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Biology, distribution and conservation of green carpenter bee (*Xylocopa aeratus*: Apidae) on Kangaroo Island, South Australia: Technical report

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Biology, distribution and conservation of Green carpenter bee
(*Xylocopa aeratus*: Apidae) on Kangaroo Island, South Australia

TECHNICAL REPORT



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Cover photograph: Female (upper) and male (lower) adults of the Green carpenter bee, *Xylocopa aeratus* (Smith, 1851)

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CONTENTS

LIST OF FIGURES AND TABLES.....	IV
ABBREVIATIONS.....	V
EXECUTIVE SUMMARY.....	1
ABSTRACT	2
INTRODUCTION.....	3
SUMMARY OF GCB BIOLOGY	4
ANNUAL LIFE-CYCLE.....	4
NESTING SUBSTRATES	7
<i>Host plants</i>	7
<i>Relationship of nest substrates to fire</i>	9
Simplified theoretical model of substrate condition/use post-fire.....	12
VIBRATORY OR “BUZZ” POLLINATION	12
GCB DISTRIBUTION.....	13
HISTORICAL RECORDS (PRIOR TO 2000).....	13
2003 SURVEY.....	16
2013 SURVEY.....	16
<i>Survey Method</i>	17
<i>2013 Survey Outcome</i>	19
Current range.....	19
Post-2007 fire changes.....	20
<i>Banksia</i> habitat	20
<i>Xanthorrhoea</i> habitat.....	20
Stable populations.....	21
HABITAT MAPPING AND FIRE MANAGEMENT.....	22
DEVELOPMENT OF A HABITAT MAP.....	22
GCB PRIORITY AREAS.....	22
PRE-BURN SURVEYS (2013).....	23
RECOMMENDATIONS FOR FIRE AND LAND MANAGERS	27
Rationale	27
Recommendations.....	28
CONCLUDING REMARKS AND FUTURE RESEARCH.....	29
REFERENCES.....	31

LIST OF FIGURES AND TABLES

Figure 1. <i>Xylocopa aeratus</i> female and male adults	3
Figure 2. Generic annual life-cycle of a GCB population on KI	4
Figure 3. GCB sealed brood chamber showing the larval provision and egg	6
Figure 4. Sectioned <i>Banksia marginata</i> trunk showing GCB nest tunnels	6
Figure 5. Nest entrances in <i>Banksia</i> and <i>Xanthorrhoea</i> substrates, white rot on <i>Banksia</i> , and GCB female in defensive pose in nest entrance	8
Figure 6. Theoretical models of substrate availability after a fire at a given site, and effect of small mosaic burns	10
Figure 7. Association of the three best known GCB aggregates with <i>Banksia</i> substrate in long unburnt remnant vegetation	11
Figure 8. Historical records (prior to 2000) of GCB occurrence on KI	14
Figure 9. Summary of GCB records by substrate for the 2003 survey combined with historical (pre-2000) records	15
Table 1: Summary of GCB surveys undertaken during 2013	18
Figure 10. Evidence of GCB nest activity	19
Figure 11. Habitat Map: current GCB habitat and distribution (by substrate) at at end of 2013	24-25
Table 2. Summary of pre-burn surveys conducted in 2013	25-26

Abbreviations

BBZ; bushfire buffer zone

CP; Conservation Park

DEH; South Australian Department of Environment & Heritage

DEWNR; South Australian Department of Environment, Water & Natural Resources

EPBC [Act]; *Environmental Protection and Biodiversity Conservation Act, 1999*

FCNP; Flinders Chase National Park

GCB; green carpenter bee, *Xylocopa aeratus* (Smith, 1851)

ha; hectare(s)

KHCP; Kelly Hill Conservation Park

KI; Kangaroo Island

KIDBPC; Kangaroo Island District Bushfire Prevention Committee

NP; National Park

NSW; state of New South Wales

RCWPA; Ravine des Casoars Wilderness Protection Area

Rd; road

SA; state of South Australia

Tk; track

WPA; Wilderness Protection Area

Executive Summary

This report presents the results of a survey of the remnant population of the endangered native green carpenter bee, *Xylocopa aeratus*, on Kangaroo Island. This large, iconic species is now extinct in Victoria and mainland South Australia. An earlier survey on KI (2003) found that the species had contracted westward on the island.

The species depends for its survival on two types of nesting substrate: large (> 15 year old), dead *Banksia* trunks that have been softened by white rot, and dead flowering stalks of grass trees that provide patchy nesting substrate for 2-6 years after fire.

The present survey signals that the contraction of the population, noted in 2003, has continued. Viable populations are now only known from the southern part of Flinders Chase NP and in Kelly Hill CP. While some nests have been found in suitable fragmented habitat along the North coast, it needs to be verified whether these, now isolated remnants are of sufficient size to support viable populations. The contraction of the species is intricately linked to the fire history and land clearing, both of which influence the availability of nesting substrate.

The data from the surveys indicate that carpenter bees can become extinct locally through:

- **complete burns of isolated patches**, which, due to their isolation, cannot be recolonised;
- **frequent burns**, which do not allow time (at least 20 years) for regrowth and death of *Banksia*;
- **burns of large areas of continuous vegetation**, which not only removes *Banksia* but also synchronises the availability of both grass tree flower stalks and *Banksia* on different time scales

The highest densities of dead, suitable *Banksia* trunks were found in areas that had been left unburnt for long periods of time (> 60 years). The fire that burnt most of Flinders Chase NP in 2007, did not only remove substantial amounts of *Banksia* nesting substrate, it also synchronised flowering of many grass trees over a large area. Now, 7 years after the fire, this otherwise patchy material is becoming rare, while *Banksia* trunks are largely unavailable in the burnt regions.

As a result, this report identifies priority areas for the green carpenter bee and provides numerous recommendations to fire and land managers, including:

- refraining from prescribed burns in areas that currently support the green carpenter bee;
- no, or very infrequent (>20 years), localised burning in priority areas with suitable *Banksia* but no carpenter bees;
- winter relocation of active nests from areas that are targeted for prescribed burning despite the presence of carpenter bees;
- obtaining funding to further explore how best to protect and enhance the current population, including assessment of genetic isolation of the KI population

Abstract

Kangaroo Island (KI) supports the last remaining population of the iconic Green carpenter bee (GCB; *Xylocopa aeratus*) in south-east Australia. GCB is generally a solitary species that is facultatively primitively social, and has very specialised nesting habits. GCB will only construct nests in pithy wood, almost exclusively in dead *Banksia* trunks/branches with "white-rot" or dead *Xanthorrhoea* flower spikes. The population dynamics of these substrates is closely related to fire and each appears to fulfill different and vital ecological niches for GCB. While *Banksia* habitat can take many years to become useable, it appears to provide a long-term refuge for GCB, and can provide substrate if killed (but not structurally damaged) by fire. By contrast, *Xanthorrhoea* appears to provide substrate for short term utilisation by nearby source populations, only ~3-6 years after fire.

Formerly occurring in suitable areas from KI to northern NSW (including around Sydney), GCB is extinct from mainland SA (last recorded 1896) and Victoria (last recorded 1938). In 2003, a survey was conducted to determine the range of GCB on KI and found that compared to historic records, GCB had contracted westward and was now mainly confined to the large areas of remnant vegetation in the west of KI. In 2007, large fires scorched much of the known habitat of GCB, primarily the Flinders Chase NP and Ravine des Casoars WPA. This raised new concerns about the integrity of the GCB population on KI, and the loss of the specialised vibratory pollination services it provides to the endemic vegetation. Increased use of prescribed burning for fuel reduction within the island's conservation estate, an outcome of the 2007 KI fires (DEH 2009, KIDBPC 2009), added to the concern for the species. Therefore, funding was obtained in late 2012 to re-survey western KI to identify extant GCB populations. Surveys were conducted over nine days and included entomologists, DEWNR staff and community volunteers. Additional *ad hoc* surveys were conducted by specialists, as were pre-burn surveys of seven areas intended for prescribed burning. These surveys showed that GCB had utilised *Xanthorrhoea* substrate from mass flowering after the 2007 fires, however numbers of spikes have now markedly reduced and GCB will likely be lost from much of the central/northern areas of the WPA because old (>15 year) *Banksia* are now rare. GCB was also apparently absent in the Gosselands; *Banksia* is a dominant plant in that area but the young age of the vegetation means that dead plants of sufficient size are uncommon. Several areas of old growth remnant vegetation contained apparently stable GCB populations, most notably north-west Kelly Hill CP and the south-east boundary of Flinders Chase NP (Sanderson Tk). Other sites with *Banksia* nests were located at Yacca Flat, the south end of Shackle Rd, and near Cape Torrens WPA. GCB has recently been recognised as Endangered at a regional level (due to a definite declining trend), the first invertebrate to be considered this way in SA.

All known GCB records were overlaid on time-filtered floristic layers representing useable *Xanthorrhoea* (~2-6 years post-fire) and *Banksia* (>15 years post fire) habitat across KI. These data were used to identify priority habitat where GCB occurs, and priority habitat for future recolonisation. This information was combined to produce a GCB habitat map for use by fire and land managers, and accompanying recommendations regarding the protection of the remaining GCB populations are provided herein. It should be noted that the priority areas require some refinement based on improved knowledge of GCB fire ecology. In order to develop meaningful conservation plans for GCB we need to better understand some key aspects of its biology. These include the genetic relationships between island sites and in comparison with NSW sites, the mechanisms and dynamics of post-fire recolonisation, foraging and substrate preferences, and the role of pathogens/parasites. With regard to substrate plants we seek to understand the complexities of their relationships with fire, factors governing *Xanthorrhoea* flowering, mechanisms and temporal variation of non fire-related *Banksia* deaths, and variables governing substrate suitability and GCB substrate choice. Other research could include adaptation of GCB to alternative (artificial) nesting substrates, translocation or reintroduction experiments, and use of fire or other stimuli to promote targeted *Xanthorrhoea* flowering.

Introduction

The Green carpenter bee (GCB), *Xylocopa (Lestis) aeratus* Smith, is an endemic Australian species belonging to the hymenopteran family Apidae. It is an iconic species being the largest bee in southern Australia (up to 2cm) and having a brilliant blue-green metallic integument (Figure 1). Despite these features, it is not often observed and collection records are very limited. Kangaroo Island (KI) is now the last refuge for GCB in southern Australia although even there, there has been a westward contraction of its range, which was highlighted by a survey in 2003 (McIlwee and Leijs 2003). In December 2007, much of the Flinders Chase National Park (FCNP) and adjoining Ravine des Casoars Wilderness Protection Area (RCWPA), which supported most of the known GCB population on KI, was burnt in a large and intense fire. This led to renewed concern for the species on KI with the post-fire situation uncertain. Furthermore, fallout from the 2007 fires led to the development of a new fire management plan characterised by significantly increased use of prescribed burning of state-owned high-value conservation regions that potentially support GCB (DEH 2009). In 2013 funding was obtained from the Foundation for National Parks and Wildlife, to conduct a new GCB survey on KI, and to assess the current state of its habitat with respect to nesting substrate. This report provides a brief summary of the biology of GCB, and details the latest known range of GCB subsequent to the 2013-2014 survey. Additionally, it provides information and recommendations for fire and land managers to facilitate conservation of GCB on KI.



Figure 1. *Xylocopa aeratus* female (upper) and male (lower) adults. Males are easily distinguished by the yellow hairs on the legs, thorax and head, and the yellow facial markings. For a formal description see Leys 2000b.

Summary of GCB biology

Annual life-cycle

The life-cycle of GCB on KI (and at Woy Woy in NSW) has been studied as part of a PhD project and this information was published in 2000 (Steen and Schwarz 2000). Figure 2 is a generic illustration of the timing of various life-cycle stages for a GCB population on KI, based on those data and observations made during the recent project.

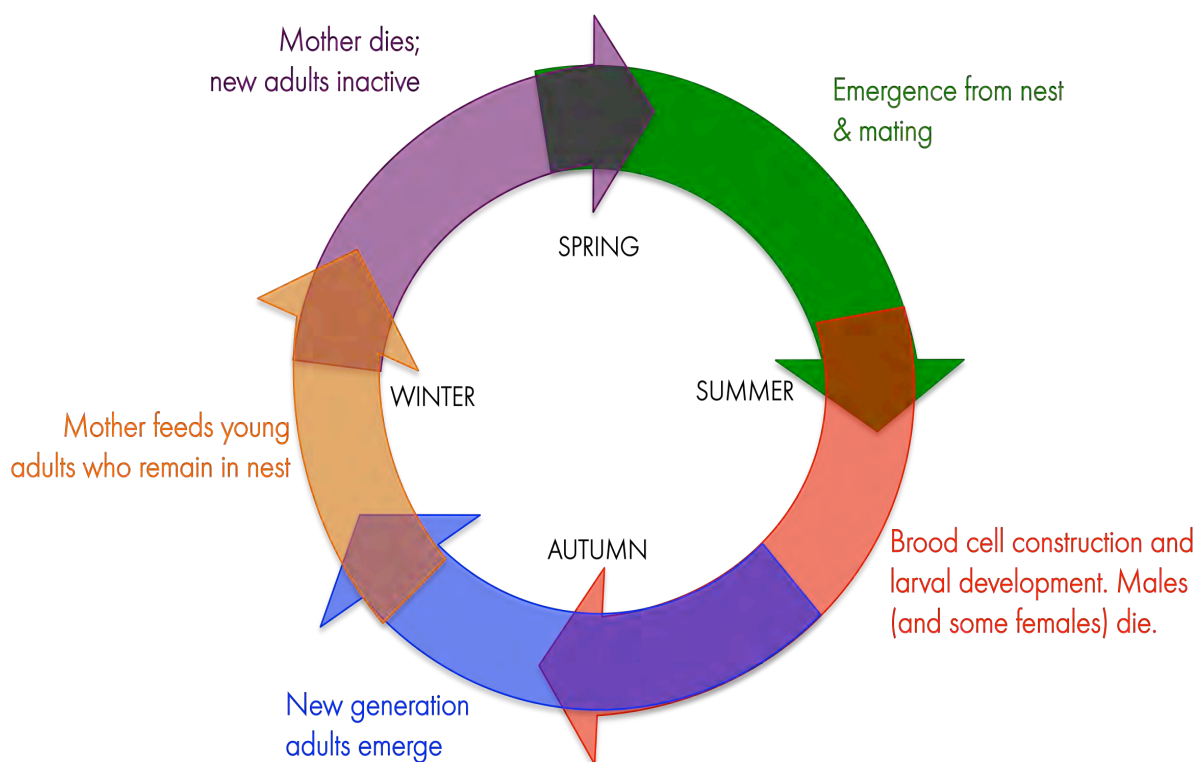


Figure 2. Generic annual life-cycle of a GCB population on KI, partly adapted from Steen and Schwarz (2000). Seasons are shown inside the cycle and corresponding behaviours are shown outside. In late winter/early spring, young adults (which have been inactive over winter) emerge from their nests and begin mating behaviour. Towards the end of spring, males die and successful individual females begin constructing brood chambers, provisioning each with a pollen/nectar mass, and laying one egg per chamber before sealing each chamber with wood shavings and oral secretions. Eggs hatch about a week later and the larva begins to feed on its provision before pupating and then emerging from the cell as an adult in late summer. The new adults remain in their nest and the mother then forages for nectar and pollen to feed the young adults. When conditions become cold, the nest becomes inactive and the mother dies. The cycle then repeats once conditions warm again. Note that the timing of these events may vary between individuals and sites, and there is overlap between the various stages at the population level.

As soon as conditions are warm enough in spring (typically late October-early November on KI), young adult bees emerge from their nests in which they have been almost inactive over the winter months (Figure 2). Mating behaviour soon follows and is characterised by males patrolling the entrances of nests containing females, and defending their territory aggressively against other males in the vicinity (Leys 2000a). GCB mating behaviour appears to be complex and is not yet well understood; mate-locating strategies for GCB are discussed in more detail in Leys (2000a). Males were often observed undertaking tight “circular” flights around nesting substrate, near the entrance. While patrolling nests in this way, males will usually immediately interact aggressively with other males and “chase” females that are either leaving or returning to nests in the vicinity (males were also witnessed briefly interacting with other passing species, presumably to assess them). Often, these females react by undertaking a slow flight low to ground, with characteristic intermittent wing movement causing a “bobbing” motion above the low vegetation. Usually one or more males will follow immediately behind the females as it undertakes such flights. This has been interpreted as a mechanism of female choice in assessing the fitness of potential mates (Leys 2000a). On other occasions, females encountering such males fly at speed above the canopy of surrounding mallee; it is not clear if this behaviour is also a test of male fitness or simply aimed at escape. Females that are not receptive will generally return to their nest quickly without undertaking these flights. Males die sometime around the onset of summer, whether they have mated or not.

Like most Australian bees, GCB is typically a solitary species, with a single female constructing a nest and provisioning the larvae and resultant young adults. This leads to strong competition between females and mated females compete aggressively for nests; during spring sisters were often seen attempting to exclude each other from their nest to obtain it for themselves. If two females begin to construct nests in the same substrate (using the same entrance) then the stronger will usually destroy the brood cells of the competitor.

GCB is also known to be facultatively and primitively social, where a sexually mature female will forego making a nest and help a “dominant” female to raise her colony although this has not been observed in the KI population (Steen and Schwarz 2000). This makes GCB an interesting species with regard to the various potential stages involved in evolution of the highly eusocial behaviour seen in species such as *Apis mellifera* (European honeybee) and native stingless bees occurring only in northern and eastern Australia (the only Australian example of eusocial bees). Our observation of nests in *B. marginata* at Kelly Hill Conservation Park (KHCP) in August 2013, revealed a nest population of 37 indicating that several independent females may have successfully utilised the same entrance to produce nests (communal behaviour), which has not been reported previously. Another possibility is that young adults had moved into the nest from unsuitable/damaged nests nearby. Regardless, a previous study of 76 *Banksia* nests from FCNP revealed colony sizes well below this number (Steen and Schwarz 2000).

Females begin to sequentially construct brood cells, each of which they provision with a mass of pollen/nectar before laying a single egg on the mass, and sealing the brood cell with wood shavings and oral secretions (Houston 1992) (Figure 3). Female adults may use a single tunnel, or may produce secondary tunnels (Figure 4), in which they continue to construct brood cells until mid summer (Steen and Schwarz 2000). Detailed descriptions of nest architecture are given in Houston (1992). Larvae undergo pupation and the earliest young (sexually immature) adults begin to emerge from mid-summer (Steen and Schwarz 2000). Once emerged, the young adult begins to chew their way out of the brood cells with the mother aiding significantly from outside the cell (pers. obs. 09 February 2014). Young adults rarely leave the nest and between the time of eclosion until activity reduces near winter, the mother makes foraging flights when conditions are favourable (temperatures approx. $\geq 20^{\circ}\text{C}$), to collect food provisions which are fed orally to the young adults. In the cold conditions before and during winter, many of the successful females die; therefore adult females live for a maximum of about 16-18 months.

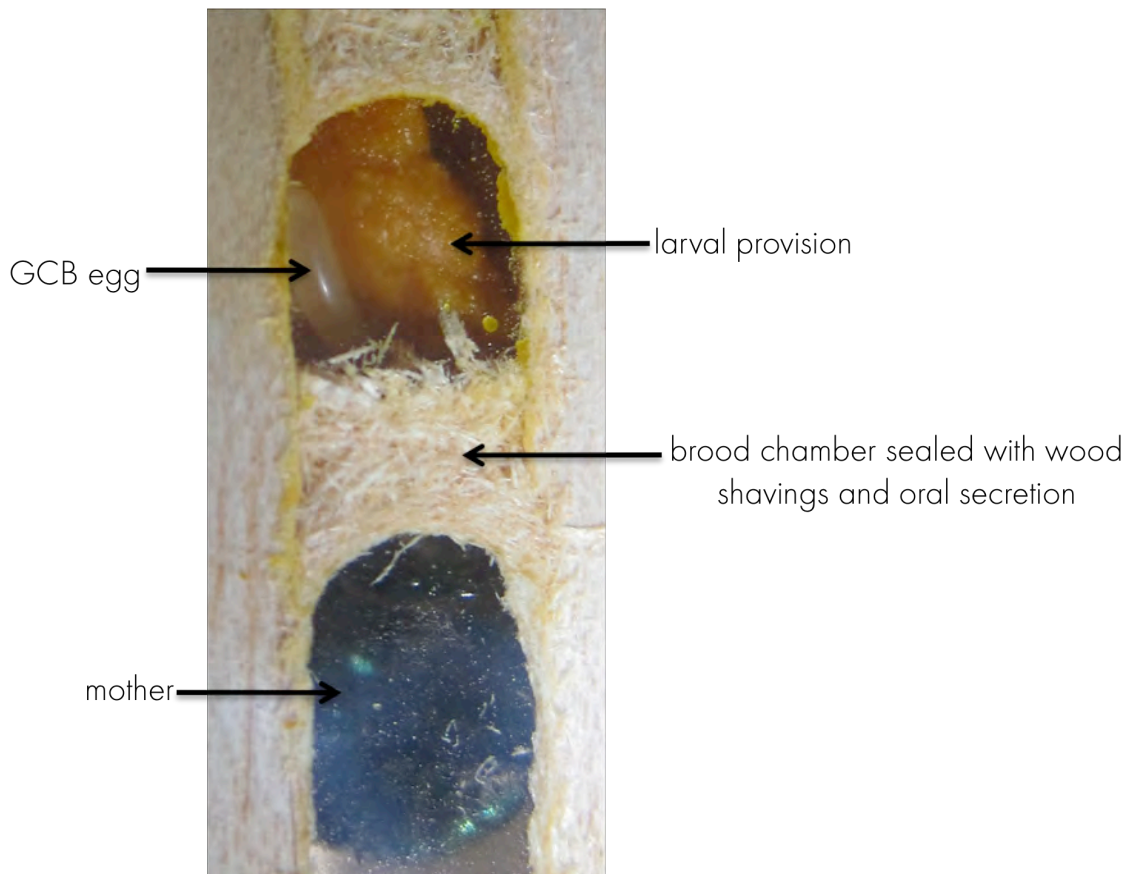


Figure 3. GCB sealed brood chamber in artificial nest on 07 December 2013, showing the larval provision and egg.



Figure 4. Sectioned *Banksia marginata* trunk showing tunnels from several generations, which have used up all of the available space (KHCP, August 2013).

Nesting substrates

Host plants

Carpenter bees are so named because they excavate nests in suitable wood using their mandibles (most bees that live in wood need to find a ready-made hollow/hole). This requires that the wood is of a pithy consistency to allow excavation, but also provide enough strength to protect a nest, and must also be largely "water-tight" (usually through a complete covering of bark). GCB nests have only been found in dead wood. On KI, GCB nests are largely confined to two substrate types; (1) trunks and branches of dead *Banksia* spp. (*B. ornata* and *B. marginata*) that usually display "white-rot" (Figs 5a & b) and (2), dead but intact flower spikes of *Xanthorrhoea semiplana* (Figs 5c & d) (Steen and Schwarz 2000, McIlwee and Leijis 2003). At Woy Woy (NSW) GCB nests are found in different species of *Banksia* and *Xanthorrhoea* and there is an isolated record of a nest found in *Melaleuca* (Steen and Schwarz 2000). Regardless of the substrate, the nest entrances are similar being close to circular, ~1 cm in diameter, and counter-sunk indicating excavation from outside the substrate (Fig 5d) in contrast to the many smaller holes common in wood, and the numerous holes of emergent wood-borers which have a flat surface.

On KI, it is clear that *B. marginata* is utilised far more often than *B. ornata* (only a few records) and it seems intuitively that this may be a result of plant architecture, in that the node length of *B. marginata* is much longer leading to trunks with less branches and increased clear area with intact bark, once plants have died and dropped most branches. *Banksia ornata* plants tend to be far more complex with many small side branches and less area of clear intact bark. As mentioned, suitable *Banksia* substrate is usually characterised by a simple structure (few remaining side branches) and externally visible patches of white-rot (Fig 5a), which is thought to produce the right consistency in the wood, for nest construction (Steen and Schwarz 2000). Also, *Banksia* entrances tend to be situated in a position that is at least slightly overhung (Fig 5b), probably to prevent water entering the nest. The relatively large size of the *Banksia* substrate (up to ~15cm diameter) allows nests to be used for 3-4 years, and *B. marginata* nests examined at KHCP in August 2013, had often been used for several years and sometimes utilised almost all of the available space within the trunks (Fig 4). Large *Banksia* often contained multiple nests, with 3 active nests per trunk being found multiple times in old growth habitat along Sanderson Fire Tk on the eastern margin of southern FCNP.

With regard to *X. semiplana*, observations suggest the utilised spikes are always dead but are generally otherwise sound, usually lacking significant infestation by other invertebrates or other physical damage (Figs 5c & d). Larger spikes (~>5cm diameter) are seemingly not used for nesting, presumably because they lack the physical characteristics sought by the female GCB. Interestingly, these larger spikes rarely display the aborted entrance holes often found in smaller spikes and *Banksia*, indicating that the females can assess the (poor) suitability of the larger spikes without chewing them. Often spikes are utilised which are ~2-3 X entrance diameter (Figs 5c & d) and can only be used for a maximum of two years as only two tunnels can be constructed. Some flower spikes containing 2 nests were observed although single nests were far more common in this substrate. In the latter stages of the project (April 2014), a member of a DEWNR fire crew constructing fire-breaks near Western River WPA, collected a small dead *Eucalyptus* branch (thought to be *E. cosmophylla*), which had a GCB nest entrance and tunnel. This is apparently the first record of GCB nesting in pithy, decaying *Eucalyptus* wood. Together with the single *Melaleuca* record at Woy Woy (Steen and Schwarz 2000) and old records from mainland Australia in *Leptospermum* and *Allocasuarina* (Houston 1992), this suggests that the bees can in rare cases opportunistically utilise many plant species where the wood is of sufficient diameter, suitable consistency and sufficiently protected from the elements. However, the occurrence of nests occurring in substrates other than *Banksia/Xanthorrhoea* appears to be rare and such niches are unlikely to play a significant role in maintaining GCB populations.

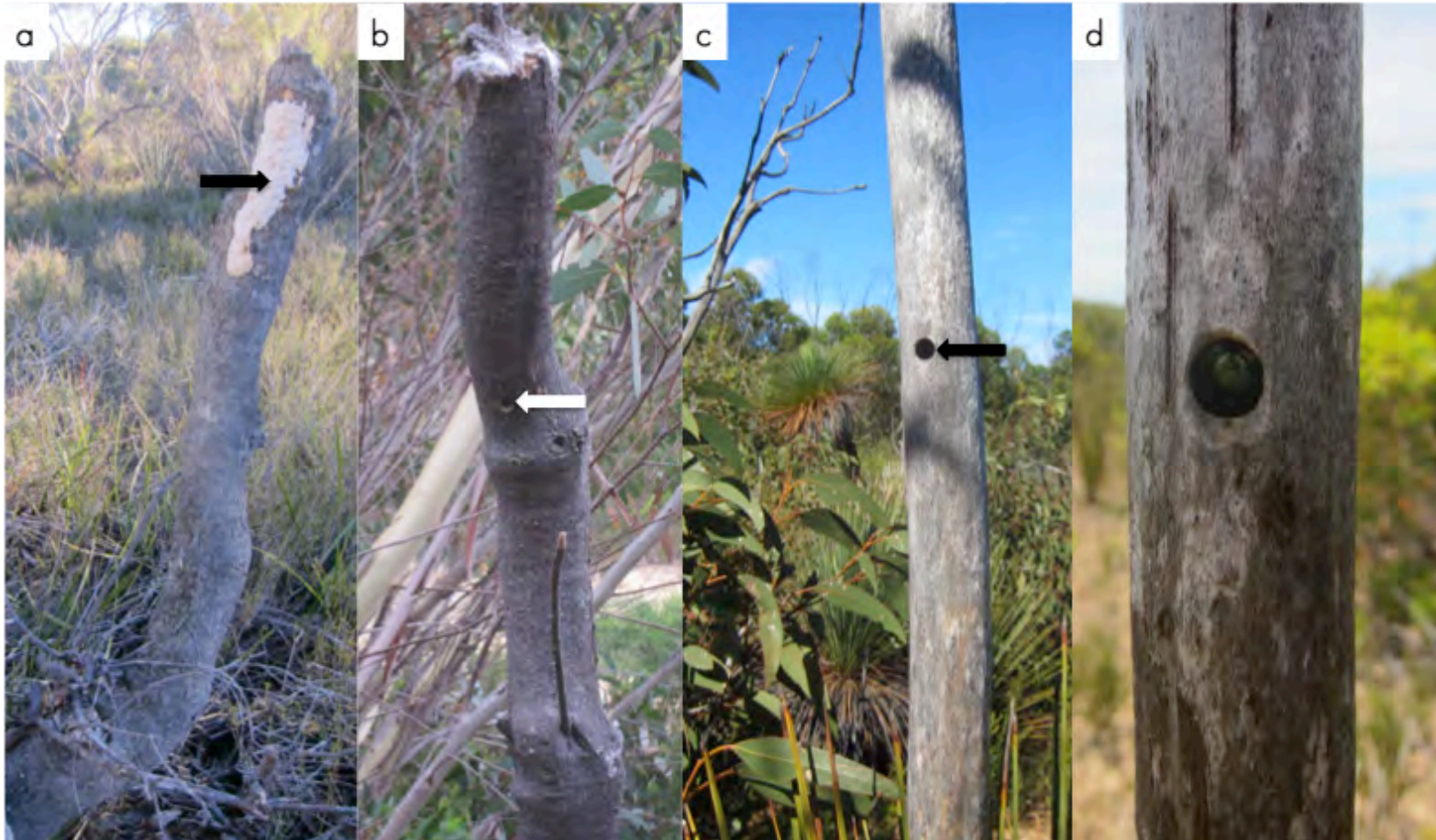


Figure 5. a: typical *Banksia marginata* substrate (non-utilised) illustrating the visible area of white-rot (arrow) which is thought to aid in producing the correct substrate consistency for GCB nesting (Lot 23 Three Chain Road, Haines); b: GCB nest entrance (arrow) in *B. marginata* substrate displaying characteristic simple structure and significant clear area of intact bark (near South Coast Rd entrance to FCNP); c: GCB nest entrance (arrow) in dead, but typically undamaged, flower spike of *Xanthorrhoea semiplana* (off West Bay Rd, FCNP); (d) typical nest entrance (~1cm diameter circle, counter-sunk) in dead flower spike of *X. semiplana* with GCB female blocking the entrance with her abdomen in a defensive pose (same location as c, 10 January 2013).

Relationship of nest substrates to fire

The relationship of the nest substrate species to environmental variables such as fire, and particularly the effect on substrate suitability, is complex and not well understood. Indeed, the response of much of the Australian biota to fire variables is poorly characterised; this is particularly so for invertebrates, microorganisms, fungi and the way in which these organisms interact with plants to drive ecosystem function and population dynamics. However, the dynamics of these relationships are one of the most important areas in terms of developing GCB conservation strategies. Along with fragmented/lost habitat (and perhaps other pressures such as disease), fire-related variables may hold the explanation as to the apparent loss of the species from large areas of mainland south-eastern Australia (see GCB Distribution).

It is clear that fire is required to generate significant *Xanthorrhoea* flowering and to renew *Banksia* populations (or provide dead *Banksia* as substrate). However, fire could also be detrimental for GCB which is reduced to a remnant population in a fragmented landscape; this is because living individuals and their nests are lost, and areas which have produced mature *Banksia* are set back possibly many years in their habitability.

Xanthorrhoea substrate can be relatively quickly generated by fire as it usually triggers flowering en masse, producing large numbers of dead flower spikes ~2-3 years after the fire. This is not always the case however, and during the survey a previous prescribed burn was visited where flowering had not been induced. The flower spikes are also subsequently produced sporadically, however, this seems to occur in much lower numbers and the drivers are not well understood (but may include high rainfall). The dead flower spikes are only suitable for a period of ~2-3 years before they degrade, fall over and become unusable. The small diameter of the *Xanthorrhoea* spikes also means that they can be used for a maximum of two years (one tunnel in each direction from the entrance). Therefore, this substrate type may occur in large numbers but is essentially lost ~6 years post burn. Sporadic *Xanthorrhoea* flowering occurs in most seasons, however, this occurs in relatively low numbers and the mechanisms are not well understood. The short-term nature of the *Xanthorrhoea* substrate means that sufficient habitat supporting good numbers of suitable dead *Banksia* are likely crucial to maintaining stable, medium-long term GCB populations. However, such habitats require long periods without disturbance to allow the *Banksia* to attain sufficient size to support nests (~10-15 years) and then to die in sufficient numbers (and be infected with white-rot) to maintain a population.

As mentioned there is little data regarding the density of useable, or potentially useable, *Banksia* substrate and its relationship to fire (and other environmental factors). McIlwee & Leijts (2003) correlated the presence of useable *Banksia* with time since last fire and suggested that *Xanthorrhoea* substrate was available for ~6-7 years after fire, fire-killed *Banksia* were important to ~16 years post-burn, and *Banksia* dying from other causes were important from 26 years to their maximum recorded value of 49 years post-burn (which can now be extended by the more recent observations below). Also, GCB nests were associated more with large patches of vegetation, and were found more in mallee compared to tall woodland. They suggested that there is a period of between approx. 16-26 years where the density of useable *Banksia* substrate becomes too low to sustain populations; thus they proposed that small scale mosaic burns may help to produce enough heterogeneity to increase the total area and time, of available substrate (see Figure 6 below from McIlwee & Leijts 2003). Note that this assumes that after a fire there is sufficient suitable dead *Banksia* produced. In fact, observations made during the recent survey suggest that this is relatively rare; most of the areas burnt in 2007 in FCNP contained only seedlings as adult plants had been completely destroyed. In other areas (near South Coast Rd entrance and N end of Ravine des Casoars Rd) there were large standing burnt *Banksia* which did not contain bees seven years post fire. All of the factors discussed, illustrate the potential complexity of the dynamics of GCB substrate availability and the effect/importance of different environmental variables. Furthermore, there is a poor understanding of the process of colonisation of recently burnt areas using

Xanthorrhoea nests, from areas where bees occur, particularly in *Banksia* habitat. All of these issues are likely to be important in developing conservation measures.

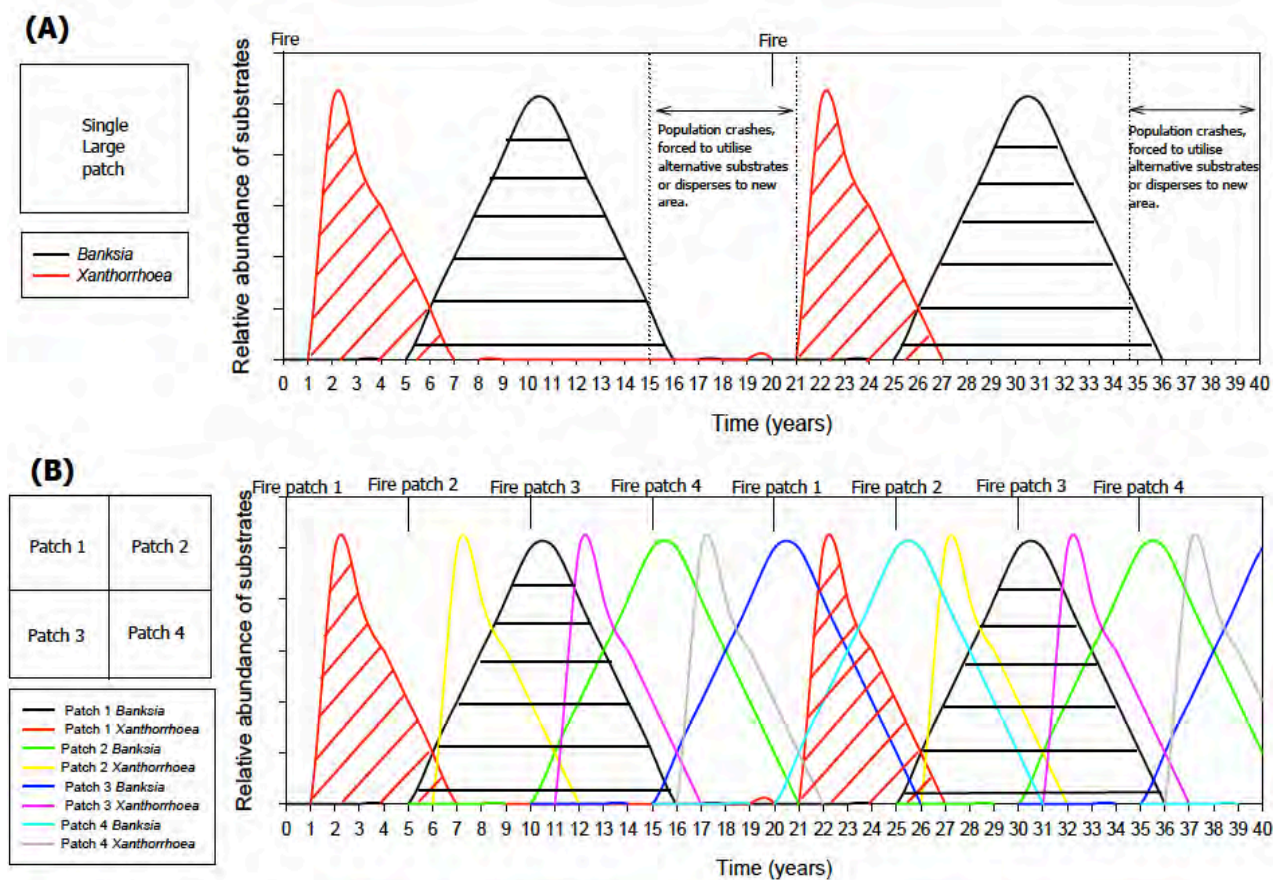


Figure 6. (A): theoretical model of substrate availability after a fire at a given site and (B): theoretical effect of small mosaic burns in increasing overall availability of substrate across a larger environment (from McIlwee & Leijs, 2003). Note that this model assumes that sufficient dead *Banksia* plants are maintained within the burnt area (which was not the case at most sites in the RCWPA after 2007).

Personal observations during the GCB surveys and pre-burn surveys (see later), suggest that the timing (since fire) of the death of sufficient *Banksia* plants by means other than fire, appears to be highly variable and can probably extend to around 100 years. For example, one of the best current GCB sites (northern end of Grassdale Rd at KHCP) has many dead and living *B. marginata* and has no record of fire (the immediate vicinity is 60-83 years post-burn) (DEWNR 2015) (Fig 7). Another good (possibly connected) site to the west (along E side Sanderson Fire Tk) is 42-56 years post-burn; the opposite side of the same track (burnt in 2007) had no available substrate (Fig 7). Similarly, at Pardana CP, good *Banksia* substrate existed on land burnt in 1975, however in this case GCB was not found (Table 1). The apparent absence from Pardana CP could possibly be due to its isolation combined with almost "complete" burn events as occurred in 1956 and 1975 (DEWNR 2015). The central bushfire buffer zone (BBZ) at Seal Bay CP contained vegetation 36-53 years post-burn but most *Banksia* plants were still living (and common in patches) and suitable dead *Banksia* were rare. All of these observations taken together, suggest that a significant time post-fire (≥ 40 years) is required to produce ideal long-term habitat in *Banksia* substrate and these areas are probably crucial for long term populations to be maintained.

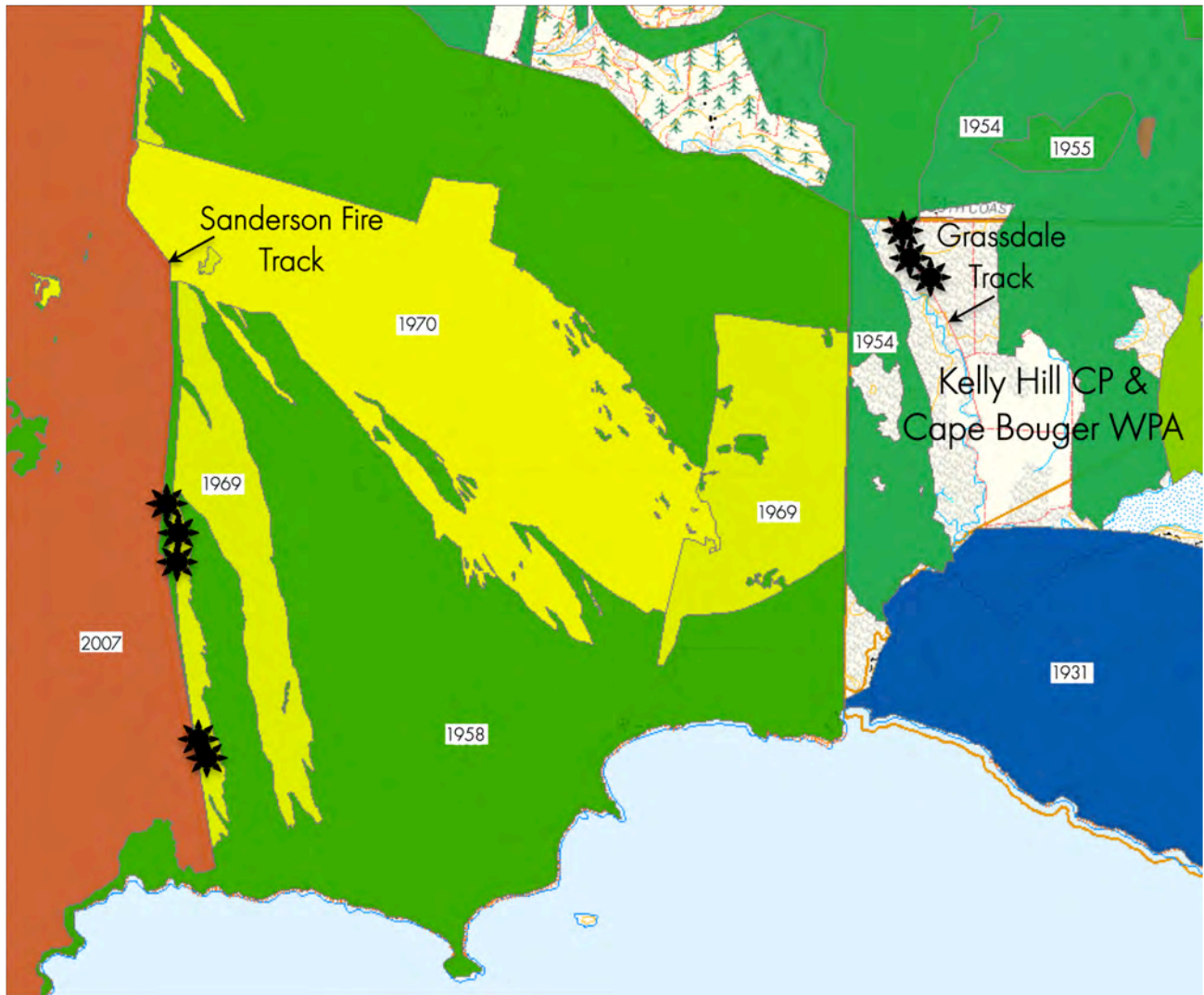


Figure 7. Association of the three best known GCB aggregates (stars) with *Banksia* substrate in long unburnt remnant vegetation at the northern end of Grassdale Rd and along Sanderson Tk. The year of last fire is shown and different years correspond to different colours. It is unknown if these aggregations are part of one larger continuous population. Fire year map downloaded from DEWNR Fire Management Map website (DEWNR, 2014) and modified.

These observations indicate that *Banksia* substrate can take many years to become useable but appears to sustain long-term populations, while *Xanthorrhoea* flowering is likely to be crucial in providing patchy short-term substrate in recently burnt areas; unfortunately there are currently only very small areas that contain sufficient numbers of *Xanthorrhoea* substrate (see recent habitat map in Fig 11). Previous reports (e.g. Leys, 2000b) and the model discussed above, have suggested that the death of *Banksia* in fires is important for GCB, however as alluded to, in the recent surveys, observations of GCB nesting in fire-killed *Banksia* were rare; most nests were located in habitats where the *Banksia* appeared to die from old age or pathogens (e.g. honey fungus). In such scenarios, the time of low substrate availability (between loss of *Xanthorrhoea* and onset of suitable dead *Banksia*) could in fact be several decades. This suggests that fragmentation is a serious issue as it may reduce recolonisation potential for such areas subsequent to this extended period. This would likely be more pronounced in areas that contain *Banksia* but not *Xanthorrhoea*, as fires do not then provide short-term substrate to maintain a population in that area. Such areas could potentially take ~30-50 years to again become useable for GCB. When inspecting *Banksia* in the recent surveys it appeared that *Banksia* killed by radiant heat were likely to become usable substrate compared to those that were directly impacted

by flame, adding a further level of complexity relating to the intensity and coverage of fire events. However, this assertion is based on observations from the 2013 survey and still requires empirical confirmation.

It is important to consider that it is not only substrate that needs to be generated after a fire. There is also a requirement that sufficient GCB need to survive or remain within a distance allowing recolonisation (hence importance of fragmentation). Furthermore, there must be sufficient floral resources to allow recolonisation (this is usually the case).

Simplified theoretical model of substrate condition/use post-fire

- GCB nest in dead wood; the decaying flower spikes of *Xanthorrhoea* and dead *Banksia*
- fire removes all GCB and useable substrate from areas impacted directly by flame or high radiant heat
- GCB need to be able to recolonise fire-impacted areas from source populations at suitable distance and through suitable connecting habitat
- *Xanthorrhoea* provides abundant nesting substrate for only ~2-6 years after fire if they flower in significant numbers
- if *Banksia* of sufficient size for nest construction die and are left standing after a fire, and were not scorched (usually low numbers in intense fires), they may become useable by GCB for a period of up to ~15 years
- *Banksia* growing from seed require at least 15 years to attain a size that is useable by GCB, and then need to die and decay appropriately to become useable
- old growth areas with sufficient numbers and area of large, dead *Banksia* (not fire-killed) appear to sustain the best long term populations on KI, but can take many years to become useable (~25-50 years post fire/clearance)
- stable GCB populations in *Banksia* act as long-term sources of medium numbers of GCB that are then able to recolonise burnt areas where *Xanthorrhoea* flowers
- processes that reduce or fragment the remaining old growth *Banksia* habitat are likely to reduce the resilience of GCB populations in producing long-term stable populations that can recolonise burnt areas

Vibratory or “buzz” pollination

One important feature of GCB biology is that it performs the vibratile/vibratory pollination (commonly referred to as “buzz pollination”) required by many endemic Australian plants, particularly some species of the families Solanaceae, Fabaceae and Liliaceae, but including members of many plant families globally. For a recent review of the biology of vibratory pollination, and other relevant literature sources, see De Luca and Vallejo-Marin 2013. Briefly, it is known that such flowers are highly adapted in that they usually do not produce nectar, and they have two types of anthers; one type provides pollen for reward only, while a second type will only release pollen when vibrated at the correct frequency (it is this pollen that is needed for successful pollination) (Luo, Zhang et al. 2008). Therefore, these plants require vibratile pollination to reproduce successfully and many Australian bees are able to perform this function for Australian plants with which they have co-evolved. It is important to note that the honeybee (widely regarded as an efficient pollinator of all flowers) cannot perform vibratile pollination and therefore cannot efficiently pollinate such flowers. These facts also illustrate the importance of conserving endemic pollinators, like GCB, for maintaining endemic plant diversity and abundance.

Records for GCB pollination of flowers are extremely rare, and most of the visitation records are for nectar rich species that are not buzz-pollinated (e.g. *Eucalyptus* & *Leptospermum*). However, on KI the only such record is for a *Hibbertia* sp. (which was observed in this survey along Sanderson Tk), which does require buzz-pollination. Around Sydney the bees have been seen on *Gompholobium* (which requires buzz pollination), one species of which occurs on KI (*G. ecostatum*) (Gillam and Urban 2014).

GCB Distribution

Historical records (prior to 2000)

From historical records we know that GCB originally existed in an area encompassing Kangaroo Island (the westward limit), the Mount Lofty Ranges, southeast SA, southern and northeastern Victoria and eastern NSW (Leys 2000b). However, it is thought that GCB has become extinct in mainland SA (last recorded in 1896 at Aldinga) and Victoria (last recorded in 1938 in the Grampians) (Houston 1992). GCB records are relatively few and rather disjunct in their distribution making it impossible to determine the degree of physical continuity or genetic homogeneity of the original mainland populations. For example, the only location records for mainland SA are Aldinga (representing Fleurieu Peninsula and Mount Lofty Ranges) and Naracoorte (representing southeast SA). The degree of continuity/overlap of former GCB populations in these regions is unknown, as is their former occurrence in other suitable regions. The exact reasons for the apparent loss of mainland populations is unknown and may be complex; however similarly to many endangered/extinct Australian taxa, it has been intuitively postulated that habitat fragmentation and altered fire regime may be responsible (e.g. McIlwee and Leijts, 2003).

Historical records are generally derived from opportunistic collections or field trips undertaken by specialists in a particular species; they are generally not systematic collections. These records are relatively few on KI, particularly prior to 1990 (Houston 1992, McIlwee and Leijts 2003), and so it is impossible to be sure of the original distribution of GCB on the island, although there is a better picture than for mainland SA and Victoria. McIlwee and Leijts (2003) produced a map summarising historical records of GCB on KI (Fig 8). While the former presence of GCB on the highly fragmented eastern end of KI (particularly Dudley Peninsula) is unknown, it is likely it did occur there as there is apparently suitable habitat. There is not much doubt that GCB was very widespread in the western half of KI.

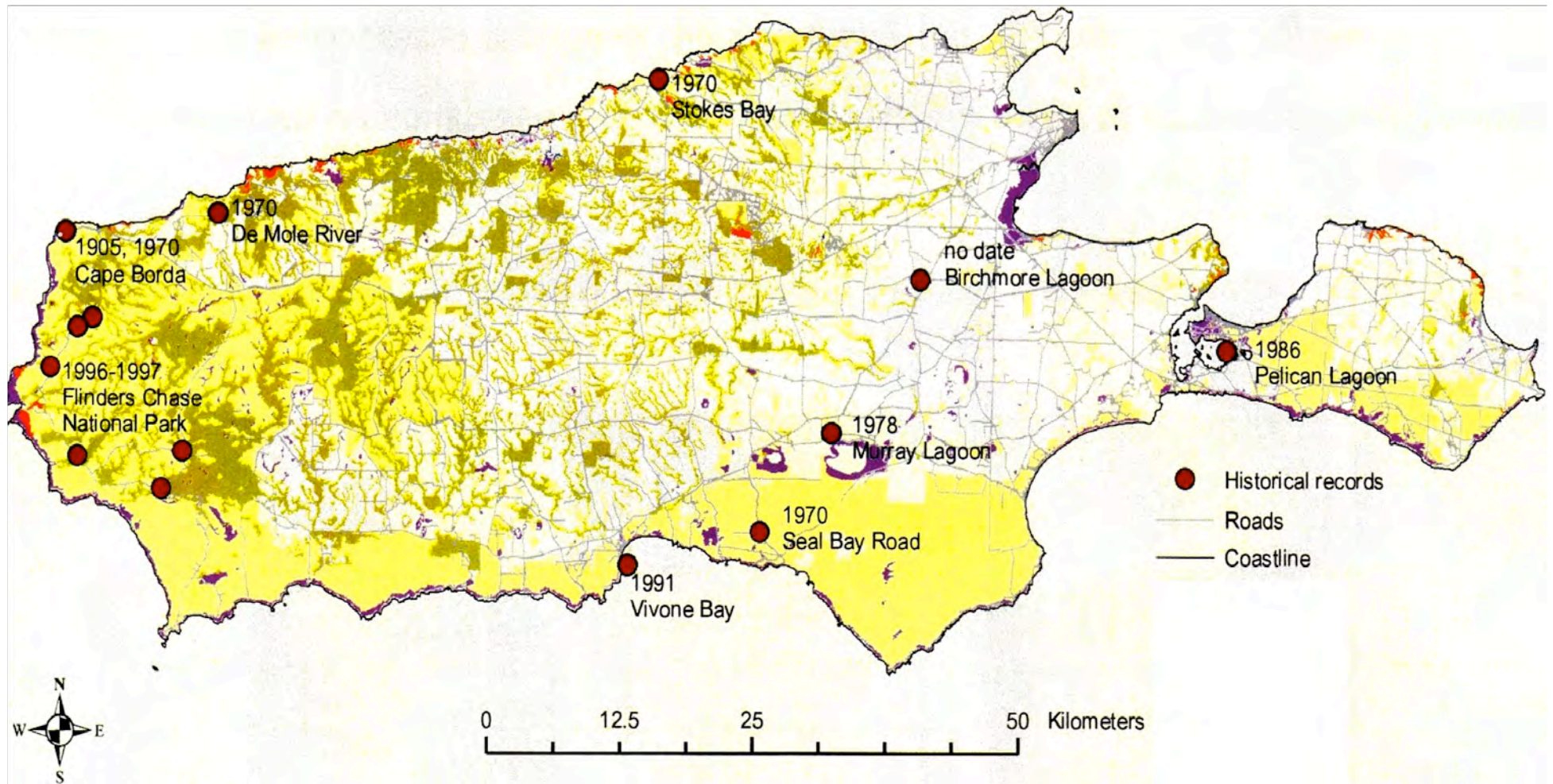


Figure 8. Historical records (prior to 2000) of GCB occurrence on KI, (from McIlwee & Leijts, 2003).

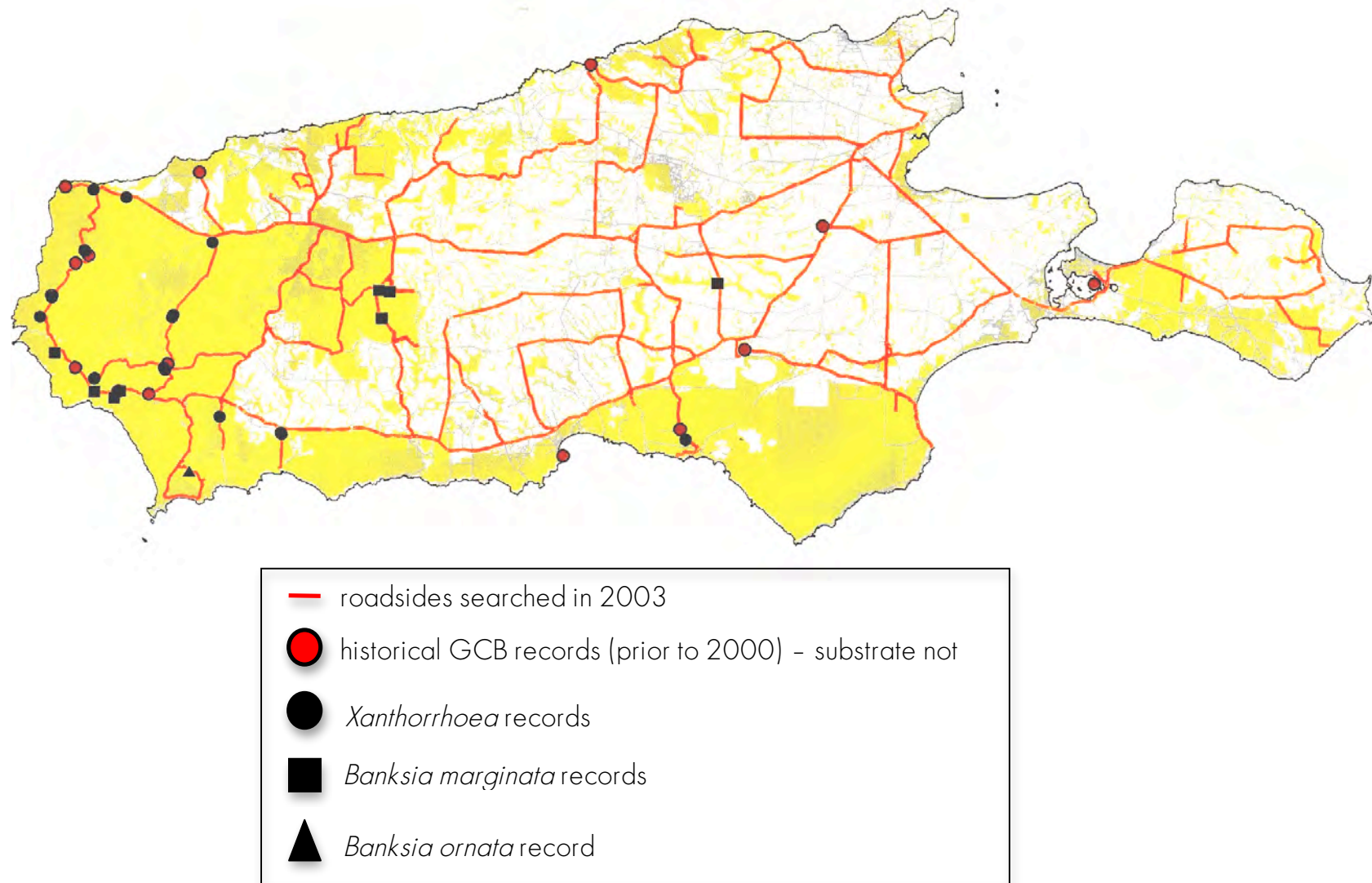


Figure 9. Summary of GCB records by substrate for the 2003 survey (black symbols), combined with historical (pre-2000) records (red circles). Roadside covered by the 2003 survey are marked red. These data indicate a historical westward contraction of GCB distribution on KI. Most of the sites containing GCB in 2003, were impacted by large fires in December 2007. Adapted from McIlwee and Leijes, 2003.

2003 survey

In August 2003, a roadside survey was conducted to determine the range of GCB on KI and compare it to the historical data mentioned above (McIlwee and Leijis 2003). This survey covered a significant proportion of roadside vegetation (see Fig 9 for surveyed roads) and indicated that GCB populations were largely confined to large patches of native vegetation in the western third of the island with only a few observations east of the Gosselands (Fig 9). Most of these nests were located in *B. marginata* with some in *Xanthorrhoea* and one site with nests in *B. ornata*. Results of the survey also suggested that there has been a westward contraction of GCB on KI, even in the preceding 20-30 years. For example, GCB does not appear to occur any longer near Pelican Lagoon but was recorded there in 1986. Similarly, occurrence of GCB at Stokes Bay (1970) and NW of Murray Lagoon (1978) are no longer obviously present. While the occurrence of small, isolated groups of GCB distant from roadsides in the highly fragmented eastern half of KI cannot be ruled out, it is considered highly unlikely.

2013 survey

In December 2007, large fires impacted most of the known remaining GCB habitat raising further concerns for the species. These fires also saw the introduction of a landscape scale fire-management plan involving vastly increased use of prescribed burning, including within the highest value public conservation areas (CPs and WPAs). The rationale for the increased burning was to protect human life and property, aid fire fighting operations, and to attempt to minimise chances of large proportions of conservation reserves burning in single events ("landscape protection"). Despite the McIlwee and Leijis report of 2003 (indicating westward contraction), and the importance of fire to GCB, no previous assessments of potential impacts on GCB were made during pre-burn environmental assessments. It has been recognised that production of BBZs based purely on fuel loads (thus requiring repeated burns over time frames of $\approx 5-10$ years) would likely cause environmental damage, and that best practice dictates these effects be researched (DEH 2009, KIDBPC 2009, Pisanu, Rogers et al. 2013). It should be noted that there are several BBZ sub-classes which are subject to different management approaches (see DEH 2009, KIDBPC 2009). However, the current burn program has no legislative (or other) requirement (and minimal resources) to make detailed (post-burn) impact assessments, although for a small number of recognised taxa mitigation of damage may be possible. Therefore, this project comprising the 2013 survey was devised to assess the post-2007 fire status/distribution and raise awareness of the plight of GCB. It was also hoped that the 2013 survey could provide data relevant to having GCB recognised as Endangered at a regional level and perhaps subsequently listed under the *Federal Environmental Protection & Biodiversity Conservation Act 1999* (EPBC Act) (Commonwealth of Australia 2014). A further aim was to begin an assessment of current and future substrate condition, and how this relates to fire frequency and intensity.

It could be argued that the reason that GCB is not already EPBC listed relates as much to the data requirements of the EPBC Act, our poor knowledge of population dynamics and measures of population health, and to the relatively poor consideration given to invertebrates generally, than to the actual conservation status of GCB. Given that the KI and NSW GCB populations are genetically isolated (and have been for some time) it is likely that they represent genetically distinct populations (or subspecies), which increases the conservation concern for the KI population and could represent good grounds for EPBC listing. This is the case for the KI subspecies of the Glossy Black Cockatoo (*Calyptorhynchus lathami halmaturinus*). Like GCB, *C. lathami* occurs as more stable populations elsewhere in Australia but there is concern (and EPBC listing) for the KI subspecies that it is now genetically isolated and historically reducing in area and population. In the absence of further research on GCB genetics and population dynamics, GCB protection will require State and local authorities to recognise the situation and be proactive in leading efforts in this area.

Survey Method

Three surveys were conducted January, May and October of 2013, concentrating mainly on public conservation regions (administered by DEWNR) in the west of KI, particularly FCNP and associated WPA, Gosselands and KHCP. Other isolated sites were searched, extending as far east as Parndana CP. Each vehicle contained an entomologist and observers comprised the authors, external entomologists, DEWNR staff, DEWNR volunteers and community volunteers. Table 1 summarises the surveys funded under this project.

Surveys were generally conducted along roadside, up to ~1.5km from the start point and up to ~500m from the road. Nests were searched either individually or in small groups with each search "unit" equipped with a GPS receiver. Habitat was broadly screened from vehicles for suitable substrate (*Xanthorrhoea* spikes or numerous dead *Banksia*). When suitable habitat was discovered, searching began by moving between potential substrates and examining them for nests. Track data from each GPS was recorded and waypoints were taken if any evidence of GCB was found, be it active nests, inactive nests or aborted entrance holes. Substrate species and size class (*Banksia* only) were also collected. Substrates that appeared usable but were unoccupied were recorded at some sites, and an attempt was also made to assess the present and likely future condition of GCB substrate. Once a site was searched, observers drove to the next identifiable substrate patch or ~2km to a new site if the substrate appeared continuous.

It is not always easy to discern if a GCB nest is active. Usually GCB adults are not seen at the nest entrances and so in these cases an active nest was scored if any of the following conditions were met:

- presence of fresh "sawdust" at entrance or below. This is most obvious when nests are being constructed (Fig 10a) and when young adults are emerging. Small amounts of sawdust may be present any time the nest contains active individuals.
- presence of excreta at nest entrance or below. This is most obvious when young adults are present in the nest (Fig 10b) but may be seen at any time of the year.
- freshly worked nest entrance. Mainly at the start of the year when GCB first emerges and/or is excavating or reworking nests.
- obvious pollen-like smell at entrance. Detectable if GCB is heavily foraging e.g. during nest provisioning.
- buzzing from the nest. Can sometimes be induced by inserting a small amount of soft foliage (e.g. grass) gently along the nest tunnel.

We found that where GCB existed it was relatively easy to locate nests as they occur largely in easily identifiable substrate and the entrances are relatively easy to find and identify as GCB-derived once an observer is experienced. Therefore, each site was generally searched for 20-30 minutes if no entrances were found and this period was extended to ~60-90 minutes if entrances were detected. The main problem that untrained observers encountered was ruling out similar holes, rather than finding GCB nest entrances.

In consultation with fire managers, several pre-burn surveys were also conducted to assess GCB presence, substrate plant distribution and substrate condition with regard to GCB use, prior to prescribed burns taking place (Table 2). GCB was not detected in these surveys and only absence data (for 2013) was contributed to the resultant survey map.

Data from several small *ad hoc* surveys by the authors (including absence data) was included in the habitat mapping. These areas included all other "absence" areas (Fig 11 shaded red areas), Tea Tree Lagoon at MacGillivray, southern third of Shackle Road, Harvey's Return to Cape Borda Tk, and the Platypus Waterholes walk.

Table 1: Summary of GCB surveys undertaken during 2013.

Date	Locations
09 January	<p>Kelly Hill CP</p> <ul style="list-style-type: none"> • Douglas Hill Boundary Tk "pre-buffer" (northern 500m)* • South Coast Road (~ 1km) & N end of Edwards TK at Little Terror Creek^E • Grassdale Road (northern 500m)** <p>West side Hanson Bay Rd (~ 1km south of South Coast Rd)</p>
10 January	<p>Flinders Chase NP/Ravine des Casoars WPA</p> <ul style="list-style-type: none"> • West Bay Rd (Shackle Rd intersection-West Bay Tk)* • West Melrose Tk* • West Bay Tk (Cape Borda Tk) (southern third)*
11 January	<p>Flinders Chase NP (~ 1km section South Coast Rd west of park entrance)*</p> <p>Gosselands</p> <ul style="list-style-type: none"> • North-South Tk • Birdsville Tk • Walsh Tk • Reedy Tk • Goss-Ritchie Rd (between Walsh & Reedy Tks) <p>Anderson bluegum plantation (Gosse-Ritchie Rd border & first creekline E along southern margin)</p>
02 May	<p>Ravine des Casoars WPA</p> <ul style="list-style-type: none"> • Ravine des Casoars Rd^E • West Bay Tk (Cape Borda Tk) (northern two thirds)
03 May	<p>Ravine des Casoars WPA</p> <ul style="list-style-type: none"> • Playford Highway (both sides; Harvey's Return campground-Shackle Rd)* • Shackle Rd (northern two thirds)*
14 October	<p>Borda Park (private property)</p> <ul style="list-style-type: none"> • recently burnt area • along easements at western end of bushland, at E end of the property <p>Jump Off Rd (~ 500m at southern end)*</p>
15 October	<p>Snug Cove Rd (south of Colmans Rd)</p> <p>Colmans Rd (until park gate at Western River WPA)</p> <p>Western River WPA</p> <ul style="list-style-type: none"> • part of Correll Boundary (encompassing small part of proposed BBZ)^E • part of Red Hill Tk <p>Berrymans Rd</p>
17 October	<p>Sanderson Tk (private property? to E of the track)**</p> <p>Yacca Flat Tk (northern half)**</p>
18 October	<p>Yacca Jacks Rd (to ~ 1km N Parndana CP)</p> <p>Parndana CP (almost entire S boundary except 2010 prescribed burn site)^H</p> <p>Margaret Investments (Private Property; along ~ 1km stretch of Cygnet River at W end of property)</p>

*at least one active nest located

** considered important stable *Banksia*-related populations

^Eevidence of previous GCB presence only (aborted entrance or inactive nest(s))

^H considered good *Banksia* habitat but apparently lacking GCB



Figure 10. Active GCB nests can be inferred from (a) fresh sawdust in the entrance or below, and (b) faeces just outside the entrance and below. Photos taken in artificial nests to show obvious examples: (a) 03 October 2013 during brood cell excavation; (b) 09 May 2014, late in season in nest with at least 10 young adults.

2013 Survey Outcome

In this section there is a broad discussion of what was located in key areas and how this differed from the pre-fire situation; for more details on exact locations see the habitat map below (Fig 11). During the project, GCB was assessed as being regionally Endangered (Gillam and Urban 2014) because of an ongoing declining trend for the species.

Current range

Firstly, it is important to note that the current (2013) surveys were not comprehensive and focused on the large areas of remnant vegetation at the western end of the island where GCB was known to occur; many of these areas were impacted by the 2007 fires. The purpose of the focus was to assess the post-fire situation in the west. Therefore, GCB in areas outside the 2013 survey are presumed to be similar to 2003 unless burnt/cleared since then. In terms of actual records, this only relates to the southern end of Seal Bay Rd (*Xanthorrhoea* substrate) and at a vegetated ford on Timber Creek Rd, ~2km N of East West Highway One (*B. marginata* substrate) (Figures 9 & 11).

In broad terms the current distribution on KI, includes:

- the southern and central (Shackle Rd) regions of FCNP
- southern mallee belt from FCNP to Seal Bay
- likely but unconfirmed occurrence in Western River and Cape Torrens WPAs and possibly other large blocks with suitable *Banksia* habitat in the vicinity (N of Playford Highway) and west to around Latham CP (where GCB appears to be absent although it was recorded at Stokes Bay in 1970)

It should be noted that suitable substrate is patchily distributed in these areas and that some of these populations are small and/or likely to be lost as they are in the last remaining *Xanthorrhoea* spikes from the post-2007 fire mass flowering event.

Post-2007 fire changes

The most obvious effect of the 2007 fires was to remove suitable *Banksia* substrate from much of the burnt area, particularly north of West Bay Road. Former *Banksia*-nesting populations along West Bay Rd and the southern end of West Bay Tk (Cape Borda Tk), have been lost. As mentioned, the relatively small number of GCB remaining in RCWPA exist in the last remaining *Xanthorrhoea* spikes from post-2007 mass flowering, and very few (none witnessed) suitable *Banksia* exist in these areas. Thus, it is likely that there will not be a significant GCB population in these areas for many years unless another significant *Xanthorrhoea* flowering occurs. Such areas provide potential for research into the use of "patch" burns to promote *Xanthorrhoea* flowering for GCB conservation.

Unfortunately, no GCB (or evidence thereof) was found in the Gosselands despite *Banksia* being a dominant plant. This appeared to be due to the loss of old *Banksia* in large areas, with the oldest plants usually around 10 years of age. In 2003, there were records of GCB in *Banksia* in the northern half of Gosse-Ritchie Rd but we did not find GCB there in 2013. It is not known if the apparent absence of GCB in the Gosselands is due to the 2007 fires, other fires since 2003, historical decline due to high frequency fires, or subsequent generations moving elsewhere in Gosselands where we did not search.

Thus, it is likely that since 2007, the GCB population in long term *Banksia* substrate on KI has been much reduced. In RCWPA this reduction in population size may impact on the long-term viability of the RCWPA GCB population (and perhaps more broadly), due to the time needed to regenerate this substrate and the distance to existing suitable substrate.

Banksia habitat

Banksia habitat of 15 years or greater is seen as crucial to the long-term survival of GCB. This is because the plants have attained enough size to be useable as substrate once they die. Therefore, a habitat layer was produced showing *Banksia* ≥ 15 years old, using DEWNR floristic and fire records (see Fig 11). This habitat is now largely confined to long unburnt areas in remnant vegetation along the south coast in western KI, and north of the Playford Highway in a more fragmented landscape from Cape Torrens WPA to Latham CP. In RCWPA, this habitat is now almost entirely gone except in small areas missed by the 2007 fires. Several BBZs are associated with this habitat class and ~ 400 ha was burnt in Autumn 2014 along the entire eastern margin of KHCP/Cape Bouguer WPA. This represents $\sim 5.7\%$ of the reserve area (pers. comm., A. Howard, 2014). It should be noted that while habitat of ≥ 15 years is shown on the habitat map, good GCB habitat only was seen in areas $\sim \geq 40$ years post fire (usually older; see Fig 7), and this is a much smaller area of habitat. Good potential *B. marginata* habitat was found in Parndana CP, however, GCB was not found there. Only a few GCB nests have been found in *B. ornata*; at Sanderson Tk (2013) and one at Yacca Flat (2003). Because this substrate is crucial for long-term GCB populations to establish, the decrease in area of this substrate is of concern.

Xanthorrhoea habitat

As discussed, *Xanthorrhoea* often flowers en-masse after fire, potentially producing large numbers of useable substrate ~ 3 years post fire and lasting for only 2-3 years subsequently before they degrade and fall, becoming unusable. Sporadic, low-density flowering occurs for reasons other than fire but are generally dispersed and alone do not appear to sustain GCB populations. This is supported by the fact that GCB is not found on mainland SA, not even in areas such as Deep Creek Conservation Park, which has a patchy high density of *X. semiplana*. The regulation of flowering in *Xanthorrhoea* is only partly understood. After the 2007 fires, mass flowering of *Xanthorrhoea* occurred across the burnt conservation areas producing large amounts of useable substrate around 2010. In the survey of 2013, there were only small numbers of dead spikes still standing, however GCB was usually present where spikes were found (West Bay Rd & West Melrose Tk). We expect that GCB will become largely absent from these areas in the upcoming few years as there are almost no useable *Banksia* present (mainly seedlings). This accounts for a large area where GCB has been established in the past and was

already the case along most of West Bay Tk (Cape Borda Tk) and through the central/northern regions of RCWPA.

The common association of GCB with remaining spikes in the south-west, and evidence of recent presence in northern areas, suggest that GCB was able to recolonise large areas that were burnt in 2007 using the *Xanthorrhoea* substrate. We know nothing about the sources and spread of GCB in this recolonisation, however, it clearly illustrates that long-term GCB source populations (in *Banksia*) are able to utilise the more volatile (and potentially more numerous) *Xanthorrhoea* substrate.

One small site at Borda Park (far north-west) had numerous *Xanthorrhoea* spikes that should become usable in good numbers from Spring 2014. It will be of interest to assess the level of useable spikes, and potential GCB recolonisation in the next few years (the post-fire situation is not known). There are also other areas with potential for such analysis. For example, a large prescribed burn on the entire eastern margin of KHCP/Cape Bouger WPA (Autumn 2014) is also likely to generate *Xanthorrhoea* substrate in the coming years, and GCB is known to occur in the area (it is part of the priority habitat we seek to protect; Fig 11). There were also *Xanthorrhoea* that may be stimulated to flower along the central BBZ at Seal Bay CP (see pre-burn surveys below); note that many 36-53 year old living *Banksia* have probably been lost. In a pre-burn survey at Latham CP, large numbers of *Xanthorrhoea* (non-flowering) were present and there was no evidence of GCB; this area will also be of interest if burnt.

Our current concern is that there is now very little area where there is *Xanthorrhoea* substrate present in good numbers, and at the desired post-fire time-frame of 3-6 years (see Fig 11). This illustrates the importance of maintaining as much long-term *Banksia* habitat as possible, and to refrain from further fragmenting such habitat. Also, research regarding the use of fire and other stimuli to cause *Xanthorrhoea* flowering, may be useful.

Stable populations

As mentioned above, the only apparently stable GCB population(s) we located, occurred in old remnant vegetation at north west of KHCP, and where *Banksia* occurred along the east side of Sanderson Tk. There were other GCB that appeared to have been maintained in old *Banksia* in small patches at the southern end of Shackle Rd and similarly at Yacca Flat, where large dead *Banksia* occur in unburnt patches or those subject to low intensity fire. There were also large numbers of *Xanthorrhoea* at Yacca Flat but similarly to north and central RCWPA, very little substrate was present and no evidence was found of previous GCB utilisation of *Xanthorrhoea* substrate there. As mentioned, the level of continuity of GCB between these sites is unknown (away from roadsides). The location of two active nests in Cape Torrens WPA (which was not intensively surveyed) (Fig 11), indicates the existence of a remnant population in the north. While this area contains some suitable habitat, the current distribution suggests that this population is at present largely isolated from the main distribution in the south-west. It is hoped that the size and isolation of the northern population does not affect its viability.

Habitat Mapping and Fire Management

Development of a habitat map

There were two main aims to producing a GCB habitat map (Fig 1 1):

- (1) to provide a recent picture of GCB distribution (post-2007 fire)
- (2) to identify priority areas of habitat for consideration by fire and land managers

All historical, 2003 and 2013 GCB records were overlaid on DEWNR floristic maps that show all native vegetation and highlighted currently useable GCB habitat (native vegetation filtered by age class using DEWNR fire records). This habitat was defined as *Xanthorrhoea* occurring in the 2-6 year age class (Fig 1 1; dark blue shaded areas) and *Banksia* in vegetation of >15 years (orange shaded areas). It has been some time since these floristic distribution layers have been ground-truthed in some areas and therefore must be treated with caution (e.g. there is not *Banksia* occurring where shown in area between Mouth Flat Rd and Black Point Tk on the Dudley Peninsula; there is also no GCB there). Areas where we recently determined GCB absence are also shown (Fig 1 1; red shading).

GCB priority areas

As mentioned, for the purposes of informing fire and land managers we attempted to identify habitat that should either be protected due to the presence of stable GCB populations in *Banksia* and/or because it is prime habitat for recolonisation in the future (Fig 1 1). In April 2014, approximately 400ha of such habitat was treated to strategically reduce fuel based on a BBZ, which spans the entire latitudinal range of eastern KHCP and Cape Bouger WPA (Fig 1 1). It is important to recognise that the KI GCB population is a remnant of a former distribution that included mainland SA and Victoria. Therefore, the accepted loss of arbitrary amounts of the remaining population under current fire plans is likely to further impact the species and may not be consistent with the "No Species Loss" strategy. For the long-term survival of GCB on KI, the protection of suitable habitat is at least as important as protecting active nests themselves. Thus, we aim to protect the remnants of the KI (and broader southeast Australian) GCB populations and to maintain integrity of large areas of former habitat for recolonisation.

It is hoped that within these priority areas, GCB (and its habitat) will be considered by fire and land managers. Regardless of habitat maps available to fire-managers, assessment of some key species is generally undertaken ahead of prescribed burns (A. Howard, pers. comm., 2014). Several points should be noted however: it is highly unlikely that BBZs will be abandoned or relocated based on our information, and altered burn timing is also unlikely given the small windows in which prescribed burning can operate safely and effectively. Also, planned prescribed burns may not be carried out if weather conditions preclude burns or there are funding constraints. Thus, it is hard to be sure of the real need to take mitigating action, such as moving colonies when they are inactive during the preceding winter. Additionally, based on current plans, the area under fuel-reduction burning is likely to increase if conditions allow it and adequate resourcing is provided. It should also be considered that while attempts are made to produce a landscape 'mosaic' by retention of a given percentage of the landscape within target age classes, there is considerable doubt about the robustness of the age classes themselves (Pisanu, Rogers et al. 2013). This reflects the high degree of uncertainty associated with fire management as it pertains to ecology.

Pre-burn surveys (2013)

Pre-burn surveys were conducted on seven BBZs earmarked for prescribed burning in Spring 2013 and Autumn 2014. Dr Glatz undertook these surveys and walked the entire length of the BBZs (or circumference where possible) assessed GCB presence, substrate plant distribution and substrate condition. These surveys are summarised in Table 2.

The aim of these surveys was to gather data that could be compared to post-fire assessments of substrate dynamics and potential recolonisation. Ultimately, it is hoped to gain a better understanding of how GCB substrate responds to various fire events and the variables affecting this. Further, we aim to understand the spatial and temporal dynamics of GCB recolonising these areas. Such surveys could also be used to locate nests for mitigating action e.g., fire break or relocation to the nearest suitable (non-BBZ) habitat. This latter option can only be undertaken in winter during GCB inactivity and therefore, early burn planning and consistency of planning with burn outcomes (so nests are not needlessly removed) would both be required to achieve this. It was a useful exercise to map substrate plant occurrences at the BBZ and then compare this to Google Earth imagery; at some sites the substrate mapping correlated with changes in vegetation imagery that could be refined to give a more accurate prediction of potential habitat, away from surveyed areas.

Potential Green Carpenter Bee Habitat with Priority Areas



Figure 11. GCB habitat and distribution (by substrate) as at 2013. Explanation overleaf.

Figure 11 (previous page): GCB habitat and distribution (by substrate) as at the end of 2013. Combines 2013, 2003 and historical occurrence records. Areas of potential *Banksia* (orange) and *Xanthorrhoea* (dark blue) habitat are shown, as are areas of known GCB absence in 2013 (filled red areas). Two kinds of priority habitat are marked, i.e. habitat where GCB is known to occur (thick border with grey shading) and/or suitable habitat needing protection for future colonization (grey diagonal lines). Some proposed and recently treated BBZs are shown as red diagonal lines. Long-term *Banksia*-related populations that were not impacted by fire in 2007 continue to maintain good GCB populations, however, they are likely to have lost from much of the RCWPA (note no 2013 records, but historical and 2003 records). Despite searching many of the tracks in the Gosselands, no evidence of GCB was found in 2013 apparently because much of the *Banksia* (which is dominant in the area) is too young to be used by GCB (GCB was present there in 2003). It should be noted that areas only ~500m from roadsides was searched and so we cannot rule out occurrence elsewhere, however, there is only evidence of small patches where older vegetation occurs across this region.

Table 2. Summary of pre-burn surveys conducted in 2013. None of the sites had evidence of current or former GCB occupation but most contained potential habitat of varying age and recolonisation potential.

Date	Location	Comments
25 July	Latham CP: Northern Boundary prescribed burn	<ul style="list-style-type: none"> walked entire perimeter & 3 eastern-most rolled lines many <i>Xanthorrhoea</i> in some parts but only a few live spikes no <i>Banksia</i> seen good site to investigate post-fire flowering/recolonisation not burnt at time of report
26 July	Seal Bay CP: Central Buffer prescribed burn	<ul style="list-style-type: none"> walked southern margin & drove northern margin <i>Xanthorrhoea</i> present in low lying areas but sporadic east of a defined point small section with <i>Xanthorrhoea</i> already pre-burnt in Spring 2013 at east end and may be useful for flowering comparison with rest of BBZ <i>B. marginata</i> common in swales between limestone rises but most still living – some usable substrate in older areas at western end of BBZ no <i>B. ornata</i> seen some examples of old <i>Banksia</i> habitat not yet ready for GCB mapping of substrate occurrence reveals ability to locate potential habitat areas using Google Earth at this site most of the area treated Spring 2014
27 July	Seal Bay CP: Range Track prescribed burn	<ul style="list-style-type: none"> walked entire margin and examined useable substrate off track <i>Xanthorrhoea</i> patchily distributed on low-lying areas of track; no dead spikes some good <i>B. marginata</i> substrate in low lying area in central region of track (apparently good habitat with <i>Xanthorrhoea</i>) and many living medium-large plants in northern section of track (need deaths to become useable habitat) no <i>B. ornata</i> seen mapping of substrate occurrence reveals ability to locate potential habitat areas using Google Earth at this site not burnt at time of report
27 July	Seal Bay CP: North burn	<ul style="list-style-type: none"> walked entire northern and eastern margin (small amount of southern margin) <i>Xanthorrhoea</i> (no old spikes) common in formerly cleared sandy ironstone section at extreme N of zone and lesser numbers within uncleared mallee. Medium numbers associated with much of road verge on E margin low numbers of medium-large <i>B. marginata</i> (but mainly living) along much of eastern margin (not north-most quarter) no <i>B. ornata</i> seen possibly good site to examine <i>Xanthorrhoea</i> post-fire flowering & recolonisation not burnt at time of report

Table 2 continued.

01 August	East Gosselands : Block 15 prescribed burn	<ul style="list-style-type: none"> • covered south, east & north margins of burn zone & small distance into zone in habitat of best potential along N margin • <i>Xanthorrhoea</i> with sporadic occurrence on N margin of burn area. More along S margin beneath stringy bark. No old spikes; a small number of new spikes • <i>Banksia</i> (both species) are dominant except beneath stringy bark and in sections of heath - mainly live plants except for a small amount of good <i>B. ornata</i> substrate associated with long unburnt stringy bark on N boundary at east end (some also in adjacent private property) • block treated in Autumn 2014 • blocks each side treated in Autumn 2013 • potential to examine <i>Xanthorrhoea</i> flowering in each block
01 August	East Gosselands - Playford Block 1 burn	<ul style="list-style-type: none"> • survey incomplete; walked only small loop along track and roadside at east end • <i>Xanthorrhoea</i> in good numbers under stringy bark and limited elsewhere along small survey route (no dead spikes) • <i>B. marginata</i> common but less than <i>B. ornata</i>. Some useable <i>B. marginata</i> substrate only under long unburnt stringy bark • young <i>B. ornata</i> plants dominate ironstone open mallee heath but minimal useable substrate (minimal dead plants) • <i>Phytophthora</i> symptoms present in substrate species • area likely too young for reburn • not burnt at time of report
01 August	East Gosselands - Playford Block 2 burn	<ul style="list-style-type: none"> • walked N margin of burn (Playford Highway) & intermittently up to 50m into BBZ when dead <i>Banksia</i> noted • <i>Xanthorrhoea</i> only sporadic occurrence in ~ 100m section (no spikes) • <i>B. marginata</i> common but mostly live and no useable substrate seen • <i>B. ornata</i> is dominant shrub plant in this area, sometimes occurring as young plants of great density. Only several useable substrates seen. Much reduced on rises with denser mallee coverage. • area likely too young for reburn • not burnt at time of report

Recommendations for fire and land managers

Rationale

The fire recommendations below are aimed at protecting the remaining GCB populations and maintaining the integrity of intact (perhaps currently unoccupied) habitat such that it can respond to natural disturbance and be recolonised by endemic plants, animals, fungi and microorganisms, with a particular focus on GCB. We recognise that the current GCB populations are now much reduced in distribution (remnant), even on KI. While the 2003 survey indicated a westward contraction of the GCB range on KI compared to historical records, the current (2013) survey indicates a contraction southwards in western KI, or at least increased isolation (in the west) of the stable southern populations from the remnant GCB in the north. Thus, while maintaining the current *status quo* is a worthwhile objective, it would be desirable to see an expansion in the range of stable populations on KI.

We note that GCB distribution is naturally locally transient due to fire occurrence and therefore emphasise the importance of maintaining sufficient stable source populations in old growth vegetation across the landscape. We also recognise that appropriate fire management (at relatively small scales) may be able to play a role in GCB protection however, research would first be required to validate such methods.

Stable populations and large areas of adjoining suitable habitat (determined by floristic age-class mapping), comprise the priority habitat for protection where GCB still occurs (Fig 1 1); thus BBZs should not be located in these areas, or further fragment similar habitat. This is particularly so, as the effectiveness of BBZs located in large vegetated areas for reducing the intensity and spread of severe fires into other vegetated areas, i.e. "landscape protection", is questionable (Enright and Fontaine 2014, Penman, Bradstocok et al. 2014). Briefly, this is because of the relatively small amount of the landscape able to be treated and that as severity of conditions increases (to those where protection of large vegetated areas becomes warranted), weather conditions and spotting begin to contribute more to fire severity than fuel load (and even low fuel loads will produce fast moving, severe fires). In fact, modelling of the 2007 fires in RCWPA/FCNP showed that complex local convective processes were likely responsible for intense fire that was far in excess of what the current severity models could predict (Peace, Mattner et al. 2011, Peace and Mills 2012). Furthermore, the landscape protection strategy requires that fires do not ignite in areas that make a given BBZ redundant e.g., within an area being buffered. Under the current prescribed burn legislation, BBZs have been established based on assessed risk to human life and/or property and other assets, and presence of GCB (or other species) will not alter the placement or establishment of such zones.

It is also possible that the current fuel-reduction model could fragment priority *Banksia* habitat due to the high frequency of burning required to maintain low fuel loads. For example, at the northern end Shackle Rd where there was evidence of recent GCB occurrence (but not active nests located), prescribed burns were undertaken on October 2013, in areas where vegetation was virtually removed in Dec 2007 (i.e. less than seven years post-burn). The time between such burns falls well below the lower ecological threshold of *Banksia* and all other major vegetation sub-types recognised (DEH 2009) this is generally considered too frequent in terms of maintaining ecological integrity (Pisanu, Rogers et al. 2013, Enright and Fontaine 2014). Indeed, ecological fire thresholds are not applied to BBZs aimed at asset protection. Whatever the other outcomes of such burns are, it is clear that they are likely to further fragment *Banksia* habitat (particularly the remaining old growth habitat) and vegetation structure across conservation regions in general. This also raises more broad concerns about invertebrates with highly restricted distribution, plants focusing on an insignificant proportion of the biota, potential for weed and pathogen spread etc. Thus, it is possible that current protocols for use of BBZs may not be consistent with the stated DEWNR strategy of having "No [described] Species Loss".

Thus, our recommendations are designed to span changes in legislation and are provided as a best-practice guide for GCB conservation rather than being modeled to fit the constraints of current legislation. Further, it is important to recognise ecological trade-offs associated with broader land/fire management legislation and objectives, and to be explicit about them (Pisanu, Rogers et al. 2013). This provides transparency as well as the opportunity to identify research priorities and opportunities to refine land management practices by adaptive management model (Sabine, Schreiber et al. 2004, Pisanu, Rogers et al. 2013).

Recommendations

The following recommendations are provided for fire and land managers.

1. refine habitat map format to a standard framework able to be replicated and updated by fire and land managers in future years.
2. update habitat map yearly to capture changes to important habitat features.
3. pre-burn surveys should be undertaken by an entomologist to assess GCB presence and substrate status.
4. set planned burn areas for coming year by August to facilitate relocation of threatened colonies.
5. as best practice, avoid placing BBZs in priority habitat where GCB occur or in priority habitat suitable for future recolonisation, as defined in the GCB habitat mapping (particularly when containing good numbers of old living *Banksia*).
6. where prescribed burning is to be conducted in areas where GCB are present, mitigating action should be taken in consultation with experts, viz:
 - remove nests to adjacent area if appropriate (winter only),
 - translocate nests (winter only),
 - protect individual nests (not much use if larger areas of surrounding forage have been removed).
7. stable GCB populations in *Banksia* substrate should be given the highest protection and not subjected to prescribed burning.
8. avoid burning below the lower ecological threshold for *Banksia* (~17 years) as this will reduce and fragment the remaining potential *Banksia* habitat.
9. outside of critical habitat, burning of GCB nests should be avoided as the GCB population is already a small remnant of a much larger (and presumably more genetically diverse) population.
10. avoid spreading *Phytophthora* as it kills both substrate plants (and potential forage plants).
11. obtain funding to facilitate research examining small, patchy burns (and other triggers) to generate *Xanthorrhoea* substrate where populations are low. This could be useful in areas where only young *Banksia* are present but also to examine *Xanthorrhoea* recolonisation from existing *Banksia* nests.
12. utilise prescribed burns for formal ecological research; here to examine dynamics of *Xanthorrhoea* flowering and recolonisation by GCB. This would value-add to the government burn funding.
13. keep abreast of latest peer-reviewed research regarding use of prescribed burning for protection of remnant vegetation and refine protocols accordingly.

Concluding Remarks and Future Research

Even though it is a relatively well-known species and the subject of several scientific publications, there is much that we do not understand about GCB. Our current knowledge of GCB encompasses merely its annual life-cycle, details of the sociality, nesting and reproductive biology, and a broad distribution (Houston 1992, Leys 2000a, Steen and Schwarz 2000). Additionally, its distribution on KI and an analysis of the relationship between active nests and vegetation age on KI, were further examined in 2003 (McIlwee and Leijis 2003).

While we do not have a detailed knowledge of the GCB distribution on KI prior to significant land clearance (and no records prior to 1970), it is likely that GCB was widespread where suitable substrate existed. Thus, it seems apparent that GCB distribution has been in a historical decline with no evidence that this has ceased. In parts of its range in 2003, we could not detect active GCB nests and in other parts they were confined to *Xanthorrhoea* spikes that will soon be lost. This is most obviously due to the extent of the 2007 fires and is not necessarily associated with an irreversible decline. The apparent absence in Gosselands is harder to explain as there are a range of vegetation age classes with significant *Banksia* and *Xanthorrhoea*; however, it appears that a high fire frequency over much of this landscape may have removed most old *Banksia* and those that remain are generally below 15 years of age (DEWNR 2015). It is perhaps this type of landscape that represents the long-term reduction in GCB populations on KI and elsewhere, although this is merely speculation based on our current understanding. Regardless, it is apparent that we are now left with the remnants of a much broader GCB population on KI.

In order to be confident about development of plans for pro-active management of GCB and their habitat, there are several areas of research that should be addressed:

1. Genetic connectedness of GCB on KI. This is a key question as it addresses whether GCB on the island forms a continuous population or whether the KI population is now fragmented into disjunct groups. This would also provide information on the number/density of GCB representing a stable population.
2. Genetic relationship of KI population with NSW population. If these populations are clearly genetically distinct then GCB on KI is likely now an endemic sub-species that only occurs on the island. This may have ramifications for determining conservation status and for fire/land management related to GCB.
3. Association of environmental variables (including weather, soil and fire-related parameters) with the development of useable *Xanthorrhoea* and *Banksia* substrate. Includes mechanisms and dynamics of flowering.
4. Effect of substrate type, density, spatial arrangement and patch size on the dynamics of recolonisation and population maintenance. Includes testing the hypothesis that long-term *Banksia* populations are the key sources of recolonisation of abundant *Xanthorrhoea* spikes after fire. Also, includes the means by which GCB detects and assesses potential substrate, which is poorly understood.
5. Effect of forage plant species and density in recolonisation and regulation of established populations. This would provide more information about post-fire requirements and habitat assessment. For example, are some pollen-producing flowers better for GCB than others? Also, it may provide information about which plant species benefit most from GCB visitation.
6. Identity and effect of potential parasites and pathogens. This is very poorly characterised and important in populations that are under stress.
7. Improved assessment of habitat quality; based on the research questions above it should be possible to better assess the current and potential future quality of a given piece of habitat as it relates to GCB. Currently this is based simply on the amount of useable substrate.

8. Active management options. Currently we have identified the following as priorities for research:
- promotion of *Xanthorrhoea* flowering through fire (or other means) in small, strategic vegetation patches to augment nearby GCB colonies
 - development of methods to successfully relocate GCB from areas to be burnt or cleared
 - investigation of protocols (perhaps involving artificial substrate) for reintroduction or relocation of GCB

The natural ecosystems of KI are still in relatively good condition in the large vegetated expanses in the south and west of the island. Despite being lost from large areas of the mainland, GCB can still be observed on KI although this is potentially threatened. It is hoped that by raising awareness of GCB, there will be more attention paid to its status and conservation. Iconic, rare species such as GCB are also crucial in stamping KI as a place of unique natural values, which has benefits for the entire community. Conservation programs are heavily reliant on volunteers and therefore, engagement of community members is crucial not only for resourcing conservation efforts, but also in informing the attitudes of relevant authorities and the broader public.

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