Guiding stinking passionflower management at Danggu (Geikie Gorge) National Park for conservation of freshwater crocodiles

Final report

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Cover photograph: Locating and studying a freshwater crocodile nest next to a patch of stinking passionflower (*Passiflora foetida*) on the banks of Fitzroy River at Danggu (Geikie Gorge) National Park © Ruchira Somaweera, CSIRO.

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1. Introduction

Native to south and central America, stinking passionflower (*Passiflora foetida* L., Passifloraceae) is one of the most significant problem weeds in the northern tropics of Australia and is particularly abundant in riparian ecosystems around the shorelines of waterways (Figure 1). The first confirmed record of this weed in Australia dates from 1892 in Queensland. Although the original point of introduction in Western Australia (WA) is not known, current observations suggest the species has most likely spread to WA from the Northern Territory. However, the first confirmed record from WA was from near Derby in 1921. Currently, *P. foetida* is locally abundant in many riparian ecosystems across the Pilbara and Kimberley regions of northern WA. This weed is listed under the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act) as being amongst the main weed threats to the highly fragmented and environmentally important rainforest patches scattered across the Kimberley region of north-west WA, as well as the monsoon vine thickets of the Dampier Peninsula.

A significant impediment for implementing effective and targeted weed management strategies for *P. foetida* is that very little is known about its ecology or the range of impacts it has on ecosystem values. An understanding on how and when *P. foetida* impacts native ecosystems is crucial to determine how and when intervention is required. Such insight is also important for underpinning an evidence-based approach to developing new control options for this weed and ensuring these controls can be deployed effectively, taking local landscape and ecosystem context, and values into account.

One of the high value landscapes where stinking passionflower threats are of particular concern to land managers is Danggu (Geikie Gorge) National Park in the Kimberley. Danggu is included in the West Kimberley National Heritage place. The park has outstanding heritage value to the nation under National Heritage Criterion (e). Specifically, the place has outstanding heritage value to the nation because of the place's importance in exhibiting particular aesthetic characteristics valued by a community or cultural group. The West Kimberley National Heritage listing Gazette notice notes "*Particular aesthetic characteristics of Geikie Gorge Conservation Park and Geikie Gorge National Park valued by the Australian community include Geikie Gorge (Danggu), its colourful gorge cliffs and sculptured rock formations carved by water through an ancient limestone reef, the lush riverine vegetation along the gorge, the fossil decoration on the gorge walls and the deep permanent waters*." As such, the area is of significance to Traditional Owners and is a popular location for tourists to visit. Danggu also has high conservation values, both flora and fauna, for significant species including the Australian freshwater crocodiles (*Crocodylus johnstoni*).

As part of a larger program on understanding weed impacts on the freshwater crocodile, the aims of this work is to (1) understand the likely localised impacts of *P. foetida* on the Australian freshwater crocodiles (*Crocodylus johnstoni*) at Danggu (Geikie Gorge) National Park in the Kimberley region and (2) develop prioritised recommendations in relation to timing, technique and extent of control efforts needed to manage the weed from the perspective of impacts to crocodile conservation at the park. While we recognise that control efforts focused on mitigating threats to crocodiles are likely to benefit other ecosystem values in the park, developing management recommendations that specifically included these outcomes was beyond the scope of this work.

Figure 1. Passiflora foetida (bright green vegetation) invading sandy river banks used as nesting sites by freshwater crocodiles on the Fitzroy River at Danggu (Geikie Gorge). Photo: Ruchira Somaweera.

2. Current need for control of *Passiflora foetida* at Danggu

Observations by staff of the WA Department of Biodiversity, Conservation and Attractions (DBCA) and Bunuba Rangers suggest that *P. foetida* was first observed in Danggu (gorge and visitor area) in the late 1990s. The initial presence of *P. foetida* was not necessarily associated with any known large-scale disturbance. The origin of the population is not known but the species is widespread further upstream in the catchment and therefore, downstream dispersal of seeds and vegetative matter or bird dispersal are both feasible introduction pathways.

Passiflora foetida has been dominating the local riparian landscapes around the visitor centre of the park ever since, being particularly abundant during the wet season (December to March). Active control of *P. foetida* in and around the visitor centre area has been undertaken since it was first detected and has been ongoing with irregular frequency each year. This control is focused on reducing vine biomass at ground level, mainly through hand-pulling or spraying, but sometimes using heavy machinery depending on quantity and/or location (Figure 2). On average, each ranger would spend at least 5 hours a week on some sort of *P. foetida* control at the park during the months the park is open (generally March to November).

Figure 2. Manual removal of P. foetida *cover at Danggu, includes rolling of vine mats and the use of heavy machinery. Photo: Richard Tunnicliffe, DBCA.*

The visual amenity impact of *P. foetida* in areas of high tourist visitation within the park is arguably significant. However, the application of current control methods is limited by access (in case of machinery), is labour-intensive and costly, and does not extend to vines growing away from the visitor centre or those growing in and overtopping trees. More importantly, these control efforts likely have very little long-term suppression effectiveness, given that the vine returns to dominate the landscape during the rainy season, germinating from the soil seed bank and resprouting from crowns (Figure 3). Despite the resources consumed, these manual control efforts have no enduring benefit on long-term control of this weed in the broader landscape at Danggu.

Figure 3. P. foetida seedlings and resprouting crowns reappearing during the wet season in the area cleared around the visitor centre at Danggu. Photo: Ruchira Somaweera.

Based on qualitative information gathered from stakeholders and ecological studies conducted as part of the broader *P. foetida* invasion program, we are aware of multiple likely impacts from the weed at Danggu (Webber et al. 2021), which include:

- **social** and cultural – overgrowing sites of Indigenous cultural value and creating a physical barrier for recreational use and tourism at the park, including access to the river;
- **economic** – costs (mostly wasted) for biomass control (see above), negative impacts on tourism via reduced visual amenity; and
- **environmental** – accumulation of biomass on trees by overgrowing them increases the susceptibility of tree damage during fires and floods, suppression of native groundcover and the flow-on effects of increasing the risk of bank erosion during flooding, potential impacts on wildlife nesting and feeding on riparian habitats.

It is possible that the impact of *P. foetida* on native vegetation could be high. However, it is logistically extremely difficult to obtain a clear and meaningful insight into the pathways and level of impact on vegetation in a relatively short time through extensive plot manipulation and maintenance experiments in a remote site like Danggu. Therefore, this project focussed on the likely impacts on an ecologically, economically and culturally significant faunal component of the Danggu system, the freshwater crocodile. It is likely that the results from this study will provide insight to impacts of *P. foetida* being studied elsewhere, and benefits flowing from control for crocodile conservation (if needed) could well have benefits for social, economic and other environmental values in this iconic ecosystem.

3. Future need for *P. foetida* control at Danggu

The scope of this report is restricted to focusing on the impact of *P. foetida* on the conservation outcomes of freshwater crocodiles in the park. These recommendations do not extend to considering impacts on native vegetation, other animals, or other biotic and abiotic impacts. However, we recognise that mitigating impacts of *P. foetida* on crocodile conservation might also have benefits for other ecosystem values, and we discuss these possible synergies when synthesising our insight as well as outlining future priorities. The impact of *P. foetida* on freshwater crocodiles may take place in three pathways.

1. Limiting nesting space for crocodiles

We developed an integrated modelling framework to resolve river dynamics and riparian zone ecohydrology at Danggu and were able to identify changes in habitat suitability for *P. foetida* and freshwater crocodiles across the riparian strip in focus (Hipsey et al. 2021). The model identified some broad similarity in suitable habitat for *P. foetida* and crocodiles when looking at the larger system scale. However, when looking at individual riverbank areas along the length of the gorge, a difference between them emerges in their life-stage specific requirements. In general, *P. foetida* was relatively insensitive to its distance from the river but was hindered by periodic inundation events (i.e. flooding events either physically stripped the weed from the bank or led to mortality in situ during longer periods of inundation), although it can withstand and recover from short-term inundation. On the other hand, crocodile habitat was focused on the river margin, even though the egg stage was highly sensitive to inundation. This makes the interaction of these two species most intensely focused at the river interface (Figure 4).

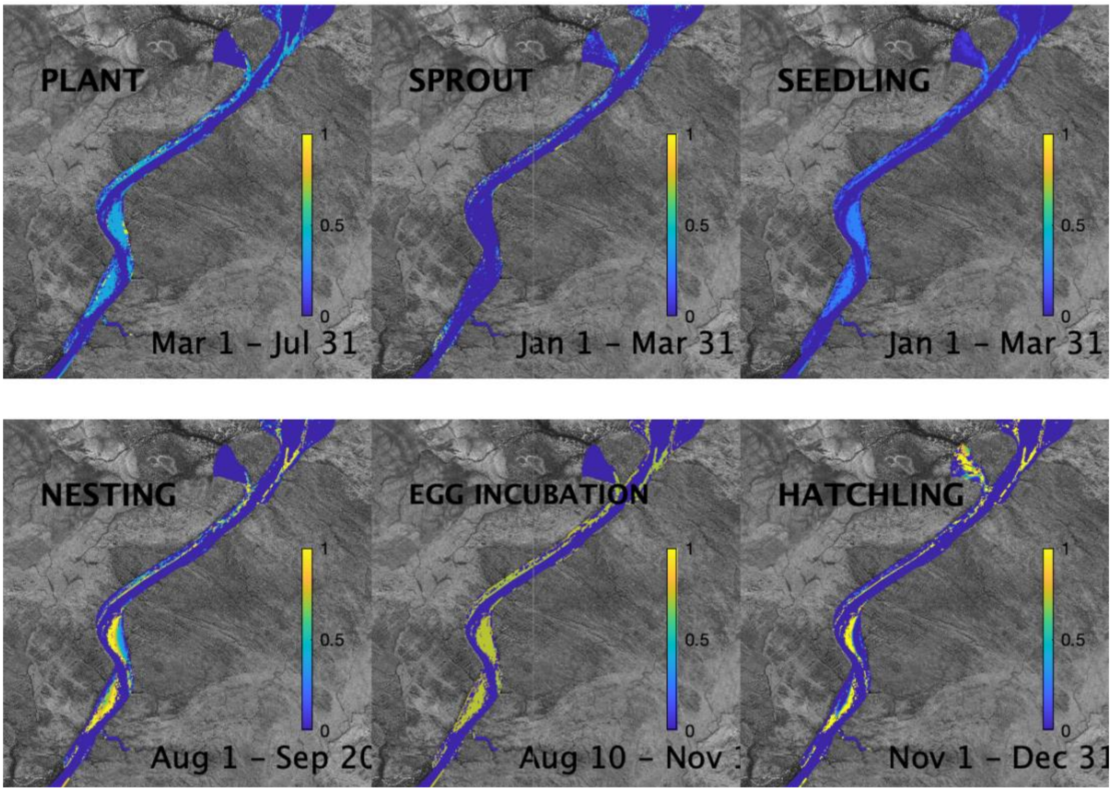

Figure 4. Summary of the habitat model output showing average habitat suitability index for different life stages of P. foetida and freshwater crocodiles within the relevant time periods at Danggu.

It is plausible that if suitable nesting substrate for crocodiles was largely covered by dense *P. foetida* biomass, then the availability of nesting space could be limited, or nests could be confined to a smaller area where accidental excavation by later nesting animals reduces overall nest success in the park. No historical records of crocodile nesting sites at Danggu are available to inform trends in fitness (i.e. nesting dynamics) over time. However, based on observations by Bunuba Rangers, crocodiles have nested in at least two locations prior to c. 2000 – just north of the boat ramp and at the edge of the east sandbank. Both areas are currently invaded by *P. foetida* with significant vegetative groundcover over the banks (Figure 5). Since commencing crocodile surveys at Danggu in 2011 (RS with DBCA and Bunuba Rangers), we have not observed any new large and enduring mats of *P. foetida* biomass establishing in riparian areas along the Fitzroy River within the park, although the density of *P. foetida* within the localised patches was noted to change significantly between years (Figure 6). Severe infestations of the vine have been limited to the same locations since surveys started in 2011.

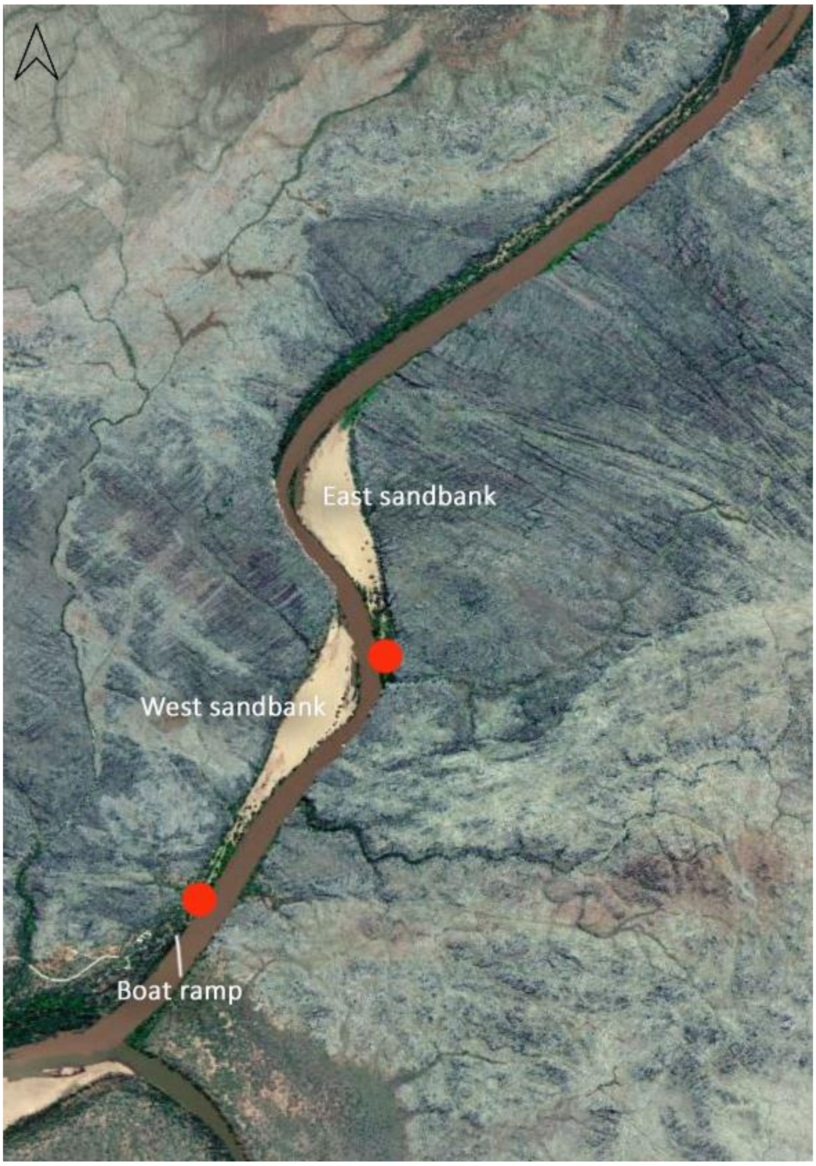

Figure 5. Locations where crocodile nests have been observed by Bunuba rangers prior to 2000 at Danggu.

Figure 6. Spread of P. foetida at the edge of the western sand bank at Danggu in September 2011 and August 2017. Photos: Ruchira Somaweera.

A spotlighting-based monitoring program for freshwater crocodiles at Danggu was designed for DBCA and Bunuba Rangers by Ruchira Somaweera (then at University of Sydney) in 2011. The primary objective of the surveys was to establish a baseline for crocodile numbers at Danggu, accounting for seasonal and annual variations in numbers, so that the impact of cane toads and other environmental changes could be evaluated systematically. Since 2014, DBCA has been conducting 2–3 annual surveys at the park coinciding with the nesting and hatching seasons of crocodiles.

Spotlighting survey data since 2011 shows consistent numbers of hatchlings over the years, indicating a consistent reproductive output (Somaweera et al, 2020: Figure 7).

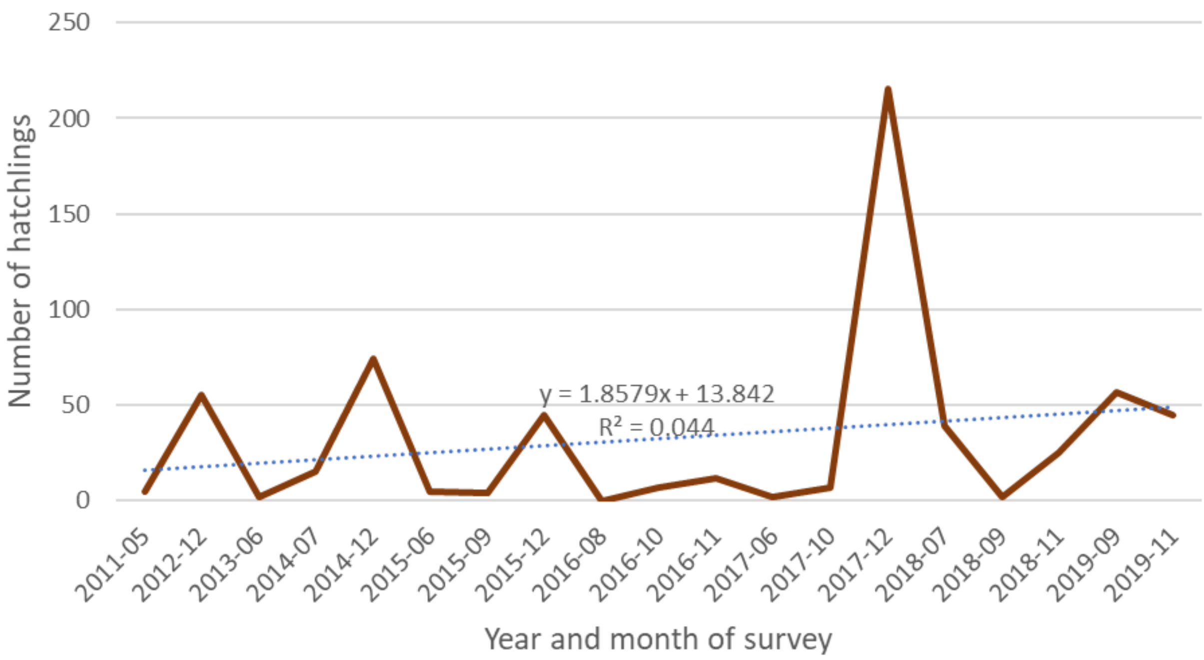

Figure 7. Crocodile hatchling numbers observed each year in December at Danggu.

Since nesting surveys started in 2016, more nests have been located at locations with *P. foetida* present in the wider riverbank area than those areas without *P. foetida* (Figure 8). In these areas, the ground covered by *P. foetida* is continuous at a small scale, but leading up to and during nesting season, ample open areas of suitable substrate for nesting have always been available along the bank and also within the patches of vine (Figure 9). Crocodile nests have been observed within these open spaces. However, importantly, all such nests had continuous open access routes from the water's edge (i.e. free from vine and other plant biomass), with some paths essentially direct (i.e. straight) and others meandering through the *P. foetida* patches (Figure 10).

Figure 8. Location of crocodile nests from 2016 to 2019 (yellow stars) and spread of P. foetida (dark green) at Danggu.

Figure 9. Open spaces along the bank (L) and within P. foetida patches (R) at Danggu. Photo: Ruchira Somaweera.

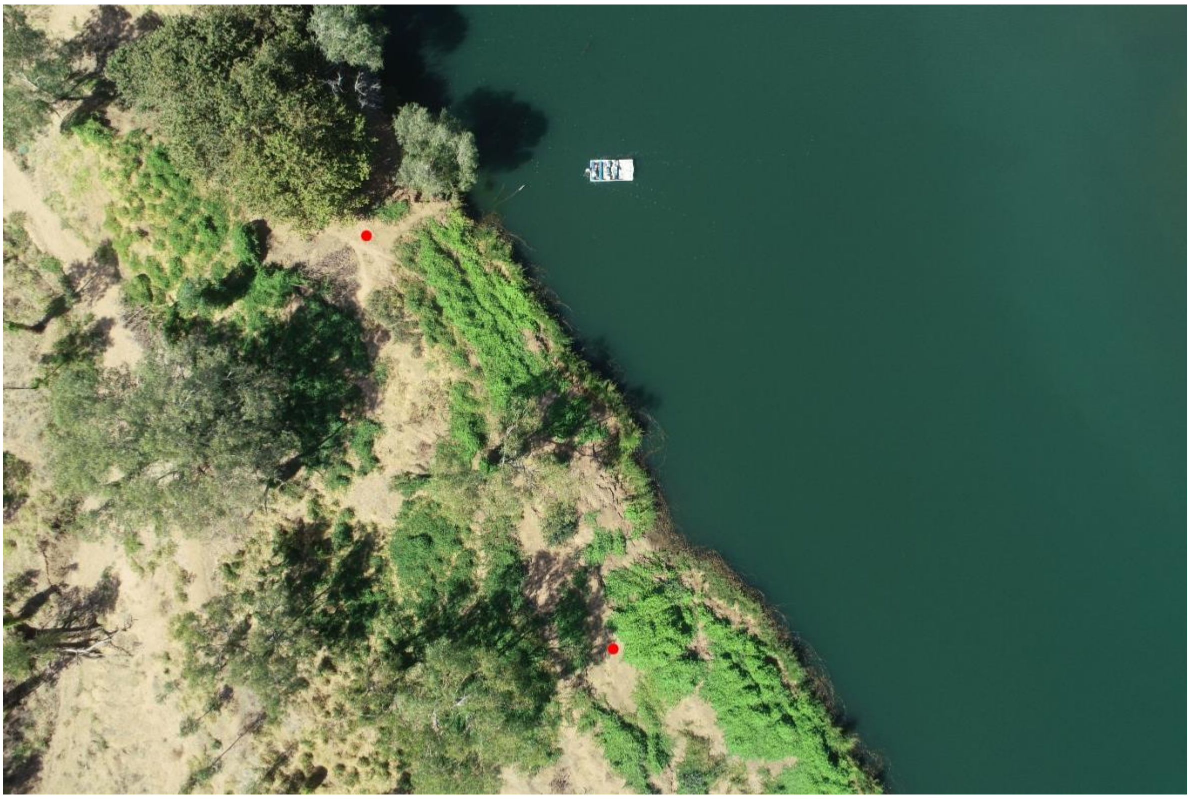

Figure 10. Nests (red dots) located within a P. foetida patch at Danggu. Note the availability of open-access paths from the water's edge to the open patch. Photo: Ruchira Somaweera.

Taken together, there is no evidence to support that *P. foetida* biomass abundance and patterning is currently limiting the availability of crocodile nesting space at Danggu. Ample suitable space has been available in recent seasons and used by nesting females as nesting sites away from the *P. foetida* patches, as well as other open patches among the *P. foetida* ground layer. Despite this insight, we have no information as to what the nesting patterns and reproductive output of crocodiles were at Danggu before the invasion of *P. foetida*. It is, therefore, impossible to know if existing crocodile nesting patterns reflect longer multi-decadal trends, or if the current consistency in hatchling output for the region is impacted by the presence of the vine due to nesting site availability.

2. Overtopping nests and changing nest conditions

If nests are laid in close proximity to vines, overtopping of nests due to vine growth can occur while the eggs are incubating, altering the microclimates of the nests. The microclimates of nests of reptiles with temperature-dependent sex determination (TDSD), such as crocodilians, can influence the lifetime fitness of individuals and affect population demographics (Mitchell et al. 2010). Therefore, vegetation overtopping nests has the potential to change incubation conditions and impact offspring viability, including influencing sex ratios (Leslie and Spotila, 2001; Somaweera et al., 2018) and embryo mortality (Thorbjarnarson and Wang, 2010).

Mechanistic modelling by Somaweera et al. (2019a) based on 10 nests without *P. foetida* overtopping and 10 nests with *P. foetida* overtopping at Danggu suggests that growth of *P. foetida* over nests of crocodiles at Danggu can reduce the projected hatchling mortality through cooling nest temperatures (Figure 11). This is because the shading from the plant reduces the probability of nest temperatures exceeding the upper thermal limits of developing crocodilian embryos. Previous studies (e.g. Webb et al. 1987) suggest that development of crocodile embryos is compromised above incubations temperatures of approximately 33°C, with high mortality observed at temperatures above this threshold. For example, in 2018, nest overtopping by *P. foetida* is projected to reduce embryo mortality from 50% to 30%.

Similarly, *P. foetida* overgrowth impacted predicted primary sex ratios (Figure 11). Both in 2017 and 2018, nests without *P. foetida* overtopping showed low male production (>20%), while nests with overgrowth produced more males (up to 40%). Therefore, by reducing the nest temperature, *P. foetida* overtopping can actually lead to positive impacts on crocodile nesting ecology, reducing embryonic mortality and resulting a more balanced sex ratio. However, we caution that the long-term effects on either of these changes on overall population fitness are not known, particularly in regard to population viability and resilience, and confirmation of a potential impact would require field testing of the model projections.

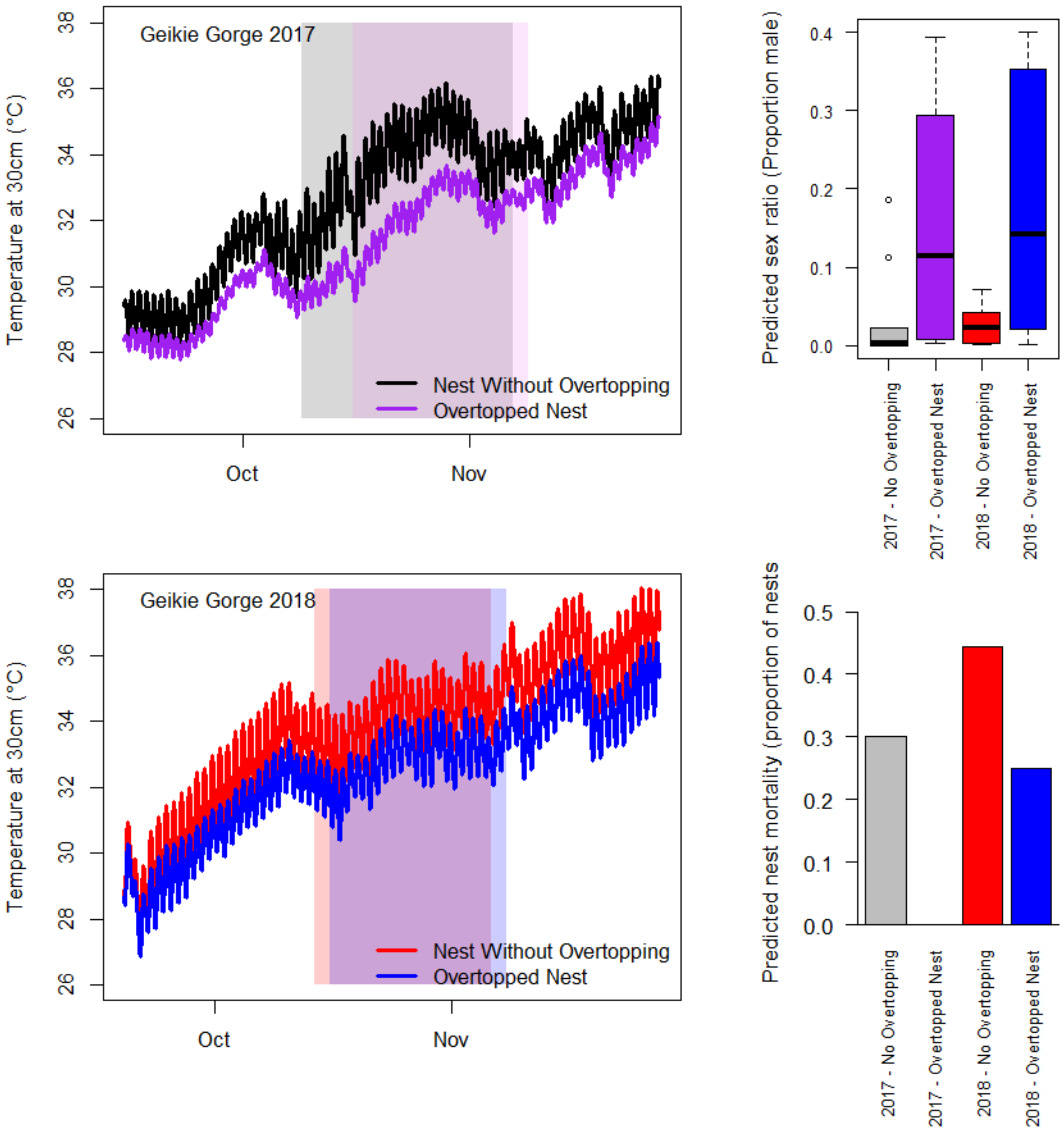

Figure 11. Average nest temperatures (at 30 cm depth) and associated thermosensitive periods (TSPs; shaded region) for nests with and without P. foetida overgrowth at Danggu for 2017 and 2018 nesting seasons. Boxplots show predicted sex ratios resulting from nests and predicted proportion of nests where embryonic mortality was expected.

3. Preventing female crocodiles digging out the nests

Parental intervention during nest exiting increases survival rate of hatchlings in crocodiles (Somaweera and Shine, 2012). Overtopping of nests by *P. foetida* may provide a physical barrier to nest exiting, inducing mortality in hatchlings. All nests located during the pre-nesting surveys over the 3-year study period were in either open areas away from *P. foetida* and other vegetation, or in large open patches within *P. foetida* groves. Additional nests that were either missed or not laid during the nesting surveys were located during the hatching surveys in December (by observing creches of hatchlings near hatched nests), and those nests were also in open spaces away from *P. foetida* biomass. Nevertheless, it is possible that some nests were overtopped by *P. foetida* during the incubation period and did not survive. However, our ability to detect such nests was severely limited with the site visitation frequency and detection methods available to this project, and would require detector dogs or other non-invasive detection methods to be successful.

Further resolution on the influence of these impact pathways, both individually and in an interactive way, would be required to understand the full range of potential impacts of *P. foetida* on crocodile conservation in the park. What our results tell us from 3 years of observation of these interactions (and a further 5 years of crocodile population surveys) is that the current inter-season fluctuations of *P. foetida* biomass, based on the variance observed in the system during the study period, are not likely to be having a significant impact on the freshwater crocodile population given the lack of constraints to nesting space across the region, and the fact that nest site fidelity is not high in this species.

4. Control of *P. foetida* for crocodile conservation at Danggu

In 2017, we conducted a manipulative study to investigate whether ongoing removal of *P. foetida* from previously known nesting sites would encourage freshwater crocodiles to recommence nesting in those sites (Somaweera et al., 2019b). We followed a paired study design in regions of high *P. foetida* density that had been identified as significant nesting sites in the recent past. In a fully crossed Before-After-Control-Impact (BACI) design, plots were either left as positive and negative controls, stripped of all vegetation, or replanted with *P. foetida* to have complete ground cover over a recently bare area (Figure 12 and Figure 13). Treatments were switched between years, where plots cleared of vegetation were replanted and vegetated plots were cleared. If removal of vegetation encourages crocodiles to resume nesting, then we would see the usage of clear patches alternated between the two years.

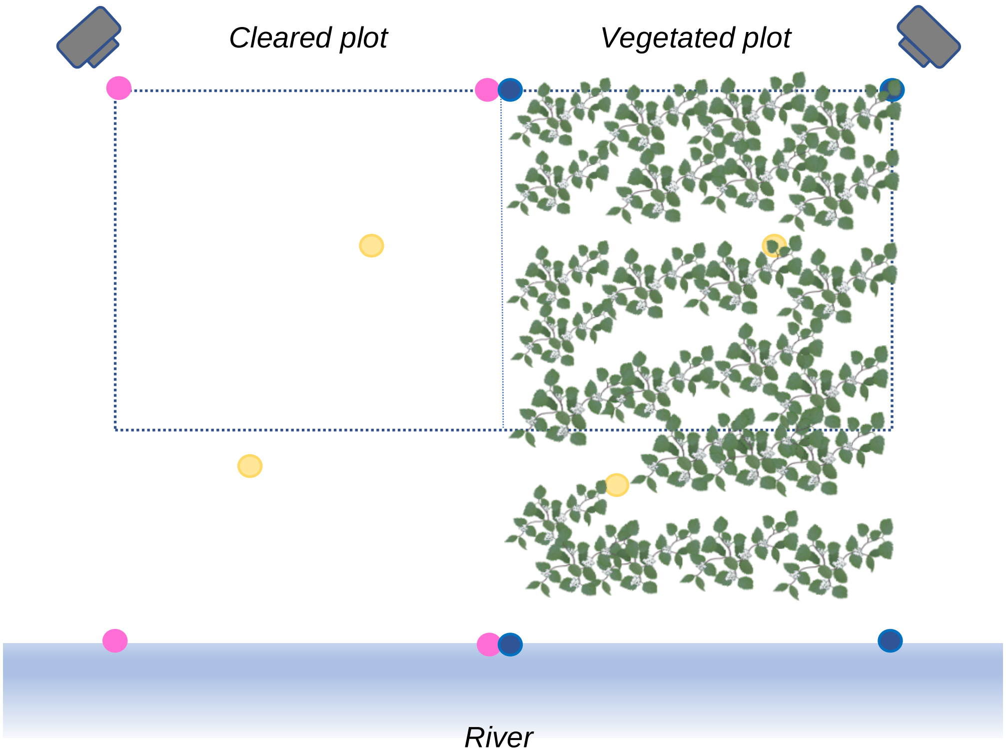

Figure 12. Paired study-plot design at each site with a cleared plot without any vegetation and the adjoining vegetated plot. Corner marks are shown as pink and blue circles, temperature loggers as yellow circles, and remote cameras as grey boxes outside the plots.

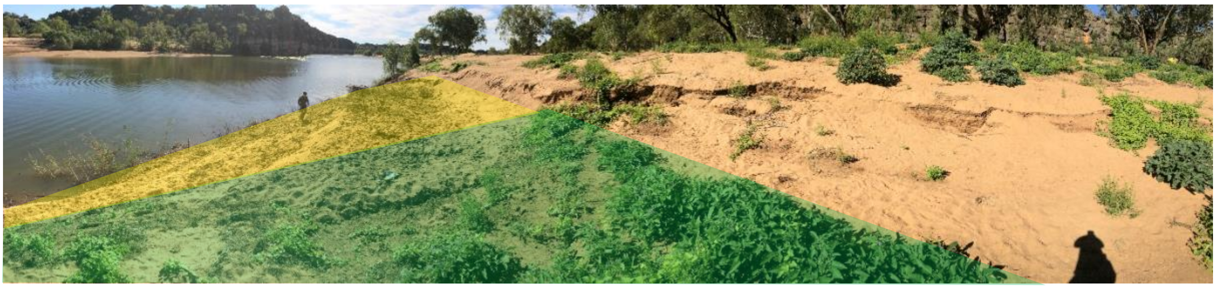

Figure 13. Vegetated plot with sporadic vegetation (foreground: green overlay) and cleared plot in background (yellow overlay) at Site 2 in September 2017.

Unfortunately, this manipulative study was not able to provide the insight it was originally designed for due to the practical difficulty in maintaining completely vegetated plots for comparison (Somaweera et al., 2019b). However, important management insight was gained during the first year before it was discontinued. Targeted weeding and the ongoing maintenance of sites to prevent weed biomass build-up consumes significant resources (time, money) and has very low enduring impact. Even with fortnightly visits by two rangers spending 20–30 minutes per site, it was not possible to keep the 25 m x 25 m plots completely weed-free in this study.

It is evident that manual removal of weeds across all nesting banks used by freshwater crocodiles is not a practical solution for minimising weed impacts on nesting ecology. Also, given that nest site selection happens 2–3 months prior to nest laying, nesting banks would need to be cleared and maintained for over six months in order for successful nest site selection, nest laying and nest emerging to take place.

Therefore, it is possible that suitable nesting sites can be created in areas overgrown by *Passiflora* via much smaller (~5 m x 5 m) clearings, as long as there are uninterrupted access paths to those patches from the water (Figure 14). Creating such paths and open patches in previously known nesting sites (Figure 8) could be an alternative to complete clearing of nesting banks. However, we caution that these paths and openings would need regular (at least fortnightly) maintenance to ensure *P. foetida* does not overgrow the nests, which again raises questions regarding whether such management is practical. There is also the risk of physical damage to nests by overstepping during weeding if they are undetected.

Figure 14. Creating access paths and cleared openings could be an alternative to complete clearing in sites with dense P. foetida cover.

Taking the above context together, a logical framework detailing timing and techniques of *P. foetida* control can be constructed to optimise management for freshwater crocodile nest site availability (Figure 15).

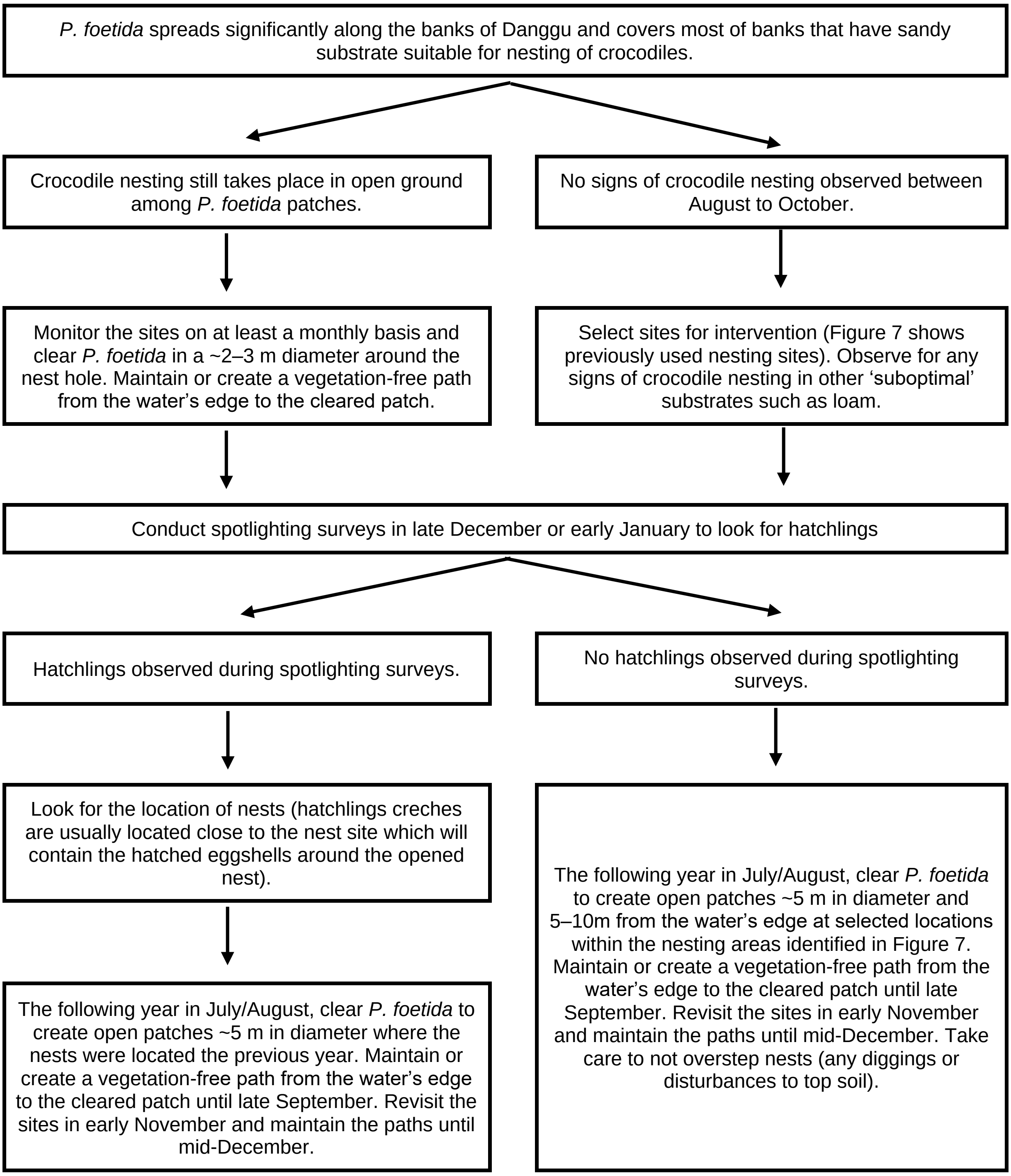

Figure 15. Framework for decision-making and intervention to control P. foetida at crocodile nesting sites at Danggu.

5. Priority knowledge gaps and effective conservation solutions

Moving forward, several knowledge gaps exist in our understanding of the crocodile–weed system and its interactions, and the following improvements may provide further insights.

- A better understanding of long-term patterns in nest site locations, recruitment trends and demography of the crocodile population. Annual spotlighting surveys have been conducted at Danggu since 2011 and nesting surveys since 2016 – the longest-running crocodile survey in west Kimberley region. Continuing these annual surveys under standardised procedures is crucial to evaluate impacts of several potential impact factors including weeds, invasive cane toads (*Rhinella marina*), other feral animals and future hydrological and environmental changes.
- A better understanding of *P. foetida* variance in location, spread and biomass abundance over time (ideally related to high water flows) in nesting areas. This could be best achieved by annual photogrammetry surveys conducted with unmanned aerial vehicles (UAVs) over selected sites and quantifying the spread and abundance of *P. foetida*.
- A better understanding of *P. foetida* dry-season growth rates (from mature plants and seedlings) to better understand overtopping risk. Quadrat sampling in the field to quantify growth rates of *P. foetida* with complementary and controlled greenhouse studies would provide these insights, combined with monitored field plots to account for microclimatic variation.
- Better detection solutions for laid crocodile nests to understand true distribution of nests each season within patches would be a priority, particularly in relation to proximity to vine biomass, and across the park. Detection of nests laid in soft substates like river sand at Danggu is sometimes hampered by difficulty to notice signs of digging or disturbances in the substrate. Usage of remotely triggered cameras and detector dogs may increase the detectability of nests.

Manual control is extremely labour intensive and as shown in this study, it is unfeasible to clear *P. foetida* to keep nesting banks open for the needed duration. Manual control may not offer the respite from vine interference with nesting, should vine removal be required (e.g. after many years of low flow without a big ‘flush’ that would allow big vines to establish and take hold). Control of *P. foetida* via flooding by manipulating water levels and river flow is not a feasible or practical solution at Danggu. This would also interfere with other parameters in the riparian ecosystems, including the microclimates of the nest site of crocodiles. Biological control solutions for *P. foetida* would mitigate any possible risk to crocodiles and would also add considerable amenity value to controlling the weed at Danggu for the benefit of other landscape values.

6. Conclusions

While knowledge gaps remain in terms of our understanding of the conservation implications for crocodile-weed interactions, we currently do not have evidence to show that *P. foetida* is impacting crocodiles in a persistent or large-scale way at Danggu. There is no evidence that *P. foetida* biomass abundance and patterning is currently limiting the availability of crocodile nesting space at Danggu. This lack of an impact appears to be mediated by the regularity of significant flooding events removing weed biomass and opening up banks. Should flooding intensity and regularity change (as it might with climate change or large constructions that impede flow), or should riverbank erosion patterns be altered by the weed, then this assumption would need to be revisited. Moreover, mechanistic modelling shows that by reducing the nest temperature, overtopping by *P. foetida* can lead to positive impacts on crocodile nesting ecology, reducing embryonic mortality and resulting a more balanced sex ratio, assuming that overtopping does not interfere physically with subsequent hatchling emergence. However, we caution that the long-term effects on these impact pathways are not known and extrapolating this interpretation to other contexts may be unjustified without further evidence.

In conclusion, we have not identified a current need to control *P. foetida* at Danggu from a crocodile conservation perspective. However, if *P. foetida* was to spread significantly throughout nesting areas and if biomass builds up over multiple seasons (e.g. following multiple low-flow years), this lack of impact could change considerably in the future. Our recommendation for management is that *P. foetida* range and abundance across crocodile nesting areas should be monitored on a seasonal basis leading into the nesting season. If available crocodile nesting space appears to be limited, we suggest implementing the framework suggested in this report to reduce the impact of *P. foetida* on the freshwater crocodile population at Danggu.

Beyond the impacts of *P. foetida* on freshwater crocodiles, we note that there is likely to be additional reasons where the impacts of *P. foetida* on other landscape values would justify prioritising weed control. Given the significant impacts that *P. foetida* has on other ecosystem characters at Danggu, there needs to be a pragmatic balance between continuing the resource intensive manual weed control (with its short-term impact) around high value assets, and not wasting resources on efforts that are only short lived in their mitigation of these weed threats.

There would likely be considerable benefits for undertaking a systematic assessment of all ecosystem impacts – environmental, social, cultural and economic – to fine tune existing investment of resources in weed control at Danggu. These impacts go beyond the threats to freshwater crocodiles, and indeed go beyond just *P. foetida*. Other threatening weeds in these riparian areas include calotropis (*Calotropis procera*) and *Jatropha gossypiifolia* (bellyache bush).

With respect to what is arguably the most threatening weed in this riparian landscape, a biological control solution for *P. foetida* is the only feasible and effective way to reduce biomass and mitigate threats at Danggu in a consistent, enduring way. A program between CSIRO and DBCA to develop a biological control solution for the weed is already underway. Danggu would represent a high value landscape in which to consider agent release, should a suitable agent be identified.

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