The effect of fire on two Eastern Cape *Cyclopia* species (Fabaceae)

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Seedling recruitment of the Eastern Cape endemics *Cyclopia longifolia* J.R.T. Vogel and *Cyclopia pubescens* Eckl. & Zeyh. was analysed after fire. *Cyclopia longifolia* seedling recruitment after treatments of fire; cleared and smoked; and cleared only was comparatively low; recruitment of 2.8 (after 10 weeks) to 3.8 seedlings (after 13 months) per adult was recorded. *Cyclopia longifolia* was found to be a resprouter as well as seeder. A population of *Cyclopia pubescens* was exposed to a veld-fire, with a resultant recruitment of 61 seedlings (5 months after burn) to 227 seedlings (17 months after burn) per adult. The difference in recruitment success can be ascribed, in part, to environmental conditions that strongly influenced seed germination and seedling survival. *Cyclopia longifolia* preferentially allocates its resources to regeneration rather than reproduction.

Keywords: *Cyclopia*, endangered species, Fabaceae, fire, seedling recruitment.

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Introduction

Fynbos is under serious threat from introduced species, amongst other human-induced threats. Species that flower infrequently, especially those on the periphery of the Fynbos Biome, are often overlooked (Cowling & Richardson 1995). The result is that many become extinct, pressured by the inevitable 'march of progress' and the biota is the poorer for their loss (Schutte 1995).

Three *Cyclopia* species are endemic to the Eastern Cape, South Africa: *Cyclopia pubescens* Eckl. & Zeyh., *Cyclopia longifolia* J.R.T. Vogel, and *Cyclopia filiformis* Kies. *C. filiformis* and *C. pubescens* are threatened (insufficiently known), and *C. longifolia* is an endangered species (Hilton-Taylor 1996).

Cyclopia filiformis was described by Kies in January 1949 as a new species (Kies 1951), and is known only from the type specimen, collected at the Van Stadens River, near Port Elizabeth at an altitude of 100 m. Several attempts by Schutte (1995) to relocate the population were unsuccessful.

Mr Noel Grey re-discovered *C. longifolia* at Moffett's Dam in the Longmore Plantation, SAFCOL, in the Eastern Cape, after it had been presumed extinct for over 20 years. Once alerted of the fact that *C. longifolia* was found on their property, SAFCOL discovered another population of between 30–60 individuals at Hellsekloof. The most recent site discovery for this species is on the eastern side of the Longmore Plantation at the Bulk River (N. Grey, pers. comm.).

One of the few remaining populations of *C. pubescens* was burnt by a wildfire in May 1996. The adult population was found in fine loamy-sand soil in the lee of a road bridge. The population consisted of two small groups of about 50 individuals each. This study investigates the survival of the species after this veld-fire. Factors affecting the establishment and mortality among young plants after fire are important because the large numbers of seedlings present per adult plant would permit a rapid increase in population size if they were all to survive. Whelan (1995) stated that in obligate-seeder species, the majority of the post-fire population must come through the seedling stage because wildfire causes mortality of established plants and germination of the seedlings appears to be confined to the immediate post-fire period. The hypothesis posed was: is fire a key environmental factor for the long term survival of marginal Fynbos species? Two additional theories are also investigated. Cocks and Stock (1997) and Bond and Van Wilgen (1996) categorise patterns of persistence in fire-prone vegetation into resprouters and seeders. Could *C. longifolia* fall into a third category, that of resprouter and seeder? Ants are considered as a method of dispersal of *C. pubescens* seeds.

Materials and Methods

Cyclopia longifolia

Moffett's Dam is a small municipal dam 1.6 km upstream of the Bulk River Dam, both found in the Longmore Plantation. The altitude is 360 m. a. s. l., with a *Pinus elliotii* Engelm. plantation surrounding the site. No *C. longifolia* seedlings or young plants were evident; however new growth at the base of the stems of mature plants near to or in the water course was observed.

Germination of *Cyclopia* spp. seeds has been shown to be very sensitive to environmental conditions (Schutte 1995). Taking cognisance of this fact, an artificial burn in the Longmore Plantation was planned for 3 September 1996. The first 10 m from the dam leading upstream were left untouched (Section A, Figure 1). The next 7 m were burnt (Section B). No clearing took place in the burnt area except for removal of a pine tree. The following 8 m were cleared to 20–30 cm in height (Section C). Section C was cleared and treated with liquid smoke extract, while section D was only cleared.

Heavy machetes were used to remove vegetation to about 10 cm above the ground. *Pinus elliotii* trees were chopped off at the base; *Prionum serratum* (L.f.) Drege ex E. Mey. was completely removed, and the *Cyclopia longifolia* plants were chopped off at the base. Due to the extreme flammability of the surrounding pines, the burning of Section B was done in a controlled manner, according to the plantation management regulations. Section C was treated with liquid smoke extract made by bubbling smoke from a Fynbos fire through water (H. de Lange, pers. comm.). A fire was started in a pile of Fynbos brush, and the smoke diverted into a large funnel. Bellows or a pump were used to bubble the smoke through a drum full of water. The water was then sprayed onto the ground with a watering can, at a concentration of 2 l m^{-2}. Transects were inspected on 19 November 1996 (10 weeks), and then on 16 October 1997 (13 months) after the experiment was initiated. One m^2 quadrats were consecutively laid along the transects. The following information was collected: total number of seedlings per quadrat; total number of seedling species per quadrat; total number of *Cyclopia longifolia* seedlings per quadrat and the original number of adult *Cyclopia longifolia* in the population.

Statistical analysis of data was done using the statistical analyses in Fig P (Biosoft, version 2.5). For the comparison of populations, Student's *t*-test for difference of means was applied. To determine difference of variances, Fisher's *F*-test was used.

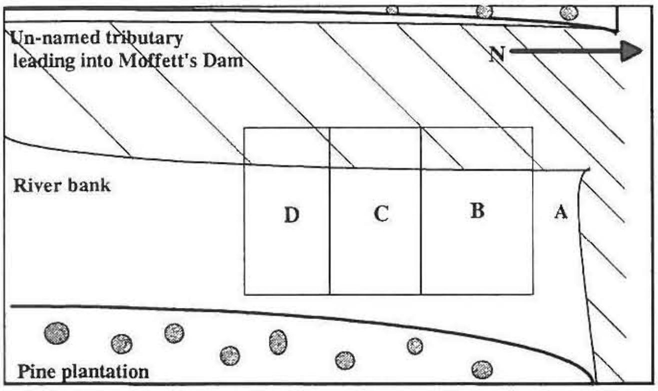

Figure 1 Sketch of Moffett's Dam experimental site. Section A represents the untreated area; Section B the uncleared, burnt area; Section C the cleared and smoked area; Section D the cleared, unsmoked area. The river course flowed due north into Moffett's Dam.

Cyclopia pubescens

The *Cyclopia pubescens* population investigated consisted of two clumps of seedlings, 20 m apart, located 1.7 km west of Port Elizabeth. A veld-fire burnt this population during May 1996.

Two perpendicular transects, crossing the western-most clump were analysed on 14 November 1996 and on 16 October 1997, approximately 5 months and 17 months after the burn. Quadrats of 1 m^2 were analysed along the transects. Aspects investigated included comparing seedling recruitment east and west of the adult population; seedling emergence outside verses inside the adult population and number of seedlings in the south and west quadrants compared to the north and east quadrants.

The following data were collected: total number of seedlings per quadrat; total number of seedling species per quadrat; total number of *Cyclopia pubesens* seedlings per quadrat; and total number of adult *Cyclopia pubescens* in the population. A minimum of 15 quadrats were recorded south, west and east of the adult population.

Results and Discussion

The results support the hypothesis that fire is a key environmental factor for the long term survival of marginal Fynbos species.

Cyclopia longifolia

The number of *Cyclopia longifolia* seedlings in the controlled 'burn' treatment was compared to the number of seedlings in the 'cleared and smoked' treatment (Figure 2). A Student's *t*-test, (using equal variances: used because of no significant difference in variances using Fishers' *F*-test for difference of variances), showed that in both samplings, the numbers of *C. longifolia* seedlings in the 'burn' treatment was not significantly different to those germinating in the 'cleared and smoked' treatment (d.f. = 28; $t_{obs} = 0.345$; $p < 0.001$); (Figure 2).

Significant increases in seedling numbers occurred in the 'burnt' and 'cleared and smoked' treatments between the sampling dates (burnt: d.f. = 4; $t_{obs} = -6.24$; $p < 0.005$, and cleared and smoked: d.f. = 4; $t_{obs} = 4.32$; $p < 0.02$) respectively. Recruitment increased within the 'burnt' treatment from 21 to 34 seedlings, and within the 'cleared and smoked' from 17 to 36 (Figure 2).

It is possible that the environmental conditions occurring at the time of the initiation of the treatments were unsuitable for immediate seed germination. Factors promoting germination include hot, dry weather before the fire and wet weather directly afterwards. A very hot fire has also been shown to be important (De Lange & Boucher 1990). Harsh environmental conditions, including heavy flooding a month to two months after the

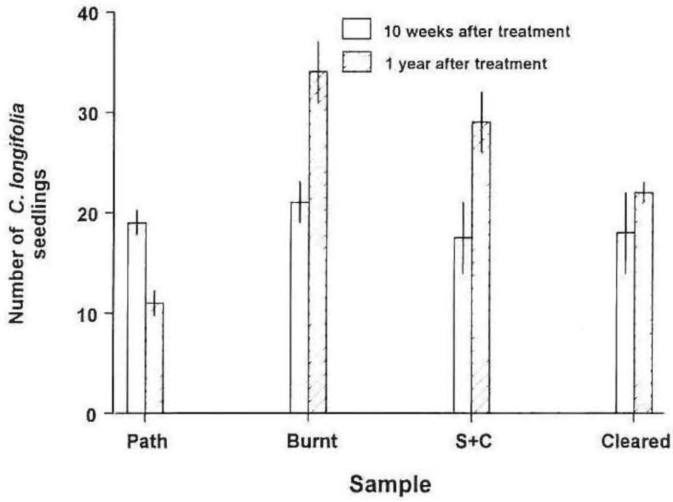

Figure 2 Total number of *Cyclopia longifolia* seedlings counted in 15 quadrats of each treatment. 'S + C' represents the smoked and cleared treatment, 'Cleared' represents the cleared only treatment (bars represent S.D.).

treatments further reduced *C. longifolia* seedling survival chances. Removal of top soil due to the clearing of vegetation and subsequent flooding would also have removed a large portion of the seed bank in the upper layers of the soil. The occurrence of 24 *C. longifolia* seedlings growing in the remaining *Prionum serratum*, 13 months after the treatments, could support this fact, in that they formed the majority (68%) of the seedlings growing in the river bed. Ten weeks after treatment, the number of *Cyclopia longifolia* seedlings in the 'cleared and smoked' treatment was not significantly different from the number of seedlings occurring in the 'cleared, unsmoked' treatment (d.f. = 28; $t_{obs} = 1.004$; $p < 0.001$). However, 13 months after the seed bank was exposed to the various treatments, 36 seedlings occurred in the 'cleared and smoked' section, more than the 21 seedlings present in the cleared only area.

It is possible that the lack of significant difference in germination between the treatments after 10 weeks is not due to a lack of seed response to smoke, fire heat, or clearing, but to the poor environmental conditions occurring at the time of the controlled burn. Fire temperatures, ambient temperature, current climatic conditions and state of vegetation are all premised to play a role in seed germination.

Cyclopia pubescens

The number of *Cyclopia pubescens* seedlings west of the adult population was compared to those east of the adult population (15 quadrats of each were compared; Figure 4). In reference to the adult population: all that remained of the previous population of *C. pubescens* 17 months after the burn were the dead stems. There was a significant difference between number of *C. pubescens* seedlings found west and east of the adult population. Five months after the burn, a total of 125 individuals were found in quadrats 1 to 15, west of the population compared to 25 seedlings found in quadrats 36 to 50, east of the adult population (d.f = 17.81; $t_{obs} = 3.886$; $p < 0.002$). Similar trends were identified 17 months later; a total of 171 seedlings west verses 105 seedlings east were recorded.

The number of *Cyclopia pubescens* seedlings south and west of the adult population were compared to those to the north and east of adult population (Figures 3 and 4). There was a difference between these groups for both the 5 month and 17 month post-fire analyses. In the 30 quadrats south and west of the adult

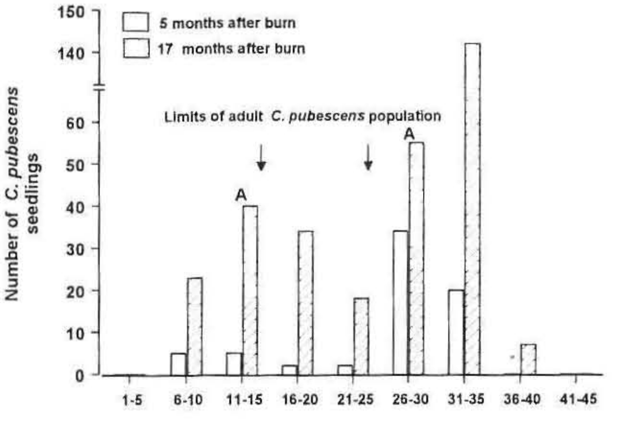

Figure 3 Density of *Cyclopia pubescens* seedlings per 5 quadrats ($5\ m^2$) along a 45 m north south transect. Quadrat 1 lies adjacent to the N2. Quadrats 1 to 15 lie north of the adult population; quadrats 26 to 45 lie south of the population. 'A' indicates the presence of a small ant mound.

population, 371 *C. pubescens* seedlings were recorded, while only 170 seedlings occurred north and east of it, 17 months after the fire. As with the environmental conditions affecting *Cyclopia longifolia* seedling recruitment, there is more than one variable influencing where *Cyclopia pubescens* seedlings will germinate. It is postulated that the governing factor in *Cyclopia pubescens* seedling densities is the presence of ants. Although micro-environmental variables such as soil quality and topography were not analysed, they were not observed to differ between the north-east and south-west of the population.

Wind is highly unlikely to play a role in seed dispersal, as the dominant prevailing wind is a south-westerly, and wind-borne seeds would be deposited north-east of the population: opposite to where the density of seedlings is the highest. The number of *Cyclopia pubescens* seedlings inside the adult *C. pubescens* population was compared to the number of *C. pubescens* seedlings outside the adult population (25 quadrats each). Five months after the burn, there was a significantly lower number of *C. pubescens* seedlings found inside compared to outside the adult population (d.f .= 3.75; $t_{obs} = 3.717$; $p < 0.001$).

The lack of shade tolerance could explain the higher numbers of seedlings found outside the adult population. Deducing from the few unburned branches of an adult *Cyclopia pubescens* plant, it is presumed that the population, in the dense stand that it forms, will block out a considerable amount of light. *C. pubescens* seedlings are shade intolerant, being found in an exposed unsheltered area. The presence of considerable numbers of seedlings within the adult population 17 months after the burn (Figure 4) confirms the theory that *C. pubescens* seedlings require full sunlight to flourish.

The highest number of *C. pubescens* seedlings were found on the periphery and immediately adjacent to the adult population (Figure 4). This correlates well with data presented by Bond and Slingby (1983) who state that seeds are seldom carried for more than 2 to 3 m by ants. They did, however, record a maximum transport distance of 17 m, for a *Leucospermum* seed, which would put the 15 m distance from the population within a feasible range for a transfer. Other strong evidence that *C. pubescens* actively attracts ants to act as vectors is the presence of an aril. There was a significant difference between the number of *Cyclopia pubescens* seedlings found in quadrats on or near ant hills compared to the number of *C. pubescens* seedlings found in quadrats 3 m or more from an anthill (d.f = 16.159; $t_{obs} = 2.265$; $p < 0.05$). Various advantages are gained by myrmecochrous plants, especially in systems subject to intermediate fire frequencies, such as Fynbos, where seedling regeneration is confined to the immediate post-fire period. Handel and Beattie (1990) established that the strong directionality of ant dispersal to nutrient-enriched nests and middens in an otherwise impoverished soil provide a competitive advantage for seedlings.

For species consisting of a few populations, such as *Cyclopia pubescens*, this has particular relevance. Wind-dispersed seeds would travel greater distances, and possibly be lost to the gene pool, while ant-dispersed seeds germinate within a close proximity to the adults, yet expand the population diameter.

Seedling recruitment

Environmental conditions strongly influenced seed germination and seedling survival for both species. Conditions conducive to high recruitment levels occurred during and after the veld-fire that burnt the *C. pubescens* site.

A representative 100 m^2 (55 quadrats from the west - east transect, 45 quadrats from the north - south transect) cross-section of the adult population and its surrounds yielded 229 *Cyclopia pubescens* seedlings 5 months after the fire, and 752 seedlings 17 months after the fire. This extrapolates to approximately 4 048 and 14 771 seedlings within the 1600 m^2 area analysed in the respective investigations.

There were 65 adult *C. pubescens* individuals, giving a recruitment of 61 seedlings per adult 5 months after the fire, and 227 seedlings per adult 17 months after the fire (Table 1). Analysis of the Moffett's Dam site 2.5 months after the treatments showed 25 *Cyclopia longifolia* adults and a total of 70 seedlings (Table 1). The low recruitment of 2.8 seedlings per adult was attributed to the unfavourable environmental conditions that occurred after the treatments. It is postulated that other factors, including the age of the adult *C. longifolia* plants and the evolutionary trend to allocate more resources to resprouting than to sexual reproduction caused a reduction in seedling numbers.

Thirteen months after the various treatments, the number of *C. longifcllia* seedlings per adult increased to 3.8, still considerably lower than recruitment exhibited by *C. pubescens* after a fire event. Even the recruitment within the fire treatment only reached 5.4 seedlings per adult.

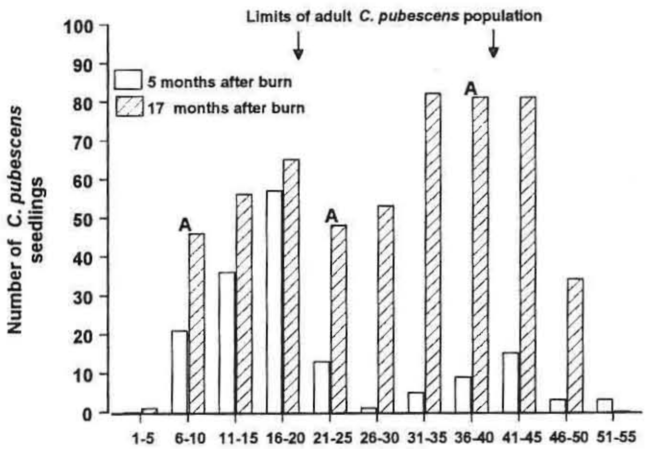

Figure 4 Density of *Cyclopia pubescens* seedlings per 5 quadrats ($5\ m^2$) along a 55 m west - east transect. Quadrats 1 to 20 were west of the adult population; quadrats 40 to 55 were east of the adult population. 'A' indicates the presence of a small ant mound.

Table 1 The total number of *Cyclopia* spp. seedlings and number of seedlings per adult analysed in this study

Cyclopia spp.	Date after treatment/ fire event	Estimated total number of seedlings	Number of seedlings per adult
C. pubescens	5 months	4 048	62
	17 months	14 771	227
C. longifolia	2.5 months	70	2.8
	13 months	140	3.8

Under natural conditions environmental factors are usually the triggers that overcome seed dormancy (Amen 1968). Once the matured seeds have been dispersed into the surrounding environment, their further development could be affected by the prevailing conditions in the environment. These conditions are determined by various factors. Fire is one of the most important factors that could control environmental conditions in various ecotypes (Sutcliffe 1994).

Fynbos, for example, can be managed by regular burning. Fire-stimulated seed germination is a mechanism to ensure rapid regeneration after a burn (Sutcliffe 1994). The fire controls the community composition by eliminating fire-sensitive species and by selecting plants capable of rapid post-fire regeneration. *C. pubescens* demonstrated rapid post-fire regeneration ability. The current study has shown that *C. pubescens* is a seeder. None of the *C. pubescens* adults had resprouted 17 months after the fire. Some species, such as *Cyclopia longifolia*, survive by producing copious new shoots from the stem base at or near ground level. Fire-sensitive seeder species germinate quickly after a fire and attain maturity and reach reproductive capacity reasonably early, so as to maximise seed production quickly, and thereby establish an effective seed bank before the next burn (Pate *et al.* 1990).

The current study has also shown that *C. longifolia* is a resprouter after fire, as well as a seeder. Cocks and Stock (1997) stated that representatives of Fabaceae with soil-stored seed banks fall into two groups according to their fire survival strategy; either being fire ephemerals that only regenerate from soil stored seed after fire, or auto-regenerative sprouters which resprout from mature tissue after fire. *C. longifolia* appears to form part of a third group, showing both resprouting after fire and fire induced seed germination. The *C. longifolia* showed buds proliferating at the bases of the stems, forming a structure similar to a lignotuber or burl as described by Bond and Van Wilgen (1996). Mitchell (1922) listed 42 species that recovered after a fire, seven of which both resprouted and produced significant numbers of seedlings.

The low recruitment of seedlings after the respective treatments might be a result of more than one limiting factor. The time of the burn (September instead of February, the preferred time) almost certainly was the predominant restricting factor. None of the environmental variables, from the thick, moist, riverine undergrowth, to the unusually heavy storms a month after the experiment started, to the erosion caused by flooding were conducive to seedling survival. The current study confirms Kruger, (in Gill and Groves 1981), who stated that *Watsonia* flowered much better following a March burn than after burns in September or November. However, data by Hansen *et al.* (in Bond & van Wilgen 1996) showed that of two co-occurring shrubs in Australia, the non-sprouter began flowering much earlier and had much higher fecundity than the resprouter. Similar to the results of this study, sprouting appears to have a profound reproductive cost relative to the precocious non-sprouter. Out of the 952 seedlings (or 22%) recorded in the *C. pubescens* transects, 207 had pods 17 months after a burn. Thirteen months after the *C. longifolia* treatments, the seedlings showed no sign of buds, although adults in another area were in full flower. As *C. longifolia* has been shown to resprout after a fire, it is also possible that energy allocated to sexual reproduction is not as great as found in other species, with the result that seedling recruitment would generally not be as high as for example *C. pubescens*.

When considering the high seedling recruitment of *Cyclopia pubescens* (Table 1) in relation to *Cyclopia longifolia*, various aspects of their biology require consideration. Schutte (1995) postulated that the ability or inability to sprout after fire represents different life histories that are genetically fixed. This character influences a wide range of other ecological adaptations, such as the ability to survive in flowing water. Other ecological adaptations include population density, habitat specificity, relative regional abundance and seedling production.

It could be inferred that fire regimes have influenced species distribution patterns, and that speciation processes in *Cyclopia* spp. were driven by ecological differentiation. Adaptations such as myrmecochory as a dispersal mechanism could have influenced speciation rates in *Cyclopia pubescens*. Schutte (1996) infers that short distance dispersal has played an important role in present-day distribution patterns. By contrast, *Cyclopia longifolia* adapted to the flowing water conditions in which it is found by expending more energy on resprouting after fire.

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