CENTRE FOR
INVASIVE SPECIES SOLUTIONS

FERAL DEER AGGREGATOR

FINAL REPORT FOR PROJECT P01-T-001

AUTHORS

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We acknowledge the Traditional Custodians of the lands on which we meet and work and pay our respects to Elders — past, present and emerging.

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FERAL DEER AGGREGATOR

FINAL PROJECT REPORT FOR P0-T-001

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EXECUTIVE SUMMARY

Existing tools to control feral deer are limited to shooting from the air, shooting from the ground, trapping, or fencing them out. The Deer Aggregator project aimed to provide landholders and conservation managers with a cost-effective tool to aggregate feral deer to better facilitate control options. A deer-specific feed structure would reduce feed and time required to replace feed consumed by non-target species and potentially provide a tool to dispense toxic bait (pending future registration of a bait) while excluding non-target animals.

In 2018, the Department of Primary Industries and Regions South Australia (PIRSA) in partnership with the Centre for Invasive Species Solutions (CISS) and Department for Environment and Water (DEW) commenced the Deer Aggregator project. The project aimed to design a deer-specific feeder that excluded non-target native species. The design of the Deer Aggregator was based on an ungulate-specific feed structure developed by New South Wales National Parks and Wildlife Service (NPWS) (Hunt et al. 2014). The original feed structure was highly target-specific, with feral goats freely able to access feed, while non-target native species were excluded. However, the feeder was less accessible to fallow deer (*Dama dama*) and red deer (*Cervus elaphus*).

The design of the Deer Aggregator exploits the difference in foot morphology of deer, macropods and emus. Over the course of the Deer Aggregator project, several prototypes were developed, tested and modified with each iteration improving the performance and durability of the device. The final prototype underwent extensive field trials in South Australia at a rural and peri-urban site with free ranging fallow and red deer.

This project has successfully developed a model for a deer-specific feeder which can be used to attract deer to specific locations for shooting or trapping or to assist with monitoring. By excluding non-target native animals including macropods, possums and birds, loss of feed and site disturbance is reduced. This cost-effective tool is easy to construct, transport and maintain in the field, making it a practical tool for a range of stakeholders. The Deer Aggregator may be useful in areas where deer numbers are low or the ability to shoot deer is limited, such as in peri-urban areas.

INTRODUCTION

CONTEXT: INCREASING FERAL DEER NUMBERS AND IMPACTS

The growing numbers and distribution of feral deer is having an increasing impact on farming and the environment. If left uncontrolled, the economic cost of feral deer is expected to rise into the billions in the next 30 years (BDO EconSearch 2022). Control of feral deer in Australia is limited to shooting, which in many places is ineffective as a single method to reduce the spread and impact of increasing populations. To combat the current and future impact of feral deer, there is a need to develop new control tools and to improve the effectiveness of existing tools and strategies.

PROJECT OBJECTIVES: A DEER-SPECIFIC FEEDER

Feral deer are highly cryptic, difficult to locate and adaptive to harassment by hunting. Attracting feral deer to specific locations using feed and lures can assist control and monitoring efforts. The Deer Aggregator project aimed to provide landholders and conservation managers with a cost-effective tool to aggregate feral deer by developing a deer-specific feeder that would attract deer but exclude non-target animals. A deer-specific feeder would reduce feed uptake by non-target species, and may assist in the safe delivery of toxic baits developed in the future.

METHODS

THE DESIGN PROCESS BUILT ON PREVIOUS NATIONAL PARKS AND WILDLIFE WORK

The concept and design of the Deer Aggregator was based on several ungulate-specific feed structures developed by the NSW NPWS (Hunt et al. 2014; R Hunt personal communication 2018). These structures exploit differences in the size and shape of the feet of the main non-target species (kangaroos and wallabies) and ungulates (goats and deer), so that the native species cannot access the feed. The previous feed structures developed in NSW were shown to be successful for feral goats but less successful with deer. The Deer Aggregator project sought to refine the design of one of the NSW feeders to work more effectively for deer.

In developing the Deer Aggregator, we followed the engineering design process:

- identify the need
- research the problem and possible solutions
- identify clear criteria and constraints
- imagine possible solutions
- design possible solutions
- create prototypes
- test and improve design.

The key criteria for designing the Deer Aggregator were that:

- fallow and red deer would readily feed from the device
- non-target species would be readily excluded
- the device would be easy to transport and construct in the field
- the device would be robust and affordable.

PROTOTYPE MANUFACTURING AND FIELD-TESTING

After we tested deer interactions with various components such as feed outlets (Figure 1) and mesh footplates, several prototypes of a deer feeder were constructed and tested on fallow and red deer in the field. Based on interactions with non-target species and deer (recorded using trail cameras), the design was improved and a final prototype manufactured in a short production run (Figure 2). This version was then tested in the field at several sites over 17 months (October 2020 – February 2022). Over this period, the prototype was further refined to exclude non-target species.

Figure 1. Testing if feral deer would feed from a feed silo during prototype development

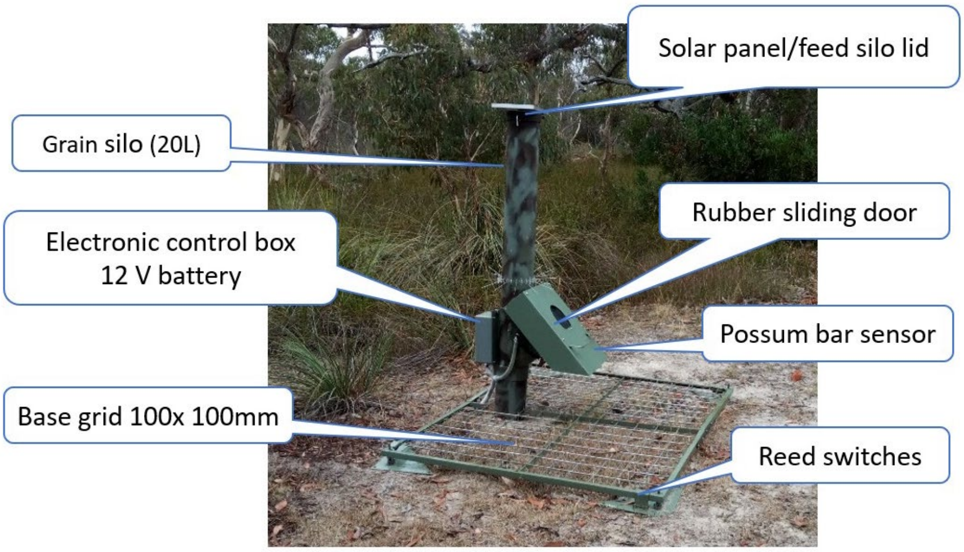

Figure 2. Final prototype in the field

In total, 26 Deer Aggregators were tested at four field sites in South Australia. Additional Deer Aggregators were sent to sites in Tasmania (2), Queensland (3), and New South Wales (3) for stakeholder feedback and preliminary information about other species' interactions with the devices.

FINAL ASSESSMENT AT A RURAL AND A PERI-URBAN SITE IN SA

Following final adjustments to the structure and electronic door-operating program settings, trials were conducted at two sites (south-east SA and a peri-urban site in the Adelaide Hills) between July 2021 and February 2022. Data from 20 Deer Aggregators was used to assess the Deer Aggregator's effectiveness to attract and feed feral deer while excluding non-target native animals. Details of the final prototype, methods of assessment and results are outlined in a manuscript submitted to the journal *Wildlife Research* (CSIRO Publishing) (Appendix 1).

RESULTS

KEY ACHIEVEMENTS

- The Deer Aggregator project developed a new cost-effective tool that will provide people with better opportunities to manage feral deer.
- Feral fallow and red deer were attracted to the Deer Aggregators and successfully accessed feed, particularly in summer months. Deer visited the Deer Aggregators during the night when feed was accessible (Figure 3) and during the day (Figure 4) when closed (to exclude birds), and frequently returned on consecutive days and nights.
- The Deer Aggregator effectively excluded non-target native animals. Macropods and emus were excluded when the differences in their foot size and shape triggered the feeder door to close after they depressed the footplate (Figure 5). Brushtail possums were excluded by triggering the base or triggering the possum bar sensor. Spikes on the face of the feeder also helped to exclude possums. Birds were excluded by closing the feeder during daylight hours.
- The cost of materials for each Deer Aggregator was AUD$800 and each was largely constructed from readily available parts. The structures are easy to transport and construct in the field by one person. The low cost of production and ease of use would mean landholders could purchase several Deer Aggregators (if made commercially available) and shift them to different locations. Alternatively, program managers, groups of land managers or conservation workers could pool funds to buy several and share/move them around.
- CAD technical drawings for the Deer Aggregator construction and assembly were produced and a draft user manual developed to assist future commercialisation of the deer-specific feeder.

Figure 3. Fallow deer feeding from an open Deer Aggregator. The mesh size of the footplate enables deer to step through the mesh holes, and not activate the feeder to close (south-east South Australia).

Figure 4. Fallow deer attracted to a Deer Aggregator located next to pasture during the day (south-east South Australia)

Figure 5. A western grey kangaroo triggers the feeder door on the Deer Aggregator to close, preventing access to feed. The feeder door automatically closes when the footplate is depressed by the large, flat feet of macropods or emus (south-east South Australia).

RECOMMENDATIONS ABOUT LOCATIONS FOR USE

The Deer Aggregator can be used within the home range of feral deer to attract them to specific locations to assist aerial or ground shooting, or can be used in large-scale traps. Monitored Deer Aggregators using trail cameras could assist people in the timing and spatial focus of their control efforts, particularly where deer numbers are low and movement seasonal. When used for either of these approaches, a deer-specific feeder would reduce the need to frequently replace feed consumed by non-target species – reducing site disturbance, feed costs and time.

Several Deer Aggregators may be required at a given location to improve habituation or feed uptake by deer. Deer aggregators in this study were mostly in forested areas where deer stayed during the day. Placing feeders in feeding areas such as paddocks may improve visitation, but livestock would have to be removed to prevent them feeding from the Deer Aggregator.

PROJECT IMPLICATIONS: DEVICE, DELIVERY, DIRECTIONS

This project has successfully developed a model for a deer-specific feeder which can be used to attract deer to specific locations for shooting or trapping or to assist with monitoring. By excluding non-target animals including native macropods, possums and birds, loss of feed and site disturbance is reduced. This cost-effective tool is easy to construct, transport and maintain in the field, making it a practical tool for a range of stakeholders. The Deer Aggregator may be useful in areas where deer numbers are low or the ability to shoot deer is limited, such as in peri-urban areas.

Deer-specific feeders such as the Deer Aggregator could also be used to trial the delivery of any future toxic baits.

The information gained through the Deer Aggregator Project will assist in developing field operating procedures for the Deer Aggregator and other ungulate-specific feeders.

END-USER ENGAGEMENT AT WORKSHOPS AND FIELD DAYS

When we demonstrated and discussed the Deer Aggregator at 20 workshops and field days (attended by 650+ stakeholders), we received feedback on the Deer Aggregator and increased community awareness of the impacts of feral deer, control options and management strategies. The National Deer Coordinator, through numerous workshops, has also assisted in bringing the tool to the attention of land managers across Australia.

End-user groups consulted during the development of the device included:

- primary producers and local agricultural groups
- peak bodies (Meat and Livestock Australia, Australian Wool Innovation, Grains Research and Development Corporation, state farming bodies, Livestock SA)
- local governments in jurisdictions where local governments have a role in feral deer management
- state agencies with feral-deer management responsibilities
- Landscape Boards SA.

A workshop with deer-management personnel from New Zealand Department of Conservation (DOC) provided opportunity to exchange practical experiences about attracting deer (using lures and different feed types) and discussing effectiveness and limitations of control measures for NZ’s rapidly increasing deer populations. The workshop emphasised the need to develop new control tools and to improve the effectiveness of existing tools and techniques.

NEXT STEPS TOWARDS COMMERCIALISATION

The Deer Aggregator project has delivered a prototype that has been field-tested and can be carried through to commercialisation to enable greater uptake and application of the tool. The next steps to progress commercialisation of the Deer Aggregator (in a future project) are to:

- refine the current design to reduce loss and spillage by rodents, and improve durability of several components
- trial the existing Deer Aggregator at sites occupied by chital, rusa, sambar and hog deer to validate use by other deer species and functionality under wider environmental conditions

(such as alpine and heavier rainfall areas). Data from trials could be used to modify and improve the existing prototype, if required, to capture a broader market and refine guidelines

- conduct market research and identify potential distribution strategies to inform a commercialisation strategy and pathway
- seek agreement with a manufacturing company to commercialise and promote the aggregator.

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(This list also includes those that are no longer with the project.)

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APPENDIX 1. JOURNAL MANUSCRIPT

Currently unpublished

Table of contents short summary

New, cost-effective tools are required to reduce the impacts of feral deer on agricultural industries. The Deer Aggregator is designed as a deer-specific feeder that can be used to attract deer to a specific location so they can be shot or trapped. The Deer Aggregator will be particularly useful in areas where deer numbers are low or the ability to shoot deer is limited, such as in peri-urban areas.

Developing a deer-specific feeder to assist feral deer control

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Running head: Feral deer-specific feeder

Abstract

*Context***.** The growing numbers and distribution of feral deer has an increasing impact on agricultural industries and the environment. Control of feral deer in Australia is limited to shooting which, in many places, is ineffective on its own to reduce the spread and impact of increasing populations. Attraction of feral deer to specific locations using feed and lures can assist control and monitoring efforts.

Development of a deer-specific feeder may also reduce feed uptake by non-target species.
Aims. Evaluate the effectiveness of a deer-specific feeder to exclude native animals and allow deer to feed.
Methods. Camera-trap images were used to assess the effectiveness of a purpose-built deer-specific feeder (Deer Aggregator) at excluding non-target native animals such as kangaroos and possums while allowing deer to feed. Trials of the Deer Aggregator were conducted on feral deer in South Australia, in peri-urban and rural settings.
Key results. Fallow and red deer were attracted to the Deer Aggregators and accessed feed, particularly in summer. The Deer Aggregator was effective in excluding non-target native animals. Macropods and emus were excluded by exploiting differences in their foot size and shape to trigger the feeder door to close when a footplate was depressed. Brushtail possums were excluded by physical deterrents. Birds were excluded by closing the feeder during daylight hours.
Conclusions. The Deer Aggregator can effectively exclude a range of native animals such as macropods, possums and birds.
Implications. The Deer Aggregator can be used to effectively attract deer to specific locations for shooting or trapping.
Keywords: invasive species, pest animals, pest management, *Dama dama, Cervus elaphus*, control techniques, ungulates, feral deer

Introduction

Feral deer have become an increasing burden to agriculture industries, causing damage to both farming and natural environments and potentially posing exotic disease risks (Davis *et al.* 2016; Cripps *et al.* 2019; Bradshaw *et al.* 2021). The economic cost of feral deer caused by direct consumption, damage or contamination of products; or by direct competition with livestock for resources was estimated to cost South Australian producers $36 million in 2020/21 (BDO EconSearch 2022). In Victoria, where feral deer populations are larger, the economic cost to the community of not controlling deer is predicted to be between $1.5 billion and $2.2 billion over the next 30 years (Frontier Economics 2022).

The most common tool for controlling deer is ground shooting by land managers, professional or volunteer shooters, or commercial harvesters (Davis *et al.* 2016). Ground shooting can be effective for low to moderate numbers of feral deer, but is time- and labour-consuming, limited to accessible and relatively open landscapes, and problematic in peri-urban and urban areas. In addition, many landholders do not have the appropriate licences, time or skills to make ground shooting effective. Commercial harvesting can reduce large deer populations at a local scale, but is not viable when deer densities are low (Bengsen *et al.* 2020). Aerial shooting is used to reduce large numbers of feral deer over large non-forested, rural areas (Forsyth *et al.* 2013) but is expensive and requires highly skilled professionals. In areas where shooting is not permitted or problematic (such as urban areas), deer traps (of various sizes) are used to confine then shoot feral deer. Traps can be costly to install, need to be checked daily, require time for deer to become habituated and have mixed success (Jackson *et al.* 2021).

In Australia, traditional control methods have not been adequate to stop the spread and impact of feral deer (Lethbridge *et al.* 2020; Watter *et al.* 2020; BDO EconSearch 2022; Cunningham *et al.* 2022), so there is a need to develop new control tools, and to improve the effectiveness of existing tools and techniques. Feral deer are highly cryptic, difficult to locate and adapt to harassment by hunting. This project aimed to provide landholders and conservation managers with a cost-effective tool to aggregate feral deer while excluding non-target animals. The purpose of an aggregator, in the form of a deer-specific feeder, is to better facilitate control by attracting feral deer to a specific location where traditional controls can be applied to greater effect. A deer-specific feeder (hereafter Deer Aggregator DA) may improve feral deer management in a range of settings, including peri-urban areas and where accessibility is limited (Forsyth *et al.* 2017).

The concept and design of the DA trialled in this study was based on several ungulate-specific feed structures developed by the New South Wales National Parks and Wildlife Service (NPWS) (Hunt *et al.* 2014; Hunt unpublished data). These structures exploit the differences in the size and shape of the feet of the main non-target species (kangaroos and wallabies) and ungulates (goats and deer) to prevent native animals accessing the feed. The previous feed structures developed in NSW were shown to be successful for feral goats but less successful with deer (Hunt *et al.* 2014; Hunt unpublished data). This project sought to refine the design of one of the

NSW feeders to work on deer, with an initial focus on excluding non-target native animals.

Here we report on the design of a DA and its effectiveness during field trials in attracting and allowing feral deer to feed while excluding non-target native animals. Effectiveness was based on the proportion of feeding attempts made by each species that were successful. The results of this study support future progress towards developing a commercially available deer-feeder for the control of feral deer.

Materials and methods

Deer Aggregator

The DA is constructed of lightweight and readily available materials for easy transport and assembly in the field (Figure 1a and 1b).

Figure 1 near here

The DA consisted of a 20-L feed silo (PVC pipe 150 mm in diameter, 124 cm high), a single feed outlet (55 cm above the ground) with an automatic rubber door, an electronic control box, and a footplate (164 cm × 124 cm) made from 0.5-mm galvanised steel mesh (aperture 100 × 100 cm) supported by springs on four corner feet. Reed switches (magnetically operated switches) located in the corners of the footplate trigger the feeder door to close when the footplate is depressed by the large, flat feet of macropods or emus. The mesh size enables deer to step through the mesh holes and not activate the switches. This activation mechanism is opposite to how the NSW feeder works, which required deer to step through the mesh to push down a treadle plate that mechanically opened a feed box. A hinged possum-bar located just below the feeder door is also connected to a reed switch, activating the door to close when pressed down by the weight of a possum or bird.

To prevent access by emus that could reach across the standard (163 cm wide × 123 cm deep) base, emu extensions made from galvanised mesh (aperture 100 mm × 100 mm) were fitted to DAs (Figure 1b) at site 1. The emu extensions increase the base by 40 cm on each side and 40 cm from the front. A two-strand barbed-wire fence was erected across the back of the DA to direct emus to the side or front of the DA (Figure 1b). In addition to the possum bar, polycarbonate and metal spikes were fitted to the faceplate of some DAs to deter possums where a few individuals had learned to be persistent (Figure 2).

Figure 2 near here

The electronic control box mounted on the back of the device (Figure 3) consists of a customised circuit board (Imagineering Design, Mawson Lakes SA) which receives inputs from the five reed switches (four on the footplate and one on the possum bar) and controls an actuator which operates the feeder door. A liquid crystal display and four toggle switches allow the operating configurations to be modified manually, and the status of each reed switch (inputs) and battery voltage to be checked. Adjustable operating configurations include operating hours, door closing and opening delays (in seconds), and the duration that the actuator is powered. The 12-V linear actuator (Motion Dynamics Australia Pty. Ltd.) has a stroke length of 150 mm and a speed of 30 mm/s.

Figure 3 near here

The DAs are programmed (via the electronic control box) to stay open at night when deer are active and attracted by visible grain, and closed during the day to exclude grain-eating birds (except emus). During operating night-time hours, the feeder door remains open unless triggered to close by a non-target animal activating a reed switch. In contrast, the NSW feeder box is always closed until it is mechanically opened by depression of the foot treadle by a goat or deer. The control box is programmed using Arduino Software (IDE). Detailed structural drawings and a circuit-block diagram are given in the supplementary material.

The control box on the DA and door actuator are powered by a 12-V rechargeable battery (Figure 3) charged by a small 5-W solar panel (Powertech, TechBrands, China) mounted on the cap of the feed silo. A solar charger (Kemo Electronic, Germany) is mounted behind the circuit board. Non-volatile memory stores the configuration information, and a real-time clock with battery backup maintains the time when the primary 12-V battery is flat or disconnected.

Study sites

Deer Aggregators were trialled on two private properties in South Australia where feral deer were frequently sighted. Site one was in rural south eastern South Australia on a property with remnant woodland vegetation surrounded by open agricultural land used for grazing (sheep/beef cattle). Site two was in the Adelaide Hills in a peri-urban area.

Site one had relatively high numbers of fallow deer (*Dama dama*), and occasional red deer (< 10% *Cervus elaphus*) (Lethbridge and Andrews 2016; PIRSA 2021). Site two was used by fallow deer.

Field trials

Nineteen DAs were trialled at the rural location (site one) and one DA at the peri-urban location (site two) between July 2021 and February 2022. DAs were located beside tracks or in open areas adjacent to tracks used by deer. The DAs were positioned facing away from the prevailing wind/rain direction to reduce feed spoilage. Distance between DAs ranged from 20–835 m at site 1. Field sites were visited every 1–2 months to download images, replace batteries and top up feed if required. Feed used in the DA silos varied over the trial period. Combinations of feed included wheat, oats, maize, lupins or fava beans. Deer were also attracted with lures (e.g. grain, lucerne hay, Molodri diatomaceous earth with molasses, and calcium molasses blocks) which were spread in the vicinity of each DA.

The DAs' automatic door was set to open just after sunset and close just before sunrise. Once triggered, the feeder door was programmed to remain closed for 30 s or 120 s to deter non-target animals from attempting to feed again.

Deer and non-target species interactions with DAs were monitored using infrared motion cameras (Digital Scouting Camera, SG560K-14mHD, Bolymedia, China). At each DA, a single camera was secured to a star picket approximately 1 m above ground level and 3 m from the DA's base. Cameras were set to take a burst of two still images with no delay between triggering.

Data analysis

Images captured at each DA were used to assess species interactions with the feeders and frequency of deer visits. For analysis, a single visit was defined as one or more individuals of the same species in a photo, and each visit ceased when that species was not observed in consecutive photos for more than 10 minutes (following Hunt *et al.* 2014). Because it was not possible to always identify individuals, independent events at the same feeder or adjacent feeders could not be determined. During each visit, the duration and maximum number of deer in any sequence of photos was recorded.

For each visit, a species was recorded as *successful* (1) if the animal was observed putting its head inside the feeder or *not successful* (0) if the feeder closed before the feed was accessed or the animal avoided the feeder. Physical contact with the DA was also recorded to examine the effectiveness of mechanical measures to exclude non-target species. Any sequence where the feeder door was seen to close (and an animal retreat) was classed as contact.

To determine the effectiveness of the DA to exclude non-target species, the proportion of successful feeding events (1) was calculated as a percentage of the total number of nocturnal visits, pooled across the sample period for each DA.

To examine effects of season on deer visitation rates, a relative visitation index (RVI) was calculated (number of visits recorded divided by the number of camera-trap nights) and compared between sites and sampling periods.

This study was approved by Department of Primary Industries and Regions Animal Ethics Committee (#176).

Results

Sample effort

Data from 20 DAs across the two sites were used to assess the effectiveness of the device to exclude non-target animals and to attract deer. The number of DAs used in analysis varied over time (Table 1) due to temporary camera malfunctions. Only data from November 2021 onwards were used in analysis of non-target species interactions, to align with upgrades in the DA program that aimed to exclude kangaroos. To examine variation in deer visitation and feeding attempts with season, data from July 2021 onwards were included. In total, 473,540 images from 3,007 camera-trap nights were analysed across both sites (Table 1).

Table 1 near here

Species that visited Deer Aggregators

Fallow deer (both sites) and red deer (site 1) were observed visiting the DAs. Other introduced species recorded on the cameras near the DAs included red fox (*Vulpes vulpes*), European rabbit (*Oryctolagus cuniculus*), European hare (*Lepus europaeus*), black rat (*Rattus rattus*) and house mouse (*Mus musculus).*

Grain-eating native mammals observed visiting the DAs during the night, when the DAs were open, included the western grey kangaroo (*Macropus fuliginosus melanops*), common brushtail possum (*Trichosurus vulpecula*), swamp wallaby (*Wallabia bicolor*), common wombat (*Vombatus ursinus*), and red-necked wallaby (*Macropus rufogriseus*) (Table 2 and 3).

Tables 2 and 3 near here

Grain-eating birds observed visiting during the day, when the DAs were closed, included the malleefowl (*Leipoa ocellata*), emu (*Dromaius novaehollandiae*), Australian magpie (*Gymnorhina tibicen*), galah (*Eolophus roseicapilla*), pied currawong (*Strepera graculina*), Australian raven (*Corvus coronoides*), Australian ringneck (*Barnardius zonarius*), crimson rosella (*Platycercus elegans*), common bronzewing (*Phaps chalcoptera*), and grey shrike-thrush (*Colluricincla harmonica*).

Performance of Deer Aggregator

Macropods were excluded from the feed in the DA on all occasions (Table 2 and 3, Figure 4a and 4b). On all 525 occasions when western grey kangaroos and swamp wallabies walked onto the base, the DA triggered to close, preventing access. Red-necked wallabies visited on 41 occasions but rarely stepped onto the base of the DA (2 occasions).

Figure 4 near here

Brushtail possums were observed to visit 11 of the 20 DAs, but only successfully fed from two. The average feeding success rate was 3.4% ± 8.7 (*SD*, n = 11). On most occasions possums triggered the base or possum bar, and were excluded from feeding. However, at two DAs, resident possums learned over an extended period to access the feed by holding onto the opening of the feeder and waiting for it to reopen. The tenacity of these few individual possums was perpetuated by initial breaches of early (less-effective) prototypes of the DA at the same sites.

Native birds were excluded on all occasions from accessing feed because the DA was programmed to be closed during the day. Only one emu and one malleefowl were observed visiting the DAs at night, but neither stepped onto the DA's base. Of 297 daytime observations of emus investigating the DAs, 92.6% (275 of 297) avoided stepping onto the base extension.

Wombats did not appear to be interested in feeding from the DA and normally walked past or around the base. On four occasions (3.8% of nocturnal visits) wombats were observed to walk across the base of the DA and either walked on the mesh (triggering the door to close), or stepped through the mesh holes but did not stop to investigate the feed. Wombats were also prevented from feeding due to the height of the feeder opening.

Black rats and house mice were observed at seven of the 20 DA and accessed feed at three, with a mean success rate of 91.4% ± 17 (*SD*, n = 7). Animals accessed the feed by climbing up the back of the silo and bypassing the possum spikes. In addition to consuming feed, rodents chewed on some of the DA's rubber doors and spilled oat grains and husks.

Both fallow deer (Figure 5) and red deer (Figure 6) of various sizes and sexes were observed visiting and attempting to feed from the DAs. Deer were observed to visit 15 of the 20 DA at night, and all 20 during the day. At the rural site, 30.0% (179 of 597) of visits recorded between spring and summer occurred at night. In contrast, at the urban site over the same period, 66.7% (14 of 21) of visits by deer occurred at night. Not all visits during the night resulted in deer attempting to feed. The average number of visits that resulted in deer feeding was 11.2% ± 18.6 (*SD*, n = 15) over the summer period.

Figures 5 and 6 near here

Of the 98 visits recorded at night over the summer sample period, 32.7% resulted in deer stepping onto the DA base. Deer readily placed 2–4 feet through the mesh base to access feed. If a deer triggered the base during a feeding attempt, they typically waited for the feeder to reopen. When deer attempted to feed by stepping onto the base, they successfully accessed the feed on most occasions (81.3%). Deer were generally alone when feeding from the DAs, and stayed for an average of 12 minutes (median, range 2–38 minutes, n = 28). Fallow deer and kangaroos were sometimes present at the same time (Figure 7a and 7b), with both species attempting to feed from the DA. When the DA closed due to a kangaroo, deer were observed to wait until the feeder reopened. Deer were also observed to attempt to feed or closely inspect the closed DA during the day, particularly at the rural site.

Figure 7 near here

Most visits by deer occurred within two weeks of fresh lures being laid at DA sites. The median time between laying fresh grain or lures and observing the first deer feeding from a DA was eight days (range 1–24 days, n = 8). The average number of deer observed during any one visit was one (range 1–4). Visitation by deer was highest in late spring and early summer, and lowest in winter (Figure 8).

Figure 8 near here

Discussion

This study demonstrated that the DA can attract deer and exclude most non-target animals by exploiting the differences in the size and shape of the feet of deer and large native herbivores. The mechanisms designed to exclude non-target animals did not prevent deer from accessing feed. Deer readily placed their feet through the holes in the mesh base to access feed and waited for the feeder to reopen if they accidently trigged the door to close. During the trial reported here and trials of previous prototypes, both fallow and red deer of various sizes and sexes were attracted to and fed from the DAs.

Deer were attracted to the DAs during the night when feed was accessible and during the day when closed. Deer also visited DA sites within days of fresh lures and feed being replaced. This suggests the DA could provide a focal point for ground or aerial shooting when deer are sparsely distributed or be used to attract deer to large-scale traps. The DA may be useful in areas where deer numbers are low or the ability to shoot deer is limited, such as in peri-urban areas. Monitoring DAs using trail cameras could also assist in the timing and spatial focus of control efforts, particularly where deer numbers are low and movement is seasonal. When used for either of these approaches, a deer-specific feeder may reduce the need to replace feed consumed by non-target animals, in turn reducing site disturbance, feed costs and time.

At the rural site, visitation rates and feeding activity by deer was variable between DAs, including those near each other. Several DAs may be required at a given location to improve habituation or feed-uptake by deer. Deer aggregators in this study were mostly in forested areas where deer stayed during the day. Placing feeders in feeding areas such as paddocks may improve visitation, but livestock would have to be removed to prevent them feeding from the DA. Studies of free-ranging deer in the northern hemisphere suggest deer are unlikely to change their movement patterns to visit feeders outside of their annual home range, but will shift core areas of activity within home ranges towards feeder locations (Darrow 1993; Kilpatrick and Stober 2002). Home ranges of deer in Australia have been shown to be variable and likely influenced by several factors such as food availability, population density and time of breeding cycle (Amos *et al.* 2014). DAs can be easily moved as landholders learn about the movement of resident deer on their properties.

Visitation and feeding activity at DAs were higher in late spring and early summer, compared to winter. Studies of captive and wild deer in the northern hemisphere have also indicated that consumption of supplemental feed by deer is seasonal (Linhart *et al.* 1993; Garner 2001). Success of attracting deer to a specific location will depend, in part, upon seasonal factors such as energy requirements, availability of alternative feed and breeding activity. A period of habituation and initial provision of lures such as lucerne hay may also be required.

The Deer Aggregator was effective in excluding non-target native animals. Macropods and emus were excluded by exploiting differences in their foot size and shape to trigger the feeder door to close when the footplate was depressed. Birds were excluded by closing the feeder during daylight hours. Brushtail possums were excluded by triggering the base or triggering the possum-bar sensor. Spikes on the face of the feeder also helped to exclude possums. Some brushtail possums may learn to navigate these mechanisms over extended periods. Two resident possums accessed two of the DAs that were within 80 m of each other. These two possums had been preconditioned by initial breaches of early (less-effective) prototypes of the DA at the same sites. Possums did not access other DAs that were within 150–200 m at the same site. Relocation of the DA to another location within a site may be required if resident possums learn to access feed.

The cost of material for each DA was AUD$800 and was largely constructed from readily available parts. The structures were easy to transport and construct in the field by one person. When disassembled, a single DA can fit in the back of a utility vehicle or the back seat of a compact sports utility vehicle. The low cost of production and ease of use would mean landholders could purchase several DAs (if made commercially available) and shift them to different locations.

With over two million deer in Australia, and abundance and distribution of many deer species increasing (Davis *et al.* 2016), cost-effective management strategies will be required to mitigate their current and future economic and environmental impacts. This project has developed a model for a low-cost, deer-specific feeder which can be used to attract deer to specific locations for shooting or trapping, or to assist with monitoring. By excluding non-target animals including native macropods, possums and birds, the loss of feed and site disturbance is reduced. The DA may be useful in areas where deer numbers are low or the ability to shoot deer is limited, such as in peri-urban areas.

Conflict of interest

The authors declare no conflicts of interest.

Declaration of funding

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Data availability statement

The data that support this study will be shared upon reasonable request to the corresponding author.

Figures

(a) **(b)**

Figure 1. Deer Aggregator structure

Deer Aggregator with (a) standard-sized base and (b) emu base extension. Fencing at the rear of the Deer Aggregator (b) directed emus to the sides and front of the feeder.

Figure 2. Possum deterrents

Polycarbonate and metal spikes fitted to Deer Aggregators were used to deter possums and limit side access.

Figure 3. Electronic control box

The liquid crystal display allowed operational settings to be changed, sensors tested and battery charge monitored onsite.

(a) (b)

Figure 4. A (a) kangaroo and (b) swamp wallaby triggering a Deer Aggregator to close

Figure 5. Fallow deer feeding from a Deer Aggregator at the peri-urban site in the Adelaide Hills

Figure 6. Red deer feeding from a Deer Aggregator in South Australia's south-east. This observation of a red deer feeding occurred prior to the sample period presented in the current analysis.

(a) **(b)**

Figure 7. Fallow deer and western grey kangaroos visiting a Deer Aggregator at (a) peri-urban and (b) rural sites.

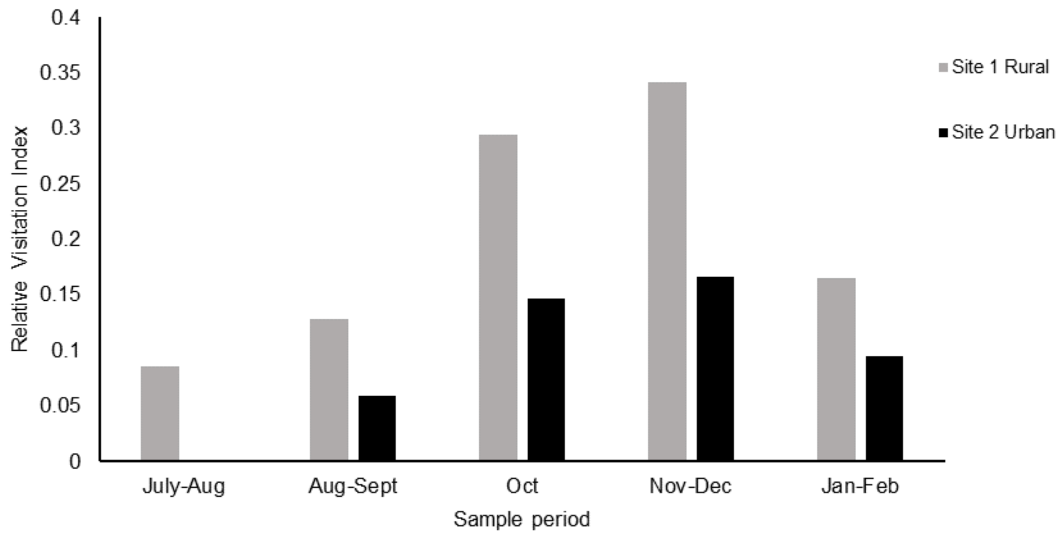

Figure 8. Seasonal variation in deer visitation rates at the two field sites
Deer visitation rates are expressed as a relative visitation index (number of visits divided by number of camera-trap nights). Data were pooled across day and night observations and multiple DAs at site 1. Data were not available for site two in the first sample period.

TABLES

Table 1. Sampling effort across seasons at each site

Deer visitation patterns and feeding attempts were examined using data collected between winter 2021 and summer 2022. Only data collected over summer were used in analysis of non-target species interactions, because of upgrades in the DA operating program made at the start of summer.

Season	Winter (Jul–Aug)	Spring (Aug–Sep)	Spring (Oct)	Summer (Nov–Dec)	Summer (Jan–Feb)
Site 1. Rural					
Camera-trap nights	329	521	657	644	680
Images	10,943	31,468	62,836	190,264	173,059
Number of DAs	10	17	18	17	19
Site 2. Peri-urban					
Camera-trap nights		34	41	48	53
Images		1,382	1,326	1,399	863
Number of DAs		1	1	1	1

Table 2. Species observed visiting the Deer Aggregators at site one (rural) during operating hours (night) and interactions observed

Total number of nocturnal visits and number of DAs visited by each species, pooled across the summer sample period (November to February). Success rate is presented as the average proportion of visits that resulted in a successful feeding event.

Species	Total visits	Number of DAs	Average success rate (%)	SD
Western grey kangaroo	575	19	00	
Brushtail possum	262	10	3.4	8.7
Swamp wallaby	184	19	0.0	
Rabbit*/hare*	136	14	0.0	
Black rat/house mouse*	114	7	91.4	17
Wombat	104	17	0.0	
Fox	87	15	0.0	
Fallow deer*	73	12	12.8	20
Red-necked wallaby	41	10	0.0	
Echidna	12	8	0.0	
Deer (unidentified)*	7	3	0.0	
Red deer*	4	3	0.0	
Emu	1	1	0.0	
Malleefowl	1	1	0.0	
TOTAL	**1,601**			

* Non-native species

Table 3. Species observed visiting the Deer Aggregators at site two (peri-urban) during operating hours (night) and interactions observed

Total number of nocturnal visits by each species and the proportion of visits that resulted in a successful feeding event. Data are pooled across the summer sample period (November to February).

Species	Visits	Success rate (%)
Western grey kangaroo	110	0.0
Fallow deer*	14	14.3
Rabbit*/hare*	28	0.0
Brushtail possum	2	0.0
Fox*	3	0.0
Koala	3	0.0
TOTAL	**160**	

* Non-native species

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