Manaaki Whenua
Landcare Research

Feasibility study on the value of semiochemical lures for dama and Bennett's wallabies

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Feasibility study on the value of semiochemical lures for dama and Bennett's wallabies

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Summary

Bennett's wallabies (*Notamacropus rufogriseus*) and dama wallabies (*N. eugenii*) are invasive mammalian herbivores that cause agricultural damage and negatively affect native vegetation in New Zealand. Toxic cereal baiting is the primary tool available to control them, although bait uptake can be low where animals are at low densities or alternative food is plentiful.

Regardless of pest densities or food availability, wallabies need to communicate their presence and social standing to find mates and maintain territories. This reliance on sensory cues creates an opportunity to exploit semiochemicals (chemical compounds released by an organism that modify the behaviour of the receiver) to increase bait uptake and detection of wallabies.

Manaaki Whenua – Landcare Research (MWLR) was contracted by the Ministry for Primary Industries (MPI) to undertake a feasibility study on the research value of developing and testing semiochemical lures (including pheromones) for dama and Bennetts's wallabies. The literature review suggests that semiochemical lures from conspecifics (i.e. pheromones) could be a promising avenue for future research. Scents from predators (i.e. kairomones) do not show much promise as a method for increasing bait uptake, but could be deployed in a trapping context or to protect valued resources.

Objectives

To assess the value of semiochemical-based lures for dama and Bennett's wallabies, we completed a literature review to:

- assess the role of pheromones and kairomones in intra- and inter-specific interactions in wallabies and other macropods
- evaluate the role of scent-marking behaviours of wallabies for intraspecific communications
- determine the feasibility of, and approaches to, chemical analysis of semiochemicals, and the feasibility of assessing the attractiveness of semiochemicals in pen trials and field experiments.

In addition to the outlined objectives, we completed opportunistically a captive trial to test the responses of Bennett's wallabies to semiochemicals from conspecifics (odours from males and females).

Methods

We searched Web of Science and Google Scholar databases for relevant literature using all possible combinations of six keywords related to wallabies and olfactory communication. We also reviewed internal scientific reports by Manaaki Whenua – Landcare Research (MWLR). We retained papers that focused on macropod species as study animals and acquired further literature from the reference lists of these papers. An additional search was done using the combination of 'marsupials' and olfactory communication keywords.

Results

The literature review revealed a knowledge gap in the role of olfactory communication in macropods. However, given the importance of olfactory communication to wallabies, our review supported the proposition that semiochemicals could be useful in a management context by demonstrating that:

- wallabies have highly developed olfactory organs from birth
- male and female wallabies engage in olfactory-mediated behaviours during the mating season
- male wallabies' reproductive hormones change after exposure to female scents
- dama wallabies have the most complex suites of compounds in their sternal gland secretion of 18 marsupial species tested.

We outline an experimental approach to identify and test wallaby semiochemicals, including potential costs and timeframes to completion. Research to identify and test attractive compounds on wallabies could be completed within 2 to 3 years.

Our captive pilot trial revealed that wallabies' feeding rates were influenced by conspecific odour. Non-toxic baits were eaten more expediently in the presence of odour from a female (non-oestrous) wallaby. Male odour had the opposite effect, increasing the time taken for wallabies to commence feeding at odour stations that were treated with male scent.

1 Introduction

Dama (or tammar) wallabies (*Notamacropus eugenii*) and Bennett's wallabies (*N. rufogriseus*) are invasive pests in New Zealand. They have a negative impact on the structure and diversity of native forests, consume pasture, and damage conifer seedlings in production forests. Bennett's wallabies were liberated near Waimate in 1874 and have increased to high densities in release areas and expanded to have low-density populations outside their designated containment area in Canterbury and Otago (Latham & Latham 2022). Dama wallabies were liberated in Rotorua district in the early 20th century and have since expanded their geographical range in the region (Latham & Warburton 2021).

Dama and Bennett's wallabies are primarily grazers, supplementing their diet with browse when in scrub and forests (Latham & Warburton 2021). Feeding activity is predominantly crepuscular and nocturnal. As significant agricultural pests, wallabies have been subjected to ongoing control and management, including shooting and toxic baiting (Eason et al. 2010).

Olfactory cues are important information sources that help animals locate resources, and they are also used for intra- or inter-specific communications (Amo & Bonadonna 2018). Scents, or odours, are often left by an animal intentionally through deposition of gland secretions, or unintentionally through excretion of metabolic waste (Wyatt 2003). These scents contain semiochemicals (chemical compounds released by an organism that modify the behaviour of the receiver) that convey information about the identity, sex, and breeding and social status of the donor (Burger 2005; Wyatt 2014; Marneweck et al. 2017).

Pheromones (scents deposited by an individual that trigger a social response in members of the same species) are semiochemicals that facilitate intraspecific communications, and they are commonly used for territorial marking and attracting mates (Soso et al. 2014; Wilson et al. 2018). Kairomones (scent deposited by one species that benefits another), on the other hand, influence interspecific interactions and can trigger 'eavesdropping' behaviour among different species (Schoeppner & Relyea 2009; Garvey et al. 2016). Because gathering information on conspecifics and heterospecifics is important for breeding success and survival, semiochemicals could be exploited to improve animal detection or to increase bait uptake for wildlife management purposes (Garvey et al. 2017; Smart et al. 2014; Suckling 2015; El-Shafie & Faleiro 2017).

Food-based lures are the primary attractant deployed for invasive species management in New Zealand. Food lures are effective when there is limited availability of natural food sources, but are less effective when intraspecific competition is low (e.g. when pest populations are at low densities after control) or where there are seasonally abundant natural food sources (Morgan 1982; Gronwald & Russell 2020).

Semiochemical-based lures might provide a way to help increase interaction rates, because animals must maintain olfactory communications regardless of food availability (Foley et al. 2018). Studies on the identification of semiochemicals from animal scents and the development of semiochemical-based lures have emerged in recent years (e.g. Clapperton et al. 2017). For example, ferret scent has been shown to increase the number of stoat detections and the time stoats spend at monitoring stations (Garvey et al. 2017), and bedding from stoats has been effective for trapping reinvading stoats (Williams 2022) and in a stoat eradication programme (Te Korowai o Waiheke 2022).

Attention has also been given to extracting and understanding the role of sex pheromones in possum behaviour (Duckworth & Brown 2015; Mockett 2017). Nevertheless, while many studies have focused on invasive predators, understanding of the role and attractiveness of scents in invasive herbivores remains limited, prompting the need for new research.

2 Objectives

To assess the value of semiochemical-based lures for dama and Bennett's wallabies, we completed a literature review to:

- assess the role of pheromones and kairomones in intra- and inter-specific interactions in wallabies and other macropods
- evaluate the role of scent-marking behaviours of wallabies for intraspecific communications
- determine the feasibility of, and approaches to, chemical analysis of semiochemicals, and the feasibility of assessing the attractiveness of semiochemicals in pen trials and field experiments.

In addition to the outlined objectives, we opportunistically undertook a captive trial testing whether semiochemicals from male and female Bennett's wallabies influence bait uptake by conspecifics.

3 Methods

We searched Web of Science and Google Scholar databases for relevant literature using all possible combinations of six keywords related to wallabies and 10 keywords related to olfactory communication (Table 1). We retained papers that focused on macropod species as study animals and acquired further literature from the reference lists of these papers.

An additional search was done using the combination of 'marsupials' and the 10 olfactory communication keywords due to the paucity of literature from the initial search. To assess the feasibility of developing, testing, and conducting semiochemical lure trials, we reviewed the literature on keywords 'invasive mammalian species', 'semiochemicals', and 'lures', and retained papers with studies conducted in Australasia. We also reviewed internal scientific reports by Manaaki Whenua – Landcare Research (MWLR).

Table 1. Keywords for literature search

Category	
Wallaby	**Olfactory communication**
Dama wallaby	scent marking
Tammar wallaby	olfactory cue
Bennett's wallaby	body odour
Notamacropus/Macropus eugenii	pheromones
Notamacropus/Macropus rufogriseus	kairomones
Macropodidaec	semiochemical
	attractants
	volatile compounds
	intraspecific communications
	interspecific communications

4 Results

4.1 Literature review

4.1.1 Semiochemical-based lures for dama and Bennett's wallabies

A literature search using keywords (Table 1) resulted in a total of 31 papers, with 14 studies on pheromones and scent-marking behaviours and 17 on kairomones and interspecific communications. Among the 14 scent-marking studies, seven were focused on dama wallabies, one on Bennett's wallabies, one on parma wallabies (*N. parma*), and six on macropods in general. Among the 17 papers on kairomones and interspecific communication in macropods, only five were focused on either dama or Bennett's wallabies.

All studies on kairomones assessed the behaviour of macropods in response to either novel or familiar predator scents. We did not find empirical studies investigating interspecific olfactory communications between macropod species, except for one that examined the foraging behaviour of Bennett's wallabies in response to the faeces of grey kangaroos to investigate interspecific transmission of parasites. Additional searches for papers using 'marsupials' as a keyword generated nine results, with most studies focusing on the grey short-tailed opossum (*Monodelphis domestica*) and brown antechinus (*Antechinus stuartii*), a marsupial mouse.

4.1.2 Olfactory systems, pheromones, and scent-marking in wallabies and macropods

The olfactory systems of macropods are well developed at birth despite other senses being underdeveloped (Salamon et al. 1999; Schneider et al. 2009). Schneider et al. (2008) examined the vomeronasal organ of newborn dama wallabies and showed that the organ and the olfactory epithelium are capable of detecting odour at birth. In that study, neonates preferred to climb towards swabs containing gland secretions from their mother over a saline control.

The olfactory bulbs, a neural structure involved in olfaction, are relatively large in adult macropods, sometimes comprising half of the forebrain (Delbridge et al. 2010; Salamon et al. 1999). This suggests that olfaction is an important sense for macropods, especially nocturnal and solitary species such as Bennett's wallabies, which rely on olfaction to detect food, predators, and conspecifics. Wallabies might be able to recognise a wide range of odours, as their genomes comprise over 1,500 olfactory receptor genes (e.g. 1,753 in dama wallabies), which is one of the highest numbers of any mammal (Delbridge et al. 2010).

Scent glands are common in macropods, located in the mouth, pouch, sternum, and cloacal region (Salamon et al. 1999). Dama wallabies have the most complex suites of compounds in their sternal gland secretion of 18 marsupial species tested, including seven macropods (Zabaras, Richardson et al. 2005). A total of 32 compounds were found in the sternal gland secretion of dama wallabies, with seasonal differences in the long-chain alkanes of females (Zabaras, Wyllie et al. 2005).

We found no reports of scent-marking behaviour in dama or Bennett's wallabies. However, this behaviour has been observed in other macropods, such as eastern grey kangaroo (*Macropus giganteus*), common wallaroo (*Osphranter robustus*), and gray forest wallaby (*Dorcopsis luctuosa*), which rub their chests against shrubs and trees to deposit sternal gland secretions (Jarman 1991; Cooper et al. 1999).

Olfactory communication appears to be important in the breeding behaviour of macropods. Male rock wallabies have been observed scent-marking objects with their chest during the breeding season (Cooper et al. 1999). Male dama wallabies are known to check the reproductive status of females through sniffing the urogenital and pouch regions, and they exhibit the characteristic 'flehmen response' during investigation. The flehmen response, whereby an animal inhales with the mouth open and upper lip curled to facilitate exposure of the vomeronasal organ to a scent or pheromone, is a common behaviour in mammals (Rudd 1994; Rose 2022). Male dama wallabies also show more interest in odour samples collected from the urogenital opening and pouch of oestrous females compared to non-oestrous females (Schneider et al. 2008; Schneider et al. 2010).

Despite being seasonal breeders, the levels of testosterone and luteinising hormone in male dama wallabies increases in the presence of females in oestrous and post-partum ovulation, even outside the breeding season (Inns 1982; Schneider et al. 2008). Dama and Bennett's wallabies, and the unadorned rock wallaby (*Petrogale inornata*), are the only macropod species showing mating behaviour within hours post-partum (Rudd 1994), suggesting the important role of female pheromones and chemical communication in the initiation of breeding in these species.

4.1.3 The role of kairomones in communication

Sharp et al. (2015) investigated the role of olfactory communication in parasite avoidance by Bennett's wallabies. Wallabies foraged less when food was contaminated with wallaby faeces compared to western grey kangaroo faeces, although they approached and sniffed both prior to selecting a food. The authors argued that wallabies share more similar gastrointestinal fauna with conspecifics than with heterospecifics, which is why odours from the former trigger greater avoidance responses.

Apart from the above study, literature on kairomones was focused on predator–prey dynamics between native Australian macropods and a native predator, the dingo (*Canis lupus dingo*) or novel invasive predators (cat, *Felis catus*; domestic dog, *Canis lupus familiaris*; and red fox, *Vulpes vulpes*). Macropods showed either anti-predator behaviours in response to predator olfactory cues or no differences in their behaviour, so predator odour was not an attractant. For example, dama wallabies increased their ventilation frequency in response to odours from cats and foxes (Mella 2009; Mella et al. 2010) and moved away from areas treated with lion odours (Cox et al. 2015), while Bennett's wallabies reduced foraging and avoided crossing boundaries treated with urine from foxes and dogs (Gibson 2008).

Similar findings were reported for other macropods, with parma wallabies avoiding areas treated with urine from a novel predator (Ramp et al. 2005). In a subsequent study, parma wallabies displayed fleeing and vigilance behaviour in response to dingo urine (Parsons & Blumstein 2010a). However, Blumstein et al. (2002) reported contrasting results, in which dama wallabies did not respond aversively to scents from foxes and dingos.

Interestingly, although none of the studies suggested attraction to predator olfactory cues, most study animals were observed approaching and sniffing the olfactory cues before displaying aversive responses (Ramp et al. 2005; Gibson 2008; Parsons & Blumstein 2010b; Heise-Pavlov et al. 2013; Mella et al. 2014; Cox et al. 2015). However, aged and degraded scent from dingo urine failed to trigger investigative behaviour from western grey kangaroos (Parsons et al. 2012).

4.1.4 Feasibility of pen/field trials and chemical analyses

The methods used to understand the behavioural responses and preferences of mammals to external stimului (including scent) are well established for both pen and field trials. Among 12 studies from the literature search that included behavioural trials, six were conducted in the field and six in captivity. Among the six captive trials, four were conducted on smaller-sized species, including dama and Bennett's wallaby, in pens with areas ranging from 30 m^2 to 200 m^2 (Ramp et al. 2005; Gibson 2008; Blumstein et al. 2002; Parsons & Blumstein 2010b).

In New Zealand, dama and Bennett's wallabies are more often studied in the field. However, two pen trial studies on the acceptance and palatability of toxic baits by Bennett's wallabies (Coleman 1997) and dama wallabies (Morris & Connor 2000) were successfully completed, with another Bennett's wallaby pen trial currently underway at MWLR. Wallabies can be captured in the field using helicopter-based net-gunning or ground-based netting, with the former incurring higher cost but lower mortality (Latham et al. 2019).

Chemical analyses of semiochemicals can be done using gas chromatography mass spectrometry (GC-MS), which allows for the identification of individual compounds. Zabaras, Richardson et al. (2005) and Zabaras, Wyllie et al. (2005) used GC-MS to identify chemical compounds in sternal gland secretions from 18 different species of marsupials and reported a great disparity in chemical composition between species.

Studies on macropods are limited, but the application of semiochemicals to invasive species management is rapidly developing. Duckworth and Brown (2015) used GC-MS to identify volatile compounds in the urine of possums and tested the attractiveness of selected compounds in both pen and field trials. Garvey and Norbury (2018) used the same technique to identify chemical compounds from ferrets (*Mustela furo*) and conducted a pen trial on stoat behavioural responses. Results from these studies showed that the suite of semiochemicals can vary between species, individuals, sexes, and reproductive status, which can result in different responses from the animals encountering the compounds. In addition, a single compound might not be as effective as multi-component compounds in attracting animals, as multiple compounds might convey the more complex information required to trigger a behavioural response (Apfelbach et al. 2015; Duckworth & Brown 2015; Garvey et al. 2017).

4.2 Pilot study

We undertook a pilot study to test the feeding responses of Bennett's wallabies in the presence of semiochemicals from conspecifics. Our study was opportunistic, as wallabies were being held in captivity at Manaaki Whenua – Landcare Research for a toxin trial. We presented olfactory cues (straw bedding) collected from a male and a female wallaby to the test animals. Bedding material probably contains semiochemicals from three sources (urine, faeces, body odour) that may individually or collectively influence wallaby foraging decisions. Our two research questions for this pilot study were:

- Do wallabies respond to the semiochemicals (male/female) of conspecifics?
- Does conspecific odour influence feeding behaviour?

4.2.1 Methods

We tested the feeding behaviour of nine wallabies (three males and six females) in response to female (non-oestrous) and male wallaby scent. Wheat-straw bedding containing wallaby scent was collected from one male and one female animal hosted at the facility a month prior to our trials. The two wallabies that donated scent were not tested in this behavioural trial.

Double-tray dog bowls were used for the trial and each dog bowl had two dishes. A hundred grams of wallaby feed was placed in one dish of each bowl every day for 1 week to acclimatise wallabies to feeding from bowls.

The behavioural trial was conducted for two nights. Two feeding bowls were placed at opposite ends of each wallaby holding pen, and a trail camera was placed in front of each bowl to record wallaby behaviour. During the first trial night, the treatment dog bowls received a handful of bedding containing male wallaby scent in one dish, coupled with 100 g of wallaby feed in the second dish. In the control bowl (opposite side of pen), new bedding (i.e., no wallaby scent) was placed in one dish, coupled with 100 g of wallaby feed in the second dish.

During the second trial night the treatment dog bowl received bedding containing female wallaby scent in one dish, plus 100 g of feed in the second dish, while the control bowl received new bedding (no scent) plus 100g in the second dish. We measured two variables: food remaining (i.e. giving-up-densities) and time taken to feed after first approach.

4.2.2 Results

Male scent reduced the feeding behaviour of both male and female wallabies (Figure 1). Feeding bowls treated with male scent and the control bowl used during that trial night both had more food remaining than the treatment and control bowls when female bedding was tested (Figure 1). Food remaining was lower at bowls with control (no scent) for both nights, except for male wallabies exposed to female scent (Figure 1).

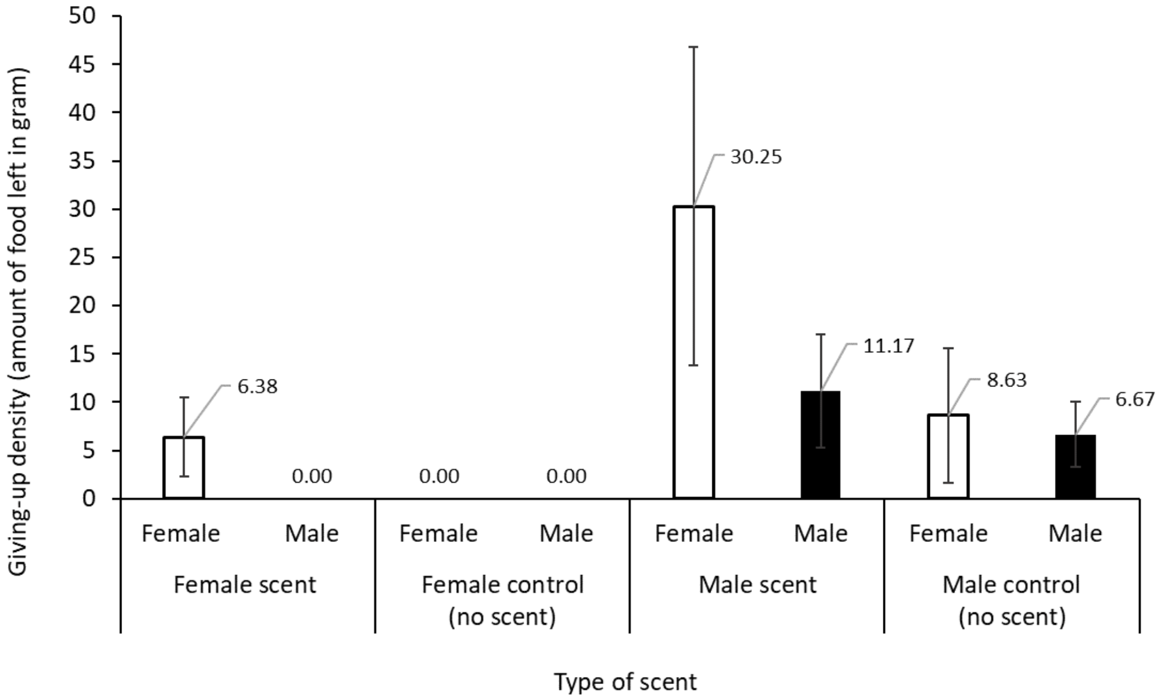

Figure 1. Giving-up density of wallabies after exposure to different types of scents.

Wallabies (males and females) took less time to start feeding at the female-scented treatment bowl compared to the control bowl on the same night. This effect was more pronounced in male wallabies, which took less than 10 seconds on average to start feeding at the female-scented treatment bowl, compared to an average of 96 minutes to feed at the control bowl on the same night. In contrast, both male and female wallabies took longer to start feeding after approaching male scent compared to the control (Figure 2).

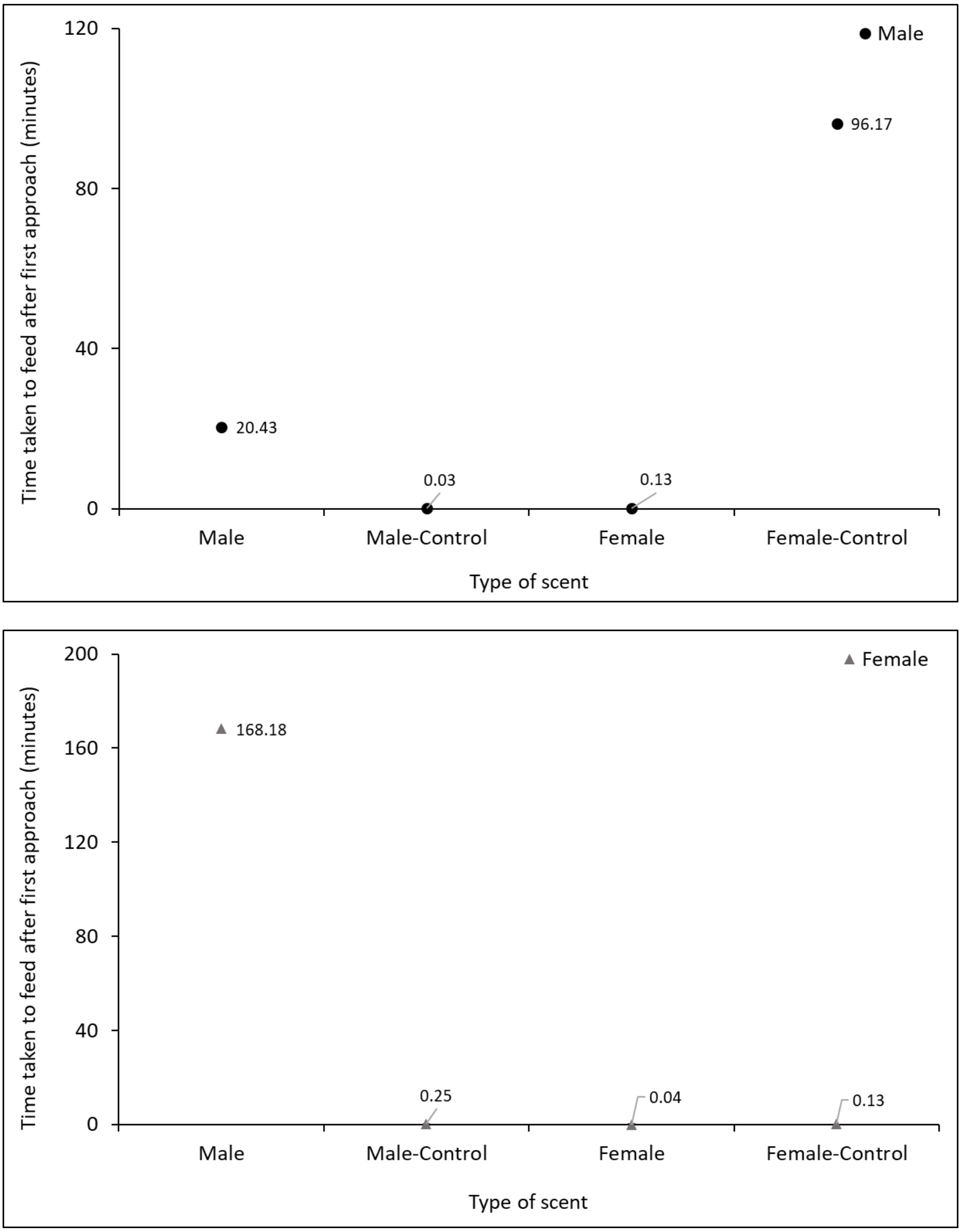

Figure 2. Time taken for male (top) and female (bottom) wallabies to feed after first approach to the feeding bowls containing different types of scent. Points represent the mean; SD was too small to display.

5 Discussion

5.1 Literature review on semiochemicals (Objectives 1 & 2)

The literature review revealed a knowledge gap in the role of olfactory communication in macropods. However, given the importance of olfactory communication for wallabies, our review supported the proposition that semiochemicals could be useful in a management context by demonstrating that:

- wallabies have highly developed olfactory organs from birth
- male and female wallabies engage in olfactory-mediated behaviours during the mating season
- male wallabies' reproductive hormones change after exposure to female scents
- dama wallabies have the most complex suites of compounds in their sternal gland secretion of 18 species tested.

While scents from predators can attract prey (Banks et al. 2014; Li et al. 2014), it is not evident in macropod species, as most either avoid or ignore predator scents after initial investigation. This implies that kairomones from predators might not be suitable for developing a long-term lure for wallabies.

Scents from sympatric species have only been tested on wallabies in a food contamination context (Sharp et al. 2015). However, there is overwhelming evidence of eavesdropping behaviour on olfactory cues from sympatric mammalian species (e.g. stoats and ferrets; Garvey et al. 2016), Norway rats and house mice (Varner et al. 2020), and voles (Hughes et al. 2010). Behavioural responses of wallabies to kairomones from sympatric wallaby species thus warrant further investigation.

5.2 Developing a synthetic lure based on wallaby semiochemicals (Objective 3)

5.2.1 Overview

Despite the lack of studies on the application of pheromones as lures for macropods, it has been successfully demonstrated in brushtail possums. Like macropods, possums possess sternal and urogenital glands, and exhibit scent-marking behaviours (McLean 2014). Mockett (2017) extracted 12 semiochemicals from possum urine and demonstrated that two compounds increased the duration of interaction of possums with lures. Similarly, Duckworth and Brown (2015) selected six compounds from possum urine, of which two increased the number of approaches and duration of interactions with lure stations by possums.

Finally, MWLR have developed a synthetic lure for stoats and weasels derived from the odour of a competition mustelid (ferret). Seven compounds were identified that increased stoat captures in field trials, with lures doubling captures rates at established trapping operations (Project Janzsoon and Ark in the Park). This lure will soon be commercially available in New Zealand with products sold by Orillion. These successes suggest the possibility of applying similar techniques to identify attractive compounds in conspecific and sympatric species' odours for a wallaby semiochemical lure.

5.2.2 Wallaby bioassay

In our pilot trial in captivity we tested the behavioural responses of wallabies to male and female odour samples (body odour, scat, urine). For a future study we could individually test semiochemicals from each source (urine, scat, body odour) and randomise the order of exposure to ensure there are no carryover effects.

We would assess wallaby behavioural responses using the following four variables: (i) latency until first approach, (ii) time spent at treatment patch, (iii) number of visits to patches, (iv) quantity of bait eaten. As part of this study we could evaluate how dama and Bennett's wallaby respond to semiochemicals of the other species. Wallabies are closely related, and the semiochemicals of a competing wallaby may warrant investigation. Hybridisation can occur in wallabies (Kirsch et al, 2010), so the semiochemicals of another wallaby species may be attractive due to commonalities in the scent profiles of wallaby species. In mustelids, the scent of a competition mustelid can drastically increase interactions (Garvey et al. 2017), so this could be a promising avenue of research.

We have opportunistically collected samples from six Bennett's wallabies (three females and three males) from their sternal gland and cloacal gland. These samples can be used to run preliminary tests on responses to different odour sources in pen or field trials.

5.2.3 Compound identification

We will follow the protocol used to develop the synthetic lure for stoat control. Odour-impregnated material collected from wallabies can be analysed by GC-MS to identify the key chemical components that influence attraction to conspecific odours. We will first collect odour samples on cotton towels from the sternal and urinogenital glands of male and female wallabies that are under sedation. A urine and scat samples will also be collected from each individual wallaby. Each towel sample will be divided in two: one piece for the wallaby bioassay (pen trials to determine the most attractive donor scent), and the second for GC-MS analysis. MWLR has a state-of-the art GC-MS machine capable of measuring and standardising multiple samples to ensure consistent compound identification.

Two approaches could be used to identify attractive compounds and compound ratios. For the first approach, important compounds can be identified by comparing the GC-MS of wallaby samples using retention time, peak area, and percentage similarity. We would distinguish between compounds from males and females and identify general compounds common to both sexes. We can then compare the most attractive donor samples with samples from less attractive individuals to pinpoint the compounds and volumes that provoke attraction.

An alternative approach would compare the ratios of compounds in samples to identify signals based on GC-MS outputs. Compound ratios can be as important a signal as the compounds themselves, as consistently tight ratios between two compounds provide reliable signals for detecting individuals. We would work with collaborators in Australia who have developed the ratio method to identify pairs of important compounds. Analysis of the donor samples (GC-MS outputs) could quickly identify the most important compound pairs, which could then be developed into a lure.

5.2.4 Developing a synthetic lure

For the final stage of a potential study, we could test our top compounds in pen trials to assess their attractiveness for wallabies. Compounds would be tested at different concentrations, based on the approximate concentrations of natural wallaby odour, as determined by the GC-MS. Our proposed research would follow protocols that we used to develop the synthetic stoat lure. This is a proven strategy to identify compounds and develop a synthetic lure to improve management outcomes.

5.3 Semiochemical lure: timeline and estimated costs

Stage 1: Compare the responses of Bennett's wallaby (*n* = 20) to odour samples from conspecifics (male/female), competitors (dama male/female), and a negative control (predator odour). Conspecific odour samples would be collected from multiple glands and sources. The field trial would be undertaken to confirm the attractiveness of the best lure for wild wallabies.

Timeline for trial: 1 year.

Estimated costs to collected samples, animal husbandry, pen and field trial: $200,000.

This is a stop-go point.

Stage 2: For the most attractive odour, we would collect 10 samples from different donor individuals (e.g. 10 samples of female sternal gland odour). Each wallaby sample is then divided into two, with the first sample tested in odour trials on wallabies and the second sample sent for GC-MS testing. Samples will then be compared to identify the attractive compounds. GC-MS results will be analysed to identify target compounds and important ratios. Attractive compounds can then be sourced commercially, and a synthetic replicate of the lure created for field testing. A pilot trial would confirm the attractiveness of the synthetic lure.

Timeline for trial: 1 year.

Estimated costs for GC-MS analyses, animal husbandry, pen and field trial: $210,000.

This is a stop-go point.

Stage 3: Based on pen-and-field-trial results, lure development may then be considered. MWLR can develop synthetic lures, suggest appropriate carriers, increase lure longevity, and test volatile loss rates.

Timeline for trial: 1 year.

Estimated costs for lure development: $100,000.

6 Conclusions and recommendations

6.1 Conclusions

We reviewed the literature on dama and Bennett's wallabies to assess the potential of semiochemicals to attract these species. Although the literature on olfaction in wallabies is relatively sparse, the review supports the assessment that semiochemicals are important for intraspecific communication. Wallabies have highly developed olfactory systems, and scent marking is conducted using four scent glands that convey breeding status and individual characteristics. Our review suggests that predator odour reduces foraging behaviour, negatively affecting food uptake and leading to spatial avoidance.

The use of conspecific semiochemicals, particularly female scent, is a promising avenue of investigation for lure research. Predator odour is likely to reduce food uptake, so research on a predator-based lure is not warranted in a baiting context. However, predator odour could be considered in a trapping context (as wallabies first approach to investigate predator odour) or to develop a deterrent to reduce wallaby damage.

6.2 Recommendations

To develop an effective semiochemical-based lure we recommend a three-stage bioassay. The first stage should focus on examining the effectiveness of sternal and urinogenital gland secretions to attract dama and Bennett's wallabies, both intra- and inter-specifically, and investigating any sexual differences in attractiveness. A pen-based bioassay can be developed for the collection of secretion samples and behavioural testing. Predator odour (e.g. dog) could be included as a negative control. Field trials can be undertaken to confirm attraction to odour samples. This could be a stop-go point for the research as significant attraction to an odour source would need to be confirmed to warrant further development.

The second stage should aim to identify and establish the profile of semiochemicals from the most attractive samples identified from stage one and conduct a second pen-based bioassay to evaluate the attractiveness of single and multiple compounds to develop a synthetic lure (Kreigenhofer 2011; McLean et al. 2012; Duckworth & Brown 2015; Garvey & Norbury 2018). The most attractive single compound or combination of compounds should then be tested in field trials to verify its effectiveness in improving rates of detection and interactions with control devices.

MWLR has facilities (e.g. a GC-MS machine, an animal facility and husbandry) and experience in conducting experiments and developing semiochemical lures for pest management. Our literature review and pilot study suggest that developing a semiochemical lure may be both desirable and feasible for wallaby management in New Zealand.

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