# The influence of baboon predation and time in water on germination and early establishment of *Opuntia stricta* (Australian pest pear) in the Kruger National Park

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The alien invader weed, *Opuntia stricta* Haw (family Cactaceae), is seriously threatening biodiversity in veld habitats of the Kruger National Park. Basic biological and ecological information on the establishment, growth and reproduction of the species is necessary for the development of effective strategies for its control. The rapid spread of the plant is apparently mainly due to seed dispersal by baboon (*Papio ursinus*). Sixty percent of seed taken from baboon faeces resulted in seedlings that established. Although palatability criteria for ripe fruit were more favourable than for unripe or medium-ripe fruit, seed from fruit at all three degrees of ripeness germinated equally well, and seedling establishment was similar. Despite their lower acidity, as well as higher total soluble sugar content and pH, cladodes are not subject to herbivory to near the extent that ripe fruit are. Freshly collected seed kept in Sabie River water showed significantly better germination/emergence after seven days submersion (83 %) than at 14 or 28 days (52 % and 66 %, respectively). Results suggest that seed dispersal of the species by animals, principally baboon, is an important cause of rapidly expanding infestations, and that dissipation in water will intensify the problem. Current findings should contribute toward the development of long-term weed management strategies aimed at containment/eradication of the weed.

Key words: alien invader, baboon, germination, *Opuntia stricta*, seed, weed.

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## Introduction

The noxious weed, *Opuntia stricta* Haw is the most problematic alien plant currently threatening the biological diversity in the Kruger National Park (KNP) (Lotter & Hoffmann 1998). The species is indigenous to South and Central America (Malan 1989). In Australia, the weed was recorded for the first time in 1843, in Queensland. By 1913, this population was growing at approximately 400 000 ha/year and infested some 24 million hectares by 1925 (Johnson 1982). According to Randall (1996), invasive alien biota are responsible for the largest loss of biological diversity on a global scale, next to direct human consumption.

Effective weed management demands knowledge of the target species and its interactions with other plants and animals. The present dearth of overall knowledge, and more specifically in the dispersal of the seed of *O. stricta* in the KNP, precludes precise predictions on the long-term distribution and impact of this alien in the park.

Baboons (*Papio ursinus*) and elephants (*Loxodonta africana*) have been observed feeding on the fruit of *O. stricta* and are thus known distributors of its seed. Little is known about the requirements for germination of *O. stricta* seed. Knowledge of the impact that ingestion by elephants and baboons have on the spread of this problem plant, through its germination at sites where their droppings are deposited, will aid future measures aimed at controlling this invader. The availability and palatability of *O. stricta* fruit undoubtedly also determines the feeding incidences of animals, and the amount of fruit (seed) consumed. It is not known whether birds or other animals (e.g. vervet monkeys, *Cercopithecus aethiops*) are important dispersers of *O. stricta* seed in the KNP.

Despite ongoing control efforts since 1987, *O. stricta* has continued to spread at an alarming rate and has established at greater densities in the KNP. A strategic management plan (Lotter 1996) was consequently compiled by the KNP's Alien Plant Control Section. This management plan is adaptive of nature. In order to ascertain whether selected animal species are contributing to the spread of *O. stricta*, it must be determined whether seeds remain viable after passing through their digestive tracts. Knowledge on these aspects is crucial for prediction of the long-term distribution patterns of *O. stricta*, as well as for the development of management strategies aimed at the containment/eradication of the species in the KNP.

The objectives of the study were to determine: (a) certain palatability factors for *O. stricta* fruit, which could impact on predation by herbivores, (b) the influence of predation by baboons, and immersion in river water, on seed viability and seedling establishment.

## Methods and Materials

Elephants and baboons are the most obvious dispersers of *O. stricta* seed. However, their movement and feeding patterns are unpredictable (Estes 1991), and this directly affects the collection of seed for research. At the time of the present field investigation, the activity of elephants was extremely low in the study area and fresh dung was unobtainable.

### *Palatability of* O. stricta *fruits*

Certain characteristics, which could determine the palatability of *O. stricta* fruit, were determined, viz. total soluble solids (TSS), acidity and pH. These properties were determined separately for the fruit peels, fruit pulp and cladodes according to the technique of Kuti (1992). Peels and cladodes were macerated separately to prepare purees for extraction by means of a vacuum pump. Allocots (15 ml) of the extracts were diluted to 30 ml with distilled water. The fruit pulp was analysed undiluted. The TSS (mainly sugars) was measured by using undiluted extracts in a refractometer. Acidity and pH was measured with a Mettler Toledo DL 21/25 titration apparatus.

### *Number of seeds per fruit, early establishment and growth rate*

Seed numbers were obtained by examining 40 fruits at each of three stages of ripeness, namely unripe, medium ripe and ripe. The totals from the three categories were divided by the number of fruit to give averages, and the overall total was divided by the 120 fruit to give an overall average. This was then compared with the seed numbers per fruit referred to in the literature.

Simple growth rate measurements based on plant height and number of cladodes were made of 56 plants, approximately 12 months after sowing. These seedlings were randomly selected from the 320 seedlings growing in pots at Skukuza and finally measured on 29 September 1997. Initially 60 seedlings were selected for measurement, but four of these failed to establish.

### *Emergence and early establishment of seedlings grown from seed contained in baboon faeces*

It was important to determine what influence the digestive system of baboon has on the germination strength of the seeds. Potter *et al.* (1984) suggested that the digestive system of animals remove the fruit pulp around the seeds, thus giving them a greater germination potential. Some of the seeds extracted from fairly recently excreted baboon faeces were kept under the local conditions where they were collected, namely Skukuza. The parent material of the Skukuza area is archaic granite and gneiss with dolorite intrusions. The soil is generally shallow and is saturated with salts where it is deeper. The height above sea level varies between 200 m and 350 m. From November to March the maximum temperature is higher than 30 °C, while frost sometimes occurs in winter. The rainfall fluctuates between 500 mm and 550 mm per year.

Twenty untreated seeds were sown in soil contained in five pots and kept within a fenced area. A second batch of the same seed was first placed in hot water that had been boiled, for five minutes, and then sown into pots. It was expected that this treatment may improve germination by causing slight swelling and opening of seed coats, thus increasing water imbibition and allowing oxygen to enter. Treatments were replicated five times.

The soil used was sampled *in situ* from the area where seed was collected. The experiment was conducted under natural (local) conditions. The seeds were sown by covering them with a very thin layer of soil and each pot was watered once by hand, taking care to use a similar quantity for each pot. Thereafter, they were left to rely on whatever natural rainfall may co-incidentally occur. Seed germination was monitored by periodically recording the number of seedlings that emerged.

### *Effect of time in water on seed viability*

Dispersal of seed in water has obvious ramifications for the spread of *O. stricta*. The influence of submersion of the seed in water on emergence and early establishment of seedlings was investigated. The resident troop of baboons at Skukuza are known to feed on the ripe fruit of *O. stricta*. These animals often overnight on the disused Selati train bridge that crosses the Sabie River. It was assumed that some seeds are periodically deposited in the river via the baboon faeces falling off the bridge, or by baboons frequenting riverine areas. These seeds may be washed further downstream and onto land where they could germinate and form stands. For the purpose of this experiment, water was taken directly from the Sabie River. On 23 May 1996, seed extracted from ripe fruit was submerged in the water and left at room temperature in an almost dark store room. After seven, 14 and 28 days, 100 seeds were removed at a time and sown in pots (20 seeds/pot; five replicates). The water was replaced with fresh water from the Sabie River, once every seven days.

Analysis of variance (ANOVA) was performed on all the data by means of the Statistical Analysis System (SAS) computer programme. Treatment means were compared at the 5 % ($P = 0.05$) level of significance.

## Results

### *Fruit characteristics*

The peels of unripe, medium ripe and ripe fruit contributed 84.5 %, 74.6 % and 78.7 % to their mass, respectively. The difference in pulp mass between the three degrees of ripeness was not significant, and the mean pulp mass was 12.7 %.

The total soluble solids (mainly sugars), the acidity and pH of the peels, pulp and cladodes appear in Table 1. The TSS of fruit at three stages of ripeness was not significantly different, but there was a tendency of an increase in sugar content from unripe to ripe fruit. There was no significant differences in the pH of both peels and fruits between the three fruit types. The acidity level of the pulp of green fruit was significantly higher than at the other stages of ripeness. Acidity of the

Table 1
*Total soluble solids (TSS; mainly sugars), pH and acidity level of unripe, medium ripe, and ripe fruit, and cladodes of* Opuntia stricta

| Plant part | Degree of ripeness | TSS (brix) | pH | Acidity |
|---|---|---|---|---|
| Pulp | Unripe | 6.2a | 2.78a | 1.79a |
| Pulp | Medium-ripe | 7.0b | 2.81a | 1.26b |
| Pulp | Ripe | 8.1c | 3.03a | 0.99b |
| Peel | Unripe | 5.5a | 3.92b | 0.39cd |
| Peel | Medium-ripe | 6.4b | 3.83b | 0.47cd |
| Peel | Ripe | 7.1b | 3.72b | 0.53c |
| Cladode | | 8.8c | 4.29c | 0.35d |

Means followed by the same letter do not differ significantly at $P = 0.05$.

Table 2

*Seedling numbers for* Opuntia stricta *recorded at specific dates after sowing of seeds (20 per treatment) recovered from baboon faeces*

| | Pre-treatment of seed | | |
|---|---|---|---|
| Date monitored | Untreated | Five minutes in hot water | Mean* |
| 11/12/96 | 0.0 | 0.0 | 0.0a |
| 08/01/97 | 0.2 | 0.0 | 0.1a |
| 21/01/97 | 12.6 | 7.2 | 9.9b |
| 06/03/97 | 9.8 | 7.8 | 8.8b |
| 09/04/97 | 11.4 | 12.4 | 11.9b |
| 23/05/97 | 11.6 | 12.4 | 12.0b |

*The main effect for date monitored was significant at $P = 0.05$.

fruit pulp decreased with an increase in the sugar content and pH of the fruit pulp. The opposite tendency occurred at the peels. The sugar contents and acidity of peels was generally lower than that of the fruit pulp. Cladodes had the highest sugar content and pH, and the lowest acidity level (Table 1). Acid titration indicated that the pulp of ripe fruit contained at least two types of acid in meaningful concentrations. The green fruit, peels and cladodes contained only one major acid type.

*Seedlings from seed in baboon faeces*

Data from the experiment using seed from baboon faeces appear in Table 2. There was a significant increase in emergence of seedlings between the monitoring dates 8 January 1997 and 21 January 1997. Other increases in seedling emergence were not significant. On average, the potential for seed to germinate and establish after being eaten by a baboon was 60 % (Table 2).

*Seedlings from seed submerged in water*

Compared to the number of seedlings that had developed from seed kept for seven days in river water, significantly fewer emerged from seeds submerged for either 14 or 28 days prior to sowing (Table 3). Germination/seedling emergence was 83 %, 52 % and 66 % for the 7-day, 14-day and 28-day treatments, respectively.

Table 3

*Seedling numbers for* Opuntia stricta *recorded at specific dates after sowing of seeds kept in Sabie River water for 7, 14 or 28 days*

| | Number of days seeds were kept in river water | | |
|---|---|---|---|
| Date monitored | 7 | 14 | 28 |
| 11/12/96 | 14.6 | 10.8 | 12.4 |
| 08/01/97 | 14.4 | 11.0 | 12.4 |
| 21/01/97 | 15.4 | 10.6 | 12.0 |
| 06/03/97 | 16.4 | 10.2 | 13.2 |
| 09/04/97 | 16.2 | 10.4 | 13.6 |
| 23/05/97 | 16.6 | 10.2 | 13.2 |
| Mean* | 15.6a | 10.5b | 12.8b |

*The main effect for period in water was significant at $P = 0.05$.

Table 4
*Seedling numbers at specific dates after sowing of seeds from fruit at three stages of ripeness (Data from an experiment done at Skukuza on a natural soil from the area)*

| | Degree of fruit ripeness | | | |
|---|---|---|---|---|
| Date monitored | Unripe | Partially ripe | Ripe | Mean* |
| 11/12/96 | 6.6 | 5.6 | 1.4 | 4.5c |
| 8/1/97 | 10.6 | 8.0 | 7.0 | 8.5b |
| 21/1/97 | 14.0 | 12.4 | 11.8 | 12.7a |

*Main effect for time (date monitored) was significant at $P = 0.05$.

### *Number of seeds per fruit, growth rate and early establishment*

The increase in plant numbers with time was expected (Table 4). The rate of emergence of seedlings was essentially the same for the three ripeness stages, as indicated by the non-significant interaction. The average number of seeds per fruit for unripe, medium-ripe and ripe fruit were 54.3, 51.1 and 66.5, respectively. The mean height for the 56 seedlings, approximately 12 months after sowing, was 93.5 mm, with the variance range 9 mm to 253 mm. Of these, 17 seedlings had two cladodes and 39 had only a single cladode.

Of a total of 320 seeds which germinated from 500 seeds (from various treatments) sown in pots between 23 August 1996 and 13 September 1996, only 30 failed to establish. These 30 seedlings had died from unknown causes by 23 May 1997. In summary, 64 % of the seeds germinated, of which 90,6 % established successfully (Lotter 1997).

## Discussion

### *Fruit characteristics*

The contribution of peels to fruit mass was dependent on the degree of ripeness. Peels of green fruit (84.5 %) contributed significantly more to fruit mass than those of ripe fruit (78.7 %). Kuti & Galloway (1994) reported that on average, fruit mass of *O. ficus-indica*, *O. humifusa*, *O. lindheimeri* and *O. inermis*, consisted of 63 % pulp and 37 % peel. In the present study, findings of Kuti & Galloway (1994) was confirmed by the progressive increase in TSS as the fruit matures, and a concomitant decrease in acidity level. According to these authors sucrose, glucose and fructose are the main soluble, neutral sugars in various *Opuntia* spp. Detection of two major acids in ripe fruit is supported by the work of Kuti (1992) who found that the degree of acidity of *Opuntia* spp. is determined by the presence of organic acids such as mallic and citric acid. As the fruit ripens, the ascorbic acid concentration reportedly increases.

The low pH and high acidity levels measured can be considered anti-quality factors that are likely to impact negatively on herbivory. The relatively low level of herbivory on *O. stricta*. in the KNP could be ascribed to poor quality (low palatability) or possibly to the availability of more attractive food.

### *Effect of digestion by baboons*

The number of seeds, if any, destroyed by mastication of baboons compared with number of seeds ingested is not known. It is not considered to be great, considering the numbers of undamaged seeds which were removed from their faeces. Relatively few damaged seeds were noticed during the extraction process. While the viability of *O. stricta* seeds was not shown to be enhanced by the digestive process of baboons, it was also not negatively affected. It was furthermore not necessary to treat the seed extracted from baboon faeces in any way, to illustrate germination potential. The early establishment of these seedlings also did not differ greatly from those in other experiments (Lotter 1997).

According to Potter *et al.* (1984), germination can be disadvantaged when seeds remain inside the intact fruit. When fruit passes through the digestive system of animals, the fruit pulp gets removed, and the seeds are chemically scoured by digestive fluid. Ingestion by rabbits in Kansas (Timmons 1941) caused a 50 % increase in germination of *O. macrorrhiza* seeds. Gonzales-Espinosa & Quintana-Ascencio (1986), fed fresh fruit of *O. streptacantha* and *O. robusta* to captive deer, peccaries, coyotes, raccoons, doves, thrashers, passerine birds, jays and ravens, as well as to humans, cattle, horses and goats. They found that peccaries destroyed some of the seed but that seeds generally remained intact after passing through digestive tracts. Wicklow *et al.* (1984) have broadly shown that certain seeds inside dung pellets could be exposed to more favourable conditions for germination.

Birds and man are the main distributors of seed in South Africa (Malan 1989). In the KNP, elephants and baboons seemingly play a large role in the spreading of *O. stricta* (Lotter 1996). Elephants managed to eradicate *O. ficus-indica* in the Addo National Park (Kruger *et al.* 1986). However, there are no noteworthy signs of herbivory on *O. stricta* plants in the KNP. Animals do sometimes break the plants and thus contribute to their spread vegetatively (Lotter 1996). Pollination studies done on the Seahorse Key island on the west coast of Florida, USA, showed that the honey bee (*Apis mellifera*) renders the greatest contribution to the pollination of *O. stricta* flowers (Spears 1987).

*Effect of time in water*

Results suggest that water-borne seeds may not be as viable as seeds deposited on dry land. However, large numbers of seed still germinate and establish after the periods of time tested for the factor of time in water. The fate of seeds deposited in the Sabie River in terms of distance transported and time period spent in water is not known and can only be estimated. More work on this aspect is required.

*Number of seeds per fruit, growth rate and early establishment*

The average number of seeds per fruit counted was considerably lower than the 180 found by Gregory *et al.* (1993). The reason for the lower number of seeds per fruit may be due to a restriction of pollination of *O. stricta* in the KNP. What pollination does occur is most likely insect pollination. Honey bees *Apis mellifera* have been observed pollinating the flowers of this plant in the KNP. Spears (1987) found that the number of seeds per fruit is influenced by the means of pollination (none, hand pollinated and insect pollinated), but not by the locality. The number of fruits and seeds formed following pollination by insects were lower than that of hand-pollinated flowers. Flowers that were not pollinated showed lowered fruit and seed production (Spears 1987).

The differences in height of seedlings measured was to be expected due to factors such as the different times at which the individuals germinated and emerged, slight differences in the conditions which they had to grow in, and due to inherent genetic differences of individual seeds. The number of cladodes per seedling was shown not to be purely a function of size. Although the 17 plants with two cladodes tended to be taller than the 39 plants consisting of a single cladode, exceptions were noted.

The relatively high percentage germination obtained with the various treatments throughout the study suggests that the seeds of *O. stricta* are resilient and tolerant of a wide range of conditions. Their viability is not easily influenced. Similarly, results suggest a high survival rate for seedlings, at least for their first year of growth. It is realised that actual survival rates in the field may differ, although such differences are not thought to be substantial considering that competition with grasses has not shown to have a great influence on survival rates of *Opuntia* (Dougherty *et al.* 1996) and because *O. stricta* are not usually utilised by herbivores (Lotter 1996).

In the KNP, each fruit produces approximately 60 seeds. Seeds which pass through the digestive systems of baboon, and seeds which spend up to four weeks in water can also be expected to germinate. High survival rates can be expected for seedlings. Gregory *et al.* (1993) found no difference in the number of seeds per fruit for *O. ficus-indica*, *O. hyptiacantha*, *O. lindheimeri* and *O. inermis*. An average of 180 seeds per fruit was reported.

Prevention of the development of ripe fruit should be the first priority to avoid the further rapid spread of the weed by vectors such as baboon. Results also suggest that areas close to the Sabie River and its main tributaries should also be considered as high priority control areas to prevent the spread of viable water-borne propagules.

The factors of competition and deposition of seeds in unfavourable sites were not investigated in this study. However, information gained on seed numbers, viability, requirements for germination, and seedling survival rates should be included in modelling programmes which will attempt to predict the future spread and long-term distribution patterns of *O. stricta*.

The stated hypothesis for the present study was essentially supported by the results in that it was shown that *O. stricta* seeds do germinate after passing through the digestive tracts of baboon. The same question regarding the effect of digestion by elephant remains unanswered. This aspect remains to be studied. It is recommended that further research be conducted on the role that water plays in the spread of *O. stricta*.

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