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Peri-Urban Deer Control Is Challenging: Three Case Studies and Strategies for Improved Outcomes

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ABSTRACT

Introduced deer are threatening Australia's natural values. Deer control is increasingly being implemented to reduce deer populations and mitigate their impacts. However, control programmes are expensive and challenging, particularly in peri-urban and agricultural landscapes. We present assessments of three typical deer control programmes from peri-urban/agricultural Victoria, south-eastern Australia. We assess programme effectiveness in reducing deer activity by using faecal pellet counts and/or camera traps, provide reflections from researchers and land managers on the potential reasons for programme successes, or lack thereof and highlight potential changes in programme strategies to improve outcomes. Ground-shooting by volunteer and/or contractor shooters removed primarily sambar (*Cervus unicolor*) in two programmes (Tarago State Forest, 2022–2023; and Jumping Creek catchment, 2017–2022), and both sambar and fallow deer (*Dama dama*) from the third programme (Yellingbo Nature Conservation Reserve, 2014–2019). In general, the deer control programmes did not reduce deer activity or impacts. Deer control was often too spatially restricted, and the frequency or intensity was insufficient to remove an adequate number of deer to reduce overall activity and subsequent impacts. Deer populations also often moved away from locations subject to control. Deer control is particularly difficult in fragmented peri-urban and agricultural landscapes due to deer immigration and emigration, and the logistical challenges of operating in a multi-tenure environment. To be effective, programmes need to be applied at appropriate spatial scales, monitored and adaptively managed. Community consultation and engagement is essential in peri-urban and agricultural areas to enable coordinated control across different land tenures, supported by adequate resourcing. Monitoring is critical to determine control effectiveness and enable programmes to be adaptively managed. Building on the successful collaborations and lessons learnt from previous control programmes, future programmes need to be more strategic and well-resourced to enable land managers to tackle the increasing threat posed by introduced deer in Australia.

1 | Introduction

Introduced deer populations are increasing in distribution across Australia and so too are their impacts on environmental, cultural and economic values and human safety (Burgin et al. 2015; Cunningham et al. 2022; DELWP 2020; Forsyth, Pople, et al. 2023). Deer damage native vegetation through trampling, browsing and rubbing, threatening plant populations

Summary

- Deer management in peri-urban and agricultural areas should be implemented strategically based on management objectives. This requires application of control at appropriate spatial scales, and adequate frequency and intensity, to reduce abundance and corresponding impacts to acceptable levels.
- Given resource constraints, improved understanding of deer movement and cross-tenure coordination are critical to improve cost-effectiveness at local and landscape scales.
- Deer control programmes need to be monitored to support adaptive management.
- Resourcing needs to be adequate to support and sustain activities 1–3.

and communities (Côté et al. 2004; Davis et al. 2016; Putman et al. 2011) with potentially dramatic impacts on vegetation structure and function (e.g., Wills et al. 2023). Deer also compete with livestock for forage (Davis et al. 2023; Smith et al. 2012; Watter, Baxter, et al. 2020), damage agricultural assets and infrastructure (Claridge 2016) and pose a risk to human life through vehicle collisions (Davies et al. 2020). The annual cost of introduced deer across Australia was estimated in 2021 to exceed $91 million and to be increasing (McLeod 2023).

In response to increasing deer populations and community concerns, deer management strategies are increasingly being implemented across Australia with the aim of reducing deer impacts. Land managers are employing a range of lethal and non-lethal deer management strategies, most commonly in the form of aerial- and ground-based shooting (Bengsen et al. 2023; Comte et al. 2024), as well as non-lethal strategies such as exclusion fencing (Forsyth 2023).

Objectives of control programmes vary depending on the values at threat, deer population density and landscape context, and following biosecurity principles, broadly fall into one of four categories: (1) prevention of new deer populations establishing, (2) removal of isolated populations, (3) containment and limiting the spread of existing deer populations, and (4) asset protection of priority values (DELWP 2020). Control programmes are expensive (Comte et al. 2024; Comte, Thomas, et al. 2023) and outcomes may be complex and varied. For example, a 5-year culling trial in the Australian Alps reduced deer abundance in some (but not all) areas and reduced some (but not all) impacts (Comte, Bengsen, et al. 2023). There is a general recognition that deer management in Australia is complicated and that management approaches need to be further tested, evaluated and improved (Forsyth, Pople, et al. 2023).

In peri-urban and agricultural settings, deer control is often limited to ground-based shooting because aerial shooting is typically unsuitable (Comte et al. 2024). Ground-based shooting may be conducted by volunteers or contractors, but there are few examples where either have substantially reduced deer populations or their impacts (Bengsen et al. 2020; Forsyth, Pople, et al. 2023).

Deer are often particularly abundant in fragmented peri-urban and agricultural landscapes. Recent models of deer density within south-eastern Australia indicate deer abundance is generally higher in landscape mosaics, likely because deer prefer locations with access to both open and forested habitat (Fedrigo et al. 2024). Similarly, models of deer density across the state of Victoria suggest density is greater in proximity to pastoral land and where there is more forest edge in the landscape (Cally and Ramsey 2023).

The increase in deer activity, distribution and impacts across Victoria, Australia, has led to the recent development of the Victorian Deer Control Strategy (VDCS; DELWP 2020), which recognises deer pose a significant risk to biodiversity, water quality, public safety, agricultural assets and Indigenous cultural heritage values. Challenges faced by early deer control and monitoring programmes spurred the development of the VDCS and a specific plan for peri-urban areas (DELWP 2021). This plan acknowledges the difficulties associated with deer control in peri-urban areas and highlights the need for research and sharing knowledge on the effectiveness of control programmes to reduce deer impacts.

Assessments of deer control programmes are necessary to determine their effectiveness in reducing deer activity and impacts, to understand the reasons for their success or otherwise, and to inform improved approaches to deer management. Here, we present assessments of the effectiveness of three 'typical' pioneer deer control programmes in peri-urban and agricultural contexts in Victoria, south-eastern Australia. We provide reflections from researchers and land managers on the potential reasons for programme successes, or lack thereof and highlight changes in programme strategies to improve outcomes.

2 | Methods

2.1 | Study Approach

We present three case studies of deer control programmes in Victoria, south-eastern Australia: Yellingbo Nature Conservation Area (NCA), Tarago Reservoir Catchment and Jumping Creek Catchment (Figure 1). For each case study we briefly present information on the study area and an outline of the deer control and monitoring programmes. We provide a summary of programme outcomes based primarily on indices of deer activity (with further detail on impacts provided in referenced technical reports) and focus our reflections on potential reasons for these outcomes and the adaptive management approaches taken. The scale and nature of these case studies is typical of pioneer deer management programmes implemented in peri-urban and agricultural areas of south-eastern Australia to mitigate impacts on environmental values and conflict with human populations.

2.2 | Deer Species

Sambar (*Cervus unicolor*; Forsyth, Bilney, et al. 2023) is the predominant deer species present in the case study areas, although fallow deer (*Dama dama;* Mulley 2023) are also common. Sambar are the largest deer species in Australia (146–192 kg), are relatively solitary or form small groups, and although primarily browsers, consume a wide variety of food plants (Forsyth and Davis 2011;

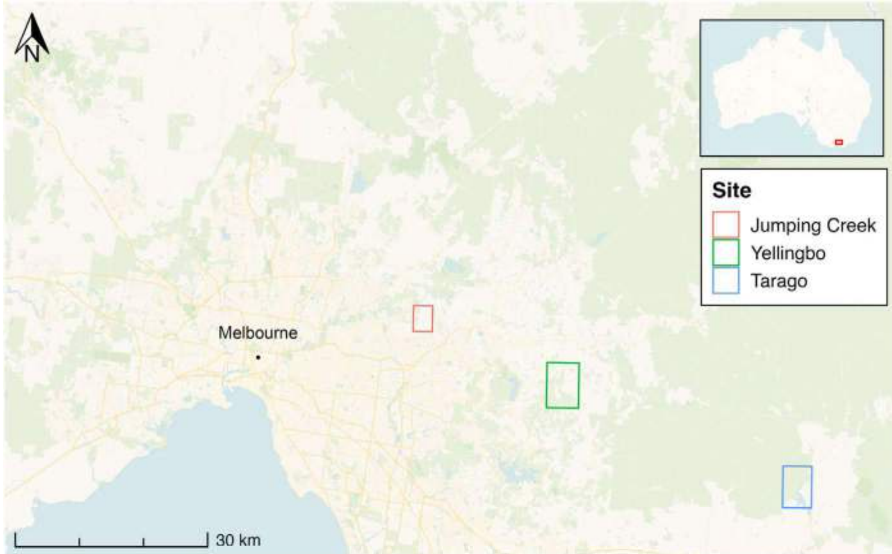

FIGURE 1 | Case study locations, east and south-east of Melbourne, Victoria, south-eastern Australia. Jumping Creek Catchment (red), Yellingbo Nature Conservation Area (green) and Tarago Reservoir Catchment (blue).

Parker 2009; Quin et al. 2024). Fallow deer are a smaller species (36–110 kg) that form small to large groups and mostly graze on grasses and herbs (Parker 2009), but do browse shrubs and trees (Davis et al. 2023; Guy et al. 2024). Deer population growth varies between species and environmental conditions and can exceed 24% annually (Forsyth et al. 2012; Hone et al. 2010; Watter, Thomas, et al. 2020). Red deer (*Cervus elaphus*; Jesser 2023) are present but uncommon in the case study areas, and although hog deer (*Axis porcinus*; Bilney et al. 2023) have been recorded in Yellingbo NCA, they are considered rare or absent.

2.3 | Case Studies

2.3.1 | Case Study 1: Yellingbo Nature Conservation Area

Yellingbo NCA (598 ha) is a peri-urban reserve on Wurundjeri Country ~50 km east of Melbourne, Victoria, comprising linear sections along several creeks including the Cockatoo and Woori Yallock Creeks. The reserve is located within a highly fragmented landscape, with adjoining land use being primarily agricultural and horticultural. The reserve is highly biodiverse and protects nationally significant vegetation communities and flora and fauna species. Notably, it supports the last wild populations of the helmeted honeyeater (*Lichenostomus melanops cassidix*) and lowland Leadbeater's possum (*Gymnobelideus leadbeateri*), and the largest remnant of the threatened Sedge-rich *Eucalyptus camphora* Swamp Community (Turner 2003).

A deer control programme was initiated by Parks Victoria in response to a notable increase in deer activity and impact on the significant ecological values within the reserve. Parks Victoria implemented a ground-shooting control programme over six years (2014–2019) conducted by volunteer shooters. A total of 133 deer (36 sambar and 97 fallow deer) were culled over that period. Parks Victoria additionally engaged professional deer control contractors to conduct ground-shooting in 2019 (20 nights; 75 deer culled, 32 sambar and 43 fallow deer) and in 2020 (21 nights; 125 deer culled, 66 sambar and 59 fallow deer).

To assess the effectiveness of this deer control programme, we compared two indices of deer activity, faecal pellet counts and camera trap detection rate, from 2012 (before control began) and 2020 (after the sixth year of the control programme). Indices of activity using faecal pellet counts (pellets/m^2) were obtained by using the method of Forsyth (2005), with this index having a linear association with deer density at other sites (Forsyth et al. 2007). Camera trap detection rates (number of independent deer detections/day) were determined from randomly distributed camera traps (Reconyx) set to focus on the closest fauna trail, facing south, mounted on a tree. The specific camera trap locations differed between the 2012 and 2020 surveys, and although the camera model specifications and field of view were similar between the two surveys, cameras set in 2012 did not use detection distance markers and we therefore included all independent (> 5 min apart) deer detections regardless of distance from the camera for both the 2012 (Reconyx model HC600) and 2020 (Reconyx model HP2X) datasets.

2.3.2 | Case Study 2: Tarago Reservoir Catchment

The Tarago Reservoir is located on Bunurong and Gunaikurnai Country near Neerim in West Gippsland, Victoria. The catchment areas to the east, south and south-west of the Tarago Reservoir are primarily private farms managed as pasture for cattle. The area north-west of the reservoir is forested and part of the Tarago State Forest. Recreational deer hunting is permitted in the Tarago State Forest but not within the catchment area adjacent to the reservoir. The reservoir is partially fenced to prevent access by the public and livestock, and there is one main vehicle access track encircling the reservoir.

In response to increasing deer impacts, deer control was implemented by the Victorian Department of Energy, Environment and Climate Action (DEECA) across the site from July 2022–November

2023. Lethal control by ground shooting was conducted by specialised contractors at dusk and night, and was primarily vehicle-based from management tracks and access roads adjacent to the reservoir. On average, four consecutive nights of control were conducted monthly July–November 2022, every second month December 2022–July 2023 and monthly August–November 2023. Over 53 nights of control, a total of 319 deer were culled, almost all sambar, with three fallow deer and one red deer also culled.

To assess the effectiveness of the control programme, deer abundance and vegetation impact assessments (Bennett et al. 2022) were conducted at 24 forested sites in November 2021 prior to the commencement of deer control, and the same sites were surveyed again in November 2023, following ~1.5 years of deer control. The surveys covered an area of 1600 ha and encompassed the forested section of the Tarago Reservoir catchment to the north-west of the reservoir, a sub-set of the broader deer control area.

2.3.3 | Case Study 3: Jumping Creek Catchment

The Jumping Creek Catchment is a peri-urban area located on Wurundjeri Country within the Manningham and Maroondah municipalities, approximately 30 km north-east of Melbourne, Victoria. The catchment comprises mixed land use including small private properties, protected bushland parks and reserves, limited agriculture and urban areas. Many private landholdings in the catchment support remnant native vegetation.

Deer populations in the Manningham municipality increased to levels that were causing council staff and community concern, in particular damage to remnant bushland and revegetation, and threats to community safety (Bennett and Davis 2017). In 2017, a 5-year deer monitoring and control programme was implemented by Council in partnership with the Jumping Creek Catchment Landcare Group (JCCLG) and the local community. This was the first programme of its kind in Melbourne to address the effects of escalating deer activity across private and public land in an organised, shared partnership model that incorporated a substantial monitoring programme. Professional deer control contractors were engaged to control deer on participating private land by ground-shooting. Between August 2017–December 2022 (~5 years) 418 deer were culled (all sambar).

A monitoring programme was set up across both private and public land to assess how effective the control programme was at reducing deer activity and impacts (Bennett and Davis 2017). The monitoring programme assessed changes in impacts of deer on vegetation (involving vegetation surveys within 10 × 10 m plots) and spatial and temporal changes in deer activity using motion-sensor camera traps (Spartan SR1-BK 8MP Trail Cameras) maintained over the 5 years at 20 locations within the control area.

3 | Results and Discussion

3.1 | Case Study 1: Yellingbo Nature Conservation Area

There was no evidence of a reduction in deer activity in response to the control programme at Yellingbo NCA between 2012 (before deer control began) and 2020 (after the sixth year of the deer control programme). Deer abundance indices based on either faecal pellet counts or camera trap detection rates did not differ between sampling periods ($p > 0.05$, Student's t-tests, df = 32; Table 1, Figure 2).

We suggest this deer control programme did not reduce deer abundance because the small spatial scale over which control was conducted enabled continual immigration and emigration of deer from the broader landscape, together with the constraints under which the volunteer programme operated, resulting in a relatively small number of deer removed.

Although it has been demonstrated elsewhere that deer control in small, concentrated areas can effectively reduce abundance (Bennett et al. 2015; Comte et al. 2024; Cromsigt et al. 2013), such reductions in density are likely to be transient, particularly for small reserves open to immigration and emigration across the broader landscape. Indeed, during 2020 there was a short-term reduction in deer activity from intensive ground-shooting by contractors in Yellingbo NCA (Bennett et al. 2021). However, cameras located in other parts of the reserve where shooting was not conducted showed increased activity, suggesting many deer simply relocated in response to the ground-shooting.

Correspondingly, assessments of vegetation also indicated that impacts did not reduce following the deer control programme (Bennett et al. 2021). In some programmes, a breakdown in ecosystem resilience is considered responsible for the lack of vegetation recovery following significant deer population reductions (e.g., Knauer et al. 2023; Royo and Carson 2022; Tanentzap et al. 2009). However, in this case, the likely reason for the lack of vegetation recovery is that insufficient numbers of deer were removed (Bengsen et al. 2020).

Our findings are concordant with a recent review of ground-based shooting which found that only 30% of programmes that used volunteer shooters or recreational hunters achieved their objectives (Bengsen et al. 2020). The low success of such programmes is often attributed to the inability to remove a sufficient proportion of the population to cause a population decline (Bengsen et al. 2020). To reduce and maintain the deer population at low densities within peri-urban reserves located in highly fragmented landscapes (such as Yellingbo NCA), frequent and intense (potentially weekly) control effort would be required to achieve sustained behavioural avoidance, but the cost would be prohibitively high (Comte et al. 2024).

TABLE 1 | Comparison of deer activity indices based on mean faecal pellet counts (FPCs; pellets/m^2) and camera trap detection rate (independent deer detections/day) at Yellingbo NCA obtained from surveys conducted in 2012 (Bennett 2013) and 2020 (Bennett et al. 2021).

	2012		2020	
Yellingbo NCA	***n***	**Mean ± SE**	***n***	**Mean ± SE**
Deer FPC (pellets/m^2)	26	0.83 ± 0.25	23	1.21 ± 0.46
Camera trap rate (deer/day)	16	0.47 ± 0.10	23	0.50 ± 0.09

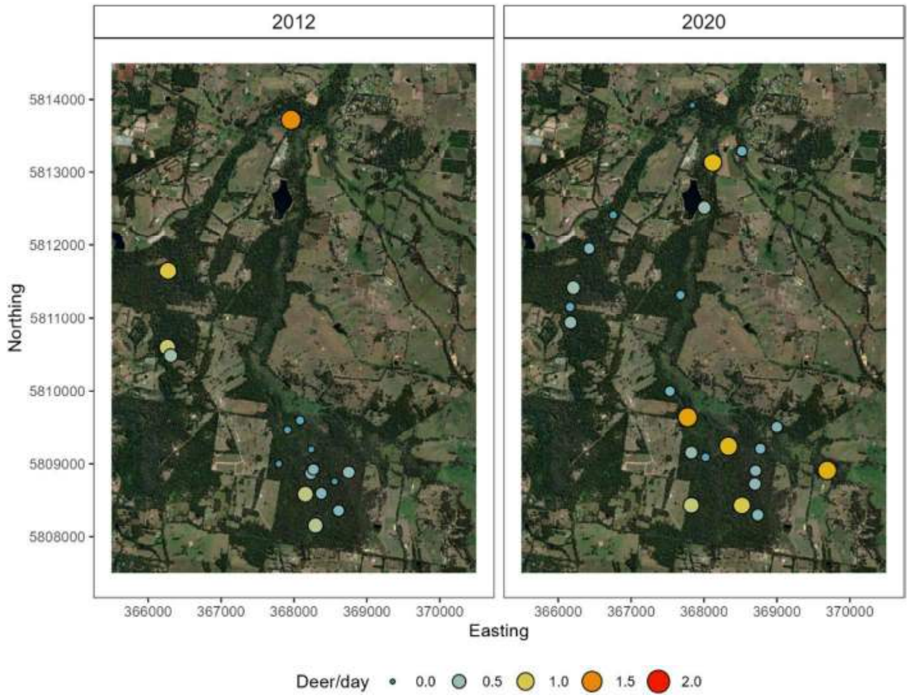

FIGURE 2 | Camera trap detection rates (independent deer detections/day) within Yellingbo Nature Conservation Area at randomly located camera traps in years 2012 (before deer control began; $n=16$) and 2020 (after the sixth year of the deer control programme; $n=23$). N.B. different random sites were surveyed in 2012 and 2020.

Land managers could consider alternative mitigation measures for small reserves (e.g., fencing), but the cost of construction and maintenance of a fence around the entire perimeter of Yellingbo NCA would be high given its linear shape, and unintended consequences may occur such as an increase of native browsers, such as the swamp wallaby *Wallabia bicolor* or exclusion of desirable species and associated ecological processes. As a compromise, in 2020, large deer-proof exclosures were constructed to protect critical areas of the reserve, coupled with a landscape-wide, tenure-blind, coordinated and sustained deer control programme across both the reserve and surrounding private land, with the aim of overall population reduction.

Lessons

- Small, fragmented reserves are susceptible to frequent immigration/emigration by deer.
- Infrequent culling or removing low numbers of deer is unlikely to reduce overall deer activity or impact.
- Volunteer shooters that lack specialised equipment and remove relatively small numbers of deer are unlikely to reduce deer activity.

Strategies to improve outcomes

- Frequent control is likely necessary to reduce deer activity in small, fragmented reserves.
- Involve adjacent private landholders in broader cross-tenure control programme.
- Engage contract shooters with specialised equipment and expertise.

3.2 | Case Study 2: Tarago Reservoir Catchment

Despite the considerable number of deer culled, deer activity and impacts did not decrease at survey sites between 2021 and 2023. In 2021, prior to deer control in Tarago Reservoir Catchment, faecal pellet density was 0.29 pellets m^{-2} on average and was highest at sites close to the reservoir (< 500 m), with few pellets recorded at sites further from the reservoir. In 2023, following ~1.5 years of deer control, faecal pellet density increased to 0.48 pellets m^{-2}. Although the change was not significant overall ($p=0.190$, paired t-test, df = 23), there was a notable increase in faecal pellet density at sites located further from the reservoir (> 500 m; Figure 3). Deer impacts on vegetation responded similarly, with impacts increasing slightly but not significantly between years overall, but increases in vegetation impact were pronounced at sites distant (> 500 m) from the reservoir (Bennett and Greet 2024).

The initial stages of this deer control programme did have significant benefits where the core control activities occurred, such as reduced deer activity adjacent to the reservoir, reduced use of farm paddocks by deer, and the building of positive relationships and acceptance of deer control within the local community. However, the focus of control activities from access tracks and roads at the forest interface likely shifted a proportion of the local deer population to less accessible refuges within forest further from the reservoir and access tracks. In turn, this resulted in an increase in deer activity and corresponding impact on vegetation in these locations.

The response of the deer population to these initial control activities in the Tarago catchment is common: many studies have reported altered behaviours in deer populations subject to culling with temporal and spatial variations in habitat use following

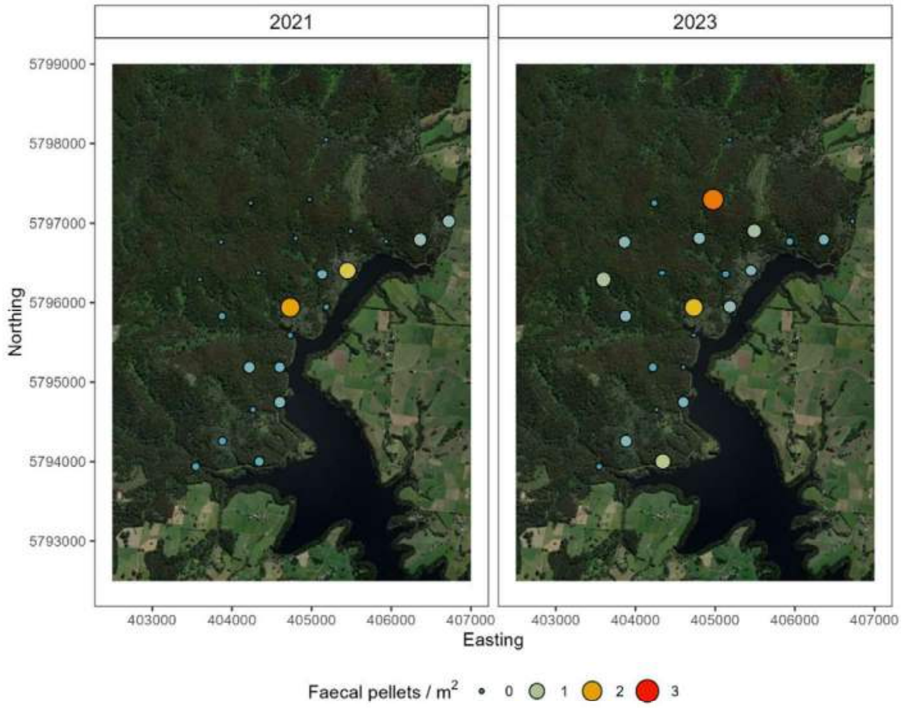

FIGURE 3 | Faecal pellet counts (pellets/m^2) at Tarago Reservoir at 24 forested survey sites in years 2021 (before deer control began) and 2023 (after ~1.5 years of deer control in which a total of 319 deer were culled).

control (Cleveland et al. 2012; Cromsigt et al. 2013; Pecorella et al. 2016; Proffitt et al. 2009). Deer will reduce their use of or avoid locations where shooting occurs to reduce their risk of being culled (Bennett et al. 2015; Comte et al. 2022).

Monitoring deer abundance and impacts during the initial 'knock down' of the population demonstrated that control strategies and tactics (Latham et al. 2018) and the scale over which control is conducted (Bennett et al. 2021; Fattorini et al. 2020) require adjustment in the next phase of this programme to reduce the abundance and impacts of the deer population across the broader forested sections of the Tarago Reservoir catchment. This includes increased effort and coverage of the state forest away from the road network, while continuing to maintain pressure on the forest interface.

Lessons

- Monitoring is critical to understand the response of the deer population to control.
- Control can cause behavioural responses, leading to unintended spatial shifts in the deer population.
- Engagement with the community is important to build acceptance of deer control.

Strategies to improve outcomes

- Maintain monitoring to enable adaptive management.
- Control strategies need to be adaptive, for example, expansion or shift in focus of control, change in control tactics.
- Maintain communication with the community, provide updates on programme progress and opportunity to participate.

3.3 | Case Study 3: Jumping Creek Catchment

Deer activity did not decrease at Jumping Creek Catchment, but rather increased over the course of the control programme from 0.28 to 0.63 independent deer detections/day in years 2018 and 2022 (Figure 4). Moreover, there was a strong seasonal pattern in activity, with notable peaks in the winter months (Figure 5).

Similar to Yellingbo NCA, the main reason for the lack of reduction in deer activity is likely to be the ready immigration (and emigration) of deer from the surrounding landscape. Immigration of the target species from adjacent areas is one of the most common reasons for the ineffectiveness of control programmes (Bengsen et al. 2020). Through the collection of genetic material from the control programme (and other programmes in the broader landscape), kinship analyses show that sambar are likely immigrating into the Jumping Creek Catchment from Kinglake National Park to the north (E. Hill, La Trobe University 2024 pers. comm.).

Seasonal migrations of deer populations are common (e.g., Coe et al. 2018; Zhang et al. 2013). In Victoria, sambar use high-elevation habitats during warmer months (e.g., October–June), and lower-elevation habitats in the colder months when high-elevation areas are covered by snow (Comte et al. 2022). The seasonal migration of sambar to lowland areas (Greene 2022) likely explains the increase in deer activity in the Jumping Creek Catchment observed in winter. In urban settings, shooting in winter can be more cost-effective because longer hours of darkness typically provide increased shooting opportunities (Comte et al. 2024).

In July 2022, the programme successfully received grant funding from the DEECA Deer Control Program (part of the VDCS)

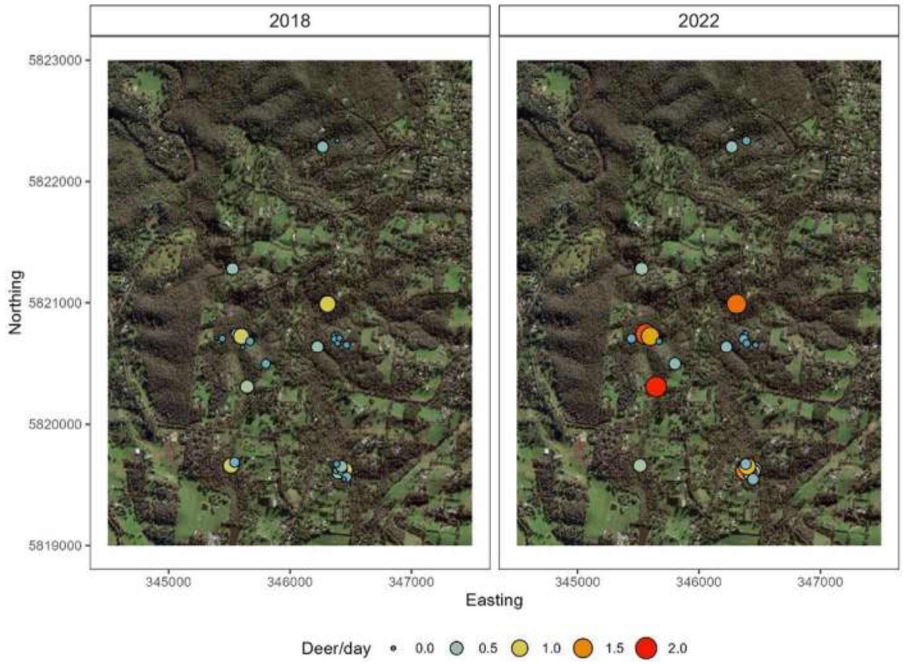

FIGURE 4 | Camera trap detection rates (independent deer detections/day) within Jumping Creek Catchment at 20 randomly located camera trap locations in 2018 (at the beginning of the control) and 2022 (after ~5 years of control).

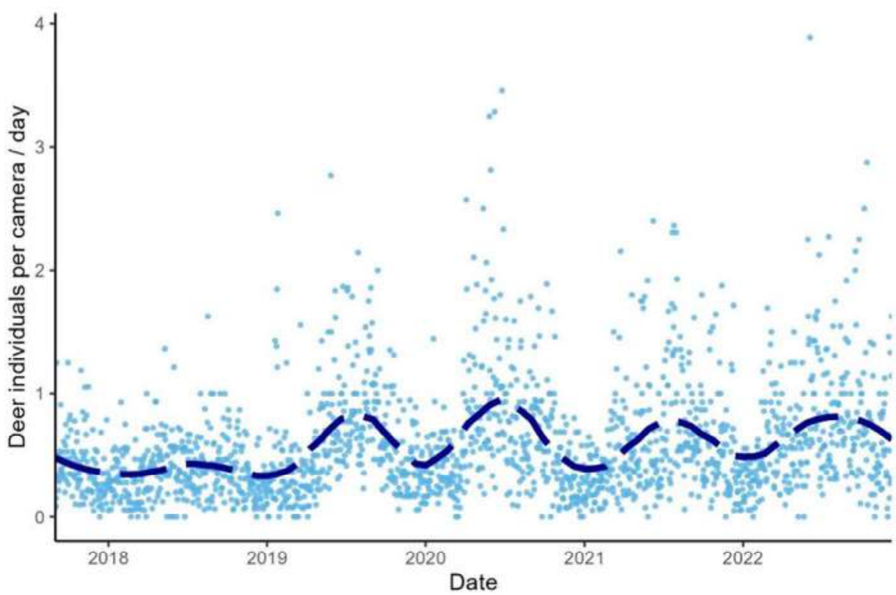

FIGURE 5 | Camera trap detection rates (independent deer detections/day) within Jumping Creek Catchment at 20 randomly located camera trap locations from August 2017–December 2022 (across ~5 years of control). Light blue dots indicate values from individual cameras and dark blue line indicates GAM fitted 'rolling average'.

as the initial 5-year programme was ending. This current programme (2022–2025) is focussed on increasing community engagement to facilitate the expansion of the control programme to cover more properties, with a focus on engagement with properties considered to be key movement corridors for deer. This has increased programme participation and success (number of deer culled), facilitated through greater (now 100%) reimbursement of the cost of deer control that landowners undertake with a professional contractor. In turn, this programme supports the effectiveness of concurrent control programmes being undertaken on surrounding public reserves by Parks Victoria, and on both private and public land in neighbouring councils.

Lessons

- It is difficult to control deer in a highly fragmented landscape because it is highly porous to deer movement.
- Deer activity patterns are often seasonal, likely related to migration.

Strategies to improve outcomes

- Increased community engagement and expansion of the control programme to more properties.
- Targeted engagement of strategic properties within deer movement corridors and to complement control programmes on surrounding land.
- Focus control efforts during times and seasons of greatest deer activity.

4 | Synthesis: Lessons for Improved Deer Control in Peri-Urban and Agricultural Areas

Deer control programmes are increasingly being implemented across Australia to reduce deer populations and mitigate their impacts. However, typical deer control programmes in peri-urban and agricultural landscapes, such as those presented here, are often too spatially restricted and/or poorly resourced to achieve these aims. To be effective, landscape-scale, well-resourced and sustained control programmes are required to sufficiently reduce deer populations and mitigate their impacts.

4.1 | Monitoring Is Critical to Enable Control Programmes to Be Adaptive

A lack of population reduction in response to deer control efforts in these programmes is not necessarily indicative of failure—the deer populations may well have further increased in abundance or extent in the absence of control. Regardless, without monitoring, putative increases or decreases following control will be uncertain. Monitoring is essential to test the effectiveness of management and enable control programmes to be adapted accordingly.

We strongly suggest deer control programmes include replicated monitoring of both deer activity and deer impacts before and after management intervention, and at successive intervals throughout the programme to enable appropriate assessment of programme effectiveness. This will enable adjustments to control strategies with respect to the location, frequency, timing and intensity of control efforts to maximise environmental and social benefits of implementing control programmes.

It is important to note that robust monitoring can be resource-intensive (including data collection, programme management and analyses). Ideally, deer control programme funding is inclusive of sufficient funding for monitoring. Where funds are limiting, monitoring resources are best targeted where risks to high value assets are greatest or programme outcomes most uncertain.

"Monitoring can help to guide targeted control and to determine deer numbers over time and whether there is a reduced impact to vegetation. It can also help inform changes that may be required to our control program. Jumping Creek Catchment Landcare Group."

4.2 | Scale (And Resourcing) Is Important and Coordination Across Different Land Tenures Is Required

The size of the area over which control needs to be conducted to be effective is site and context dependent, but in general, programmes at small scales are unlikely to meet project objectives (Bengsen et al. 2020). Given the mixed land uses in peri-urban and agricultural areas, successful deer control requires coordination across land tenures and land use types at broad scales. Substantial immigration into the control area such as from neighbouring refuge sites, indicates that the area over which control is being conducted is too small (Bengsen et al. 2020). However, simply expanding the control area may not necessarily improve programme outcomes if effort is spread too thinly, and increased frequency and intensity of control effort across or at specific locations within the area of control may also be required (Bengsen et al. 2020; Comte et al. 2024).

While intensive deer control at local scales may achieve short-term localised reductions of deer activity and protection of assets (Bennett et al. 2015; Cromsigt et al. 2013), to achieve an overall reduction of the deer population, a landscape-wide approach is required. In peri-urban areas, this is a complex undertaking because they comprise multiple management jurisdictions and land tenures, they are more densely populated by people and subject to high levels of public scrutiny. Thus, peri-urban deer control often requires extensive consultation, cooperation and community support across a wide geographic area, and sufficient funding to implement community engagement activities over many years, in addition to the resources required to undertake a monitoring and control programme (Comte et al. 2024).

4.3 | Control Strategy Is Important

A recent review of ground-based shooting programmes to control wildlife populations concluded that the approach must be suitable for achieving the desired outcomes, objectives should be clearly defined, and the programme sufficiently resourced (Bengsen et al. 2020). Accordingly, deer management should be implemented strategically with consideration of management objectives relative to biosecurity principles. Where high priority values occur, management effort may need to be intensive at a local scale to mitigate impacts. This approach should be supported by broader scale management undertaken to reduce impacts on lower priority values. Research on deer population movement (e.g., Hill et al. 2023) should be prioritised to identify strategic locations where deer control will be most cost-effective.

Although recreational hunting is a popular activity in Victoria with >120,000 deer reportedly removed in 2022 (Moloney and

Flesch 2023), there is little evidence to indicate recreational hunting reduces overall deer abundance (Forsyth, Pople, et al. 2023). Furthermore, deer hunting is not permissible in peri-urban areas in Australia and is similarly limited in agricultural settings. In most peri-urban environments, the use of professional contractors is necessary to meet legal and safety requirements, expedite approval of firearm use and control activities by police, and for many residents, alleviates safety concerns, fostering a greater level of trust and acceptance of control programmes within the community.

Professional wildlife management contractors typically use rifle suppressors, thermal devices and/or night vision equipment during culling operations. The use of specialised equipment increases the effectiveness of ground-based shooting (Comte, Thomas, et al. 2023). Although the use of professional contractors is more expensive, they usually kill deer at much higher rates; thus, the cost/deer culled is comparable (Comte, Thomas, et al. 2023).

4.4 | Community Consultation and Engagement Is Essential

Community consultation and engagement is critical to the success of deer control programmes in peri-urban and agricultural areas. Public land is typically fragmented in such areas and high rates of movement by deer are expected between public reserves and privately owned land, which often also support significant natural values. To protect such values and successfully reduce deer activity, coordination with private landholders, in particular participation and provision of access to contractors, can deliver significant operational support and time savings, ultimately improving control programme outcomes. For example, increasing the control area provides increased shooting opportunities and a greater variety of (typically limited) vantage points from which deer can be safely shot, reduces avoidance behaviours by deer of these few specific locations, and vehicle access enables efficient carcass removal.

Successful community consultation and engagement requires a mix of strategies. These may include ‘town hall’ meetings, written correspondence and even home visits. In all of the case studies presented here, community consultation was critical to programme establishment and the programmes were, by and large, well supported by a community motivated by concerns of the risks posed by deer to environmental and economic values and human safety. Where possible, financial support for local residents to become an integral part of the programme (e.g., to host control or monitoring activities) are likely to increase programme participation, scope and potential for success, as well as sustaining ongoing interest and involvement.

“Feedback from landowners during our initial programme highlighted the cost involved was one of the greatest barriers to landowner participation and continued interest. Now that we are able to support 100% of the cost, there has been a big improvement to landowner participation and we have significantly increased the size of the control area in our program. Manningham Council Environment Officers.”

5 | Conclusion

The case studies presented here demonstrate that the approaches to deer management in peri-urban and agricultural landscapes were at best holding deer populations and impacts steady. For peri-urban and agricultural settings, monitoring to facilitate adaptive management, coordination across land tenures at appropriate scales, community involvement, and sufficient resourcing to undertake these activities are critical to the success of deer control and the protection of Australia's unique natural environment.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

All de-identified data and code used in analyses for this study will be freely provided upon reasonable request. Some of the references provided in this study are internal research and government reports, these will be made available upon reasonable request.

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