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Land degradation is not a necessary outcome of communal pastoralism in arid Namibia

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In Otjimbingwe, a region of arid south-central Namibia, human population densities are high and these communal pastoralists own large numbers of livestock. Such situations are commonly perceived to lead to the 'tragedy of the commons'. This region lends itself to a comparison of the effects of communal and commercial farming (with private land ownership) because the communal area is completely surrounded by commercial farms. In spite of far higher stocking densities on the communal areas and the absence of an overall grazing strategy, we found no evidence of the 'tragedy of the commons' on Otjimbingwe. Indeed, the communal areas did not differ in a number of soil and vegetation parameters from the commercial farms. These results point both to the resilience of arid environments to high stocking levels and the over-riding influence of abiotic variables on environmental quality.

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Introduction

It is widely believed that overgrazing and other human impacts on the environment in communally farmed areas are greater than in commercially farmed areas (Archer *et al.*,

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1989). This is largely due to the fact that communal areas are not individually owned and may have poor management strategies. Communal ownership is frequently assumed to lead to the 'tragedy of the commons' because nobody looks after land they are not personally responsible for (Hardin, 1968). However, a number of recent studies have shown that this is not always the case (e.g. Ellis & Swift, 1988; Archer *et al.*, 1989; Tapson, 1993).

In a landmark paper in 1988, Ellis and Swift challenged the following assumptions of the conventional ('tragedy of the commons') paradigm of pastoral ecosystems: (1) African pastoral ecosystems are potentially stable (equilibrial) systems; (2) these systems are frequently destabilized by improper use by pastoralists; and (3) alterations of system structure (reducing livestock numbers, changing land tenure patterns, etc.) are needed to return these systems to an equilibrial and productive state. They used examples from their work in the Turkana region of Kenya that showed that: (1) stable equilibria are not achievable in many pastoral ecosystems, although long-term persistence is; (2) interventions aimed at achieving stability in non-equilibrial systems are likely to be irrelevant at best, or disruptive and destructive at worst; and (3) successful interventions will be designed to accommodate system dynamic variation rather than aimed at maintaining equilibrial conditions (Ellis & Swift, 1988).

In the light of this revised approach to the effects of communal pastoralism on African rangeland, we set out to determine some of the impacts of communal and commercial (i.e. privately-owned and fenced) rangelands in arid central Namibia. Conventionally, tests of the effects of different farming practices on the environment are plagued by problems of improper comparisons due to inherent prior environmental differences between farms that are independent of farming practice (see, e.g., Tapson, 1993). This problem is particularly acute in post-colonial Africa because the colonial governors typically parceled out the worst areas to indigenous communal farmers and the best areas to European commercial farmers (see, e.g., Mossolow, 1993). The communal farming area of Otjimbingwe in central Namibia is a notable exception to this because it is roughly circular in shape and is completely surrounded by commercial farms (Fig. 1). Also, all farms in the region experience similar rainfall, and are similar in soil and vegetation characteristics (Van der Merwe, 1983).

Preliminary observations indicated that stocking rates at Otjimbingwe were extremely high, as were human population densities (see below). In the dry season, the area appears almost completely devoid of grass as a result of heavy grazing. Furthermore, we noted that many of the original inhabitants of Otjimbingwe, the Herero people, appear to have left the area. The Hereros now constitute roughly half of the population, along with the Damara people (Fuller, 1993). The Hereros are predominantly cattle farmers (called cattle ranchers in North America) while the Damaras are predominantly goat farmers. This change in main stock type, coupled with an apparent change in land ownership, suggested to us that Otjimbingwe was suffering land degradation (defined here as a decline in vegetation productivity and/or soil quality) because large grazing animals such as cattle could no longer be sustained on the vegetation, while small browsers/grazers such as goats could still be maintained. A sociological survey of the inhabitants of Otjimbingwe (Ward *et al.*, submitted) revealed that there was no central management of grazing areas. Thus, it appeared that several of the components likely to lead to a 'tragedy of the commons' situation could occur in Otjimbingwe.

Otjimbingwe

The Otjimbingwe communal farming area was proclaimed in 1903 by the German colonial government (Namibia was a German colony from 1884 until 1915). It borders on the Namib Desert in the region known as the Pro-Namib. The area was first

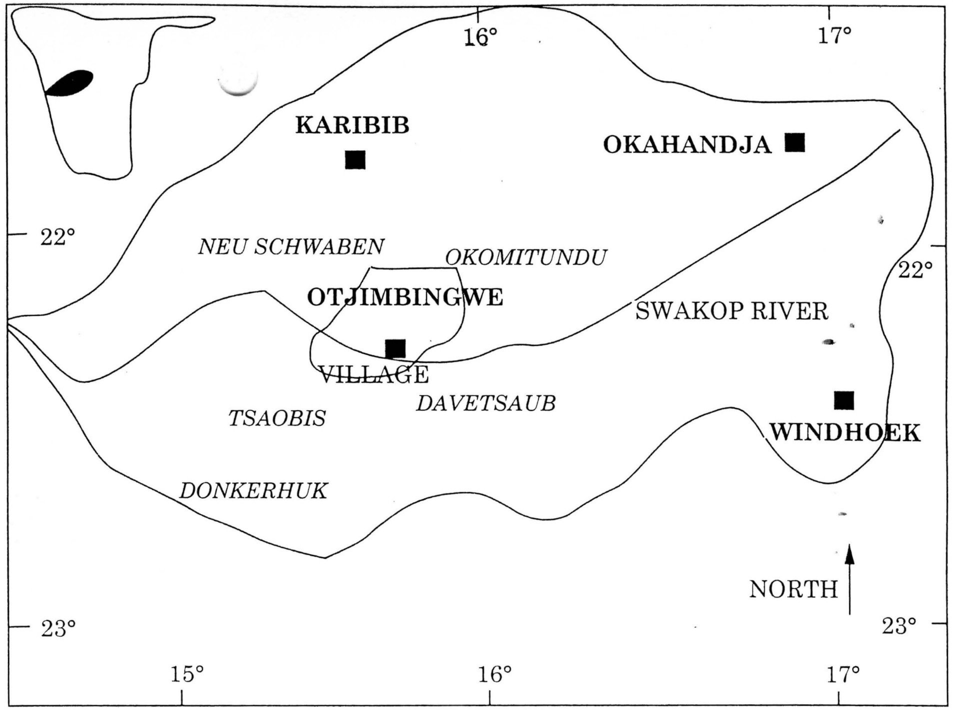

Figure 1. Map of the Swakop catchment (modified from Jacobson *et al.*, 1995), showing the position of Otjimbingwe. Inset: position of the Swakop catchment in Namibia.

established in 1903 for the Herero-speaking population. (For a more detailed history of human use of this region, see Ward *et al.* (submitted).) With an average annual rainfall of 165·4 mm (coefficient of variation = 69·4%), the Otjimbingwe area falls in the desert savanna transition zone (Van der Merwe, 1983). It is a communal area about 117,000 ha in extent, with an unfenced interior which makes the regulation of grazing areas difficult. Livestock numbers are high (currently 18·99 ha per large stock unit (LSU) where an (LSU) is equivalent to a 450 kg cow (Meissner *et al.*, 1983)). This stocking rate is considerably higher than the 27·6 ha per LSU recommended for Otjimbingwe (Fuller, 1993). In contrast, the surrounding commercial farms have lower stocking densities (40–378 ha LSU^{-1}) with fenced interiors and stock rotation camps. We note that stocking rates have been high in Otjimbingwe for at least 150 years (Ward *et al.*, submitted). For example, an early European trader at Otjimbingwe, C.J. Andersson, noted that 'Restored tranquility had given confidence to the Damaras [note: he called the Hereros 'Damaras', while the Damaras were known as 'Hill-Damaras'], who were now flocking in great numbers with their cattle to the banks of the Swakop, the result of which was that every blade of grass was consumed for miles around on both sides of the river' (Andersson, 1856).

After the German–Herero war (1904–1907), there was a long period of erosion by European farmers' pressure groups of the original 130,000 km^2 Otjimbingwe reserve granted to the Hereros by the German colonial goverment in 1903. In 1915, South African troops, on behalf of the British government, overthrew the Germans. From then on, and especially during the apartheid era in Namibia (1948–1990), the number of European settlers increased enormously. Between 1913 and 1962 the area of European-owned commercial farms in Namibia increased by 346% (Fuller, 1993). This pressure on the land resulted in very high stocking rates in the small areas that the

Hereros were restricted to. In 1921, for example, the farm Otjimbingwe Nord (13,000 ha a subset of the current Otjimbingwe) was a largely Herero-controlled communal farm (declared a native reserve by the German colonial government in 1902) with 10,000 small stock and 800 large stock (Fuller, 1993). This is equivalent to a stocking rate of 6·8 ha LSU^{-1}. These high stocking rates became particularly problematic because the increased land area of commercial farms prevented people in Otjimbingwe from moving out in drought years in order to find better grazing further north, as they traditionally had done (Lau, 1989). As Black people, the residents of Otjimbingwe did not have the option to purchase land elsewhere, such as in commercial areas, particularly from the time of the South African occupation in 1915.

As the result of government reviews and deputations from the residents, Otjimbingwe was established in its present form in 1923. The Otjimbingwe reserve consisted of six farms, comprising 83,053 ha (Fuller, 1993). In 1929 another farm was added to bring the reserve size up to 92,000 ha. Since independence from South Africa in 1990, two further farms have been added to Otjimbingwe to increase the total area to 117,000 ha. Although most members of the population were involved in stock farming (it is too dry to grow crops outside of the riverbeds), much crop farming was conducted in the seasonal Swakop River. Crop farming was a relatively successful enterprise in the first half of the 20th century. For example, in 1949, 70 ha were planted throughout the reserve. A mean wheat harvest of 24 tons $year^{-1}$ was recorded (Fuller, 1993). Since the damming of the Swakop River 50 km upstream from Otjimbingwe in 1977, little water flows in the river during the annual summer rains, and crop farming has virtually ceased (see Ward *et al.*, submitted). As a result, pastoralism is the main economic activity.

The Otjimbingwe human population increased exponentially from about 1954, with a growth rate very similar to the national average (about 3%). By the time of the 1981 national population census, 2500 people were recorded as living in Otjimbingwe, of whom 60% were Damaras and 40% Hereros (Fuller, 1993). Today, some 5000–6000 people live in the Otjimbingwe communal area, although there are reports of as many as 8000 people. Between 800–2000 of these people live in the village, and the rest live in the surrounding farming area. All respondents in 1996–1997 recorded Herero- and Damara-speaking people as being approximately equally abundant, with small numbers of Namas and Oshivambos also present. The large increase in the number of people in Otjimbingwe between 1981 and 1997 is largely due to immigration from local commercial farms and even further afield, particularly since independence from South Africa.

The number of farming families per unit of farming area is much greater today than it was in the past. For example, in 1952, 224 families had 406 ha $family^{-1}$ to graze their stock (Fuller, 1993), while in 1996, 472 families had 248 ha $family^{-1}$ for their stock. In 1927, 952 people on Otjimbingwe had 3665 large stock and 16,593 small stock (= 5549 LSU), with 16·58 ha LSU^{-1} (Fuller, 1993). In 1952, 1164 people had 7001 large stock and 12,977 small stock (= 8443 LSU), with 10·90 ha LSU^{-1} (Fuller, 1993). Today, there are 6200 LSU on Otjimbingwe (= 17·8 ha LSU^{-1}). It is therefore clear that Otjimbingwe has long had, and still has, a large human population and high livestock population densities.

Methods

Study area

The Otjimbingwe reserve lies 200 km north-west of Windhoek on an undulating plain on the banks of the Swakop River. The wet season is from December to March. The reserve is completely surrounded by fenced commercial farms. The major rock type is Donkerhuk granite. The soils are sandy and are vegetated with *Acacia tortilis*, *Acacia reficiens*, *Boscia albitrunca* and *Schotia afra*. *Faidherbia albida* is the dominant tree on the banks of the Swakop River. We initially compared the ecology of Otjimbingwe with the neighbouring Tsaobis commercial farm (21,000 ha; stocking rate 378 ha LSU^{-1}) which has similar geology and vegetation types. We also compared the soils of Otjimbingwe and Tsaobis with those of Donkerhuk farm, some 30 km distant on the same soil and with a similar vegetation type. Donkerhuk farm differed from the other two sites in that it had some grass at the time of the first phase of the study (December 1996) (see below). In September 1997, we extended our survey to include four commercial farms (Okomitundu, Davetsaub, Neu Schwaben and Tsaobis) on the periphery of the communal Otjimbingwe area. These farms are on the north-east, south-east, north-west and south-west of Otjimbingwe, respectively. This sampling design precluded bias due to comparison of communal and commercial sites on different ends of natural environment gradients. Within each commercial farm we had one study site immediately adjacent to the communal area and one in the centre of each farm, while in Otjimbingwe, sites were chosen on the edge of the communal farm closest to each of these commercial farms and in the interior of Otjimbingwe. This design was used in order to ensure that sites that differed in farming practice only were being compared.

Parameters sampled

As might be anticipated in an arid area such as Otjimbingwe, vegetation productivity is rainfall-driven. Thus, comparisons of vegetation may be limited by the particular rainfall in a given year. For example, a very high rainfall year might eradicate all signs of differences in grass availability between farms, while a drought year could do the same. Yet, in the long run, one type of farm may have more vegetation than another, and this may be related to grazing strategy (Tapson, 1993). To circumvent this problem, we examined vegetation parameters in an extremely wet, a wet and a dry year. If there is serious degradation of soil nutrients, then vegetation should not recover after rains. Thus, wet season grass measurements should prove more important than dry season measurements in differentiating between degraded and non-degraded areas. We also examined several parameters of soil quality. Soil quality may indeed be a more reliable indicator of long-term degradation of the environment due to a particular management practice because it reflects the ability of the environment to sustain vegetation for any given rainfall (see, e.g., Mokwunye 1996).

Vegetation sampling

Grass height

We used a point-frequency frame to measure grass height and density. The frame is made from aluminium and is 1 m high and 1 m long, and has ten guide holes bored perpendicularly through the two horizontal fixed bars (Mueller-Dombois & Ellenburg, 1974). A steel rod of the same length as the legs is slid through the holes which are equally spaced, 10 cm apart, along the linear frame.

The point-frequency frame is placed with its legs over the vegetation to be measured and the pins are lowered vertically one after the other. Wherever the pin touches the vegetation the height is recorded. Ten placements of the frame result in 100 sample points. We took the average of each placement of the frame as a single data point in our analyses to avoid pseudo-replication. This provides a measure of percentage cover for the species that are intercepted by pins, as well as the mean grass height (Mueller-Dombois & Ellenberg, 1974). We found a strong positive correlation between grass mass m^{-2} and mean grass height ($r = 0{\cdot}87$, $F = 40{\cdot}59$, $p < 0{\cdot}001$, error df. = 13) at Otjimbingwe. The best-fit regression equation is:

$$\text{grass mass } (\text{g m}^{-2}) = 0{\cdot}181 \times \text{mean grass height (cm)} + 4{\cdot}746. \quad \text{(Eqn 1)}$$

Perennial plant diversity

We used McAuliffe's (1990) log-series survey method to record percentage cover, species richness and species diversity of perennial plants in the communal areas of Otjimbingwe and in the four surrounding commercial farms. This method has proved to be one of the most effective means of recording desert vegetation (Ward *et al.*, 1993). The plots used had a 13 m radius.

We used detrended correspondence analysis (DECORANA) for the analysis of differences in perennial plant community composition between communal and commercial farms. DECORANA is an improved eigenvector technique based on reciprocal averaging (also called 'correspondence analysis') but correcting its main faults (Hill & Gauch, 1980; Gauch, 1982).

Soil sampling

In December 1996, we took soil samples from two sites (north and south) close to (200 m) and two sites far away from (about 1200 m) the village of Otjimbingwe. Note that we did not use greater distances for our 'far' comparison to facilitate direct comparison with the commercial farms, which are divided into grazing camps (= paddocks) that are seldom larger than this; thus, the lowest impact of stock is likely to be found at the furthest point in the camp from the waterpoint. Furthermore, homesteads on the communal area of Otjimbingwe are about 2–3 km apart, so this 'far' distance represents the point of minimum grazing impact between adjacent farmers' herds. For Tsaobis farm, we took soil samples close to the homestead (about 200 m away) where grazing pressure is heaviest (near the waterpoint) and far away (about 1200 m). At Donkerhuk farm, we chose a site that had relatively high grass cover (mean ± SE grass height = $4{\cdot}85 \pm 1{\cdot}79$ cm) in order to compare the effect of grass cover on the organic carbon and soil quality with the relatively unvegetated soils of the Otjimbingwe reserve. In August 1997, we sampled soil on Otjimbingwe and on four commercial farms (Okomitundu, Davetsaub, Neu Schwaben and Tsaobis) on the periphery of the communal Otjimbingwe area. In all surveys, soil was collected from the uppermost 5 cm, after litter and large organic matter had been scraped off.

Soil organic carbon

This is a good measure of overall soil quality (Foth & Turk, 1972; Nelson & Sommers, 1996). Organic matter is frequently highly positively correlated with two of the most important soil nutrients, nitrogen and phosphorus, in many African soils. For example, Van der Merwe (1962) found high positive correlations across the arid soils of southern Africa between organic carbon and total nitrogen ($r = 0{\cdot}80$, $p < 0{\cdot}001$) and phosphates ($r = 0{\cdot}41$, $p < 0{\cdot}04$). Similarly, Richards *et al.* (1997) found high correlations between per cent organic carbon and total nitrogen ($r = 0{\cdot}98$, $p < 0{\cdot}001$) and total phosphorus ($r = 0{\cdot}97$, $p < 0{\cdot}001$) in Cape fynbos soils. Adepetu & Corey (1977) found that in tropical African soils, soil organic matter contains practically all of the nitrogen and 20–80% of the phosphorus. In soils from the Pro-Namib region near Otjimbingwe, we found a high positive correlation between total nitrogen and organic carbon ($r = 0{\cdot}91$, $F = 196{\cdot}57$, $p < 0.001$, $N = 45$ samples). Furthermore, Brams (1971) found a very high correlation between organic carbon and the cation exchange capacity of African soils ($r = 0{\cdot}85$).

We determined organic carbon content by soil mass loss after combustion at 400°C for 16 h in a muffle furnace. Prior to combustion, soil was sieved (mesh size 2000 μm) to remove larger particles such as stones and sticks.

Total nitrogen and total phosphorus

We measured total nitrogen in the soils using standard Kjeldahl techniques (Bremner, 1996), and total phosphorus following Olsen & Sommers (1982) (see also Kuo, 1996). The extractant used was sodium bicarbonate. Absorbance was measured spectrophotometrically at 882 nm. Soil samples were collected as stated above (see *Soil sampling* above) on Otjimbingwe, and on Tsaobis and Donkerhuk commercial farms.

Bioassay

This is an effective and inexpensive method of determining soil quality as the growth of a plant is used as a bioassay—by inference, plants growing more are able to extract more nutrients from the soil (Olsvig-Whittaker & Morris, 1982). For each site we had five pots in each of which we planted 10 seeds of the experimental plant, radish (*Raphanus sativus* L.) of the Cherry Belle variety. This plant is an effective bioassay because it is able to grow in a wide variety of conditions, and therefore differences in growth of the plant are unlikely to be due to differences in preferences for specific nutrients (Olsvig-Whittaker & Morris, 1982). The soil was maintained at field capacity by addition of water collected from a fog-harvesting project two or three times a day depending on the rate at which the surface layer dried out. After a period of 8 days we recorded the length of the root and the length of the stem separately for each plant.

Results

Vegetation

Grass height

In spite of the higher stocking densities at Otjimbingwe, there was no significant difference in grass height between Otjimbingwe and Tsaobis in December 1996 (Analysis of Variance (ANOVA): $F = 1{\cdot}86$, $p = 0{\cdot}154$, error df. = 36). That is, all sites were similarly denuded of grass at the end of this dry season in a particularly dry year (September 1995–April 1996 rainfall = 59·5 mm).

In December 1996, there was no significant difference in mean ±SE grass height close to Otjimbingwe village ($1{\cdot}060 \pm 0{\cdot}645$ cm), where most livestock are concentrated, and far from Otjimbingwe village ($0{\cdot}030 \pm 0{\cdot}021$ cm) where livestock densities are lower due to the scarcity of waterpoints (Student's *t*-test: $t = 8{\cdot}20$, $p = 0{\cdot}128$, df. = 18). The same applied to the comparison of sites on Tsaobis close ($0{\cdot}420 \pm 0{\cdot}182$ cm) and far ($0{\cdot}150 \pm 0{\cdot}073$ cm) (Student's *t*-test: $t = 1{\cdot}37$; $p = 0{\cdot}187$, df. = 18) from the stock watering point.

In April 1997, after an exceptionally wet period (September 1996–April 1997

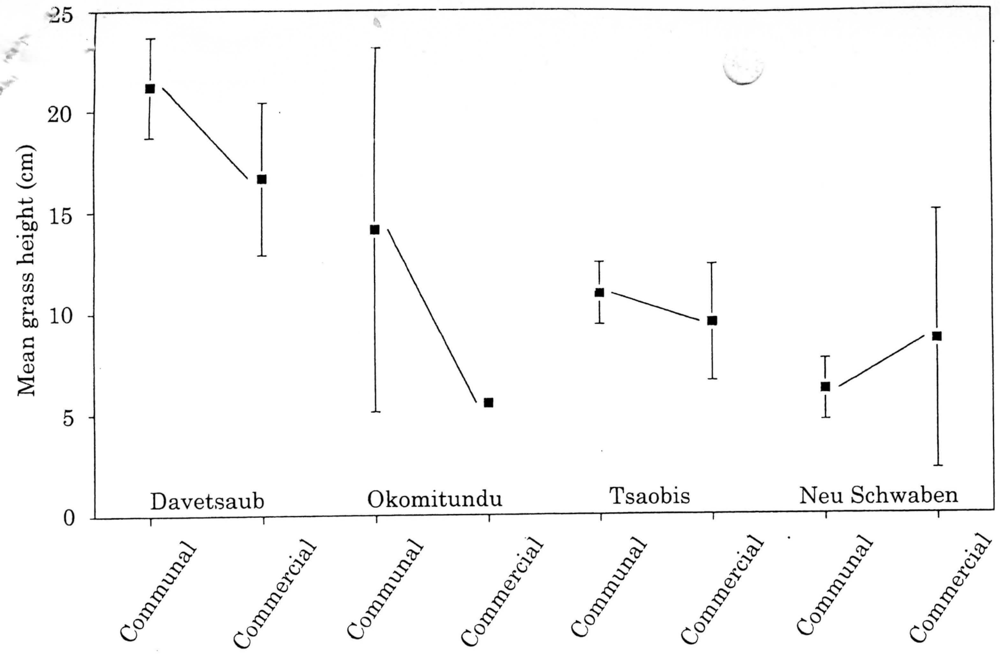

Figure 2. Mean ± SE grass height in Otjimbingwe (communal area) and adjacent commercial farms, February 1998. Names under values are the names of commercial farms and adjacent communal areas on which comparisons were done. Note that in the single case where the mean value for the communal area is lower than that of the corresponding commercial area (Neu Schwaben), the commercial farm is not currently stocked with domestic livestock. The commercial farm Okomitundu also does not have domestic livestock at present, but is rather heavily stocked with wild antelope and zebras.

rainfall = 213·4 mm), mean grass heights did not differ significantly among sites on Otjimbingwe (Nested ANOVA: $F = 0{\cdot}253$, $p = 0{\cdot}622$, error df. = 16). Mean ± SE grass heights at two sites close to Otjimbingwe village (north and south of the village) were 19·28 ± 2·45 cm, while far from Otjimbingwe village mean ± SE grass height was 18·93 ± 2·96 cm. Grass species richness was similar in these sites (ANOVA: $F = 1{\cdot}565$, $p = 0{\cdot}229$, error df. = 16), being 3·10 ± 0·43 species close to Otjimbingwe village and 2·70 ± 0·21 species far from Otjimbingwe village.

In the dry period of September 1997, the mean ± SE grass height (21·048 ± 1·105 cm, $N = 80$) on the four commercial farms surrounding Otjimbingwe was significantly greater than on the communal areas of Otjimbingwe (9·847 ± 0·942 cm, $N = 110$). This difference was highly significant (Nested ANOVA: $F = 12{\cdot}390$, $p < 0{\cdot}001$, error df. = 182).

In the subsequent wet season (February 1998), mean ± SE grass height (10·384 ± 1·613 cm, $N = 40$) on the four commercial farms surrounding Otjimbingwe was slightly but not significantly (Nested ANOVA: $F = 1{\cdot}813$, $p = 0{\cdot}182$, error df. = 87) lower than on the communal areas of Otjimbingwe (13·257 ± 1·397 cm, $N = 55$) (Fig. 2).

Perennial plant diversity

There was no significant difference in percentage plant cover (Nested ANOVA:

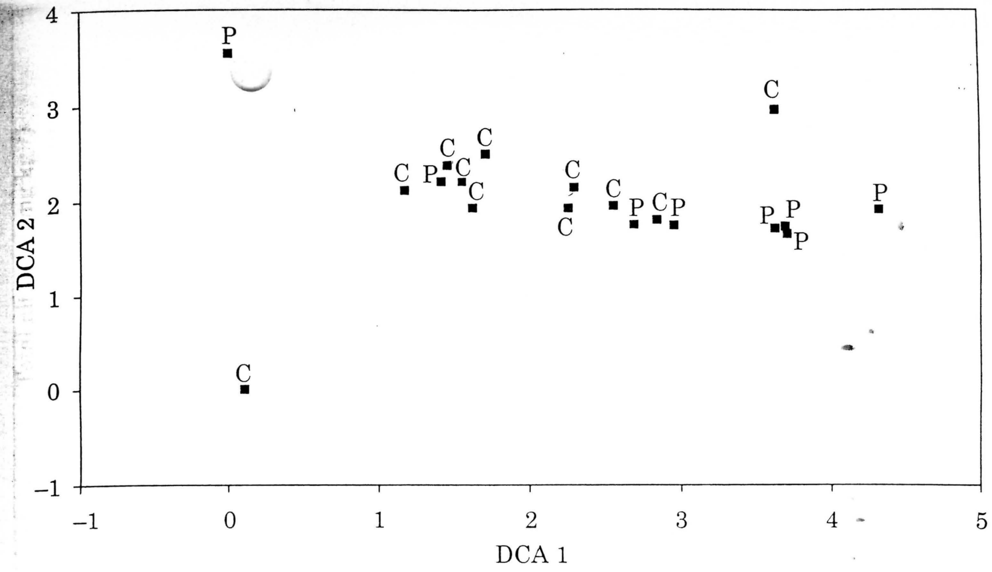

Figure 3. Detrended correspondence analysis plot of perennial plant communities on communal and commercial farms at Otjimbingwe. Eigenvalues for the first and second DC axes are 0·923 and 0·320, respectively. Cumulative per cent of variance explained by the first and second DC axes = 43·4%. P = private (commercial) farms; C = communal farms. Note that while most commercial farms fall on the right half of this plot and most communal farms on the left, there is no significant difference between the values of commercial and communal farms on either DC axis (see **Results**).

$F = 0{\cdot}141$, $p = 0{\cdot}963$, error df. = 11), species richness (Nested ANOVA: $F = 1{\cdot}642$, $p = 0{\cdot}233$, error df. = 11) or Shannon–Wiener diversity (Nested ANOVA: $F = 0.831$, $p = 0{\cdot}533$, error df. = 11) of perennial plants between communal and commercial areas. Mean ± SE percentage cover in communal areas was 11·29 ± 3·34% and on commercial areas was 11·78 ± 3·32%, while species richness was 3·73 ± 1·19 species plot^{-1} on communal areas and 4·13 ± 0·58 species plot^{-1} on commercial farms. Shannon–Wiener diversity was 0·82 ± 0·09 on Otjimbingwe communal areas and 0·86 ± 0·14 on the adjacent commercial farms.

Although there was a tendency for plots of commercial farms to cluster on the lower right side of the plot of the first and second DECORANA axes (Fig. 3) and communal farms on the upper left side, we found no significant difference between commercial and communal farms on either the first DECORANA axis (Student's t-test: $t = 1{\cdot}507$, $p = 0{\cdot}160$, error df. = 16) or the second axis ($t = 0{\cdot}139$, $p = 0{\cdot}892$, error df. = 16). Thus, there is no evidence of a difference in community structure of perennial plants between commercial and communal farms.

Soil

Soil carbon

In our soil survey of December 1996, the mean ± SE per cent organic carbon in the soil on the communal farm at Otjimbingwe (1·15 ± 0·101 %) was significantly higher than that of the commercial farms Tsaobis and Donkerhuk (0·70 ± 0·051%) (ANOVA: $F = 12{\cdot}744$, $p = 0{\cdot}001$, error df. = 34). In our second soil survey in August 1997,

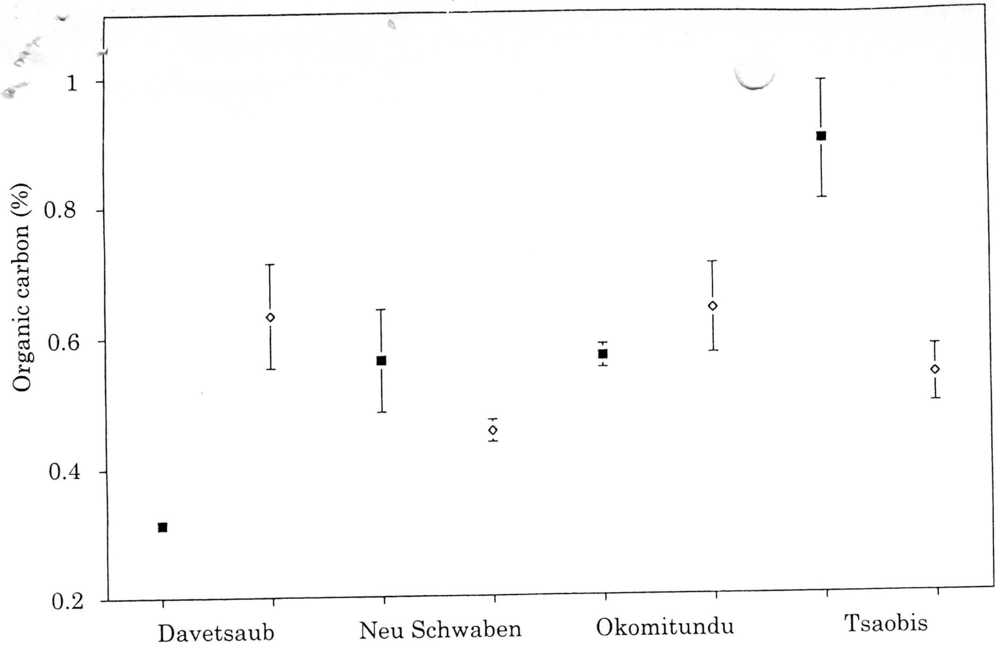

Figure 4. Mean ± SE per cent organic carbon in soils during the second soil survey in August 1997. Values represent mean values of sites in each commercial farm (◇) and the part of the Otjimbingwe communal farm nearest to that farm (■).

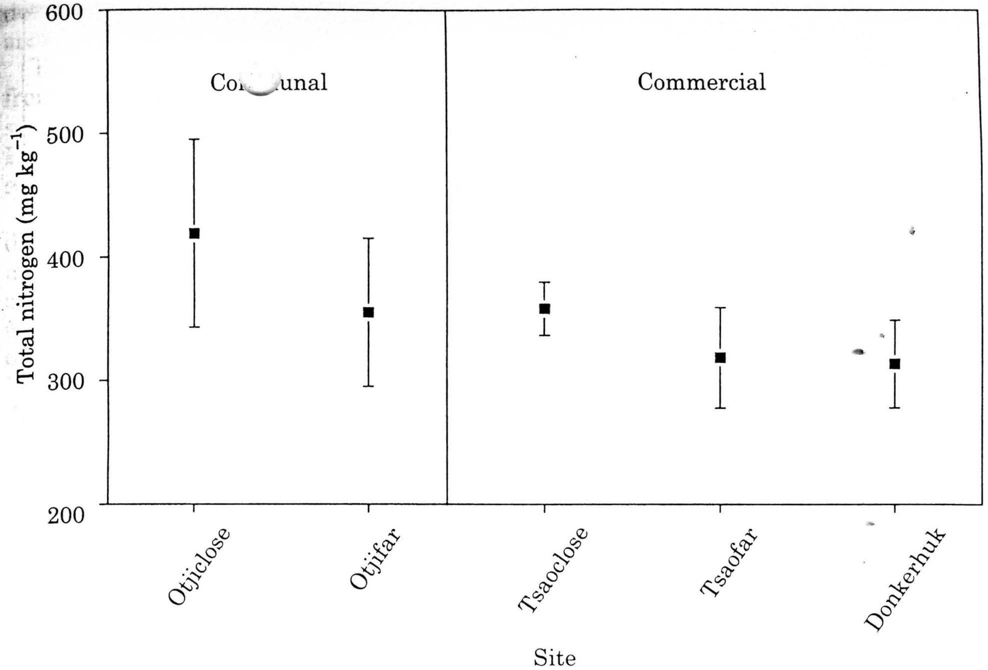

Figure 5. Total nitrogen (mg kg^{-1}) in soils. Otjiclose = close (200 m) to Otjimbingwe village; Otjifar = far (1200 m) from Otjimbingwe village; Tsaoclose = close to Tsaobis farmhouse (200 m); Tsaofar = far from Tsaobis farmhouse (1200 m); Donkerhuk = Donkerhuk Ost farm (with grass in the dry season).

mean ± SE per cent organic carbon in the soil at Otjimbingwe (0·610 ± 0·073%) was higher than that of the four commercial farms Tsaobis, Neu Schwaben, Davetsaub and Okomitundu (0·566 ± 0·062%), although this difference was not statistically significant (ANOVA: F = 0·154, p = 0·700, error df. = 17) (Fig. 4).

Total nitrogen

Mean ± SE total nitrogen in the soil at Otjimbingwe (386·35 ± 33·739 p.p.m) was not significantly different from that of the commercial farms Tsaobis and Donkerhuk (329·60 ± 18·795 p.p.m.) (ANOVA: F = 1·798, p = 0·189, error df. = 34) (Fig. 5).

Total phosphorus

Mean ± SE total phosphorus in the soil at Otjimbingwe (9·10 ± 0·593 p.p.m.) was not significantly different from that of the commercial farms Tsaobis and Donkerhuk (9·67 ± 0·532 p.p.m.) (ANOVA: F = 0·470, p = 0·498, error df. = 34) (Fig. 6).

Bioassays

There was no significant difference in seed germination among sites on communal and commercial areas (ANOVA: F = 0·540, p = 0·744, error df. = 24). There was also no significant difference in seed germination between soils from areas of heavy (i.e. close to the village) and lower (far from the village) grazing within the communal area (Student's t-test: t = 1·80, p = 0·24, df. = 28). The mean ± SE per cent germination in the heavy grazing area was 41·3 ± 3·32% and in the lower grazing area far from the village it was 55·3 ± 3·72%.

There was no significant difference (ANOVA: F = 0·693, p = 0·629, error df. = 123) in the root length of plants grown in soil from close and far from the heavy grazing area near Otjimbingwe village. Similarly, the stem lengths of plants grown in soil close and far from the heavy grazing areas did not differ significantly (ANOVA: F = 2·254, p = 0·053, error df. = 123).

There was no significant difference (ANOVA: F = 0·232, p = 0·637, error df. = 15) in total dry mass of radish plants grown in soil from the communal area of Otjimbingwe (mean ± SE = 0·876 ± 0·137 g, N = 10 sites) and the adjacent commercial farms (0·773 ± 0·163 g, N = 7 sites on four farms).

Discussion

The high human population density and low carrying capacity of the Otjimbingwe Reserve results in livestock having to compete for scarce natural vegetative cover, which in turn causes heavy grazing in the 117,000 ha area. However, in spite of the clear differences in human and livestock population densities between the communal and commercial farms, we found few differences in their long-term impacts on the environment (e.g. Fig. 2).

There was no significant difference in grass height between areas with heavy and low grazing pressures in Otjimbingwe and on the commercial farms, and between

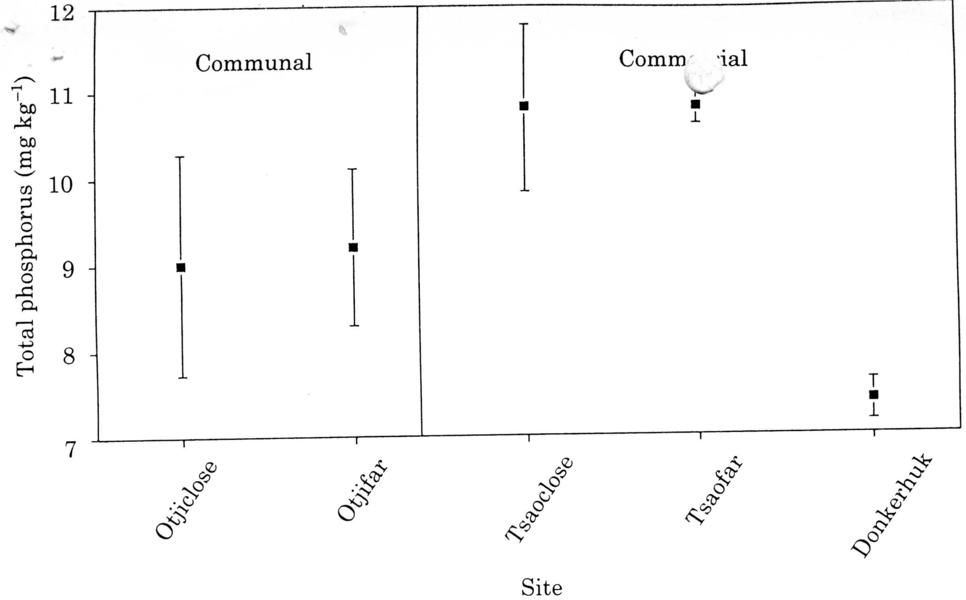

Figure 6. Total phosphorus (mg kg^{-1}) in soils. Otjiclose = close (200 m) to Otjimbingwe village; Otjifar = far (1200 m) from Otjimbingwe village; Tsaoclose = close to Tsaobis farmhouse (200 m); Tsaofar = far from Tsaobis farmhouse (1200 m); Donkerhuk = Donkerhuk Ost farm (with grass in the dry season).

Otjimbingwe and Tsaobis commercial farm at the low point of the dry season. This result could be due to the fact that all areas have been equally overgrazed. It is important to note that there is a long-term effect of grazing on the availability of grass. In a sociological survey, all respondents in Otjimbingwe communal area considered the distance to grazing areas to have increased over time (Ward *et al.*, submitted). Thus, the few differences between heavy and low grazing pressures in Otjimbingwe and on the commercial farms may reflect an overall decline in grass availability under both the commercial farms may reflect an overall decline in grass availability under both management strategies. That is, there may be a threshold effect of heavy grazing (long-term grass production is not linearly related to stocking rate) masking the effect of heavier grazing on the communal areas.

The Otjimbingwe communal area had less grass than the commercial farms in August 1997, indicating a negative effect of the higher stocking rate in the communal areas. However, the low grass availability on both communal and commercial areas at the low point of the dry season indicates that heavy grazing occurs under both strategies. The lower stocking strategies of the commercial farmers may benefit them in that they have more grass per animal for longer into the dry season than the communal farmers.

Otjimbingwe had higher levels of organic carbon in the soil than the surrounding commercial farms (Fig. 4). This result may be attributed to the fact that organic carbon is deposited in the Otjimbingwe area when the Swakop River floods during good rainfall years. However, the river was dammed in 1977, and last flooded at Otjimbingwe in 1988. Thus, if this hypothesis is correct, it indicates that irregular inputs of allochthonous organic carbon may have long-term benefits for the ecosystem in the proximity of the river. An alternative possibility is that the high stocking rates on Otjimbingwe have a positive effect on soil organic carbon through higher levels of defaecation. Either way, this result is a good indication that the soil in the Otjimbingwe area is not exhausted of its nutrients.

The data on soil nitrogen (Fig. 5) and phosphorus (Fig. 6) are consistent with those from the bioassay. That is, there was no significant difference in nitrogen, phosphorus, seed germination or plant growth between Otjimbingwe and the commercial farms. Even though the communal area has 20 times more stock than the commercial farms, soil quality is similar.

Thus, in sum, it is apparent that communal farming in Otjimbingwe is not more destructive to the natural environment than commercial farming. The facts that the soil in the Otjimbingwe area contains high levels of organic carbon, has similar nitrogen and phosphorus levels to those of the commercial farms, and can sustain as much plant growth as the commercial farms suggests that the 'tragedy of the commons' does not occur here, in spite of the area possessing all the characteristics required thereof in Hardin's (1968) formulation of the paradigm. Our results point to the resilience of desert margins in Namibia in the face of heavy human and livestock pressure. Additionally, these results lend credence to those critics of the notion that rampant desertification is occurring (reviewed by Forse, 1989; Behnke & Abel, 1996). This is not to say that we do not consider that degradation and/or desertification have occurred (see e.g. Ward & Ngairorue, in press), but rather that we believe that the high inherent variability in rainfall tends to mask the relatively smaller impacts by pastoralism in such regions (see also O'Connor, 1985; Milchunas *et al.*, 1989; Venter *et al.*, 1989; Parsons *et al.* 1997). We concur with Ellis & Swift (1988), Tapson (1993), Werner (1994) and Sullivan (1996) that rainfall in arid regions is the major driving variable and has the ability to 'recharge' a system that suffers heavy grazing pressure. However, we note that our results (and theirs) do not exclude the possibility that slow, long-term degradation has occurred on both commercial and communal farms. Only comparisons over a far longer time period can assist in determining whether gradual degradation is occurring.

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References

Adepetu, J.A. & Corey, R.B. (1977). Changes in N and P availability from P fractions in Iwo soil from Nigeria under intensive cultivation. *Plant and Soil*, **46**: 309–316.

Andersson, C.J. (1856). *Lake Ngami; or explorations and discoveries, during four years' wanderings in the wilds of south western Africa* (2nd edn). London: Hurst and Blackett. 338 pp.

Archer, F.M., Hoffman, M.T. & Danckwerts, J.E. (1989). How economic are the farming units of Leliefontein, Namaqualand? *Journal of the Grassland Society of southern Africa*, **6**: 211–215.

Behnke, R. & Abel, N. (1996). Revisited: the overstocking controversy in semiarid Africa. *World Animal Review*, **87**: 4–27.

Brams, E.A. (1971). Continuous cultivation of West African soils: organic matter dimunition and effects of applied lime and phosphorus. *Plant and Soil*, **35**: 401–414.

Bremner, J.M. (1996). Nitrogen—total. In: Sparks, D.L. (Ed.), *Methods of soil analysis. Part 3-Chemical methods*, pp. 1085–1121. Madison, WI: Soil Science Society of America. 1390 pp.