# Population structure, soil seed bank dynamics, germination requirements and fire response of the critically endangered *Cyphanthera odgersii* (F. Muell.) Haegi subspecies *occidentalis* Haegi (Solanaceae)

FINAL REPORT

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## SUMMARY

*Cyphanthera odgersii* (F. Muell.) Haegi subsp. *occidentalis* Haegi (Solanaceae) is an extremely rare taxon with a single remaining wild population of less than 150 plants. It is located on a degraded railroad verge near Cowcowing, 90km northwest of Merredin, Western Australia (30° 59' 16" south 117° 26' 79" east). Major threats to the long-term survival of this taxon include loss of habitat, accidental damage, weed invasion and small population size. This study aimed to determine a number of important ecological and biological features of this taxon including population structure, soil seed bank dynamics, response to disturbance, reproductive biology and seed longevity. Results from this study indicate that *C. odgersii* subsp. *occidentalis* maintains a small (98 seed/$m^2$) but moderately viable (49% germination) soil stored seed bank which contributes to the genetic diversity and stability of the population. Although this subspecies has the ability to resprout when damaged, plants are killed by fire and regenerate from seed. Plants appear to be fast growing (up to 34cm seedling growth over 8 months since fire), but possibly senescing after less than 10 years. The fruit to flower ratio is low, with an average of 700 fruit set per plant, compared to an average of 18,000 flowers produced per plant. The reasons for low fruit set are not known, although lack of resources (pollen, pollinators or nutrients) and/or genetic reasons (self-incompatibility or genetic defects) may contribute to this low fruit set. Fresh seeds were innately dormant, but dormancy was reversible by treating seeds with smoke and the growth hormone gibberellic acid (GA3, 25mg/L) during imbibition. Germination levels of 89% were attained under optimal conditions.

This study has put forward three major management recommendations. These include fencing of the population to prevent accidental damage, urgent survey for further populations and the implementation of a translocation program to ensure safety of the species in the wild. Germplasm collections for long term storage have already been made and are held at CALM's Threatened Flora Seed Centre. This *ex situ* strategy for conservation of the genetic diversity of the taxon will be a complement to any *in situ* conservation measures adopted.


## INTRODUCTION

*Cyphanthera odgersii* (F. Muell.) Haegi subsp. *occidentalis* Haegi (Solanaceae) is an open woody shrub to 2.5m tall and 2m wide with soft grey woolly-tomentose foliage (Figure 1). This subspecies differs from the typical subspecies (*C. odgersii* subsp. *odgersii*) in having longer hairs on the branches, bigger leaves and being of a larger size. Flowers are purple and held in dense clusters (Figure 2). It is a winter to spring flowering taxon that fruits in late spring and early summer. The fruit is a dehiscent capsule containing 4 to 6 pale brown rugose seeds (Figure 3). This subspecies was originally known from 2 populations in the northern wheatbelt of Western Australia. The 1939 collection from Lake Moore has not been rediscovered despite extensive survey effort between 1991 and 1996. It is now known only from the one locality at Cowcowing, 20km south of Koorda and 90km northwest of Merredin (30° 59' 16" south 117° 26' 79" east). There are less than 150 live plants in the population. It is found on a railway siding in disturbed pale orange sandy soils associated with *Acacia* and *Eucalyptus* species, weeds and herbaceous plants (Figure 4 and 5). Due to its restricted distribution and low numbers of plants, *C. odgersii* subsp. *occidentalis* was gazetted as Declared Rare Flora (DRF) and ranked by the Western Australian Threatened Species and Communities Unit (WATSCU) as Critically Endangered in 1997.

**Figure 1: Woolly-tomentose foliage of *Cyphanthera odgersii* subsp. *occidentalis***

Little is known about the ecology or biology of *Cyphanthera odgersii* subsp. *occidentalis*. There is no data on population or seedbank dynamics, response to disturbance, phenology or reproductive characteristics for this taxon. Preliminary observations have indicated that plants may be in senescence, that plants appear to resprout when damaged and that reasonable quantities of moderately viable seed are produced over a long period of time. Plants also seem to be fast growing and may be short lived. Seed collection for long term storage had been undertaken and a preliminary assessment of the germination requirements of the taxon has been made in the past few years.

The biology and ecology of very few rare taxa have been studied in great detail. The efficient management of species threatened by processes such as habitat degradation, weed invasion, accidental damage and small population size depends on knowledge of those processes affecting population dynamics. Information on the abundance and viability of seed in the soil seedbank, as well as the dynamics of the seedbank are critical for predicting the outcome of different management regimes (eg. disturbance). An understanding of the reproductive biology of the species or its response to fire is essential for the successful recovery of a species.

This study made investigations into population structure, soil seedbank dynamics, response to disturbance, reproductive biology including germination requirements and reproductive phenology and seed longevity issues for *Cyphanthera odgersii* subspecies *occidentalis*. This information will be utilised in the efficient and effective management and conservation of the taxon in the wild.

**Figure 2: Dense terminal clusters of pale purple flowers**

**Figure 3: Rugose seeds held in dehiscent capsule**

**Figure 4: Degraded habitat of *Cyphanthera odgersii* subspecies *occidentalis* at Cowcowing rail siding**

**Figure 5: Habitat of *Cyphanthera odgersii* subspecies *occidentalis* at Cowcowing showing associated species**

## MATERIALS AND METHODS

*Population Structure*

Population structure was assessed in mid February 1999. All live plants were measured for height and canopy width in two directions (width at widest point and at 90°C to widest point). The number of stems were counted at ground level and the diameter of the largest stem measured. Four health classes were determined by the proportion of live shoot apices for each plant (class 1 - 0-25% alive; class 2 - 25-50% alive; class 3 - 50-75% alive and class 4 being 75-100% alive), this being a relative measure of the proportion of live and dead branches. The projected foliage cover for each plant was assessed and again comprised 4 classes 0-25%; 25-50%; 50-75% and 75-100%. These classes represented the proportion of the canopy that had leaf foliage and was a relative measure of leaf density. At the same time, all dead plants that could be readily identified as *C. odgersii* subsp. *occidentalis* were counted and measured for stem diameter, number of stems and height (length if fallen).

*Soil Seed Bank Dynamics*

A seed bank trial was conducted on *C. odgersii* subsp. *occidentalis* in February 1999. The size and composition of the soil-stored seedbank of a particular taxon can be assessed by counting the number of seeds within a soil sample or indirectly by counting the number of seedlings that emerge from a soil sample when exposed to conditions which stimulate seed germination. This seedling emergence method requires absolute knowledge of the germination requirements of the target species. Estimation of the soil seed reserve can therefore be influenced by imperfect knowledge of the conditions necessary for germination. Counting the actual number of seeds within the soil, although more time consuming, is a more accurate method for estimating the soil seed reserve. In this study soil was collected from beneath the canopy of 50 randomly selected live plants throughout the population. Each sample was 15cm x 15cm in size and taken to a depth of 2cm. A total of 1.125m$^2$ of soil was taken for analysis. The soil was sieved and examined under a dissecting microscope for the presence of whole seed and seed fragments. The seed recovered was germinated using protocols previously proven to be the most successful for *C. odgersii* subsp. *occidentalis* (A. Cochrane unpublished data).

*Response to Disturbance*

Experimental plots were established in early May 1999 to determine the effect of fire on the population dynamics of *C. odgersii* subsp. *occidentalis*. Two questions were asked. Firstly, does fire stimulate germination of the soil-stored seed reserve? And secondly, what impact does fire have on adult plants. Are they killed or do they resprout? For this experiment, six live and six dead plants were used in each of a control and two treatments (fire and smoke application). A 2m$^2$ area was delineated around each of the 36 plants as the experimental plots. Each plot for the burn treatment was covered with dry litter at a density of approximately 20 tonne/hectare, and sustained a cool to medium slow burn for approximately 1 hour (Figure 6). Six 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 (Easy Wetta by Brunnings) at 20ml/m$^2$ to ensure even penetration of the smoke solution. Controls were left untreated. Half of each of the treatment and control plots were fenced with

90cm bird wire dug into the ground to exclude small herbivores and prevent grazing of germinants (Figure 7).

**Figure 6: Fuel loading of plots prior to conducting of a cool to medium slow burn**

*Reproductive Biology*

*Germination Requirements*

Viability trails conducted in 1997-98 established optimal conditions for seed germination of *C. odgersii* subsp. *occidentalis* (A. Cochrane unpublished data). Seeds were incubated in 90mm glass Petrie dishes on a 0.75% (w/v) agar solution in temperature and light controlled incubation cabinets, using a 12-hour photoperiod under three treatments (smoke, growth hormone, and smoke and growth hormone in combination) and a control. Prior to incubation, seed was nicked to determine whether a healthy endosperm was present. Treatments requiring aqueous smoke solution involved soaking seed for 24 hours in a full strength smoke solution (provided by Environmental Management Services, Perth). Seed was then rinsed prior to incubation. Where growth promoters were required to cue germination, the growth hormone Gibberellic Acid as $GA_3$, was added to the agar medium at $25mg/L^{-1}$.

*Phenology*

The phenology of *C. odgersii* subsp. *occidentalis* was monitored from flowering to seed production. In early July 1999 an estimate was made of the total number of flowers per plant (total number of floral spikes x mean number of flowers per floral spike). Ten randomly selected plants were used for this assessment. The total number of floral spikes for each of the ten plants was counted. Ten floral spikes per plant were selected for further analysis and the number of flowers on each of these floral spikes counted. The length of each floral spike was also measured. In early September and late November 1999 the number of developing fruits on each of the tagged floral spikes was counted to calculate the flower to fruit ratio.

**Figure 7: Caging of research plots with 90cm birdwire after treatment to prevent herbivore damage to seedlings**

*Seed Longevity*
This experiment aimed to assess the response of seeds of *C. odgersii* subsp. *occidentalis* to weathering in their natural environment. Five seeds and 20grams of washed river sand were sealed into each of 20 nylon muslin bags 6cm x 6cm (200 seeds in total). Two transects 10m in length were selected 1m apart on site. At each 1m interval a bag of seed and sand was buried to a depth of 3cm. The bags were buried on site in early March 1999. Four retrieval dates were scheduled at 2 monthly intervals from burial (May, July, September, November). Retrieved seeds were carefully checked for evidence of germination or disintegration. Any whole, undamaged, seed was incubated under conditions favourable for germination.

## RESULTS

*Population Structure*
A total of 145 live plants (49 on the eastern side of the rail line and 96 on the western side) were counted over a 1km distance in February 1999. Measurements were made for individual plants for height, width, stem diameter, stems number, health class and foliage density (Appendix 1). Four additional live plants were seen in adjacent private property, but were not included in measurements. No seedling or juvenile plants were observed within the population during the course of investigations. A total of 74 dead plants (both standing and fallen) were counted (36 on the east side, 38 on the west side) and each plant measured for stem diameter, number of stems and length (height) (Appendix 2). These dead plants were still attached at ground level and were positively identified as *C. odgersii* subsp. *occidentalis*. Additional dead plants were present but were no longer attached at ground level. These plants were considered as

being dead for longer and there was less chance of positive identification. Mean values for height, width, stem diameter, stem number, health class and foliage measurements have been calculated for both live (Table 1) and dead plants (Table 2).

**Table 1. Population structure of 145 live plants of *C. odgersii* subsp. *occidentalis*, Cowcowing, February 1999.**

| Measurement | Mean | Range |
|---|---|---|
| Stem Diameter (cm) | 2.75 | 0.5-12 |
| Height (cm) | 93.55 | 12-189 |
| Canopy Width (cm) | 94.14 | 5-270 |
| Canopy Width 90° (cm) | 65.47 | 4-182 |
| No. Stems | 1.74 | 1-15 |
| Health Class | 2.70 | 1-4 |
| Foliage Cover | 1.53 | 1-4 |

*C. odgersii* subsp. *occidentalis* is a sparsely foliaged shrub affirmed by more than half the population (65%) having a foliage density of 1 (0-25% leaf foliage density) (Figure 8). Forty percent of live plants had a health class of 4 (75-100% of foliage alive) (Figure 9), although only 4% had a high foliage density. More than 67% of live plants were single-stemmed, with over 90% of dead plants being single-stemmed.

**Table 2. Population structure of 74 dead plants of *C. odgersii* subsp. *occidentalis*, Cowcowing, February 1999.**

| Measurement | Mean | Range |
|---|---|---|
| Stem Diameter (cm) | 3.05 | 0.5-9 |
| Height (cm) | 113.46 | 44-250 |
| No. Stems | 1.15 | 1-7 |

**Figure 8: Frequency distribution of health classes of live plants of *C. odgersii* subsp. *occidentalis***

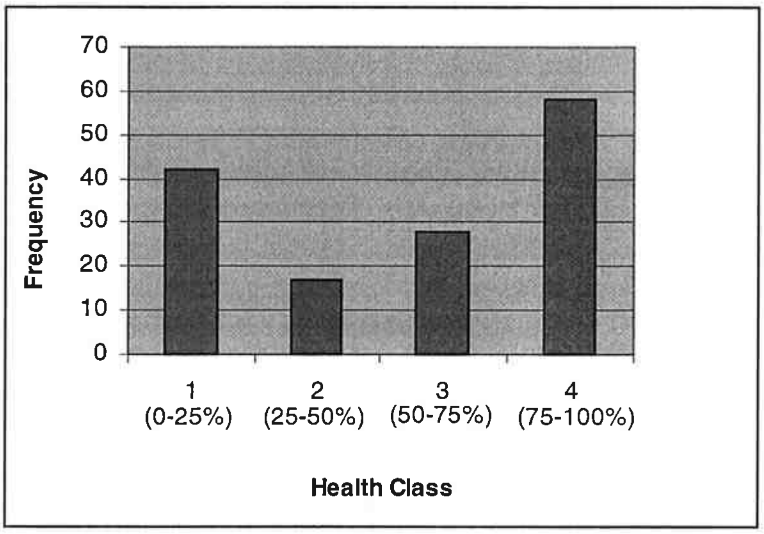
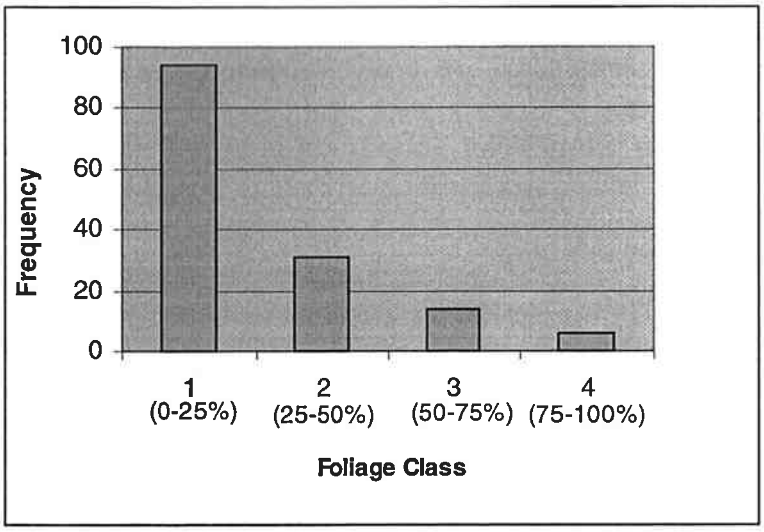


**Figure 9: Frequency distribution of foliage classes of live plants of *C. odgersii* subsp. *occidentalis***




During the course of biological and ecological investigations of *C. odgersii* subsp. *occidentalis* at Cowcowing three plants died. Two further plants appeared to be dying at the conclusion of the study and four plants had suffered damage from either vehicle or stock passes through the population.

*Soil Seed Bank Dynamics*

A total of 318 whole seeds were recovered from the 50 soil samples (Appendix 3). When the seeds were nicked for germination, it was found that only 112 of these seeds (35%) contained embryos. The number of seed with embryos per sample ranged from 0 to 10 with an average of 2.24 seed per sample, or 98 potentially viable seed per $m^2$ (Table 3). Most samples contained large amounts of seed fragments attesting to a high proportion of the seed crop being either predated and/or aborted. All seeds retrieved from the soil seedbank were treated under previously described conditions and incubated in growth cabinets to determine germinability. A mean of 49% germination was attained for retrieved soil-stored seed with some samples reaching 100%.

**Table 3: Total number of seed of *Cyphanthera odgersii* subsp. *occidentalis* with endosperm retrieved from soil beneath reproductive adults (1.125m$^2$). Seed viability determined by laboratory germination trials under optimal conditions.**

| | |
|---|---|
| Total no. of seed | 112 |
| Mean no. seed in 15cmx15cm sample | 2.24 |
| Seed in 1m$^2$ of soil from beneath reproductive adults | 98 |
| Seed viability | 49% (range 0-100%) |

*Response to Disturbance*

The results of this experiment show that *C. odgersii* subsp. *occidentalis* is killed by fire but is capable of regeneration from seed (Figure 10). Seedling emergence occurred only in plots treated with fire. No germination of soil-stored seed occurred in either the smoked water treatment or control plots (Table 4). There were greater numbers of seedlings emerging in plots with dead plants, as compared to live plants, after fire. There was no evidence of resprouting after fire. Caging appears to have had some effect on the growth and establishment of seedlings in the burned plots with an almost doubling of seedling numbers evident in the caged plots. Despite this increase in numbers of seedlings in fenced plots, there were no visible signs of herbivore activity on plants despite kangaroo scats being noted quite frequently around the fences. Sheep also do not appear to have found the plants palatable (A. Cochrane pers. comm.).

Several other species emerged in the burn plots including *Codonocarpus* sp., *Dampiera* sp., *Acacia* spp., *Grevillea* sp., *Guichenotia* sp., *Glishrocaryon aureum* and a perennial grass. Although there are a number of prominent weeds within the site, few regenerated after fire or responded to smoke water treatment. The latter treatment elicited some germination of the *Dampiera* sp. and everlastings, with no sign of germination of any species occurring within the control plots.

**Figure 10: Seedling growth of *C. odgersii* subsp. *occidentalis* after fire**

**Table 4: Total seedling numbers of *Cyphanthera odgersii* subsp. *occidentalis* in each treatment on 20 January 2000, 8 months after prescription (6 plots per treatment).**

| | Control | | Smoke | | Burn | |
|---|---|---|---|---|---|---|
| | Live Plant | Dead Plant | Live Plant | Dead Plant | Live Plant | Dead Plant |
| **Cage** | 0 | 0 | 0 | 0 | 19 | 30 |
| **Uncage** | 0 | 0 | 0 | 0 | 4 | 24 |

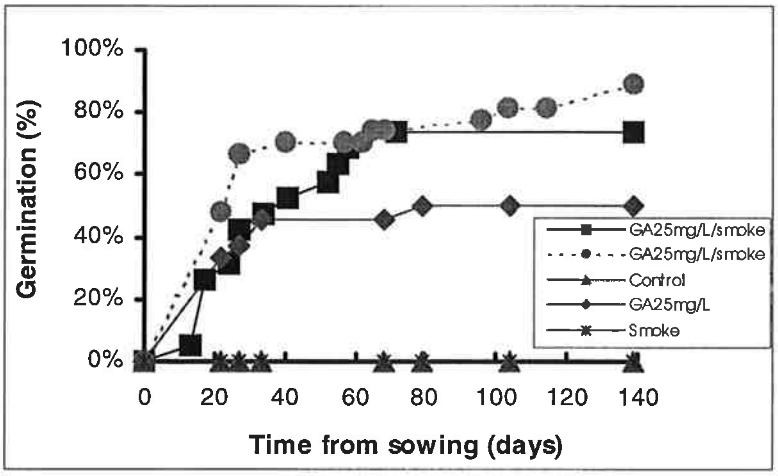
*Reproductive Biology*

*Germination Requirements*

Germination trials for both fresh and stored seed (1 year at $-18^0$C) produced high germination under optimal conditions with both smoke and growth hormone treatment

(74% vs. 89%) attaining maximum germination after 140 days (Figure 11). Other treatments (control, smoke, GA) were less successful in achieving good germination and were not used for testing seeds from the burial/retrieval and the soil seed bank experiments. Seedlings were transferred to a soil medium and given to Kings Park and Botanic Gardens for display purposes or to CALM scientists for further research.

**Figure 11: Germination of fresh and 1-year old stored seed of *C. odgersii* subsp. *occidentalis* under different treatment regimes** (Solid line represents germination of fresh seed; Broken line represents germination after 1 year storage at -18°C).




*Phenology*

The results of these measurements indicate a wide variation in flower production per floral spike and per plant (Table 5). The average length of floral spikes also varied considerably (mean 9.34cm, range 5.35-13.05cm, se=1). The number of fruit per spike ranged from a low 0.4 to 120 with an average of 18 fruit per spike, calculated on the basis of number of fruit present on each of ten tagged floral spikes divided by 10. The mean number of fruit per plant has been estimated at 704 with an average fruit to flower ratio of 1: 25.

*Seed Longevity*

No weathering was apparent on the exterior of the seed coat at any of the retrieval dates over the eight-month burial period, and no seed germinated during the burial period. All seeds retrieved from the burial/retrieval experiment were treated under optimal conditions and incubated in growth cabinets to determine percent germination. Although no weathering of the seed coats was evident there was a reduction in viability of the seed over the burial period. After burial seed germination ranged from 19% to 32% with a mean of 27% (Table 6).

**Table 5: Mean no. of flowers per floral spike, mean length of floral spike and total no. of floral spikes and flowers per plant with estimated fruit yield and fruit/flower ratio per plant for each of ten study plants of *C. odgersii* subsp. *occidentalis*** (standard error in brackets after sample mean value).

| Plant ID | Health/ foliage class | Mean no. of flowers per floral spike | Mean length of floral spike (cm) | Total no. of floral spikes per plant | Mean no. of fruit per floral spike | Estimated total no. of flowers per plant | Estimated fruit yield per plant | Fruit/ flower ratio |
|---|---|---|---|---|---|---|---|---|
| 1 | 1/1 | 19 | 6.05 | 83 | 1 | 1536 | 33 | 1:46 |
| 2 | 3/2 | 61 | 16.2 | 238 | 3 | 14613 | 809 | 1:18 |
| 22 | 3/2 | 62 | 8.35 | 900 | 1 | 55980 | 90 | 1.622 |
| 91 | 2/1 | 31 | 6.1 | 68 | 7 | 2101 | 279 | 1:7 |
| 103 | 1/1 | 14 | 7.75 | 116 | 12 | 1624 | 325 | 1:5 |
| 108 | 4/3 | 81 | 13.05 | 1200 | 120 | 96600 | 4680 | 1:20 |
| 112 | 3/2 | 8 | 9.55 | 155 | 16 | 1240 | 186 | 1:7 |
| 113 | 1/1 | 38 | 5.35 | 18 | 3 | 682.2 | 50 | 1:13 |
| 131 | 4/3 | 31 | 10.85 | 148 | 15 | 4647 | 163 | 1:28 |
| 138 | 2/1 | 34 | 10.15 | 52 | 8 | 1758 | 426 | 1:4 |
| **Sample Mean** | | 38 (±7) | 9.34 (±1) | 298 (±129) | 18.3 (±11) | 18078 (±10245) | 704 (±447) | 1:25 |

**Table 6: Viability of seed retrieved after 2, 4, 6 and 8 months of on site burial**

| Burial Date | Retrieval Date | Percent Germination |
|---|---|---|
| March 1999 | May 1999 | 32% |
| March 1999 | July 1999 | 32% |
| March 1999 | September 1999 | 19% |
| March 1999 | November 1999 | 26% |

## DISCUSSION

*Cyphanthera odgersii* subsp. *occidentalis* is an extremely rare taxon with a single remaining wild population of less than 150 plants. This small population is being impacted upon by threatening processes such as habitat degradation, accidental damage and weed invasion. Over the 12-month period of demographic investigations into *C. odgersii* subsp. *occidentalis*, the population suffered a small decline in total numbers with no evidence of natural regeneration in the absence of fire or similar disturbance. Disturbance plays an important role in the regeneration of many species and the effect of fire on germination of native species has been widely documented (Bell 1987; Brown 1993; Keeley 1995). Although the population remained relatively stable in numbers over the period of investigations, the lack of natural recruitment coupled with a slow decline in plant numbers due to senescence and accidental damage may render the population extinct within the next 30 years unless active management of the population is undertaken.

This study determined that there is a small and moderately viable soil-stored seedbank. Knowledge of the abundance and dynamics of a species in the soil seedbank is of importance for predicting the outcome of different management strategies. The soil seedbank is a very important component of the genetic potential of the species and is especially significant for small populations that are locally restricted. The seedbank input is determined by the seed rain and is influenced by seed germination, predation, burial, redispersal, dormancy and seed death through natural senescence. The presence of numerous seed fragments within the soil seedbank indicates that greater than 98 seeds per $m^2$ are produced by plants within the population. Seeds are either destroyed through weathering or by predation. It is obvious from the number of seeds retrieved without embryos or endosperm (206 per $m^2$), and the small fruit to flower ratio that there are limitations to seed production. These limitations may be due to a range of biotic and/or genetic factors that require further investigation.

The apparent inability of *C. odgersii* subsp. *occidentalis* to recruit in the absence of fire indicates that the soil-stored seedbank is vitally important for the maintenance and restoration of the population should the standing vegetation be adversely disturbed. The larger numbers of seedlings recruited after fire in plots with long-dead plants is encouraging for the longevity of soil-stored seed, despite the results of the burial /retrieval experiment. Percent germination of fresh seed buried in soil over an 8-month period differed in viability from seed retrieved from the soil seed bank and from freshly collected seed (27% vs. 49% vs. 89% respectively).

## *Recommendations for Management*

This study suggests that the rare *C. odgersii* subsp. *occidentalis* is in danger of considerable loss of genetic diversity and even extinction, over the next 30 years. An ageing population and random disturbance events such as accidental vehicle damage and stock movements have the potential to severely disrupt the population. In January 2000 there were 142 live plants, a decrease of almost 1% in total plant numbers over the previous year. No recruitment of plants was noted in the absence of fire. Several management options are available.

### *1. Fencing and Further Survey*

The major management actions recommended from this study are fencing of the existing population to minimise disturbance and possible damage to plants by vehicles and stock and urgent survey for further populations.

### *2. Translocation*

Translocation of this taxon to a safe site should be of high priority. Unfortunately, cultivation of this taxon has not been easy. Although percent germination for seed can be high (89% for seed collected in 1997 and frozen for 1 year), cultivation of these seedling to juvenile stage for reintroduction has proven difficult with less than a 1% survival rate for seedlings (pers comm. Amanda Shade, Kings Park and Botanic Gardens). This difficulty, coupled with a low strike rate for vegetative propagation (0-69% depending on genotype, with survival after potting on very low) (pers comm. Amanda Shade, Kings Park and Botanic Gardens) necessitates some other form of propagation such as *in vitro* tissue culture to be investigated.

### *3. Disturbance*

This project has demonstrated the responsiveness of this taxon to regeneration after fire. Smoke water application has shown to be ineffectual as a factor in eliciting regeneration. Sections of the existing population could be burnt to encourage regeneration, although this may be considered unwise due to the small size of the population. A poor season (low rainfall, high temperatures leading to desiccation) could lead to failure of seedling regeneration. Burning of dead plants may be an option for regeneration, as well as the possibility of conducting a patch burn through the population. If fire is to be a tool for regeneration we recommend watering of seedlings be carried out over the first one or two summer seasons to ensure maximum survival of plants.

*Research Opportunities*

This project had originally proposed investigations into seed predation through the use of a cafeteria experiment. Due to the paucity of seed collected and the critical nature of the population, the authors considered that storage of all available seed for recovery purposes wiser than wastage on further experimentation at the present time. If it were possible to collect large amounts of seed then investigations into predation of seed resources is warranted. It is also advisable that further seed of *C. odgersii* subsp. *occidentalis* is collected for storage until the long term safety of the taxon is assured, either through translocation or the discovery of additional population through survey. The investigation of new techniques for seed collection, other than hand picking, may be useful, as hand picking is very time consuming. The erection of seed traps around individual plants may be warranted and has proven a successful means of collection of large quantities of seed for other genera (eg *Adenanthos*).

The burn of an experimentally created soil seed bank away from existing plants, but on site (to see if there is a natural soil seedbank present), may be worth investigating. If it is possible to boost population numbers and increases the structural variability of the population in this manner we would recommend this technique be employed at a secure site such as a nature reserve, in lieu of a translocation.

## ACKNOWLEGEMENTS

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**Appendix 1: Measurements and health assessment of all living plants of *C. odgersii* subsp. *occidentalis* at Cowcowing in February 1999.**

| Plant No. | Diameter (largest stem) (cm) | Height (cm) | Width (cm) | Width 90° (cm) | Standing/ Fallen | No. of Stems | Health Class (1-4) | Foliage Density Class (1-4) | Seedbank (Y/N) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 3 | 141 | 60 | 50 | S | 2 | 2 | 2 | Y |
| 2 | 2.5 | 96 | 170 | 110 | S | 5 | 3 | 2 | Y |
| 3 | 5 | 104 | 130 | 108 | F | 1 | 1 | 1 | N |
| 4 | 5.5 | 88 | 163 | 115 | F | 1 | 1 | 1 | N |
| 5 | 5.5 | 70 | 159 | 152 | F | 1 | 4 | 1 | N |
| 6 | 5 | 74 | 78 | 67 | F | 1 | 1 | 1 | N |
| 7 | 4.5 | 86 | 150 | 100 | F | 1 | 1 | 1 | N |
| 8 | 3 | 75 | 165 | 97 | F | 2 | 3 | 1 | N |
| 9 | 2 | 83 | 76 | 70 | F | 1 | 2 | 1 | N |
| 10 | 4 | 108 | 150 | 130 | F | 5 | 1 | 1 | N |
| 11 | 4.5 | 95 | 85 | 45 | F | 1 | 1 | 1 | N |
| 12 | 2 | 102 | 165 | 82 | F | 3 | 1 | 1 | N |
| 13 | 3 | 84 | 125 | 115 | S | 1 | 2 | 1 | N |
| 14 | 1 | 73 | 17 | 16 | S | 1 | 4 | 1 | N |
| 15 | 2.5 | 114 | 60 | 45 | S | 1 | 1 | 1 | Y |
| 16 | 4.5 | 160 | 95 | 95 | S | 1 | 1 | 1 | N |
| 17 | 1.5 | 84 | 40 | 20 | S | 1 | 2 | 1 | N |
| 18 | 1 | 79 | 12 | 7 | S | 1 | 1 | 1 | N |
| 19 | 1 | 90 | 37 | 24 | S | 4 | 1 | 1 | N |
| 20 | 3 | 65 | 25 | 12 | F | 1 | 1 | 1 | N |
| 21 | 5 | 117 | 148 | 89 | S | 1 | 4 | 2 | Y |
| 22 | 9 | 110 | 270 | 168 | F | 2 | 3 | 2 | Y |
| 23 | 3 | 40 | 73 | 53 | S | 1 | 4 | 1 | N |
| 24 | 3 | 42 | 116 | 58 | F | 1 | 4 | 4 | N |
| 25 | 2.5 | 75 | 148 | 86 | F | 2 | 4 | 2 | Y |
| 26 | 2.5 | 52 | 124 | 50 | F | 4 | 1 | 1 | N |
| 27 | 1.5 | 84 | 82 | 66 | S | 4 | 1 | 1 | N |
| 28 | 1 | 71 | 46 | 38 | S | 2 | 4 | 2 | N |
| 29 | 3 | 60 | 93 | 85 | F | 1 | 1 | 1 | Y |
| 30 | 1 | 74 | 44 | 14 | S | 1 | 4 | 4 | Y |
| 31 | 3 | 45 | 29 | 24 | S | 1 | 4 | 3 | Y |
| 32 | 2 | 113 | 67 | 65 | S | 3 | 4 | 4 | Y |
| 33 | 2 | 96 | 61 | 59 | S | 2 | 4 | 3 | N |
| 34 | 2 | 82 | 77 | 48 | S | 1 | 4 | 2 | Y |
| 35 | 3 | 100 | 70 | 68 | S | 1 | 4 | 3 | N |
| 36 | 7 | 105 | 152 | 145 | S | 1 | 4 | 3 | Y |
| 37 | 2 | 86 | 34 | 29 | S | 1 | 4 | 1 | N |
| 38 | 2 | 98 | 64 | 48 | S | 1 | 4 | 2 | N |
| 39 | 3 | 124 | 100 | 84 | S | 2 | 4 | 3 | Y |
| 40 | 4 | 58 | 35 | 30 | S | 1 | 3 | 2 | N |
| 41 | 4.5 | 81 | 130 | 125 | S | 1 | 4 | 4 | Y |
| 42 | 2.5 | 144 | 70 | 50 | S | 1 | 4 | 2 | Y |
| 43 | ? | 59 | 98 | 68 | P | 1 | 1 | 1 | N |
| 44 | 0.5 | 37 | 29 | 26 | F | 2 | 1 | 1 | N |
| 45 | 4 | 107 | 150 | 125 | S | 1 | 3 | 1 | Y |
| 46 | 6 | 128 | 240 | 145 | F | 7 | 4 | 4 | Y |
| 47 | 3.5 | 150 | 165 | 98 | S | 1 | 3 | 2 | N |
| 48 | 5 | 123 | 130 | 105 | F | 1 | 3 | 1 | Y |
| 49 | 2.5 | 135 | 186 | 150 | S | 6 | 4 | 2 | Y |
| 50 | 9 | 184 | 216 | 182 | S | 1 | 4 | 4 | Y |
| 51 | 1 | 120 | 180 | 114 | S | 1 | 4 | 1 | Y |
| 52 | 6 | 145 | 150 | 126 | S | 1 | 2 | 2 | Y |
| 53 | 12 | 93 | 215 | 100 | F | 1 | 2 | 2 | Y |

| Plant No. | Diameter (largest stem) (cm) | Height (cm) | Width (cm) | Width 90° (cm) | Standing/ Fallen | No. of Stems | Health Class (1-4) | Foliage Density Class (1-4) | Seedbank (Y/N) |
|---|---|---|---|---|---|---|---|---|---|
| 54 | 5 | 93 | 245 | 110 | S | 1 | 3 | 1 | N |
| 55 | 1.5 | 95 | 129 | 42 | S | 2 | 3 | 1 | Y |
| 56 | 1 | 55 | 120 | 63 | S | 1 | 4 | 1 | N |
| 57 | 2 | 97 | 80 | 76 | F | 1 | 2 | 1 | Y |
| 58 | 2 | 88 | 75 | 50 | S | 1 | 3 | 1 | N |
| 59 | 6 | 132 | 145 | 100 | F | 1 | 2 | 1 | Y |
| 60 | 1.5 | 95 | 25 | 25 | S | 1 | 3 | 3 | N |
| 61 | 1.5 | 52 | 16 | 16 | S | 1 | 4 | 3 | N |
| 62 | 2 | 50 | 150 | 100 | F | 3 | 3 | 2 | N |
| 63 | 5 | 103 | 220 | 140 | S | 2 | 3 | 1 | Y |
| 64 | 5 | 125 | 115 | 100 | S | 1 | 4 | 3 | Y |
| 65 | 1.5 | 38 | 95 | 74 | F | 1 | 4 | 1 | N |
| 66 | 3 | 115 | 59 | 43 | F | 1 | 2 | 1 | Y |
| 67 | 1.5 | 110 | 56 | 22 | F | 2 | 1 | 1 | N |
| 68 | 3 | 105 | 162 | 115 | F | 1 | 1 | 1 | N |
| 69 | 3 | 100 | 100 | 77 | F | 2 | 3 | 1 | N |
| 70 | 3 | 124 | 45 | 42 | F | 1 | 3 | 1 | N |
| 71 | 3 | 140 | 56 | 40 | F | 1 | 4 | 1 | Y |
| 72 | 2.5 | 115 | 64 | 52 | F | 1 | 3 | 1 | N |
| 73 | 1.5 | 97 | 32 | 15 | F | 1 | 1 | 1 | N |
| 74 | 3 | 138 | 92 | 92 | F | 4 | 3 | 1 | N |
| 75 | 4.5 | 40 | 110 | 65 | F | 1 | 1 | 3 | N |
| 76 | 1.5 | 90 | 85 | 65 | F | 2 | 4 | 1 | N |
| 77 | 1 | 138 | 33 | 26 | F | 1 | 4 | 1 | N |
| 78 | 2 | 100 | 64 | 40 | S | 1 | 3 | 1 | N |
| 79 | 1.5 | 75 | 55 | 47 | F | 2 | 1 | 1 | N |
| 80 | 1 | 77 | 17 | 15 | S | 4 | 1 | 1 | N |
| 81 | 1 | 105 | 85 | 52 | S | 1 | 4 | 1 | N |
| 82 | 1 | 50 | 50 | 45 | S | 1 | 4 | 1 | N |
| 83 | 3 | 87 | 100 | 85 | S | 1 | 3 | 1 | Y |
| 84 | 2.5 | 105 | 78 | 24 | S | 1 | 1 | 1 | N |
| 85 | 3 | 92 | 143 | 110 | S | 1 | 4 | 1 | N |
| 86 | 4 | 140 | 200 | 110 | S | 3 | 2 | 2 | N |
| 87 | 4 | 50 | 185 | 140 | F | 5 | 1 | 1 | Y |
| 88 | 1 | 52 | 36 | 20 | S | 4 | 1 | 1 | N |
| 89 | 3 | 180 | 110 | 80 | S | 1 | 3 | 2 | Y |
| 90 | 1.5 | 79 | 30 | 20 | S | 1 | 4 | 2 | N |
| 91 | 1 | 59 | 95 | 48 | F | 1 | 2 | 1 | N |
| 92 | 2.5 | 68 | 100 | 94 | F | 1 | 4 | 1 | N |
| 93 | 1 | 63 | 19 | 15 | S | 1 | 4 | 2 | N |
| 94 | 2 | 120 | 80 | 80 | S | 3 | 2 | 1 | N |
| 95 | 5 | 92 | 220 | 120 | F | 3 | 4 | 3 | Y |
| 96 | 1 | 55 | 45 | 35 | F | 1 | 1 | 1 | N |
| 97 | 1.5 | 84 | 105 | 86 | S | 2 | 4 | 1 | N |
| 98 | 1 | 92 | 50 | 45 | S | 1 | 4 | 1 | N |
| 99 | 1 | 55 | 57 | 35 | S | 1 | 4 | 1 | N |
| 100 | 3 | 80 | 176 | 100 | F | 3 | 4 | 1 | Y |
| 101 | 1.5 | 29 | 14 | 10 | S | 1 | 1 | 1 | N |
| 102 | 1 | 46 | 37 | 23 | S | 1 | 4 | 1 | N |
| 103 | 2 | 189 | 110 | 100 | S | 2 | 1 | 1 | N |
| 104 | 0.75 | 12 | 5 | 4 | S | 2 | 1 | 1 | N |
| 105 | 3 | 105 | 120 | 55 | S | 1 | 1 | 1 | N |
| 106 | 0.75 | 24 | 27 | 14 | S | 15 | 1 | 1 | Y |
| 107 | 1.5 | 93 | 60 | 50 | S | 2 | 4 | 1 | N |
| 108 | 7 | 176 | 210 | 180 | S | 1 | 4 | 3 | Y |
| 109 | 3 | 98 | 44 | 37 | F | 1 | 3 | 3 | N |
| 110 | 2 | 92 | 64 | 30 | F | 1 | 3 | 1 | N |
| 111 | 2.5 | 73 | 200 | 50 | F | 5 | 1 | 1 | N |

| Plant No. | Diameter (largest stem) (cm) | Height (cm) | Width (cm) | Width 90° (cm) | Standing/ Fallen | No. of Stems | Health Class (1-4) | Foliage Density Class (1-4) | Seedbank (Y/N) |
|---|---|---|---|---|---|---|---|---|---|
| 112 | 2.5 | 100 | 200 | 100 | F | 4 | 3 | 2 | Y |
| 113 | 2 | 88 | 100 | 68 | S | 1 | 1 | 1 | N |
| 114 | 2.5 | 120 | 120 | 64 | S | 1 | 4 | 2 | N |
| 115 | 3 | 78 | 175 | 115 | F | 2 | 4 | 2 | N |
| 116 | 4 | 115 | 100 | 92 | F | 1 | 4 | 2 | N |
| 117 | 3.5 | 62 | 105 | 49 | F | 1 | 4 | 1 | Y |
| 118 | 3 | 110 | 94 | 72 | S | 1 | 3 | 2 | Y |
| 119 | 2.5 | 123 | 230 | 140 | F | 1 | 4 | 1 | N |
| 120 | 4 | 92 | 125 | 120 | F | 1 | 4 | 2 | N |
| 121 | 2.5 | 112 | 90 | 67 | S | 1 | 3 | 1 | Y |
| 122 | 1 | 86 | 36 | 22 | S | 1 | 4 | 1 | N |
| 123 | 2 | 92 | 30 | 21 | S | 1 | 2 | 2 | Y |
| 124 | 1.5 | 96 | 55 | 30 | S | 1 | 2 | 1 | N |
| 125 | 1.5 | 74 | 53 | 12 | F | 1 | 4 | 1 | N |
| 126 | 2 | 94 | 70 | 55 | S | 1 | 4 | 1 | Y |
| 127 | 1.5 | 124 | 64 | 31 | S | 1 | 4 | 1 | N |
| 128 | 2 | 76 | 134 | 100 | F | 3 | 3 | 3 | N |
| 129 | 1 | 156 | 16 | 8 | S | 1 | 4 | 1 | N |
| 130 | 1 | 71 | 47 | 42 | S | 1 | 4 | 1 | N |
| 131 | 3 | 177 | 48 | 48 | S | 1 | 4 | 3 | Y |
| 132 | 1 | 60 | 34 | 25 | S | 1 | 4 | 2 | Y |
| 133 | 5 | 187 | 45 | 37 | S | 2 | 1 | 1 | N |
| 134 | 4 | 76 | 84 | 70 | F | 1 | 3 | 2 | N |
| 135 | 3 | 58 | 65 | 52 | F | 1 | 1 | 1 | Y |
| 136 | 3 | 63 | 69 | 59 | F | 1 | 3 | 2 | N |
| 137 | 2 | 76 | 28 | 12 | F | 1 | 1 | 1 | N |
| 138 | 2 | 96 | 80 | 42 | F | 1 | 2 | 1 | Y |
| 139 | 0.7 | 76 | 23 | 14 | S | 1 | 2 | 1 | N |
| 140 | 1.5 | 100 | 32 | 16 | S | 1 | 2 | 1 | N |
| 141 | 1 | 38 | 48 | 36 | F | 4 | 1 | 1 | N |
| 142 | 2 | 103 | 72 | 61 | F | 3 | 1 | 2 | Y |
| 143 | 0.8 | 88 | 23 | 5 | S | 2 | 1 | 1 | Y |
| 144 | 2.5 | 107 | 64 | 48 | S | 4 | 1 | 2 | Y |
| 145 | 2 | 150 | 38 | 30 | S | 1 | 1 | 1 | N |

**Appendix 2: Measurements of all dead plants of *C. odgersii* subsp. *occidentalis* at Cowcowing in February 1999.**

| Dead Plant No. | Diameter (largest stem) (cm) | Height (Length) (cm) | Standing/ Fallen | No. of Stems |
|---|---|---|---|---|
| 1 | 4 | 151 | F | 1 |
| 2 | 1.5 | 65 | F | 1 |
| 3 | 9 | 155 | F | 1 |
| 4 | 7 | 140 | F | 1 |
| 5 | 4.5 | 151 | F | 1 |
| 6 | 4 | 170 | F | 1 |
| 7 | 2.5 | 100 | F | 1 |
| 8 | 6 | 130 | F | 1 |
| 9 | 1.5 | 160 | F | 1 |
| 10 | 1 | 109 | S | 1 |
| 11 | 0.5 | 55 | S | 1 |
| 12 | 1 | 54 | S | 1 |
| 13 | 1 | 64 | S | 1 |
| 14 | 0.5 | 64 | S | 1 |
| 15 | 1 | 67 | S | 1 |
| 16 | 1.5 | 75 | S | 1 |
| 17 | 2 | 84 | S | 1 |
| 18 | 3 | 138 | S | 1 |
| 19 | 2 | 135 | S | 1 |
| 20 | 1.5 | 92 | S | 1 |
| 21 | 1.5 | 90 | S | 1 |
| 22 | 4 | 148 | F | 1 |
| 23 | 5 | 140 | F | 1 |
| 24 | 2 | 150 | F | 1 |
| 25 | 2.5 | 105 | F | 1 |
| 26 | 1.5 | 44 | F | 1 |
| 27 | 3 | 145 | F | 1 |
| 28 | 2.5 | 130 | F | 1 |
| 29 | 3 | 130 | F | 1 |
| 30 | 6 | 90 | S | 1 |
| 31 | 2.5 | 105 | S | 2 |
| 32 | 3 | 79 | S | 1 |
| 33 | 1 | 45 | S | 1 |
| 34 | 1 | 57 | S | 1 |
| 35 | 9 | 118 | F | 1 |
| 36 | 9 | 150 | S | 1 |
| 37 | 4 | 140 | F | 7 |
| 38 | 3.5 | 97 | S | 1 |
| 39 | 6 | 200 | S | 1 |
| 40 | 1 | 93 | S | 1 |
| 41 | 3.5 | 150 | F | 1 |
| 42 | 1 | 72 | S | 1 |
| 43 | 5 | 133 | S | 1 |
| 44 | 3.5 | 145 | S | 1 |
| 45 | 2 | 110 | S | 2 |
| 46 | 3.5 | 130 | F | 1 |
| 47 | 2 | 133 | S | 1 |
| 48 | 2.5 | 100 | S | 1 |
| 49 | 3.5 | 120 | S | 1 |

| Dead Plant No. | Diameter (largest stem) (cm) | Height (Length) (cm) | Standing/ Fallen | No. of Stems |
|---|---|---|---|---|
| 50 | 2.5 | 120 | F | 1 |
| 51 | 2 | 62 | S | 1 |
| 52 | 5 | 180 | F | 1 |
| 53 | 3.5 | 155 | F | 1 |
| 54 | 2.5 | 73 | S | 1 |
| 55 | 4 | 172 | F | 1 |
| 56 | 4 | 86 | S | 1 |
| 57 | 3 | 148 | F | 1 |
| 58 | 3 | 85 | S | 4 |
| 59 | 1 | 90 | S | 1 |
| 60 | 3 | 100 | S | 1 |
| 61 | 3.5 | 138 | F | 1 |
| 62 | 3 | 80 | S | 1 |
| 63 | 3.5 | 85 | F | 1 |
| 64 | 2 | 66 | S | 1 |
| 65 | 4 | 140 | F | 1 |
| 66 | 1.5 | 105 | F | 1 |
| 67 | 1 | 100 | F | 1 |
| 68 | 2.5 | 90 | F | 1 |
| 69 | 1.5 | 77 | S | 1 |
| 70 | 3 | 88 | S | 1 |
| 71 | 2 | 93 | S | 1 |
| 72 | 4.5 | 250 | F | 1 |
| 73 | 6 | 180 | F | 1 |
| 74 | 1.5 | 125 | S | 1 |

**Appendix 3: Number of seed fragments and whole seed found in the soil seedbank ($1.125m^2$) and whole seed viability determined by germination trials.**

| Sample No. | No. of seed fragments | Total no. of whole seed | Total no. of seed with endosperm | Viability as determined by laboratory germination trials |
|---|---|---|---|---|
| 1 | 0 | 0 | 0 | - |
| 2 | 3 | 1 | 0 | - |
| 3 | 35 | 22 | 3 | 67% |
| 4 | 7 | 4 | 0 | - |
| 5 | 19 | 17 | 7 | 71% |
| 6 | 3 | 3 | 3 | 67% |
| 7 | 16 | 8 | 4 | 50% |
| 8 | 8 | 36 | 7 | 71% |
| 9 | 0 | 0 | 0 | - |
| 10 | 1 | 1 | 0 | - |
| 11 | 6 | 6 | 2 | 100% |
| 12 | 1 | 1 | 1 | 0% |
| 13 | 1 | 1 | 0 | - |
| 14 | 0 | 0 | 0 | - |
| 15 | 0 | 0 | 0 | - |
| 16 | 0 | 1 | 1 | 100% |
| 17 | 5 | 6 | 4 | 50% |
| 18 | 4 | 1 | 1 | 0% |
| 19 | 2 | 13 | 10 | 40% |
| 20 | 0 | 2 | 0 | - |
| 21 | 2 | 2 | 1 | 0% |
| 22 | 0 | 3 | 1 | 100% |
| 23 | 10 | 5 | 1 | 0% |
| 24 | 5 | 25 | 6 | 50% |
| 25 | 5 | 6 | 3 | 67% |
| 26 | 50 | 5 | 0 | - |
| 27 | 3 | 7 | 3 | 100% |
| 28 | 68 | 17 | 1 | 0% |
| 29 | 3 | 1 | 1 | 100% |
| 30 | 3 | 2 | 1 | 0% |
| 31 | 9 | 24 | 4 | 50% |
| 32 | 9 | 4 | 2 | 100% |
| 33 | 6 | 8 | 6 | 17% |
| 34 | 3 | 11 | 6 | 0% |
| 35 | 2 | 8 | 5 | 80% |
| 36 | 2 | 13 | 7 | 43% |
| 37 | 20 | 6 | 3 | 33% |
| 38 | 9 | 18 | 5 | 40% |
| 39 | 2 | 3 | 3 | 33% |
| 40 | 0 | 1 | 1 | 0% |
| 41 | 0 | 1 | 0 | - |
| 42 | 1 | 2 | 1 | 100% |
| 43 | 2 | 6 | 1 | 0% |
| 44 | 5 | 6 | 3 | 100% |
| 45 | 2 | 3 | 0 | - |
| 46 | 0 | 0 | 0 | - |
| 47 | 5 | 5 | 2 | 50% |
| 48 | 0 | 3 | 2 | 50% |
| 49 | 2 | 0 | 0 | - |
| 50 | 0 | 0 | 0 | - |