The status of alien invasive plants in the major rivers of the Namib Naukluft Park

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ABSTRACT

The major rivers of the Namib Naukluft Park were surveyed to determine the degree of infestation of alien invasive plants. The Swakop and Kuiseb Rivers had the densest infestations, the Tsondab and Tsauchab Rivers had less dense infestations, while no alien plants were found in the Awasib and Koichab Rivers. *Datura innoxia* and *Nicotiana glauca* were the most abundant alien plant species.

While it may not be possible to eradicate *D. innoxia*, an ephemeral species, using mechanical methods, it is suggested that this species may have little impact on the indigenous vegetation and therefore is of less importance than the perennial alien species. The perennial species, *Prosopis* spp., *N. glauca* and *Ricinus communis* appear to have a greater impact on indigenous vegetation than the emphemeral species and priority should be given to their control.

INTRODUCTION

Conservation of biotic diversity is one of the main aims of nature conservation authorities. The existence of alien invasive species within natural parks poses a threat to indigenous communities.

Invasive alien plant species have been introduced to southern Africa both directly and inadvertantly, often as seeds in imported fodder (Brown & Gubb 1986). Some species have now spread throughout much of South West Africa/Namibia, colonizing, in particular, areas which have been disturbed either by man's activities or through natural causes.

At present little is known of the distribution, density or competitive abilities of alien invasive species in the Namib Desert. This paper is intended to provide a synopsis of the occurrence of these species, and their levels of infestation, within the major river systems in the Namib Naukluft Park.

METHODS

The major rivers of the Namib Naukluft Park (Figure 1) were surveyed using the river transect method developed by the South African Botanical Research Institute (Henderson & Musil 1984). The method used was to record alien plants from a slow moving vehicle, travelling, with the exception of a small section of the Koichab River, in the centre of the riverbed. All rivers were surveyed from west to east.

Three rivers, the Tsondab, Tsauchab and the eastern 75 km of the Kuiseb River were surveyed during December 1987. These rivers had all last flowed at the beginning of 1987. The Koichab and Awasib Rivers, which apart from some local run-off had not flowed for a number of years, were surveyed in February 1988. The western section of the Kuiseb River, a 54 km-section downstream of Gobabeb, and the Swakop River were surveyd in April 1988, three months after they had last flowed.

The Swakop River was surveyed from the western boundary of the park to the eastern boundary, a distance of 86 km. The Kuiseb was surveyed from the western park boundary to the point where vehicular travel is no longer possible (129 km).

The Tsauchab and Tsondab Rivers were surveyed from their vleis to the eastern boundary of the park (70 and 49 km respectively). The small loop of the Tsauchab River outside the park was not surveyed.

The Awasib River was surveyed from a point about 5 km east of the Awasib Pan to the eastern park boundary; a total distance of 16 km.

The Koichab Depression (20 km) and western section of the Koichab River (21 km) were surveyed from tracks alongside the watercourse. The river was surveyed in the water course from the main Water Affairs pumping station eastwards to the park boundary (63 km).

Abundance and frequency ratings were recorded for each 1 km of river traversed and these are reported as mean ratings for sections of the river. Each section was normally 10 km in length except for the last section of each river. Vleis were reported seperately. Abundance ratings were those used by Macdonald & Nott (1987) and are summarized in Table 1.

TABLE 1: Abundance ratings used for surveying alien plant species in rivers (from Macdonald & Nott 1987).

RATING	DEFINITION
9	Species forming a virtually continuous, almost monospecific stand at least 1 ha in extent.
8	Species co-dominant in a virtually continuous stand at least 1 ha in extent.
7	20 or more plants per 1 km-section
6	10 19 plants per 1 km-section
5	5 9 plants per 1 km-section
4	2 4 plants per 1 km-section
3	1 plant per 1 km-section

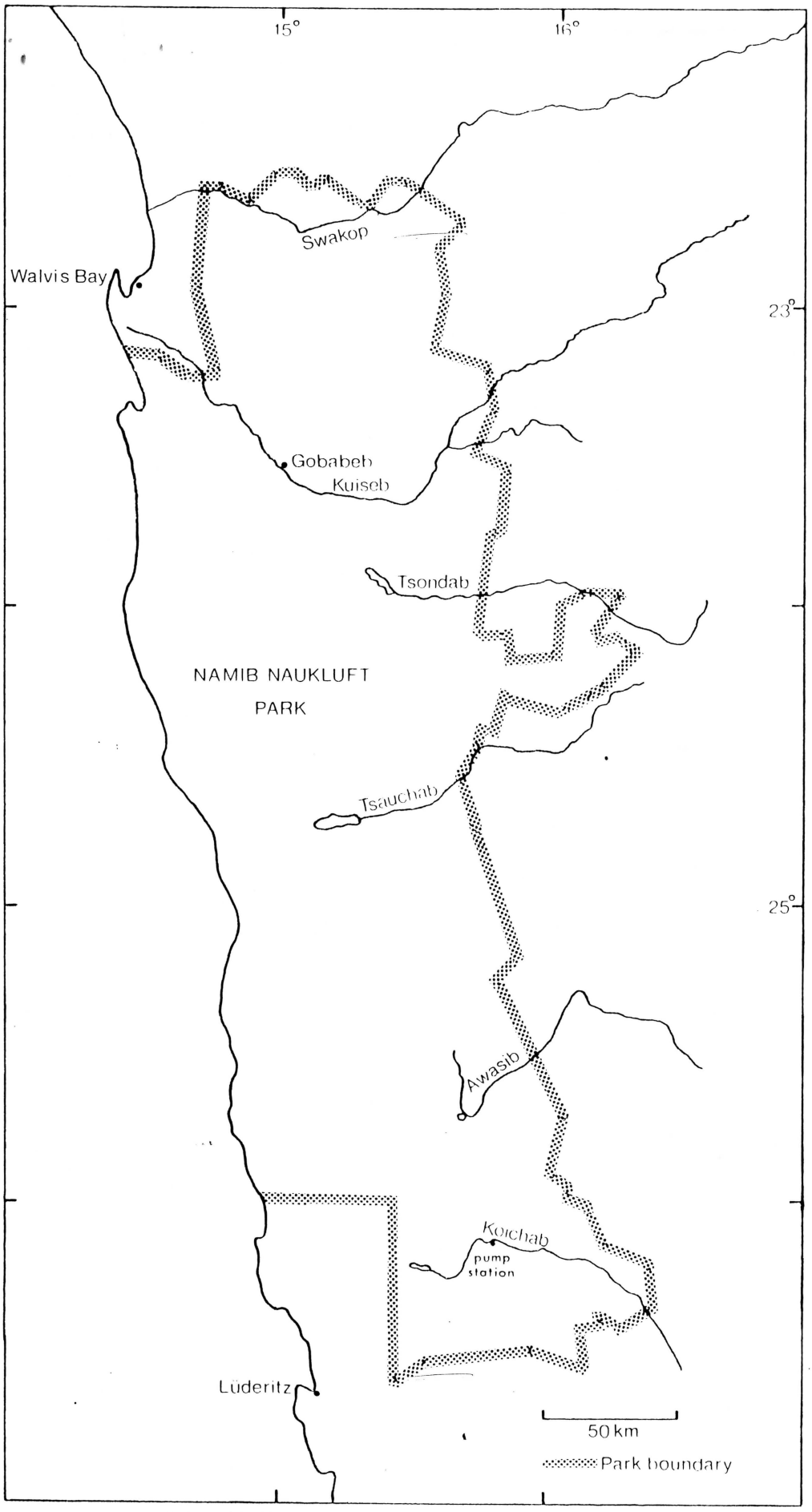

FIGURE 1: The six major rivers of the Namib Naukluft Park.

Mean abundance ratings (A) were then calculated for each species within each 10 km-section of each river, using the formula:

$$A_Z = \frac{\text{Sum of 1 km abundance ratings of species Z/section}}{\text{Number of 1 km-sections having species Z}}$$

Two frequency ratings were calculated. The frequency of occurrence (F_O) is the percentage of 1 km-sections within which a species was found to occur, and was calculated as follows:

$$F_{O(z)} = \frac{\text{No. of 1 km-sections in which species Z occurred}}{\text{Number of km traversed (normally 10)}} \times 100$$

To give an indication of the management implications involved in controlling each species a rate of frequency of occurrence of dense infestations (F_i) was calculated. A dense infestation was taken as any section with an abundance rating of 5 or greater (more than 20 plants per 1 km traversed) of that particular species.

This was calculated using the formula:

$$F_{i(z)} = \frac{\text{No of 1 km-sections where Az} > 4}{\text{Number km traversed (normally 10)}} \times 100$$

All original data are stored at the Namib Research Institute, Namib Naukluft Park.

RESULTS

The genus *Prosopis* is currently under revision and specific names cannot be given with any confidence. The species found in the Namib are therefore referred to as *Prosopis* spp.

Swakop River

This river had the most alien invasive species of all the rivers surveyed, a total of six species (Tables 2 & 3), i.e. *Argemone ochroleuca* Sweet (Mexican Thistle), *Nicotiana glauca* R.C. Graham (Wild Tobacco), *Ricinus communis* L. (Castor Oil Bush), *Datura innoxia* Mill. (White Thorn Apple), *D. stramonium* L. (Purple Thorn Apple) and *Prosopis* spp. (Mesquite).

D. innoxia had the greatest abundance rating and occurred more frequently than the other species. Except for the upper 20 km of the river, this species occurred throughout at a rate of more than 20 plants/km. *D. stramonium* and *Prosopis* spp. also occurred less frequently in the upper region. *N. glauca* was found throughout the river, with dense infestations in about one third of all the 1 km-sections. While *R. communis* was found throughout the river, it only occurred at low densities. *A. ochroleuca* was rarely seen.

Twenty-one palm trees (*Borassus aethiopum* and *Phoenix reclinata*) were recorded. While these species are probably non-invasive in the Namib, they are, however, alien to this region.

Kuiseb River

Five alien species were detected in this river (Tables 4 & 5). *N. glauca* and *D. innoxia* were found in most of the 1 km-sections (Tables 6 & 7), and occurred more densely than any of the other alien species. *A. ochroleuca* and *R. communis* occurred most frequent-

TABLE 2: The abundance ratings (A) of alien plants in the section of the Swakop River within the Namib Naukluft Park.

Distance from west (km)	*Argemone ochroleuca*	*Datura innoxia*	*Datura stramonium*	*Nicotiana glauca*	*Prosopis* spp.	*Ricinus communis*
0 – 10	–	7,0	5,4	5,2	6,6	4,8
11 – 20	–	7,0	5,6	6,0	6,6	4,3
21 – 30	3,0	7,0	5,3	6,0	6,7	3,3
31 – 40	–	7,0	5,2	6,5	6,1	3,9
41 – 50	3,0	7,0	6,4	5,8	7,1	4,4
51 – 60	3,3	7,0	6,8	5,8	7,5	3,9
61 – 70	–	7,0	6,6	6,4	5,8	3,6
71 – 80	–	6,3	5,0	5,9	4,3	3,0
81 – 85 (east boundary)	–	5,0	4,0	5,8	4,3	4,3
Mean	3,1	6,8	5,6	5,9	6,1	4,0

TABLE 3: The percentage frequency of occurrence (F_O) and percentage frequency of dense occurrence (F_i) of alien plants in the section of the Swakop River within the Namib Naukluft Park.

Distance from west (km)	*Argemone ochroleuca*		*Datura innoxia*		*Datura stramonium*		*Nicotiana glauca*		*Prosopis* spp.		*Ricinus communis*	
	F_O	F_i	F_O	F_i	F_O	F_i	F_O	F_i	F_O	F_i	F_O	F_i
0 – 10	–	–	100	100	100	20	100	–	100	60	80	–
11 – 20	–	–	100	100	100	30	100	20	100	60	30	–
21 – 30	10	–	100	100	90	20	100	30	100	70	40	–
31 – 40	–	–	100	100	100	20	100	80	100	50	90	–
41 – 50	10	–	100	100	100	50	100	30	100	30	90	–
51 – 60	10	–	100	100	100	80	100	20	100	90	70	–
61 – 70	–	–	100	100	100	60	100	50	80	20	50	–
71 – 80	–	–	100	70	50	–	90	20	70	–	40	–
81 – 85	–	–	100	17	100	–	100	50	33	–	50	–
Mean	3	–	100	92	93	33	99	35	90	52	66	–

TABLE 4: The abundance ratings (A) of alien plants in a 53 km section of the Kuiseb River, downstream from Gobabeb.

Distance from west (km)	*Argemone ochroleuca*	*Datura innoxia*	*Datura stramonium*	*Nicotiana glauca*	*Ricinus communis*
0 – 10	5,3	6,3	5,4	6,7	3,0
11 – 20	4,8	6,5	4,5	6,8	4,0
21 – 30	6,6	6,3	5,2	7,0	–
31 – 40	5,3	7,6	7,0	7,0	5,0
41 – 50	5,0	6,5	6,7	6,9	3,0
51 – 54 (Gobabeb)	5,8	4,0	–	6,5	–
Mean	5,6	6,6	6,0	6,9	3,7

TABLE 5: The abundance ratings (A) of alien plants in a 75 km section of the Kuiseb River, upstream from Gobabeb.

Distance from Gobabeb (km)	*Argemone ochroleuca*	*Datura innoxia*	*Datura stramonium*	*Nicotiana glauca*	*Ricinus communis*
0 – 01	5,7	6,7	3,8	6,0	3,0
11 – 20	6,6	6,0	3,8	6,6	4,0
21 – 30	6,5	7,0	4,0	4,6	6,9
31 – 40	3,5	7,0	–	3,0	6,1
41 – 50	6,4	7,0	3,0	5,8	6,7
51 – 60	6,5	7,0	3,3	6,3	6,2
61 – 70	6,9	7,0	4,7	6,7	5,4
71 – 75	7,0	7,0	4,8	6,8	6,0
Mean	6,3	6,9	4,2	6,1	5,9

TABLE 6: The percentage frequency of occurrence (F_o) and percentage frequency of dense occurrence (F_i) of alien plants in a 54 km section of the Kuiseb River, downstream of Gobabeb.

Distance from west (km)	*Argemone ochroleuca*		*Datura innoxia*		*Datura stramonium*		*Nicotiana glauca*		*Ricinus communis*	
	F_o	F_i	F_o	F_i	F_o	F_i	F_o	F_i	F_o	F_i
0 – 10	40	20	90	70	70	20	100	90	20	–
11 – 20	60	10	80	70	40	10	100	80	10	–
21 – 30	100	80	90	60	50	10	100	100	–	–
31 – 40	40	10	100	100	100	100	100	100	10	–
41 – 50	50	20	80	50	60	50	100	90	20	–
51 – 54 (Gobabeb)	100	10	–	–	–	–	100	30	–	–
Mean	61	27	81	65	59	35	100	87	11	–

TABLE 7: The percentage frequency of occurrence (F_o) and percentage frequency of dense occurrence (F_i) of alien plants in a 75 km section of the Kuiseb River, upstream from Gobabeb.

Distance from Gobabeb (km)	*Argemone ochroleuca*		*Datura innoxia*		*Datura stramonium*		*Nicotiana glauca*		*Ricinus communis*	
	F_o	F_i	F_o	F_i	F_o	F_i	F_o	F_i	F_o	F_i
0 – 10	70	40	60	50	40	–	80	40	20	–
11 – 20	90	80	70	50	40	–	100	70	60	–
21 – 30	60	50	100	90	30	–	80	–	100	90
31 – 40	40	–	100	100	–	–	10	–	80	50
41 – 50	70	40	100	100	10	–	90	40	100	80
51 – 60	100	50	100	100	30	–	100	60	100	40
61 – 70	90	80	100	100	90	–	90	70	100	30
71 – 75	100	100	100	100	100	–	100	80	100	60
Mean	76	52	91	85	39	–	68	43	81	43

ly in the upper region of the river, while *D. stramonium* was more frequently found in the lower region.

Prosopis spp. occurs in this river, downstream of the western boundary. However, no *Prosopis* spp. were found in the section of the Kuiseb within the park.

Tsondab and Tsauchab Rivers

D. innoxia was the most common alien plant species in these rivers, occurring with high abundance ratings in all regions (Tables 8 & 9). *A. ochroleuca* and *R. communis* were found in both rivers but a much lower abundance ratings. *R. communis* occurred most frequently in the upper region of each river (Tables 10 & 11).

Four *Prosopis* spp. trees were found in the Tsauchab River, but this species was not detected in the Tsondab River. *N. glauca* occurred at fairly low abundance ratings throughout the Tsondab River, but was not detected in the Tsauchab River. A very small infestation of *D. stramonium* occurred in the middle region of the Tsondab River.

TABLE 8: The abundance ratings (A) of alien plants in the section of the Tsauchab River within the Namib Naukluft Park.

Distance from vlei (km)	*Argemone ochroleuca*	*Datura innoxia*	*Prosopis* spp.	*Ricinus communis*
0 – 1	–	8,0	3,0	
2 – 11	–	4,7		
12 – 21	–	6,7		
22 – 31	–	7,0	3,0	3,0
32 – 41	–	6,7		3,0
42 – 51	–	7,0	3,0	6,8
52 – 61	3,0	7,0		4,4
62 – 70	4,3	6,7	3,0	3,0
Mean	4,0	6,3	3,0	5,1

TABLE 9: The abundance ratings (A) of alien plants in the section of the Tsondab River within the Namib Naukluft Park.

Distance from vlei (km)	*Argemone ochroleuca*	*Datura innoxia*	*Datura stramonium*	*Nicotiana glauca*	*Ricinus communis*
0 – 13	–	6,5			3,0
14 – 23	3,0	7,0		3,8	
24 – 33	3,7	7,0	3,0	3,9	4,0
34 – 43	–	7,0	–	3,0	4,0
43 – 49	–	7,0		3,0	3,0
Mean	3,5	6,9	3,0	3,7	3,8

TABLE 10: The percentage frequency of occurrence (F_o) and percentage frequency of dense occurrence (F_i) of alien plants in the section of the Tsauchab River within the Namib Naukluft Park.

Distance from vlei (km)	*Argemone ochroleuca*		*Datura innoxia*		*Prosopis* spp.		*Ricinus communis*	
	F_o	F_i	F_o	F_i	F_o	F_i	F_o	F_i
0 – 1	–	–	100	100	100			
2 – 11	–	–	90	20	–	–	–	–
12 – 21	–	–	100	80				
22 – 31	–	–	100	100	10	–	10	
32 – 41	–	–	100	90		–	20	
42 – 51	–	–	100	100	10	–	80	
52 – 61	10	–	100	100	–	–	50	
62 – 70	50	–	100	78	11	–	20	
Mean	8	–	99	84	4	–	27	–

TABLE 11: The percentage frequency of ocurrence (F_o) and precentage frequency of dense occurrence (F_i) of alien plants in the section of the Tsondab River within the Namib Naukluft Park.

Distance from vlei (km)	*Argemone ochroleuca*		*Datura innoxia*		*Prosopis* spp.		*Nicotiana glauca*		*Ricinus communis*	
	F_o	F_i	F_o	F_i	F_o	F_i	F_o	F_i	F_o	F_i
0 – 13	–	–	85	54	–	–	–	–	8	
14 – 23	10	–	100	100			80			
24 – 33	30	–	100	100	10	–	90	–	10	
34 – 43	–	–	100	100			10		60	
44 – 49	–	–	83	83	–	–	17	–	17	
Mean	8	–	95	89	2	–	39		20	

Awaşib and Koichab Rivers

No alien invasive plants were found in these rivers. One of the tributaries of the Koichab River on the farm Alabama (No. 140) was noted to contain several plants of *D. innoxia* just outside of the park boundary.

DISCUSSION

The limitations of this type of census must be recognized and the results are presented with this in mind. No attempt has been made to determine precise density counts of alien plants. One transect along the centre of each river yielded data on the visible plants. Variable river widths, multiple channels, different sampling times and conditions and a multitude of other factors rule out precise counts.

It is also possible that small, less obvious species may have been overlooked. For example one *Prosopis* spp. tree and a few *D. ferox* L. (Large Thorn Apple) plants have been recorded in the Kuiseb River subsequent to this census.

The data presented do, however, give an indication of the status of alien plants in this region and can be used by managers in making decisions regarding the control of alien species.

In addition this type of survey has the advantage of repeatability. Each river took a day or less to survey and further surveys will be possible even in the absence of experienced observers.

Ecological aspects

Of the rivers surveyed, the Swakop and Kuiseb Rivers had the highest abundance ratings of alien plants.

In the upper 25 km of the Swakop River *Prosopis* spp. was almost absent, the result of manual removal of this species between 1985 and 1988. The reduced ocurrence of other alien species in this region may also be due to human activity and removal, despite being non-target species.

In the Kuiseb River two species, *D. innoxia* and *R. communis,* occurred less frequently and at lower abundance rates in several sections than in other areas. In most of these sections Topnaar goats are kraaled and watered and the reduced abundance, and often absence of these two species in areas close to the goat kraals suggests a correlation. *R. communis* is heavily browsed by goats and *D. innoxia* seedlings appear to suffer from the trampling effect of the goat-herds (Vinjevold *et al.* 1985).

In the upper portions of the Kuiseb River and in the other rivers surveyed where goats are absent, indigenous large herbivores are more common, but browsing and trampling of alien plants has not been observed. Baboons *Paprio ursinus* utilize *N. glauca* (C. Brain pers. comm.), but this impact is very localized and probably has little effect on the viability of this species.

In the upper region of the Kuiseb River *D. innoxia, A. ochroleuca* and *R. communis* occurred with high abundance and frequency of occurrence ratings. This section of the river receives flood waters more frequently than the lower regions and the higher density of these alien plants may be related to this. Similarly the increased frequency and abundance of *R. communis* and *A. ochroleuca* in the upper regions of the Tsondab and Tsauchab Rivers may be due to the more frequent availability of surface water.

D. innoxia was the most common alien species in the Tsondab and Tsauchab Rivers, having similar abundance and frequncy of occurrence ratings as in the Kuiseb River. Other species were less common in the Tsondab and Tsauchab Rivers than the Kuiseb River, with the exception of *Prosopis* spp. which was not found in the Kuiseb River.

While the Awasib and Koichab Rivers appear to be free of alien plants at present, the occurrence of *D. innoxia* on the park boundary in the Koichab River catchment area and of many *Prosopis* spp. trees on the farms within the catchment areas of both of these rivers, suggests that under suitable conditions infestations could occur.

The results of a similar census of the Swakop River and a portion of the Kuiseb River performed in 1984 (Macdonald & Nott 1987) can be compared to the present census.

In the Swakop River *Prosopis* spp. occurred at the same frequency in both censuses, but appeared to be more abundant in the present survey.

A. ochroleuca occurred at the same rating, whereas *D. innoxia, D. stramonium* and *R. communis* were not recorded in 1984. *N. glauca* has increased in both frequency and abundance.

Prior to the 1984 census (Macdonald & Nott 1987) serveral small flows of surface water were recorded in the Swakop River, upstream of the eastern park boundary (Unpubl. data, Division Hydrology, Dept. of Water Affairs, S.W.A./Namibia). Whether these floods reached the park is unkown, but if so, they were likely to have had little effect on the river vegetation. Apart from these small floods no other floods were recorded in the Swakop River between 1977 and 1984. Since 1984 serveral large floods have passed through the park, in 1985 and in 1988, while a small flood was recorded east of the park in 1986 (Unpubl. data, Division Hydrology, Dept. of Water Affairs, S.W.A./Namibia).

It is therefore suggested that a large amount of the variation between the 1984 and the present surveys can be attributed to the different amounts of flood waters received prior to each survey, reflecting the dependence of these alien species on water.

The sections of the Kuiseb River censussed by Macdonald and Nott (1987) correspond to the first 20 km of the region upstream of Gobabeb. All species record-

ed in the present census were found in the 1984 census. *A. ochroleuca* and *D. innoxia* occurred more frequently and in greater abundance, while *D. stramonium* was less common in the present survey than in 1984.

The Kuiseb River flowed for the first time in six years in 1984 (M. Seely pers. comm.), and has flowed every year since (D.C.B. pers. obs.). As both censuses occurred following a flood the similarity of the results is not unexpected.

Management recommendations

One of the main aims of natural parks is to "maintain biotic diversity" and therefore the introduction and continued existence of any alien flora or fauna should be prevented if at all possible. While alien plants, particularly if they are invasive species, are considered undesirable in any conserved area, some species may be so abundant and occur with such frequency that their removal cannot be economically justified. In such instances indigenous species from the previously natural plant community may be lost.

Most of the alien plant species occurring in this region have originated from river catchment areas on the escarpment (Brown & Gubb 1986). These areas are outside of the park and constitute a seed source over which the authorities have little control. As alien plants are unlikely to be eradicated from these areas, reinfestation of conserved areas will be a continual problem. Unless biological control is introduced, manual control of alien plants must be an annual activity in order to be effective.

At present, the manual removal of alien plants and chemical poisoning of indivdual plants are the only feasible control methods accepted within the Namib Naukluft Park. As these are time-consuming and expensive, research into other methods of control, such as biological control, should be encouraged. *Ad hoc* observations suggest that *Prosopis* spp. can outcompete indigenous vegetation (Vinjevold *et al.* 1985). This has resulted in considerable effort being expended to eradicate this species from the Swakop River. Little is known of the competitive abilities of the other alien plant species occuring in the Namib, and ecological studies on these plants are required.

Some alien species may now form part of a climax vegetation community, as *Prosopis* spp. appears to do in parts of the Swakop River. If a species is found to be actively invading a community, its removal must be of highter priority than the removal of those species which already form part of a climax community. Studies to determine which species should be given highest management priority are urgently required.

In general the perennial alien species *N. glauca, R. communis* and *Prosopis* spp. occurred at lower abundances and had lower frequencies of occurrence than the annual species. Perennial species are slower growing and the mere fact of their greater longevity and potential impact on the local vegetation makes them more important and easier to control than annuals. They occur mainly on the banks of the main river channels, usually in association with the indigenous vegetation. The potential for competitive impact is therefore present and *ad hoc* observations indicate that in some areas the local vegetation has suffered from the presence of these alien species (D.C.B. pers obs.).

R. communis occurred in all four of the northern rivers, but dense infestations were found only in the Kuiseb River. *R. communis* now occurs throughout the Kuiseb River and may be actively invading sections where it was absent serveral years ago (D.C.B. pers. obs.). This could also be a result of changes in the environment enabling a succession of plant communities to occur. Between 1979 and 1983 the Kuiseb received little flood water (M. Seely pers. comm.). *R. communis* seems to require fairly moist conditions and from 1984 until the present, the Kuiseb has flowed regulary (pers. obs.) providing an ideal environment for vigorous growth and expansion of this species.

The status of *R. communis* is under question, with some authorities maintaining that it is indigenous to the area (Lenssen in prep.) Archaeological evidence suggests that this species occurred in the Namib over 3000 years B.P. (Sandelowsky 1977). Deacon (1986) suggested that it was introduced by stoneage man and therefore should still be considered alien. Until its status has been determined, any populations which are shown to be invading an area should be controlled.

The central river bed region of desert ephemeral rivers is being occupied by annual or relatively short-lived perennial alien species; *D. innoxia, D. stramonium* and *A. ochroleuca.* As this area normally contains few indigenous plants (D.C.B. pers. obs.) these alien species are thought to have little direct impact on indigenous vegetation.

D. innoxia is beyond mechanical control in all of the northern river systems. Dense infestations occurred in more than 80% of all river sections. Biological control of this species is the only realistic control method that is acceptible in conservation areas. A potentially new infestation of *D. innoxia* may be imminent in the Koichab system. Encouragement and assistance should be given to boundary farmers in this region to eradicate this species before it enters the park.

Macdonald and Nott (1987) suggested that as *D. stramonium* may be competitively inferior to its congener *D. innoxia* eradication is unnecessary. The present survey yielded no evidence that *D. stramonium* occurred in greater densities in areas of reduced *D. innoxia* abundance as would be expected, although abiotic conditions may have masked such processes. As *D. stramonium* was absent from the Tsauchab River and only one plant was found in the Tsondab River, it should be easily controlled in these rivers. *D. stramonium* had a fairly high frequency of occurrence in the Kuiseb and Swakop Rivers, but dense infestations oc-

curred only in the latter. However, until it is shown to have some impact on the indigenous vegetation removal of this species should not be given priority.

As dense infestations of *A. ochroleuca* occurred in over 50% of the sections of the Kuiseb River it would be difficult to eradicate. In the other rivers this species occurred with very low abundance ratings or was absent. It may be possible to control in these rivers, but until it has been shown to have an impact on the indigenous vegetation, removal should be considered to be of a low priority.

SUMMARY

The populations of alien plants in rivers of the Namib Naukluft Park were investigated and the rivers were assessed for degree of infestation. Management recommendations based on these results suggest that highest priority should be given to the removal of the perennial species; *Prosopis* spp., *N. glauca* and *R. communis* (Table 12). These species should be removed immediately from the Tsondab and Tsauchab Rivers and reinfestations searched for and removed annually.

If maintenance of natural species diversity is to be accorded high priority for the Namib Naukluft Park, these three species should be removed from the Swakop and Kuiseb Rivers.

Research into the competitive ability and impact of alien plant species on the indigenous vegetation should be initiated.

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REFERENCES

BROWN, C.J. & GUBB, A.A. 1986. Invasive alien organisms in the Namib Desert, Upper Karoo and the semi-arid savannas of western southern Africa. In: MACDONALD, I.A.W., KRUGER, F.J. & FERRAR, A.A. (eds.). The ecology and management of biological invasions in southern Africa. Cape Town: Oxford University Press: 93–108.

DEACON, J. 1986. Human settlement in South Africa and archaeological evidence for alien plants and animals. In: MACDONALD, I.A.W., KRUGER, F.J. & FERRAR, A.A. (eds.). The ecology and management of biological invasions in southern Africa. Cape Town: Oxford University Press: pp 3–19.

HENDERSON, L & MUSIL, K.J. 1984. Exotic woody plant invaders of the Transvaal. *Bothalia* 15(1 & 2): 297–313.

MACDONALD, I.A.W. & NOTT, T.B. 1987. Invasive alien organisms in central SWA/Namibia: Results of a reconnaisance survey conducted in November 1984. *Madoqua* 15(1): 21–34.

SANDELOWSKY, B.H. 1977. Mirabib – an archeological study in the Namib. *Madoqua,* 10(4): 221–284.

VINJEVOLD, R.D., BRIDGEFORD, P. & YEATON, R. 1985. Invasive aliens plants in the Namib-Naukluft Park. In: BROWN, C.J., MACDONALD, I.A.W. & BROWN, S.E. (eds.). Invasive alien organisms in South West Africa / Namibia. *South African National Scientific Programmes Report No. 119.* Pretoria: C.S.I.R: 24–27.

TABLE 12: A summary of management recommendations to eradicate alien invasive plants from the rivers of the Namib Naukluft Park.

Species	Annual/ Perennial	Probable ecological effect	Present method of eradication	Priority rating
Prosopis spp.	Perennial	High	Mechanical/chemical	High
R. communis	Perennial	Medium	Mechanical	Medium
N. glauca	Perennial	Medium	Mechanical	Medium
D. innoxia	Annual	Locally high	None	Locally high
D. stramonium	Annual	Little	None	Low
A. ochroleuca	Annual	Little	None	Low