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Further observations on ecology of *Blandfordia cunninghamii*: flowering responses to rainfall and fire, and juvenile growth rates

David Coleby

Convener, Sublime Point Bushcare Group, 11, Willoughby Road, Leura 2780, Australia. Email: davidcoleby@bigpond.com.au

Abstract: A population of 700 *Blandfordia cunninghamii* Lindl. (family Blandfordiaceae) plants in the Blue Mountains, 100 km west of Sydney, New South Wales was monitored over a period of seven years, during which a part of the population area was burnt in a Hazard Reduction Burn (HRB). The survey measured flowering of *Blandfordia cunninghamii* in both the burnt and unburnt areas. In part of the unburnt area flowering (in December) was strongly correlated with previous September rainfall, but in another unburnt area there was no flowering at all over the seven years. An enhanced flowering response after fire was found in the burnt area and the diminution of this enhanced response in subsequent years was found to be logarithmic (taking into account potential rainfall effects). No recruitment of juvenile plants after fire was observed. 87% of seeds of *Blandfordia cunninghamii* were found to be germinable. Slow juvenile growth of *Blandfordia cunninghamii* in the field was measured over seven years. Seed was collected for two major seedbanks, the NSW Plantbank at the Australian Botanic Garden, Mt Annan and the Millennium Seedbank at Kew in the United Kingdom.

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Introduction

Blandfordia cunninghamii Lindl. (family Blandfordiaceae) is one of four *Blandfordia* species in Australia, all confined to the eastern states; three on the mainland, and one in Tasmania. All are known colloquially as Christmas Bells. All three mainland species occur in New South Wales. *Blandfordia nobilis* Sm is endemic in coastal regions south of Sydney (34° S) to about Bega (36° S). *Blandfordia grandiflora* R.Br ranges from Sydney to Fraser Island in Queensland (24° S), including occurrences in the lower and middle Blue Mountains (Porter et al 1992; Johnson 1998). *Blandfordia cunninghamii* Lindl. is a tufted perennial herb with leaves up to 1 m long. It is a rare species (Briggs & Leigh 1995) and is restricted to a narrow range of habitats in the Blue Mountains (lat 33° 40' S, long 150° 20' E) and the Illawarra areas of eastern New South Wales (Porter 1992).

While fire response of many other genera are known (eg see Campbell and Clarke 2006; Croft, Hofmeyer and Hunter 2006; Keith 1996; Pyke 1983) field data on fire responses have only been published for *Blandfordia nobilis* (Johnson 1998; Johnson 1996; Johnson Morrison and Goldsack 1994). In Coleby (2006) we investigated distributional and ecological aspects of *Blandfordia cunninghamii* but did not document flowering in response to fire. Since 2004 we have monitored a *Blandfordia cunninghamii* population in south Leura (Cliff View Road) in the upper Blue Mountains over a period of seven years allowing us:

to compare the seasonal flowering responses with rainfall records,

to measure the flowering response in a burnt part of the population

to collect seed for germination testing, and

to monitor a trial planting of 12-month old seedlings in the natural environment over seven years.

This paper provides a summary of our results.

Methods

Location and fire history

The Cliff View Road *Blandfordia cunninghamii* population (GDA map reference 535649 on 1:25,000 Katoomba 8930–1–S topographic map, Lat 33º 43' 36.5", Long 150º 20' 23", elevation 910 m) (Figure 1) contains nearly 700 plants in the area of south Leura in the upper Blue Mountains and is part of the total population of 4300 plants of *Blandfordia cunninghamii* described in Coleby (2006).

The Cliff View Road population inhabits a steep hillside of average slope 30 degrees with a southerly aspect; both distinguishing features of populations of *Blandfordia cunninghamii*. It lies halfway down the 200 m slope between Cliff View Road in the north and Dundas Creek in the south, both of which have east-west alignments. The population lies at an altitude of about 910 m, in an east-west arc about 250 m long x 40 m wide, which dips in the west towards westward-flowing Dundas Creek. The eastern portion of the population lies in two private properties north of Leura Golf Club's dam on Dundas Creek. The remainder to the west lies in the Blue Mountains National Park. The unmade Carleton Road Reserve (10 m wide) runs north and south up the 30 degree slope and divides private property from National Park.

Part of this *Blandfordia* population was burnt in a Hazard Reduction Burn (HRB) in April 2008 which burnt the shrub understorey almost completely but only singed the eucalypt canopy. National Parks and Wildlife Service (NPWS) categorised the HRB as a cool burn, not as hot as a natural bushfire. The Cliff View Road Population in our study is divided into three areas (Figure 1):

Sub-Population 1a, unburnt (250 plants on either side of the burnt area)

Sub-Population 1b, burnt in April 2008 (250 plants in a block 60 m long (E–W) and 40 m wide (N–S), i.e. 2400 m^2)

Sub-Population 2, unburnt (200 plants).

Sub-Populations 1a and 1b occupy habitat within Blue Mountains Sandstone Plateau Forest (Map Unit 9i Keith & Benson 1988). The dominant canopy species are *Eucalyptus piperita* subsp. *piperita* and *Eucalyptus sieberi*, plus occasional *Eucalyptus dendromorpha* and *Eucalyptus stricta.* The shrub storey is largely *Leptospermum trinervium*, *Banksia cunninghamii, Banksia serrata,* and *Hakea dactyloides,* with *Callicoma serratifolia*, *Petrophile pulchella* and *Lambertia formosa.* The understorey includes *Epacris microphylla*, *Olearia myrsinoides*, *Lomatia silaifolia, Lycopodium deuterodensum* and *Gahnia microstachya.*

Population 2 is closer to Dundas Creek and occupies a markedly different habitat to that of Population 1: its landform is a series of short steep cliffs (3–5 m high) on which *Blandfordia cunninghamii* are a dominant component of vegetation. The slopes adjoining the Creek are much more shallow than the usual 30 degree preference of *Blandfordia cunninghamii*, and the vegetation exhibits aspects of cool temperate rainforest with *Pteridium esculentum*, *Gleichenia dicarpa* and *Callicoma serratifolia*.

Recording of flowering and seedlings

The boundary of the population in the investigation was slightly larger than the 662 plants recorded in 2004 because 38 more outlying plants had been subsequently identified. An old power pole on Carleton Road on the north-south boundary between National Park and private property was used as a datum from which the population extends 80 m east into private property, and 170 m west and then south into National Park.

The entire population was surveyed using 100 contiguous 10 x 10 m quadrats encompassing every plant and every flower stem, though not every quadrat contained *Blandfordia cunninghamii* plants. Field recording was conducted in the six summers of 2007–08 through 2012–13. Each year we counted flower stems, usually in late December after the peak of each flowering season. The counts included flower stems that had gone to seed and late stems with buds. The prominence and persistence (many stems persist for a year or more) of all stems up to 80 cm tall made identification easy.. We checked later in each season that no new stems had appeared. Each year at the same time we searched for evidence of recruitment of *Blandfordia* seedlings.

Seed collection

Richard Johnstone (NSW Seedbank Officer, Australian Botanic Garden, Mount Annan) took advantage of enhanced flowering in 2008–09 to collect nearly 20 g of seed with the assistance of the author. The collection was made in mid-March 2009, at a time when at least 90% of the available seed had already been shed into the environment.

Seedling propagation and growth

Prior to this study seeds of *Blandfordia cunninghamii* had been collected from a private property in south Leura and propagated in a nursery in December 2005. In December 2006 25 seedlings from this collectiom, each with 3–4 leaves about 30 mm long and less than 1 mm wide, were planted out in south Leura on a southern slope at a location separate from that surveyed above. This location had similar native vegetation with 9i Open Forest as above, and was chosen because it was within an existing population

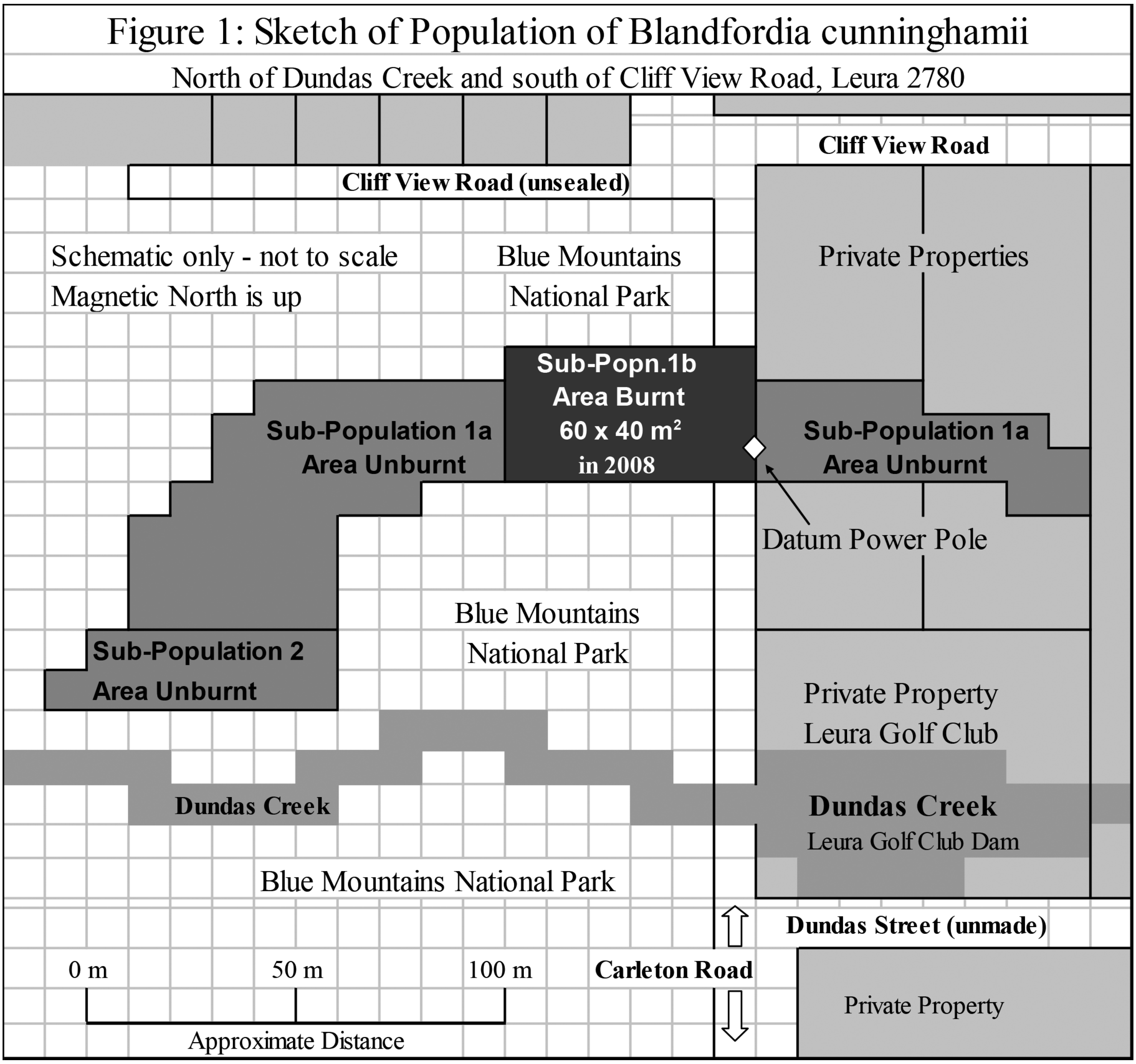

Fig. 1. Location of subpopulations of *Blandfordia cunninghamii* at Cliff View Road Leura.

of mature *Blandfordia cunninghamii*, thus guaranteeing suitable habitat. The seedlings were planted at 2 m intervals in a five-by-five array, with minimum disturbance to the environment, each marked with a white topped bamboo cane for easy identification. There was no further treatment of the seedlings in the field.

Rainfall

Rainfall was measured daily over the seven-year period at a site 300 m southeast of and at the same elevation as the Cliff View Road population. These data were used in preference to the Bureau of Meteorology (BoM) official figures because rainfall patterns in the Blue Mountains are highly variable, and the nearest BoM recording station is at Mount Boyce, 13.5 km northwest of the Cliff View Road population.

Results

Effect of rainfall on flowering

Over a ten year period no flowering was recorded for any of the 200 (unburnt) Population 2 plants. In contrast some flowering was recorded in every year in the similarly (unburnt) Sub-Population 1a plants which presumably received the same rainfall. For Sub-Population 1a, Table 1 shows the number of flowering stems recorded each year in late December (for the period January 2007 to December 2012) and the locally-recorded monthly rainfall totals over the same period, together with correlation coefficients between the annual number of flowering stems (first column) and total rainfall for each separate month of the year (bottom line).

Table 1. Number of flower stems per year in Sub-Population 1a and correlation with rainfall (mm) in each month for the years 2007–2012, September was the one month where a correlation coefficient (0.92) was significant (at the 1% level).

No.of Stems	Month Year	J	F	M	A	M	J	J	A	S	O	N	D	Total
8	2007	68	314	167	66	51	403	22	139	47	24	370	202	1873
16	2008	162	245	62	163	9	153	39	39	105	94	79	73	1223
7	2009	33	278	57	213	166	49	42	21	22	168	42	109	1200
6	2010	125	465	93	25	108	104	79	66	42	142	184	188	1621
18	2011	162	84	173	103	99	136	46	34	125	95	191	158	1406
1	2012	203	233	284	131	23	142	40	17	33	32	62	61	1261
Correlation Coefficient		**0.1**	**-0.55**	**-0.4**	**0.1**	**-0.05**	**0**	**-0.1**	**-0.03**	**0.92**	**0.15**	**0.12**	**0.2**	**0.1**

September was the one month where a positive correlation coefficient (0.92) was significant at the 1% level. Regression of the number of flower stems (Column 1 of Table 1) against September rainfall for that year is shown in Figure 2.

Effect of fire on flowering

The April 2008 burning of the 250 plants in Sub-Population 1b had an immediate effect on flowering in the following season with the number of flowering stems increasing from 4 in 2007 to 115 in 2008, followed by irregularly diminishing numbers in succeeding years (Table 2, Figure 3). The possibility that subsequent flowering might have been enhanced by a smoke effect on the plants during the burn was considered, but no evidence was observed. Indeed, mature plants only 1m from the edge of the burn showed no increase in flowering, and observations suggested that even plants that were singed on the edge of the burn exhibited no increase in flowering. The possibility that subsequent flowering might have been enhanced by nutrients arising from higher up the slope percolating downwards to an unburnt part of the population was also considered but observations did not support this.

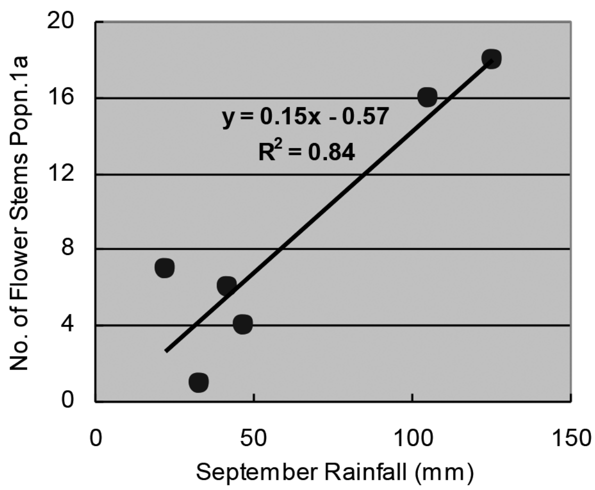

Fig. 2. Linear regression of the number of flower stems recorded annually in December (2007–2012) compared with rainfall in the previous September for Sub-Population1a (unburnt) plants.

Table 2. Number of annual flower stems in Sub-Population 1b for period 2007–2012 (burnt in April 2008)

Year	Number of flower stems
2007	4
2008	115
2009	43
2010	13
2011	18
2012	3

A simple hypothesis is that in Sub-Population 1b the two effects of fire and September rainfall are additive and independent, and that the relationship is linear. In order to separate the fire response we subtracted the rainfall component from the total response shown in Table 2 and Figure 3. To do this we used the rainfall from Sub-Population 1a as a proxy for that in Sub-Population 1b, not using actual

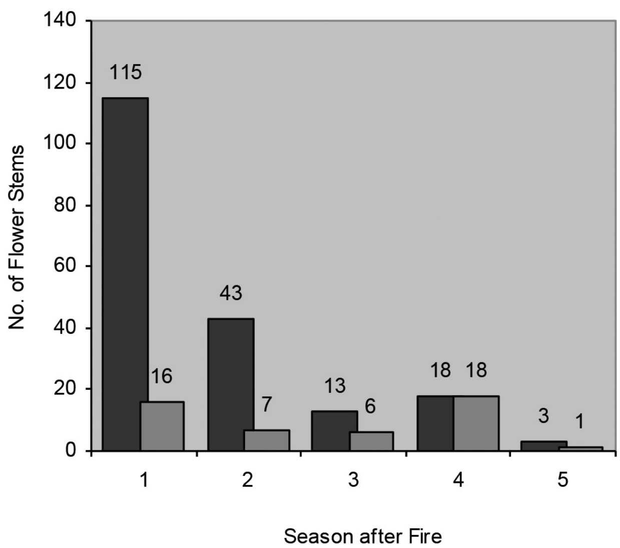

Fig. 3. Number of flower stems in Sub-Population 1b (▮ burnt in April 2008) and Sub-Population 1a (▮ unburnt) in 2008–2012 (1–5) seasons.

Table 3. Separating the effects of fire and September rainfall on the number of flower stems in Sub-Population 1b (burnt in 2008). See text for explanation

1 Year	2 September Rainfall (mm)	3 Expectation $y = 0.15x - 0.57$ (from Fig 2)	4 Stems in Burnt Popn.1b	5 Difference Col 4-Col 3	6 Adjust Origin Col 5 + 2.5	7 Log 10 (Col 6)	8 Season After Fire
2008	105	15.18	115	99.82	102.32	2.01	1
2009	22	2.73	43	40.27	42.77	1.63	2
2010	42	5.73	13	7.27	9.77	0.99	3
2011	125	18.18	18	-0.18	2.32	0.37	4
2012	33	4.38	3	-1.38	1.12	0.05	5

values, but the *expected* values determined by the regression equation $y = 0.15x - 0.57$, from Figure 2. These expectations are shown in Column 3 of Table 3. The actual numbers of flower stems in the burnt Sub-Population 1b are shown in Column 4 of Table 3, and the difference between expectation and actual numbers is shown in Column 5. The two negative numbers in Column 5 were removed by adding 2.5 to all numbers in Column 5, and the adjusted numbers are shown in Column 6. This manipulation did not materially alter the outcome. We calculated the logarithm of these adjusted numbers, and show them in Column 7. Column 8 records the season after fire. We graphed Columns 7 and 8 of Table 3 in Figure 4.

We concluded from Figure 4 that there would be a semi-logarithmic relationship between the number of flower stems in any one year and the season after fire in the absence of any rainfall effect. The correlation coefficient of the data (r^2=0.994) is significant at the 0.1% level Over the five-year

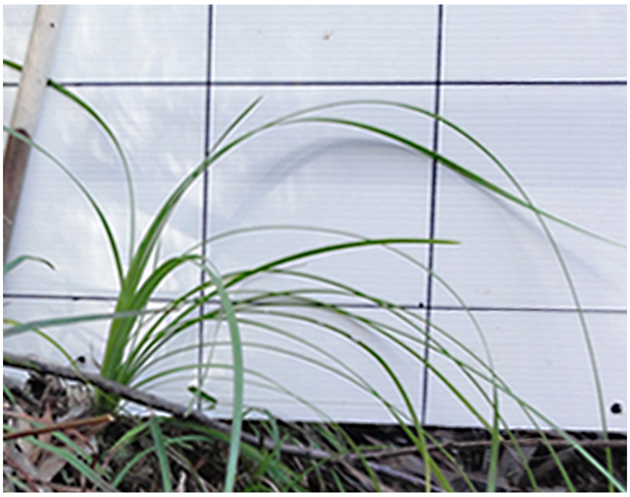

Fig. 5. (left) Immature *Blandfordia cunninghamii* (six years old) in natural environment (Scale = 10 cm)

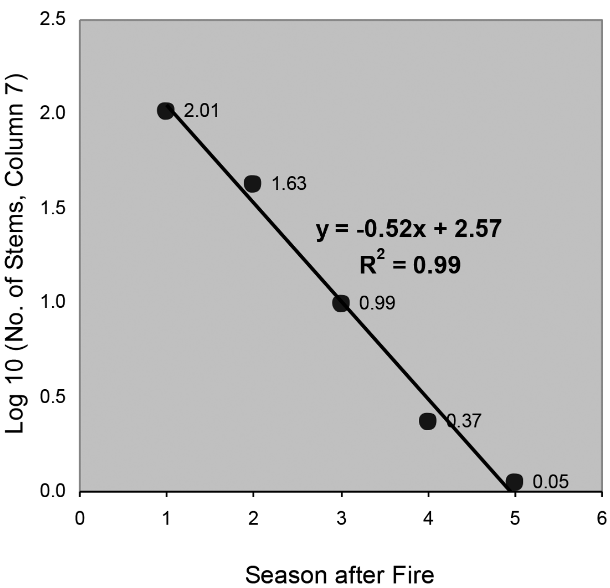

Fig. 4. Semi-logarithmic graph of adjusted numbers of flower stems in Sub-Population 1b (from Columns 7 and 8, Table 3), r^2 = 0.99; Slope = -0.52; Intercept = 2.57; y= -0.52x + 2.57

Fig. 6. (right) Mature *Blandfordia cunninghamii* (age not known) in natural environment (Scale = 10 cm)

period the slope of the semi-logarithmic decline is - 0.52, the equation of the line is y = - 0.52x + 2.57, and R^2 = 0.99.

Seed collection and recruitment

Seed testing at the Australian Botanic Garden, Mount Annan showed that, after cleaning, the germination rate was 87%. The high measured germinability of fresh *Blandfordia cunninghamii* seed is likely to decline over time, even under controlled seed storage conditions, but the rate of that decline is unknown. Part of the seed was sent to the Millennium Seedbank at Kew Gardens, UK, and the remainder retained in the NSW Plantbank at the Australian Botanic Garden.

No recruitment of juvenile *Blandfordia cunninghamii* to the population was observed, either in the burnt portion or in the unburnt portion. Recruitment may have occurred, especially in the burnt portion, but was not detected because of small size of juveniles in the short time since the fire. Their small size renders them almost indistinguishable from similar leaves of other monocotyledons.

Seedling survival and growth

Twelve of the 25 seedlings planted in 2006 survived to May 2013, but their growth was slow. Only one plant (see Figure 5) showed significant development: it had 21 leaves (mostly between 300 and 410 mm length and about 2.5 mm wide). Among the other eleven plants the average number of leaves was 6; none was more than 450 mm long or more than 2.5 mm wide. The plants in Figures 5 and 6 inhabit the same sloping site, only 2 m apart.

Only the longest leaves exhibited the beginnings of two small veins, parallel to and on either side of the prominent central rib of the leaf. Leaves on mature plants (see Figure 6) are commonly up to 1 m long, 10–15 mm wide, with 8–15 distinct veins on either side of the central rib. These observations suggest that recruitment to maturity is a slow process, probably measured in decades.

Discussion

The results show that fire appears to promote flowering in *Blandfordia cunninghamii* in the season immediately following fire, but neither nutrient transfer nor smoke exposure had any noticeable effect on plants outside the burn area. The maximum response occurred when the plants themselves were burned, removing all leaves and leaving only a charred but intact hypocotyl at or below ground level. Population flowering response to a fire stimulus was not limited to the flowering season immediately following fire. Enhanced flowering continued in subsequent years, but at a diminishing and highly variable rate (Figure 3). Over a period of five years the flowering rate in the burnt area (Sub-Population 1b) diminished to the point where it had reverted to background levels of 1–2% of plants flowering per year, as in the unburnt area (Sub-Population 1a). These observations are similar to those of Johnson, Morrison and Goldsack (1994) in relation to *Blandfordia nobilis.* In contrast, Pyke (1983) found that in the woody shrub *Telopea speciosissima* the percentage (or density) of plants in flower, the average number of flowers per inflorescence and the average number of fruits per inflorescence all appear to peak two years after a summer fire and decline thereafter. In the shrub *Lambertia formosa* Pyke (1983) also reported that the density of inflorescences reaches a peak 2 or 3 years after a summer fire. Woody shrubs such a *Telopea* and *Lambertia* are more likely to flower on older wood, whereas *Blandfordia* flower stems emerge directly from the hypocotyl.

Flowering response may also be influenced by a host of environmental factors such as the burn status (whether cool, intermediate or hot), the yearly variations in temperature and rainfall, the regeneration of canopy and other vegetation layers, and access to nutrients that might enhance flowering (Lamont et al 2000; Myerscough 2009; Pyke 1983). Considerations of this nature were mostly beyond the scope of this study.

An unexpected finding was the strong correlation (r^2=0.92) between the annual count of flower stems in unburnt Sub-Population 1a and total rainfall in September of that year. There is no obvious relationship with any of the other eleven months. Were September rainfall alone to be responsible for flowering then we would expect Sub-Populations 1 and 2 (where no flowering was recorded) to behave similarly. That they do not suggests that whatever flowering stimulus is present, it is not *direct* rainfall, in September or in any other month. This observation suggests that local habitat conditions play a part in flowering responses and may vary over the range of the species. For example September rainfall in Sub-Population 1 may provide access to the water table in that area, at a time when plants are receptive to a trigger for flowering later that year. In Sub-Population 2 the nearby creek dominates the water table, there is little variation in depth of the water table (it is well below the plants on the small cliffs) and the flowering stimulus is thus removed.

The seed germinability results are consistent with this author's earlier observation that at 75% of fresh *Blandfordia cunninghamii* seeds will germinate. In the natural environment, there are large numbers of seeds per capsule (~50) and of capsules per flower head (~25) (Coleby, 2004). However, recruitment of seedlings to juveniles and beyond is very low: seed and seedling mortality through predation by unknown vectors (but probably insects), competition from established plants, and/or lack of follow-up available water are probably dominant factors. Data collected in the present study indicate that seedlings may remain very small for several years, and thus difficult to recognise amid a welter of regrowth of other species after fire.

Summary

This study found a strong correlation (r^2=0.92) between September rainfall and flowering rate later that year for part of the Cliff View Road population of *Blandfordia cunninghamii.* Observations of habitat of different parts of this population suggest that this effect may not be brought

about by direct rainfall itself, but by contact with the water table at a time when the plants begin to produce flower stems.

The study found that *Blandfordia cunninghamii* showed a marked response to fire as a stimulus to flowering in the first season after fire, much as reported for *Blandfordia nobilis* and other genera. This flowering response diminished in later years after fire: when the effects of variable September rainfall were removed, the diminution in flowering response was semi-logarithmic.

This study found that fresh seed, after cleaning, was 87% germinable but no natural seed recruitment was observed. It appears that plant development from seed to mature plants is a long process, probably measured in decades.

To paraphrase Frances Crick (quoted in Ridley 1999) "the arguments and assumptions which we have had to employ to deduce these results are too precarious for us to feel much confidence in them on purely theoretical grounds. We put them forward because they rest upon the correlations in a neat manner and from reasonable physical postulates."

Fig. 7. The distinctive flowers of *Blandiflordi cunninghamii*

Acknowledgements

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