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Stingless bee (*Tetragonula carbonaria*) foragers prioritise resin and reduce pollen foraging after hive splitting

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Abstract – Stingless bees are increasingly in demand as pollinators in agricultural crops within the tropics and subtropics. Hive splitting, where one strong managed hive is “split” into two independent daughter colonies, is commonly used to increase hive numbers. However, how splitting impacts foraging behaviour or the time taken for the colony to recover from splitting has not previously been studied. We assessed the impact of splitting on the foraging behaviour of *Tetragonula carbonaria* colonies. The number of returning forager trips and foraged proportions of pollen, nectar and resin was observed after splitting and compared with unsplit control hives over a 31-day period. We found the total amount of returning foragers in split hives reduced to less than a third of unsplit hives (unsplit median, 184–288; split median, 19–61) for 16 days, while returning nectar (unsplit median, 89–147; split median, 16–28) and pollen (unsplit median, 55–155; split median, 1–7) foragers reduced to less than a quarter of unsplit hives for 9 days following splitting. After 31 days, the number of total, nectar and pollen foraging trips had still not recovered to levels observed in unsplit hives. Resin foraging trips however were not significantly different to unsplit hives after only 10 days. The colony foraging allocation to resin (proportion) increased after splitting and was significantly higher in split hives until day 16 of the experiment (unsplit median, 0.03–0.05; split median, 0.10–0.16). Our results demonstrate that split colonies prioritise resin collection and foraging on floral resources is reduced. We recommend that hives should not be split within 31 days of being used for pollination, and resin sources should be conserved where possible and supplemented where necessary due the vital roles of the resource.

Australia Meliponini / Stingless bees / Stingless bee propagation / Stingless bee foraging / Hive splitting

1. INTRODUCTION

Stingless bees (Apidae: Meliponini) are a eusocial group of bees numbering over 500 species across tropical and sub-tropical regions globally (Roubik 1992; Michener 2007; Grüter 2020). They are increasingly used as managed pollinators in many food crops, prompting

demand for commercially propagated hives (Heard 1999; Slaa et al. 2006; Halcroft et al. 2013; Meléndez Ramírez et al. 2018). Stingless bees require pollen, nectar and resin from plants for food, nesting and to support the health of the colony (Roubik 1992, 2023; Michener 2007; Kaluza et al. 2017). Pollen is the major source of protein, including fatty acids, vitamins and minerals, while nectar is processed to provide energy (carbohydrates) for worker bees and developing brood (Michener 2007; Brodschneider and Crailsheim 2010; Nicolson 2011). Resin foraged

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from plants is used for many functions within the hive (Langenheim 2003; Wallace and Lee 2010; Shanahan and Spivak 2021). It is mixed with beeswax to create propolis, which is then used as a building material to build structures within the hive such as brood cells, storage pots, batumen and entrance tunnels (Wille 1983; Roubik 1992, 2006; Heard 2016). Resin plays a vital role in establishing new daughter colonies, as a virgin queen will only conduct her mating flight and move to the new colony when the hive structures required to commence laying eggs and producing brood are in place (Kerr et al. 1962; Wille and Michener 1973; Wille 1983). Resin is also essential for physical, chemical and biological defence (Greco et al. 2010; Halcroft et al. 2011; Drescher et al. 2014; Leonhardt 2017; Shanahan and Spivak 2021).

Colony foraging behaviour is determined by both individual bees and the flow of information among the colony's population, depending on the resource needs of the colony (Wille 1983; Michener 2007; Beismeyer and de Vries 2001; Biesmeijer and Slaa 2004; I'Anson Price et al. 2021). Colonies may modify foraging behaviour such as foraging trips and proportion of foraged resources in response to environmental factors including weather and climatic changes and also resource availability (Heard and Hendrikz 1993; Biesmeijer et al. 1999; Leonhardt et al. 2014; Kaluza et al. 2017; Toledo-Hernández et al. 2022; Zhao et al. 2021). Stingless bees, unlike honeybees, mass provision brood cells (Roubik 1992; Heard 2016) and have showed increased brood production in line with increased stored pollen (Maia-Silva et al. 2016), while pollen foraging intensity is thought to be driven by availability in the field rather than brood amount (Biesmeijer et al. 1999). Colony foraging behaviour may also change in response to disturbance, both natural and anthropogenic (Michener 2007; Ramirez et al. 2013). This response may be driven by a colony's need to restock food resources (pollen and nectar), repair hive damage (resin) or defend the hive (resin) (Michener 2007; Roubik 2006; Shannahan and Spivak 2021). Human disturbance most often takes the form of habitat modification for wild

colonies (Samejima et al. 2004; Potts et al. 2010) and the process of colony propagation (e.g. hive splitting) in managed hives (Heard 1988, 2016; Kaluza et al. 2016).

Human propagation of stingless beehives occurs in many sub-tropical and tropical regions globally (Heard 1988; Roubik 1992; Gutierrez et al. 2002; Quezada-Euán 2018; Mounika et al. 2019; Grüter 2020). This process expedites the production of daughter colonies, a process that can be highly variable in wild colonies depending on geographic location, resource availability and species (Wille and Orozco 1975; van Veen and Sommeijer 2000; Grüter 2020). Stingless beehive propagation is driven by a need for hives for pollination, honey production and hobbyist beekeepers (Heard and Dollin 2000; Quezada-Euán et al. 2001; Cortopassi-Laurino et al. 2006; Halcroft et al. 2013; Mustafa et al. 2018). Hive splitting is a common method of hive propagation used to create two stingless beehives from one colony (Heard 1988; Mythri et al. 2018; Mounika et al. 2019; Shilan et al. 2022). Splitting hives expose colonies to the outside environment and can introduce physical and biological pressures to the colony. After splitting, colonies must regenerate the worker population in each half of the split hive (Heard 1988, 2016). It takes approximately 50 days to complete the process of egg-laying to the emergence of an adult bee, after which a new bee will progress from a "house bee" (provisioning brood cells, removing waste, guarding entrancing) to a "field bee" (resource foraging) near the end of its approximately 100-day life span (Roubik 1992; Heard 2016). Roubik (1992) found that complete turnover of the worker population occurs every 40–50 days. Hive splitting requires a colony to replenish stores of plant resins used to reconstruct and repair damaged hive structures and defend the compromised hive. The colony also needs to replace lost stores of pollen and nectar. To date, no study has examined how stingless bee colonies alter their foraging behaviour in response to hive splitting. Furthermore, there is no information on the length of time it takes for foraging to recover after splitting.

The aim of our study was to assess how the foraging behaviour of the stingless bee species *Tetragonula carbonaria* responds after hives are split. This species is commonly used for crop pollination on the east coast of Australia (Heard 1999; Heard and Dollin 2000; Slaa et al. 2006; Halcroft et al. 2013; Ramírez et al. 2018). We had two main research questions: (1) How does hive splitting affect total, pollen, nectar and resin foraging trip numbers and how long does it take the number of foraging trips to recover? and (2) How does hive splitting affect colony foraging allocation (as measured by proportion) to pollen, nectar and resin and how long does the colony take to recover? This research will lead to a greater understanding of how the hive splitting propagation technique modifies the foraging behaviours of *Tetragonula carbonaria* and provide insights into recovery times of colonies following a splitting event. In turn, this knowledge can also improve the management and effectiveness of hives used for pollination.

2. METHODS AND MATERIALS

2.1. Study site and stingless bees

Our study was conducted on a commercial macadamia farm located approximately 10 km NE of Bundaberg (−24.769058° S, 152.270949° E), QLD, Australia. The site consisted of 30 rows of the “A16” macadamia cultivar (located within a larger farm of 65 ha). Tree and row spacing were 4 m and 7 m, respectively. Each row was approximately 400 m long. A windbreak of *Corymbia trachyphloia* (brown bloodwood) was located approximately 10 m from the study block’s eastern boundary and 60 m from the closest study hive. Twelve stingless beehives containing colonies of *T. carbonaria* were initially installed at the study site on the 2nd of September 2020 and placed on cement blocks approximately 20 cm off the ground, with all hive entrances facing north. Hives selected for the experiment weighed between 2 and 4 kg (excluding hive box weight). This weight indicates that the internal hive structure (brood and stored

resources) and colony population occupy $\geq 70\%$ of the hive volume, a size where the colony may undergo fission naturally. Each hive was also required to have a foraging rate of at least 20 returning foragers per minute (Heard 2016; Kaluza et al. 2018). Hives were installed 7 days prior to the start of the period of mass flower for macadamia (Trueman et al. 2022) in the block, though hives still had access to floral resources within their foraging range. Macadamia flowers provide an abundance of both pollen and nectar sources for foraging bees in the mass flowering period (Heard 1994; Wallace 1994; Trueman et al. 2022). Hive installation coincided with the onset of the macadamia mass flowering period; hence, the available pollen and nectar sources massively increased during the experiment. Our study site offers low diversity and abundance of floral resources when macadamia is not flowering (Kaluza et al 2016, 2017; Wilson et al. 2021). Stingless bees are known to be resource exploiters (Bartareau 1996) and are also known to massively increase pollen foraging rates (more than double) in macadamia mass flowering periods (Heard 1994; Wallace 1994). Six hives were placed into each of two rows, and the hives were in rows that were located approximately 50 m apart. Hives were spaced 50 m from each other within each row, starting 50 m into each row to avoid edge effects. The potential edge effect within our study refers to the increased sunlight intensity on the end of each macadamia row, which may prompt a colony placed in this position to forage earlier or more intensely due to the increase in direct sunlight and hence temperature (Heard and Hendrikz 1993).

2.2. Hive splitting protocol and forager counts

Observations of hive forager activity were carried out on 15 days over a 45-day period between the 9th of September 2020 and the 23rd of October 2020. Observations commenced 7 days after hives were placed in the study site. The number of returning foragers carrying pollen, nectar or resin was recorded

at the hive entrance for a 5-min period in the morning between 0900 and 1100 h and in the afternoon between 1300 and 1500 h, totalling 10 min for each hive on each day. These observation periods were chosen based on reported peak stingless bee foraging periods in the literature (Heard and Hendrikz 1993; Heard 1994; Wallace 1994). Pollen and resin foragers were identified via resource loads carried on their corbiculae and nectar foragers were identified via a lack of carried resources and a distended abdomen. Note that a very small number of the foragers identified as nectar foragers may have potentially been returning worker bees removing waste from the hive, as they too may have a distended abdomen and an absence of pollen or resin on their corbiculae. Foraging counts for all 12 study hives were conducted for 4 days over the 2 weeks prior to splitting. The order in which counts were conducted was randomised to account for potential differences in foraging behaviour based on sampling time. Of the 12 study hives, 6 were randomly selected to

remain unsplit (control), and 6 hives selected to be split (treatment). Therefore, 18 hives were examined in total (6 unsplit, 12 split). Hives were split on the 22nd of September 2020, 21 days after the hives were installed. Hive splitting involves the colony being split in two, and each split half then receives an empty top or bottom box (Figure 1) (Heard 1988, 2016). The half that was given a new entrance was left in the original position, and the hive with the original entrance was moved approximately 2 m away; this distance was maintained for the experiment (Heard and Dollin 2000; Heard 2016). Care was taken to ensure the presence of a queen in one half of the split colony and the presence of queen cells in the other. Often stingless bee colonies will allow one or multiple virgin queens to live within the hive at the same time as the laying queen, as a precautionary measure in the case that the laying queen dies (Roubik 1992; Heard 2016). Colonies also regularly construct and provision queen cells on the outer edge of the brood chamber



Figure 1. Hive splitting protocol. **a** Hive of *Tetragonula carbonaria* (right) is full and the splitting target (mother colony). The empty box (left) is used during the splitting process. **b** Full hive is opened with hive tool. **c** The two sections of the hive are separated, leaving approximately half of the brood and stored resources in each section. **d** The full top section is coupled to an empty bottom box. **e** Hive margin cleaned of debris, spilled honey and bees. **f** Full bottom section of hive coupled to empty top box, completing the splitting process and resulting in two independent colonies from the original mother colony.

to allow them to quickly rear a new queen if needed (Wille 1983; Roubik 1992; Imperatriz-Fonseca and Zucchi 1995).

After splitting, forager counts were conducted as described above on all hives on days 1–3, 7–9, 15–16, 23–24 and 31 (11 observation days). Forager counts were conducted on fine sunny days conducive to bee foraging (Heard and Hendrikz 1993), with temperatures ranging between 22 and 30.3 °C (Online Resource 1). We anticipated a drop in foraging levels of individual split hives, given that the foraging population was essentially halved by the splitting process; however the foraging population will also increase as new bees are reared and contribute to resource collection. Our study species *Tetragonula carbonaria* rears approximately 300 new adults per day (Roubik 1992; Michener 2007; Heard 2016) which means that the foraging population will increase from its initial drop in foragers quite rapidly, particularly when coupled with abundant resource availability (Kaluza et al. 2017; Trueman et al. 2022) and conducive foraging conditions (e.g. temperature) (Roubik 1992; Heard and Hendrikz 1993). Increases in the colony size and hence foraging trips of unsplit hives would be much less noticeable given limitations of colony growth imposed by the volume of the hive boxes already occupied by the colony ($\geq 70\%$) (Heard 2016).

2.3. Statistical analysis

Daily individual resource (pollen, nectar and resin) foraging trips for each hive were calculated by pooling AM and PM (peak foraging periods) observations together for each resource. Pooling of AM and PM foraging trips on pollen allowed us to get an overall measure of daily pollen foraging, as we were most interested in the efficiency of split hives as pollinators of macadamia. Total daily foraging for each hive was calculated by adding the number of foraging trips for all resources (pollen, nectar and resin) observed. The daily proportion of pollen, nectar and resin was then calculated for hive (proportion of foraged resource per day = number of pollen, nectar or resin foraging trips per day/total foraging trips per day).

Data were analysed in two ways: (1) treating split hives as individual hives (analysed separately) to observe foraging behaviour of the split hives now functioning as two independent colonies (and the subsequent regrowth of the foraging population) and (2) combining the foraging numbers of the two halves of each split hive (analysed together) to compare the combined foraging effort (total foraging trips, numbers of pollen nectar and resin foragers and proportions) of the split hives with that observed in unsplit hives.

We tested the effect of splitting (for split hives analysed separately and combined) on total foraging numbers and numbers of resin, nectar and pollen foragers returning using GLMMs with a Poisson distribution and “log” link function. We used *splitting treatment* (split or unsplit) and *day* as fixed effects. Due to significant interactions between *day* and *splitting treatment* (split or unsplit) in all tests, we then tested for differences between unsplit and split hives on each day of observation.

We also tested the effect of splitting (for split hives analysed separately and combined) on the colony foraging activity allocated to resin, nectar and pollen (proportion). We used GLMMs with a quasibinomial distribution and “logit” link function. Due to significant interactions between *day* and *splitting treatment*, we analysed differences in resource foraging for each day separately, again using *splitting treatment* as a fixed effect in our model. R statistical software (version 4.1.2) in the RStudio environment was used for all statistical analysis (R Core Team 2022; RStudio Team 2022).

Medians for total, resin, nectar and pollen foraging trip numbers and foraged proportions (resin, nectar, pollen) are presented with ranges of observed medians.

3. RESULTS

3.1. Total foraging

Contrary to our expectations, halving the foraging population (via splitting) of the split hives led to a more drastic reduction in foraging trips than anticipated. The total number of returning foragers

in split hives (analysed separately) was less than a third of unsplit hives immediately after splitting, until day 16 of observations (unsplit median, 184–288; split median, 19–61). Split hives continued to display significantly lower total returning foragers compared to unsplit hives until day 31 of the experiment (Figure 2). When the total returning foragers of the two halves of the split hives were analysed together (combined), split hives still had less than half of the total foraging trips observed in unsplit hives from days 1 to 9 after splitting (unsplit median, 184–288; split median, 66–111) (Online Resource 2). Total combined foraging in split hives continued to be significantly lower than unsplit hives until day 16 of the experiment. Split hives analysed together showed significantly higher total returning foraging numbers than unsplit hives in only the last 3 days of the experiment (23, 24, 31) (Online Resource 2). Some significant differences for total and individual resource foraging trips were identified between the control (unsplit) and treatment (split) hives prior to splitting; however, these were not consistent (Figures 2, 3, and 4).

3.2. Resin, pollen and nectar foraging trips

Our results show that split colonies also modified foraging on individual resources in response

to splitting. The number of resin foraging trips in split hives dropped in comparison to unsplit hives in 3 days immediately after splitting (split median, 5–9; unsplit median, 7–15). Resin foraging trips were also significantly lower in split hives on days 7 and 9; however, there was no significant difference compared to unsplit hives after day 9 until the end of the experiment (Figure 3a). Nectar foraging trips reduced in split hives after splitting, to less than a quarter of that seen in unsplit hives from days 1 to 9 (split median, 16–28; unsplit median, 89–147). Nectar foraging trips in split hives continued to be significantly lower than unsplit hives until day 31 of the experiment (Figure 3b). The number of returning pollen foragers in split hives was also less than a quarter of unsplit hives from day 1 until day 9 after splitting (split median, 1–7; unsplit median, 55–155). Pollen foraging in split hives continued to be lower than unsplit hives until day 31 of the experiment (Figure 3c).

Resin foraging trips were seen to increase in split hives when foraging trips from both halves were combined and were significantly higher than the unsplit hives from day 7 until day 31 of the experiment (split median, 10–15; unsplit median, 5–9) (Online Resource 3a). Nectar foraging trips for combined split hives were significantly lower from day 1 to day 16 after splitting, with split hives displaying higher nectar foraging

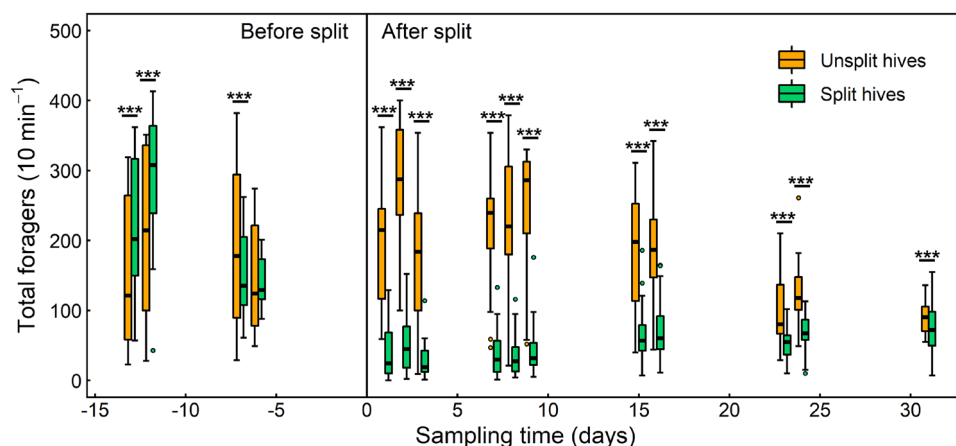


Figure 2. Total foraging trips (halves of split hives analysed separately) per 10 min (AM: 5 min+PM: 5 min) of resin, nectar and pollen combined. Asterisks above boxes denote days where a significant difference was found between unsplit and split hives (* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$). Day 0 indicates the splitting event.

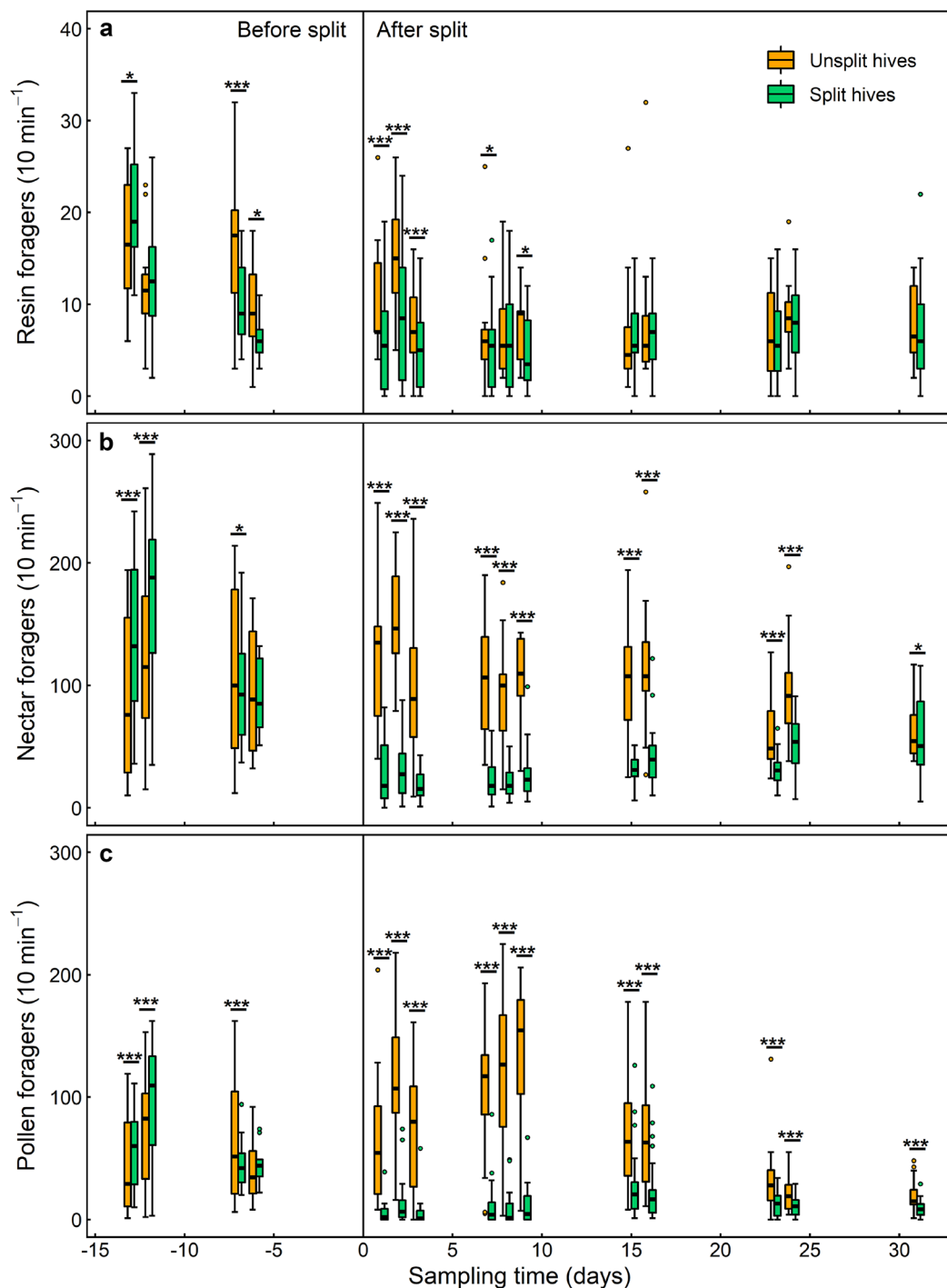


Figure 3. Number of foraging trips observed per 10 min (AM: 5 min+PM: 5 min) for **a** resin, **b** nectar and **c** pollen (halves of split hives analysed separately). Asterisks above boxes denote days where a significant difference was found between unsplit and split hives (* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$). Day 0 indicates the splitting event.

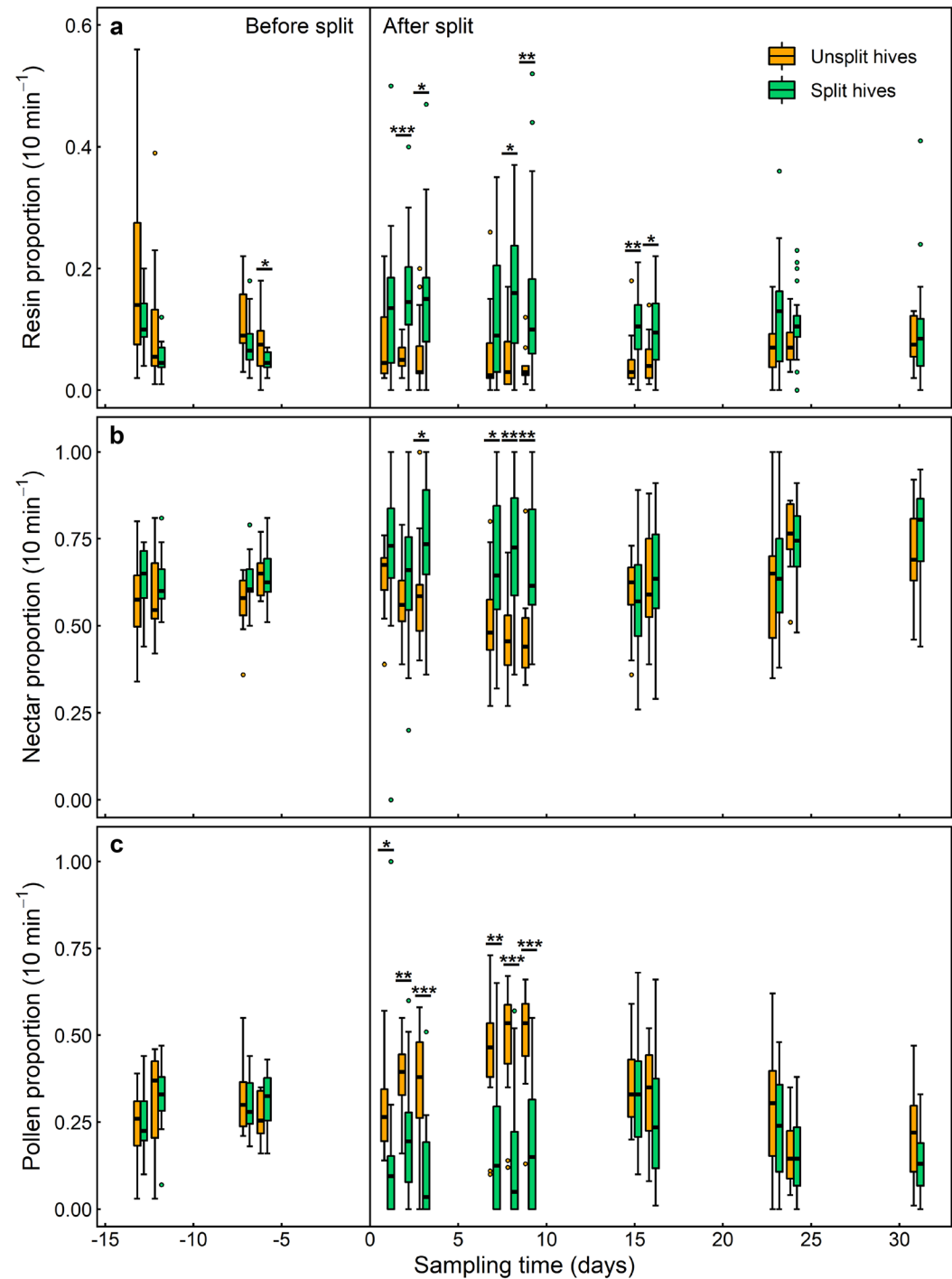


Figure 4. Proportion of **a** resin, **b** nectar and **c** pollen foraging trips observed per 10 min (AM: 5 min + PM: 5 min) (halves of split hives analysed separately). Asterisks above boxes denote days where a significant difference was found between unsplit and split hives (* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$). Day 0 indicates the splitting event.

on the final 2 days of the experiment (days 26 and 31). Pollen foraging trips were significantly lower in split hives from days 1 to 16 after splitting, when foraging trip numbers from the two halves of split hives were combined (Online Resource 3b and 3c).

3.3. Proportions of foraged resources

We found that split hives also altered the colony foraging allocation to resin, nectar and pollen, as measured by the proportions of each resource foraged after splitting. Splitting increased the proportion of trips allocated to resin foraging, and it was significantly higher than in unsplit hives on days 2, 3, 8, 9, 15 and 16 (unsplit median, 0.03–0.05; split median, 0.10–0.16) (Figure 4a). Splitting also increased the proportion of trips allocated to nectar foraging, with split hives being significantly higher than unsplit hives from day 3 to day 9 after splitting (unsplit median, 0.44–0.59; split median, 0.62–0.74) (Figure 4b). The proportion of foraging trips allocated to pollen following splitting was lower in split hives compared to unsplit hives from days 1 to 9 after splitting (unsplit median, 0.27–0.54; split median, 0.05–0.20) (Figure 4c).

Resin foraging proportions for the two halves of split hives combined were significantly higher than unsplit hives from days 1 to 24 after the splitting event (unsplit median, 0.03–0.05; split median, 0.10–0.17) (Online Resource 4a). When the nectar and pollen foraging proportions of the two halves of split hives were analysed together, foraging proportions for these resources displayed similar trends to that of the separate hive analysis (Online Resource 4b and 4c).

4. DISCUSSION

Our results show that splitting stingless bee hives significantly alters the foraging behaviour of the split colonies. Splitting hives greatly reduced total number of foraging trips and numbers of pollen and nectar foraging trips compared with unsplit control hives, and split hives

had still not recovered after 31 days. Splitting hives can cause damage to the nest structure (Heard 1988, 2016), and the drop in total, pollen and nectar foraging numbers suggests that the colonies allocate energy to nest repair, maintenance and defence rather than foraging for floral resources. The significant loss of adult foragers is also a factor impacting foraging trip numbers in split hives. In the splitting process, each colony's foraging population is effectively halved (Heard 1988, 2016). Stingless bees take approximately 50 days to mature from egg to adult worker, and during this time, individuals are not contributing to resource collection (Roubik 1992; Michener 2007; Heard 2016). Therefore, the time needed for replacement adult workers to mature contributes to the length of time it takes for the split colony's foraging population and commensurate trip numbers to recover to unsplit hive levels.

When the two halves of split hives were analysed together, split hives also had less than half the number of total foraging trips compared with unsplit hives for at least 9 days after. In addition, the total number of pollen foraging trips of the two halves analysed together was also still significantly less than the unsplit hives for 16 days after splitting. This indicates that previously active foragers in the split colonies may have changed tasks from foraging to duties within the hive such as repair and maintenance. Other studies have shown that colony individuals may change tasks based on age (Roubik 1992), caste (Hartfelder et al. 2006; Hammel et al. 2015), changes in resource availability (Hofstede and Sommeijer 2006) and disturbance (Leonhardt and Bluthgen 2009). The reduction in pollen and nectar foraging trips may impact the production of brood and hence colony growth, as stingless bees have shown to regulate brood production based on the quantity of stored pollen and nectar required for the mass provisioning of brood cells (Biesmeijer et al. 1999; Maia-Silva et al. 2016). Reduced nectar foraging trips can reduce the amount of the stored energy source for foraging workers. Reduced nectar intake may also impact wax production within the colony, which is mixed with resin to construct and repair nest structures (Roubik 1992; Michener 2007). The effect of hive splitting on resin foraging trips

in split hives was less pronounced than that seen for nectar and pollen. Resin foraging trips initially reduced after splitting (split hives analysed separately); however, after only 9 days and until the end of the experiment, they were not significantly different from the unsplit control hives. This indicates that resin foraging trips recovered relatively quickly for this resource, likely driven by the critical role the resource plays within the nest. Furthermore, when the two halves of the hives were analysed together, resin foraging increased after splitting and was significantly higher than in the unsplit control hives from days 7 to 31. Resin is known to play a vital role in stingless bee nest construction and maintenance and is mixed with wax to build all structures within the nest (Wille 1983; Roubik 2006; Michener 2007). Splitting can damage many of these structures, including brood cells, resource storage pots and the protective seals which prevent antagonist insects from entering through the joined hive sections (Heard 1988, 2016). In addition, the colony in each half of the split hive needs to rebuild structures lost in the splitting such as resource storage pots and progressively fill the empty space within the new hive. Resins also aid in hive defence via their physical and chemical characteristics (volatile and non-volatile compounds), which helps to repel insects and protect against environmental pathogens that the colony can be exposed to during and after splitting (Greco et al. 2010; Simone-Finstrom and Spivak 2012; Leonhardt 2017; Wang et al. 2018; Shanahan and Spivak 2021). Our results suggest that resin foraging was prioritised over pollen and nectar to enable rapid hive rebuilding, maintenance and defence.

The proportion of foraging activity allocated to pollen also reduced immediately following splitting, only recovering to levels seen in unsplit hives after 15 days (hives analysed separately). In contrast, the proportion of resin foraging increased immediately following splitting and remained significantly higher than the unsplit hives until day 16 of the experiment (hives analysed separately). When observing the resin foraging proportion of the combined halves of split hives, we found a further resin proportion increase in

response to splitting. Split hives also remained significantly higher than the unsplit hives until day 31 of the experiment; further evidence that the splitting disturbance stimulated the split hive colonies demands for resin. Studies have shown that environmental conditions (Leonhardt et al. 2014; Aleixo et al. 2017), resource availability (Kaluza et al. 2016; Wilson et al. 2021) and inter-species behaviour (Leonhardt et al. 2014) can lead to differences or drive changes in the proportions of foraged resources including resin. Leonhardt and Blüthgen (2009) found significant increases in foraged resin proportions in stingless bees following ant attack and intentional destruction of hive entrance tunnels. Our study results show a similar strong increase in resin proportions, driven by physical disturbance and the need to defend the hive from opportunistic insects seeking to exploit the weakened hive.

In conclusion, our results demonstrate that while hive splitting is an effective stingless bee propagation method, it significantly impacts the foraging behaviour of the disturbed colonies and requires significant recovery time. Colonies in newly split stingless beehives do not forage strongly on pollen, despite an abundance of available floral resources. Hive colonies appear to prioritise hive repair and protection while maintaining or increasing resin foraging. This suggests that hives will be at less effective for pollination services in this recovery period. Based on our results, we would recommend that stingless bee pollination hives should not be split within 31 days prior to pollination and potentially longer to ensure effective pollination in the target crop.

SUPPLEMENTARY INFORMATION

The online version contains supplementary material available at <https://doi.org/10.1007/s13592-023-01018-8>.

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AUTHOR CONTRIBUTION

RN, HW, CF: study conception and experimental design; RN, JN, RW, CF: fieldwork; RN wrote the paper; MF, SHB, and all other authors were involved in data interpretation and manuscript revisions.

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DATA AVAILABILITY

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

CODE AVAILABILITY

Not applicable.

DECLARATIONS

Ethics approval Not applicable.

Consent to participate Not applicable.

Consent for publication The authors affirm that consent was given for the use and publication of the image contained in Figure 1 by Tim Heard, Sugarbag Bees, Brisbane, Australia.

Competing interests The authors declare no competing interests.

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