Gobabeb WADE Site Characterization

Desert Research Foundation of Namibia
Gobabeb Training & Research Centre

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Introduction

The Gobabeb WADE research site (23°33'S, 15°02'E) is located in the lower course of Namibia's Kuiseb River at about 400 m above sea-level (Henschel et al 2000). The Kuiseb is an ephemeral river that flows some 440 km from its catchment area in the Khomas Hochland near Windhoek down to the ocean near Walvis Bay; in its lower reaches the river divides the ancient Namib dune sea to its south from the gravel plains to its north, two of the driest environments on the planet (Huntley 1985b). At Gobabeb, mean rainfall is just 21 mm per year, although even this figure is distorted by the highly-variable character of desert precipitation (CV=122% at Gobabeb); median annual rainfall is actually just 12 mm (Henschel et al 2000). length, elevation, rainfall isohyets, all in ELAK material in library at GBB → **Anna, I couldn't find these ELAK materials; Inge says all we have here are workshop reports. Perhaps you have them in Windhoek with the materials Nadia and Carole were using?**

In the midst of this harsh environment the river serves as a "linear oasis", allowing many plants and animals to survive and even to thrive (Seely et al 1981; Theron et al 1980). People, too, depend on the Kuiseb: the commercial farmers of the river's upper reaches, Topnaar pastoralists in the lower Kuiseb, and the people of Walvis Bay, Namibia's second-most-populous city. Other cities, such as Swakopmund, and industrial projects such as the Rossing Uranium Mine and the new Langer Heinrich uranium mine, draw on the Kuiseb to some extent.

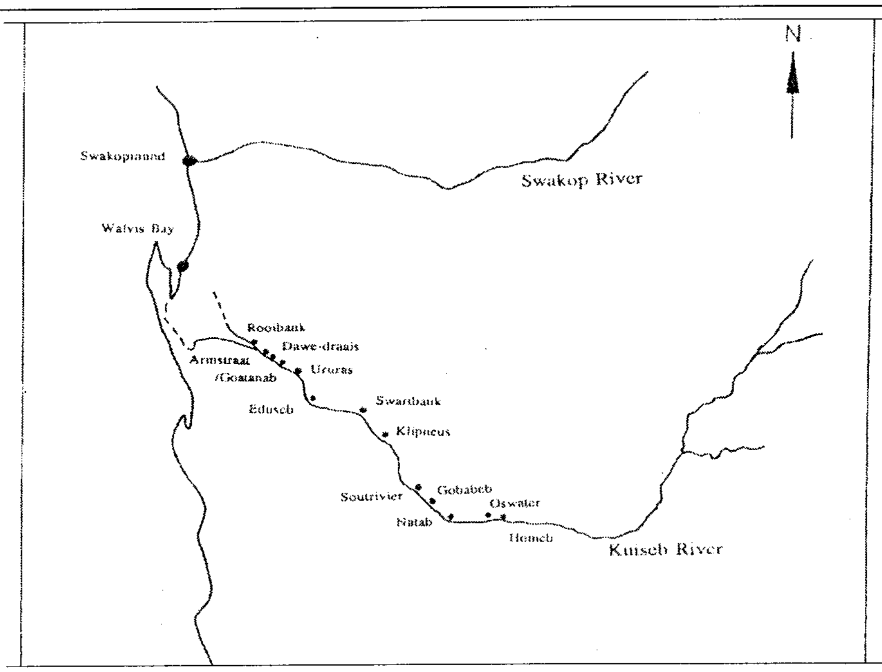

Figure 1: Shows course of lower Kuiseb and communities along it. From Van den Eynden et al 1992.

But the flow of this river is not enough to depend on: it depends entirely on extremely variable rains in the area of Windhoek, where the coefficient of variation in annual rainfall is some 30-40% (Mendelsohn et al 2002), and at Gobabeb the river generally flows for several days to a few weeks a year, although months-long flooding periods have been recorded (Henschel et al 2000; Theron et al 1980: 107). Only 16 times since 1837 has the Kuiseb actually reached the sea near Walvis Bay, and in Gobabeb's history there have been several times when the Kuiseb never even reached the station, some 55 km away from the Atlantic (Theron et al 1980: 328; Van Wyk et al 1985: 107).

Since they can depend on neither surface water nor rainwater, plants, animals, and people needing to survive in the central Namib must therefore depend on other sources of water. One of these is fogwater, which supplements rainfall to the tune of 39 mm per year. It is also highly variable, however, with a coefficient of variation of 43% (Henschel et al 2000), and for many species fog can only be depended on as an occasional supplement to surface water. Practically, then, the people, plants, and animals of the Kuiseb depend largely on floodwater seeping into the sand aquifer of the riverbed each year. Over the years this has built up groundwater reserves of about $1500x10^6$ m^3; the precise extent of recharge is unknown—hence the importance of the WADE project—although sustainable abstraction rates have been estimated at 5×10^6 m^3 yr^{-1} (Lenz et al 1995).

This report aims to provide needed background on the geomorphology, groundwater status, aquifers, ecology, and socioeconomics of the Kuiseb; specifically the lower Kuiseb and the area immediately around the study site at Gobabeb. Much of the information here has been assembled from research that has been carried on at the Gobabeb Training and Research Centre since 1962, although specific research was also carried out during mid- to late-2005 into the geomorphic setting, plant community distribution and sediment characteristics.[1]

I. Geomorphic Setting

As the Kuiseb makes its way from the Khomas Hochland down to the coast, its geomorphology changes considerably. While the river begins in a highly rugged, hilly area, once the Kuiseb reaches the escarpment its course runs through a steep-walled canyon (Bate & Walker 1993: 85). The gorge is narrow—sometimes less than 50 m across—but by the time the river passes Gobabeb the walls of the canyon have almost disappeared and the river is essentially flowing across open desert, allowing its course to be much broader. At Gobabeb the river is generally less than a kilometre across; this broadens to two kilometres and more by the time the river reaches the coast. Figure 1 broadly illustrates the change that takes place between the canyon and the delta; Gobabeb's geomorphology falls roughly into the middle class—although, as we will see, transects taken at Gobabeb reveal a somewhat more complicated profile than Figure 1 suggests. As Huntley (1985b) notes, in this lower section of the river, the sandy river bed is divided into compartments separated by intrusions of bedrock, which occur at Narob (some 10 km downstream of Gobabeb), Swartbank, Rooibank, and Mile 16 (see Figure 1); within these compartments the river is filled with sand and alluvium "bounded on the northern side by impervious bedrock" (13). The southern side of the river is generally abutted by dunes, although there are also rock formations beneath the dunes.

There is a dynamic relationship between the dunes of the Namib and the river course: each year powerful southwesterly winds move the dunes northwards towards the gravel plains, and each year their progress across the Kuiseb is wiped out by the flood. These floods can lead to dramatic changes in the river's course if enough water flows to shift a large, obstructing sand dune, but the dunes also move fast enough that long dry periods can allow the river to be reshaped by the sand (Seely et al 1981). Three separate multi-year studies of dune movement have placed the speed at which dunes move at between 1.2 m yr^{-1} and 3-4 m yr^{-1}, which means that we would expect the dunes to completely block the river were the Kuiseb to experience several decades without flooding (Mizuno 2005; Ward & Brunn 1985; Seely et al 1981).

Such a dramatic change anytime soon is unlikely, however; perhaps more interesting is the way in which sand movement can affect short-term topography and vegetation distribution. Mizuno (2005) has speculated that the deposition of large amounts of sand by floods on the banks of the main channel and over lower fluvial terraces is responsible for tree death (see section II.2), while small

1. In particular, four students from the Polytechnic of Namibia spent four months working on studies into the Kuiseb's vegetation with the specific goal of integrating their results into this report. Where appropriate their work is cited; copies of their reports are available on request from the DRFN library.

sand dunes in the riverbed (between lower and middle terraces) are caused by accumulation of wind- and flood-borne sand in forest undergrowth, particularly the densely-packed trunks of *Salvadora persica* (Mizuno & Yamagata 2005).

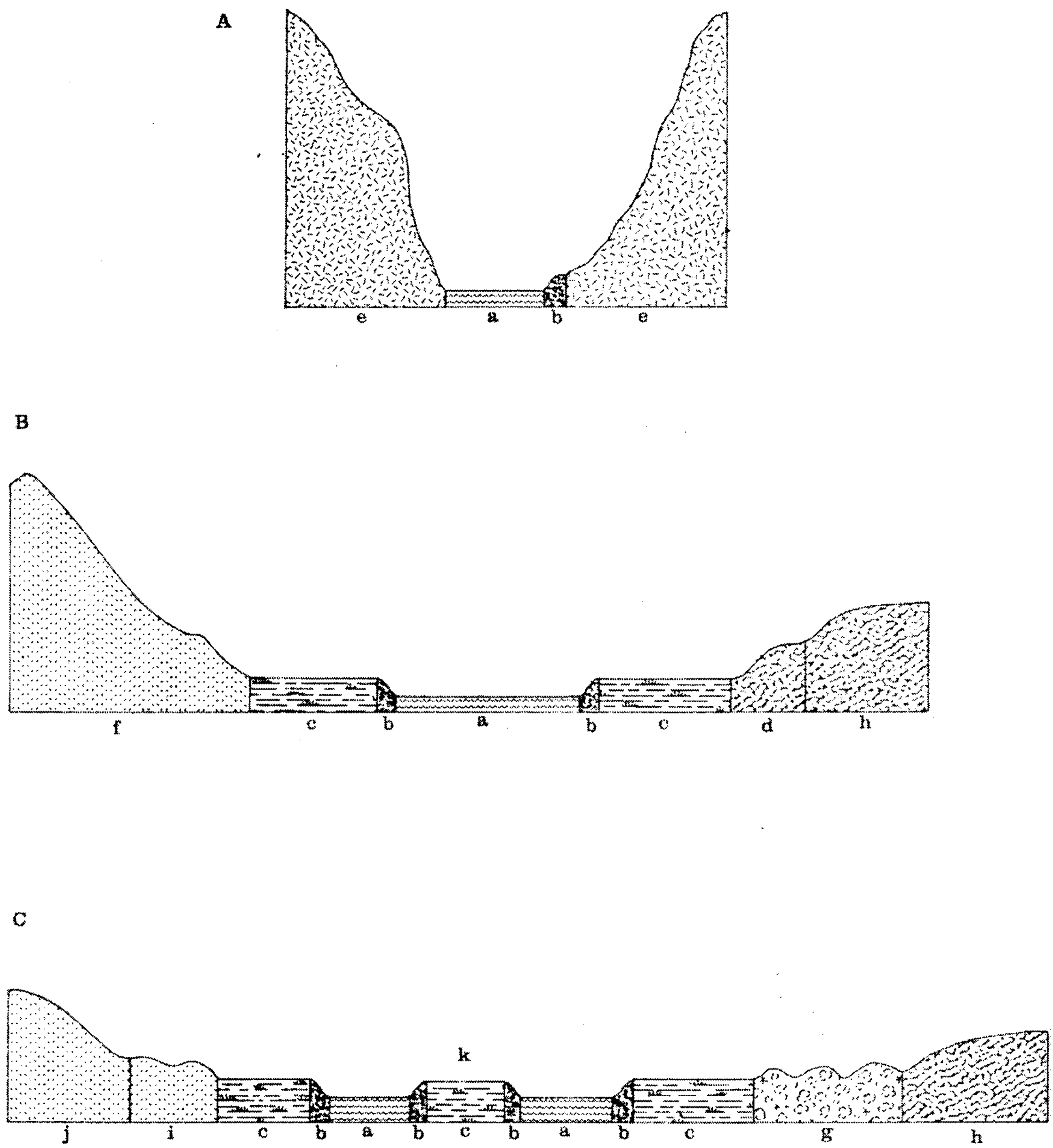

Figure 2: Diagrammatic presentation of cross-sections through the Kuiseb River: A = Nareb to Homeb; B = Homeb to Swartbank; C = Swartbank to Rooibank; a = river-bed; b = embankment; c = floodplain; d = terrace; e = cliffs/outcrops; f = steep, high dune; g = knob dunes; h = gravel plains i = small dunes; j= less steep, high dune; k = island. Adapted from Theron et al 1981.

Several studies have recently been undertaken showing profiles across the Kuiseb. Figure 3 shows a topographic profile of the Kuiseb in the immediate vicinity of Gobabeb. There is a clearly defined active river channel (marked as "present river bed"), as well as a number of fluvial terraces representing remnants of older, broader river channels. In a recent study on landform development in the Kuiseb near Gobabeb, Yamagata and Mizuno (2005) argue that the river valley near Gobabeb has four fluvial terraces, which they classify as "Lower", "Middle 1", "Middle 2", and "Higher" terraces, although these broadly correspond to the terraces listed in Figure 3. Figure 5 shows the locations of ten transects taken near Gobabeb in July-August 2005. These transect profiles, which were taken using a simple dumpy level, are included in Appendix A. All transects show a relatively flat profile with clearly defined active river channels and several fluvial terraces, although the presence of some features, such as the knob dunes found in Figure 3, is only occasional.

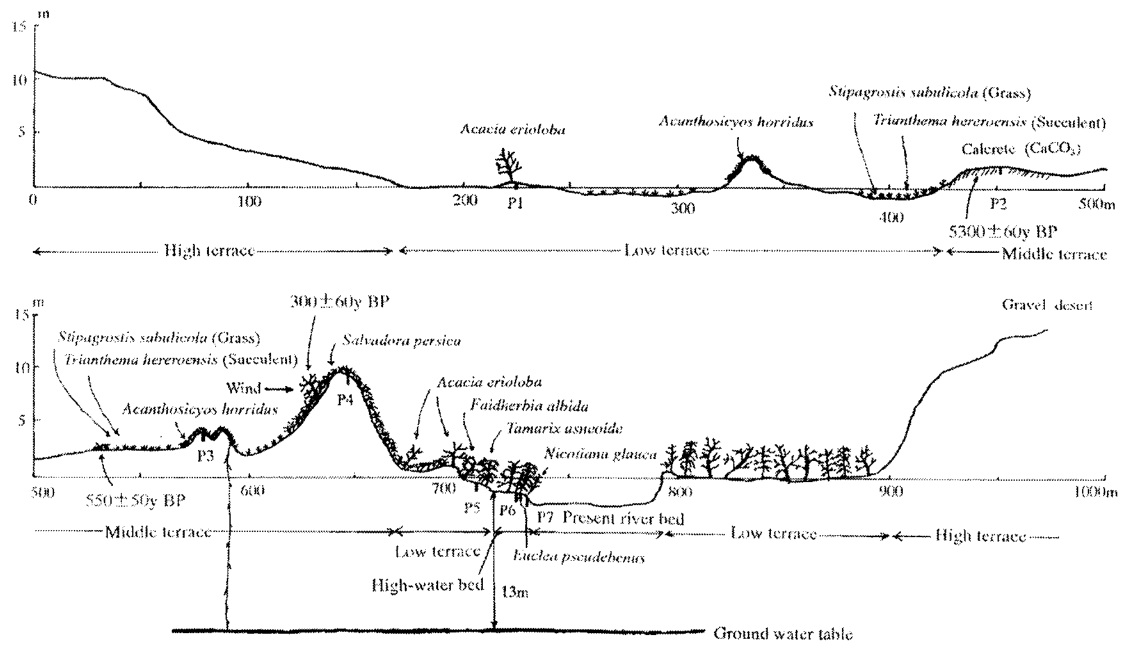

Figure 3: Shows a topographic profile taken near Gobabeb (see Figure 4, below), showing three terraces, as well as accompanying vegetation. Note that inclusion of *T. hereroensis* may be a mistake; this species is normally not found in the river (Robinson 1976). P1-P7 represent points at which soil profiles were taken. From Mizuno & Yamagata 2005.

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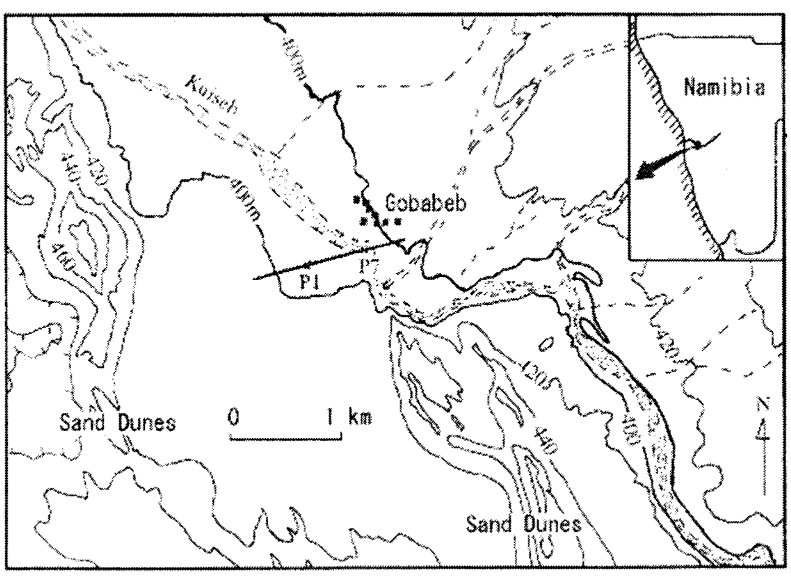


Figure 4: Shows the location of transect in Figure 3, as well as soil profiles in Figure 7. From Mizuno & Yamagata 2005.

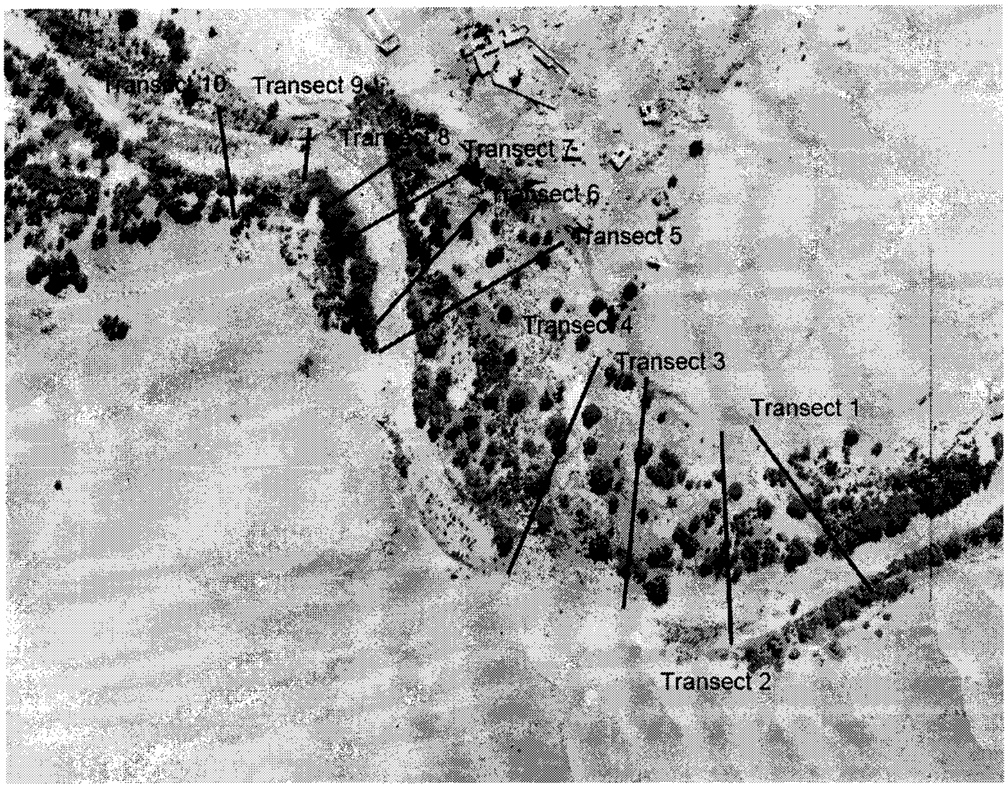


Figure 5: Locations of ten transects at Gobabeb taken in 2005.

Figure 6 shows the areas covered by the main channel, islands, secondary channels (where water is only likely to flow in years of unusually high flow, but which are still largely free of vegetation), and principal floodplains in the section of the Kuiseb immediately adjacent to Gobabeb.

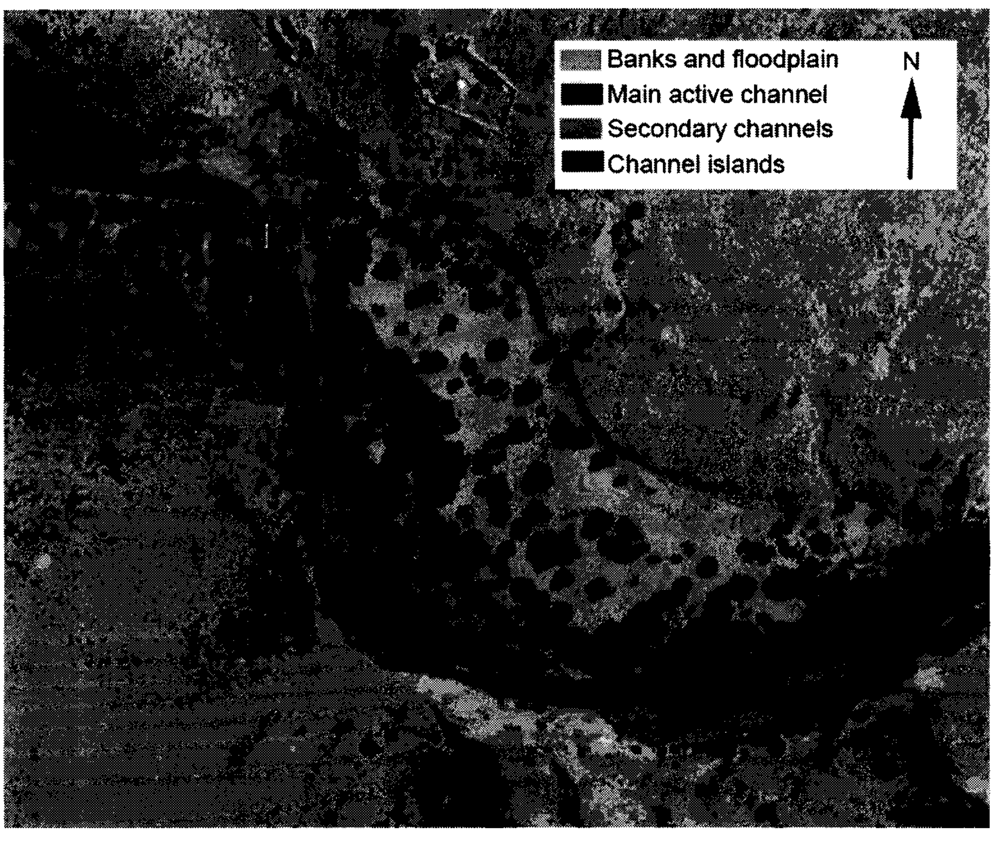


Figure 6: Active river channel, floodplains, islands, and secondary channels adjacent to Gobabeb.

II. Sediment Characterisation

II.1. Texture Analyis Study

Sediment sampling for texture analysis, i.e grain diameter, was done at three of the transects in Figure 5. A detailed report of this analysis follows. Useful studies have been done on this in the past; in their excellent summary report on Kuiseb sand dynamics, Ward & Brunn (1985), for instance, reveal that some 40-50% of the sand in the riverbed is dune-derived.

II.1.1 Study Area

Seven samples were taken at Transect 9, eleven samples approximately 300 m up river at Transect 5 and ten samples approximately 400 m further up river at Transect 2. The three samples shall be referred to as T 9, T 5 and T 2 respectively.

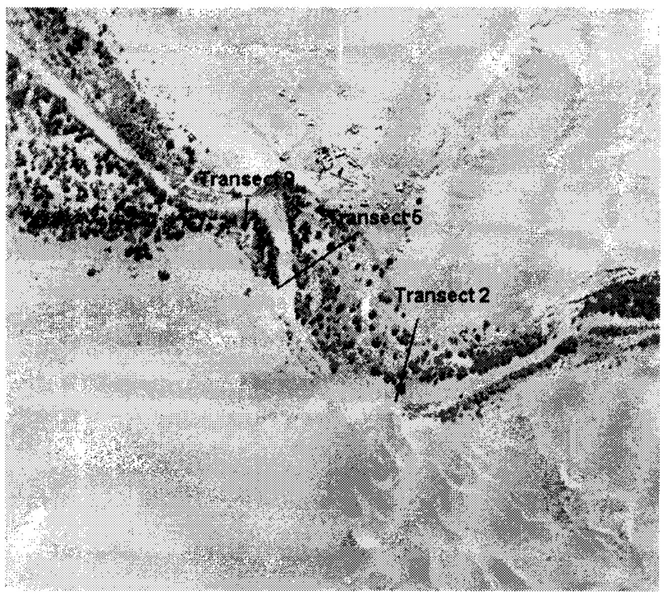


Figure 7: Study area with transects.

The transects extend over the whole width of the riverbed, i.e. the flooded area during a flood event, with samples taken at greater proximity to one another within the main river channel due to more extensive flooding at this point.

Due to the fact that the riverbed is very narrow at T1 as a result of an obstructing rock outcrop on the northern side, the main river channel takes up almost the entire width of the riverbed; therefore samples were taken at greater proximity to one another at this point compared to the other transects.

II.1.2. Methods

The sampling was done using an auger at a depth of approximately 35 cm. This depth was considered appropriate, considering that the granulometry should be described regarding the hydrological and hydraulic properties and the sediments should therefore consist mainly of fluvial deposits and not of recent aeolian deposits. After test measurements in the riverbed showed no moist sediment even at a depth of almost 120 cm (the whole length of the available auger), 35 cm was for this reason also considered appropriate.

Each sample was then weighed and subsequently analysed according to the USDA system, which separates texture into four major texture classes: **gravel** (coarse fragments greater than 2 mm in diameter), **sand** (2 mm to 0.063 mm in diameter), **silt** (0.063 mm to 0.0039 or 0.002 mm in diameter) and **clay** (less than 0.0039 or 0.002 mm in diameter). The silt-clay boundary varies according to different sources (see Table 1). Detritus, consisting mainly of small leaves and twigs, was also collected and weighed, while the sediment loss as a result of sifting was calculated.

Table 1: Sediment characterization table. From Anderson 2005.

Phi	Grade		Mm.	Microns
	Boulder	GRAVEL		
-8			256	256,000
	Cobble			
-6			64	64,000
	Pebble			
-2			4	4,000
	Granule			
-1			2	2,000
	Very Coarse	SAND		
0			1	1,000
	Coarse			
1			0.50	500
	Medium			
2			0.25	250
	Fine			
3			0.125	125
	Very Fine			
4			0.0625	62.5
	Coarse	SILT		
5			0.0313	31.3
	Medium			
6			0.0156	15.6
	Fine			
7			0.0078	7.8
	Very Fine			
8			0.0039	3.9*
	Clay			

* Some use 2 microns (9ϕ) as the silt-clay boundary

Sieves with the following mesh sizes were used: 2000, 1000, 560, 250, 125 and 63 microns. The texture classes can be seen in Table 2, below:

Table 2: Texture classes used in Gobabeb study

Texture classes	GRAVEL	SAND very coarse	SAND coarse	SAND medium	SAND fine	SAND very fine	SILT
[microns]	>2000	2000>x>1000	1000<x<560	560<x<250	250<x<125	125<x<63	x<63

Using this standard array of sieves, sediment greater than 2 mm and less than 0.063 mm could only be generally classified as gravel and silt/clay respectively and not separated into sub-classes. However, sand could be separated into five classes and classified as very coarse, coarse, medium, fine and very fine.

II.1.3. Results and Discussion

II.1.3.1 Texture comparison of Transects 1, 2, 3

The arithmetic mean of the percentage of the measured texture classes is shown per transect in the table below (Table 3): (Note: sub-classes will be described at a later stage)

The map below (Figure 9) shows the location of the transects and sample sites in the riverbed and the measured texture classes in percentage:

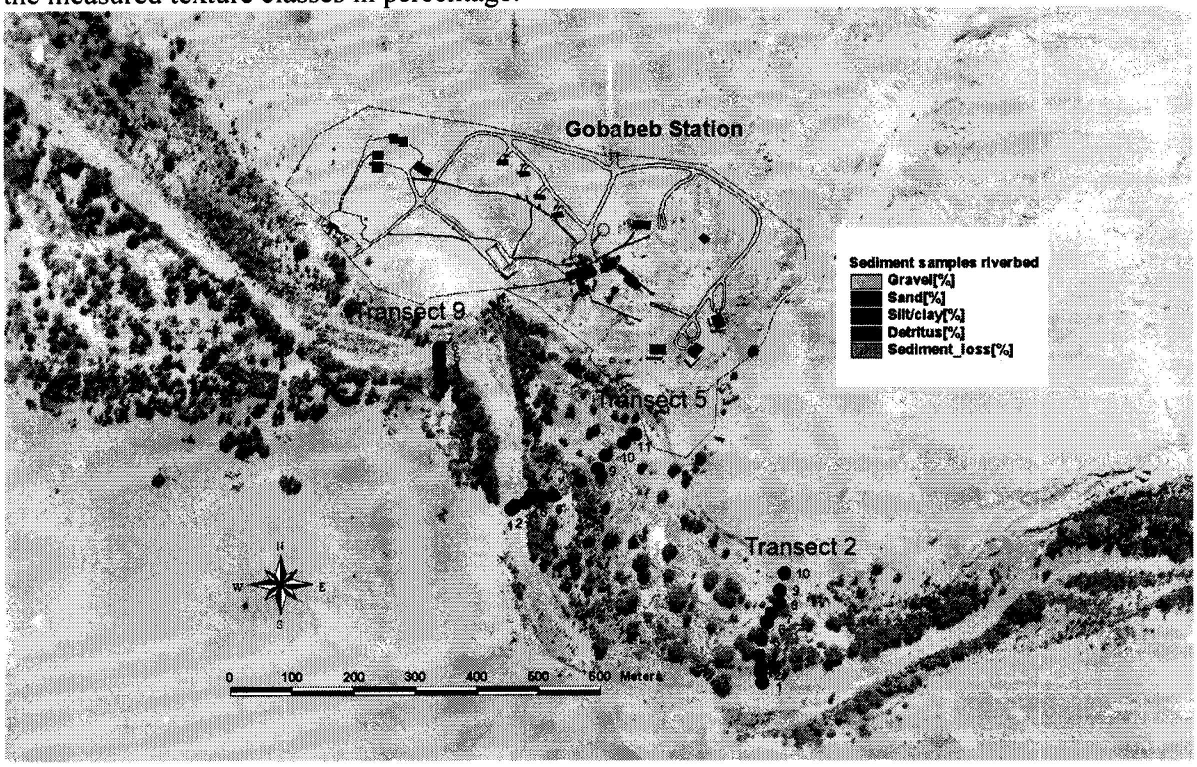


Figure 9: Transects 1, 2 and 3 with samples.

? Are we supposed to see something from this

II.1.3.2 Texture comparison of samples within each transect

Transect 9

The texture classes for each sample of T 9 are shown in Table 4 and in the corresponding graphs (Figure 10):

Table 4: Percentage of sediment [%] per texture class [microns], detritus and sediment loss. 'x' represents the sediment per class.

	GRAVEL [%]	SAND [%] very coarse	SAND [%] coarse	SAND [%] medium	SAND [%] fine	SAND [%] very fine	SILT/ CLAY [%]	Detritus [%]	Sediment loss [%]
sample no	>2000	2000>x>1000	1000<x<560	560<x<250	250<x<125	125<x<63	x<63		
1	0.00	0.00	0.98	28.76	43.04	20.01	4.10	2.67	0.46
2	0.00	0.00	3.11	34.05	45.64	13.39	2.87	0.27	0.68
3	0.00	0.00	0.10	11.80	59.08	23.93	4.22	0.82	0.06
4	0.00	0.00	2.93	6.58	43.61	34.80	10.99	0.67	0.41
5	0.00	0.00	1.33	8.78	53.68	27.58	8.16	0.39	0.08
6	0.00	0.00	2.08	30.50	49.75	14.05	2.68	0.11	0.83
7	0.00	0.00	0.86	39.87	46.66	11.17	1.13	0.24	0.08

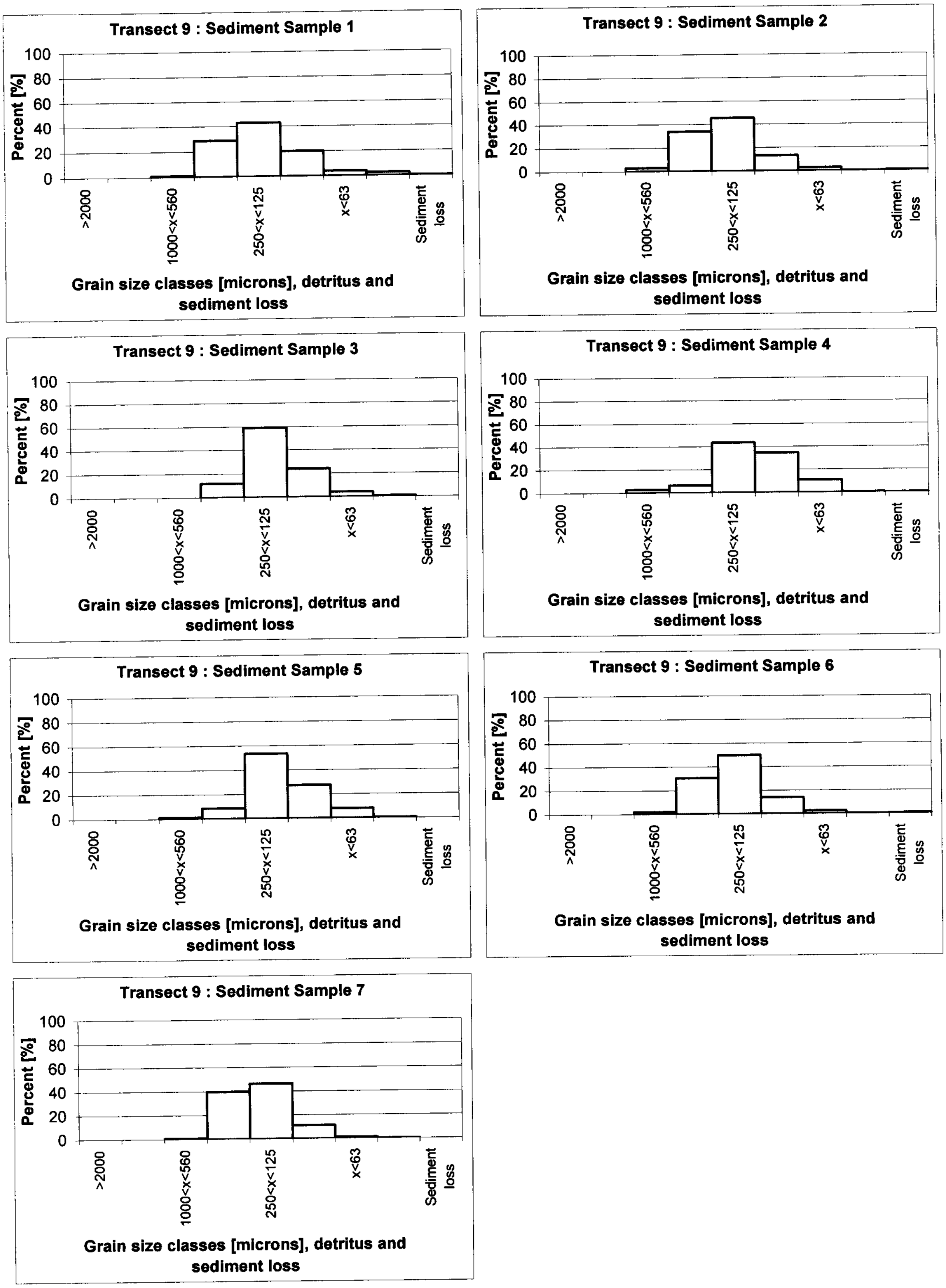


Figure 10: Percentage of sediment [%] per texture class [microns], detritus and sediment loss. 'x' represents the sediment per class.

As with the other transects, less detritus was found in the main river channel (samples 5, 6 and 7) and in areas with little vegetation. Sample 1 has a high amount of detritus, originating most probably from the Salvadora bushes (*Salvadora persica*) next to the sample site (Figure 11).

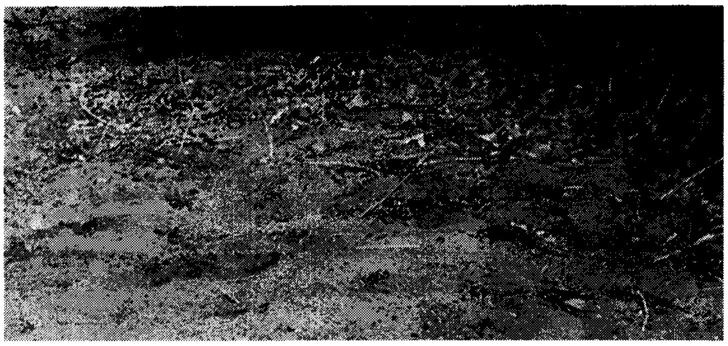


Figure 11: Detritus from *S. persica* at Sample 1 (K. Wouters, 2005).

As mentioned before, T 9 contains greater amounts of silt/clay (< 63 microns) than the other transects. In addition to that, Table 4 and the graphs (Figure 10) show that the greatest percentage of sand falls into the fine sand category (125 – 250 microns) and a relatively large percentage into the very fine sand category (63 – 125 microns) compared to the other transects.

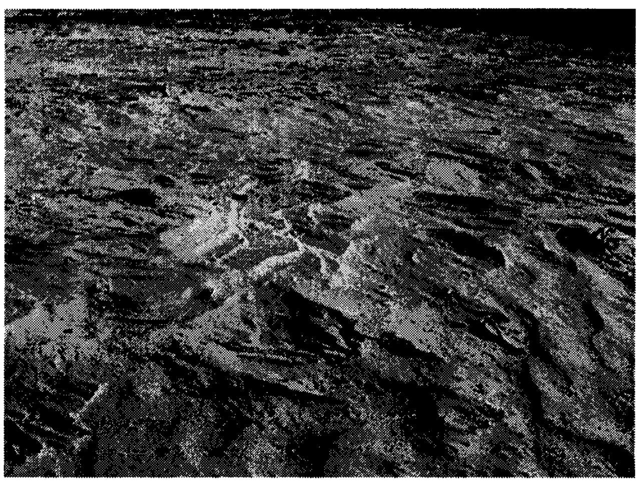


Figure 12: Silt/Clay deposits in the main river channel of T 9 *(Source: K. Wouters, 2005)*

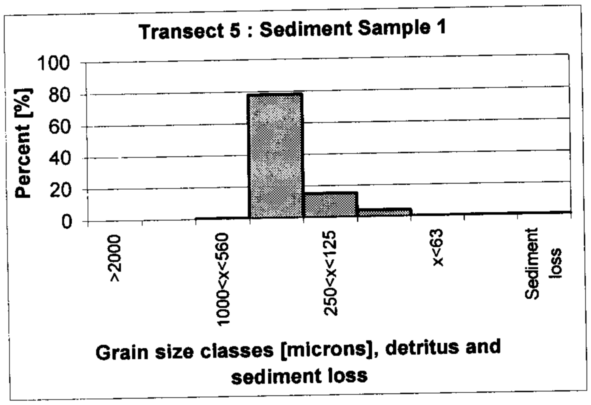
Transect 5

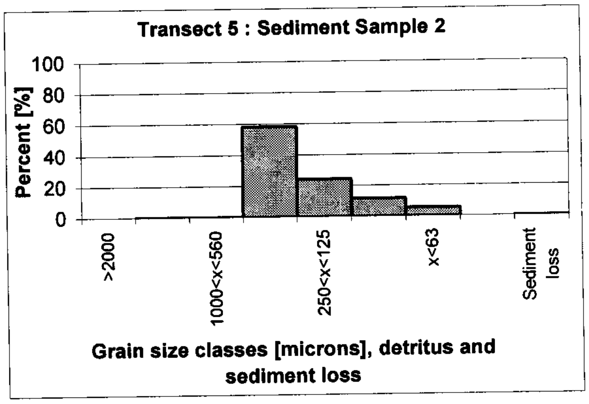
The texture classes for each sample of T 5 are shown in Table 5 and in the corresponding graphs (Figure 13):

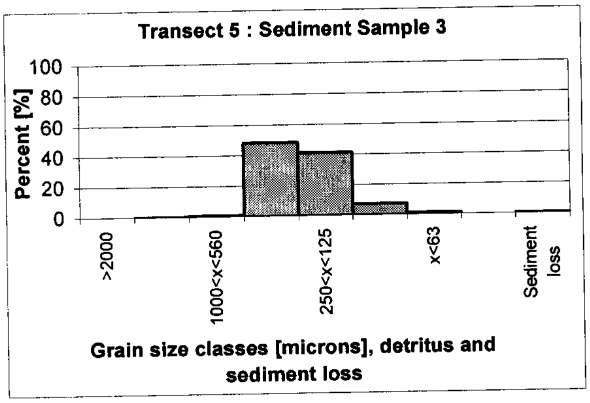
Table 5: Percentage of sediment [%] per texture class [microns], detritus and sediment loss. 'x' represents the sediment per class.

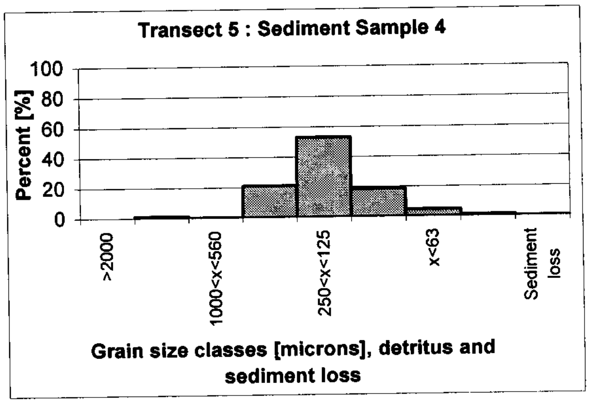
	GRAVEL[%] (Granules)	SAND [%] very coarse	SAND [%] coarse	SAND [%] medium	SAND [%] fine	SAND [%] very fine	SILT/ CLAY [%]	Detritus [%]	Sediment loss [%]
sample no	>2000	2000>x>1000	1000<x<560	560<x<250	250<x<125	125<x<63	x<63		
1	0.07	0.03	0.50	78.07	15.35	4.34	0.43	0.61	0.60
2	0.00	0.16	0.23	58.38	24.23	11.48	5.41	0.00	0.12
3	0.00	0.16	0.72	48.48	41.55	7.31	1.26	0.04	0.47
4	0.00	1.02	0.28	21.06	53.20	18.71	4.58	0.95	0.20

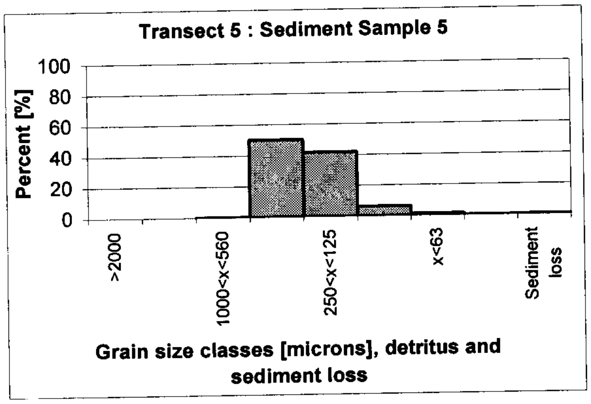
5	0.00	0.00	0.17	50.20	41.81	6.18	1.09	0.22	0.33
6	0.00	0.03	0.01	30.18	56.13	11.23	1.93	0.02	0.47
7	0.00	0.00	0.20	4.61	57.02	30.65	6.41	0.35	0.76
8	0.00	0.04	0.13	28.20	59.84	10.49	1.04	0.08	0.18
9	0.00	0.00	0.04	27.96	59.07	11.22	1.52	0.05	0.15
10	0.02	0.05	0.23	57.41	35.91	5.68	0.56	0.00	0.15
11	0.00	0.06	0.07	31.47	53.25	12.65	1.66	0.08	0.76

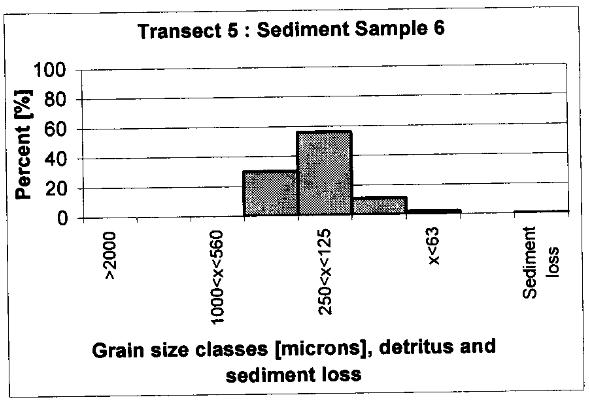












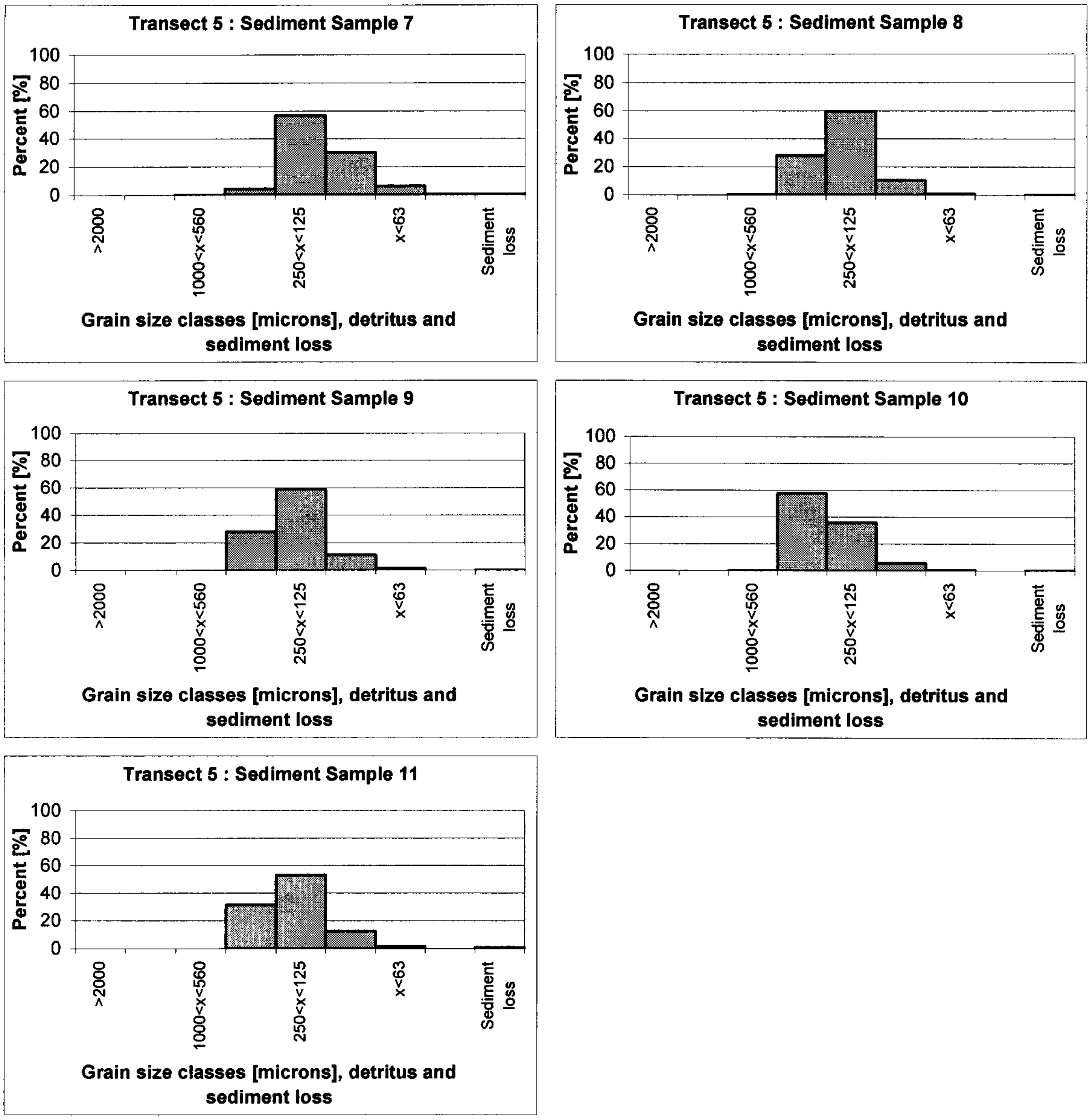


Figure 13: Percentage of sediment [%] per texture class [microns], detritus and sediment loss. 'x' represents the sediment per class. Transect 5

Unlike T 9, the samples of T 5 show a high percentage of sediment in the fine as well as in the medium sand grain category.

As with the other transects, less detritus was found in the main river channel (samples 2 and 3) and in areas with little vegetation.

Sample 1 was taken at the base of the dunes (Figure 13–Sample 1, and Figure 14) and has the highest amount of medium sand grains compared to the other samples, which confirms that dune sand consists of larger grains than riverbed sediment (Lancaster 1981; Ward & Brunn 1985).

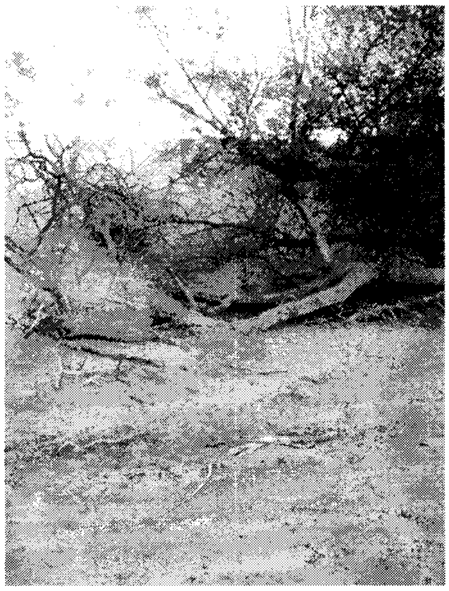


Figure 14: Sample 1 from T 5 taken at base of dune (K. Wouters, 2005).

Sample 3 was the only sample of all transects to contain moist sediment, making it the only sample with comparatively high moisture content. The sediment crumbled when touched.

Figure 15: Moist sediment of sample 3 from T 5 (K. Wouters, 2005).

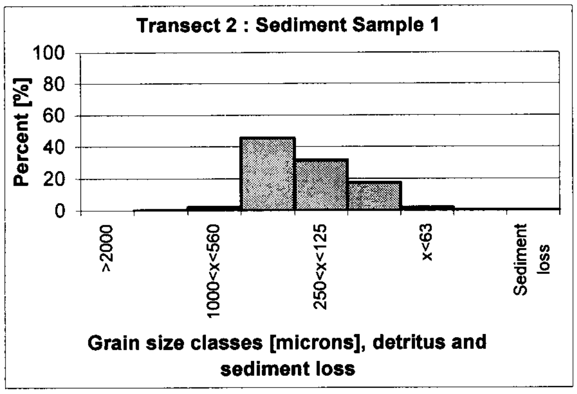
Transect 2

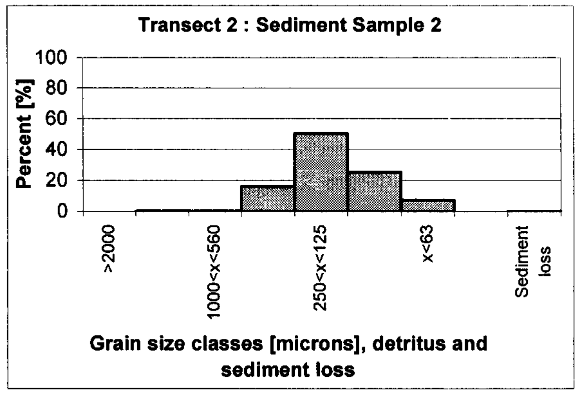
The texture classes for each sample of T 2 are shown in Table 6 and in the corresponding graphs (Figure 16):

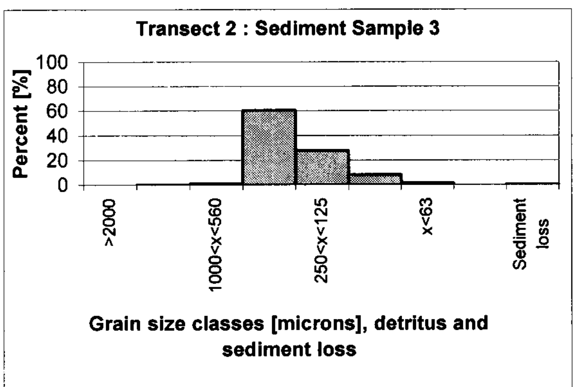
Table 6: Percentage of sediment [%] per texture class [microns], detritus and sediment loss. 'x' represents the sediment per class.

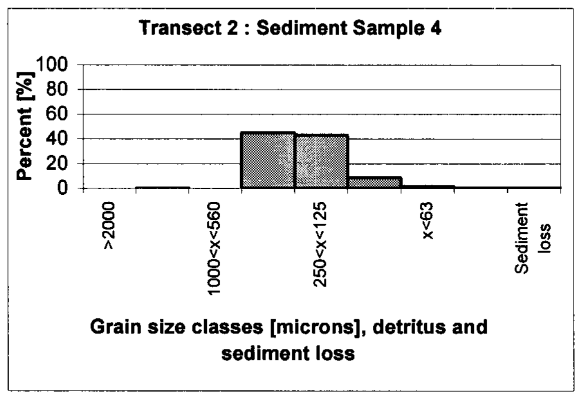
	GRAVEL[%] (Granules)	SAND [%] very coarse	SAND [%] coarse	SAND [%] medium	SAND [%] fine	SAND [%] very fine	SILT/ CLAY [%]	Detritus [%]	Sediment loss [%]
sample no	>2000	2000>x>1000	1000<x<560	560<x<250	250<x<125	125<x<63	x<63		
1	0.00	0.11	2.35	45.71	31.62	17.55	2.06	0.30	0.31
2	0.05	0.21	0.19	16.15	50.47	25.48	7.20	0.06	0.18

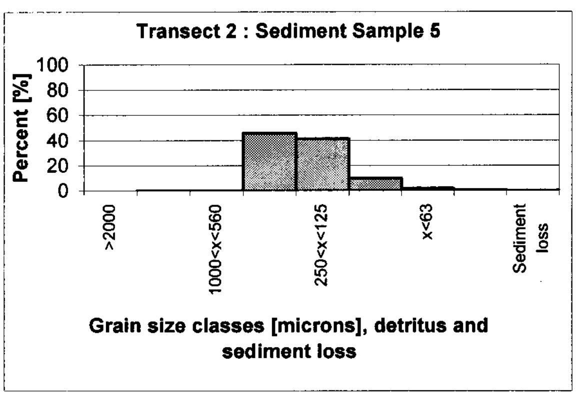
3	0.01	0.30	0.87	60.49	28.08	8.22	1.47	0.00	0.56
4	0.00	0.15	0.11	45.15	43.29	8.75	1.61	0.50	0.44
5	0.01	0.17	0.17	45.76	41.45	10.09	1.83	0.39	0.13
6	0.03	0.17	0.38	35.79	44.23	14.64	3.54	0.78	0.43
7	0.08	0.24	0.96	82.69	11.80	2.52	0.43	0.98	0.53
8	0.00	0.14	2.04	84.76	8.29	3.07	0.72	0.72	0.27
9	0.63	2.61	47.04	41.14	7.70	0.70	0.07	0.00	0.10
10	0.29	0.23	13.92	75.90	8.85	0.76	0.04	0.00	0.02

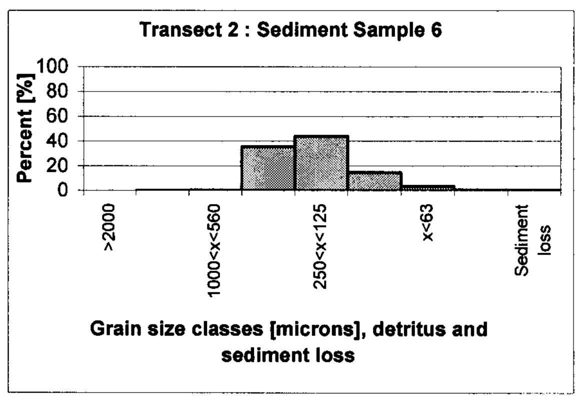


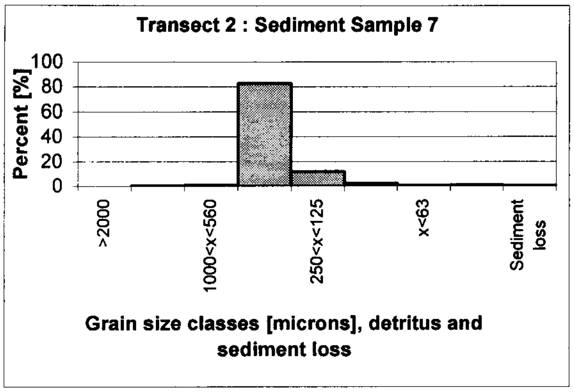


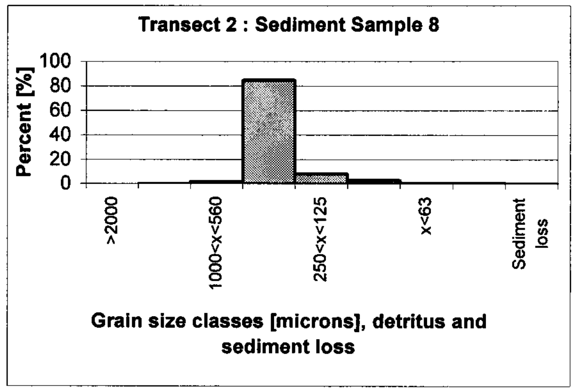


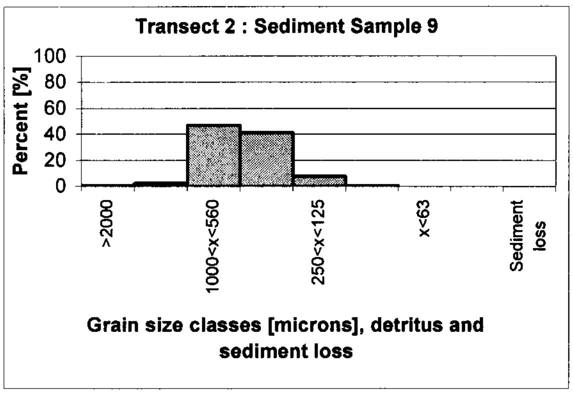












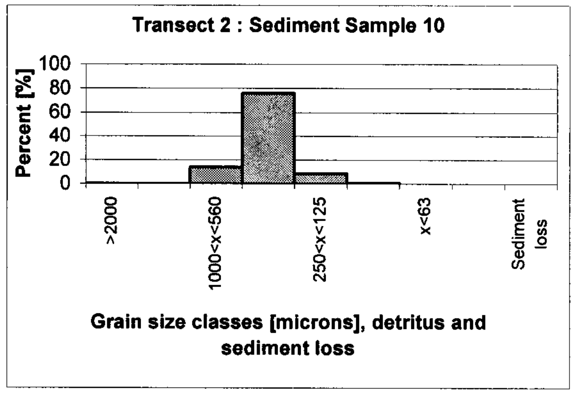


Figure 16: Percentage of sediment [%] per texture class [microns], detritus and sediment loss. 'x' represents the sediment per class.

Compared to T 9 and T 5, the samples of T 2 contain on average a higher percentage of medium sand grains than fine sand or silt/clay (Figure 17), with the exception of Sample 2, which comprises more silt/clay (Figure 18).

Figure 17: Sandy sediment along T 2 (K. Wouters, 2005).

Figure 18: Silt/Clay deposits at Sample 2 in the main river channel of T 2 (K. Wouters, 2005).

While T 9 and T 5 border on rock outcrops on the northern side and are situated at a greater distance to the gravel plains, the northern side of T 2 borders directly on the gravel plains with a gradual transition and relatively little difference in altitude. This could explain why samples 7, 8 and 10 have a larger percentage of medium sand (250 – 560 microns) and samples 9 and 10 a larger percentage of coarse sand (560 to 1000 microns), compared to the other samples. These could possibly be fluvial or aeolian deposits originating from the gravel plains. What sort of Aeolian materials from the gravel plains? Not clear. **[Honestly--I have no idea. Kristin Wouters wrote this whole section. Shall I ditch this paragraph?]**

As with the other transects, less detritus was found in the main river channel (samples 2 and 3) and in areas with little vegetation.

II.1.4. Conclusion

The sediment in the riverbed contains very little detritus, making it difficult to form an organic layer. It therefore has almost no A and B horizon; the solum or true soil. Most of the sediment forms the C-horizon, also called parent material, as it shows little biological activity or soil development other than mineral decomposition of rock.

It has been shown that there are variations in the texture classes between and within the transects, depending on the width of the riverbed and main river channel as well as on geomorphologic areas bordering directly on the riverbed, e.g dunes, rock outcrops, gravel plains.

II.2. Water holding capacity of sediment

The water holding capacity of the sediment was not measured specifically for this report due to lack of necessary equipment. However, since all the samples at the depth of 35 cm fall into the category of a very sandy soil (greater than 80 % sand), they could potentially hold 8 to 12 % water depending on the size of the sand particles (IALC 2001).

Sandy soil on the low terrace in the *Acacia erioloba*-dominated forest has a water content by volume of about 4 – 10 % up to a depth of 100 cm. In depths of 100 – 150 cm, where the sediment consists of sandy loam mixed with humus, 12 – 35 % water content by volume is measured. Sandy soil on the middle terrace, supporting *Acanthosicyos horridus* and *Salvadora persica* and about 2 m higher in altitude than the low terrace, has a water content by volume of only about 3 – 4 %. A soil profile along the transect by Mizuno and Yamagata (2005, see Figure 3) with water content by volume and different plant species is shown below:

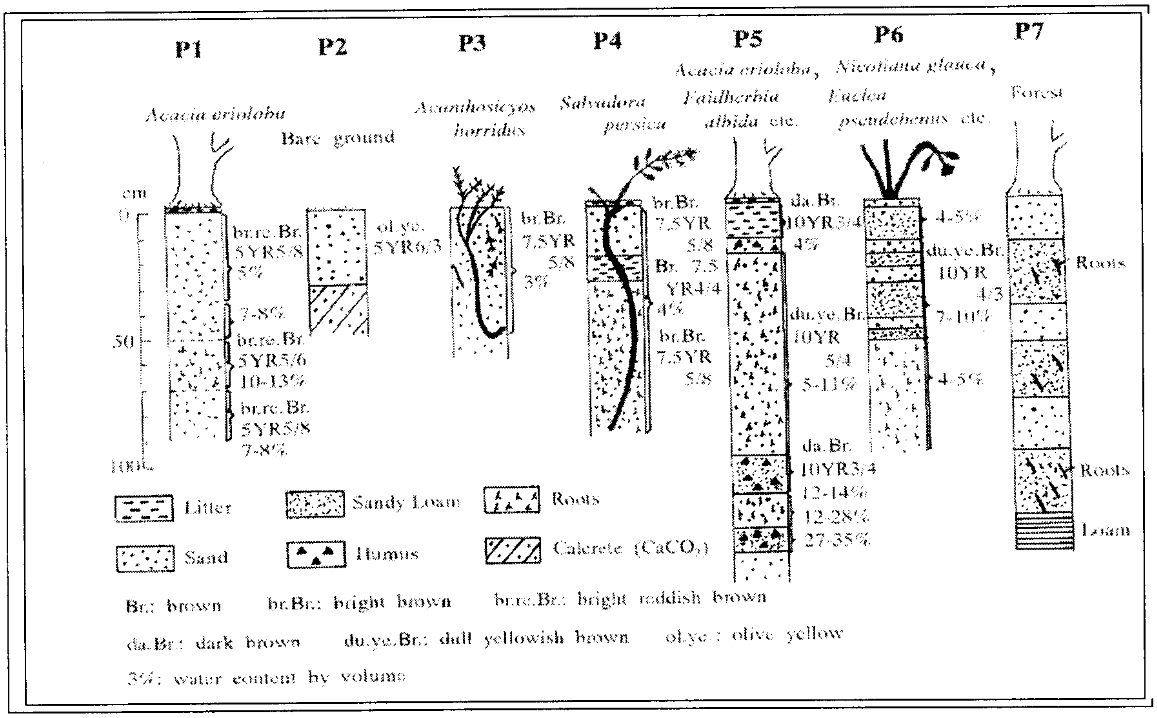


Figure 19: Soil profile of plots depicting soil water content by volume. From Mizuno & Yamagata 2005.

X-ray diffraction by Yamagata & Mizuno (2005) of samples taken in the Kuiseb revealed a calcrete duricrust on the middle terrace, and a gypcrete duricrust on the high terrace. They also found no calcite or gypsum deposits in the floodplain; they did find clay mineral deposits such as chlorite and illite resulting from rock weathering.

II. 3. Environmental change in relation to tree death

In a further study by Mizuno (2005), the cause of tree death in the riverbed near Gobabeb was analysed in relation to sediment. It is suggested that the cause of tree death is linked to sand redeposition from flooding by which advancing sand dunes are eroded and the sand is subsequently deposited downstream, building up along tree trunks. Figure 20 shows the topography with distribution and health state of trees near Gobabeb. The rate of sand advance measured at point K is 120-145 cm/year, which, as was mentioned in section I, is slower than that measured in other studies. Note, however, that trees such as *Faidherbia albida* and *Acacia erioloba* do not impede sand movement nearly as much as the shrublike *Salvadora persica*; herbaceous species such as *Stipagrostis sabulicola* seem to cause the most sand accumulation (Ward & Brunn 1985). **[Mary, you asked about Ward & Brunn tree depth—this is all they had on sand accumulation that I could find.]**

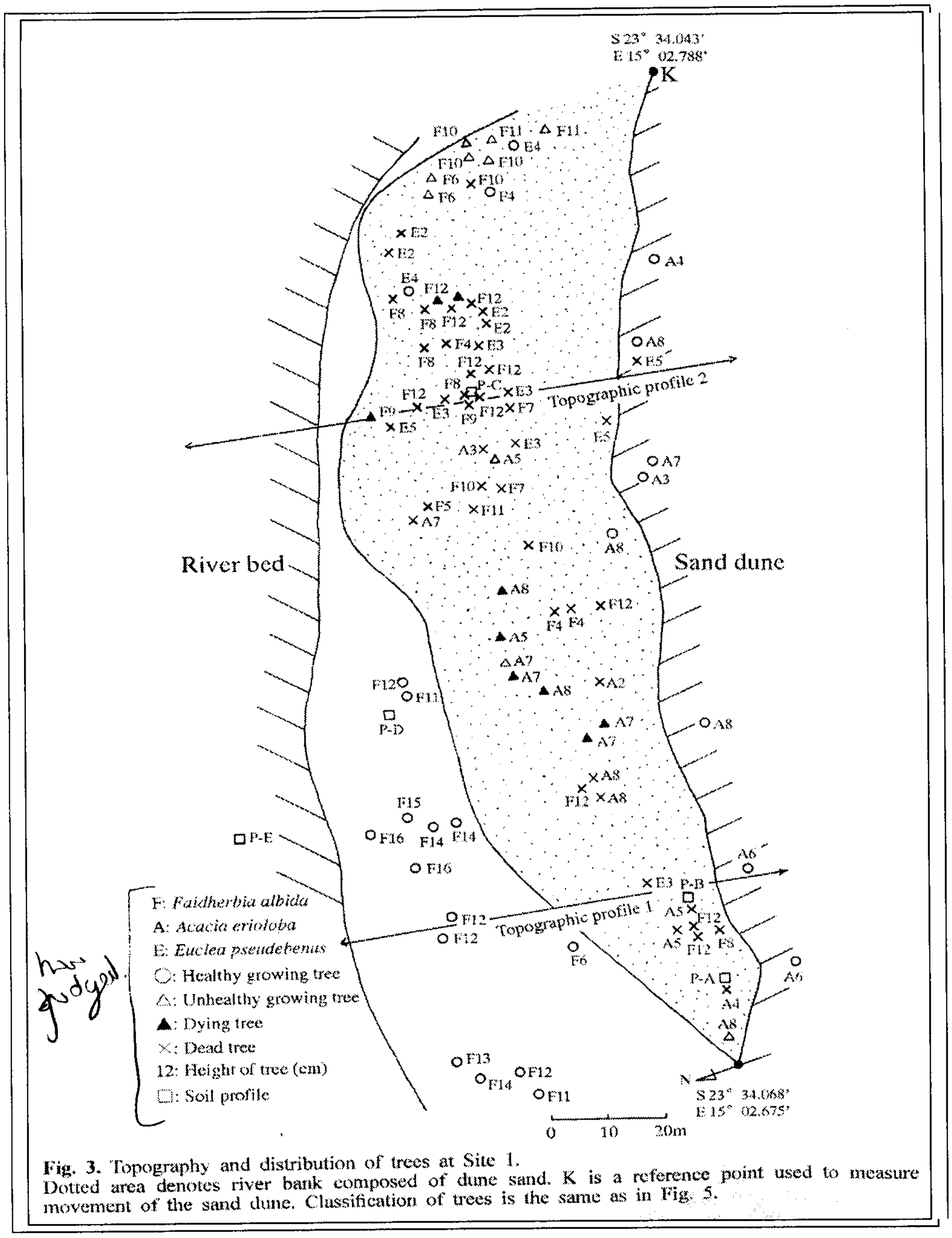


Fig. 3. Topography and distribution of trees at Site 1.
Dotted area denotes river bank composed of dune sand. K is a reference point used to measure movement of the sand dune. Classification of trees is the same as in Fig. 5.

Figure 20: Topography with distribution and health state of trees near Gobabeb. From Mizuno 2005.

A greater number of dead or dying trees can be found on the river bank composed of dune sand (dotted area) than elsewhere on the river bank (Figure 20). Soil colour is used as an index of its origin. The upper soil of the forest along the river is dull yellowish-brown (10YR5/3, 10 YR 5/4, 10 YR4/3), the sand dunes are bright reddish-brown (5YR5/6), orange or dull brown (7.5YR5/4). Different soil profiles distributed on the river bank (Figure 20) are depicted with water content by volume and soil colour in Figure 21.

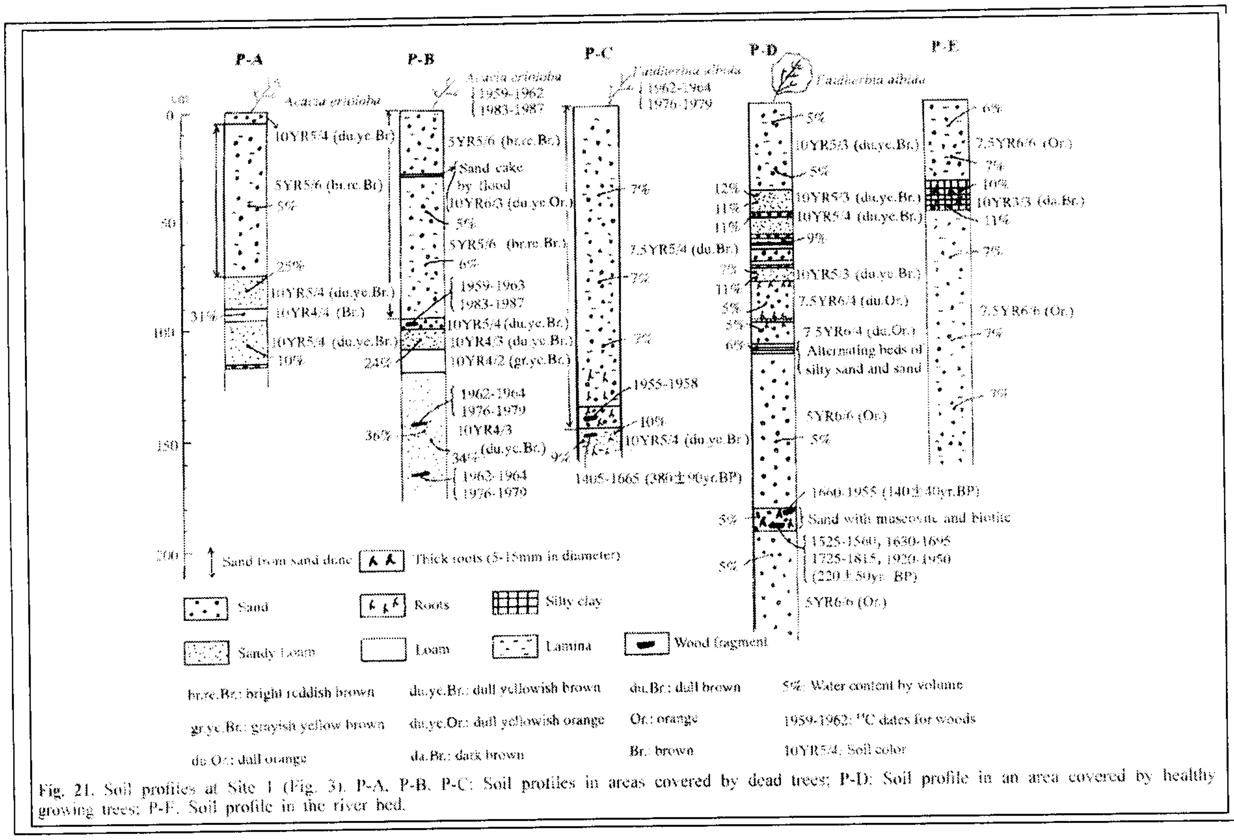


Figure 21: Soil profiles P-A, P-B, P-C, P-D and P-E near Gobabeb. From Mizuno 2005.

According to Mizuno (2005: 38), the upper layers of profiles P-A, P-B and P-C, suggest "that the terrace has been recently formed by remarkable redeposit of dune sand". In profile P-D dune sand (5YR5/6) is absent, the trees are still alive and the water content by volume is over 10 % at 40 cm depth, compared to less than 10 % at the same depth in profiles P-A, P-B and P-C.

III. The Riparian Ecosystem

III.1. Classification and Characterisation include bibliography for each species. **[a list of texts on each and every species mentioned? Or only for the ones described in Appendix C? Or the "author" of each species—listed in Appendix B?]**

Life in the riverbed and on the banks of the Kuiseb is heavily constrained by the harsh conditions of the area, but the ecosystem exhibits surprising species richness. Within 20 kilometres up- and downstream of Gobabeb, researchers have observed some 130 plants species occurring in the riverbed, representing 40 different plant families (Henschel et al in press). Appendix B shows a full table of the plants found near Gobabeb. Note that all of the tree species listed are indigenous to southern Africa, but only *Acanthosicyos horridus* is "truly desertic" (Seely et al 1981: 63); the rest can only survive relatively close to the river, where they can access underground water sources.

While Appendix A suggests a richly diverse plant population in the Kuiseb, an estimated 80% of the vegetative biomass found in the river is made up of just four woody tree species: *Acacia erioloba*, *Faidherbia albida*, *Euclea pseudebenus* and *Tamarix usneoides* (Bate & Walker 1993: 86). These four plant species will be considered in detail along with three other plant species common near Gobabeb: *Salvadora persica*, *A. horridus* and *Nicotiana glauca* (an invasive species). These seven plant communities are most likely to affect the Kuiseb's aquifer through evapotranspiration due to large leaf area and or large-scale tapping of deep groundwater, and deserve close attention.

Robinson (1976) was the first to group and classify plant stands of the Namib Desert Park (now the Namib-Naukluft Park). His study, which used the Zūrich-Montpellier classification system, suggested that the vegetation stands in the lower Kuiseb consisted of sub-communities of the *A. erioloba* community, as well as the *Datura spp. – Argemone ochroleuca* community[2]. Robinson recognizes both a "typical" sub-community with *A. erioloba* forming a "scattered tree stratum" and a more diverse "acacia albida" (*F. albida*) sub-community of the *A. erioloba* community (85). The former sub-community is found both in and out of the riverbed, but always in situations where permanent water is available underground. Typical substrate for this sub-community is sandy of various grain sizes, with an average soil depth of 0.5 m. Trees form the dominant stratum, although shrubs also comprise part of the cover in this community, and Robinson reports generally finding three vegetation strata for this community.

The *F. albida* sub-community consists of the trees *F. albida, T. usneoides, E. pseudebenus* and *S. persica,* as well as lower strata of *N. glauca* and *Chenopodium ambrosiodes*, a nanopherophyte and a therophyte, respectively. Robinson only found the *F. albida* sub-community along the river—principally on the banks of the river, but also in the bed itself in places where floods were not strong enough to uproot the trees—and generally in a substrate classified as "young flood-loam", of loose to soft consistency with an upper crust on terraces and a fine texture, with mica present (89). This sub-community seems to only grow where water is readily available—where water is in places less than a metre below the surface, although many of the sub-community's members have roots than can reach considerably deeper than that.

Robinson's *Datura spp. – A. ochroleuca* community is an ephemeral community found in the river during the dry season, consisting largely of two *Datura* species and a number of other therophytes, as well as *Eragrostis trichophora*, a hemicrytophyte that behaves as a therophyte, and *N. glauca.* It is found in the riverbed or on the edges of terraces bordering the river in a similar substrate to the *F. albida* sub-community, except the crust and litter layers occasionally found in that sub-community were generally washed or blown away in the more exposed conditions. Most of the plants found here are annuals and generally do not survive the flooding of the Kuiseb. This community also contains more invasive species than the others (Robinson 1976: 94).

A late 1970s study by Theron et al using aerial photography and ground verification identified 14 communities in the lower Kuiseb—a more fine-grained classification than Robinson advocated. Table 1 lists the communities according to Theron et al. According to Theron et al (1980) the *F. albida* community is found largely along riverbanks, with pure stands common further upriver and an *F. albida – T. usneoides* variation most conspicuous near Gobabeb. Further downstream more variations of the community, mostly mixes with herbaceous species, become more common as the river grows wider. While Theron et al report that *F. albida* is dominant in the narrower upper reaches of the river, *A. erioloba* thrives in the lower reaches of the river where the course is wider (and ground water may be too low for other trees). The *A. erioloba* community also has a wider range; it is found not only on the banks but also outside the river itself, in the dunes and on the gravel plains. The other woody communities are less common, and occupy a variety of habitats within the river: flood-plains, banks, and the edge of the sand dunes. With the exception of "dead plant areas" and *A. horridus*, the other ten communities identified by Theron et al all consist of herbaceous species largely found in the lowest reaches of the Kuiseb. The dead plant community is found all along the river, mostly in the river-bed and is mostly made up of ephemeral plant species; it corresponds roughly to Robinson's *Datura spp. – A. ochroleuca* community. The *A. horridus*

2 See Robinson (1976) pages 85-94 for detailed descriptions of each community, including accompanying species tables and cover values.

community is properly a dune community, but it does occasionally occur in river in the Gobabeb area and much more often in the delta, and even individuals found in dunes at the edge of the river may have roots long enough to tap the alluvial aquifer.

Table 7: Lower Kuiseb plant communities identified by Theron et al 1980.

F. albida	*Pechuel-loeschea leubnitziae*
A. erioloba	"Knopduin" or knob dune community
T. usneoides	*A. horridus*
S. persica	*Psilocaulon* sp. cf. *salicornioides*
S. persica – A. erioloba – T. usneoides – E. pseudenbenus	*Zygophyllum simplex* and *Zygophyllum stapfi*
Suaeda plumosa	*Odyssea paucinervis*
Eragrostis spinosa	Dead plant areas

Appendix C contains more detailed descriptions of the most important riverine plant species, including what is known about each plant's adaptations to the Namib's extreme aridity and its relation to the Kuiseb's aquifer.

III.2. Distribution of Plant Communities

Table 8 shows estimates of percentage occurrence and densities of various tree species at Gobabeb, as well as *A. horridus*. At Gobabeb *A. erioloba* is by far the most common tree in the river. Recent estimates are that it constitutes some 47-57% of trees in the Kuiseb near Gobabeb (used in Nghishidi 2005; Kaaronda 2005; Gobabeb 2000). *F. albida* is the second most-prevalent species, followed by *T. usneoides*, *S. persica*, and *E. pseudebenus*, in that order. F. sycomorus is present but only represented by one or two specimens within several kilometres of Gobabeb, while *A. horridus* only occurs occasionally in the river itself.

These frequencies compare well to values found for the Kuiseb as a whole, also summarized in Table 8, although some species are under- and some over-represented at the Gobabeb site: *E. pseudebenus* is markedly rarer at Gobabeb than in the Kuiseb as a whole, as is *A. horridus* (which is most prevalent at the lowest reaches of the river), while *A. erioloba*, *F. albida*, and especially *S. persica* all seem to be over-represented at Gobabeb.

Table 8: Frequencies and densities of trees found in ten transects taken in immediate vicinity of Gobabeb covering a total area of roughly 2 ha (n = 162). Adapted from Kaaronda 2005 and Nghishidi 2005. Occurrence of N. glauca was not measured. Occurrence for Kuiseb as a whole from Seely et al 1981.

Tree species	**Percent**	**Tree Density**	**Percentage occurrence in Kuiseb**
Acacia erioloba	53	43	44
Acanthosicyos horridus	0	0	8
Euclea pseudebenus	5	4	12
Faidherbia albida	23	19	21
Ficus sycomorus	0.5	0.5	0.4
Salvadora persica	8	6.5	2
Tamarix usneoides	10	8	12

As has been mentioned, there is a fairly clear pattern to the distribution of the various plant communities found in the Kuiseb. Figure 22 represents a stretch of river near Homeb, some 20 km upstream of Gobabeb: the *F. albida* community sticks fairly tightly to the active river channel, while the other, more drought-resistant communities are found further away. This figure fits with findings from Seely et al (1981), who found that only *A. erioloba*, *E. pseudebenus*, and *T. usneoides* occur from from the water course with any great frequency. *F. albida* had fully of 50% of its canopy cover occur within 100 m of the watercourse.

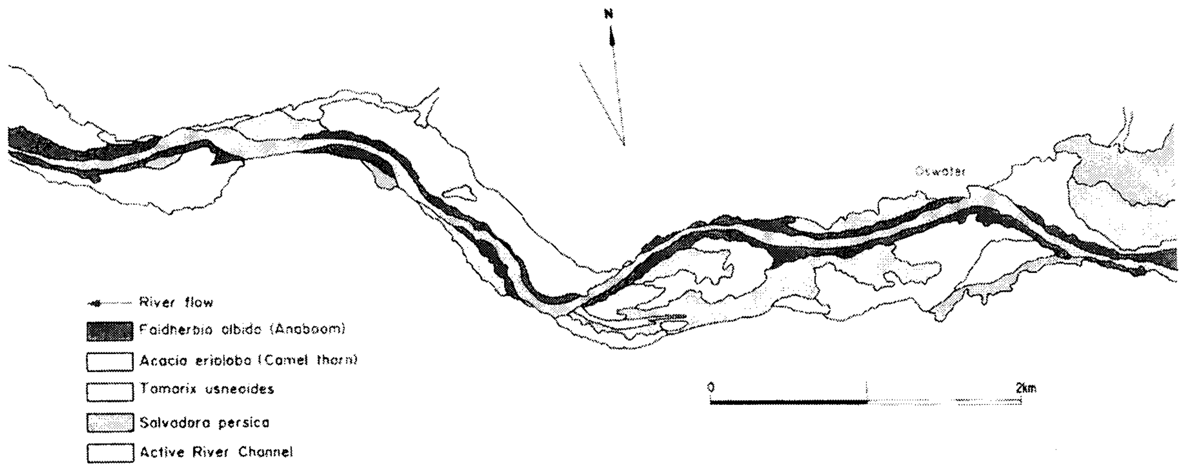


Figure 22: Vegetation map of Kuiseb upstream of Gobabeb. From Jacobson et al 1995.

Recent tree mapping at Gobabeb (Figure 23), performed along the ten transects used in section II, confirm this. *F. albida* is mostly clustered close to the active river channel (although some individuals occur farther in the floodplain), while *A. erioloba* occurs with higher frequency further from the water course. On the other hand, there are some *S. persica* individuals far from the watercourse at Gobabeb, which contradicts the Seely et al findings, and *T. usneoides* largely occurs next to the watercourse. As expected, almost all N. glauca individuals occurred in the main river channel.

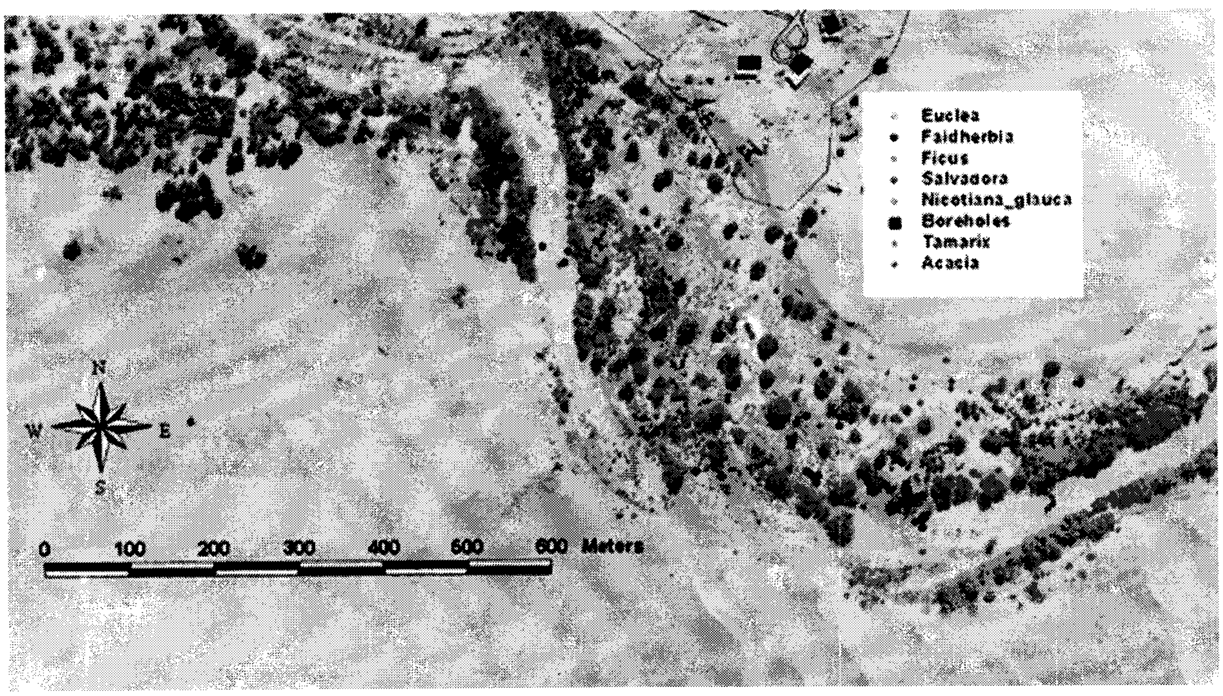


Figure 3: Trees found along ten transects taken near Gobabeb (see Figure 4), in addition to N. glauca individuals found within study area as a whole. Adapted from Kaaronda 2005.

The profile in Figure 3 also shows that *A. erioloba* occurs much further from the active channel than any other species, and that *F. albida* in particular is found much closer to the channel. It also includes representatives of *A. horridus* and of herbaceous species, such *Stipagrostis sabulicola*, indicating that these plant communities do occur in the vicinity of Gobabeb (although, as is discussed in III.3, these likely do not have a great overall effect on the ecosystem's relationship with the aquifer).

III.3. Evapotranspiration losses

In 1993, Bate and Walker carried out a study on evapotranspiration in the Kuiseb, using a model to estimate the total amount of water lost to transpiration and sand evaporation in a given year. Table 9 shows maximal transpiration rates (measured at noon) for the four tree species that make up the most vegetative biomass in the river. Note that *F. albida* and *A. erioloba* together have almost five times the leaf biomass of the other two species, making their rates much more important in determining overall transpiration losses.

Table 9: Maximal transpiration rates for four species in the Kuiseb, along with standard errors and sample sizes. From Bate & Walker 1993.

Species	*Transpiration rate (g H_2O g^{-1} hr^{-1})*	*SE (g^{-1} hr^{-1})*	*n (sample)*
F. albida	1.50	0.05	145
A. erioloba	1.03	0.03	226
E. pseudebenus	0.54	0.04	202
T. usneoides	1.07	0.03	232

Bate and Walker's model estimated that the total volume of water in the aquifer was some 10.7 x 10^5 m^3 water km^{-1} immediately after a flood, and that some 24% of this (2.59 x 10^5 m^3 km^{-1}) would be lost due to evapotranspiration. Of this 2.02 x 10^5 m^3 km^{-1} is due to vegetative transpiration, and 0.57 x 10^5 m^3 km^{-1} is caused by evaporative losses from sand in the riverbed. The authors do caution, however, that the 24% loss to evapotranspiration is likely an overestimate; for instance, on many days in the year morning fog can limit transpiration from leaves, and estimates for losses from sand do not account shaded areas. Accounting for these and other factors, they estimate that a "more realistic" figure for annual water loss is likely 15-20% of the total aquifer volume (90).

They further estimate that this would lead to a "dry depth" of 2.92 m in the riverbed 51 weeks after a flood, although the capillary fringe above the water table means that the table itself should be slightly deeper than this.

III.4. Coppicing

One notable phenomenon in the lower Kuiseb is a relatively high incidence of coppicing, specifically the sprouting of new shoots off of a dead tree that has fallen down: Table X shows a estimate of how many trees in the river coppice based on a study over 22.4 ha near Gobabeb. Coppicing is of interest because of what it may reveal about past floods. In Israel, for instance, the age of fallen and coppiced tamarisk trees has been found to correlate strongly to previous large flood events. The data are supportive of a link between flooding and coppicing: most of the coppiced trees found occurred close to the active river channel (Nghishidi 2005). However, attempts to find a more precise link between flood occurrences and coppice ages have not been successful, as tree-rings are not reliable indicators of tree age in Namibia.

Table 10: Estimated tree species densities and coppice densities observed in a 22.4 ha study area adjacent to Gobabeb (from Nghishidi 2005).

	Estimated number of	Total number of	Percentage of

Tree species	trees per species	coppicing trees	trees coppicing
A. erioloba	843	2	0.2
F. albida	320	17	5.3
T. usneoides	139	22	15.9
E. pseudobenus	53	6	11.3
S. persica	128	0	0.0
Total	**1483**	**47**	**3.2**

Note also that a recent study found the water content in coppicing trees to be somewhat higher than in other trees; this relationship may be of further interest, although it could also be because trees more readily-identified as coppiced shoots tend to be younger, and younger trees generally have higher water content in leaves than do older trees (Mamili 2005).

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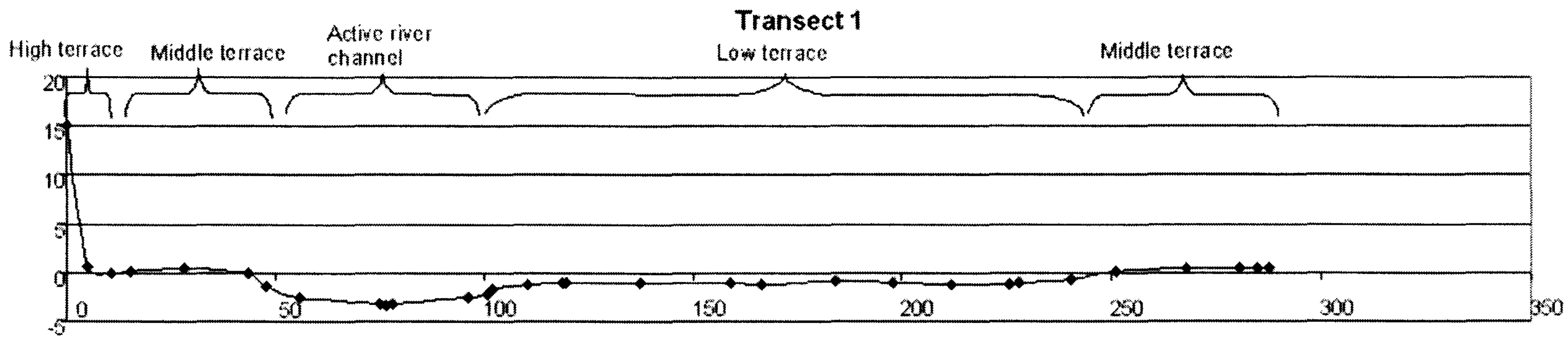
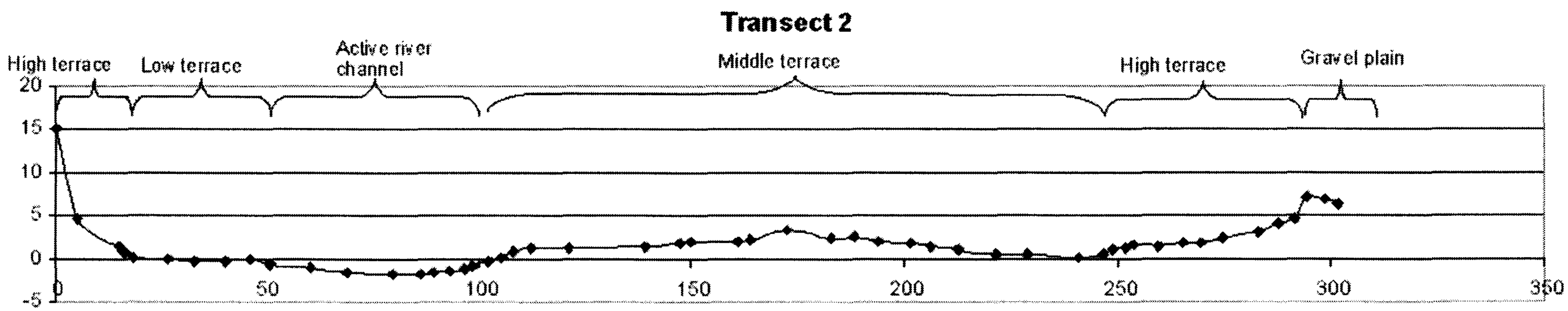
Appendix A: Transects taken at Gobabeb. All distances in metres, note that profiles are not drawn to scale (vertical and horizontal axes are drawn at different scales to exaggerate height differences).





Appendix B: Plant species found near Gobabeb. Habitats are categorised as gravel plains (G), dunes (D) or river bed (R). Perennial plants are classified according to their growth form: tree, shrub, succulent shrub (=succ), or grass. Table adapted from Henschel et al (in press).

Family and species	Author	Perennial	Alien	G	D	R
Moraceae						
Ficus sycomorus	L.	tree				R
Urticaceae						
Forsskaolea hereroensis	Schinz					R
Polygonaceae						
Polygonum aviculare	L.					R
Polygonum plebeium	R.Br.					R
Rumex lanceolatus	Thunb.					R
Aizoaceae						
Aizoanthemum dinteri	(Schinz) Friedrich			G		R
Galenia africana	L.			G		R
Gisekia africana	(Lour.) Kuntze			G		R
Glinus lotoides	L.					R
Hypertelis salsoloides	(Burchell) Adamson					R
Limeum argute-carinatum	Wawra & Peyr.			G		R
Limeum sulcatum	(Klotzsch) Hutch.					R
Mollugo cerviana	(L.) Ser. ex DC.					R
Sesuvium sesuvioides	(Fenzl) Verdc.	succ		G		R
Trianthema hereroensis	Schinz	succ			D	R
Mesembryanthemaceae						
Psilocaulon salicornioides	(Pax) Schwantes			G		R
Portulacaceae						
Portulaca oleracea	L.					R
Illecebraceae						
Corrigiola littoralis	L.					R
Chenopodiaceae						
Atriplex lindleyi	Moq.					R
Chenopodium ambrosioides	L.					R
Suaeda plumosa	Aellen					R
Amaranthaceae						
Nelsia quadrangula	(Engl.) Schinz					R
Papaveraceae						
Argemone ochroleuca	Sweet		alien			R
Capparaceae						
Cleome carnosa	(Pax) Gilg & Benedict					R
Cleome foliosa	Hook. f.			G		R
Cleome gynandra	L.					R
Maerua schinzii	Pax	tree		G		R
Brassicaceae						
Coronopus integrifolius	(DC.) Sprengel					R
Vahliaceae						
Vahlia capensis	(L. f.) Thunb.					R
Fabaceae						
Acacia erioloba	E. Meyer	tree		G		R
Adenolobus garipensis	(E. Meyer) Torre & Hillc.	shrub				R
Cullen obtusifolia	(DC.) C.H. Stirton					R
Dichrostachys cineria	(L.) Wight & Arn.	tree				R
Faidherbia albida	(Del.) A. Chev.	tree				R

Indigofera auricoma	E. Meyer			G		R
Prosopis glandulosa	Torrey	tree	alien			R
Sesbania pachycarpa	DC.					R
Tephrosia dregeana	E. Meyer	shrub		G	D	R
Geraniaceae						
Monsonia umbellata	Harvey			G		R
Zygophyllaceae						
Tribulus cristatus	C. Presl					R
Tribulus terrestris	L.			G		R
Tribulus zeyheri	Sonder			G		R
Zygophyllum simplex	L.			G	D	R
Euphorbiaceae						
Chamaesyce glanduligera	(Pax) Koutnik			G		R
Euphorbia phylloclada	Boiss.	shrub		G		R
Ricinus communis	L.	shrub	alien			R
Salvadoraceae						
Salvadora persica	L.	tree				R
Sterculiaceae						
Hermannia modesta	(Ehrenb.) Masters			G		R
Tamaricaceae						
Tamarix usneoides	E. Meyer ex Bunge	tree				R
Loasaceae						
Kissenia capensis	Endl.			G		R
Cucurbitaceae						
Acanthosicyos horridus	Welw. ex Hook. f.	shrub		G	D	R
Citrillus ecirrhosus	Cogn.			G		R
Lythraceae						
Nesaea luederitzii	Koehne					R
Ebenaceae						
Euclea pseudebenus	E. Meyer ex A. DC.	tree		G		R
Asclepiadiaceae						
Asclepias buchenaviana	Schinz	shrub		G		R
Rubiaceae						
Kohautia lasiocarpa	Klotzsch					R
Boraginaceae						
Heliotropium oliveranum	Schinz	shrub				R
Heliotropium ovalifolium	Forsskal					R
Solanaceae						
Datura innoxia	Miller		alien			R
Datura stramonium	L.		alien			R
Lycium cinereum	Thunb.	shrub				R
Nicotiana glauca	Graham	shrub	alien			R
Solanum nigrum	L.					R
Scrophulariaceae						
Anticharis inflata	Marloth & Engl.			G		R
Anticharis linearis	(Benth.) Hochst. ex Asch.					R
Anticharis scoparia	(E. Meyer ex Benth.) Hiern ex Schinz					R
Aptosimum spinescens	(Thunb.) Weber	shrub		G		R
Diclis petiolaris	Benth.					R
Limosella grandiflora	Benth.					R
Sutera canescens	(Benth.) Hiern			G		R
Sutera corymbosa	(Marloth & Engl.) Hiern					R
Sutera lyperioides	(Engl.) Engl. ex Range					R

Sutera maxii	Hiern		G		R
Sutera pallida	(Pilger) Overk. ex Roessler				R
Veronica anagallis-aquatica	L.				R
Selaginaceae					
Walafrida saxatilis	(E. Mey.) Rolfe				R
Acanthaceae					
Petalidium setosum	C.B. Clarke ex Schinz	shrub	G		R
Pedaliaceae					
Rogeria longiflora	(Royen) Gay ex DC.				R
Sesamum abbreviatum	Merxm.			D	R
Campanulaceae					
Wahlenbergia androsacea	A. DC.				R
Lobeliaceae					
Lobelia angolensis	Engl. & Diels				R
Lobelia erinus	L.				R
Asteraceae					
Aspilia eenii	S. Moore				R
Berkheya spinosissima	(Thunb.) Willd.		G		
Blumea cafra	(DC.) O. Hoffm.				R
Blumea decurrens	(Vahl) Merxm.				R
Conyza bonariensis	(L.) Cronq.				R
Cotula anthemoides	L.				R
Dicoma capensis	Less.				R
Dimorphotheca polyptera	DC.				R
Emilia marlothiana	(O. Hoffm.) C. Jeffrey				R
Epaltes gariepina	(DC.) Steetz				R
Flaveria bidentis	(L.) Kuntze				R
Geigeria plumosa	Muschler				R
Helichrysum argyrosphaerum	DC.				R
Helichrysum gariepinum	DC.				R
Launaea intybacea	(Jacq.) Beauv.				R
Melanthera marlothiana	O. Hoffm.				R
Nicolasia stenoptera	(O. Hoffm.) Merxm.				R
Nidorella resedifolia	DC.				R
Osteospermum microcarpum/Tripteris microcarpa?	(Harvey) Norlindh		G		R
Pechuel-Loeschea leubnitziae	(Kuntze) O. Hoffm.	shrub	G		R
Pseudognaphalium luteo-album	(L.) Hilliard & Burtt				R
Pulicaria scabra	(Thunb.) Druce				R
Senecio apiifolius	(DC.) Benth. & Hook. F. ex. O. Hoffm.				R
Senecio consanguineus	DC.				R
Senecio eenii	(S. Moore) Merxm.				R
Sphaeranthus peduncularis	DC.				R
Tagetes minuta	L.				R
Xanthium spinosum	L.				R
Poaceae					
Brachiaria glomerata	(Hackel) A.Camus		G	D	R
Cenchrus ciliaris	L.	grass			R
Chloris virgata	Sw.				R
Cladoraphis spinosa	(L.F.) S. Phillips	grass		D	R
Cynodon dactylon	(L.) Pers.				R
Dactyloctenium aegyptium	(L.) Willd.				R
Entoplocamia aristulata	(Hackel & Rendle) Stapf				R
Eragrostis lehmanniana	Nees				R

Eragrostis porosa	Nees				R
Eragrostis rotifer	Rendle				R
Eragrostis trichophora	Coss. & Dur.				R
Polypogon monspeliensis	(L.) Desf.				R
Setaria verticillata	(L.) Beauv.				R
Sporobolus consimilis	Fresen.				R
Stipagrostis lutescens	(Nees) De Winter	grass	G	D	R
Stipagrostis sabulicola	(Pilger) De Winter	grass		D	R
Stipagrostis subacaulis	(Nees) De Winter		G		R
Stipagrostis seelyae	De Winter	grass		D	R
Arecaceae					
Phoenix dactylifera	L.	tree			R
Cyperaceae					
Bulbostylis exilis	(Humb., Bonpl. & Kunth) Roemer & Schultes				R
Cyperus marginatus	Thunb.				R

APPENDIX C: Notable plant species in the Kuiseb.

C.1 *Acacia erioloba*

Family: *Fabaceae*

Other names: Camelthorn (common name), *A. giraffae* (an old classification now out of favor)

Relevant characteristics and adaptations: This extremely hardy tree, which can grow to 15 m high in places and live for up to 300 years, is indigenous to southern Africa, and particularly common across Namibia. It is well-equipped to endure the highly-variable temperatures and hydrological conditions it faces in a desert environment; it can even survive in frosty conditions. It typically flowers in the Southern Hemisphere's early spring, and produces earlobe-shaped seed pods. (Barnes et al 1997)

A. erioloba is of socioeconomic interest due to the fodder-value of its seed pods and its usefulness as fuel, and also has come under investigation as potentially highly-important in "restoring and increasing productivity of non-arable lands"—in combating desertification (Barnes et al 1997: 1). The Topnaar particularly value the tree as a source of fuelwood (although they are not permitted to fell trees within the boundaries of the Namib-Naukluft Park), and while its wood is too hard to be used in construction, they do use it for building furniture and fences for their kraals. The goats and cattle of the Topnaar also enjoy eating the trees' pods (Van den Eynden et al 1992: 45). The tree is also important to several animal species

Its importance in combating desertification is largely tied to two factors: its ability to improve the soil and its importance as a link to underground water sources.

Like all other acacias, *A. erioloba* is leguminous, and fixes nitrogen in the soil (Wickens 1998). However, it is unusual in two ways. First, studies indicate that its roots rarely nodulate: Barnes et al (1997: 14) report that less than 1% of acacia in a field test nodulated, against 64% of *F. albida* seedlings. Second, analysis of isotope ratios in its leaves indicates that it fixes mostly nitrogen obtained from groundwater rather than atmospheric nitrogen—although Barnes et al (1997: 15) point out that this is "no less valuable" to the ecosystem, as groundwater nitrogen would not come into surface circulation without *A. erioloba*'s long subterranean reach.

A. erioloba seems to be better-adapted to desert conditions than other trees in the Kuiseb. Even more than the other tree species found in the Kuiseb, *A. erioloba* is decidedly phreatophytic, relying on immensely long roots to provide it with water throughout the year; specimens in the Kalahari have been recorded with roots of up to 60 m, although more typically *A. erioloba*'s roots are not found much deeper than 45 m (Canadell et al 1996; Barnes et al 1997). This means that during extended dry periods, such as the lower Kuiseb experienced in the early 1980s, *A. erioloba* suffered nowhere near as severe a decline as other species (Ward & Breen 1985). Its long roots and subsequent tolerance of "drought" conditions affects its distribution in the river, a topic that will be further explored in section III.2.

C.2 *Faidherbia albida*

Family: *Fabaceae*

Other names: Ana tree (common name); Acacia albida (*F. albida* was re-classified into a stand-alone genus in the 1980s)

Relevant characteristics and adaptations: Formerly classified as a member of the acacia genus (it is distinguished from acacia primarily by its deeply-layered bark and its distinct phenology), *F. albida* was named for its distinctively white wood, twigs, and thorns (Wood 1989; Van den Eynden 1992: 44). This tree, which can grow up to 30 m in height, is widely distributed across Africa: its range covers Southern, Eastern, and Western Africa and even extends north as far as Lebanon. Its distribution does not correspond to climatic zones; rather, this riverine species is found in areas with permanent surface groundwater or along ephemeral rivers with saturated alluvium (Wickens 1998; Wood 1989). It lives for up to 150 years, although 70-90 is a more typical lifespan, and has the curious habit of shedding its leaves at the beginning of the rainy season, producing new leaves and flowers at the beginning of the dry season. Botanists speculate that this adapation may help *F. albida* to withstand weeks to months of root water-logging that accompany rises in the water-table near rivers, but the question has not yet been settled (Wood 1989; Wickens 1998).

Like *A. erioloba*, *F. albida* has been identified as potentially of great developmental value. Its spiralled seedpods make good fodder, while studies have shown that *F. albida* can improve soil conditions considerably as far the needs of crops are concerned. *F. albida* is leguminous and, as was mentioned above, nodulates at a considerably higher rate than *A. erioloba*, the other dominant tree species in the Kuiseb, making it an important fixer of atmospheric nitrogen in the riparian ecosystem; field studies in other areas have found *F. albida* to increase levels of soil nitrogen by as much as 100%. It also increases soil pH and raises soil carbon levels (at a lower rate than nitrogen increases) (Barnes et al 1997; Wood 1989). In the Kuiseb, the Topnaar value the "Ana tree" particularly for the fodder value of its pods—the most significant food source in the river for their livestock—as well for the value *F. albida*'s wood has in construction (Van den Eynden 1992).

While *F. albida* loses a great deal of water to evapotranspiration it has, like *A. erioloba*, evolved significantly smaller leaves that enable it to minimize these losses (Van den Eynden 1992; Wood 1989). It has a taproot that grows very rapidly to as much as 40 m in depth (Wood 1989). However, *F. albida* is not often found far from water courses; it is not nearly as drought-resistant as *A. erioloba.*

C.3 *Tamarix usneoides*

Family: *Tamaricaceae*

Other names: Tamarisk (common name); Daweb (Nama-Damara)

Relevant characteristics: A southern African native, *T. usneoides* is halophytic, and thrives in the often-saline hydrological environment of the Kuiseb. *T. usneoides* can can grow to up to 9 m in height, although trees of such size are rarely found in the Kuiseb.

T. usneoides is evergreen, with small, scale-like leaves (Palmer & Pitman 1972). *T. usneoides* is notable for its networks of extremely shallow roots, which can lead to stands of smaller trees growing up around a parent tree (Van den Eynden et al 1992).

It is perhaps most notable for its ability to excrete excess salt through pores in these leaves; it does this at midday and the salt deposits on the leaves serve to limit evapotranspiration (Van den Eynden et al 1992). The leaves of the tamarisk can serve as fodder for livestock or other animals, although Van den Eynden et al do not note *T. usneoides* as an important fodder crop for the Topnaar's livestock. Instead, they report that the Topnaar most value the tree for its roots' medicinal properties.

T. usneoides is also a phreatophyte, although its tap root certainly does not reach as deep as that of

The fruit of the tree is edible, and the leaves can be browsed by livestock, although animals generally only browse the tree during droughts when other plants are not available, since *S. persica*'s leaves have reliably higher water content than other species (Van den Eynden et al 1992; Van Wyk et al 1985; Mamili 2005).

S. persica is also a phreatophyte, with a long tap root that allows the tree to access groundwater.

C.6 *Acanthosicyos horridus*

Family: *Cucurbitaceae*

Other names: !nara (Nama-Damara); nara (common name)

Relevant characteristics and adaptations: This remarkable plant is endemic to coastal areas of the Namib, and grows all along the Kuiseb, although as we have noted it is classified as properly and primarily a dune community (Robinson 1976). *A. horridus* is a spiny cucurbit, which grows dense tangles; like *S. persica*, the thick growth of the !nara causes sand to build up over it, meaning that over centuries large hummocks can accumulate around a single individual, with each plant often constituting its own miniature dune sometimes over ten metres in diameter and several meters high (Henschel pers. comm.; Van den Eynden et al 1992). Each plant is either male or female, with males flowering all year round (Henschel pers. comm.).

The plant is enormously important to both the dune ecosystem and to the Topnaar. Animals and people value the !nara melon, which is both healthy and an important source of water. The Topnaar and other humans in the Namib have been using *A. horridus* as a food source for some 8000 years (Van den Eynden et al 1992).

A. horridus has adapted to the Namib by losing all its leaves, photosynthesizing entirely throughts its bright green thorns and stems. Its tap roots have been measured at up to 40 m, allowing it access to water throughout the year and making it a crucial species for providing minerals and nutrients to surface animals (Van den Eynden et al 1992; Henschel & Moser 2004b).

C.7 *Nicotiana glauca*

Family: Solanaceae

Other names: Wild tobacco, tree tobacco

Relevant characteristics and adaptations: N. glauca is an invasive alien species originally from Argentina, introduced into the South African region via horse fodder (Brown & Gubb 1986). It is a perennial shrub usually 1 m high but occasionally can exceed even 8 m (Curtis & Mannheimer 2005). N. glauca is considered a weed which impinges on other species, either endemic plants or animals, and therefore demonstrates a threat to the endemic wildlife; alien species such as N. glauca take up space and consume groundwater resources. It is difficult to control them mechanically because of their high number, biological and chemical removal would be undesirable and would affect the whole ecosystem (Jabs 1991).

N. glauca generally grows along ephemeral rivers, either in its riverbeds or on riverbanks and on alluvial sites but it also appears in lower frequencies at the escarpment catchment area in the Khomas Hochland. It prefers open, bare disturbed ground in open patches (usually areas which would be flooded when the river flows) although shade does not prevent it from growing (Jabs

1991).

N. glauca has blue green, leathery leaves with long petioles. The evergreen leaves contain alkaloids and sterols, which are known to kill ostrich and cattle. The fruit contain very fine, toxic seeds, which are dispersed by wind and water. It ripens mainly from November to May. The tubular, light yellow flowers, which grow in hanging clusters flower all year round but mainly in the rainy season (Curtis & Mannheimer 2005). The tough, waterborne seeds are transported down river during floods and left on the soil surface as the river dries out.

N. glauca is not a significant food source for animals; its toxic leaves make it inedible. It can be used by baboons but only on rarely (Hamilton 1986; Jabs 1991). For the Topnaar N. glauca represents a source of firewood and its green stems are used for minor constructions (e.g. to secure hut frames) (Van den Eynden 1992).

Beside its deep roots which can access the ground water, N. glauca has a number of advantages over indigenous vegetation in the Kuiseb: for one, it has a long flowering season with a high seed production and widespread dispersal opportunities. The seeds are able to survive over several years to wait for conditions, which allow them to germinate. In addition to that seeds may germinate more rapidly at an earlier stage or may be xerophytic, germinating when moisture levels are too low for the indigenous vegetation, allowing the plant to dominate the community. The seeds are distributed underneath and around the canopy of the parent plant forming dense monospecific stands. Also, N. glauca can survive in frosty conditions, it is halophytic, and it benefits from a high water absorption ability, which makes it to a well-adapted plant in environments with extreme climatic conditions such as the Namib desert. Observations in the Kuiseb, however, suggest that N. glauca does not tolerate root-flooding: plants growing in the riverbed or near it die off right after floods, even after suffering no apparent damage (Robinson 1976: 94).

Figures