Seedling survival, soil seed bank status and disturbance response of the endangered *Dryandra ionthocarpa* A.S George ssp. *ionthocarpa* ms (Proteaceae)

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DEPARTMENT OF
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SUMMARY

This project investigated factors affecting seedling recruitment and survival in the endangered Western Australian shrub, *Dryandra ionthocarpa* A.S. George ssp *ionthocarpa* ms.

The soil-stored seed bank was confirmed to be low although a burial retrieval experiment demonstrated that a significant percentage of viable seed persisted in the soil for up to nine months. Laboratory studies show *D. ionthocarpa* ssp. *ionthocarpa* seed to be readily germinable, with smoke treatment not significantly improving germination.

The canopy-stored seed bank was variable with a high percentage of cones aborted or decayed. Less than one third of cones were intact.

Fire was the major cue for recruitment with negligible germination following aqueous smoke application. The small number of seedlings that recruited naturally failed to survive through summer. Post-fire seedling recruitment was variable and lower than that recorded for the same sub-population in a previous study. Survival of seedlings was low (ca. 30%) over the nine-month monitoring period, but was considerably higher for irrigated plants compared with non-irrigated. Survival was highest for plants that were both irrigated and fenced.

It would appear that drought conditions were the main cause of seedling mortality although vertebrate and invertebrate grazing also affected plant health and survival.

This report recommends ongoing monitoring to document second season survival as well as time to first flowering and survival rates through to reproductive maturity. Monitoring in spring 2004 is recommended to see if any additional recruitment occurs. The use of small-scale patch burning may be warranted as a tool to promote recruitment if population decline continues, with irrigation and fencing of seedlings post-fire. Predator control pre-fire should also be considered as recommended by Monks (2000).

INTRODUCTION

Dryandra ionthocarpa A.S. George was first discovered and collected by P. Luscombe near Kamballup in 1987 (Robinson and Coates 1995). Despite numerous surveys no other populations have been found. In 1989 the species was declared as Rare Flora and ranked Critically Endangered according to IUCN criteria in 1995 (IUCN 1994). In 1999 a purported new population of this species was located near Narrogin. However, as plants in this northern population resprout from a lignotuber in contrast to the Kamballup plants that are non-lignotuberous and therefore killed by fire, they have been separated into two subspecies. *D. ionthocarpa* A.S. George ssp. *ionthocarpa* ms (Kamballup) and *D. ionthocarpa* A.S. George ssp *chrysophoenix* ms (Narrogin).

D. ionthocarpa ssp. *ionthocarpa* is a caespitose, tufted prostrate shrub with a very short stem and long leaves up to 50 cm (Brown *et al* 1998) (Fig 1 - front cover). Pale yellow flowers are borne close to the ground within the leaves. This species has characteristic follicles that are about 5 mm in size and covered in 7-8 mm long erect hairs (Fig 2). The name is taken from the Greek *ionthas* (shaggy) and *carpos* (fruit). This taxon is currently known from some 950 plants in 2 sub-populations. It grows in low scrub on shallow loam soil on spongelite in a C Class Reserve vested in the Shire of Plantagenet near Kamballup, north of Albany (Fig 3).

Fig 2. Characteristic hairy follicle of D. ionthocarpa *ssp.* ionthocarpa

Threats

The main threats to species survival are drought, inappropriate fire regimes, disease, weed invasion and lack of remaining suitable habitat.

Drought potentially threatens both sub-populations because of the skeletal soils and rocky substrate on which plants grow. Drought may directly impact the species by reducing flowering, seed set and population recruitment, and by increasing plant mortality. Under the current conditions, both sub-populations are in gradual decline. Sub-population 1 numbered 612 individuals in 2002 (89% of the 682 recorded in 1994). Sixty-six dead plants were observed in 2002 of which 6% were recent deaths. Sub-population 2 numbered 340 individuals in 2002 (71% of the 474 recorded in 1994), with 54 deaths recorded.

Fig 3. Low shrub and shallow soil habitat of D. ionthocarpa *ssp.* ionthocarpa

Inter-fire recruitment of seedlings has not been recorded (Barrett unpub., Monks 2000). It is therefore assumed that fire is required for recruitment or else drought conditions in recent years has inhibited natural regeneration. Inappropriate fire intervals may affect the long-term viability of a population. With no long lived soil seed bank, too frequent fire may result in population extinction if regenerating or juvenile plants have not reached reproductive maturity. Occasional fires are, however, needed for the recruitment and regeneration of plants and so restricting fire from the populations may be detrimental for the long-term survival of *D. ionthocarpa* ssp. *ionthocarpa*. Both sub-populations at Kamballup are even-aged and long unburnt with the last fire estimated to have been about 25 years ago. Recent mortality may be attributed to plant senescence.

Weeds occur on the edge of sub-population 1 which adjoins farmland. A shelter belt of endemic mallee *Eucalyptus* species was planted in 1998 to act as a barrier against wind-blown weed seed. The weed status of the population has not changed significantly since 1999.

Testing of the susceptibility of *D. ionthocarpa* ssp. *ionthocarpa* plants to *Phytophthora cinnamomi* by CALM Science Division found that 50% of plants died following inoculation, placing the species in the moderately susceptible group (Crane pers. comm.). While its habitat at Kamballup is currently *Phytophthora*-free, introduction of the pathogen could have a significant impact.

Past land clearing may well have resulted in loss of populations, the effect of landscape fragmentation on genetic fitness and pollination are unknown.

An Interim Recovery Plan was written for *D. ionthocarpa* (Kershaw *et al.* 1997) that identified a range of management requirements for ensuring the continued survival of the species. These included research into reproductive biology, the effect of disturbance on recruitment and factors affecting seedling survival. Increased knowledge of the biology and ecology of the species would provide a scientific basis for management of the species in the wild.

Previous Research

Previous research conducted on the two Kamballup sub-populations indicated that *D. ionthocarpa* ssp. *ionthocarpa* is only weakly serotinous and does not have a significant canopy-stored seed bank. Only 2 to 42% of seed was stored in the canopy beyond one year (Monks 2000). Seed does not appear to be retained for long in the soil as no seed was recovered from a spring sampling (Monks 2000). On this basis, a spring or summer fire has the potential to significantly reduce population size due to loss of flowers in spring or developing fruit in summer. While seedlings germinated after burning live individuals in autumn, survival was poor after the first summer (1.4 seedlings per parent in sub-population 1, 0.2 per plant in sub-population 2). This mortality was attributed to summer drought (Monks 2000) and no seedlings survived beyond 24 months. No seedlings emerged after burning a small number (3) of dead plants, however this result was not statistically significant (Monks 2000). Smoke application as a means of promoting seedling recruitment was not attempted. All plants were caged in this study, so the impact of grazing on seedling recruitment post-disturbance was unknown (Monks 2000).

In 1999-2000, 283 plants were translocated to Kalgan Plains Nature Reserve, near Kamballup. By 2001 67 individuals had survived. Irrigation of translocated plants at Kalgan Plains Nature Reserve over the first summer resulted in greater survival compared with non-irrigated plants (Monks pers. comm. 2004). Survival was also lower for non-caged plants (Monks pers. comm. 2004).

This current project investigates the soil seed bank status, response to disturbance and factors affecting seedling survival in *D. ionthocarpa* ssp. *ionthocarpa*. This research aims to build on data from the previous study and its recommendations (Monks 2000) and will assist with *in situ* management and conservation of the species.

MATERIALS AND METHODS

Soil Seed Bank

In May 2003 soil was collected from beneath the canopy of 24 randomly selected plants throughout sub-population 1 (Fig 4). Two samples were taken from beneath each of 12 live and 12 dead plants, giving a total of 48 samples per population. Each sample was 15cm x 15cm in size and taken to a depth of 2cm. A total of just over 1

m^2 of soil was taken for analysis. The soil was sieved and examined under a dissecting microscope for the presence of whole seed.

Fig 4. Collecting soil samples for seed bank analysis

The seed recovered was germinated in the laboratory using protocols previously proven to be the most successful for *D. ionthocarpa* spp. *ionthocarpa* (Cochrane unpub.). The remaining soil from eight randomly selected samples taken from beneath live plants was spread in four nursery flats at a depth of 5 mm on top of sterilised potting mix to order to assess whether any remaining seed of *D. ionthocarpa* ssp. *ionthocarpa* may have been missed.

Burial Retrieval

To assess the response of *D. ionthocarpa* ssp. *ionthocarpa* seeds to weathering in the natural environment and their potential soil-stored seed longevity, a burial retrieval experiment was established. Ten seed and 20 grams of washed river sand were sealed into each of 15 nylon muslin bags 6cm x 6cm in size (150 seed in total). The bags of seed and sand were buried to a depth of 3cm on site on 27 August 2003. Three retrieval dates were scheduled at three-monthly intervals from burial (November, February and May). Retrieved seeds were carefully checked for evidence of germination or disintegration. Any whole, undamaged, seed was incubated in the laboratory under conditions favourable for germination.

Ex Situ Conservation

In May 2003 seed was collected from 50 live plants distributed throughout the population (Fig 5). A total of 683 seed was stored at the CALM Threatened Flora Seed Centre in Perth under low temperature and low moisture conditions as an insurance against loss in the wild. Four samples of 50 seed each have also been stored under the same conditions and the viability of these seed will be monitored over the next 40 years.

Fig 5. Follicles collected in May 2003.

Germination requirements

Laboratory germination trials were conducted to determine the viability of freshly collected *D. ionthocarpa* ssp. *ionthocarpa* seed. Four replicates of 25 seed in each of a control (no treatment) and a smoke treatment (seed soaked in 1:100 Regen for 24 hours and rinsed prior to incubation) were incubated in 90mm glass Petrie dishes on a 0.75% (w/v) agar solution. Dishes were placed in a temperature and light controlled incubation cabinet with a 12-hour photoperiod and checked twice weekly until all seed had germinated or died. Germination was determined by radicle emergence.

Fig 6. Measuring canopy width and height of adult plants selected for treatment.

Canopy seed banks
The canopy held seed bank of 12 live plants selected for burning was estimated by counting the number of cones present in 50% of the canopy of each plant. A sub-sample of cones was collected to estimate the number of follicles per cone (each follicle contains one seed).

The role of disturbance in stimulating germination of the soil stored seed reserve
Experimental plots were established in sub-population 1 in May 2003 to determine the effect of disturbance (fire and smoke water application) on the population dynamics of *D. ionthocarpa* ssp. *ionthocarpa*. Twelve live plants were used in each of a control and two treatments (fire and smoked water application). Each plant chosen was measured for height and width in two dimensions, and an assessment of canopy seed storage made (Fig 6). A 2 m x 2 m area was delineated around each of the plants as the experimental plots. Six plots in each treatment were fenced to exclude herbivore grazers (Fig 7).

Fig 7. Fencing individual 2 x 2 m plots to prevent herbivore grazing

On May 20th 2003 between 1255 and 1440 hours, 12 experimental plots were subjected to a moderately hot autumn burn for roughly five minutes per plot (Fig 8).

Prior to ignition an area of approximately 1 m around each plot was raked free of litter and plants to minimise the encroachment of fire on the surrounding bushland. Fuel loads were manipulated by placing dry litter in each plot to ensure a successful burn as there was very little actual fuel in the majority of the plots. The air temperature on the day was approximately 19°C with northerly winds up to 30 km/h. The soil moisture content was estimated to be 30%. The plots were ignited using a drip torch to light the upwind edge of the plot and the fire was allowed to run through the plot. Areas that continued to burn outside the plot were extinguished, although this was only necessary in the case of three plots. Flame heights ranged between 1 to 2 m with rates of spread in the 200- 400 m/hr range.

Fig 8. A plot containing D. ionthocarpa *ssp.* ionthocarpa *being subjected to a moderately hot burn in May 2003.*

Each plot was assessed to have sustained between 95-99% burn, and the burning was of moderate intensity for this sparse vegetation type (Fig 9). One of the plots (quadrat 4) had two adjacent *D. ionthocarpa* ssp. *ionthocarpa* plants and it was not possible to clear the edge of this plot and the fire was allowed to burn these. This plot burnt well with behaviour more typical of a natural event. In total, 14 plants were burnt.

Fig 9. Charred remains of burnt plants with evidence of open cones.

Twelve plots were treated with an aqueous smoke solution (Regen 2000®) at 100ml/m^2. Each of these smoke treated plots was pre-treated with a soil wettener

(Wettasoil^{HG} by Garden King) at 5ml/m^2 to ensure even penetration of the smoke solution.

All plots were subjected to soil wetting agent to prevent confounding of the experimental design. Controls were left untreated except for the application of the soil wetting agent.

Monitoring was conducted monthly from September 2003 to May 2004 and consisted of counting the number of seedlings recruited and noting evidence of grazing (Fig10).

Fig 10. Germinated seedlings were tagged and monitored for 9 months.

RESULTS

Soil Seed bank

No seed was retrieved in soil samples taken from beneath live plants, although small amounts of seed particles were observed and some old seed coats suggesting post-dispersal predation of seed had occurred. Six recently germinated seedlings of *D. ionthocarpa* ssp. *ionthocarpa* were found in four samples taken from beneath three dead plants. In addition, no seedlings of *D. ionthocarpa* ssp. *ionthocarpa* or any other species emerged from soil samples taken from beneath live plants and spread in nursery flats.

Burial retrieval

The percentage of intact seed retrieved after burial in muslin bags ranged from 64% in November 2003 at three months post-burial to 76% intact 9 months post-burial (Table 1). Loss of buried seed to decay and/ or germination ranged from 24% to 36%. Decayed seed ranged from 10% to 16 % per sampling period while germinated seed ranged from 14% to 22%.

Table 1. Mean number and percentage (in parenthesis) of intact, decayed or germinated Dryandra ionthocarpa *ssp.* ionthocarpa *seed buried in late August 2003. N = 5 bags of 10 seed.*

	Intact seed	Decayed seed	Germinated seed
3 months	32 (64%)	8 (16%)	10 (20%)
6 months	32 (68%)	5 (10%)	11 (22%)
9 months	38 (76%)	5 (10%)	7 (14%)

Seed Germination

Germination trials conducted on fresh seed produced moderately high germination under control and smoke treatments (Table 2). As smoke treatment was less successful in achieving good germination it was not used for testing seeds from the burial retrieval experiment. All intact seed retrieved from the burial retrieval experiment was assessed for viability through germination trials lasting approximately 6 weeks. After burial seed germination ranged from 50% to 65% (Table 2).

Table 2. Percentage germination of fresh Dryandra ionthocarpa *ssp.* ionthocarpa *seed in smoked water and no treatment, after burial and after two storage periods.*

Percentage germination	Control (no treatment)	Smoked water
Fresh	78%	63%
After 3 months burial	50%	-
After 6 months burial	53%	
After 9 months burial	65%	-
After –20°C storage 1 year	64%	-
After ambient temperature storage 10 years	62%	-

Additional germination trials were conducted on previous collections of seed of *D. ionthocarpa* ssp. *ionthocarpa* that had been stored for one year at –20°C and for 10 years at ambient temperature as a comparison to germination results from fresh and soil store seed (Table 2)

All germinated seedlings were transferred to a soil medium and given to CALM scientists for further research on susceptibility to *Phytophthora cinnamomi*.

Canopy-stored seed bank

Mean canopy height and volume were lower for burnt plants compared with smoke treated and control plants (Table 3). A high proportion of the cones assessed had aborted or were predated with approximately one third assessed to be intact. The canopy cone and seed load varied considerably amongst the 12 plants assessed (Table 4). Estimated numbers of intact cones per plant ranged from 28 (plant 8) to 356 (plant

4). There was a relatively linear relationship between crown volume and total number of cones ($R^2 = 0.6$, $P < 0.01$). Estimated total seed load per plant ranged from 8 seed (plant 9) to 1,573.8 (plant 3) with a mean seed load per plant of 462.7.

Table 3. Mean canopy measurements of Dryandra ionthocarpa *ssp.* ionthocarpa *plants from 36 experimental plots prior to three treatments*

	Height (cm)	Canopy width (cm)	Canopy width 90° (cm)	Crown volume (m^3)
Burn n=12	35.2	73.5	61.0	0.16
Smoke n=12	40.3	89.6	73.2	0.2
Control n=12	46.3	76.4	66.0	0.3

Table 4. Estimated number of cones and follicles /seed per plant for 12 Dryandra ionthocarpa *ssp.* ionthocarpa *plants burnt in May 2003*

Plant no.	Number of cones per plant	Number of follicles / total seed per plant
1	133	304.0
2	250	645.0
3	258	1573.8
4	356	1530.8
5	100	37.0
6	164	616.6
7	80	154.0
8	108	84.2
9	28	8.0
10	82	18.0
11	82	126.0
12	288	455.0
Mean	**160.8**	**462.7**

The role of disturbance in stimulating germination of the soil-stored seed reserve

Seedling recruitment began in late September, approximately 4 months after experimental treatment, and was monitored until May 2004 (Table 5). Recruitment in the burnt plots peaked at 59 seedlings in early November 2003 with 4.2 seedlings per parent plant. There included 28 seedlings associated with the two burnt plants adjacent to, but outside of, the plots. At this time one seedling was seen in a smoke treated plot and five seedlings noted outside plots that had recruited naturally.

Weeds that germinated in burnt plots were hand removed in spring 2003. As there were additional germinants outside one burnt quadrat, approximately half of these were caged to eliminate possible herbivore action on seedlings (Fig 12).

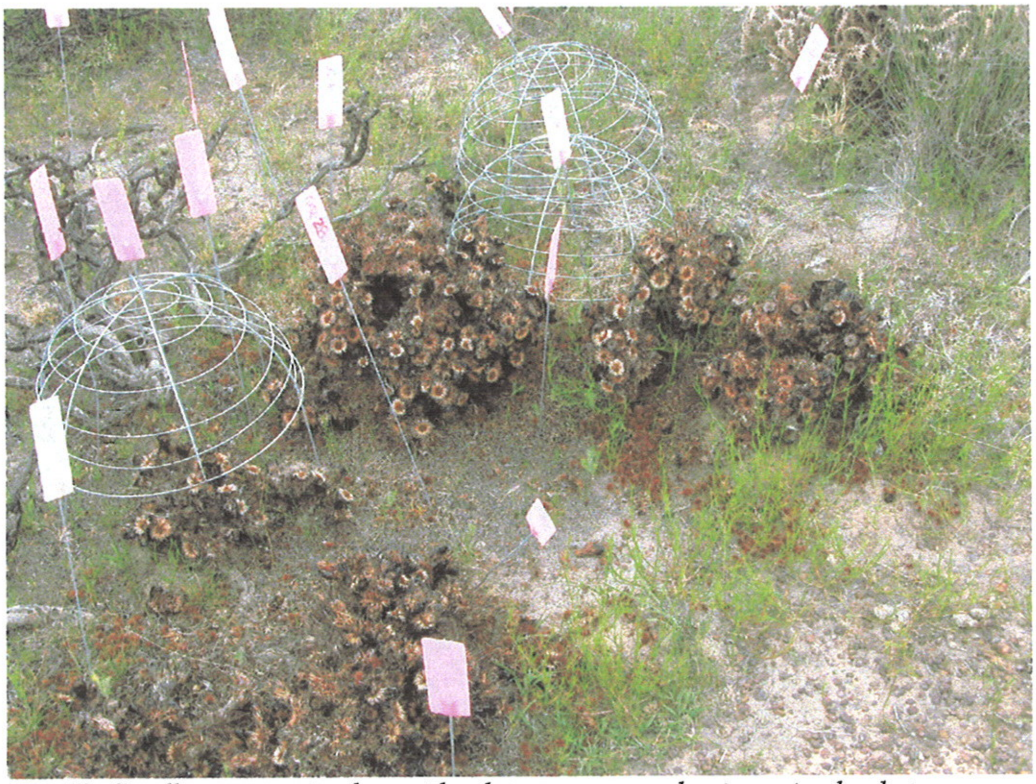

Fig 12. Seedlings recruited outside plots were caged using wire baskets.

Fig 13. Establishment of irrigation pipe to recruited seedlings

Fig 14. A 4,500 litre tank provided water for irrigating seedlings.

Table 5. Total number of seedlings of D. ionthocarpa *ssp.* ionthocarpa *recruited between September 2003 and May 2004*

Treatment	Sept 2003	Oct 2003	Nov 2003	Dec 2003	Jan 2004	Feb 2004	Mar 2004	April 2004	May 2004
Control	0	0	0	0	0	0	0	0	0
Smoke	0	0	1	1	1	0	0	0	0
Burn*	4	18	59	47	36	33	28	23	19
Unburnt outside plots	0	0	6	5	3	0	0	0	0
Total	**4**	**18**	**66**	**53**	**40**	**33**	**28**	**23**	**19**

* includes seedlings recruited from plants outside plots burnt accidentally

Within the plots recruitment post-fire was patchy, with an overall mean of less than three seedlings per plant recruited around burnt plants (range 0-9 seedlings per plant). There was no recruitment recorded from the vicinity of four of the burnt plants. Recruitment of three seedlings or more was associated with plants with larger canopy stored seed banks (500 + seeds) (Table 6). There was a relatively linear relationship between total seed per plant and post-fire recruits ($R = 0.57$, $P < 0.01$).

Between November 2003 and May 2004 there was a 70% mortality rate for all seedlings recruited post-fire. The decline in total seedlings numbers occurred gradually during that time.

Seedling mortality was first observed in December 2003 when the number of post-fire recruits dropped from 59 to 47. (Table 5). In December 2003 a watering system consisting of a small 4500 litre water tank with irrigation pipe and drippers was installed on site (Fig 13 and Fig 14). At this time 34 of the seedlings in the burnt plots were selected for drip-irrigation and watered every 2 weeks for 30 minutes from December 2003 to April 2004. Drippers were set at 4 litre/hour. Nineteen seedlings were not watered, 13 of these being in burnt plots. Of the 59 seedlings that recruited post-fire, 31 were fenced and 28 not fenced.

Table 6. Canopy-stored seed bank and post-fire recruitment of D. ionthocarpa *ssp.* ionthocarpa *plants burnt May 2003. Note: Does not include seedlings recruited from two plants accidentally burnt outside plots.*

Plant no.	Seed number	Post-fire recruits Nov 2003
1	304.0	2
2	645.0	9
3	1573.8	6
4	1530.8	7
5	37.0	1
6	616.6	3
7	154.0	0
8	84.2	1
9	8.0	0
10	18.0	2
11	126.0	0
12	455.0	0

Table 7. Numbers of post-fire recruits of D. ionthocarpa *ssp.* ionthocarpa *fenced and / or irrigated in December 2003*

Treatment	Fenced	Not fenced	Total
Water	18	16	34
No water	8	5	13
Total	26	21	47

Mortalities continued amongst post-fire recruits from December 2003 to May 2004. By April 2004 all of the six seedlings that had recruited in unburnt vegetation had died. At the final assessment of post-fire recruitment, 19 (40.4%) seedlings survived or a mean of 1.4 seedling per parent plant (Table 8). Survival was greatest for seedlings watered and fenced with 4.3 seedlings per parent alive (72.2%). There was 52.9% survival of watered seedlings (4.5 seedlings per parent plant) compared with 7.7% (0.2 seedlings per parent plant) for non-watered. Survival of fenced seedlings was 50% compared with 28.6% for unfenced.

Both vertebrate and invertebrate grazing was observed throughout the monitoring period. The latter caused considerable defoliation of some 11 seedlings in March and April 2004, although by May 2004 eight of these seedlings had recovered. Six uncaged plants went missing and this was attributed to kangaroo grazing which impacted on another two seedlings without causing mortalities.

Table 8. Number and percentage (in parenthesis) of post-fire recruits of D. ionthocarpa *ssp.* ionthocarpa *surviving in relation to fencing and irrigation from December 2003 to May 2004.*

Treatment	Fenced	Not fenced	Total
Water	13 (72.2)	5 (31.3)	18 (52.9)
No water	0 (0)	1 (20)	1 (7.7)
Total	13 (50)	6 (28.6)	19 (40.4)

DISCUSSION

Sampling of the soil seed bank in autumn failed to reveal any significant soil-stored seed bank for *D. ionthocarpa* ssp. *ionthocarpa,* a similar result to that of Monks (2000) after spring sampling. However, a proportion of seed that was placed with sand in muslin bags and buried for up to nine months persisted in the soil remaining viable for the duration of burial. This suggests there may be potential for recruitment in the second spring post-fire. Another scenario is that the muslin bags protected buried seed from predators in the soil. The effect of post-dispersal predation on soil-stored seed was not assessed but is likely to be considerable in light of the discrepancy between *D. ionthocarpa* ssp. *ionthocarpa*'s poor soil seed bank and its ability to persist in the soil. While the majority of cones opened post-fire in this study, follicles were still visible in some cones the following spring as well as on the ash bed. Whether this seed will survive to germinate in spring to 2004 is unknown. On-going monitoring is required to determine this. In contrast, no seed of the critically endangered *Dryandra anatona* persisted in the soil eight months after burial (Barrett and Cochrane unpub.).

Seed of *D. ionthocarpa* ssp. *ionthocarpa* does not display a high degree of dormancy under laboratory conditions with more than 70% of viable seed capable of germinating without treatment, yet more than three-quarters of buried seed remained intact after nine months in the soil. Subsequent germination of retrieved seed showed a decrease in viability from fresh seed. Likewise there was also a similar decrease in seed viability after low temperature and low moisture storage for one year and after ambient storage for a decade. Despite these decreases in seed viability, these data indicate the potential longevity of seed of the species under a range of storage conditions. Any inferences about comparative longevity under these range of storage conditions must take into account the difference in years of collection of seed which may have impacted on seed storage potential.

Cone load of *D. ionthocarpa* ssp. *ionthocarpa* varied considerably between plants and was related to canopy volume while the magnitude of post-fire recruitment was related to the canopy seed bank. However, the greatest number of seedlings recruited around the two plants that burnt adjacent to quadrat 4 which were not assessed pre-fire. While these plants were relatively large, recruitment may also have been related to fire behaviour (eg greater fire intensity). Although the mean height of 0.35 m per plant burnt was slightly less than the 0.4 m recorded by Monks (2000), the estimated total cones per plant and seed per plant were higher. In the current study, total cones and seed load per plant were 160 and 462 respectively, compared with the 132 cones and 322 seed per plant recorded by Monks (2000). However, while in the current study aborted or decayed cones were not included in estimates of cones per plant, follicles were not assessed for predation. Monks (2000) recorded predation in approximately one third of follicles assessed. Furthermore, in the latter study, total seed per plant was based on viable seed numbers following germination trials of seed sampled. Both of these factors would account for the higher seed bank figure recorded in the current study.

Fire provided by far the most significant stimulus for seedling emergence. Smoke treatment did not stimulate germination of the soil-stored seed to any significant degree, concurring with our laboratory germination studies. The application of smoke in either aqueous or aerosol form has been shown to increase stimulation of germination in species from Mediterranean fire-prone environments (for example see Brown and van Staden 1997; Keeley and Fotheringham 1998; Roche *et al* 1998), although whilst reviewing recent literature on germination in Australian species, Bell (1998) noted that a number of studies reported that smoke-induced seed germination was less successful than heat in the induction of germination. The continued monitoring of plots is required in case of smoked-induced recruitment in the second year post-treatment (ie spring 2004). This may be possible as studies have shown that the action of smoke induced germination may be more effective in the second year after application (Roche *et al* 1997). A new smoked water product developed by Kings Park and Botanic Gardens following isolation of the active germination principle in smoke may be considerably more effective (Dixon pers. comm. 2004). This product could be trialed on *D. ionthocarpa* ssp. *ionthocarpa* in the future. The few recruits observed around unburnt plants failed to survive through summer and confirms observations that inter-fire recruitment is unlikely to significantly augment population numbers.

Seedling numbers peaked at 4.2 per parent in November compared with 42.6 per plant in the same sub-population and 2.4 per plant in sub-population 2 in a previous study in 1996 (Monks 2000). Seedlings recruited around 10 of 14 burnt plants in the current study compared with nine of ten in sub-population 1 and five of 10 in sub-population 2 in 1996 (Monks 2000).

Total seedling numbers declined considerably through summer in both studies to 1.4 per plant in this study compared with 1.7 per plant (same population) and 0.2 per plant (sub-population 2) (Monks 2000). However, fenced and watered seedlings surviving at one year post-fire in this study was 72.2% or 4.3 per parent plant which was considerably higher than survival for fenced, non-irrigated plants in 1996/97 (Monks 2000).

These results suggest that recruitment varies considerably within and between sub-populations and from year to year. The canopy-stored seed bank of individual plants and pre-dispersal predation may contribute significantly to this variation. Post-dispersal predation may also affect recruitment (Auld and Denham 2001; Regan *et al* 2003), particularly when small experimental plots are burnt and predator satiation does not occur. It is possible that recruitment under a more extensive burn may have been higher.

Seedling survival through summer was poor in both the previous and the current study and the results suggest that drought is the most significant factor in this decline. Grazing pressure by kangaroo and invertebrate fauna in the current study also affected plant health and survival. Total annual rainfall from June 2003 to May 2004 was 526.5 (recorded from nearby property 'Warakana'). Past rainfall records have ranged from a low of 350 mm in 1967 to 670 in 1992 for the same property. While 159 mm fell in September 2003, only 66.5 mm fell in the six months from November through to April, a mean of 11 mm per month. As no seedlings survived at two years post-fire in the earlier study (Monks 2000), ongoing monitoring is required to determine if any of the 2003 recruits from this current study survive to reproductive maturity.

RECOMMENDATIONS

Further monitoring is recommended to determine:

- Whether any further recruitment occurs in spring 2004
- Seedling survival over the second summer (irrigation to continue in 2004/05)
- Percentage of seedlings that survive through to reproductive maturity
- Time to first flowering and seed set

Use of small-scale patch burning as a tool to promote recruitment with irrigation and fencing of seedlings post-fire. Predator control pre-fire may also be considered as recommended by Monks (2000).

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