

Using vital statistics and core-habitat maps to manage critically endangered orchids in the Western Australian wheatbelt

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Abstract. Vital-statistics data concerning population viability were gathered for four of the rarest orchids in Western Australia using surveys to define population sizes and habitat areas and annual measurements of plant demographics. These orchids were *Caladenia melanema*, *C. graniticola*, *C. williamsiae* and *Drakaea isolata* from the wheatbelt of Western Australia. This agricultural area has a Mediterranean climate with unreliable rainfall, and is >80% cleared of native vegetation. Surveys with 10–30 volunteers increased population-size estimates by up to 10 times and provided spatial data to define core habitat areas. These areas included most of the individuals of a species, but were only 2–10 ha in size. Within these areas, orchids were often highly aggregated in patches a few metres wide, potentially resulting in a high degree of intraspecific competition. Vital statistics were obtained using 4-m wide and 30–50-m-long transects to measure rates of emergence, flowering, grazing and seed-set for each orchid. Plants emerging at the same position in different years were considered to be the same individual, but most emerged in new positions. Many plants emerged just once in 4 years, and 2–3 years of dormancy was common. Emergence frequencies were used to provide estimates of population sizes that were two or three times larger than suggested by data from a single year. Seed production was typically very low. Grazing by kangaroos and rabbits was most severe for *C. melanema*, but was greatly reduced by fencing. Severe drought prevented flowering of *C. graniticola* in the driest year, whereas other species were more resilient. These orchids are likely to persist as long as there are some years where rainfall is sufficient for flowering and seed set followed by a year with adequate rain for seed germination. Populations of all these orchids were stable or increasing, but they are still at high risk of extinction because of the impacts of increasing soil salinity or fire on their habitats. These species are unlikely to spread elsewhere in the highly cleared and fragmented wheatbelt. Intervention by hand-pollination, grazing protection and translocation to new locations is required to mitigate these risks. Results were summarised in vital statistics report cards with thresholds set to inform conservation management for these species. Core habitat maps and vital-statistics report cards should also be valuable new tools for terrestrial-orchid conservation in other biomes.

Additional keywords: demographics, orchid conservation, pollination, rare flora, seed set.

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Introduction

The South-west Floristic Region of Western Australia is a globally recognised centre of plant species richness and endemism, coupled with a high degree of habitat loss (Myers *et al.* 2000; Hopper and Gioia 2004; www.biodiversityhotspots.org, accessed 2009). This high plant diversity is linked to a long period since major tectonic or glacial disturbance, highly infertile soils and periodic minor disturbances such as drought (Hopper 2009). Unfortunately, the exceptionally high biodiversity in south-western Western Australia (WA) faces many threats that are primarily of human origin. This is one of the most stressed regions in Australia, with a high degree of land clearing (>80%) and fragmentation, as well as declining vegetation health linked to secondary soil salinity, drought, weeds and other factors (Commonwealth of Australia 2002).

As the largest plant family globally (>25 000 species), the orchids are considered to have the highest rate of speciation, the highest rate of extinctions and the most rare species of any plant family (Molvray *et al.* 2000; Chase *et al.* 2015). Most WA orchids occur in the south-west, which has a Mediterranean-type climate with cool, wet winters, followed by 5–8 months of summer drought when orchids aestivate as dormant tubers. Despite the long, dry summer, south-western WA is one of the world's diversity hotspots for terrestrial orchids with ~400 species, most of which are endemic; however, their diversity is highest in coastal areas with more rainfall (Brundrett 2014). In 2013, there were 40 taxa of WA orchids designated as *Rare Flora* and 55 as *Priority Species* requiring further surveys (florabase.dpaw.wa.gov.au, accessed December 2003). The *Rare Flora* meet IUCN criteria for population size and habitat area,

suggesting that they are threatened with extinction (IUCN 2012; Table 1). The majority of both rare and common orchids in WA have highly specific associations with mycorrhizal fungi and insect pollinators and this may explain why some of them are restricted to very small habitat areas, despite having wind-dispersed seeds (Brundrett 2007). Orchids in the present study are listed as *Critically Endangered* (the most threatened category of *Declared Rare Flora* in WA) because they are likely to become extinct in the wild without intervention. The main threats to these orchids result from the scarcity and fragmentation of suitable new habitats and the impacts of factors such as weeds, herbivores, infrequent pollination, salinity, drought and fire (Brown *et al.* 1998).

This publication presents some of the results of the Wheatbelt Orchid Rescue (WOR) Project, which was a Lotterywest-funded collaboration between the Western Australian Native Orchid Study and Conservation Group (WANOSCG), the Friends of Kings Park and the Department of Environment and Conservation (DEC). The work presented here concerns four of the rarest orchids in WA, including the granite spider orchid (*Caladenia graniticola*), the ballerina orchid (*C. melanema*), William's spider orchid (*C. williamsiae*) and the lonely hammer orchid (*Drakaea isolata*). The present research aimed to help conserve these *Critically Endangered* orchids by obtaining knowledge required for conservation management and directly contributing to actions listed in existing recovery plans (Table 1). More specifically, the present research aimed to (1) provide better estimates of population sizes by harnessing volunteer assistance, (2) measure orchid mortality, seed set and recruitment, (3) measure orchid habitat areas and (4) identify the most important threats to species. The second phase of the present project, which concerned recovery actions such as the propagation and translocation of orchids, will be described in a subsequent paper.

Materials and methods

Characteristics of species and their habitat types, rainfall and the approximate locations of the orchid populations studied are summarised in Table 1 and Fig. 1. The orchids studied were all long-lived perennial geophytes that are readily identifiable and have been monitored by periodical surveys for several decades (Fig. 2). Soils of these sites were sandy loams with very low fertility levels (Brundrett 2011).

Extensive habitat-area surveys

All surveys were run by the author and attended by DEC conservation staff whenever possible. These survey trips were attended by up to 30 volunteers (WANOSCG members) who had up to five decades of experience in recognising and locating uncommon orchids. There was a substantial commitment from volunteers because trips lasted 3–6 days and involved travel distances well over 1000 km (Brundrett 2012). At each location, volunteers and staff were divided into several groups, each of which recorded numbers of leaves, plants, flowers and seed associated with a GPS coordinate. The impacts of threats such as grazing or weeds were also recorded. The number of plants counted was compared with data published in Interim Recovery Plans for each species (Table 1) to assess population-size trends and investigate the impact of survey effort and rainfall on numbers of orchids detected at the same locations. The overall condition of vegetation was assessed using Landmonitor vegetation-change imagery based on satellite images from 1988 and 2013 (landgate.wa.gov.au, accessed 2011). Recorded GPS coordinates were used to map areas of 'critical' and 'core' habitats for each species, as defined below.

Critical habitat is identified in the Australian *Environment Protection and Biodiversity Conservation Act* 1999 as being habitat essential for the survival of a listed threatened species or community. Habitat means the biophysical medium or media (1) occupied (continuously, periodically or occasionally) by an organism or group of organisms, or (2) once occupied (continuously, periodically or occasionally) by an organism or group of organisms, and into which organisms of that kind have the potential to be reintroduced.

Core habitat, as defined here, is the most essential area(s) for survival of the taxa with highest densities of and/or the majority of currently known individuals. This area is also the most susceptible to threats such as, for example, disturbance, fire, weeds and animal grazing. Multiple separate areas, if defined, are ranked in order of importance.

Intensive demographics studies

Permanent transects were used to measure flowering, seed set and survival rates in a fixed area for 4 years in a row for three orchid species (*C. melanema*, *C. graniticola*, *C. williamsiae*). For each orchid, a 30–50-m long × 4-m wide transect was established in the largest (or only known) population. The length of transects was dictated by the size of habitats and was

Table 1. Status of four selected *Critically Endangered* Western Australian wheatbelt orchids at the start of this project, using data from the cited Interim Recovery Plans

Name	Common name	Number of populations	Estimated number of plants	Interim recovery plan
<i>Caladenia graniticola</i> (Hopper & A.P.Br.)	Granite spider orchid	5	250	Kershaw <i>et al.</i> 2003
<i>Caladenia melanema</i> Hopper & A.P.Br.	Ballerina orchid	1 (now 4)	300	Department of Environment and Conservation (2007a)
<i>Caladenia williamsiae</i> Hopper & A.P.Br.	Williams' spider orchid	1	150	Department of Environment and Conservation (2007b)
<i>Drakaea isolata</i> Hopper & A.P.Br.	Lonely hammer orchid	1	250	Phillimore <i>et al.</i> 2000

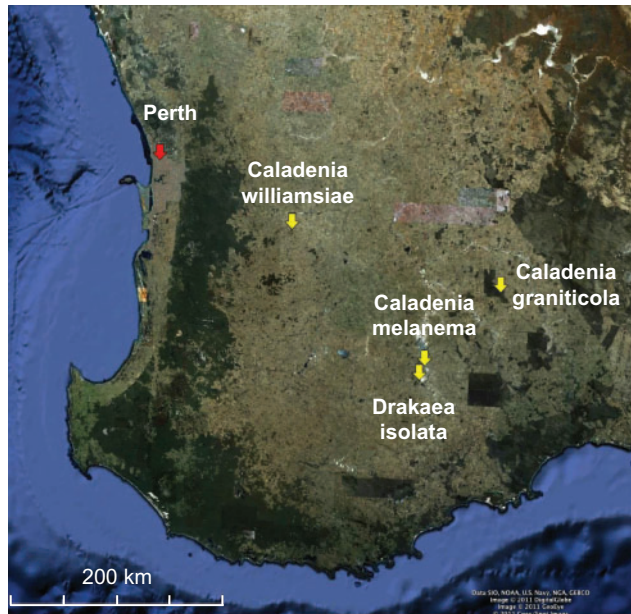


Fig. 1. Approximate locations of rare orchid populations included in the present study within the wheatbelt of Western Australia – a large area (155 000 km²) where most native vegetation is cleared for agriculture. Map data: Google, DigitalGlobe.

oriented to include as many individuals as possible in the densest area of occupation for each species. Transects established in 2007 were marked with steel posts at both ends and monitored several times each year until 2010. Plants on transects were counted during spring (August or September) to assess plant emergence, flowering and preliminary seed set, and again in late spring to determine final seed set (October or November). Grazing was assessed in each visit because it often increased during the year. The relationship between total annual or winter rainfall and the number of emerging and flowering plants was also investigated using data from nearby weather stations published by the Australian Bureau of Meteorology (www.bom.gov.au, accessed 2011).

For each orchid plant, the distance along the transect axis and perpendicular distance from it was recorded. These coordinates were used to identify plants that were assumed to be the same individual if they emerged at the same location on different years (within 2 cm). The accuracy in measurements was increased by inserting permanent steel pegs as fixed reference points every 5 m along transects. The identification of individual plants was used to determine how often each plant emerged or flowered over the 4-year period of observation.

For *Drakaea isolata*, photo monitoring of tagged plants was used instead of establishing a transect because of the widely scattered nature of clumps of individuals and the existence of a series of older photos showing the relative position of the prostrate leaves within groups of plants next to a fixed point (a steel peg with label). Photographs of the same location taken on different years were compared by tracing outlines of leaves from these photos. The resulting circles were rotated and transformed in a vector-drawing program (Adobe Illustrator, Adobe, San Jose, CA, USA), so that the relative positions of the fixed post and

leaves were as close together as possible. These transformations were necessary because each photo was taken from a different direction and angle downward.

Results

Population surveys

The population survey for *C. graniticola* occurred in 2008, on a year when substantial numbers of orchids emerged as a result of above-average rainfall in winter (Fig. 3). A team of 30 experienced volunteers searched in suitable habitats for 3 days within Dragon Rocks Nature Reserve, where three populations of this orchid were known to occur. This survey resulted in the discovery of over 300 plants, being an order of magnitude increase in the size of populations from earlier surveys (Fig. 4). The majority of plants were flowering; however, it was also possible to reliably identify non-flowering individuals by distinguishing their leaves from those of other orchids. These orchids were primarily associated with sheoak woodlands (*Allocasuarina huegiana* and *A. campestris*) over granite rock, although some were in other habitat types nearby. All of the areas occupied by *C. graniticola* were very small patches, totalling 18 ha in a very large nature reserve (332 km²). For this species, the number of plants emerging and flowering is strongly influenced by rainfall (Fig. 5a). The most important core habitat area contained 217 plants and was only 150 × 150 m in size. These plants are densely aggregated into two smaller areas less than 50 m wide. In total, there were ~300 plants in all three local populations, so the granite spider orchid is a highly threatened species (small populations occur in 2 other reserves).

Surveys for the ballerina orchid (*Caladenia melanema*), with the assistance of several volunteers, occurred over several years in *Melaleuca lateriflora* shrublands on the margins of salt lakes. These surveys found four new subpopulations of this orchid and two new populations that were ~10 km from the main population. These, presumably, arose recently by seed dispersal, because the number of plants within all subpopulations has increased substantially since monitoring began (Fig. 5d). Even though a greater number of plants and several new populations were found, 90% of known plants of this species were confined to small patches of fringing shrubland within chain of salt lakes with a total area 3 × 1 km in size (Fig. 6a). Satellite imagery provides evidence that the canopy of shrubs under which *C. melanema* grows has substantially declined in cover over the past 20 years (Fig. S1, available as supplementary material for this paper). Because most *C. melanema* plants occur under the canopy of *M. lateriflora*, the long-term sustainability of these shrubs is likely to be critical for orchid populations. Recruitment of *M. lateriflora* seedlings has not been observed at the site and needs to be encouraged by grazing protection or planting seedlings raised in a nursery.

A full survey of suitable habitats in the nature reserve where *Caladenia williamsiae* occurs was undertaken by three people in 2010 to count individuals and to accurately map habitat areas for this extremely rare orchid. Despite the low rainfall in 2010 (Fig. 3), considerably more plants were counted than expected on the basis of earlier surveys of the same area (450), but these were concentrated in a very narrow strip of core habitat ~2 ha in

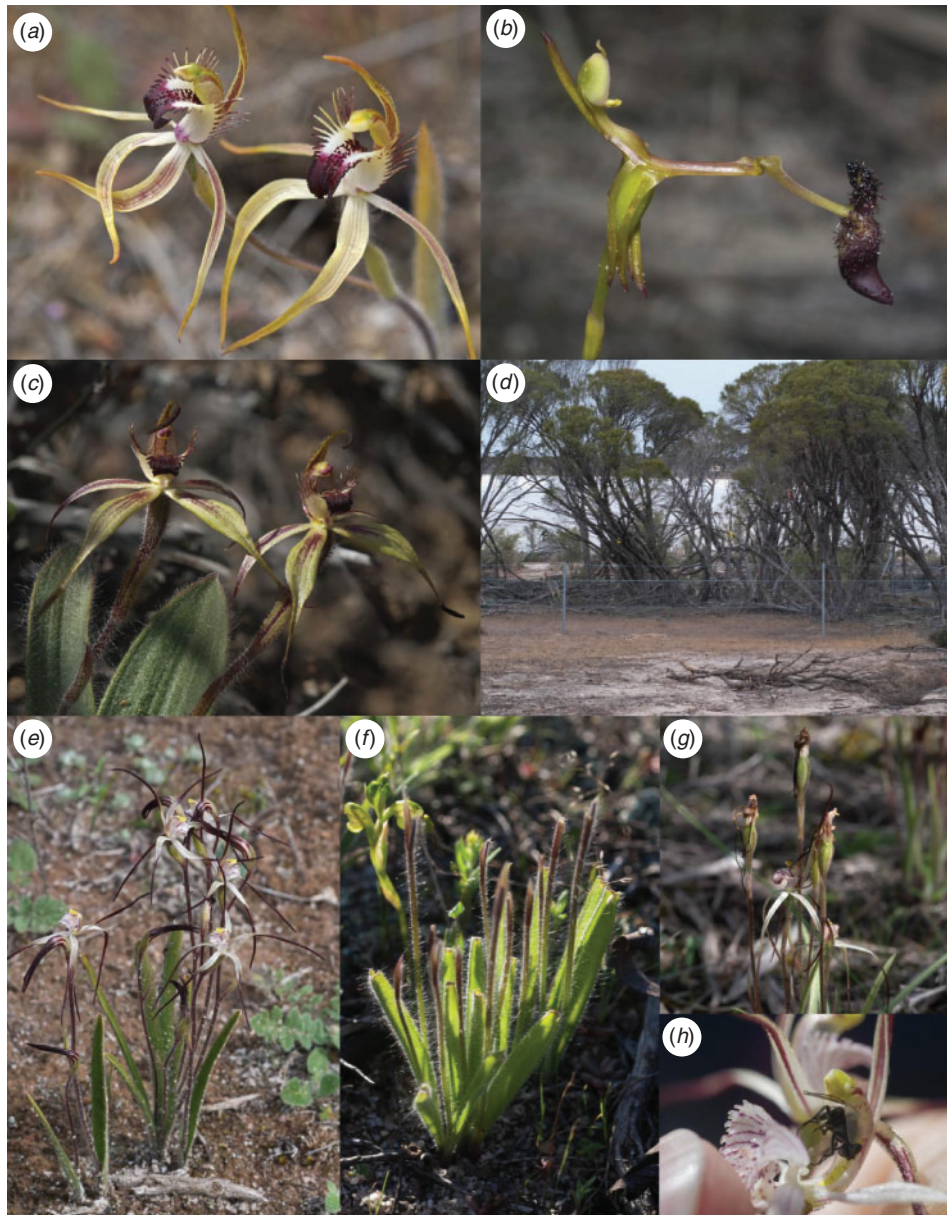


Fig. 2. (a) *Caladenia graniticola*. (b) *Drakaea isolata*. (c) *C. williamsiae*. (d) Habitat of *C. melanema*, showing fence enclosure near salt lake. (e) *C. melanema* plant. (f) Grazed leaves and flower spikes of *C. melanema*. (g) Seed pods on *C. melanema*. (h) Flies stuck to the stigma of a *C. melanema* flower prevent pollination by other insects.

size (Fig. 6b) and plants were grouped together in small patches within this area. All populations of this orchid occur within a critical habitat area of ~1 km² in a single nature reserve. This orchid was discovered in 1999 and surveys of the same area between 2000 and 2006 detected from 6 to 143 plants (Department of Environment and Conservation 2007b). The apparent increase in population size following the 2010 survey is probably due to increased survey effort, which was required to overcome detectability problems, as *C. williamsiae* is a small orchid that often grows under shrubs.

Survey data for *Drakaea isolata* in 2007 with 29 volunteers revealed almost 300 individuals, of which 50 were flowering. The number of plants found was determined, to a large extent,

by the number of people searching for them, because earlier surveys found as few as 77 plants in the same area, whereas a major survey with volunteer assistance found 250 plants in 1989 (Phillimore *et al.* 2000). Thus, the population size and habitat area for this orchid have not changed much since 1989. Leaves of this species were aggregated into 56 groups, which may represent the number of individuals of this species, because up to 50 leaves were found in each group and probably arise from clonal division. Almost all known plants of *D. isolata* occur in a small square area of ~10 ha. This area is at a very high risk from rising saline groundwater, because it is next to a salt lake where severely salt-affected areas are expanding (Fig. S1).

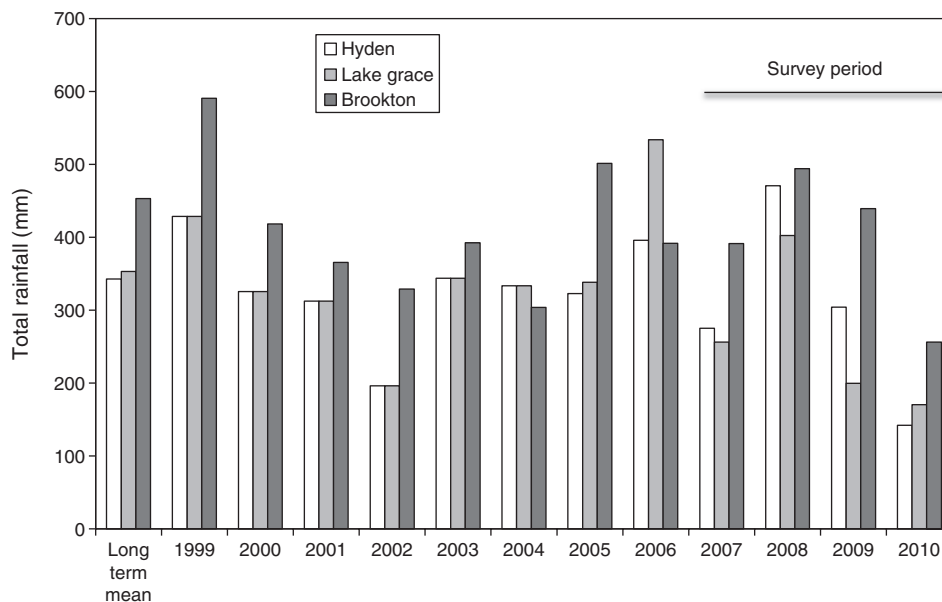


Fig. 3. Rainfall recorded at the weather stations closest to locations where the four orchids in the present study occur (www.bom.gov.au, accessed 2009–2011). The present research occurred during the last 4 years on the graph and 2010 was exceptionally dry.

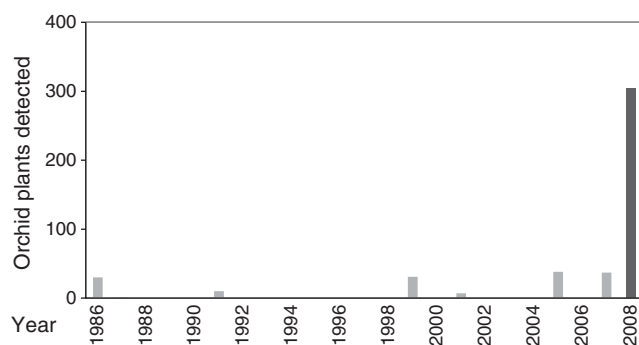


Fig. 4. Numbers of *Caladenia graniticola* plants counted in surveys of the same populations, including data from the 2008 survey reported here (dark bar) and earlier surveys reported in Kershaw *et al.* (2003) as light bars.

Detailed demographic studies

Caladenia graniticola

Severe winter drought had a substantial impact on flowering of *C. graniticola*, especially in 2010 when rainfall was less than half of average (Fig. 3) and all plants aborted before flowering. Emergence and flowering of *C. graniticola* were correlated with rainfall (Fig. 5a).

The emergence of plants at different positions on the transect (Fig. 7a) allowed individual plant emergence to be observed over 3 years (data from Year 4 were not available because of severe drought). For this orchid, only ~1/2 of emergent plants produced a single flower and very few set seed or produced two flowers, even on years with a relatively wet winter (Figs 8a, 9a). As shown by Fig. 10a, b, on average, 37% of plants emerged each year and 17% flowered. It seems that ~1/2 of the orchids that exist as dormant tubers emerged in 2008, which was a wet year, whereas only 1/3 or 1/4 of these plants emerged in years with winter drought. There were limited

impacts of grazing at this site. This orchid has a relatively low frequency of annual emergence from dormant tubers and the proportion of plants that emerge, but fail to flower, is also greater than for other species and none flowered more than twice over 4 years (Fig. 10a, b). The average length of dormancy was close to 2 years, but was measured only for 3 years because of drought in Year 4 (Fig. 11a).

Data on orchid emergence rates were used in combination with survey data, to provide a revised estimate for orchid population size. Because ~1/2 of the detected plants on the transect emerged in 2008 when 300 plants were counted during surveys, it would suggest that there are ~600 plants in total in all three populations in the single nature reserve where most plants of this species occur (Table 2). This confirms that *C. graniticola* is at high risk of extinction (populations occur in 2 other reserves, but contain less than 150 additional plants).

Caladenia melanema

There was no strong correlation between rainfall and plant numbers for *C. melanema*, but annual trends tended to be overwhelmed by the steady population-growth trend over time (Fig. 5b, d). As shown in Fig. 8b, plants were very densely aggregated at several points along the 50-m transect where clumps of plants are almost touching, with 50–62% of all plants on the transect growing in a single patch ~1 m wide. This made identifying individual plants within the most crowded area impossible, so only plants in the first 15 m of the transect were identified by location (Fig. 7b). Dense clumps of orchids result from clonal division by daughter-tuber production next to the parent tuber, and these locations were also hotspots for reproduction from seed, resulting in new clumps of orchids within close proximity to each other. Each clump had 1–30 leaves and 1–14 flowers, with an average of 4.6 leaves and 2.5 flowers per clump in 2009. All flowers were

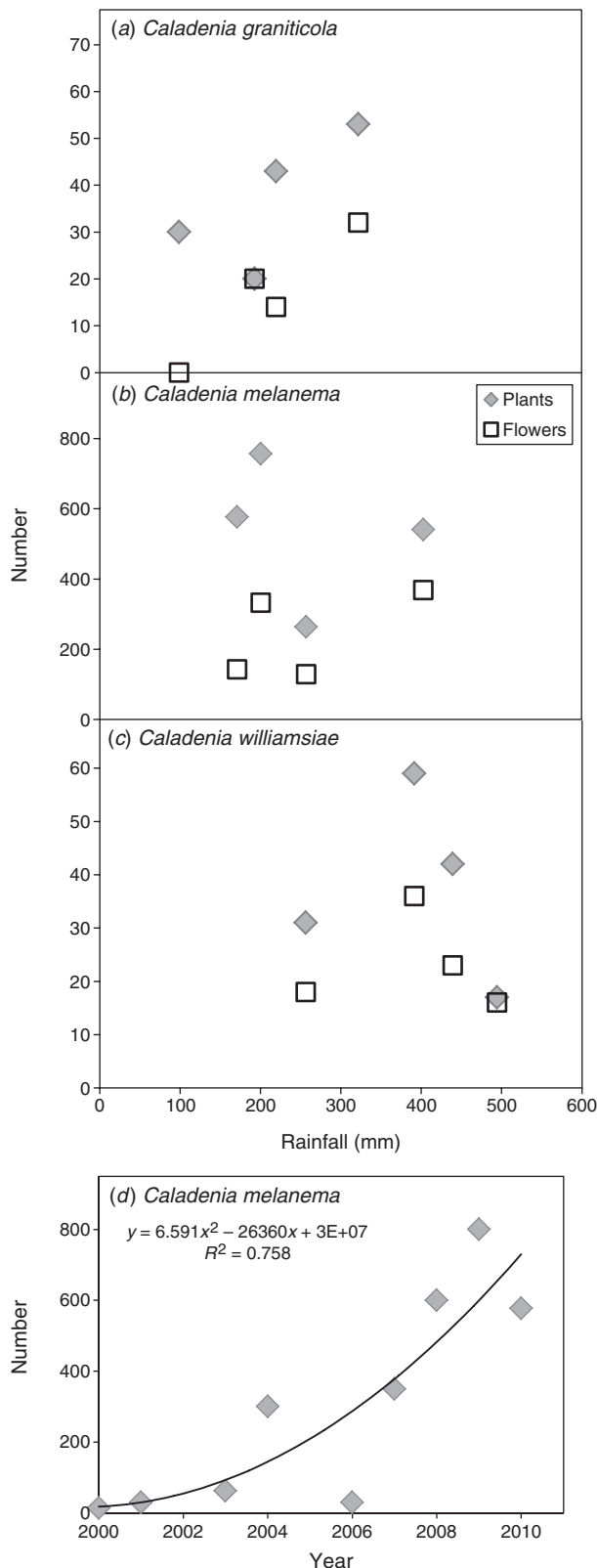


Fig. 5. (a–c) The relationship between annual rainfall and numbers of emergent and flowering plants for three orchids. (d) Numbers of plants recorded for one entire *Caladenia melanema* population over one decade show a strongly increasing trend.

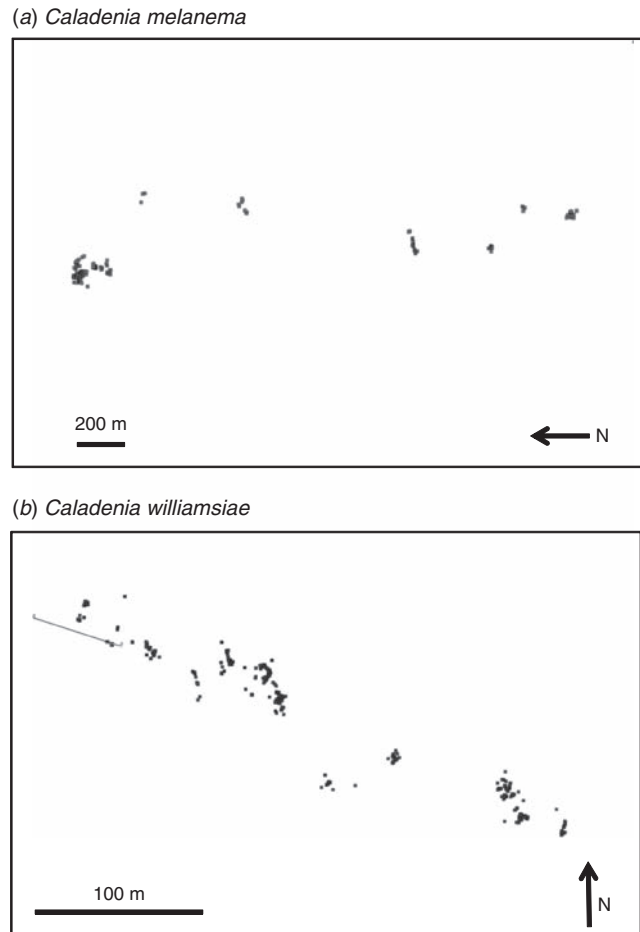


Fig. 6. (a) *Caladenia melanema* plants are highly aggregated into six subpopulations separated by small salt lakes (imagery not shown) within a narrow critical habitat area 3 km long. (b) In total, 95% of known plants of *C. williamsiae* which occur within a narrow 400 × 50 m zone of vegetation. The 50-m transect where detailed demographics studies occurred is also shown (line).

single (Fig. 9b). There was good pollination of *C. melanema* flowers, but many were grazed before seeds matured (Fig. 8b). A thynnid wasp (*Rhytidothynnus* sp.) was observed to be a potential pollinator, whereas flies were abundant on years with warm winter weather and became stuck in flowers. Flies block the stigma because they are not strong enough to escape, and so prevent pollination by other insects (Fig. 2h).

Data on relative plant positions (Fig. 7b) showed that, on average, 40% emerged each year and 16% flowered, whereas seed set was only 2% of all plants (dormant plus emergent). Over 60% of plants emerged and flowered only once in 4 years (Fig. 10c, d), and 3 years of consecutive dormancy or two episodes of dormancy within 4 years were most common (Fig. 11b). These data suggest that there were ~1350 plants on the transect (including dormant plants), so there was an estimated total of 4000–5500 plants within the 3-km² critical habitat area of this species (Table 2).

In response to severe grazing of plants observed throughout the critical habitat area in 2007, a 10 × 10 m enclosure of 1-m-high rabbit-proof fencing was erected on the transect that

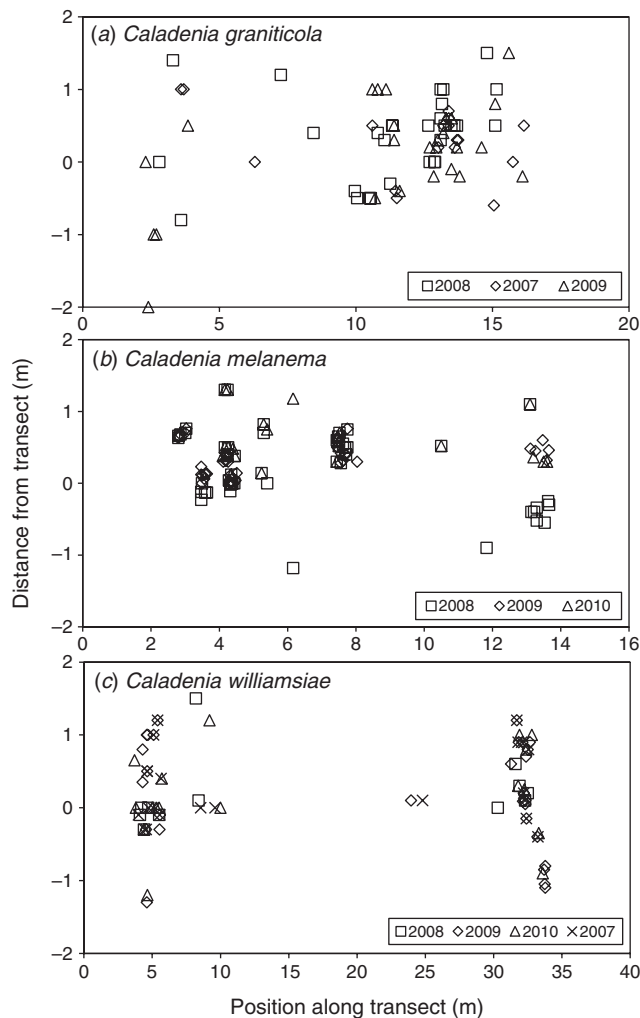


Fig. 7. (a) Individual plants of *Caladenia graniticola* emerging on one or more years over 3 years identified by their relative positions along a transect. Plants aborted before flowering because of drought in Year 4. (b) The relative position and density of leaves and flowers of *C. melanema* emerging over 4 years. (c). The relative position and density of leaves and flowers of *C. williamsiae* emerging over 4 years. Note that the vertical scale is much finer than the x-axis scale in all graphs.

summer when plants were dormant. Subsequently, 75–100% of uneaten seedpods on the transect were located in the enclosure. The type of grazing differed within the enclosure, where flowers were sometimes eaten, but there was almost no grazing of leaves. Four new enclosures were erected in 2009 to protect other subpopulations and these also greatly reduced grazing, but did not eliminate it. It is not clear what caused grazing within fenced enclosures.

Caladenia williamsiae

Monitoring plants on a 50 × 4 m transect for 4 years showed that grazing and infrequent seed production were the most significant threats to *C. williamsiae* (Figs 7c, 8c). Grazing impacts, especially of flowers, varied from 6% of plants in 2008 and 2010, to 26% in 2009 (Fig. 8c). The numbers of plants emerging or flowering varied considerably from year

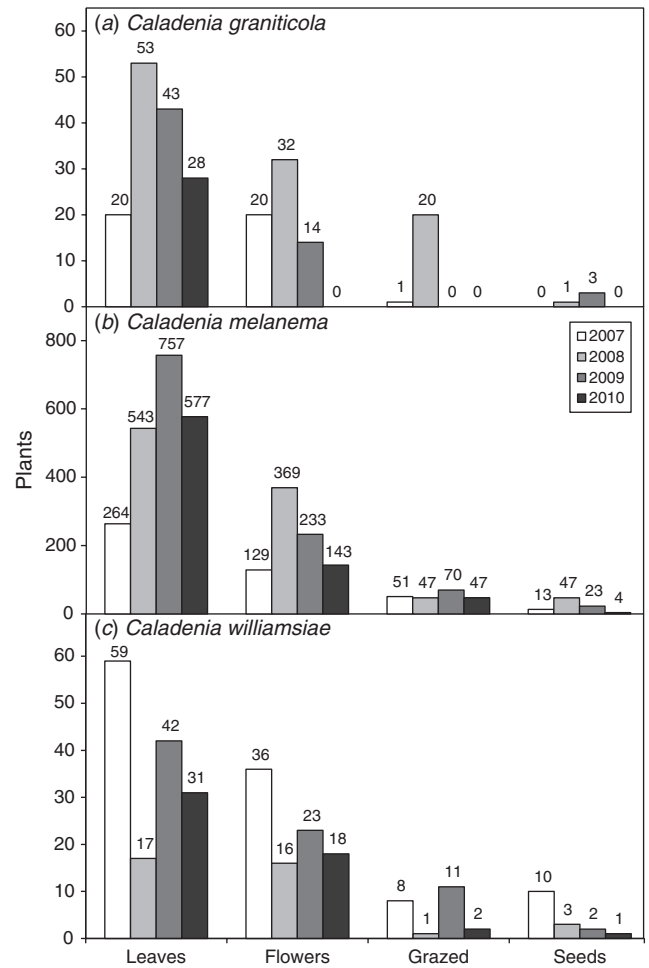


Fig. 8. (a–c) Seasonal variation in emergent plants, flowering, grazing and seed set for three orchids over 4 years, using data from transects.

to year, but remained low each year and were not strongly linked to rainfall (Fig. 5d). Relatively few plants set seed, except in 2007, where 28% had capsules (Fig. 8c), so pollination (presumably by a thynnid wasp) is unreliable. Overall, rates of seed set are probably adequate, whereas the volume of seed in capsules is low compared with that in most other *Caladenia* species. As shown in Fig. 9c, from 60% to 90% of plants flowered, and most of these produced a single flower. The fact that most plants remain dormant each year limits their reproductive potential and may be due to the exposed habitat of this orchid, which grows on upland ridges within very well drained lateritic gravel. It was also observed that grazed plants are often growing in the open, whereas those protected under the canopy of shrubs were less likely to be grazed. There is clear evidence of high kangaroo population levels at the site (tracks, scats and sleeping areas).

Comparison of the same plants showed that most appeared only once in 4 years and flowering was even less frequent (Fig. 10e, f). Only 32% of plants emerged more than once at the same position, only 29% of plants flowered more than once and 16% did not flower at all in 4 years. The majority of plants were dormant for 2 or 3 years in total, with one or two dormancy

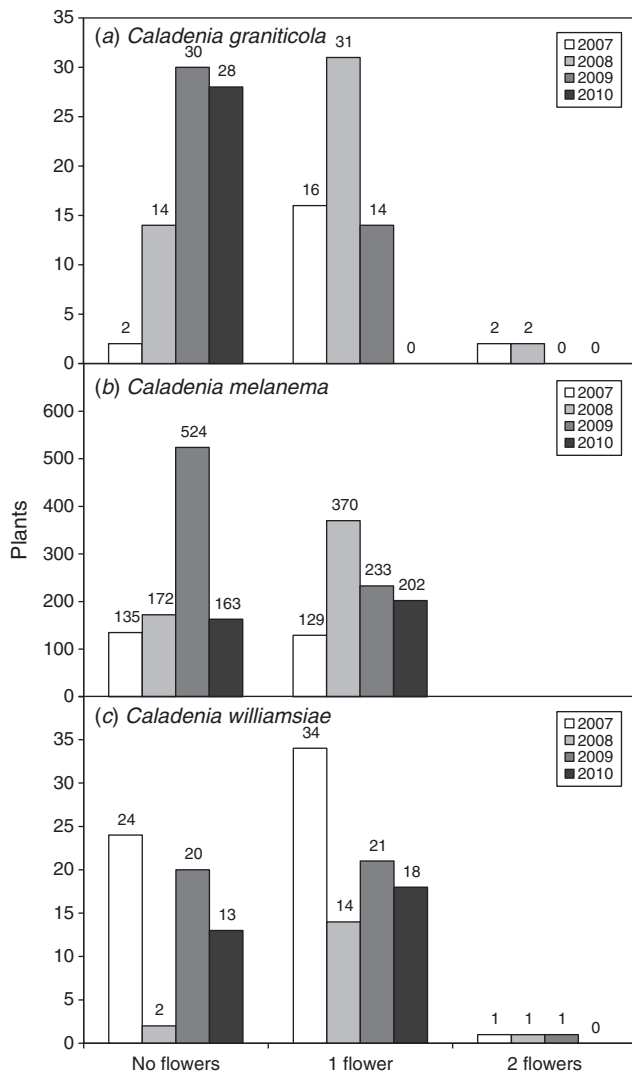


Fig. 9. (a–c) The flowering effort (flowers per plant) for three orchid species.

episodes in 4 years (Fig. 11c). The number of individuals on the transect was estimated to be 108, of which 34% emerged and 22% flowered, on average, each year (Table 2). The transect emergence data in combination with survey data provided a revised estimate for an orchid population size of ~1400 plants for all populations of the William's spider orchid (Table 2).

Drakaea isolata

Photographs taken by DEC staff of a tagged group of leaves in 2003 and 2004 were compared with those taken by the author in 2007 at the same coordinates to compare leaf and flower numbers (Fig. S2, available as Supplementary material for this paper). Comparisons of photos required image transformation to overcome varying camera positions. Many leaves occupy similar positions in all photos, whereas others present in 2007 appear to have recruited since 2004. There are also two leaves present in the first photos that may have died since 2003, or were dormant. In 2004, there were eight inflorescences at this

location, but all were grazed. Comparison of five groups of tagged plants showed that most of the plants observed in 2003 were also found in 2007; however, Groups 4 and 5 may no longer exist (Brundrett 2011). It seems that the larger groups of *D. isolata* are stable over time. Unlike the *Caladenia* species, there was little evidence that substantial numbers of *D. isolata* plants were dormant, because most leaves appear in all three photographs of each group. Leaves of this orchid are relatively xeromorphic (Brundrett 2014). Each leaf is connected to a separate tuber, whereas all those in a group are likely to be the same clonal individual.

Discussion

The Wheatbelt Orchid Rescue Project established that surveys that included substantial numbers of highly experienced volunteers were very effective at both counting numbers of individuals and mapping their core habitat areas within large nature reserves. Both the time spent at locations and areas covered increased considerably in surveys with volunteers. Comparisons with earlier surveys established that surveys with one or two people substantially underestimated numbers of plants in many cases. Unfortunately, the large number of rare species in WA has resulted in very limited resources to survey many of these species (Coates and Atkins 2001; West Australian Auditor General 2009). For example, there are 125 plants designated as *Rare Flora* in the wheatbelt region of WA (florabase.dpaw.wa.gov.au, accessed April 2015), but only two Flora Conservation Officers to manage them. The comparative merits and risks of including volunteers in surveys need to be considered (if locations are not already fairly well known), and it also needs to be recognised that effective monitoring is not possible without volunteer support if areas to be surveyed are very large. In WA, locations of rare orchids are generally fairly well known by enthusiasts, who often have key roles in discovering and monitoring these locations.

A key outcome of surveys was the identification and mapping of core habitat and critical habitat areas for each species, which is required to manage orchid populations within nature reserves, especially from disturbance and fire. These areas were defined, listed in order of importance and provided to the land manager as reports and GIS datasets (Brundrett 2011). Core habitat areas are the highest priority for fire protection, grazing control or weed management. These areas were very small for rare wheatbelt orchids, varying from 2 to 10 ha. Core habitats are smaller than the area of occupancy of a rare species, as defined by the IUCN (2012), and arise because these rare orchids had aggregated distributions where most individuals occur in a few small patches within their area of occupancy. For example, ~50% of all known individuals of *C. graniticola* occur within a 1-ha area that contains the largest of its five populations, whereas the area of occupancy is much larger (5 km²). Unfortunately, many of the core habitat areas are highly vulnerable to fire or salinity (Table 2).

The distributions of orchids were aggregated at three or more nested spatial scales, including (1) critical habitat areas of a few square kilometres enclosing each population and other habitat with similar vegetation and landforms, (2) core habitat areas of 2–10 ha where most individuals occur and

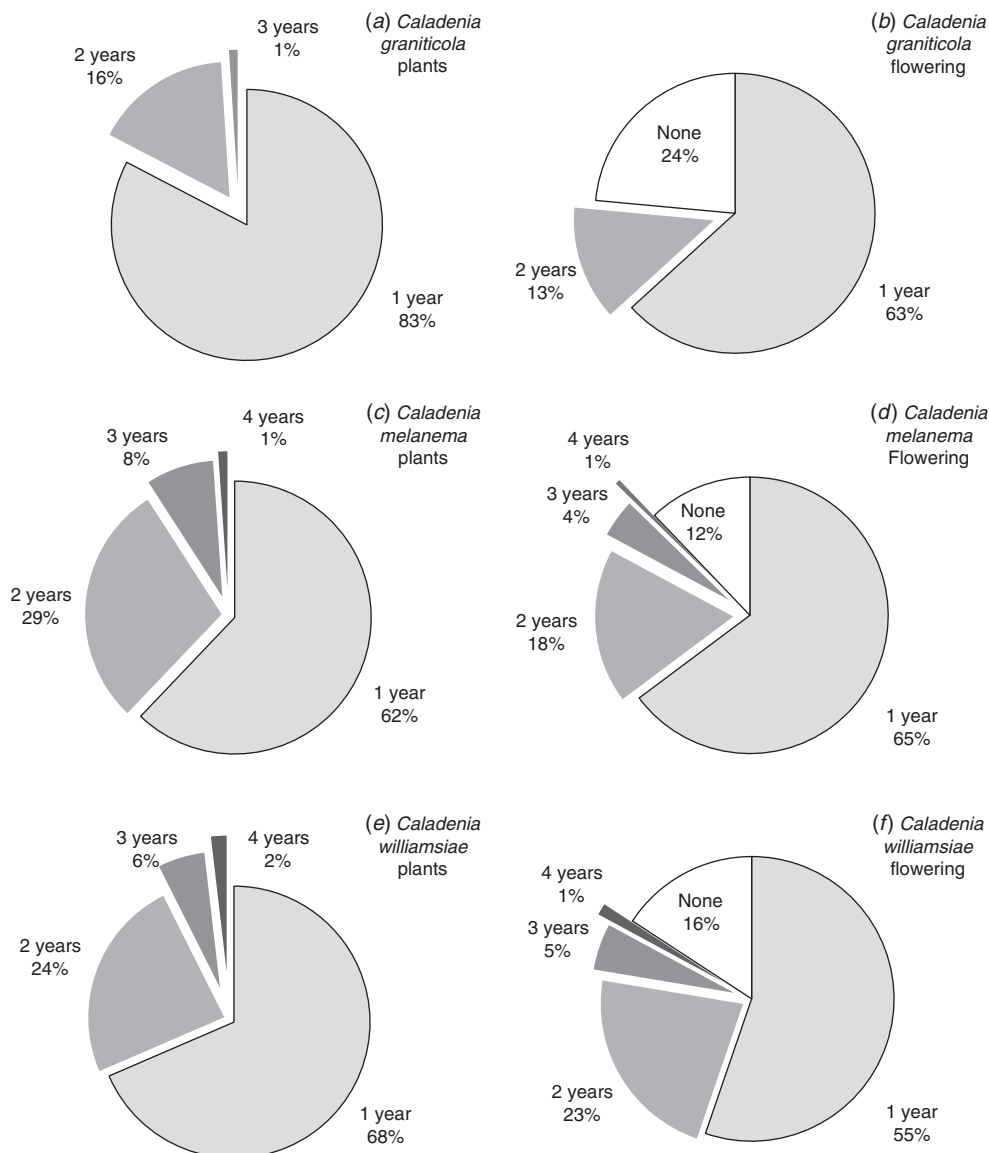


Fig. 10. (a, c, e) Average values for the total number of years in which plants emerged from dormancy over 4 years. (b, d, f) Averages for the total number of years in which flowers were produced by these orchids over 4 years. 'None' indicates that orchids emerged at least once but did not flower in any year.

(3) dense patches of orchids a few metres wide within the core habitat where many individuals grow. The aggregated distributions of the orchids studied here suggest that intense competition for resources, such as nutrients provided by mycorrhizal fungi or pollinator visitations, is likely to occur in the densest patches. The resources required by mycorrhizal fungi would primarily consist of coarse soil organic matter and litter where the inoculum of orchid fungi is most concentrated (Brundrett *et al.* 2003). Individual insect pollinators quickly learn to avoid areas where sexually deceptive flowers occur (Alcock 2000; Menz *et al.* 2013), so pollination is more frequent if plants are widely dispersed. Density-dependent impacts on orchid fitness may be less severe in non-productive years when more plants remain dormant. In the case of *C. melanema*, overcrowding is most severe in one densely occupied area, with over 500 plants within 1 m². In the case of

clonal orchids such as the *C. melanema*, it is recommended that some tubers be moved to less crowded areas to determine whether this is beneficial to future flowering and division. It should be possible to do this when plants are dormant in the summer without harming them, as dormant tubers can be handled without harm when they are re-potted in *ex situ* collections. For *C. melanema*, individuals in the same clump are likely to be genetically identical because of clonal division.

Estimating mortality and recruitment for these orchids would require longer survey times. However, there is already sufficient evidence that these populations were steady (2 species) or growing (2 species), on the basis of long-term monitoring of specific subpopulations (see Table 2). Clonal recruitment-rate estimates were also provided for *C. melanema* and *D. isolata*. There has been a steady increase in numbers of individuals and populations for *C. melanema*, from a few individuals

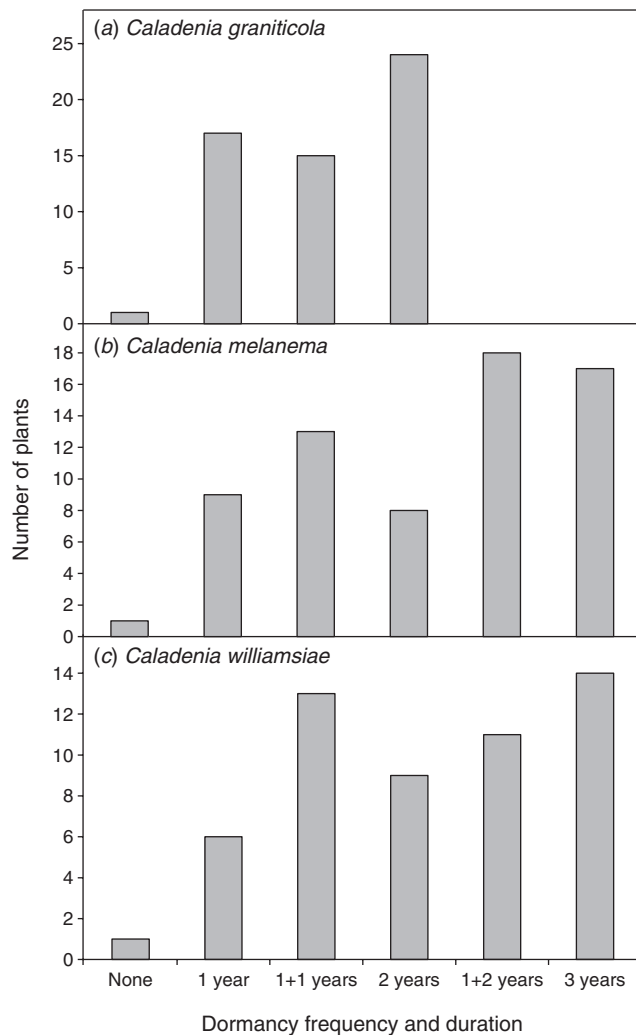


Fig. 11. (a–c) The length and frequency of dormancy for three orchids measured over 3 years (*Caladenia graniticola*) or 4 years (*C. melanema* and *C. williamsiae*).

discovered in 1985 to over 5000 in 2010. This trend and the absence of records before 1985 suggest that this species is of recent hybrid origin. It is part of a large species complex that includes many similar species requiring further taxonomic investigation (Brundrett 2014).

Annual assessments that identify orchids by their locations within a fixed area each year for 4 years were used to accurately measure vital statistics such as emergence, flowering, pollination and grazing rates. These studies revealed annual variations in numbers of plants that emerge from dormant tubers, produce flowers, set seeds or are grazed, so it was much easier to determine the impacts of these factors with 4 years of data. However, longer surveys are required to measure rates of recruitment and estimate the lifespan of individuals (see below). Vital-statistics data gathered from fixed areas were used in combination with overall population-size data from surveys, to provide an overall estimate of orchid population size, based on an estimated emergence rate for the year of the survey. This approach overcame problems with previous

population data for these species that were not based on a consistent area or survey effort and occurred irregularly.

Because only a fraction of dormant orchids emerged each year, long-term monitoring of the same areas was required to allow population-size estimates to be obtained and to investigate the impact of climatic factors such as rainfall on orchid emergence and flowering. For the three *Caladenia* species, emergence frequencies were lower than expected, with many plants emerging only once in the 4-year period. These data revealed that orchids in dry habitats are time travellers that tend to skip multiple years, even in years with relatively wet winters. This makes accurate counting of these rare terrestrial orchids much more difficult. Other studies of terrestrial orchids have found that they can remain dormant for 1–2 years (Shefferson *et al.* 2005), or 1–4 years (Kéry *et al.* 2005); however, occasionally they have been observed to re-emerge after as long as 7–18 years (Light and MacConaill 2005). In these studies, it was observed that orchids that remain dormant for more than 4 years were likely to be dead.

There is a trade-off in terms of duration of demographic studies relative to the accuracy of estimates of population size, because increases or decreases in populations over longer time-frames would become more important than annual fluctuations in emergent orchids. In the present study, it was not possible to confirm that plants flowering at the same location (within 2 cm) were the same individual, because it is possible that several orchids emerged on different years, which is a potential source of underestimation for population size. However, there were also potential sources of overestimation errors in identifying individual orchids by their position, such as position-measuring errors and the fact that growth from tubers is not always vertical (they usually grow upward through the remains of the previous year's plant base). Excavation of these rare species to confirm that assumptions are correct was not permitted. Grazing can also have an impact on numbers of orchids counted, because it may not be possible to separate dormant orchids from those that are eaten (in most cases, leaf bases could still be counted). Another assumption was that newly observed plants were not seedlings; however, this can be ruled out as most were of flowering size. None of these issues is likely to substantially affect numbers of plants counted.

Several different approaches have been used to estimate the size and dynamics of orchid populations where dormancy is common. Kéry *et al.* (2005) recommend multistate capture–recapture models after comparing methods to estimate survival rate. Pfeifer *et al.* (2006) used matrix models to estimate long-term survival probabilities on the basis of rates of transition between life states. Tremblay *et al.* (2009a) used a Bayesian capture–recapture multistate analysis for nine Australian *Caladenia* species to estimate dormancy and survival probabilities. Only *C. graniticola* is included in both Tremblay *et al.* (2009a) and the present study, allowing comparisons to be made. For this species, most of the parameters estimated by modelling approaches are similar to those measured in the present study, except one, which is different (dormancy for *C. graniticola* was several years longer in the present study). It is worth noting that the population of *C. graniticola* where data for the Tremblay *et al.* (2009b) were collected seemed to be relatively viable in the past (their quasi extinction rate for 50% of

Table 2. Vital-statistics report card for four rare Western Australian terrestrial orchids

Statistic	<i>Caladenia graniticola</i>	<i>Caladenia melanema</i>	<i>Caladenia williamsiae</i>	<i>Drakaea isolata</i>	Threshold for action
A. Population size and habitat area					
1a. Overall number counted (maximum)	304	2270	450	297	See 4a
1b. Populations where data was collected (total populations)	3 (of 5)	1 (of 4)	1 (of 1)	1 (of 1)	
2a. Variability in counted data (high/low counts)	10×	3×	4×	5×	See 2c
2b. Annual variability with same methods and area	2.7×	2.9×	3.5×	1.7×	See 4a
2c. Survey issues (effort, detection, area)	Effort, area	Effort, grazing	Effort, detection	Effort	Any issue
3. Population trends	Increasing	Increasing	Steady	Steady	Decreasing
4a. Population-size estimate for measured populations (including dormant plants)	600	5000	1350	300	Decrease greater than normal variability (2b)
4b. Population-size estimate for entire species	750	5500	1350	300	Major decrease
5. Estimated area of critical habitat (km ²)	5	3	1	0.5	Current area
6a. Area of main core habitat (ha)	2	2	2	10	Current area
6b. Proportion of all plants in main core habitat	70%	50%	95%	95%	50%
7. Spatial dispersal of populations (fragmentation)	High	Moderate	n.a.	n.a.	High
8. Spatial aggregation of plants within critical habitat	High	Very high	Moderate	High	High
9. Presence of weeds, disturbance, or other adverse factors in or near plots		Salinity		Salinity	Any factor
10. Vegetation health ^A	Declining	Seriously declining	Healthy	Seriously declining	Declining
B. Vital statistics from annual fixed-area data					
11. Number of orchids in plot (range over 4 years)	20–53	264–757	17–59	20–33	Current number (lower end of range)
12. Proportion of emerging plants that flower	46%	41%	67%	18%	Current number
13. Number of flowers per flowering plant	1.1	1	1.05	1	
14. Proportion of flowers setting seed	6.0%	8.3%	15.2%	85% ^B	10%
15. Recruitment from seed	Not seen	Low	Not seen	Not seen	Low
16. Recruitment from clonal division (over 4 years)	0	400 of 800 ^C	0	9 of 33 ^D	Current number
17. Grazing of leaves, flowers, or seeds	11%	22%	13%	29%	20%
18. Dormancy frequency (no. of events/no. of years)	0.32	0.43	0.36	Low	Current number
19. Dormancy in years, range (average)	1–3 (1.4)	1–3 (1.6)	1–3 (2)	n.a.	Current number
20. Average annual emergence (proportion of estimated total plants)	37%	40%	34%	most	Current %
21. Overcrowding in some parts of core habitat ^E	Moderate	Very high	Low	High	High
22. Impact of rainfall on emergence and flowering ^F	High	Low	Low	Low	High
C. Seed germination and pollination					
23. Seed viability (bioassay or sterile culture)	High	High	High	n.a.	Low
24. Fungal inoculum levels in soils (germination in soil bioassays – proportion of samples)	15%	30%	Trace	n.a.	Requires study
25. Pollinator identity (abundance)	Not seen (likely to be a thynnid wasp)	Thynnid wasp (not confirmed) (rare)	Not seen (likely to be a thynnid wasp)	Not seen (may self-pollinate)	Requires study

^AVegetation-change data from satellite imagery. ^BData from Phillips *et al.* (2014). ^CEstimated from Fig. 5c. ^DEstimated from counting plants in colonies.

^EMost plants within 10% of core area. ^FFrom Fig. 5.

Table 3. How vital-statistics data can be used to sustainably manage rare orchid populations

Factor	Data (Table 2)	Potential management actions if impact exceeds threshold set
Population size	1, 2, 3, 4	Continue monitoring of populations and set threshold for actions Overcome survey problems, owing to detection or effort Monitor outcomes of management actions
Habitat area	5, 6	Locate additional unoccupied apparently suitable habitat(s) within or outside local protected area for translocation
Genetics	4, 7	Undertake taxonomic or genetic studies, if deemed necessary
Spatial factors	7, 8, 20	Translocate propagated seedlings or move plants to reduce localised overcrowding Address habitat fragmentation, if possible
Habitat viability	9, 10	Manage habitats to control weeds, exclude grazers, reduce human disturbance Manage major impacts to landscapes such as fire and other disturbances, if possible Address declining vegetation health by restoration, if possible
Threats to orchids	9, 17	Continue monitoring and set thresholds for actions Reduce grazing by fencing, or cages Manage localised human impacts such as trampling and harvesting
Flowering and seed production	12, 13, 14, 24	Protect flowers from grazing Undertake supplemental cross-pollination
Seed viability and germination	22, 23	Test seed viability and fungal inoculum potential in soils Artificial propagation of seedlings
Recruitment	11, 15, 16	Artificial seed dispersal Translocation of plants
Climate	18, 19, 22	Investigate impacts of rainfall or other climatic factors on emergence, flowering, reproduction and mortality

populations was 24 years); however, no plants have been seen in the plot where these data were obtained for a decade (they are still growing nearby). This highlights a problem with estimates of long-term population viability produced by models, because they must assume that habitat conditions are relatively constant or change gradually and predictably. However, this is often not the case for many of the WA rare orchids because impacts such as fire, rising saline groundwater, the severity and frequency of drought, grazing pressure, or weed invasion have the capacity to rapidly change habitat conditions and often become more severe over time.

Numbers of flowering, vegetative, seedling and dormant plants need to be accurately measured to determine orchid lifespans and dormancy; however, some of these cannot be directly measured (germination and dormancy are subterranean). In the case of the rare WA orchids studied here, it was easy to measure numbers of emergent, flowering and seeding plants, but seedlings were rarely observed. It will not be possible to use these data to model the probability of long-term persistence of these populations without more data on seedling establishment. The low rates of seed production noted here would be expected to cause low recruitment. However, very good seed germination was observed for two of these species when seed and organic matter were combined in a controlled environment off site, showing that both seed and mycorrhizal fungi within natural habitats were viable (Brundrett 2011).

Seed germination in these habitats seems to either be very rare or, else, is more dependent on soil moisture than are emergence and flowering. It may be necessary to have two consecutive years with sufficient rainfall, the first to support flowering and seed set, coinciding with conditions suitable for pollinator activity, and the second to support fungal activity and seed germination. Thus, we should expect that the productivity of some orchids may be lower in the future because of expected

climatic trends, because rainfall is expected to decline and become less consistent in the WA wheatbelt (<http://www.environment.gov.au/climate-change/climate-science/impacts/wa>, accessed 2015). Fortunately, these orchids are time travelers that often remain dormant for multiple years, so should persist as long as there are some years when rainfall is sufficient. If seed germination is less than plant mortality, it is reasonable to assume that populations will eventually become extinct. This contrasts with observations summarised in Table 2 that show that the populations studied here seem to be stable or increasing over several decades of observations. In the case of *C. melanema*, this primarily results from the multiplication of tubers and *D. isolata* also spreads clonally. The other species probably had occasional years when reproduction was sufficient to maintain or expand populations of these long-lived individuals. The present 4-year study was sufficient to estimate population sizes; however, longer-term studies are required to measure recruitment from seeds or mortality, because these were infrequent.

The capacity of rare orchids in WA to spread to new habitats is expected to be very low owing to infrequent pollination, grazing impacts on seeds and the highly cleared and extremely fragmented landscapes where they grow (Brundrett 2014). Consequently, they require intervention in the form of supplemental pollination, watering to promote seed germination, protection from grazing and translocation of plants or seeds to new locations to reduce the risk of extinction. This risk is especially high for *C. melanema* and *D. isolata* because of rising saline groundwater, whereas the habitats where *C. graniticola* and *C. williamsiae* grow may be highly vulnerable to fire. Thus, evidence that populations were stable in the past does not guarantee future survival if habitat conditions deteriorate or change suddenly. In the case of *C. graniticola* tree-canopy decline, possible linked to drought or an extended time since the last fire, has resulted in increased light levels in the

understorey and a substantial increase in the numbers of plants observed recently (Brundrett 2011). In the longer term, declining canopy vigour could also be detrimental to orchids because of increased competition from other native plants and weeds in the understorey. Research on impacts of climate change and the duration of intervals between fires on rare orchids in WA is required.

For *C. williamsiae*, low seed set and small population size, coupled with a small area of occupation (2 ha), were major threats to the long-term survival of this unique orchid that has no close relatives. The long-term viability of all the rare orchids studied here is threatened by altered rainfall patterns in the wheatbelt of WA linked to climate change, because this area is already on the margin of the orchid diversity hotspot in the South-west Floristic Region of WA (Brundrett 2014). Changes in rainfall patterns may also affect orchids indirectly, if canopy decline opens up the habitat and results in increased competition with other species. The available evidence suggests that *C. graniticola* is more susceptible to drought than are the other species examined and this species occurs in a lower-rainfall area. These impacts should be evaluated by long-term monitoring of transects established in the present study.

Additional research is required to develop an understanding of habitat specificity and why the majority of apparently suitable habitat is unoccupied for most orchids. The role of mycorrhizal fungi in determining habitat preferences should also be investigated further. This requires seed-baiting experiments, where seed germination is used to detect suitable fungi in soil, and compatibility testing of mycorrhizal fungi to determine whether they also associate with co-occurring orchids that are more common (Brundrett *et al.* 2003; Bonnardeaux *et al.* 2007). For the orchids studied here, seed-baiting trials confirmed that: (1) seed of these orchids was highly viable; (2) compatible fungi were more widespread than their orchids in most suitable habitats; and (3) sites likely to be suitable for translocation of these orchids could be identified (Brundrett 2011).

Conclusions and recommendations

Table 2 provides an example of a report card for gathering and interpreting vital statistics using orchids from the present study. This report card identified the main threats to these rare-orchid populations as grazing, low seed set and inconsistent recruitment. These statistics were also used to set thresholds for management actions for each species (Table 2). In most cases, thresholds were set at levels close to those measured during the present study, because these species are already designated as *Critically Endangered* owing to low populations sizes and small areas of occupation following IUCN Criteria (IUCN 2012). Management actions that are available to reverse a gradual population decline include supplemental pollination, grazing control, weed management and habitat restoration. However, vital-statistics measurements may not detect impacts of catastrophic events such as fire or rising saline groundwater in time to prevent the loss of populations or subpopulations. Many of the vital statistics are rainfall dependant, so can also be used to monitor impacts of climate on orchid populations (i.e. Factors 11–22 in Table 2).

Making conservation plans for rare orchids is complicated by the fact that some of the key data from Table 2 are often missing. Further research is required to determine whether we can use surrogate data from other closely related species growing in similar habitats. Table 3 demonstrates how vital-statistics data can be combined to identify key threats to the viability of orchid species and provides examples of management actions that could address these threats. For example, the identification of grazing as a threat during the present study resulted in fences being erected to protect core habitat areas for *C. melanema* and substantially increasing seed set in subsequent years. Further information about conservation actions for these species are provided in reports (Brundrett 2011) and summarised in the Australian Species Profile and Threats Database (www.environment.gov.au/sprat, accessed 2015). Propagation and translocation trials for these orchids will be described in a subsequent publication.

I determined that vital statistics data were relatively easy to obtain from fixed area transects within the time constraints caused by travel to remote locations (2–4 h per site) and should be feasible despite the limited resources available for monitoring rare flora in WA. Population-size estimates required 3 or 4 years of data to compensate for annual variations in emergence and 1–3-year dormancy periods. Long-term measurements of fixed plots are the best approach to obtain population-size and -viability data for orchids. Pfeifer *et al.* (2006) found that 4 years of data are usually adequate for modelling population size for terrestrial orchids, whereas longer periods of observation are better for studying population dynamics. Unfortunately, there are no annually repeated measurements of fixed plots for most of the rare orchids in WA and the existing population-size census data for these species is of limited use for assessing plant population size because of infrequent surveys, variations in sampling intensity and detectability problems (West Australian Auditor General 2009; Brundrett 2011). It is recommended that monitoring protocols that allow population size and viability to be better estimated be adopted in the future. Volunteers from community groups are increasingly becoming major contributors to rare flora surveys in WA (Brundrett 2011; Adopt and Orchid Project, available at www.dpaw.wa.gov.au, accessed 2015) and would have the capacity and skills (with some additional training) to undertake annual fixed-area surveys for rare orchids. Planning for new monitoring programs of this type is currently underway.

Vital-statistics data are essential decision-making tools for orchid conservation in WA, because they allow changes to population size and viability to be detected before populations are lost and can be used to allocate conservation resources to the most threatened orchids. These data can be gathered from a relatively small fixed area, so are an efficient means of determining the most important threats to orchid populations without having an impact on them. It is recommended that these data are summarised in a report-card format, with thresholds set for management actions for key criteria such as population size and reproduction. Mapping of core habitat areas was also found to be a vital tool for conservation planning for rare species and management of the areas where they occur. Vital-statistics report cards with thresholds set for conservation actions should

also be valuable tools for the management of rare terrestrial orchids in other biomes.

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