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Invasive alien woody plants of the northern Cape

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Keywords: alien, invasive woody plants, Kalahari, Nama-Karoo Biome, northern Cape, *Prosopis* spp., roadside survey, Savanna Biome

ABSTRACT

The frequency and abundance of invasive alien woody plants were recorded along roadsides and at watercourse crossings in 31% (90/286) of the quarter degree squares in the study area. The survey yielded 23 species of which the most prominent invaders were *Prosopis* spp. The most prominent remaining species were: *Opuntia ficus-indica*, *Nicotiana glauca* and *Melia azedarach*.

The greatest abundance and diversity of alien invader plants were recorded near human settlements. More than half of the total recorded species have invaded perennial riverbanks. The episodic Molopo and Kuruman Rivers have been invaded almost exclusively by *Prosopis* spp., which in places have formed extensive stands.

UITTREKSEL

Die frekwensie en volopheid van uitheemse houtagtige indringerplante is langs paaie en by oorgange oor waterlope in 31% (90/286) van die kwartgraadvierkante in die studiegebied aangeteken. Daar is 23 spesies aangetref waarvan die prominentste indringers *Prosopis* spp. was. Die prominentste oorblywende spesies was *Opuntia ficus-indica*, *Nicotiana glauca* en *Melia azedarach*.

Uitheemse indringerplante was die volopste en het in die grootste verskeidenheid voorgekom naby plekke waar mense woon. Meer as die helfte van die spesies wat aangeteken is, het die oewers van standhoudende riviere ingeneem. Die tydelike Molopo- en Kurumanriviere is feitlik uitsluitlik ingeneem deur *Prosopis* spp. wat op sommige plekke uitgestrekte stande gevorm het.

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INTRODUCTION

Survey history and objectives

This study of the northern Cape is the fourth of eight regional surveys which together are designed to reflect invasion by woody alien plants in the Republic of South Africa as a whole. Surveys have been completed for the Transvaal (Henderson & Musil 1984), Natal (Henderson 1989) and Orange Free State (Henderson 1991). This survey of the northern Cape was undertaken in April 1989.

The objectives of the survey are: to produce a checklist of the major invasive alien woody plants of streambank, roadside and veld habitats in the study area; to determine the pattern of alien woody invasion as a whole and for individual species; to attempt to relate distribution to environmental factors and to determine which are the most prominent and potentially important invaders.

The study area

The study area is the Cape Province north of the Orange River. It is bounded by Botswana in the north, Namibia in the west, and the Transvaal and Orange Free State in the east. It lies between latitudes 25° and 30°S and longitudes 20° and 26°E (Figure 1).

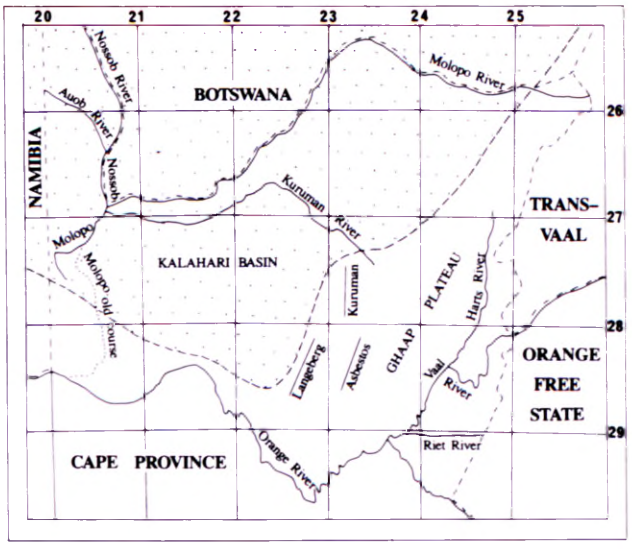

FIGURE 1.—The study area, showing the major physical features and its relation to surrounding territories.

The study area incorporates the southern end of the Kalahari basin which is a virtually continuous surface of red or whitish sand stretching from the Orange River in the south to equatorial Africa in the north (Wellington 1955). Longitudinal dune ridges are most strongly developed in the south-western parts of the study area. Towards the east the sand forms a flat to undulating surface. The altitude of this sandy area ranges from 600 to 1 200 m above sea level (King 1951). The southern periphery of the basin is bordered by a plateau of higher-lying rocky terrain. The most prominent features are the Langeberg, Kuruman and Asbestos Mountains and the Ghaap Plateau (Figure 1). The latter lies about 1 500 m above sea level and is an outlier of the extensive Highveld plateau of South Africa, detached from it by the Harts, Vaal and Orange Rivers.

The major rivers draining the plateau of the study area are the Orange, Vaal, Harts and Riet Rivers, all of which are usually perennial and flow from east to west. The Kalahari basin is drained by the Molopo and Kuruman Rivers from the east, and the Auob and Nossob Rivers from the north-west. All four rivers converge in the centre of the basin, the Molopo receiving the other three as tributaries. These rivers are usually dry, flowing only for short periods during abnormally wet seasons. The rare floodwaters that reach the lower course of the Molopo River are diverted by a sand dune across the old river course into a large pan (Leistner 1967).

The climate ranges from arid in the west to semi-arid in the east (Schulze & McGee 1978). Rain falls mainly in summer and is extremely variable (Tyson 1986). The mean annual rainfall ranges from less than 200 mm in the west to about 500 mm in the east (King 1951). Summers are very hot with temperatures frequently exceeding 30°C (Tyson 1986) and maximum temperatures generally in the vicinity of 40°C and occasionally higher (Bands & Britton 1977; Leistner 1967). Winter temperatures can drop below 0°C (at least 30 days per annum in the east) (Tyson 1986) and frost varies from light in the west to moderate in the central and eastern parts (Poynton 1972).

There are two biomes, Savanna and Nama-Karoo, in the study area (Rutherford & Westfall 1986) (Figure 2). The Savanna Biome, characterized by the codominance of hemicryptophytes (mainly grasses) and phanerophytes (trees and shrubs) is situated in the central and eastern semi-arid parts. The Nama-Karoo Biome, characterized by the codominance of hemicryptophytes (mainly grasses) and chamaephytes (dwarf shrubs), is situated in the western arid parts. Both these Biomes incorporate parts of the Kalahari basin and the stony plateau.

Seven Acocks Veld Types (Acocks 1988) occur in the study area (Table 1) of which Kalahari Thornveld (No. 16) is the most extensive and occupies the greater part of the region. This is a very broad veld type and occurs in one of Acocks's most under-sampled areas (Rutherford & Westfall 1986). More intensive studies by Gubb (in prep.) have revealed 21 major vegetation units in the northern Cape Savanna alone.

Rutherford & Westfall's (1986) delineation of the Savanna and Nama-Karoo Biomes cuts across Acocks's Veld Type categories in this region (Table 1). The main reason for this is the occurrence of different life form combinations in the same veld types (Rutherford & Westfall 1986).

The greater part of the study area is sparsely populated and is used for stock farming. The eastern regions of the Savanna Biome are primarily cattle farming areas, whereas the western regions of the Savanna Biome and the Nama-Karoo Biome are sheep farming areas (Gubb 1985). Intensive agricultural land use is mainly restricted to the land bordering the perennial rivers.

METHOD

Sampling method

The method used in this survey was basically the same as that used in previous surveys but with changes to the abundance scale for streambank habitats recommended by Henderson (1989) (see next subheading). The presence and abundance of all naturalized alien trees and large shrubs were recorded for each veld type category, habitat type (roadsides and adjoining veld, and streambanks) and

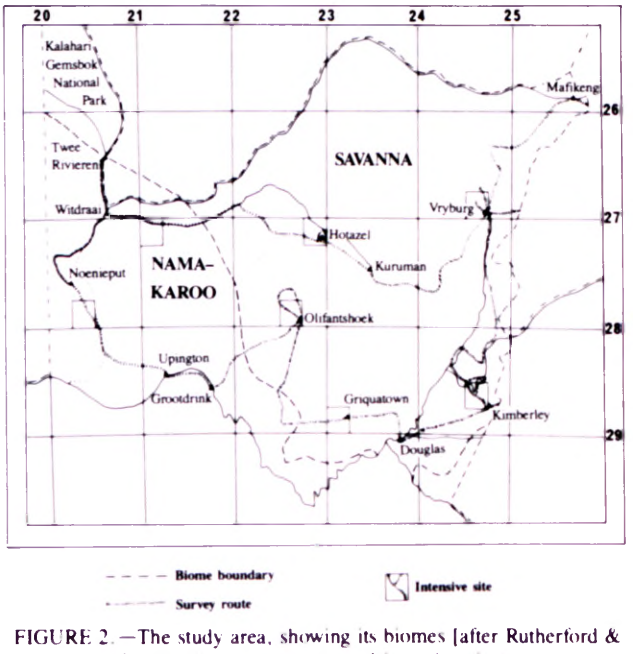

FIGURE 2.—The study area, showing its biomes [after Rutherford & Westfall (1986)], survey route and intensive sites.

TABLE 1.—Biomes [according to Rutherford & Westfall (1986)], Acocks Veld Type groupings and Veld Type numbers (Acocks 1988) sampled in the study area

Biome	Acocks Veld Type grouping	Acocks Veld Type No.
Savanna	Tropical bush and savanna types	16, 17, 19
	Karoo and False Karoo types	32, 40
Nama-Karoo	Tropical bush and savanna types	16, 17
	Karoo and False Karoo types	27, 32, 36

quarter degree/fifteen minute square traversed by road. Seven quarter degree squares were selected for more intensive surveying (Figure 2). They may be used at a later date for a quick resurvey of the study area to assess any changes that may have taken place.

Recordings of roadside and veld invaders were made from a moving vehicle along road transects of between five and ten kilometres in length. The average transect length was 8,9 km for the general survey and 5,0 for intensive sites. Abundance estimates were based on the frequency of encounter of invader species within each transect. Recordings of streambank invaders were made at watercourse crossings or at regular five kilometre intervals along watercourses with few or no crossings. The latter situation applied to the dry riverbeds of the Kuruman, Nossob and Molopo Rivers where roads travelled were either adjacent to the watercourses or in the riverbeds.

An unusual situation arose during this survey in that most of the roads used to survey the Nama-Karoo Biome followed watercourses very closely. Roadside recordings were continued as normal along these routes even though at times the road travelled was in the riverbed. This must be taken into account when interpreting the results for invaders of roadside and veld habitats in the Nama-Karoo Biome.

Abundance ratings

The abundance ratings for invaders of roadside and veld habitats and streambank habitats are given in Table 2. Henderson (1989) recommended that the abundance scale for streambank habitats be revised or replaced with a cover-abundance scale. In this survey the Braun-Blanquet cover-abundance scale has been used. Like the scale used in previous surveys, it has seven numbered ratings. The ratings in the old and new scales are roughly comparable. The new scale differs from the Braun-Blanquet scale, which is numbered from one to five with two ratings, r and +, below one. The upper four scale values refer only to cover, which is understood as the vertical crown or shoot-area projection per species. The lower scale values are primarily estimates of abundance, that is number of individuals per species (Mueller-Dombois & Ellenberg 1974). Whereas the Braun-Blanquet scale is intended to be applied to a reference area of uniform size, this has not been the case in this survey. Instead the reference area has been defined by the width of the watercourse and the distance (up to 100 m on either side of the crossing) to which invaders can be observed.

Sampling level achieved

The sampling level achieved was 31% (90 out of the total 286 quarter degree squares) at an average of 22,8 km travelled per square. An average of 17,7 km of road transects were sampled per quarter degree square for abundance estimates of roadside and veld invaders.

The coverage of each biome, Acocks Veld Type grouping and the whole study area is given in Table 3.

Data treatment—formulae used

Frequency

The percentage frequency of occurrence of a species x in a given category (biome or study area) y was calculated as follows:

$$\text{frequency} = \frac{\text{No. of watercourse recordings/road transects in category y having species x}}{\text{total no. of watercourse recordings/road transects in category y}} \times 100$$

TABLE 2.—Abundance ratings

Rating	Roadsides and veld	No.*	Streambanks	Rating
9	A virtually continuous, almost pure stand	1000+	Any number, with cover more than 75% of the reference area	7
8	The commonest species in a generally continuous tree or shrub layer	500–999	Any number, with 50–75% cover	6
7	Less abundant than above but greater than 20 individuals or groups per km	200–499	Any number, with 25–50% cover	5
			Any number, with 5–25% cover	4
6	10–20 individuals or groups per km	100–199	Numerous, but less than 5% cover or scattered, with cover up to 5%	3
5	5–10 individuals or groups per km	50–99		
4	2–5 individuals or groups per km	20–49	Few, with small cover	2
3	± 1 individual or group per km	5–19	Solitary, with small cover	1
2	Less abundant than above but more than 1 individual or group per 5 km	2–4		
1	± 1 plant or group per 5–10 km	1		

* Approximate numbers of individuals/groups per 10 km transect.

TABLE 3.—Sampling coverage of each biome, Acocks Veld Type grouping and the study area

Biome and Acocks Veld Type grouping	¼ degree squares	Road transects	Distance (km)*	Watercourse recordings
Savanna Biome	63	139	1 107	87
Tropical bush and savanna	60	129	1 031	74
Karoo and False Karoo	7	10	76	13
Nama-Karoo Biome	30	59	483	107
Tropical bush and savanna	25	47	383	66
Karoo and False Karoo	8	11	100	41
Study area	90	198	1 590	194

* This represents the distance along which abundance recordings were made. Total distance along which observations were made is approximately 1,3 times that given.

Prominence value

The prominence value is a combined measure of a species' frequency and abundance relative to that of all other species within a given category (biome or study area).

In streambank habitats the prominence value for species x in category y was calculated as follows:

$$\text{prominence value} = \frac{\text{total weighted abundance of species x in category y}}{\text{sum of the weighted abundances of all species in category y}} \times 100 + \frac{\text{frequency of species x in category y}}{\text{sum frequency of all species in category y}} \times 100$$

The abundance ratings were weighted according to the minimum percentage cover in each scale rating (see Table 2). Thus ratings 7, 6, 5 and 4 had weighted values of 75, 50, 25 and 5 respectively. Ratings 1, 2 and 3 each had weighted values of 1.

In roadside and veld habitats the prominence value for a species x in category y was calculated as follows:

$$\text{prominence value} = \frac{\text{total abundance* of species x in category y}}{\text{sum of the abundances* of all species in category y}} \times 100 + \frac{\text{frequency of species x in category y}}{\text{sum frequencies of all species in category y}} \times 100$$

Mean species abundance rating in roadside and veld habitats (see Table 7)

The mean abundance rating** of species x in a given category (biome or study area) y was calculated as follows:

$$\text{mean no. of individuals or groups per 10 km} = \frac{\text{total no. of individuals or groups of species x in category y}}{\text{total distance along which species x was rated in category y}} \times 10$$

Mean abundance of invaders per km in roadside and veld habitats (see Table 5 and Figure 4)

The mean abundance of invaders per kilometer in a given category (biome or study area) y/quarter degree square z was calculated as follows:

$$\text{Mean abundance} = \frac{\text{total abundance* of all species in category y/quarter degree square z}}{\text{total kilometres rated for abundance estimates in category y/quarter degree z}}$$

RESULTS

The survey yielded 23 naturalized alien species. These species are listed in the Appendix together with a further 13 species of trees and large shrubs which were obtained from Gubb (1985) and Brown & Gubb (1986). The distributions and high abundance areas of the 12 most prominent species are given in Figure 6.

In previous surveys the results were presented for each biome and their constituent veld type categories based on Acocks's Veld Type groupings. In this survey the results are only presented for each of the biomes as a whole. There are two reasons. Firstly, insufficient data was obtained for the separate analysis of the Karoo and False Karoo veld type categories. Secondly, as can be deduced from the introduction, Acocks's Veld Type categories are in need of revision in the study area.

The streambank habitat

The whole study area

One hundred and ninety four watercourse crossings were sampled in which 14 species were recorded, with up to eight species in one sample (Table 4). Invaders were present at 46,4% of all crossings and 7,2% of all crossings were heavily invaded (Table 4).

* each abundance rating was expressed in numbers of individuals or groups recorded per transect (see Table 2). To be both conservative and consistent the minimum number was used in each instance, e.g. an abundance rating of 5 over ten kilometres = 50 and an abundance rating of 5 over five kilometres = 25.

** mean no. of individuals or groups per 10 km converted to rating (see Table 2).

TABLE 4.—Streambank statistics for each biome and the study area

Biome	Total no. of spp.	Average no. of spp./crossing	Max. no. of spp./crossing	% crossings heavily invaded*	% crossings invaded**
Savanna Biome	12	0,7	4	3,4	40,2
Nama-Karoo Biome	10	0,7	8	10,3	51,4
Study area	14	0,7	8	7,2	46,4

* 1 or more species scored an abundance rating of 5 or more.
** invaders present.

TABLE 5.—Statistics for roadside and veld habitats in each biome and the study area

Biome	Total no. of spp.	Average no. of spp./¼° sq.	Max. no. of spp./¼° sq.	% transects invaded	% transects heavily invaded*	Mean abundance of invaders per km**
Savanna Biome	19	3,1	10	88,5	3,6	0,8
Nama-Karoo Biome	7	1,4	4	81,4	25,4	3,4
Study area	20	2,6	10	86,4	10,1	1,6

* 1 or more species scored an abundance rating of 5 or more.
** see data treatment—formulae used.

TABLE 6.—Alien species occurring in streambank habitats

Biome	Savanna Biome			Nama-Karoo Biome			Total study area		
No. watercourse crossings	87			107			194		
	F	I	P	F	I	P	F	I	P
Arundo donax	2,3		4,9	1,9		3,2	2,1		3,6
Eucalyptus sp. cf. *camaldulensis*	2,3	1,1	22,3	0,9		1,5	1,5	0,5	4,9
spp.	4,6		9,8	*			2,1		3,6
Melia azedarach	11,5		24,5	0,9		1,5	5,7		9,8
Nicotiana glauca	13,8	1,1	49,7	8,4		13,9	10,8	0,5	21,1
Opuntia ficus-indica	3,4		7,3				1,5		2,6
Parkinsonia aculeata	1,1		2,4				0,5		0,9
Populus sp. cf. *deltoides*	1,1		2,4				0,5		0,9
Prosopis spp.	13,8	1,1	49,7	48,6	10,3	173,8	33,0	6,2	139,6
Ricinus communis				0,9		1,5	0,5		0,9
Salix babylonica	6,9		14,7	0,9		1,5	3,6		6,2
Schinus molle	5,7		12,2				2,6		4,5
Tamarix sp.?				1,9		3,1	1,0		1,6

F = % frequency of occurrence; I = % crossings heavily invaded; P = prominence value; * species occurring in the given category but not included in a formal recording at a watercourse crossing.

Analysis according to veld type

There was more invasion in the Nama-Karoo Biome than the Savanna Biome in terms of percentage crossings invaded and percentage crossings heavily invaded (Table 4).

Analysis according to species

Frequency

Only *Nicotiana glauca* and *Prosopis* spp. were recorded at 10% or more crossings in the whole study area (Table 6). *Prosopis* spp. were by far the most frequently encountered species in the whole study area (33,0%) and particularly in the Nama-Karoo Biome (48,6%). They were much less frequent in the Savanna Biome (13,8%) but were still, along with *Nicotiana glauca* (13,8%) and *Melia azedarach* (11,5%), the most frequently recorded species.

Prominence

Prosopis spp. were the most prominent invaders in the study area with a prominence value of 139,6 out of a combined total for all species of 200 (Table 6). They were particularly prominent in the Nama-Karoo Biome where they were heavily invasive (i.e. scored an abundance rating of 5 or more) at 10,3% of all watercourse crossings (Table 6). Only *Eucalyptus* sp. cf. *camaldulensis* and *Nicotiana glauca* were also recorded as heavily invasive but much less frequently (Table 6).

Roadside and veld habitats

The whole study area

Ninety quarter degree squares and 198 road transects were sampled in which 20 species were recorded. Up to 10 species were recorded per quarter degree square. Invaders were recorded in 86,4% of all road transects sampled and 10,1% of all transects were heavily invaded (Table 5).

Analysis according to veld type

More invasion was recorded in the Nama-Karoo Biome than in the Savanna Biome in terms of percentage transects heavily invaded and the mean abundance of invaders per km. However, more species were recorded and a greater percentage of road transects were invaded in the Savanna Biome (Table 5).

Analysis according to species

Frequency

The most frequently recorded species in the study area were: *Prosopis* spp. (54,5%), *Opuntia ficus-indica* (41,9%), *Melia azedarach* (18,7%) and *Nicotiana glauca* (12,6%) (Table 7).

Prosopis spp. with a percentage frequency of 81,4% were by far the most frequently recorded species in the Nama-Karoo Biome. They were the only species to be recorded in more than 10% of all transects in the biome.

The most frequently recorded species in the Savanna Biome were *Opuntia ficus-indica* (56,8%), *Prosopis* spp. (43,2%) and *Melia azedarach* (26,6%). Other species which were less frequent but which were recorded in more than 10% of all transects were *Nicotiana glauca*, *Opuntia* sp. cf. *robusta* cultivars and *Agave americana*.

Prominence

Prosopis spp. scored the highest prominence values in the whole study area (109,8) and in the Nama-Karoo Biome (186,5) (Table 7). *Opuntia ficus-indica* was the most prominent invader in the Savanna Biome with a prominence value of 65,2 followed by *Prosopis* spp. and *Melia azedarach*.

Prosopis spp. were the only species recorded as heavily invasive (i.e. scored an abundance rating of 5 or more) in the Nama-Karoo Biome. In the Savanna Biome *Prosopis* spp., *Opuntia ficus-indica* and *Nicotiana glauca* were the only species recorded as heavily invasive.

Patterns of invasion

In roadside and veld habitats there was a general trend for increased species diversity of alien woody invaders from the arid west to the less arid east (Figure 3). In streambank habitats there was no clear west-east trend (Figure 4) but rather a trend for increased species diversity from dry or seasonal rivers to perennial rivers. For example, only three species were recorded along the Kuruman, Molopo amd Nossob Rivers while up to nine species were recorded along each of the Orange and Vaal Rivers and a combined total of 13 species along both rivers.

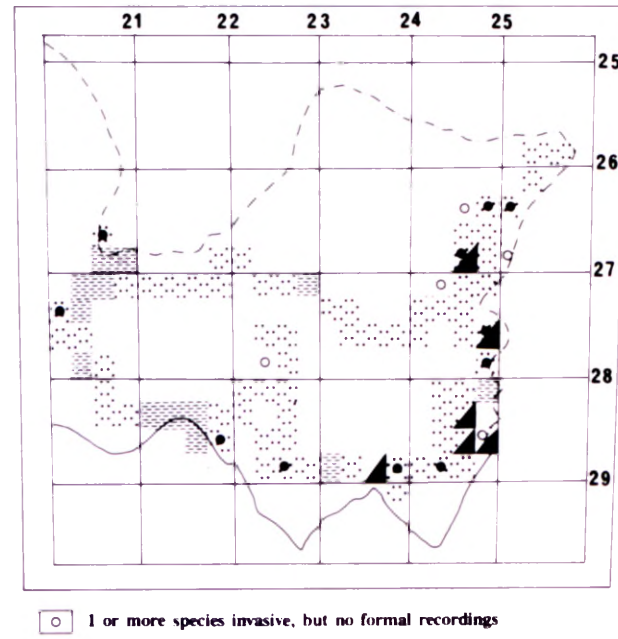

FIGURE 3.—Invasion in roadside and veld habitats in terms of the intensity of invasion of road transects and species diversity per quarter degree square.

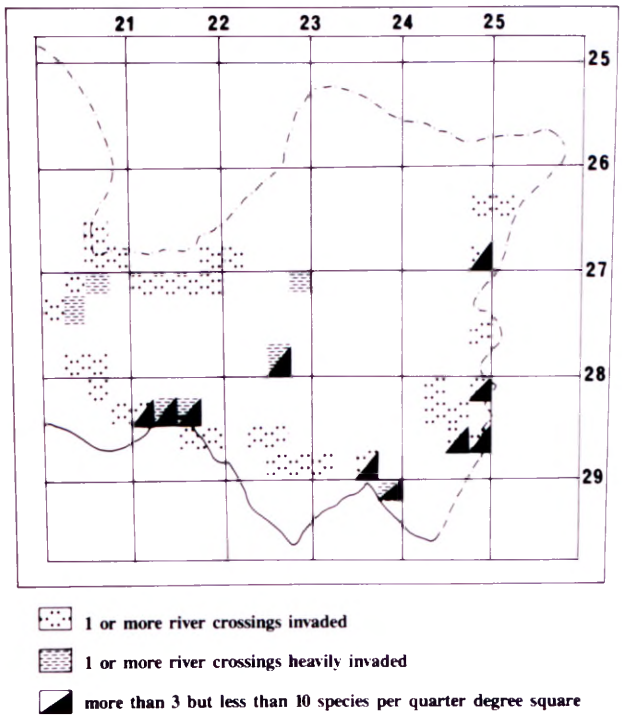

FIGURE 4.—Invasion in streambank habitats in terms of the intensity of invasion of watercourse crossings and species diversity per quarter degree square.

Heavily invaded watercourses and road transects were almost entirely due to infestations of *Prosopis* spp. The details regarding infestations of *Prosopis* spp. are given in Table 8. Heavily invaded road transects occurred almost exclusively where roads travelled were either adjacent to seasonal or perennial watercourses such as at Upington, Douglas and Hotazel or in dry riverbeds such as along the Molopo and Kuruman Rivers (Figures 3 & 5). The most severe invasion of watercourses in terms of the abundance of invaders was recorded along the dry riverbed of the Molopo River south of Witdraai and along dry or seasonal tributaries of the Orange River between Upington and Grootdrink (Figure 4, Table 8).

DISCUSSION

Sampling level achieved and validity of results

The sampling level achieved (31,9%) was considerably less than in previously surveyed regions (Transvaal—60%, Natal—87%, and Orange Free State—66%). This was considered justifiable due to the greater aridity and uniformity of the indigenous vegetation, smaller human population and lesser development of the present study area compared to previously surveyed regions. Previous studies have shown that one can expect less invasion in drier regions and in areas with less disturbance (Henderson & Musil 1984; Henderson 1989, 1991).

The survey route was carefully designed to cover a wide area, to traverse all major veld types and to sample as wide a range of habitats as possible. More extensive sampling of the perennial rivers, which appear to be the habitats most susceptible to invasion, would have been desirable. It may be possible to extend this coverage *en route* to the central and western Cape regions which are to be surveyed at a later date.

The tall grass cover over most of the study area at the time of the survey made it difficult to see certain species, particularly the low-growing *Opuntia* spp. It is suspected that the presence of these species was sometimes overlooked and their abundances underestimated.

Prominent and potentially important species

Most invasion in the study area can be attributed to *Prosopis* spp. The identification of the taxa within this genus is difficult because the characteristics used in identification (details of the leaflets, pods and spines) vary under different climatic conditions and there is evidence of hybridization (Harding 1987). As a result of these difficulties all invasive taxa of *Prosopis* have been referred to as *Prosopis* spp. in the results of this survey. However, some specimens were collected and these were identified as *P. glandulosa* var. *glandulosa*, *P. glandulosa* var. *torreyana* and *P.* cf. *velutina*.

P. glandulosa var. *glandulosa* appeared to be the least invasive and this is in agreement with findings by Harding (1987). *P. glandulosa* var. *torreyana* appeared to be the most prominent invader in the densely infested area along the Molopo River south of Witdraai. *P.* cf. *velutina* and *P. glandulosa* var. *torreyana* were prominent in the Upington area. According to Harding (1987), *P. velutina* is invasive in the Mafikeng area.

At least four other species of *Prosopis* have been introduced into southern Africa, the earliest known introduction date being 1879 or before (Poynton 1990). They were mainly introduced as a source of fodder, as they produce highly nutritious pods, and for shade (Harding 1987; Poynton 1990). In Leistner's (1967) study of the plant ecology of the southern Kalahari, which includes the major part of the Nama-Karoo Biome covered in the present survey, there is no mention of *Prosopis* spp.

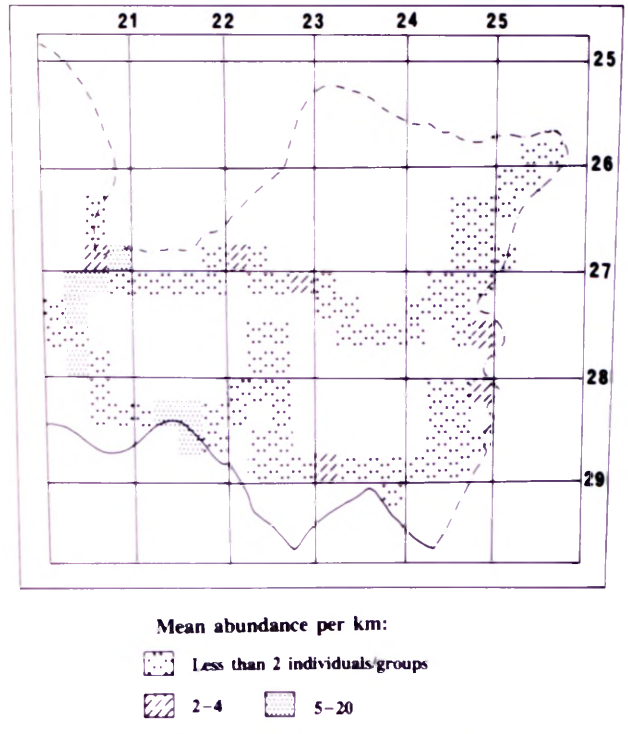

FIGURE 5.—Invasion in roadside and veld habitats in terms of the mean abundance of invaders per kilometre in each quarter degree square.

TABLE 7.—Alien species occurring in roadside and veld habitats

Biome	Savanna Biome			Nama-Karoo Biome			Total study area		
No. road transects	139			59			198		
	F	A	P	F	A	P	F	A	P
Agave americana	10,8	1,0	7,5				7,6	1,0	5,3
Arundo donax	2,2	1,0	1,5				1,5	1,0	1,0
Atriplex nummularia				1,7	2,0	1,9	0,5	2,0	0,4
Caesalpinia gilliesii	1,4	1,0	0,9				1,0	1,0	0,7
Eucalyptus spp.	2,2	2,0	1,7				1,5	2,0	1,1
Gleditsia triacanthos	*						*		
Melia azedarach	26,6	2,0	20,4				18,7	2,0	13,8
Nicotiana glauca	16,5	2,0	14,9	3,4	1,0	3,8	12,6	2,0	10,1
Opuntia ficus-indica	56,8	2,0	65,2	6,8	1,0	7,7	41,9	2,0	38,7
imbricata	5,0	1,0	3,7				3,5	1,0	2,5
rosea	0,7	2,0	0,6				0,5	2,0	0,4
sp. cf. *robusta*	11,5	1,0	8,4	*			8,1	1,0	5,8
stricta	2,2	1,0	1,5				1,5	1,0	1,0
Parkinsonia aculeata	0,7	1,0	0,5				0,5	1,0	0,4
Populus sp. cf. *deltoides*	3,6	3,0	7,2				2,5	3,0	3,4
Prosopis spp.	43,2	3,0	58,2	81,4	4,0	186,5	54,5	4,0	109,8
Ricinus communis	1,4	1,0	0,9				1,0	1,0	0,7
Schinus molle	7,2	1,0	5,3				5,1	1,0	3,7
Trichocereus sp. cf. *spachianus*	2,2	1,0	1,6	*			1,5	1,0	1,1

F = % frequency of occurrence; A = mean abundance rating; P = prominence value; * species occurring in the given category but not included in formal recordings in a road transect.

TABLE 8.—The most severe infestations of *Prosopis* spp.

$^1/_4$ degree square	Locality	Abundance rating/recording	
		Road transects	River crossings
2620 DC	Andriesvale, along Molopo River	5 over 7 km	
2620 DD	Askham, along Kuruman River	6 over 10 km	
2622 CC	Vanzylsrus, along Kuruman River	6 over 5 km	
2720 AB	Between Loch Maree and Linlithgow, along Molopo River	6 over 10 km	
2720 AD	Koopan-Suid, along Molopo River (at least 5 km of dense infestation)	7 over 10 km	7 (× 1)
2720 BA	Bonus to Loch Maree, along Molopo River (at least 6 km of dense infestation between Inkbospan and Loch Maree)	7 over 20 km	7 (× 1)
2720 CD	Vrouenspan to Soutpanputs	5 over 5 km 6 over 5 km 7 over 5 km	
2722 BB	Hotazel, along Ga-Mogara River	6 over 5 km	5 (× 1)
2821 AC	Upington, outskirts of town	5 over 5 km	
2821 AD	Upington-Grootdrink road, along Orange River	5 over 10 km 6 over 10 km	7 (× 6)
2821 BC	Upington-Grootdrink road, along Orange River	5 over 10 km 6 over 10 km	7 (× 2) 6 (× 1)
2821 DA	Upington-Grootdrink road, along Orange River	7 over 5 km	
2823 CC	Griquatown	6 over 5 km	

being naturalized and only *P. chilensis* is mentioned as a cultivated plant. Leistner (pers. comm. 1990) confirms that at the time of his survey (1957–1963) there were no thickets of *Prosopis* spp.

Invasions of *Prosopis* spp. only became obvious between 1976/77 and 1985 (Macdonald 1985). Macdonald (pers. comm.) has concluded that this was probably an episodic invasion event correlated with the exceptionally good conditions for establishment of seedlings during the high rainfall event of the 1970s.

Prosopis spp. have been estimated to cover an area of 200 000 ha in the north-western Cape, centred around Vanwyksvlei and Kenhardt (Harding 1987), which are situated to the south of the study area under discussion here. The habitats favoured are areas where ground water is assured and which 'unfortunately' are also the most fertile habitats in these arid regions (Harding 1987).

In the present study *Prosopis* spp. were most abundant along the dry riverbeds of the lower Molopo and Kuruman Rivers and tributaries of the Orange River between Upington and Grootdrink (Figure 6). The most extensive stands of *Prosopis* spp. were noted along the Molopo River. Since roads closely follow watercourses in this region, *Prosopis* spp. scored high abundance ratings in roadside as well as veld habitats. They were not confined to the riverbed of the Molopo River but in places had invaded dune valleys and the lower slopes of dunes.

Prosopis seed germination is enhanced by its passage through the digestive tract of animals (Harding 1987). This feature and the prolific seed production of the invasive *Prosopis* spp., and the effective dispersal of seed by water, domestic stock and a wide range of indigenous animals (Brown & Gubb 1986), all favour the further expansion of these species. All watercourses are potentially at risk from invasion by *Prosopis* spp. and it is predicted that without drastic control measures dense infestations could develop along large stretches of the Molopo and Kuruman Rivers. Cultivation along the banks of the Orange River could prevent the development of dense stands but seed washed down to the very arid uncultivated lower reaches of the river outside of the study area could also result in infestations of *Prosopis* spp.

A study of water-stress patterns in *P. glandulosa* var. *glandulosa* by Haas & Dodd (1972) showed that this species, while 'an extravagant user of readily available water', can protect itself from excessive stress when soil water becomes limiting. This drought-endurance mechanism together with its seed dispersal by many animals suggests that *Prosopis* spp. may have the potential to spread beyond watercourses to drier sites.

Hybridization could also result in the selection of hardy forms that can invade progressively more arid habitats. Already there have been observations of 'habitat-linked natural segregation' of hybrid swarms (Poynton 1990). 'Where mixed populations have colonised watercourses, site variation exercises a selective influence on genotype performance and survival, segregants resembling *P. chilensis* tending to dominate on deep, alluvial soils with a comparatively high water table, those resembling *P. glandulosa* var. *torreyana* occupying mesic situations and those with the velvety hairs of *P. velutina* being found mostly on dry, stony slopes' (Poynton 1990).

There appears to be little information on the ecological impacts of invasive *Prosopis* spp. The dense stands that flourish where ground water is available such as along the Molopo River, and the evidence provided by Haas & Dodd (1972) concerning the 'extravagant' water use by *P. glandulosa* var. *glandulosa*, leads one to speculate that *Prosopis* spp. could have a major impact on the hydrology of the ecosystems they invade.

Prosopis spp. were originally planted to provide shade and fodder for livestock. However, where thickets have developed, pod production has decreased (H.G. Zimmermann pers. comm.) and the dense, thorny growth not only restricts the movement of livestock but also results in their injury and even death (R. Price pers. comm.).

Cattle ranching areas in the Savanna Biome could be threatened by invasive *Prosopis* spp. Studies by Brown & Archer (1989) in south-western North America have shown that seedling emergence and survival of *P. glandulosa* var. *glandulosa* in grasslands is enhanced by herbaceous defoliation regardless of grazing history. They have a hypothesis that the recent invasion of grasslands in south-western North America by *P. glandulosa* var. *glandulosa* is related to the introduction of cattle and the effective dispersal of large quantities of viable seeds away from the riverine systems to which they were largely confined.

In an integrated approach to the control of *Prosopis* spp., research has been directed towards chemical and biological control and a means of utilizing the plants as a source of fodder, honey, pulp and firewood (G.B. Harding pers. comm.). The first releases of the seed-feeding beetle *Algarobius prosopis* were made in December 1987 and by August 1989 there were favourable reports concerning their dispersal from release sites and damage caused to *Prosopis* seeds (Olckers & Harding 1989).

Several *Opuntia* spp. were recorded in the study area and these occurred mainly or only in the Savanna Biome. *Opuntia ficus-indica* was the most frequently recorded species. Although it was widespread, it was rarely abundant. Both spiny and spineless forms were recorded. The smaller *Opuntia* spp. may have been underestimated, since they were difficult to see amongst the tall grass cover that prevailed over most of the study area. *O. stricta* is known to be abundant on several farms in the Stella area (H.G. Zimmermann pers. comm.) but only a few plants were seen scattered along roadsides during the survey. *O. rosea* has long been known to infest several farms in the Douglas District (Stirton 1978) but only a few plants were visible from the road. This species has also been noticed at Vryburg, Jan Kempdorp and Hartswater (De Beer 1986a) and at Kathu (M.J. Wells pers. comm.). *O. imbricata* is also likely to have been underestimated. *O. aurantiaca* was not seen during this survey but is known to be invasive in the south-eastern parts (Brown & Gubb 1986; Stirton 1978). All the *Opuntia* spp. recorded during this survey, with the exception of the blue-leaved cultivars (*O.* cf. *robusta* varieties), are the targets of biological control programmes. There has been substantial control of *O. imbricata* and *O. ficus-indica* (Zimmermann *et al.* 1986).

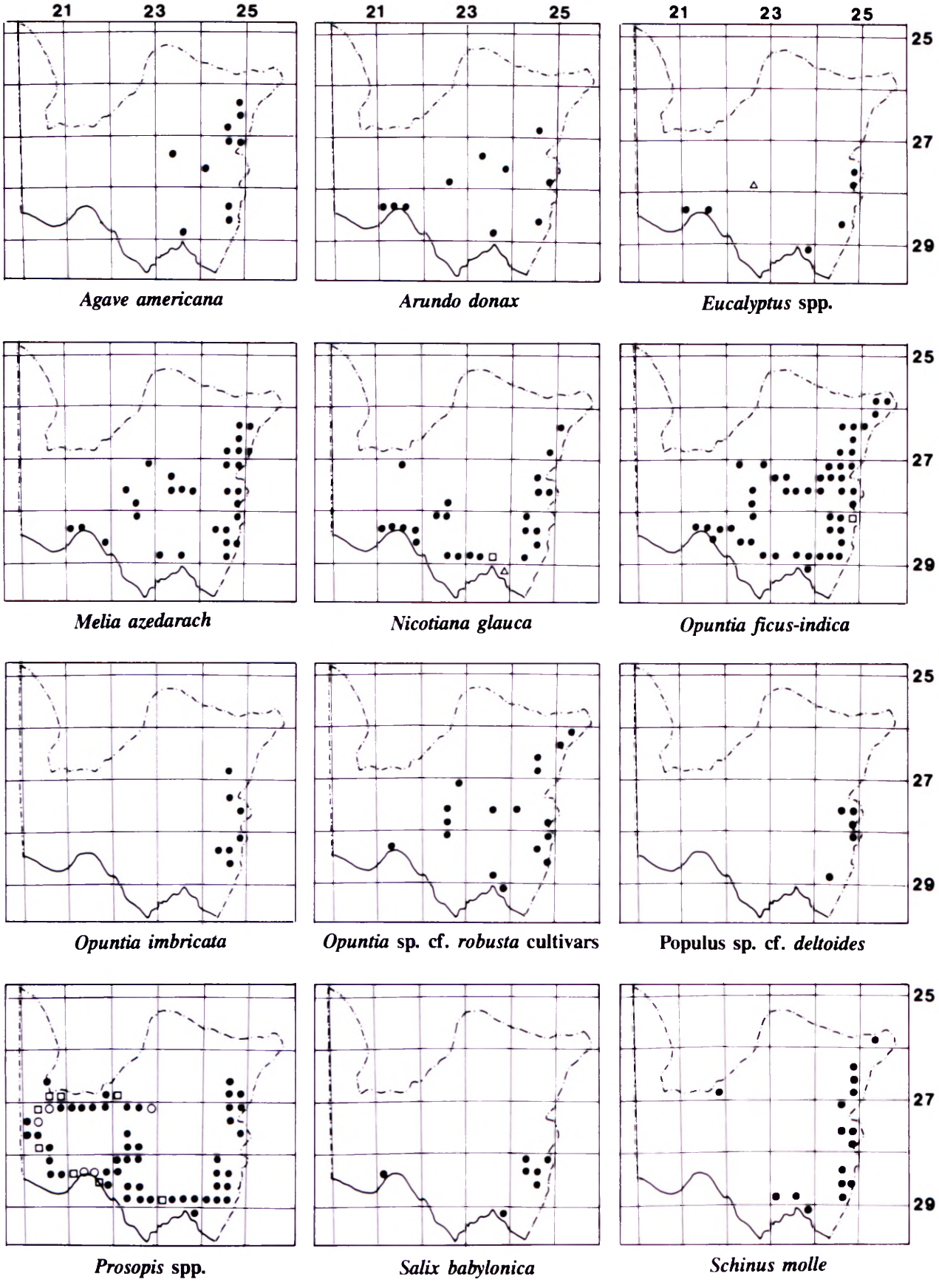

FIGURE 6.—Distribution of the most prominent species. Highest abundance rating of 4 or less: ●. Highest abundance rating of 5 or more: roadside and veld habitats, □; streambank habitats, △; streambank, roadside and veld habitats, ○.

A small cactus, possibly *Trichocereus spachianus*, which has been planted as a hedge and for ornament, has escaped locally. The much larger *Cereus peruvianus* (= cf. *jamacaru* fide H.F. Glen pers. comm.) which is invasive in the Savanna Biome of the Transvaal (Taylor & Walker 1984; Henderson & Wells 1986), and reported by Brown & Gubb (1986) as invasive in the northern Cape savanna, was rarely seen and only as a cultivated plant. These species should be regarded as potentially important invaders and naturalized plants should be eradicated. Since *C. peruvianus* is a declared weed in South Africa (Republic of South Africa 1984) all cultivated plants of this species should also be eradicated.

Nicotiana glauca is widely naturalized in southern Africa and in South Africa the greatest densities of plants occur in the dry western and central parts of the Cape (Stirton 1978). It is exceedingly abundant along the lower reaches of the Orange River through the Richtersveld (pers. obs.) and dense infestations occur along the lower 20 km of the Ugab River in northern Namibia (Brown & Gubb 1986). In the study area it was mostly recorded as isolated plants or small groups of plants in disturbed places such as along roadsides and road cuttings, around habitations, on piles of rubble and along perennial and seasonal watercourses.

Most *Eucalyptus* spp. were confined to the immediate surroundings of habitations and plantations. However, *Eucalyptus* sp. cf. *camaldulensis* was recorded along watercourses far from any plantings. According to Brown & Gubb (1986) *E. camaldulensis* and *E. microtheca* are highly invasive in the northern Cape savanna. Apart from their occurrence in virtually all habitats disturbed by human agency they have invaded naturally disturbed and undisturbed habitats. These include dry river alluvium, episodic river banks, rocky and sandy habitats, and islands in perennial rivers (Brown & Gubb 1986).

Most records of *Melia azedarach* were of isolated plants or small groups of plants. This species was largely confined to the Savanna Biome where it occurred most frequently along roadsides and around habitations, but it also occurred along perennial and seasonal watercourses. It was only recorded along the Orange River in the Nama-Karoo Biome. It could become an important invader of perennial rivers judging by its success in these habitats in other parts of South Africa (Henderson & Musil 1984; Henderson 1989).

Salix babylonica is widely naturalized along watercourses in the Grassland Biome of South Africa (Henderson in press). In the study area it was recorded mainly along the Vaal River in the Barkly West District. Since it only propagates vegetatively from detached branches (Henderson in press) its further spread in the study area will be limited to perennial and seasonal watercourses.

Arundo donax occurred mainly as small groups of plants along the Orange and Vaal Rivers and occasionally along roadsides, around habitations, and at watering points. Since it is very similar in appearance to the indigenous reeds (*Phragmites* spp.), there is a danger that it will spread unnoticed. It is capable of forming dense stands by propagating vegetatively from rhizomes. In the study area it may also spread from seed, since flowering plants were seen at Upington.

Agave americana was seen only in the immediate vicinity of habitations. It appears to propagate mainly vegetatively from suckers and bulbils in South Africa. Its spread is therefore very restricted except where plants may be dispersed by floodwaters.

Populus sp. cf. *deltoides* was only prominent between Jan Kempdorp and Taung in the Vaalharts irrigation scheme area where it has been planted as a windbreak for at least 20 km. Spread from this windbreak was restricted mainly to the adjacent veld and roadside. Its presence on islands within perennial rivers (pers. obs.; Brown & Gubb 1986) indicates that this species is also capable of invading habitats undisturbed by human activities.

Schinus molle was confined to the Savanna Biome. It was most frequently recorded along roadsides and in disturbed sites around habitations and mining areas but was also seen along watercourses. Its popularity as a shade and ornamental tree, its hardiness to drought and frost and its fleshy fruits which are attractive to birds (Ridley 1930) are all factors that should favour the further spread of this species. The same predatory wasp that has been found in the seeds of *Schinus terebinthifolius* and which may have prevented it from becoming a serious weed in Natal, has been found in the seeds of *S. molle* in various parts of South Africa (S. Neser pers. comm.). This wasp, however, appears to damage fewer seeds of *S. molle* than of *S. terebinthifolius* (S. Neser pers. comm.).

Relation of invasion to environmental factors

The greatest abundance and diversity of alien invader plants were recorded in disturbed sites near human settlements, such as the outskirts of towns, villages and farm homesteads. *Prosopis* trees planted in the dry riverbeds of the Molopo and Kuruman Rivers for shade and fodder are probably the major source of the infestations in these sites. Domestic livestock, wild animals and occasional floodwaters would all have assisted in the dispersal and germination of *Prosopis* seed.

Evidence that *Prosopis* seed is dispersed by episodic floodwaters in the southern Kalahari comes from the Kalahari Gemsbok Park. Macdonald (1985) reports that regular clearing operations have to be undertaken to remove *Prosopis* trees which come from seed washed in from Namibia during flood years. Seed germination of *Prosopis* spp. is also only likely to occur after rains or river floods. These conditions are necessary for the germination of indigenous plants in the southern Kalahari as the moisture supplies in the upper soil layers are otherwise inadequate (Leistner 1967).

There have been at least four major flooding events in the southern Kalahari this century. These were in 1918, 1934, 1963 (Leistner 1967) and 1972–1976 (Anon. 1974a; Van der Walt 1976). Although the floodwaters reached the lower Molopo River in the first three instances, there were no *Prosopis* infestations recorded until after the run of high rainfall and flooding events of the 1970s (Kruger *et al.* 1986; Macdonald 1985). Exceptional rainfall was recorded in the Kalahari Gemsbok Park in 1974–1976 (Anon. 1974a & b; Rodrigues 1987; Van der Walt 1976). The Auob River flowed in five consecutive years from 1972–1976 (Anon. 1974a; Rodrigues 1987), the Nossob in at least

two years, 1972 and 1974 (Anon. 1974a). The Kuruman River flowed for the first time in living memory in 1974 and again in 1975 and 1976, reaching the lower Molopo River at Andriesvale in each instance (Haagner 1976).

Perennial rivers not only provide a reliable means of dispersal for alien species, but conditions in the streambank habitat may also play a role in reducing water stress and thereby allowing acclimatization to the arid climate. Most of the alien species which have spread far from plantings have done so along watercourses. These include *Nicotiana glauca, Eucalyptus* sp. cf. *camaldulensis, Prosopis* spp., *Melia azedarach* and *Salix babylonica*.

Humans and animals are the most important agents in the dispersal of the *Opuntia* spp. (H.G. Zimmermann pers. comm.). *O. ficus-indica*, the most widespread species, reproduces both vegetatively from detached plant parts, and from seed which is dispersed by humans, baboons, cattle and possibly other animals. *O. stricta* is very localized at present, which suggests that only *in situ* vegetative propagation from plant fragments has occurred. Its fruits are sour and therefore likely to be less attractive to humans and animals than the fruits of *O. ficus-indica*. However, it is dispersed by baboons in the Kruger National Park (K. Maggs pers. comm.), and in Australia, where it became a major pest, it was spread by many species of birds and animals (Mann 1970).

Opuntia rosea and *O. imbricata* are spread vegetatively from plant fragments which are easily detached. Barbed hooks on the spines enable these fragments to become easily attached to passing humans and animals. *O. rosea* can also be dispersed by farm implements and vehicles (De Beer 1986a, b).

CONCLUSION

Several factors have contributed to the relatively low level of alien plant invasion in the northern Cape. The most important of these are the arid climate and extremes of temperature which have drastically limited the number of alien species that could be grown here successfully. Compared to the regions further east, there has been little agricultural development and human settlement and hence fewer propagules of alien plants and less disturbance of the natural plant cover.

The invasive *Prosopis* spp. are a cause for major concern. All watercourses are potentially at risk from invasion by these species and there is a possibility that they may spread to drier sites. Already they have formed dense stands along stretches of the Molopo and Kuruman Rivers and tributaries of the Orange River. Dense stands along the episodic rivers could have a serious impact on the hydrology of these ecosystems. This, together with the impenetrability of the infestations and injuries caused to livestock, could threaten the livelihood of farmers along these watercourses.

The *Opuntia* spp. known to be invasive in this region are not considered to be a serious problem since various methods of control are available for all of them. The danger lies in their uncontrolled spread and this applies particularly to *O. rosea* for which there is no effective biological control at this stage (H.G. Zimmermann pers. comm.). There is also a danger that new species of *Opuntia* or other genera of the family Cactaceae may become invasive.

The perennial rivers have been invaded by a spectrum of alien species and the intensity of invasion is likely to increase in the future. Until studies have been undertaken to assess the ecological impacts of these invaders, efforts should be made to control the spread of all alien plant species along rivers and to discourage the planting of alien trees along riverbanks.

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APPENDIX

The names of 36 species of naturalized alien trees and shrubs are listed. Some non-woody species are included. Names and dates in brackets: literature references.

Agave americana L., century plant
Arundo donax L., giant reed
Atriplex nummularia Lindl., saltbush
Caesalpinia gilliesii (Wall. ex Hook.) Benth., bird-of-paradise
Cannabis sativa L. (Brown & Gubb 1986), dagga
Casuarina equisetifolia G. Forst. (Brown & Gubb 1986), horsetail tree
Cereus peruvianus (L.) Mill. [= cf. *jamacaru* DC. (fide H.F. Glen, pers. comm.)] (Brown & Gubb 1986), queen of the night
Crotalaria juncea L. (Brown & Gubb 1986), deccan hemp
Eucalyptus
 camaldulensis Dehnh. (Brown & Gubb 1986), red gum
 microtheca F. Muell. (Brown & Gubb 1986)
 *sideroxylon*A. Cunn. ex Woolls (Brown & Gubb 1986), black ironbark
Gleditsia triacanthos L., honey locust
Melia azedarach L., syringa
Nicotiana glauca R.C. Grah., wild tobacco
Opuntia
 aurantiaca Lindl. (Brown & Gubb 1986), jointed 'cactus'
 ficus-indica (L.) Mill., sweet prickly pear
 imbricata (Haw.) DC., imbricate prickly pear
 rosea DC., rosea 'cactus'
 stricta Haw., pest pear of Australia
 sp. cf. *robusta* cultivars
Parkinsonia aculeata L., Jerusalem thorn
Physalis peruviana L. (Brown & Gubb 1986), Cape gooseberry
Populus deltoides Bartr. ex Marsh. (Brown & Gubb 1986), match poplar
Prosopis
 glandulosa Torr.
  var. *glandulosa*, mesquite
  var. *torreyana* (Benson) Johnston
 sp. cf. *velutina* Wooton, velvet mesquite
 spp. [possibly *P. chilensis* (Mol.) Stuntz, *P. juliflora* (Swartz) DC. and *P. pubescens* Bentham according to Gubb (1985)]
Ricinus communis L., castor-oil plant
Salix babylonica L., weeping willow
Schinus molle L., pepper tree
Sesbania punicea (Cav.) Benth. (Brown & Gubb 1986), red sesbania
Tamarix
 ramosissima Ledeb. (Brown & Gubb 1986), pink tamarisk
 ? sp.
Trichocereus cf. *spachianus* (Lemaire) Riccobono