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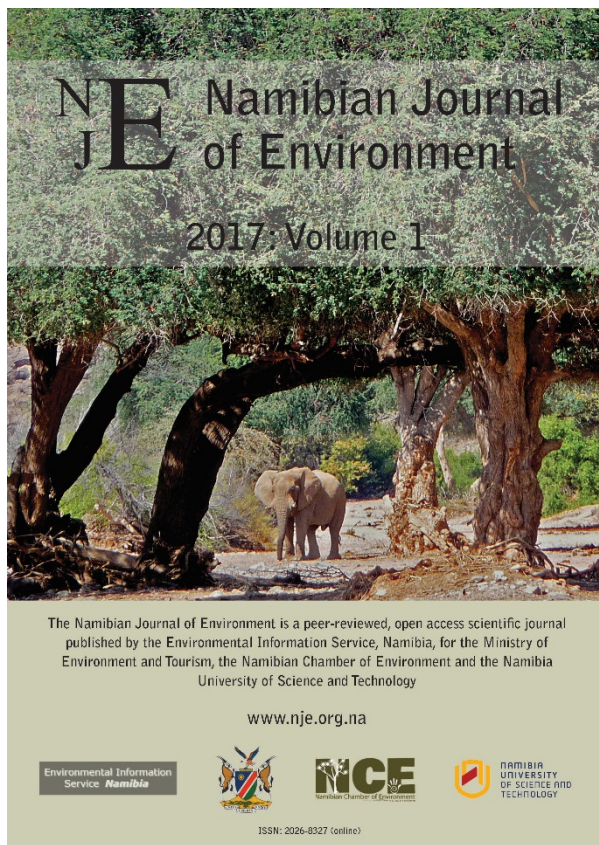
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SECTION A: PEER-REVIEWED PAPERS

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The status of *Faidherbia albida* trees in the Hoanib River, Namibia

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ABSTRACT

The Hoanib is an ephemeral river flowing from the highlands of Namibia through the hyper-arid Namib Desert to the Atlantic Ocean. Seasonal floods recharge groundwater that supports riparian woodlands, which are vitally important to wildlife and livestock. Previous studies prior to 2001 found that mega-herbivores are having an impact on the main tree species in the river system, *Faidherbia albida*. In 2002 two permanent boreholes were drilled for wildlife in order to reduce competition with livestock. This paper presents the results of a survey carried out in October 2012 to assess the current population structure and damage to *F. albida* in the lower Hoanib River, and to compare it with previous surveys. There was great variability in population structure, growth form, regeneration and elephant damage between the transects surveyed in different sections of the river. Khowarib Schlucht, where there are few elephants, showed a healthy demography, with many juveniles, regeneration, and little damage. Dubis wetland, which is utilised by game and livestock, had no mature trees and one clump of juveniles. Transects between the two boreholes showed low recruitment, little regrowth, and a marked 5m-high browse-line. They were dominated by mature, single-trunked trees with old elephant damage, and healthy canopies. From the “President’s Borehole” downstream there were juvenile trees, fewer mature trees, and thickets. Juvenile trees showed pruning from above and the sides. Near the floodplain, there were only highly pruned juveniles and a few trees in the 20-40 cm DBH size-class. Another visit, in 2014, showed changes to the juveniles at Dubis wetland, but no other changes. Overall lack of *Faidherbia* recruitment along the mega-herbivore frequented section of the river is of concern for the long-term survival of this important linear oasis. Suggestions are made on key interventions that could be implemented to prevent the loss of these woodlands, which would be a conservation and ecological disaster

Keywords: ephemeral river, *Faidherbia albida*, Hoanib River, mega-herbivore, Namib Desert, population structure, recruitment, regeneration, riparian woodland

INTRODUCTION

Located along the western seaboard of southern Africa, Namibia is an arid to hyper-arid country. Rainfall is both erratic and highly variable, increasing from almost nothing at the coast to an annual average of *ca.* 650 mm in the north east (Mendelsohn et al. 2002). The ancient Namib Desert extends from the coastal plain inland for approximately 150 km to the escarpment, which separates it from higher altitude areas in the interior of the country. Twelve westward-flowing ephemeral rivers drain the central highlands, channelling seasonal floodwaters through this arid landscape (Jacobson et al. 1995). These rivers form ‘linear oases’ in the desert and act as biological corridors between the interior and the coast. Most support riparian woodlands dominated by various *Acacia* (*sensu lato*) and other woody species (Curtis & Mannheimer 1995). These woodlands are of vital importance to wildlife as well as to the local human communities and their livestock that depend on them (Jacobson et al. 1995, Leggett et al. 2003a, Moser

2006, Moser-Nørgaard & Denich 2011). Many of the larger wildlife species, including the African elephant (*Loxodonta africana*), Angolan giraffe (*Giraffa giraffa angolensis*) (Fennessy et al. 2016), gemsbok (*Oryx gazella gazella*), springbok (*Antidorcas marsupialis*) and baboon (*Papio cynocephalus*) are able to extend far into the true desert, using these riparian resources.

The Hoanib River flows from the mountainous interior west of Etosha National Park westwards through communal conservancies for about 270 km, draining into the Atlantic Ocean just south of Möwe Bay in the Skeleton Coast National Park (Fennessy & Fennessy 2004) (Figure 1). The riparian woodland is dominated by *Faidherbia albida* (Del.) A.Chev. (formerly *Acacia albida*). This species can reach heights of 20-30 m, with a trunk diameter of over 2 m (references in Barnes & Fagg 2003). It is generally an erect, single- or multi-stemmed tree, with a spreading canopy. Since it has a strong capacity for regeneration, often sending up new shoots from exposed roots or producing a number of new stems from a fallen trunk, it is often hard to

determine whether one is looking at a group of trees growing close together or a single, multi-stemmed tree. Its wide distribution in Africa attests to its ecological adaptability (CTFT 1989, Barnes & Fagg 2003). In areas with low herbivore pressure, branching generally starts near the ground and higher branches often droop to the ground. However, in areas such as the lower Hoanib River, excessive pruning by mega-herbivores results in trees with trunks bare of branches until the base of the canopy at around 5 m (Figure 2). Seedlings and juveniles generally have a single stem, with numerous lateral branches. In Namibia it is commonly known as Anaboom or Ana tree, but elsewhere in Africa it is known as Winter thorn, since it is dormant in summer and produces new leaves and flowers in winter. This tree provides valuable browse and shelter to numerous animals, ranging from invertebrates (Theron 2010), reptiles, birds and small mammals to mega-herbivores such as giraffe (Fennessy 2004) and elephant (Viljoen 1988, 1989, Jacobson & Jacobson 1998, Leggett et al. 2001, 2003b). As a legume, its leaves and pods are high in protein (Barnes & Fagg 2003). Owing to its unusual ‘reverse’ phenology, producing new growth in the dry season (Curtis & Mannheimer 1995), the tree is vital to wildlife, people and livestock at a time when other resources are limited (Moser-Nørgaard & Denich 2011). Although present along most of the river’s length, *F. albida* reach their greatest abundance and size in the lower

reaches (Nott 1987, Jacobson 1995, Fennessy et al. 2001, Fennessy 2004).

Various factors affect the growth and recruitment of *F. albida* (Barnes & Fagg 2003). In riparian woodlands, flooding (Jacobson 1995) and herbivory (Barnes 2001a, Fennessy 2004) have the greatest effects. In ephemeral systems, erratic seasonal floods bring water and nutrient-rich sediments from inland (Jacobson et al. 1995). Flooding occurs during most years in the Hoanib River, but the duration and intensity of floods are highly variable (Department of Water Affairs records, Appendix 1). Since rainfall is very low in the lower Hoanib River (~25 mm/yr), germination and recruitment are dependent on flood water. However, floods are both a blessing and a curse to the riparian vegetation. Apart from recharging the groundwater upon which the trees depend, and providing sufficient moisture for germination, heavy discharges uproot and undermine mature trees, and flatten or drown younger trees (Jacobson et al. 1995, Moser 2006, pers. obs.). Lack of floods and declining groundwater can also have a detrimental effect on riparian vegetation (Huntley 1985, Douglas 2014).

Trees have evolved, and continue to evolve, in association with herbivores, and are dependent on them for dispersal and germination of seeds (see Barnes & Fagg 2003, Sebata 2013). Minor browsing probably shapes them into single-stemmed trees from the multi-stemmed juveniles, however, high

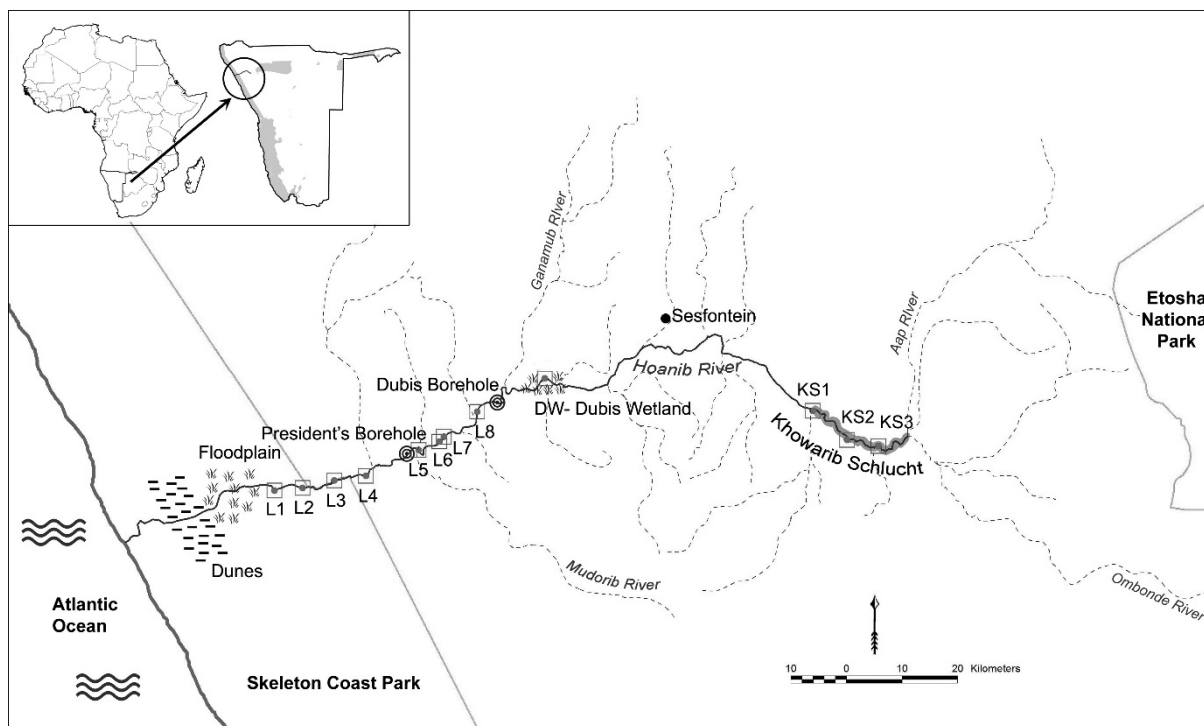


Figure 1. Map of the lower and mid-sections of the Hoanib River, Namibia, showing survey sites and other features mentioned in the text.

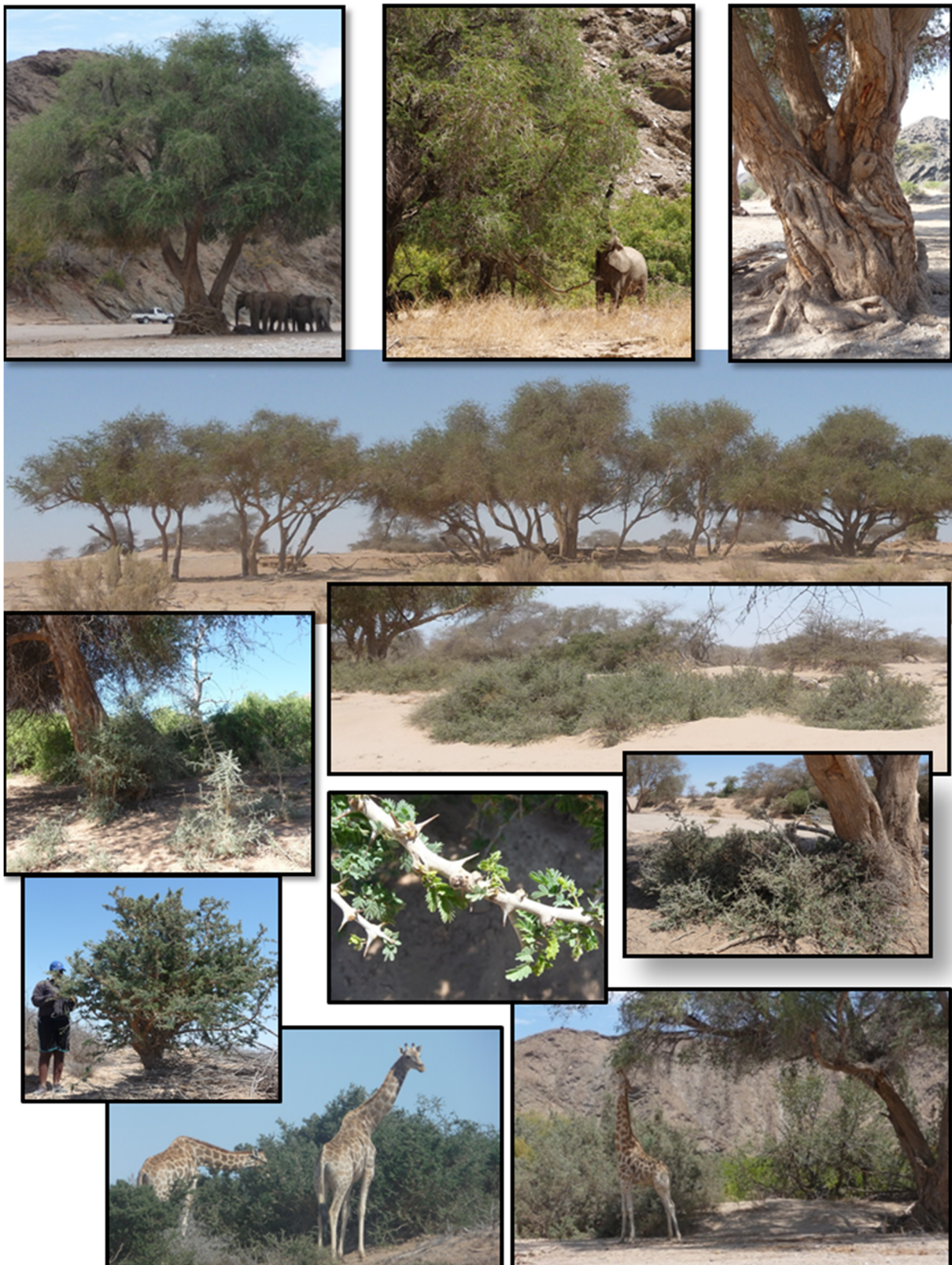


Figure 2: *Faidherbia albida* in the Hoanib (and Ugab) River, 2012. Left to right from top: Elephants under a mature tree near Dubis borehole (note flood debris at the base of the tree); elephant in the Ugab River reaching above the kudu browse-line; old elephant bark damage; row of mature trees along the edge of the main channel, showing distinct browse-line and lack of undergrowth; unbrowsed root coppice in Khowarib Schlucht; thicket at site L2; pruned floodplain tree; stunted leaves on pruned branch; browsed root coppice in section L; giraffe pruning trees at site L1; giraffe eating at browse-line in section L.

herbivore pressure can be detrimental (Bergström 1992, Sebata 2013). Repeated browsing from below often results in a distinct browse-line on trees, while browsing from above by giraffe leads to rounded bushes and thickets (pers. obs.) (Figure 2). In searching for nutrients, elephant often break branches and strip bark off the trees, sometimes entirely ring-barking them or pushing trees over to reach food (see Barnes & Fagg 2003). Trampling of seedlings additionally reduces recruitment (Barnes 2001b, 2001c, Moser 2006). Elephant, giraffe and other herbivores use the river year-round, moving up and down, as well as in and out of the main river bed in response to available water and flushes of new growth and fruit (Viljoen 1988, Jacobson 1995, Leggett et al. 2001, Fennessy 2004). In the 1980s the wet season core activity area of elephant and other wildlife was the Hoanib River floodplain, while this shifted east during the dry season to the Dubis wetlands approximately 50 km upstream (Viljoen 1988).

The increase in mega-herbivore numbers in the 1980s in the lower Hoanib River raised concerns about the impact of these animals on the *F. albida* populations, especially around the Dubis wetland. The latter deteriorated from a 'healthy climax population' with recruitment of juvenile trees at 30% (Viljoen & Bothma 1990) to 0.2% in 1995 (Jacobson 1995). The situation improved to 9% over the next five years — the result of improved rainfall and flooding — combined with a range extension of the elephant population into areas away from the Hoanib River (Fennessy 2004, Leggett 2006).

Elephant damage in the Hoanib River has previously been reported to be highest near the permanent water of the Dubis wetland (Fennessy 2004, Jacobson 1995). In November 2002, two permanent boreholes were established in the lower Hoanib River to provide water for wildlife, which subsequently changed the seasonal movements, use and density of elephant (Leggett 2006). It is feared this may have an adverse impact on the trees near the boreholes. Thus, it is of utmost importance to monitor the trees in the entire river as the maintenance of a healthy *F. albida* population in the western rivers is essential to the survival of desert-dwelling wildlife (Jacobson 1995) that are an integral part of the riparian ecosystem and a major tourist attraction. This paper presents the results of a recent survey to assess the current population structure and damage to *F. albida* in the lower Hoanib River, and to compare it with previous surveys and the situation in the upper Hoanib River.

METHODS

Study Area

The ephemeral Hoanib River of northwestern Namibia, with a catchment of 17,200 km² (Fennessy & Fennessy 2004), rises in the hills around western Etosha National Park, flows westwards, and cuts through the escarpment in a narrow, meandering canyon known as the Khowarib Schlucht (ca 137 km from the coast) (Figure 1). The canyon length is about 17 km in a direct line over the mountains, or 27 km following the river. The river bed ranges from 70-120 m in width, with silt or rocky banks in most places. The riparian woodland, for the most part, comprises a row of trees and shrubs along one or both sides of the main channel, dominated by *F. albida*, with *Acacia (sensu lato) tortilis*, *A. erioloba*, *Colophospermum mopane*, *Combretum imberbe* and *Salvadora persica*. Towards the western end of the canyon are a series of springs, with variable discharges depending on seasonal floods. At the time of the survey (October 2012), a stream of about 1.5 m width and depth of up to 0.3 m was flowing. Grass, sedges and various small shrubs lined the stream. Elephant and giraffe historically occurred in the upper reaches of the Khowarib Schlucht, although they seldom frequent the area now. The Schlucht falls within the Anabeb Conservancy, an area of 1,570 km² with a population of around 1,400 people, three small villages and two tourist camp sites (NACSO 2017). Cattle and goats browse in the river.

Over the next 40 km the river flows westwards through the wide, open Sesfontein valley, with a human population of around 1,500 centred in the village of Sesfontein (NACSO 2017). At about 78 km from the coast, the river narrows to a valley through the mountains. At the start of this mountainous area is another spring, which creates the permanent Dubis wetland of about 8 km in length. This wetland supports reed beds for most of its length, and virtually no large trees. Livestock graze in this area. Dubis borehole (installed by government in 2002 to supply water for wildlife in order to reduce human-wildlife conflict at water-points nearer Sesfontein) is situated about 10 km downstream of this wetland, near the Hoanib-Ganamub confluence. From here to the floodplain (section L, described in the Data Collection section) are the main riparian woodlands, which support healthy numbers of herbivores, including giraffe and elephant. Livestock generally do not come down this far. The main river channel varies in width from 50-200 m, sometimes diverging around islands. In places there are floodplains of varying width. The large trees are mainly found as a single row along the edges of the channel or on the islands, but in some reaches of the river trees occur across the

channel and onto the floodplains. Apart from the species mentioned previously, *Combretum watti* and *Cordia sinensis* are also common shrubs. The 'President's Borehole' is situated at the Hoanib-Mudurib confluence, about 53 km from the coast. At about 40 km from the coast the river enters the Skeleton Coast National Park. Between the Sesfontein valley and the park, the river separates the Sesfontein Conservancy to the north (2,465 km²) from the Palmwag Tourism Concession to the south (NACSO 2017). This section of the river is used by tourists hoping to see desert elephants and giraffe. There is an upmarket tourist lodge on the south bank of the river near the park.

Roughly 60 km downstream of Dubis wetland the river widens into an extensive floodplain area located within the Skeleton Coast Park. Floodwaters blocked by the dunes further west spread out across this plain, which extends from about 17-27 km inland and is about 2-4 km wide. Vegetation here varies with flood events. In wet years it is covered in small shrubs, forbs and grasses that are an important food source for wildlife. In 2012 it was densely covered with woody shrubs of 1-2 m high, with very occasional larger trees that were stunted and heavily pruned by browsers. The lowest section of the river from the coast until about 17 km inland is hyper-arid and is blocked by dunes, with no trees. Only in years of exceptionally heavy rainfall inland does floodwater break through to reach the sea (Jacobson 1995).

Data Collection

Faidherbia albida was surveyed in the Hoanib River from the eastern end of the floodplain to the eastern end of the Khovarib Schlucht (between 13° and 14° E; see Figure 1) in late October 2012. This was the hot-dry season, approximately six months after the last flood in early 2012, and at the end of the leafing and flowering season for *F. albida*. For this study, the river was divided into four reaches, based on the marked differences in *F. albida* structure and recruitment. Moving downstream, these were: 1) KS = Khovarib Schlucht, middle of the Hoanib River; 2) DW = Dubis wetland, approximately 80 km from the coast; 3) L = Lower Hoanib from Dubis borehole to the floodplain; and 4) the Hoanib floodplain. The section of river from the western end of KS to DW (Sesfontein valley) was not surveyed. All previous studies concentrated on section L, with the exception of Fennessy et al. (2001) who looked at the entire river.

In total, 12 transects were surveyed over a combined distance of 78 km: three in KS (27 km), one at DW and eight in section L (51 km). Transects in KS and L were selected randomly, at roughly 5 km intervals (see Table 1). At DW, there were only two mature

trees and one patch of juveniles some distance away from the mature trees. Only the juveniles were surveyed. The results from the DW transect therefore do not reflect the entire wetland area, but serve to illustrate what recruitment in this section of the river can be like. Owing to the very low density of trees, no transects were surveyed in the floodplain, but measurements were made on ten individual trees.

The length of each transect was about 0.5 km and the width corresponded to the width of the river along that section (except for DW, where the transect width was the width of the area covered by the trees) (see Table 1). In each transect, the following measurements were made for every *F. albida* individual: (i) height: Trees were classified into height classes of <=0.5 m; 0.5-2 m; 2-5 m; 5-10 m; 10-20 m; >20 m. Individuals less than 0.5 m high were regarded as seedlings which were assumed to have germinated after the 2012 floods; (ii) circumference: For trees >1.5 m high, circumference at breast height (1.3 m) was measured and converted to diameter at breast height (DBH) in 20 cm intervals in order to compare with previous studies. (All saplings 0.5-1.5 m tall had diameters far less than 20 cm); (iii) Vitality, or general health of the plant: this was estimated on a scale of 1-5, where 0 = totally dead; 1 = mostly dead; 2 = several live branches; 3 = half tree alive; 4 = a few dead branches; 5 = no dead sections; and additionally, (iv) Growth form, browse-lines, coppicing and regrowth: these were noted along with recent elephant damage – bark stripping (BS), main stem breaking (MSB) and branch breaking (BB).

All individuals >0.5 m high, but with stem diameter of <20 cm, were regarded as juveniles. For purposes of comparison with previous studies, juveniles and mature trees were grouped together and proportions of each diameter class were calculated. For comparisons between sites in 2012, juveniles and mature trees with DBH >20 cm have been presented separately in Table 1 because of the differing importance of juveniles and adults in the population, and the differing growth forms and impacts of herbivores on these two groups.

In December 2014, a brief follow-up survey was undertaken, principally to look at the survival of the seedlings and juvenile trees.

No statistical comparisons could be made between this survey and previous studies as different areas were assessed. Nott (1987) counted all trees greater than 2 m high from Dubis wetland to the floodplain, but did not measure them; Viljoen and Bothma (1990) selected specific trees for size classification in 1982; Jacobson (1995) measured all trees within the first 12 km from Dubis westward, and thereafter

all trees within the first kilometer of six equally spaced sections along the remaining 53 km to the floodplain; Fennessy (2004) measured all trees within the stretch from Dubis to the floodplain. The last three researchers all measured diameter at breast height.

RESULTS

Population structure and recruitment in 2012

In total, 812 *F. albida* trees over 0.5 m tall and 232 seedlings under 0.5 m tall were recorded over the length of the surveyed sections of the Hoanib River in 2012. Densities varied considerably, from 2-5 trees/ha in transects L4 – L8 to 41 trees/ha in L1. The overall mean of the 12 transects was 14±13 trees/ha (Table 1). In all transects, the density of mature trees >20 cm in diameter was low. In contrast, the density of juveniles (>0.5 m high but with DBH <20 cm) was indicative of the overall density patterns, with the highest density being in L1, followed by DW. Density of seedlings was low in all transects, except L1 (Table 1).

There was a marked difference in the population structure of *F. albida* between the different sections of the river, and within each section (Figure 3). Transects KS1-3 had a healthy age structure, with

many juveniles and decreasing numbers of older trees, and yet still having old trees with diameters of ≥120 cm. Only juveniles were observed at DW. In the upper reaches of L (L5-8), there were few juvenile and young trees, with a high proportion of old trees, suggesting low recruitment. The number of juveniles increased again nearer the floodplain, with fewer old trees. Transect L1 had no very big trees, but many juveniles, as well as seedlings.

Growth form, regeneration and vitality in 2012

Growth form and regeneration in the form of coppice growth varied along the length of the river. Most of the trees observed were healthy, with an average vitality score of 4-5 (Table 1). Trees in L4 had the lowest vitality (with a mean score of 3), with many broken and almost dead trees. This transect had a very wide floodplain, and trees furthest from the main river channel had lower vitality scores than those nearer the main channel. This was most likely to be due to water stress, since a lower water table has been shown to adversely affect this species (Ward & Breen 1983). This transect was 9 km west of the President’s Borehole where larger numbers of mega-fauna occur.

All tree canopies in the Khovarib Schlucht started near the ground, and young growth had not been substantially modified by browsers, despite some evidence of browsing having taken place. The only browsers encountered were cattle, although old giraffe droppings were observed. The percentage of trees coppicing from the roots in KS was the highest of all (mean of 49%), suggesting that this form of regeneration has not been restricted by browsing and trampling, as it has been lower downstream. There did not appear to be any marked differences in growth form or population structure between the three transects in this section, despite the fact that the two downstream transects (KS1-2) were in areas with a permanently flowing stream.

The juvenile trees at Dubis wetland (DW) exhibited the same growth form as those in KS, branching low down, with long branches, unlike the cropped-off juveniles of further downstream in the L transects.

All the mature trees in section L showed a totally different growth form from those in the KS. Every tree with a diameter >10 cm had one or two unbranching trunks up to a 5m-high browse-line, above which the canopy was spreading and generally healthy, with the exception of individuals within L4. The juvenile trees in this reach of the river were all highly pruned from above,

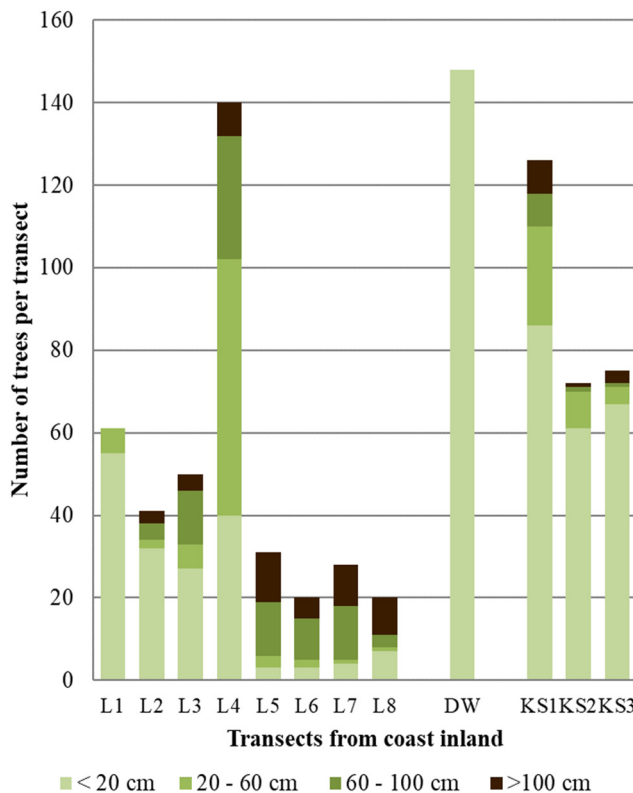


Figure 3: Number of *Faidherbia albida* trees measured per transect in the Hoanib River 2012, showing the relative proportions of trees per DBH category.

Table 1: Location and details of 12 transects in the lower and mid Hoanib River, with density and growth characteristics of *Faidherbia albida* in October 2012.

Transect	L1	L2	L3	L4	L5	L6	L7	L8	DW	KS1	KS2	KS3
River reach	Lower Hoanib floodplain to Dubis borehole								Dubis wetland	Khowarib Schlucht		
Co-ordinates S (degrees, mins)	19 23.29	19 23.04	19 22.32	19 21.87	19 19.36	19 18.55	19 18.07	19 15.67	19 12.43	19 15.90	19 18.38	19 18.97
Co-ordinates E (degrees, mins)	13 00.02	13 02.76	13 05.83	13 08.91	13 14.01	13 16.02	13 16.48	13 19.69	13 26.26	13 52.98	13 55.61	13 58.64
Direct distance from coast (km), approx	27	34	37	44	53	56	59	64	77	121	126	132
Section of river downstream of Dubis (km)	45+	40-45	35- 40	25-30	15-20	15	12	5-10	not applicable			
Length (m)	376	544	476	650	625	560	554	510	450	800	450	473
Average width (m)	40	60	90	400	145	195	147	170	100	110	70	72
Area (ha)	1.5	3.3	4.3	26	9.1	10.9	8.1	8.7	4.5	8.8	3.2	3.4
Seedling density/ha	30.7	5.5	0.7	2.1	0.2	2.1	0.6	0.9	4.9	2.5	2.2	6.5
Juveniles (DBH <20cm)												
density/ha	36.7	9.7	6.3	1.5	0.3	0.3	0.5	0.8	30.9	9.8	19.1	19.7
Mature (DBH >20cm)												
density/ha	4.0	2.7	5.3	3.8	3.1	1.6	3.0	1.5	none present	4.5	3.4	2.4
average vitality	5	4	4	3	4	4	4	5		4.0	4.0	4.5
% trees BS	0.0	55.6	21.7	3.0	39.3	5.9	37.5	46.2		old damage only		
mean % BS	0.0	16.0	40.0	10.0	20.0	15.0	10.0	40.0		0.0		
% with BB	0.0	22.2	26.1	30.0	14.3	23.5	29.2	7.7		old damage only		
% with MSB	0.0	0.0	8.7	6.0	3.6	11.8	0.0	7.7		old damage only		
% root coppicing	25.0	33.0	13.0	15.0	7.1	17.6	12.5	46.2		27.5	45.5	75.0
Total # trees >0.5 m	61	41	50	140	31	20	28	20		148	126	72
Density per hectare	40.7	12.4	11.6	5.4	3.4	1.8	3.5	2.3	32.9	14.3	22.5	22.1
# thickets	2	12	3	19	0	0	0	0	0	0	0	0
Comments					President's Borehole					running water	running water	

resulting in short, stumpy, very spiny branches, with short leaves clustered tightly among the thorns (Figure 2). Almost all of them had dense, spiny branches from ground level, presumably as a defense against bark stripping. Virtually no broken branches or stems were observed among the juveniles.

A feature of the woodland between L3 and L8, apart from the growth form of the mature trees, was the lack of undergrowth, not only of juvenile and coppicing *F. alibida*, but plants in general. Root coppicing was recorded in 21±14% of mature trees, but all new growth had been heavily browsed. Thus there were no new trees developing from this coppice. There was no correlation between coppicing and distance from DW, as had been found by Fennessy (2004), with coppicing highest in L8, nearest to the wetland.

In the four transects nearest to the floodplain (L1-4), there were thickets of *F. alibida* (Figure 2). This phenomenon was most marked at L1, where the main channel was confined between silt banks. These thickets ranged from 1-20 m in length, with a height range of 0.5-5 m, but most were less than 2 m high.

On the floodplain, and just to the west of it, were scattered individual trees that had been stunted by pruning, possibly aided by the wind. These trees ranged from 1.5-6 m in height, with spreading canopies of 1.5-3 m in diameter touching the ground.

The general health of most of the trees was good. Mature trees whose canopies were above the reach of herbivores mostly showed healthy leaf production, many still with flowers (main flowering time is around August and September (Curtis & Mannheimer 1995)), and fresh new pods. Those nearer the floodplain had less healthy leaves and little pod production, compared with those nearer DW.

Elephant and other damage in 2012

No ring barking was observed on any of the trees examined. Jacobson (1995) noted alteration in cambium growth on many of the damaged trees, which resulted in “numerous deep convolutions.... parallel to the longitudinal axis of the trunk”. This phenomenon was noted in the present study on all the mature trees >40 cm DBH downstream of Dubis, as well as on some of the younger ones (Figure 2). Fennessy (2004) classified the age of bark damage into three categories: ‘recent’ being less than one month old with green gashes; ‘current year’ damage no longer green gashes but with no cambium regrowth; and ‘old’ where the cambium was starting

to grow over the scar. No recent (green) damage was noted in the present study, and very little current damage, but there was extensive evidence of old bark damage.

There was also little sign of browse and trampling on the juveniles in the DW. On some of the bigger juveniles a few strips of bark had been removed and a few lateral branches pruned, but overall these individuals resembled those found where there were no mega-herbivores.

Most elephant damage was recorded in section L, the lower reaches (Table 1). About 30% of mature trees showed signs of damage within the last year, with an average of 20% of the bark of these individuals having been stripped. Only 5% of trees had one of their main branches broken by elephant, and only 22% showed broken branches. In most cases new shoots were growing from the damaged branches, but wherever these were within reach of mega-herbivores, the new growth had been severely pruned. Mortality was low, with only ten dead stumps or trees found, compared with 391 living trees in this section. Seven fallen trees that were still living were recorded in this stretch. One of these appeared fairly healthy, the others being almost dead, with a few highly browsed coppice shoots. Three stumps had coppice shoots of up to 1 m, heavily browsed into a thicket. It was not possible to tell whether the fallen trees had been eroded by floods or pushed over by elephant, but we suspect the former, since there was no evidence of trees having been uprooted by elephant. Stumps may have been the remnants of trees broken or ring-barked by elephant in the past. Outside of the transects, there was evidence of trees having fallen due to flood erosion.

Changes from 2012 to 2014

There were no major changes in population structure between the two survey periods, but the overall health of the trees had deteriorated by almost one category, probably due to the poor rains and lack of flooding in 2012/3 and 2013/4. The greatest changes were noted among the seedlings and juvenile trees, particularly at site DW. Whereas in 2012 there were 22 seedlings, 133 juveniles and no mature trees over 20 cm DBH here, in 2014 there were no seedlings, 121 juveniles and 15 trees in the 20-40 cm category, with two dead juveniles. Thus at least five seedlings must have been recruited into the juvenile category (23%), while the others did not survive. Recruitment of juveniles into the adult category was 11%. Far more browser damage was noted in 2014 than in 2012 (Figure 4), while average vitality decreased from 4 to 3. Coppicing decreased from 21% of trees to 15%. Five trees had been cut with axes, but all

were coppicing. This was the only evidence of human impact encountered along the entire river.

The only place seedlings were found in 2014 was at transects L1-2, nearest the floodplain (12 in total). In L1, six of the 2012 seedlings (13%) had grown into the juvenile category, while three juveniles had grown into adults (5%). Many of the previous seedlings appeared to have become thickets. No recruitment of seedlings into the juvenile category had taken place in any of the other transects, and few juveniles had become adults. There was no new bark stripping since 2012, but at L3 many of the lower branches were broken off. The vitality of most trees was lower, with far less coppice growth, which was in poor health. At a number of sites, the clambering shrub, *Salvadora persica*, was smothering many of the trees.

DISCUSSION

Population structure and recruitment

When comparing the results for section L (from Dubis waterhole to the floodplain) with the previous studies, one can see changes in the demography of these trees, with the greatest variability being in the juvenile age class (Figure 5), from almost 0% (Jacobson 1995) to 44% in 2012. Viljoen and Bothma (1990) recorded a healthy population structure in 1982, with relative proportions of each age class decreasing from 30% juveniles, 25% young trees in the 20-40 cm age class to relatively very few old trees with trunk diameter of >120 cm. The years preceding 1982 had very poor flooding. In the summer of 1981/82 there was an above-average flood, which probably gave the surviving seedlings enough moisture to grow into juveniles (Department of Water Affairs records, Appendix 1).

By 1995 the population structure had changed drastically, with almost no recruitment (0.2%) in the juvenile class, a low percentage in the 20-40 cm class, and most of the trees being 40-60 cm in diameter (Jacobson 1995). Because of the low proportion of juveniles, the proportions of the older age classes were higher than that recorded by Viljoen and Bothma (1990), but still showing the same decline in numbers from 40-60 cm to 100-120 cm. It is interesting that there was a higher proportion of >120cm diameter trees compared with 100-120 cm trees. This would suggest growth of some of the latter trees into the next size class. Flood data show generally low flooding from 1984/85 to 1993/94, which would have stressed and weakened the surviving young trees. The big flood of 1994/95 destroyed most of the trees in the juvenile and 20-40 cm class (Jacobson 1995). A similar effect was noticed in the Kuiseb River after an exceptionally big flood (Curtis in prep.). The 40-60 cm trees were

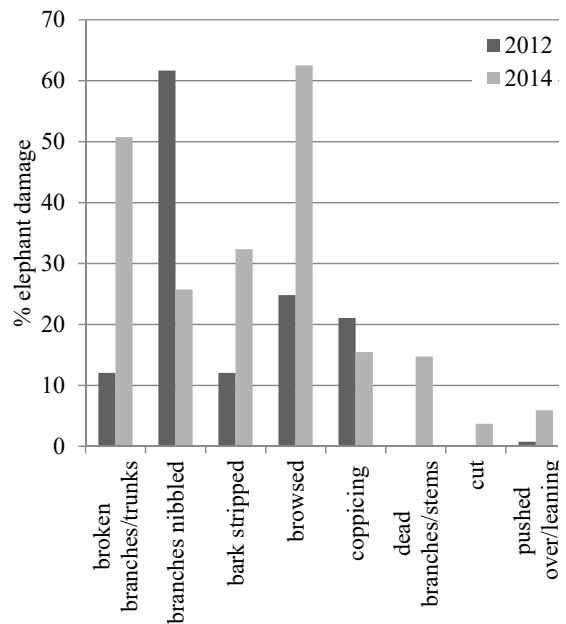


Figure 4: Increases in damage to juvenile trees near the Dubis wetland in the Hoanib River from 2012 to 2014.

strong enough to withstand this, and formed the highest proportion that year.

Five years later, Fennessy (2004) recorded a slight increase in juveniles, but this was still much lower than previously recorded. From 1996/97 to 1998/99 there were three years of average flooding, which would have given the juveniles a chance to establish themselves, and thus not as many were destroyed in the extremely big flood of 1999/2000. The low proportion of 20-40 cm trees was a result of the lack of recruitment in 1995, with the 60-80 cm class being the dominant one, following Jacobson’s (1995) dominant 40-60 cm class. The larger size classes followed a similar pattern to that shown by Jacobson (1995).

The eight years between Fennessy’s (2004) study and this 2012 survey generally had average to above-average flooding, resulting in apparently high recruitment, with the peak of mature trees being in the 60-80 cm class. The lower proportion in all size classes was due to the high proportion of juveniles (44%). The pattern, however, was not the same as shown by the two previous data sets, with a low proportion of really old trees (5%), which was still higher than that shown in 1982.

Transect DW near the Dubis wetland was very different from the other transects, with no mature trees, and the entire subpopulation consisting of juveniles and a few seedlings. This was probably a result of the high water-table and high salinity. Thickets in the lower reaches could have resulted from clumps of seeds germinating together and

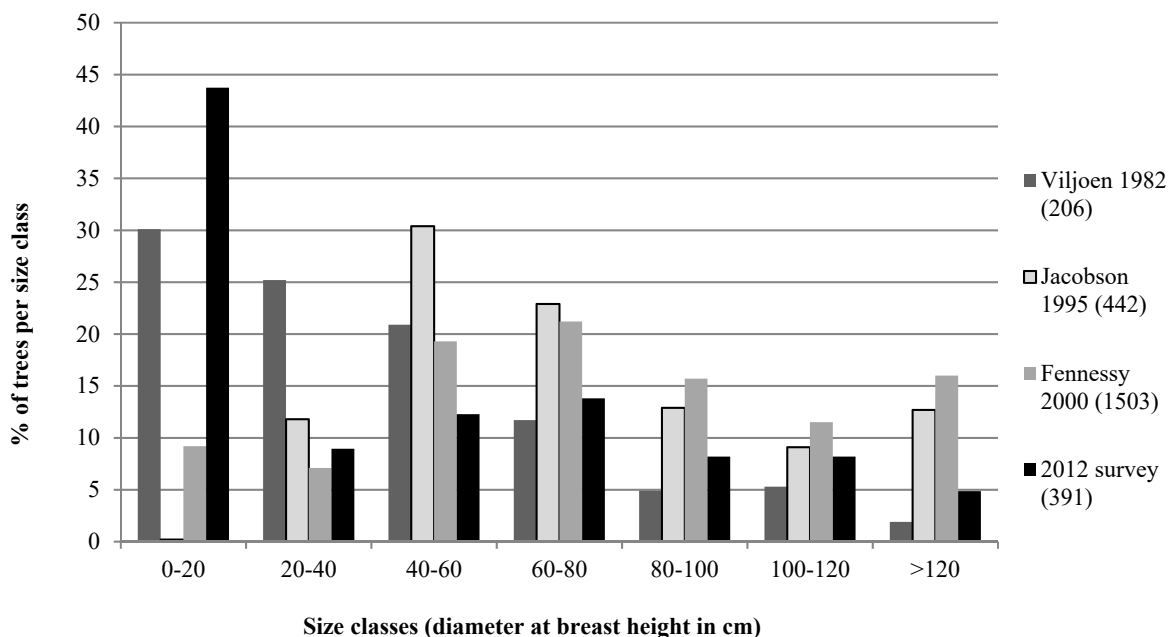


Figure 5: Changes in population structure of all trees measured from 1982 till 2012 in the lower Hoanib River between Dubis and the floodplain (L1 - L8 of current survey). Numbers in brackets after the author indicate sample size.

growing up as one, or could have sprouted from fallen trees.

The low seedling density between Dubis and the floodplain (with the exception of L1 at the start of the floodplain) was probably due to trampling by elephant and giraffe. In L1, where there are no large trees to attract elephant, seedlings had a better chance to survive. It could also be attributed to the flood waters slowing down here, and depositing more seeds and debris.

The changes in recruitment and age structure of the lower Hoanib *F. albida* trees over the years is of concern, particularly the almost total lack of juveniles in 1995, and low numbers in most of the sites in 2012. One must, however, be careful of comparisons when different sampling methods and sampling sites are compared. Fennessy’s (2004) work is the most comprehensive since that study was a total count which measured every single tree, whereas the other studies are sample surveys. The current work underlines this importance, as well as the masking effect of combining data for a long stretch of river. Our survey indicated healthy recruitment in 2012, but only for small sections and not for the river as a whole. Had we included every tree between Dubis and the floodplain, our results would have been different, with a lower proportion of juveniles and higher proportions of the older trees. There is no doubt that recruitment has improved overall, since Jacobson found no young trees in year 1995 (Jacobson 1998), but the low recruitment in the areas where herbivore density is highest is of concern.

The marked increase in juveniles found in our survey would be encouraging, were it not for the fact that most of the recruitment was in the lower portion of the river. The transects from Dubis waterhole to the floodplain showed low recruitment, but not as low as that recorded by Jacobson (1995). There was an average of 18% in the <20 cm age class for these four transects, indicating some recruitment in the last 17 years. There were almost no trees in the 20-40 cm age class. Most of the trees in this stretch of river were mature and had survived from 1995 and before. Moving downstream towards the floodplain, the proportion of juveniles increased, while the proportion of very old trees with a DBH of >120 cm decreased. In the last transect before the floodplain, there were essentially only juveniles, with a few trees in the 20-40 cm age class. The increase in recruitment from Dubis downstream towards the start of the floodplain mimics the increase in total density of tree.

Both stem diameter and height are functions of the age of a tree, to a certain extent. Fennessy (2004) found that the mean height of trees decreased downstream of Dubis, suggesting a decrease in age downstream. This trend was also observed in this study, and is largely attributable to the large number of juvenile trees in the lower sections of this reach. Possible reasons for the greater numbers of trees nearer the floodplain are seasonal floods depositing nutrients and seeds, which would result in the increased recruitment, as observed in 2012 (Fennessy 2004).

The absence of mature trees in the vicinity of Dubis wetland, as noted in all three studies, could possibly be due to the increased salinity recorded by Jacobson et al (2000) as suggested by Fennessy (2004), although this species is generally regarded as tolerant of high salinity (Orwa et al 2009 cited in Feedipedia 2017, WorldAgroForestryCenter 2017). In 2012, there was a section of the river between L8 and Dubis borehole that was currently dry, but had recently had standing water, as evidenced by the sedges, new seedlings and *Tamarix usneoides* and other water- and salt-tolerant plants growing there. This area was not surveyed, but the vitality of the mature trees was noted. In a stretch of river about 5 km long, we counted 42 mature trees, of which 8 were dead (19%), 29 (69%) were more than half dead and only 5 were healthy.

Mega-herbivores and other impacts

Elephants have been reported by various authors to affect recruitment. The decrease in recruitment noted in 1995 was attributed to impacts by elephant, as has been observed elsewhere in Africa and for other species of *Acacia* (Ben-Shahar 1993, 1996, Laws 1970, Barnes 2001b, 2001c, Makhabu et al. 2006). In addition to elephant, other herbivores also favour young growth and have impacts on juvenile trees (CTFT 1989, Fennessy et al. 2001). Fennessy (2004) attributes the increase in recruitment between 1995 and 2000 to favourable rainfall and flood events in the intervening years – there were well-above average floods in 1994/95 and 1999/2000 (Department of Water Affairs records, Appendix 1). During this period browsing pressure was reduced due to more reliable seasonal water sources elsewhere, and the re-expansion of elephant ranges away from the Hoanib River (Leggett et al. 2001). There has been a continuation in this trend, with average to above-average floods recorded for most years between 2001/02 and 2009/10. Since 2010/11 floods, have been below average, which explains the low numbers of seedlings and low recruitment in 2012. The current healthy population structure in the Khovarib Schlucht, where there are few elephant, illustrates the effect that elephant are having on this tree species. The suggestion made by Jacobson (1995) to encourage elephant to move from the lower Hoanib River east into the Khovarib Schlucht is not feasible due to increasing development and potential human-wildlife conflict. The river in the Khovarib Schlucht is narrow, and is used extensively by the local inhabitants to feed and water their livestock.

The Khovarib Schlucht has historically been foraged by elephant, as evidenced by some old scars on the trunks of the larger trees. However, the past damage is not as great as in the lower Hoanib River, with no current bark damage observed. Some broken

branches high in the trees were noted, but were more likely due to baboons rather than elephant, especially as the bark had also been stripped from these higher branches. Most of the juvenile trees had a typical young *F. albida* growth form, with one or two main stems, and a few lateral branches from near the ground. No marked herbivore impact on the juvenile trees was observed, whilst a number of trees appeared to have been knocked over by floods, with the majority re-sprouting. The only mortality observed in the Khovarib Schlucht was one tree that had been struck by lightning.

Elephant damage in the lower Hoanib River has historically been high, but has decreased in recent years. In the early 1980s Viljoen and Bothma (1990) recorded bark damage scars on 72% of trees observed, of which 32% (45 of 142) had greater than 20% of their bark removed. By the late 1980s Nott (1987) recorded 74% (124 of 168) trees with more than 20% damage, whilst in 2000 Fennessy (2004) recorded that only 58% of trees were damaged, and of these only 23% (333 of 1466) had damage greater than 25%. Our findings show nearly 100% of trees had old bark damage, presumably inflicted mostly in the late 1980s and 1990s. Current damage was low – at 11.5% (45 of 391 trees), and only 4.3% (17 trees) had more than 20% damage. Thus elephant impact in terms of bark damage has definitely declined over the years and may be linked to the declining elephant numbers in the river (Ramey & Brown 2016).

The current data do not show a strong link between bark usage and the presence of permanent water, unlike previous studies (Nott 1987, Viljoen & Bothma 1990, Fennessy 2004), which observed that the percentage of trees with bark damage was high nearest the Dubis wetland, decreasing westwards, with distance from permanent water. Viljoen and Bothma (1990) showed 100% utilisation at Dubis, with a marked decrease downstream to almost no utilisation at the floodplain. This was in contrast to Nott's (1987) findings round about the same time. He noted 100% of trees utilised as far downstream as 20 km, thereafter decreasing, and increasing again at the floodplain. Fennessy (2004) noted a similar trend to that found by Nott (1987), but with lower percentages of trees affected, and the increase occurring around 25-30 km downstream. Our results showed signs of 90-100% previous utilisation the entire way along that reach, but there was no link between current elephant damage and distance from Dubis. Branch breaking occurred in 84% of 1,678 trees observed by Fennessy (2004), compared with a mean of only 22±8% in 2012.

Giraffe, too, have an impact on *F. albida* in the Hoanib River. Jacobson (1995) regarded elephant as having the greater impact, while Fennessy (2004)

suggested that the vegetation was equally impacted by giraffe. Elephant cause major physical damage by bark stripping, branch and stem breaking, and uprooting trees, whilst giraffe create a distinct browse-line, as well as pruning young trees and coppice growth. The browse-line on all mature trees in the river was around 5 m, which is typical giraffe feeding height. Giraffe also cause the ‘topiary or hedging effect’ noted on all the smaller trees downstream of Dubis wetland, and absent in the Khovarib Schlucht. This pruning impact has been noted by Fennessy (2004) and other authors cited therein.

Elephant cannot generally reach as high as giraffe. Rather than browsing high parts of intact trees, they will reach up and break off a branch, which does not result in a distinct browse-line (Fennessy 2004). This was clearly noted in Namibia’s ephemeral Ugab River in December 2012, where there are no giraffe, and elephant were seen reaching above the cattle/kudu browse-line to pull off small branches (pers. obs.) (Figure 2). Therefore, it is important to look at the combined impact of all mega-fauna on *F. albida*.

The effect of floods on mature trees appears to be greater than that of elephant and giraffe. After the 1995 flood, Jacobson (1995) observed that 2.8% (18 of 638) of trees with diameters ranging from 30-190 cm were undermined by lateral channel erosion. Many of these trees were washed away, but some were merely toppled, and held in place by intact roots. These trees were subsequently impacted by elephant and giraffe, and destroyed within three months, with branches of up to 8 cm diameter being consumed. This is in contrast to the ephemeral Kuiseb River in the central Namib, where there are no elephants or giraffe, and where, when trees topple but remain rooted, they will regenerate from the fallen trunk, producing a line of new trees (pers. obs.); a phenomenon not observed in the lower Hoanib River. Fennessy (2004) noted that 6% of mature trees were uprooted after the 1999/2000 flood and there was a marked increase in mortality compared to pre-flood data. There was little evidence of flood damage in the current study.

Other factors potentially affecting the trees in the Hoanib River are human impacts as well as the smothering of trees, especially younger ones, by clambering plants, notably *Salvadora persica*, which cover a number of other species as well and prevent them from growing properly. The only evidence of tree cutting was noted in 2014, where some of the juveniles at Dubis wetland had been cut.

Mortality

Tree mortality was lower in this study than previously recorded. Jacobson (1995) noted that 31% of the 638 trees observed were dead, apparently killed by elephant, compared with only 6% dead among 238 observed by Viljoen and Bothma (1990). Most of the dead trees observed in 1995 were in the 20-40 cm category. There was no difference in mortality percentage nearer Dubis wetland and the sections westwards towards the floodplain. Neither the present study nor the previous ones found evidence of trees being uprooted by elephant, contrary to reports in other habitats (Laws 1970). The previous authors attribute this to *F. albida*’s strong tap root (CTFT 1989) since they are regularly subjected to the pressure of floodwater and debris battering their trunks, which they generally survive. Elephant pressure would be minor in comparison.

As previously stated, elephant appear to be responsible for damage to bark and breaking of branches and stems, while giraffe, and possibly other browsers, are responsible for pruning and dense cropping (Fennessy 2004). Mortality through trampling of seedlings and young trees is probably caused by the suite of herbivores in the river, not only elephant and giraffe but also oryx (*Oryx gazella*) and springbok (*Antidorcas marsupialis*). In the Khovarib Schlucht, livestock replace wild herbivores, but do not appear to have much of an impact on mortality.

The effect of mega-herbivores on regeneration poses a serious threat to the Hoanib river *F. albida* population as a whole. In the ephemeral central Kuiseb River, where there has been no elephant activity in the past century, resprouting fallen trees send down new roots and grow into new trees, creating stands of closely packed trunks (Gardiner et al. 2006, pers. obs.). In addition, coppice from damaged roots can grow up into new trees. New recruits formed have the added advantage of the deep root system of the parent tree, and are more likely to survive than are independent juveniles. In the Hoanib River, coppice shoots are severely browsed, forming short, spiny tufts, which will never grow into new trees (Figure 2). No regeneration of fallen trees was noted in the Hoanib River, which could be an issue for long-term regeneration.

Effect of boreholes

In November 2002 two boreholes were drilled in the lower Hoanib River to attract wildlife away from nearby human settlements. One was at the end of the Dubis wetland, and the other approximately 18 km downstream at the ‘President’s Borehole’ (Leggett 2006). At the time there was concern that the introduction of these permanent water-points may

have a negative impact on the trees of the lower Hoanib River. Since animals, in particular elephant, historically used the Dubis wetland, the introduction of the borehole may not have significantly affected pressure on the trees in this area. However, Leggett (2006) showed that the distribution and density of elephant did change between 1998 and 2004, with a movement away from the Dubis wetland to the area of the President's Borehole. Like Jacobson (1995), this study found very few trees within the first 10 km of Dubis, and almost no recruitment. The President's Borehole appears to have had a slight negative impact on the already low recruitment of the area, with very few juveniles and no seedlings. It does not appear to have affected the mature trees adversely, except that root coppicing was lowest here. Fennessy (2004) predicted a change in population structure in this area, and tree mortalities downstream. With few exceptions, bark damage was highest near Dubis wetland and the President's Borehole.

From 1982-1995 the elephant population remained at around 25 animals (references cited in Leggett 2006) but has declined in recent years to only 18 individuals (Ramey & Brown 2016). As a result of forage and water availability, both elephant and giraffe numbers are, on average, lower near the floodplain than nearer Dubis (Fennessy 2004), thus allowing seedling establishment and juvenile development, which in turn results in higher densities, but decreased mean heights and age structure.

CONCLUSIONS

Only the Khowarib Schlucht subpopulation had a truly healthy *F. albida* population and physical structure. The small patch of juveniles in the Dubis wetland as well as transects near the floodplain show that germination has taken place within the last five years. However, these young trees cannot adequately provide the recruitment needed for the whole lower Hoanib River. Importantly, the 2014 survey showed that as these trees increase in size they are becoming more impacted by elephants. The fact that recruitment in the areas with highest mega-herbivore activity is so low remains a concern for long-term viability, and ongoing monitoring is key.

These trees, along with the other species comprising the riparian woodlands of the lower Hoanib River, form an essential source of food and shelter for all the inhabitants of the river, and the loss of these woodlands would be a conservation and ecological disaster. The old trees are currently providing abundant shade and food, but they will not last forever, and greater recruitment is required. It is evident that germination does occur, but the young seedlings and saplings are not being allowed to

reach maturity. Since removal of mega-herbivores from the system is not an option, one recourse could be to create exclosures where seedlings can be protected until they are large enough to withstand trampling and browsing. This has been done very effectively in Amboseli National Park in Kenya, where two wires, one live one earth, at elephant eye height have been sufficient to keep out elephants in most plots, allowing the woodland to regenerate (Western & Maitumo 2004, Western in lit.). This would not keep out the smaller herbivores and would allow floodwater to flow past. Another option would be to put up bee-hives to deter elephants (Cook et al. 2018).

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Appendix 1: Flood records for the Hoanib River at Sesfontein. Courtesy of Department of Water Affairs, Windhoek, Namibia.

Hoanib River at Sesfontein.
 Catchment Area = 11,000 km²

