The geometric tortoise (*Psammobates geometricus*) in a fragmented habitat along a national highway: status and mitigation

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DECLARATION

I the undersigned hereby declare that the work contained in this thesis is my own original work and has not previously in its entirety or part been submitted at any university for a degree.

SUMMARY

The geometric tortoise, *Psammobates geometricus*, found in the Western Cape, South Africa, is one of the world's rarest tortoises. At present, it is only known from five isolated geographical areas, one being the Worcester-Tulbagh Valley. The primary aims of my study were to determine the status of geometric tortoise subpopulations along the N1 highway in the Worcester Valley, to determine the population structure of these subpopulations and, if necessary, to provide recommendations for the mitigation of N1 highway-induced impacts on geometric tortoise subpopulations along the road. All Renosterveld remnants along the N1 between Du Toitskloof and Worcester were surveyed for the presence of geometric tortoises, and tortoise density and population structure were determined for each remnant that supports tortoises. Two geometric tortoise subpopulations on opposite sides of the N1 were identified. In the larger remnant of the two, females dominated both the subadult and adult classes, whereas in the other remnant male frequency was slightly higher than female frequency for the adult class only. In both remnants, adult females were significantly larger than adult males in mean carapace length. Mean body mass for adult females and males also differed significantly in both remnants. Analysis of habitat quality showed that both remnants supporting the geometric tortoise are seriously infested by encroaching indigenous and alien plants. The barrier effect of the N1 highway can be mitigated by constructing underpasses, linking the two remnants on opposite sides of the road. Furthermore, road mortality of tortoises can be avoided by erecting tortoise proof fencing along appropriate sections of the highway in the Worcester Valley. By

linking the remnants, the largest single area available to the geometric tortoise in the Worcester Valley will also be formed. An additional aim of my study was to investigate the correspondence of geometric tortoise density in individual habitat remnants to the West-to-East change in vegetation composition/characteristics occurring along the N1 in the Worcester Valley. Vegetation composition/characteristics were thus determined in all remnants also surveyed for tortoises. The West-to-East change in vegetation composition/characteristics of the study area indicates that there is a transition from Renosterveld in the West to karroid veld in the East.

OPSOMMING

Die geometriese skilpad, *Psammobates geometricus*, wat in die Wes-Kaap, Suid-Afrika, voorkom, is een van die wêreld se skaarste skilpaaie. Vandag word hierdie skilpad net nog in vyf geïsoleerde geografiese streke gekry, een van hulle die Worcester-Tulbagh Vallei. Die primêre doel van my studie was om die status van geometriese skilpad subpopulasies langs die N1 snelweg in die Worcester Vallei te ondersoek en om die populasiestruktuur van hierdie subpopulasies te bepaal. Verder was die doel ook, om aanbevelings te maak oor hoe die impakte van die pad op die geometriese skilpad subpopulasies langs die N1 verminder kan word. Al die Renosterveld oorblyfsels langs die N1 tussen Du Toitskloof en Worcester, en binne die bekende gebied van die geometriese skilpad, is deursoek vir geometriese skilpaaie. Populasiedigtheid en populasiestruktuur van die skilpaaie is bepaal vir elke oorblyfsel wat skilpaaie bevat. Twee geometriese skilpad subpopulasies is gekry aan teenoorgestelde kante van die N1. In die groter oorblyfsel, het wyfies albei die onvolwasse en volwasse klasse gedomineer. In die ander oorblyfsel is gevind dat die frekwensie van mannetjies ietwat hoër was as die frekwensie van wyfies, maar vir slegs die volwasse kategorie. Binne albei oorblyfsels is gevind dat volwassse wyfies betekenisvol groter in gemiddelde doplengte is as volwasse mannetjies. Gemiddelde liggaamsgewig het ook betekenisvol verskil tussen volwasse wyfies en mannetjies in albei oorblyfsels. 'n Analise van habitatkwaliteit het gewys dat beide oorblyfsels wat die geometriese skilpad ondersteun grootliks ingeneem is deur inheemse indringers, sowel as uitheemse plante. Die versperrings effek van die N1 snelweg kan verminder word deur duikwege te skep wat die twee ooblyfsels, op teenoorgestelde kante van

die pad, verbind. Bowendien, deur 'n ondeurdringbare heining langs passende dele van die snelweg in die Worcester Vallei op te rig, sal skilpadmortaliteit vermy word. Deur oorblyfsels te verbind, sal ook die grootste enkele area, beskibaar aan die geometriese skilpad in die Worcester Vallei, gevorm word. 'n Addisionele doel van hierdie studie was om veranderinge in vegetasie langs 'n wes-na-oos gradient binne die studie area te korreleer met die teenwoordigheid van skilpaaie langs hierdie gradient. Vegetasie samestelling/eienskappe is dus bepaal vir elke oorblyfsel wat deursoek is vir skilpaaie. Die wes-na-oos verandering in vegetasie samestelling/eienskappe binne die studie area wys dat daar 'n oorgang van Renosterveld in die weste na 'n karooagtige veld in die ooste is.

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INTRODUCTION

Roads play a major role in the fragmentation of habitat all over the world (Forman & Alexander 1998). The effects of roads and vehicles on populations of animals usually can be divided into three categories: (1) mortality of individuals trying to cross the road, (2) road avoidance behaviour and (3) the very important 'barrier effect' (Forman & Alexander 1998). During the last three decades, roads with vehicles probably overtook hunting as the leading direct human cause of vertebrate mortality on land (Forman & Alexander 1998). Overall, however, road kill rates do not seem to impact healthy populations significantly, but it appears to affect species negatively that are endangered or threatened (Forman 1995; Bekker & Canters 1997; Forman *et al*. 1997). Traffic noise seems to be the most important cause of road avoidance by animals, although visual disturbance, pollutants, and predators moving along a road are alternative hypotheses. The barrier effect, however, may emerge as the greatest ecological impact of roads with vehicles. All roads serve as barriers or filters to animal movement and it is this effect that thereby tends to create meta-populations, i.e. roads often divide a large continuous population into smaller, partially isolated local populations (subpopulations). These subpopulations fluctuate more widely on a temporal scale and therefore have a higher probability of extinction than do larger populations (Van der Zande *et al*. 1980; Soulé 1987; Opdam *et al.* 1993). If a local extinction occurs within such a small isolated population, then the road often also prevents the re-colonization process by blocking animal movement across the road. Long-term consequences of such isolation are, for example, inbreeding and skewed sex ratios resulting in a loss of genetic variation as well as decreased reproductive output in the isolated populations (Lindenmayer & Lacy 2002).

Today, Renosterveld is extremely threatened due to past agricultural practices that resulted in the destruction of more than 95% of this vegetation type (Low & Rebelo 1998). Lowland Renosterveld is also the preferred habitat of the geometric tortoise, *Psammobates geometricus,* and the distribution of this tortoise consequently is strictly limited to the low-lying regions of this fynbos vegetation type (Baard 1995). A high degree of specialisation by the tortoise to the Renosterveld environment seems to be the explanation for the tortoise's distributional confinement (Baard 1992). The destruction and fragmentation of lowland Renosterveld habitat thus, in a synergy with threats such as alien plant infestation, overgrazing, erosion, trampling and too frequent fires, have been and continue to be the main reasons for the decline in geometric tortoise numbers (Baard 1992). It is therefore self-explanatory why the geometric tortoise has become critically threatened and is currently regarded as the most endangered of the southern African, and even one of the world's most endangered, tortoises (Baard *et al.* 1999). Nationally and globally, the geometric tortoise has become a conservation priority and is listed as 'Endangered' in the 2000 IUCN Red List of Threatened Species (Hilton-Taylor 2000).

Presently, *P. geometricus* occurs in five isolated geographical areas, which are the Ceres Valley, the Worcester-Tulbagh Valley, the Helderberg basin, the Klapmuts area and Agtergroenberg area (north of Wellington) (Baard 1993; Baard & Mouton 1993). The Agtergroenberg and Klapmuts populations, however, are reportedly the only viable populations left on the southwestern coastal lowlands, with the Harmony population near Gordon's Bay being close to extinction (Baard pers. comm.). The Ceres and Worcester-Tulbagh valleys, on the other hand, apparently still contain viable populations of geometric tortoise, which, nevertheless, are in need of urgent conservation action to secure their survival (Baard 1990; Baard pers. comm.).

Conservation priority, at this stage, should be the Worcester Valley population since the environment here is under extreme pressure from urban and agricultural development. In the Worcester Valley, the geometric tortoise has been recorded on Renosterveld habitat along a narrow band roughly following the N1 highway, extending from the Jan du Toit River in the West to Worcester's Brandwacht residential area in the East (Greig & Boycott 1977; Baard 1990; Baard 1993). The status of geometric tortoise subpopulations in the Worcester Valley, however, has only last been evaluated in 1985/6 and 1989/90, which was prior to the construction of the present N1 highway (Baard 1990). The construction of the present N1 highway contributed to further fragmentation of the already severely fragmented Renosterveld in the Worcester Valley. The proposed N1 N2 Winelands Toll Highway Project, which will include upgrading of the N1, as well as the construction of interchanges and toll plazas, may further impact on the geometric tortoise in the Worcester Valley (Fig. 1). The proposed toll project, however, also offers the opportunity to mitigate current impacts of the N1 on the Worcester Valley geometric tortoise population. In a specialist study on the potential impacts of the proposed N1 N2 Winelands Toll Highway Project on the terrestrial fauna, Mouton (2002) identified road kills and the barrier effect as current impacts on the geometric tortoise and habitat destruction through the construction of an interchange as a future impact. He pointed out, however, that the presence of the geometric tortoise on habitat remnants along the N1 is uncertain and that surveys are urgently required to assess the current status of the tortoise in this area. The aims of my study therefore were to determine the presence of the geometric tortoise on Renosterveld remnants bordering the N1 in the Worcester Valley, to determine the population structure of the subpopulations found, and, if necessary, to make recommendations for the mitigation of N1 highway-induced fragmentation effects on the subpopulations on either side of the road. With known location and structure data of geometric tortoise populations, appropriate conservation measures can also be recommended.

A better understanding of the preferred habitat requirements of the geometric tortoise may allow for more effective management and conservation of the Renosterveld remnants supporting the geometric tortoise. In the vicinity of the N1 in the Worcester Valley, a gradual change in vegetation from a Renosterveld vegetation type in the West to a more karroid vegetation type in the East is clearly recognisable. An additional aim of my study was to investigate the correspondence of geometric tortoise density in individual habitat remnants to the West-to-East change in vegetation composition/characteristics occurring along the N1 in the Worcester Valley. Such an investigation could reveal important biogeographical information regarding the requirements and key environmental factors determining the distribution of the geometric tortoise.

METHODS AND MATERIALS

Study Area

The study area comprised Renosterveld remnants along the N1 highway immediately West of the town of Worcester in the Western Cape. The Jan du Toit River represented the western boundary of the study area with the western outskirts of Worcester delimiting the eastern boundary (Fig. 2). All Renosterveld remnants along the N1 between Du Toitskloof and Worcester were surveyed. Adjacent remnants were treated as separate when a barrier, such as a road, river or trench, prevented, or strongly impaired the exchange of geometric tortoises between remnants.

Tortoise Survey

A tortoise search team from the Western Cape Nature Conservation Board, having extensive experience in searching for tortoises in Renosterveld vegetation, assisted in surveying transects within the selected remnants. For each remnant, one or more representative transects were surveyed and by extrapolation from the tortoises counted, the tortoise density for the remnant was estimated. Dimensions of transects varied from 40 x 200 m (0.8 ha) to 40 x 700 m (2.8 ha). The number of transects per remnant was 1-2 for smaller remnants and 3-4 for larger remnants. During August 2002, a week long sampling period was undertaken and every transect was thoroughly surveyed by a team of 10-12 people walking 2-3 m apart in a straight line perpendicular to the long axis of the transect. Half of the transect area was covered when walking in one direction and the other half when walking in the opposite direction on the way back. Straight carapace length, body mass and sex were determined for each geometric tortoise found. Lengths were recorded to the nearest millimeter with a ruler and mass to the nearest 10 g with a Salter spring balance. For sex determination, the presence of a characteristically deepened plastron concavity, long tail and bulging supracaudal carapace shield was used to identify males. Male geometric tortoises develop these distinguishable secondary sexual characteristics at an approximate straight carapace length of 85-90 mm and it can therefore be assumed that males reach sexual maturity at this carapace length (Baard 1990). Due to the lack of any secondary sexual characteristics in female tortoises, accurate assessment of maturity in females is not possible (Baard 1990, 1995). Consequently, I used a straight carapace length of 85 mm as the length at which sexual maturity could be determined for both sexes with 100% confidence. Sex determination based on secondary sexual characteristics, however, was also confidently done on individuals with a straight carapace length of between 50-84 mm. Before being released at the point of capture, each individual was marked with non-permanent white eraser-fluid on the ventral side to avoid being recorded twice during the course of a census.

Vegetation Survey

Stratified sampling of Renosterveld remnants was conducted to determine vegetation composition/characteristics of all remnants surveyed for tortoises. A total of 40 plots were sampled across the study area, where each sample plot had 10 x 10 m dimension. The number of plots sampled per remnant was determined by the size of the remnant and the heterogeneity of the vegetation. During September 2002, the following information was collected for each plot: percentage canopy cover of succulents, shrubs, grasses (perennial/annual), restios, geophytes and herbaceous plants (perennial/annual). For shrubs, a species list was also compiled, identifying and recording the most dominant species and their individual percentage cover contributions. The percentage ground cover of stones and rocks in the plot was also noted. For each remnant, representative final cover values for each category were derived by determining the mean of the cover values recorded in each plot and assigning a 5% tolerance range.

RESULTS

Tortoise Survey

A total of 28 transects, representing eleven Renosterveld remnants (Fig. 2), were surveyed during the course of the study. By dividing the total number of geometric tortoises counted in each remnant by the area that was surveyed in the remnant, it was possible to calculate an approximate geometric tortoise density for the respective remnants (Table 1). Geometric tortoises were found on only three of the 11 remnants surveyed (Fig. 2). I recorded a tortoise density of 8/ha for Remnant A, 3/ha for Remnant B, and 1/ha for Remnant E. Structure of the geometric tortoise subpopulations on Remnants A and B was determined by recording the frequency of individuals falling into predetermined carapace length classes (Fig. 3). In Remnant A, females dominated both the subadult and adult classes, whereas in Remnant B male frequency was slightly higher than female frequency for the adult class only. In both Remnants A and B, I recorded more large females than large males. In Remnant A, adult females (mean = 13.1 ± 1.36 cm, N = 72) differed significantly from adult males (mean = 11.5 ± 1.03 cm, N = 35) in mean carapace length (t-test; $P < 0.05$). In Remnant B, adult females (mean = 13.0 ± 1.53 cm, N = 9) did also differ significantly from adult males (mean = 11.3 ± 0.93 cm, N = 14) in mean carapace length (t-test; $P < 0.05$). In Remnant A, body mass of adult females (mean = 527.5 ± 139.3 g, N = 72) differed significantly from that of adult males (mean = 275.0 ± 57.2 g, N = 35) (t-test; $P < 0.05$). In Remnant B, body mass of adult females (mean = 522.2 ± 145.3 g, N = 9) also differed significantly from that of adult males (mean = 267.9 ± 55.3 g, N = 14) (t-test; $P < 0.05$). In Remnant A, male to female ratio (adults) was biased towards females whereas the juvenile/subadult to adult ratio was biased towards adults (Table 1). In Remnant B, male to female ratio was biased towards males whereas the juvenile/subadult to adult ratio was also biased towards the adult class (Table 1). A population size estimate for Remnants A and B was obtained by multiplying the tortoise/ha density by the total area of each of the remnants (Table 1).

Description of vegetation in Remnants A and B

In all sections of Remnant A, members of the Restionaceae were found in a dense patchy distribution. It is estimated that restios cover approximately 30% of Remnant A's area. Dominant grass species in this remnant at this time of year were Staggers Grass *Melica decumbens* (Poaceae) and Gum Grass *Eragrostis gummiflua* (Poaceae) occurring at cover values of 2-6%. Succulents were very scarce and occurred at cover values of between 0-4%. Annual herbaceous species were mostly from the Asteraceae and were found to occur at cover values of 2-10%. Geophytes occurred at cover values of 0-3% in plots. Dominant species in this category were members of the *Oxalis* genus (Oxalidaceae). In Remnant B, Luibos *Lobostemon fruticosus* (Boraginaceae) occurred commonly in small patches. Similar to Remnant A, restios occurred in a patchy distribution across Remnant B and were estimated to cover approximately 30-35% of its area. Grass species found here were very few with a low cover value (2-10%), including *E. gummiflua*. Succulent species included Kinkelbos *Tetragonia fruticosa*

(Aizoaceae), but only occurred at very low cover values of 0-2%. Herbaceous species included Gousblom *Gazania krebsiana* (Asteraceae), Purple-gorse *Muraltia heisteria* (Polygalaceae), Skraalbossie *Senecio pubigerus* and Hongerblom *Senecio angustifolius* (Asteraceae). Cover values for herbaceous plants ranged from 5-10%. Similar to Remnant A, dominant geophyte species were also of the *Oxalis* genus (Oxalidaceae), but other genera also present included Slime Lily *Albuca* sp. (Hyacinthaceae), Blousuurkanol *Aristea* sp. (Iridaceae) and other members of the Iris family (Iridaceae). Geophytes were present at cover values of 2-4% in Remnant B.

Alien vegetation

Dense stands of the alien invasive Port Jackson willow *Acacia saligna* (Mimosaceae) were found in section A2 of Remnant A (Fig. 4). The other sections of this remnant only showed minimal signs of infestation by this plant. *A. saligna* was also recorded in Remnant B, but at a lower density than in Remnant A (Table 2).

Encroachment by indigenous shrubs

In section A1 of Remnant A encroachment is taking place by Cone Bush *Leucadendron salignum* (Proteaceae), Hartebeeskaroo *Stoebe* sp. (Asteraceae) and *Anthospermum spathulatum* (Rubiaceae). These all had relatively high percentage cover values (Table 2). Section A3 is heavily encroached by Steek Bos *Cliffortia ruscifolia* (Rosaceae). In section A4, *Stoebe* sp., *C. ruscifolia*, Blombos *Metalasia* sp. (Asteraceae) and Wild Rosemary *Eriocephalus africanus* (Asteraceae) are encroaching and present at high cover values (Table 2, Fig. 4). The section A5 also showed a high degree of encroachment by *C. ruscifolia*. Other dominant shrubs are Renosterbos *Elytropappus* *rhinocerotis* (Asteraceae) and *E. africanus* (Fig. 4). An encroaching shrub in Remnant B is an *Aspalathus* sp. (Fabaceae). According to Kemper *et al.* (1999), the above indigenous species are often seen to increase dramatically in disturbed Renosterveld, especially under high grazing pressure.

Vegetation Gradient

A density gradient for members of the Restionaceae as well as succulent plants was observed from West to East in the study area. The percentage canopy cover of succulents increased from West to East, whereas that of restios decreased from west to east (Fig. 5). For the other plant categories no clear trends could be identified. Species composition and individual cover contributions of shrub species, however, do show change from West to East (Table 4). The western parts of the study area harbour species such as *Aspalathus* sp. and *L. salignum*. In the eastern section of Remnant A, *C. ruscifolia* and *Stoebe* sp. were encountered. *Cliffortia ruscifolia* was found in several remnants towards the east (Table 4). The central section of the study area (Remnants B (eastern section), C, D, E, F, G) seemed to represent a 'transition' zone in that typical Renosterveld species such as *Aspalathus* sp., *Stoebe* sp., and *E. africanus* disappeared and species such as Sand Olive *Dodonaea angustifolia* (Sapindaceae), Penny Pod *Wiborgia obcordata* (Fabaceae), and Kraalbos *Galenia africana* (Aizoaceae) became dominant (Table 4). In the most eastern sections of the study area (Remnants H, I, J, K), *D. angustifolia* then became the dominant species together with Langsteel Korentebossie *Rhus dissecta* (Anacardiaceae), although some *C. ruscifolia* was found in these areas (Table 4). No clear trend in grass cover changes along the study area was observed. Neither herbaceous plant nor geophyte percentage cover values indicated any trend present. Rock cover values also did not reveal any trend.

DISCUSSION

Geometric tortoise records in the Worcester Valley

Within the Worcester Valley, confirmed sightings of geometric tortoises had been made in the Olifantsberg and Goudiniweg areas by Greig & Boycott (1977) (Fig. 2). In his 1985/6 and 1989/90 tortoise surveys of the Worcester Valley, Baard (1993) confirmed the presence of geometric tortoises at five localities in the Worcester Valley: Farm Kanaan, Farm Somarso, Farm Morgenrood, the former Hartebeestrivier Nature Reserve (Remnants E and F) and Farm Onderplaas (Remnant A and L) (Fig. 2). Baard (1990), reported that at least 19 geometric tortoises had been recorded from the, then, Hartebeestrivier Nature Reserve. Baard (1990) further mentioned that a wildfire destroyed most parts of this area implying high tortoise mortality. The presence of grazing, the isolated nature of the former reserve, the construction of the present N1 and the casualties caused by the wildfire in 1988 most probably are the reasons why only one geometric tortoise was found there (in Remnant E) during this study. With the vegetation in this area becoming very karroid, it can probably be assumed that this area previously represented the most eastern region of the tortoise's distribution within the Worcester Valley.

According to Baard (1990), the farm Onderplaas supported the densest known geometric tortoise population in the Worcester Valley. The results of this study also indicate that this area still supports a dense geometric tortoise population, even though, with the construction of the present N1 highway a few years ago, the area was effectively divided into two remnants (Remnants A and B) on opposite sides of the N1. Since no geometric tortoise surveys have previously been conducted there, it was not possible to describe a population trend. However, because of the geometric tortoise population density observed in this study, Remnants A and B should become the focus of future conservation efforts for the geometric tortoise along the N1 in the Worcester Valley.

Tortoise population structure

Knowledge of population structure is as important in tortoise populations as in any other species (Baard 1990). Similar to the population at Elandsberg Private Nature Reserve, the large proportion of adults in Remnants A and B points to slow recruitment into a relatively long-lived adult class (Baard 1990). A likely explanation for the high number of adults observed in the subpopulations of Remnant A and B could be that age groups telescope because the growth rate in adults decreases, which is a phenomenon that has been observed in other tortoise species (Baard 1990; Hailey 1990). Hailey (1990) mentions that tortoise population structures often show a scarcity of juveniles and that a great longevity in captivity, together with a scarcity of juveniles in the wild, have led to a 'high adult survival – high juvenile mortality' impression of tortoise population dynamics. Whether this pattern, as such, is applicable to geometric tortoise populations in general, remains to be investigated. With a juvenile/subadult to adult ratio of 1:11.9 and 1:5.8 for Remnant A and B, respectively, it looks, however, as if not enough juveniles/subadults are present in both subpopulations. The low numbers of juveniles could be the consequence of high juvenile mortality (due to factors such as fire, predation or habitat alteration) or low adult reproductive output (Hailey 1990). On the other hand, it is also possible that, due to their smaller size, juvenile and subadult individuals were under-represented in the survey because of their low detectability, sampling error therefore creating a skewed picture. Overall tortoise sampling efficiency (the total number of adults and juveniles recorded) was probably also affected by weather conditions in that on sunny days, due to higher temperature and thus higher tortoise activity level, more tortoises would be recorded than on cloudy days. In Baard's (1990) study of the large Elandsberg geometric tortoise population, a sex ratio and juvenile/subadult to adult ratio of roughly 1:1.1 was found. According to Hailey (1990), however, field observations of chelonians often show that sex ratios deviate from equal numbers of males and females, although it is not known how far these ratios reflect true population structure. Hailey's (1990) statement, however, supports the sex ratio results obtained in this study (Table 1). Since sex is determined after the eggs are laid and offspring have no interaction with the parents, an uneven sex ratio may result from the spatial structure of the population, indirectly linked to habitat fragmentation, or an altered temperature exposure during the critical stage in the development of the tortoise embryos (Hailey 1990; McCarthy *et al.* 1994). Due to their small sizes, the isolation from other populations, and the observed population structures, both subpopulations should be regarded as threatened and if no action is taken within the near future they will probably be lost.

Habitat quality of Remnants A and B

The future of the geometric tortoise not only depends on the size of remnants, but also on the quality of the remaining habitat, that is the condition of the vegetation in those remnants. Although the geometric tortoise was found to be abundant in Remnants A and B, these remnants must be regarded as highly threatened in terms of the number of alien and encroaching plants present. Low & Rebelo (1998) describe undisturbed, natural Renosterveld of the Worcester Valley as being an open to medium-dense cupressoid and small leaved, low to mid-high shrubland where emergents in the overstorey are only scattered and include species such as Sweet Thorn *Acacia karroo*, Bitter Aloe *Aloe ferox*, Common Guarri *Euclea undulata* and *Rhus* spp. Furthermore, Low & Rebelo (1998) state that the understorey often lacks grasses when overgrazed, and also contains a fair number of herbaceaous plants at various densities, often with a high proportion of succulents. When referring to Low & Rebelo`s (1998) description of Central Mountain Renosterveld, it is obvious that overgrazing by sheep and cattle most probably allowed unpalatable shrubs to encroach. Also have alien invasive plants such as *A. saligna* invaded large areas of Remnant A, completely altering the landscape and leaving no space for indigenous species to grow beneath their canopies. These plants are a threat to the geometric tortoise since the natural habitat of the tortoise is destroyed. The high fertility of these trees is a problem, which makes them very difficult to eliminate easily (Le Roux & Schelpe 1988). Other problem plants in Remnant A include *C. ruscifolia* and *Stoebe* sp., both occupying large areas. Since dicotyledonous plants and grasses, considered important elements of the animal's diet (Baard 1990), are greatly reduced, or not be present at all in this remnant, survival will be very difficult for the geometric tortoise. For the tortoises, finding sufficient food might become problematic, which is again reflected in the health of the population. The geometric tortoise seems to use the abundant shrub cover as a hide-away from the sun and potential predators, whereas the more open areas (often inundated areas next to little streams), with abundant grass and annual growth, are used for feeding (pers. obs.). These 'feeding' areas are, however, very few and can therefore probably not balance the vegetation deterioration taking place in this remnant.

Acacia saligna has also invaded Remnant B, although not as extensively as in Remnant A. If not stopped, however, the whole area will soon be invaded by this plant. At the moment, however, the encroaching *Aspalathus* sp. probably has a much more severe impact on the geometric tortoise. Although shoot tips and pods of *Aspalathus* spp. have been identified as food items for the geometric tortoise (Baard 1990), large areas of Remnant B are almost solely covered by this plant, allowing barely any undergrowth that can serve as alternative food items for the tortoise. Overgrazing by sheep probably has created a situation which favoured the increase of this species, because of the plant's unpalatability. Furthermore, deep drainage trenches are present where this remnant borders on the N1. These trenches not only represent deadly pitfall traps for the tortoises but could also induce changes in the water table which again could then be reflected in the vegetation composition or health and possibly lead to many other drainage-related habitat problems, thereby indirectly affecting the geometric tortoises in this remnant. If the land use practices are not changed, the situation may even worsen for the geometric tortoise and may then eventually be responsible for the disappearance of the geometric tortoise from this remnant.

Conservation and mitigation measures

Most existing roads were built before the explosion in ecological knowledge, and many are therefore poorly located in an ecological context (Forman & Alexander 1998). This is the case with the N1 highway in the Worcester Valley, where no consideration was given to its effects on the resident geometric tortoise populations. Highway traffic affects the survival of tortoises and other small vertebrates because it raises the mortality rate and restricts movement between populations or population fragments (Guyot & Clobert 1997). To thus successfully mitigate the impacts of the N1 on the remaining tortoise populations, the first priority should be the prevention of further geometric tortoise mortality induced by the N1 and at the same time to facilitate gene flow between the two subpopulations in Remnants A and B. Fencing the N1 along the section between Remnants A and B with a tortoise proof fence (Table 3, Fig. 6) will prevent individuals from crossing the road, saving them from a guaranteed death (Mouton 2002). In order to facilitate gene flow between the subpopulations of Remnant A and B, exchange of tortoises between the remnants has to be made possible. The most practical and feasible way to create such a scenario is to build passages below the N1 (Table 3, Fig. 6). Wildlife passages are being increasingly promoted as a means of mitigating the impacts of roads on animal populations (Bekker *et al.* 1995; Forman & Hersperger 1996; Van Bohemen 1998) and are now becoming a routine requirement for major road corridors. Such passages have been used successfully all over the world for animals such as badgers, various amphibian species and even large mammals such as deer and moose (Forman & Alexander 1998). These mitigation structures are normally combined with fencing and vegetation to enhance animal crossing and almost all such passages are successful in that the target species crosses at least occasionally, most being used by many other species as well. Whether being designed to reduce road-kill and barrier effects, to facilitate movement, or to increase population viability, it is usually assumed that passages provide a safer environment for animals than the roads they cross and mitigation passages can be considered effective in perforating road barriers to maintain horizontal natural processes across the land (Forman & Alexander 1998; Little *et al*. 2002). In the case of the geometric tortoise, these passages should be in the form of a tunnel or culvert, at least 1-2 m wide and 1-2 m high to ensure sufficient lighting to enter the structure so that tortoises will voluntarily enter it. Construction of these tunnels should be such that they are elevated enough not for water to be able to flow through or accumulate in the tunnel. The fencing material, directing the animals towards these passages, should preferably be a traditional sheep wire fence plus additional fine wire mesh covering 40 cm from ground level and buried 10 cm deep in the ground. This will prevent immature or adult tortoises from slipping through or digging underneath the fence and has been shown to work successfully for other similarly sized tortoise species (Guyot & Clobert 1997). Boarman (1993, 1995), Boarman & Sazaki (1996) and Guyot & Clobert (1997) showed that culverts or tunnels, in association with barrier fencing, were successfully used by tortoises to cross a major highway, resulting in a reduced traffic death rate of tortoises and a successful exchange of individuals between subgroups on opposite sides of the road.

Linkage to other geometric tortoise subpopulations

Geometric tortoise subpopulations are also found in remnants North of Remnant A (Baard pers. comm.). These constitute a private geometric tortoise reserve adjacent to the regional road R43 and a remnant of veld used for grazing purposes (Remnant L; Fig.

2). Unfortunately, exchange of tortoises between these remnants and Remnant A currently is not possible because of a railway line. The fragmentation effect of the railway line definitely has to be addressed in the future by applying appropriate mitigation measures to enable the tortoises to move between the remnants. Once mitigation across the N1 for the populations of Remnant A and B is underway, similar measures should be considered to perforate the railway barrier and thereby create a large single area for geometric tortoises in the Worcester Valley. By mitigating the effects of the railway line, the largest single area available to geometric tortoises in the Worcester Valley will increase from 520 ha (Remnants A and B) to approximately 690 ha, thereby considerably increasing the chances of survival for the tortoise in the Worcester Valley. The funding for the required mitigation of the railway line, however, could be a problem that has to be addressed by approaching the appropriate authorities. Cape Action Plan for the Environment (C.A.P.E.), however, has set itself the goal to conserve those habitats on the south-western lowlands that have a high conservation value and are extremely vulnerable to threats (Ashwell & Younge 2000). The high conservation value and vulnerability to threats certainly applies for the lowland habitat of the geometric tortoise. Furthermore, to achieve the conservation targets, ideally all untransformed land, irrespective of the size of the remnant, should enjoy some form of conservation action (Ashwell & Younge 2000). Therefore, for the long-term conservation of the geometric tortoise and its habitat in the Worcester Valley it is not only important that the Remnants A and B are protected from further disturbance and conserved, but conservation action should also be directed at other remnants known to harbour geometric tortoises in the Worcester Valley. Everything possible should be done to create corridors between the isolated populations to make as much habitat available to the tortoise as possible, thereby considerably increasing its chances of survival in the Worcester Valley as well as protecting its extremely threatened lowland habitat.

Vegetation transition and geometric tortoise presence

The increase in percentage canopy cover values of succulents from West to East across the study area is an indication that there is a transition from Renosterveld in the West to succulent, karroid veld in the East. The Succulent Karoo is characterised by dwarf, succulent shrubs, of which the Vygies (Mesembryanthemaceae) and Stonecrops (Crassulaceae) are particularly prominent (Low & Rebelo 1998). Assuming a marked decrease in precipitation from West to East in the study area, this increase in succulent plant abundance is evidence for a transition from Renosterveld in the West to more arid, succulent karroid veld in the East. Similarly, the West to East decrease of the restio component, characteristic of the Fynbos biome (Low & Rebelo 1998), is another indication that this area represents a transition zone between Fynbos and Succulent Karoo. The change in plant species composition of remnants from West to East only supports this reasoning (Table 4). Typical Renosterveld genera such as *Aspalathus* (Fabaceae), *Eriocephalus* and *Helichrysum* (Asteraceae) are present in the western sections of the study area whereas typical Karoo species such as *D. angustifolia*, *W. obcordata* and *R. dissecta* become more prominent towards the East. The fact that each of the sampled remnants has a different land use history, however, makes the determination of a clear trend very difficult since the natural species assemblages that would exist in the absence of any human interference are not there anymore, or altered to a great degree. Thus species might occur at places in the gradient where they would naturally not, thereby obscuring clear trends to the observer and making interpretation of the obtained data very difficult. The fact that most of the geometric tortoises were found in the western part of the study area could be because the microclimate, elevation and floral characteristics in the eastern sections are not preferred by the geometric tortoise and are unsuitable as habitat. According to Baard (1990), however, geometric tortoises were found in Remnants E and F, more than ten years ago. The fact that none were found in Remnant F during this study probably is the result of the continuous habitat deterioration due to overgrazing, the construction of the present N1 highway, the isolated nature and a severe wildfire that occurred in 1988. Remnants C, D, G, H, potentially could have harboured geometric tortoises then as well, but this has not been confirmed at any stage. It is very likely, however, that Remnants E and F represented the most eastern limits of the distribution of the geometric tortoise in the Worcester Valley due to a complete change to Karooveld further East (Remnants I, J, K), which this tortoise does not seem to be associated with (Baard 1990, 1995).

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Table 1. Geometric tortoise population statistics for Renosterveld Remnants A and B.

	Remnant A	Remnant B
Adult sex ratio (male : female)	1: 2.1	1: 0.6
Juvenile/subadult : adult Ratio	1:11.9	1:5.8
Geometric tortoises/ha	8	3
Total area surveyed (ha)	15. 2	8.8
Total area of remnant (ha)	442	80
Estimated tortoise population on remnant	~ 3300	~ 245

Table 2. Dominant shrub species on Renosterveld Remnants A and B.

Remnant A	Estimated Percentage Cover
A1 (3 plots sampled)	
Leucadendron salignum	15-20%
Stoebe sp.	25-30%
Anthospermum spathulatum	5-10%
A2 (1 plot sampled)	
Acacia saligna	80-90%
A3 (4 plots sampled)	
Cliffortia ruscifolia	55-60%
A4 (5 plots sampled)	
Stoebe sp.	30-40%
Cliffortia ruscifolia	35-45%
Metalasia sp.	20-30%
Eriocephalus africanus	10-15%
A5 (4 plots sampled)	
Cliffortia ruscifolia	25-30%
Elytropappus rhinocerotis	5-10%
Eriocephalus africanus	10-15%
Remnant B (6 plots sampled)	
Aspalathus sp.	45-50%
Acacia saligna	5-10%

Table 3. Co-ordinates for the location of tortoise underpasses and tortoise proof fencing along the N1 highway in the Worcester Valley.

Fencing	From	To
Remnant A	S 33^0 37' 59.0"	S 33^0 38' 04.3"
	E 19^0 20' 05.6"	E 19^0 21' 35.5"
Remnant B	S 33^0 38' 00.2"	S 33^0 38' 04.8"
	E 19^0 20' 22.6"	E 19^0 21' 35.5"
Underpasses at		
1)	2)	3)
S 33^0 38' 03.6"	S 33^0 38' 02.5"	S 33^0 38' 01.3"
E 19^0 21' 22.0"	E 19^0 20' 57.4"	E 19^0 20' 38.4"

Table 4. Dominant shrub species composition and percentage cover along the West-to-East vegetation gradient in the study area.

Remnant	*Leucadendron salignum*	*Cliffortia ruscifolia*	*Nylandtia spinosa*	*Elytropappus rhinocerotis*	*Lobostemon fruticosus*	*Struthiola cilliata*	*Wiborgia obcordata*	*Galenia africana*	*Aspalathus* spp.	*Stoebe* sp.	*Athanasia trifurca*	*Eriocephalus africanus*	*Dodonea angustifolia*	*Helichrysum cymosum*	*Rhus dissecta*	*Hermannia alnifolia*
A	15	21	5	7						23.5		14				
B	5				20				32.5			5				
C											50					
D						10							30			
E							10							9		
F				10			55	15	10							
G							8	7					15			20
H				10				7	10				8			7
I		5											25		12	
J		5											27		15	
K													28		15	

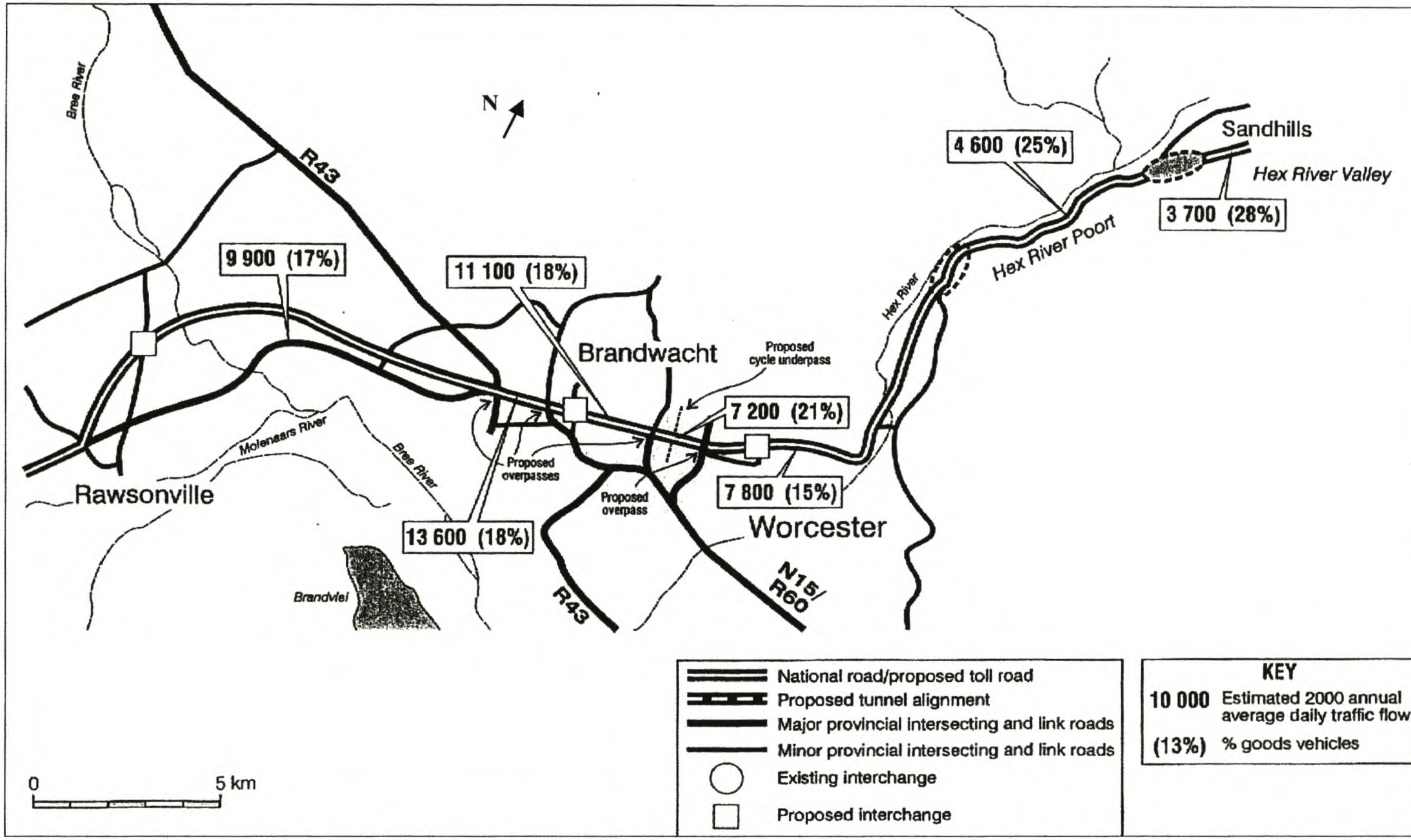

Fig. 1. Map indicating the proposed modifications to be made to the N1 highway in the Worcester Valley as part of the N1 N2 Winelands Toll Highway Project (taken from Crowther Campbell & Associates 2002).

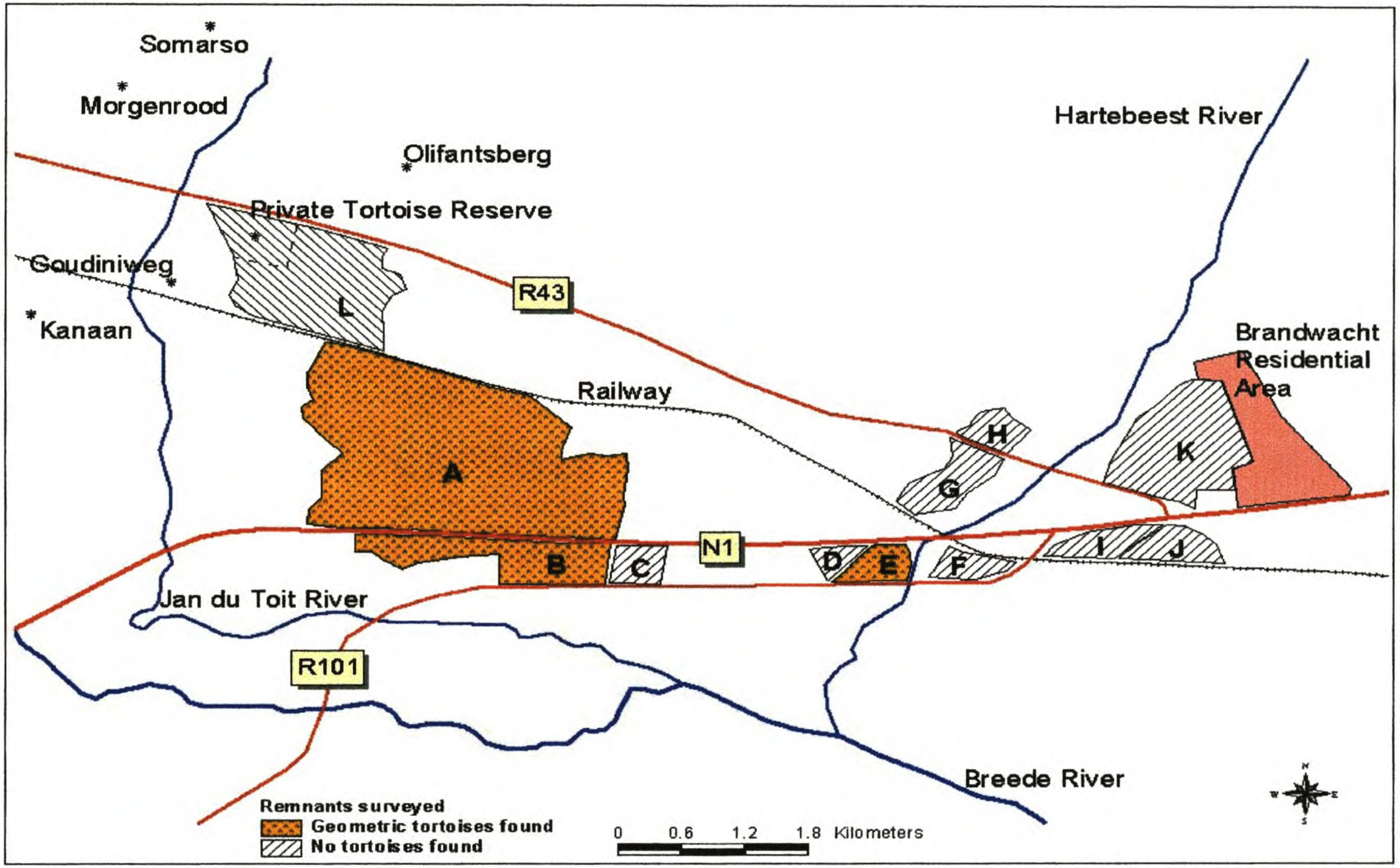

Fig. 2. Remnants of natural veld along the N1 in the Worcester Valley surveyed for the presence of geometric tortoises.

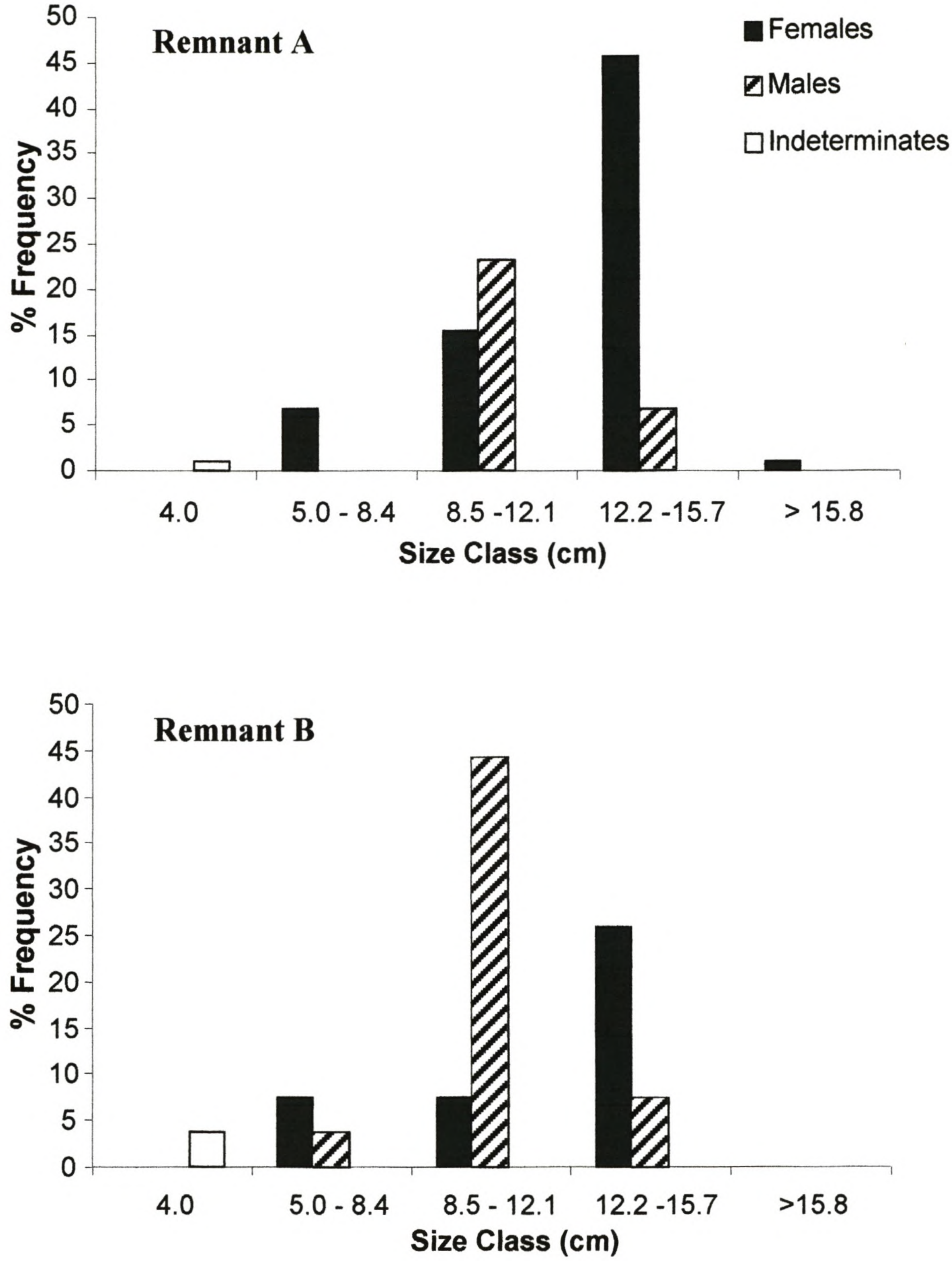

Fig. 3. Carapace length distributions for the geometric tortoise subpopulations on Remnants A and B.

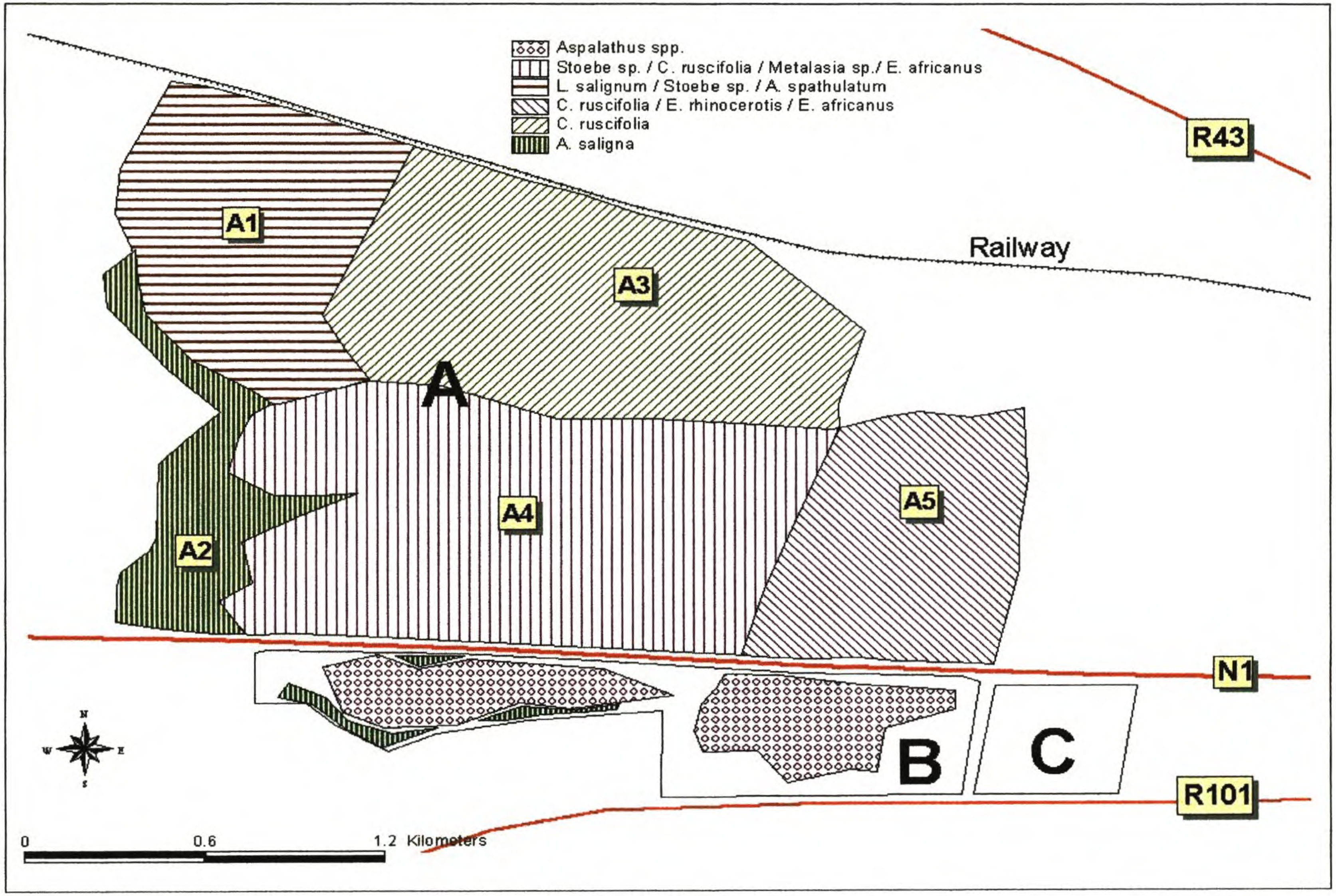

Fig. 4. Map showing dominant shrub/tree species occurring on Remnants A and B.

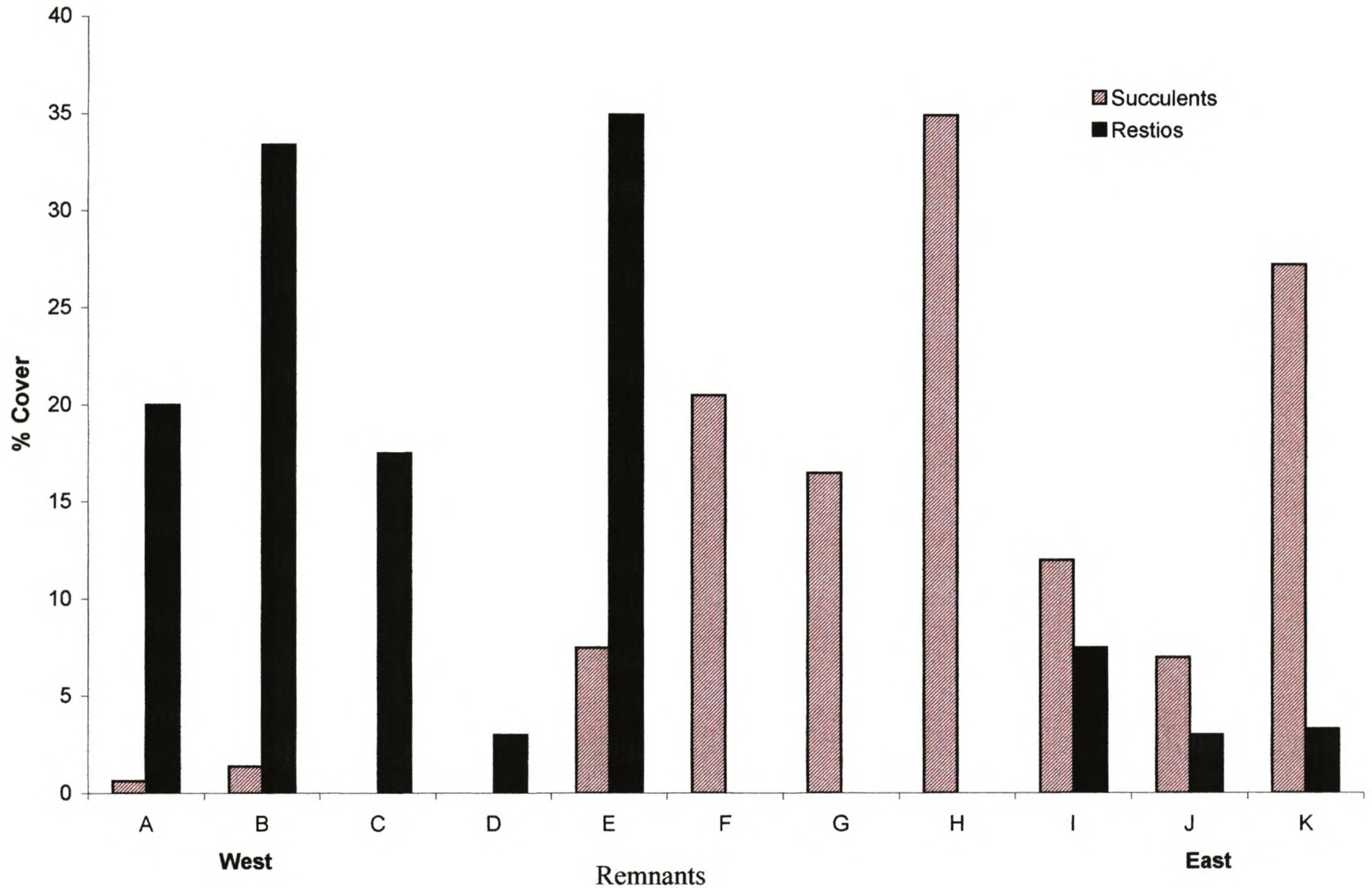

Fig. 5. Graph showing the West-to-East change in succulent and restio percentage canopy cover across the study area.

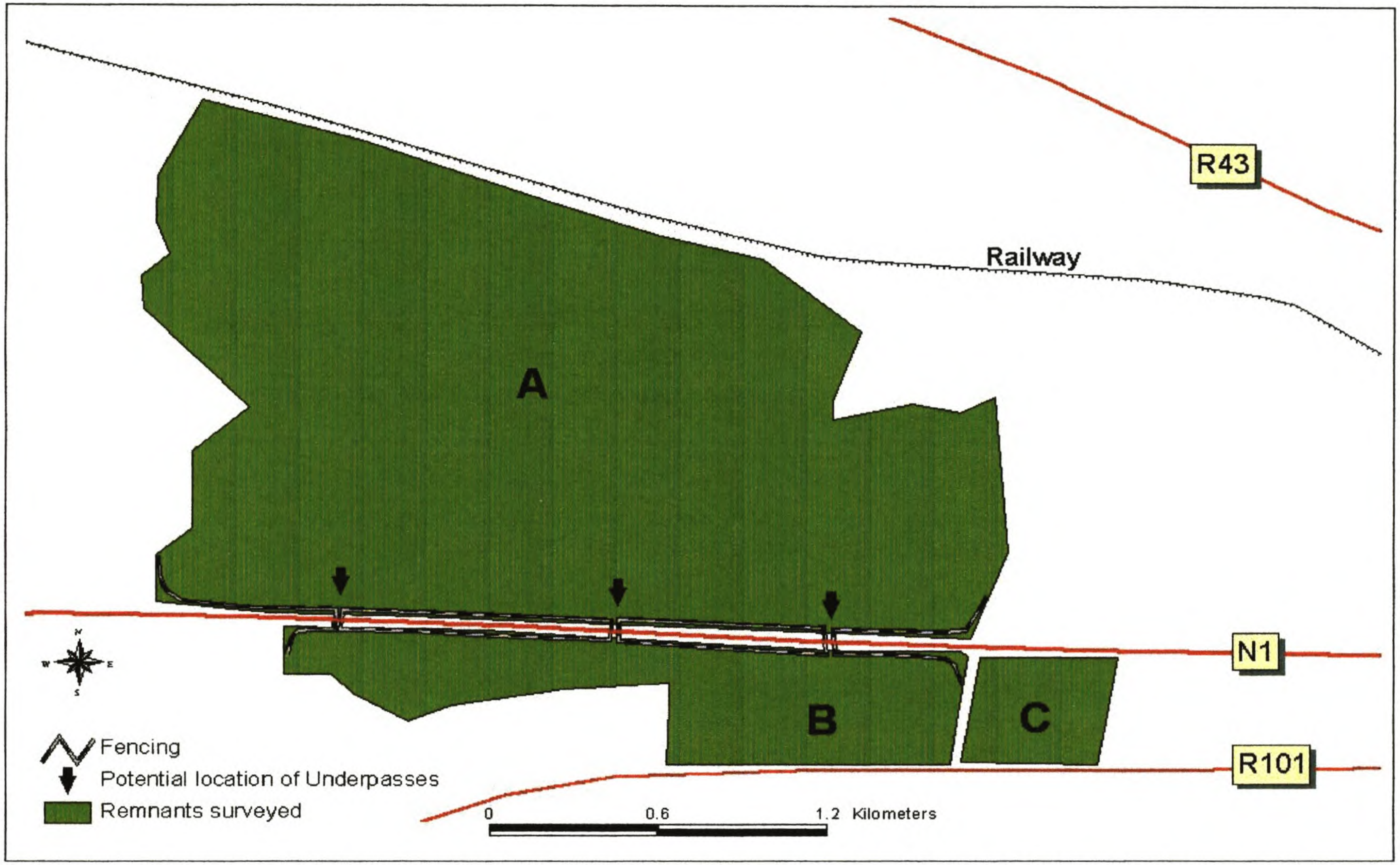

Fig. 6. Map indicating the potential location of underpasses and fencing to facilitate movement of tortoises between Remnants A and B.