rarity", in a strict sense, is a reflection of the abundance of a species (that is the number of individuals in a defined area). This type of information is hardly ever available for this scale of assessments and range size was therefore used as a proxy for rarity.

Biodiversity importance in the study area is a relative rating in the context of this landscape, providing a means of prioritisation. It does not mean that areas of "fair" biodiversity importance do not warrant protection or are not important for biodiversity. The biodiversity zoning in this study clearly indicates the ecological importance of river systems and mountain areas in this arid landscape as well as the overriding influence of winter rainfall. Biodiversity importance of the landscape units considered of "poor" data quality, largely due to the lack of rain in these areas (the plains north of the Huns Mountains and the eastern section of the mountains along the Orange River) and difficult access (e.g. the Huns Mountains) could change if additional data are incorporated, particularly for those units presently rated as "fair" (Arimas and Moedhou plains, northern Huns Mountains) (Table 4).

The development of the class intervals to assign biodiversity importance could be considered arbitrary, but the proposed algorithm was developed for this particular area and purpose and also presents a relative, but not absolute measure of "biodiversity importance". The method is area-specific and class intervals are adapted to the resulting data range and the spread of the data to provide a means of prioritisation. While this provides a structured process, it still maintains some flexibility which is tied to the species richness of the study area and is therefore site-specific. Incorporating species values adapted to a particular situation has also been applied in conservation planning at continental and regional scales (Margules & Usher 1981, Burgess et al. 2006). This approach has proved useful not only in conservation planning, but also in environmental and other biodiversity assessments in Namibia (Burke et al. 2008, Burke 2011) and could be applied elsewhere.

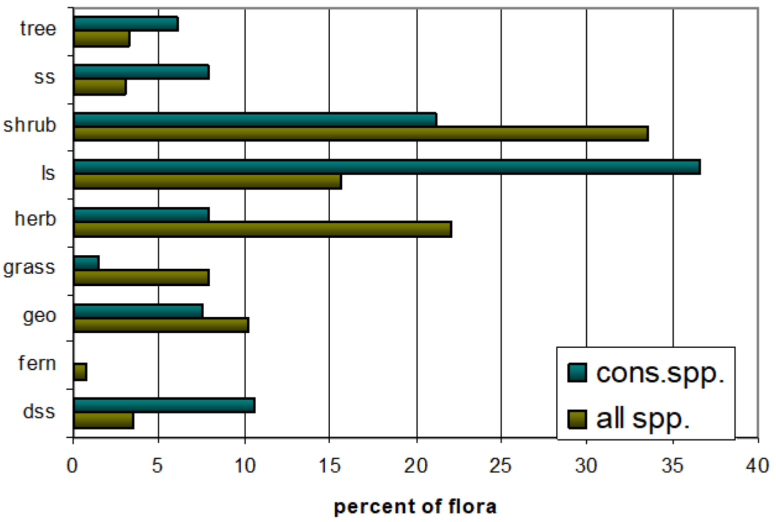

Figure 6: *Distribution of growth forms amongst the Greater Fish River Canyon Landscape flora (all spp., n=835) and species of conservation importance in this landscape (cons.spp., n=265) (dss=dwarf stem-succulents, ls=leaf-succulents, ss=stem-succulents).*

It is recognised that habitat units with plants as indicators do not provide the complete picture of biodiversity patterns, but as the core element of the food chain and indicators of many ecosystem services (Cardinale et al. 2012), plants are considered a reasonable proxy to present biodiversity patterns. Where adequate data are available for selected fauna indicators, a similar approach could be used to rate fauna indicators and incorporate these in biodiversity zoning (Linder et al. 2012). Also, where information is available at the level of detail required for a particular study area, ecosystem services could also be included as indicators to provide a more holistic approach (O'Farrell et al. 2010). Of potential consideration is the fact that spatial interpolation methods are affected by sampling design, spatial distribution, data quality, correlation between primary and secondary variables and interaction among factors (Li & Heap 2014) and this applies to this study as to many others in conservation planning (Cowling & Lombard 1998).

Implications for conservation

This biodiversity zoning provides a means of prioritisation and is a relative measure within the study area, which is positioned in the Gariep Centre of Endemism (van Wyk & Smith 2001), and therefore already recognised as an area of high conservation importance. At present, a large part of the most important area for biodiversity in the Greater Fish River Canyon Landscape is formally protected in the Ai-Ais –Richtersveld Transfrontier Park, and the adjoining private nature reserves provide further protection in the form of buffer areas or corridors (Figure 1). Nevertheless, exploration and mining take place along the Orange River, including the section in the Ai-Ais Hotsprings Game Park, and the lack of environmental management associated with these activities threatens some rare plant species (e.g. *Portulacaria pygmea*). Further, nearly half of the most important area in the west (the western Namus mountains, Succulent Karoo sand plains and Dreigrat plains) are on private farmland, where livestock farming is practiced, and the townlands of the mining town, Rosh Pinah. The expansion of townships around Rosh Pinah comes with concomitant overutilisation of natural resources and these activities may pose a threat to some of the rarer plants. Management guidelines developed on the basis of this zoning attempt to address this aspect (Burke 2013), but these need to go hand-in-hand with addressing the underlying challenge of increasing numbers of people moving from rural to urban areas in search of jobs and better services, and more stringent implementation of environmental assessments and management plans for development activities as prescribed under Namibia's Environmental Management Act.

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