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TITLE: CULLING REDUCES FECAL PELLET DEPOSITION BY INTRODUCED SAMBAR (*RUSA UNICOLOR*) IN A PROTECTED WATER CATCHMENT

RH: BENNETT ET AL. • CULLING REDUCES FECAL DEPOSITION BY SAMBAR

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1 ABSTRACT

2 Introduced sambar (*Rusa unicolor*) occur at high density within the Upper Yarra Catchment,
3 an important watershed for the supply of water to Melbourne, Victoria, Australia.
4 Contamination by zoonotic pathogens in sambar fecal pellets poses a serious risk to water
5 quality. We describe spatial and temporal patterns in distribution and density of sambar in the
6 Upper Yarra Catchment, and assess ground-based culling as a technique to reduce the risk of
7 fecal contamination of the water supply. Sambar density, as indexed by fecal pellet
8 deposition, was inversely related to distance from the reservoir, and aggregations of up to 70
9 sambar occurred on open flats adjacent to the reservoir, where they foraged mostly at dusk.
10 Culling by ground shooting halved fecal pellet density on these flats, primarily through short-
11 term deterrence rather than a significant reduction of the population. As culling continued,
12 fecal pellet deposition declined further, reducing the likely risk to water supplies. We
13 conclude that localized deterrence through targeted culling of sambar at this site is an
14 effective management technique for decreasing deer fecal deposition and the risk of
15 contamination by zoonotic pathogens of Melbourne's water supply.

16 Conflicts between humans and deer populations are prevalent, particularly in regions where a
17 heightened protection status has allowed deer densities to increase (Messmer 2000). Common
18 problems that arise include consumption of agricultural crops by deer (Wilson et al. 2009;
19 Bleier et al. 2012), deer browsing impacts on forestry resources (Putman and Moore 1998;
20 Gheysen et al. 2011), a high rate of deer-vehicle collisions (Hothorn et al. 2012), and
21 increased safety risk to aircraft where deer use airfields (Biondi et al. 2011). Moreover,
22 pathogen transmission from wild populations of deer to domestic livestock may occur via
23 shared food and water resources (Böhm et al. 2007). Human populations may also be at risk
24 of disease through the contamination of drinking water supplies with zoonotic pathogens
25 found in deer feces (Kistemann et al. 2001; Robinson et al. 2011; Parker et al. 2013).

26 Sambar (*Rusa unicolor*), a large species of deer native to Asia (Leslie 2011), was introduced
27 to Australia in the state of Victoria during the 1860s (Bentley 1998). Sambar are now widely
28 distributed throughout eastern Victoria, and other parts of Australia including south-eastern
29 New South Wales and the Australian Capital Territory (Bilney 2008; Gormley et al. 2011;
30 Menkhorst and Knight 2011). Within Victoria, sambar are most commonly found on the Alps
31 and foothills in dense, wet forest (Downes 1983; Gormley et al. 2011). Sambar are generally
32 described as browsers (Burke 1982) or mixed feeders (Forsyth and Davis 2011), although at
33 times they are primarily grazers consuming mostly grasses (Forsyth and Davis 2011), and in
34 some locations they utilize crops and open pastures (Bentley 1998; Mason 2006). The species
35 is typically solitary but may occur in small groups of 3 or 4 (Bentley 1998; Leslie 2011). In
36 Victoria, sambar are classified as wildlife under the Wildlife Act 1975; however, permits may
37 be obtained to hunt the species in specified areas throughout the year. Sambar are also listed
38 as a Potentially Threatening Process in Victoria under the Flora and Fauna Guarantee Act
39 1988, for the ‘reduction of biodiversity of native vegetation’, primarily due to antler rubbing
40 on two threatened tree species (Scientific Advisory Committee 2007), and additional impacts

41 may occur if sambar act as vectors for the dispersal of weeds in Victoria (Department of
42 Sustainability and Environment 2008).

43 Sambar occur at particularly high density in the Upper Yarra ranges (Upper Yarra
44 Catchment) in the Yarra Ranges National Park of Victoria (Forsyth et al. 2009), an important
45 watershed for the supply of drinking water to Melbourne (Viggers et al. 2013). The highest
46 densities recorded by Forsyth et al. (2009) were on grassy flats adjacent to the reservoir
47 within the Upper Yarra Catchment, where large groups of sambar were observed grazing, and
48 high densities of fecal pellets were recorded (Forsyth et al. 2009). The high fecal pellet
49 density indicated the importance of this forage site because deer deposit fecal pellets near
50 where they feed (Bennett et al. 1940), and the population of sambar was shown to remove
51 substantial quantities of biomass at this location (Bennett 2008). High sambar fecal pellet
52 density adjacent to the reservoir has also been identified as a potential risk to the water supply
53 in this catchment (Cinque et al. 2008), because of elevated risk of pathogens entering the
54 reservoir (Ferguson et al. 2009). Of most concern for the health of human populations are the
55 protozoan parasite species of *Cryptosporidium* and *Giardia*, which are resistant to common
56 water treatments such as chlorination (Korich et al. 1990) and can cause disease at low dose
57 levels (Rendtorff 1954; DuPont et al. 1995). Furthermore, *Cryptosporidium* spp. can persist
58 in fecal material and the environment for several months (Robertson et al. 1992). The
59 management authority, Melbourne Water, monitors the water transferred from the reservoir
60 for the presence of protozoa on a monthly basis, and has funded a research program
61 examining protozoa in fecal material from native and introduced herbivores and predators in
62 9 water catchments that supply Melbourne (Nolan et al. 2013). Hundreds of fecal samples
63 were collected from the Upper Yarra Catchment, including from the introduced sambar deer,
64 European rabbit (*Oryctolagus cuniculus*), feral cat (*Felis catus*) and wild dog (*Canis*
65 *familiaris*), and from the native common wombat (*Vombatus ursinus*) and water birds

(unspecified species). Although the overall prevalence of potentially human-infectious *Cryptosporidium* and *Giardia* species was low (5.4 %) during this study (Nolan et al. 2013), sudden outbreaks can occur. For example, *Cryptosporidium* and *Giardia* species were detected in the water supplies following high rainfall and flood events in the catchment for Sydney, Australia during 1998 (McClellan 1998). Because the Upper Yarra system is not treated for protozoa, detection of human-infectious protozoa, particularly *Cryptosporidium* spp., beyond acceptable levels would render the entire supply unusable. Given that water supply from the adjacent Thomson Catchment is also transferred into the Melbourne supply system via the Upper Yarra Reservoir, Melbourne's water supply would be reduced dramatically. Fencing along the fluctuating boundary between the reservoir and grassy flats was not considered feasible because the cost of installation and ongoing maintenance would have been prohibitive and sambar could swim around the ends of a fence. Instead, Melbourne Water investigated culling as a method to reduce the deposition of fecal pellets adjacent to the reservoir, thereby reducing the risk to the water supply.

The objectives of this study were to (1) examine the distribution over time and space of sambar fecal deposits in the Upper Yarra Catchment, with particular reference to grassy flats adjacent to the reservoir, (2) investigate the demographic composition and abundance of the sambar population using grassy flats adjacent to the reservoir and (3) assess the effectiveness of culling as a technique to reduce fecal deposition on grassy flats adjacent to the reservoir.

STUDY AREA

The Upper Yarra Catchment, located approximately 100 km north east of Melbourne, Victoria (Figure 1), is 1 of 3 catchments that encompass the majority 84% (64 500 ha) of the Yarra Ranges National Park. Together with the O'Shannassy and Maroondah catchments, these forested areas are classified as Designated Water Supply Catchment Area and public

90 access is prohibited. The Upper Yarra Catchment was closed to the public in 1888 to allow
91 the supply of high quality, minimally treated water to Melbourne, and from 2003 - 2012 has
92 generated approximately 24% of Melbourne's water supply (S. Haydon, Melbourne Water
93 2013, pers. comm.). Water supply from the Thomson Catchment in West Gippsland, which is
94 transferred via the Upper Yarra Reservoir for supply to Melbourne, additionally contributed
95 23% of total water supply during this time.

96 Much research on sambar in Australia has focused on a site in the Upper Yarra Catchment
97 known as The Flats. This grassy flat is an open, ephemeral, herb-rich area of approximately
98 50 ha, which forms the base of the eastern arm of the Upper Yarra Reservoir where the Yarra
99 River enters the main water body (Figure 1). The Flats is an artificial feature of the Upper
100 Yarra Catchment, present since the completion of the Upper Yarra dam wall in 1957 (Viggers
101 et al. 2013). The size of The Flats fluctuates depending on the level of the reservoir, which is
102 dictated by rainfall and Melbourne Water operations. Due to variation across the site, we
103 divided The Flats into 3 floristic zones: Open Herb-rich Zone, Grassy Rush Zone and Rush-
104 sedge Zone (Figure 1). The Open Herb-rich Zone located at the western end of The Flats is
105 prone to flooding and is covered mainly by herbaceous species, while the eastern end of The
106 Flats floods infrequently, and is dominated by rush and sedge tussocks. Between 2000 and
107 2009, the Open Herb-rich Zone was exposed (above the water line) on average for 7.5
108 months of the year, compared with only 1 month between 2010 and 2012.

109 The Flats is surrounded by forest which varies markedly with aspect and topography, ranging
110 from the south-facing, dense Wet Forest in deep gullies, to drier forest types with heathy
111 understoreys on the north facing slopes and ridges (see full descriptions by Forsyth et al.
112 (2009)). An access track runs along the southern margin (Figure 1). Sambar is the only deer
113 species present on The Flats; other herbivores include the native common wombat, swamp

wallaby (*Wallabia bicolor*), swamp rat (*Rattus lutreolus*) and wood duck (*Chenonetta jubata*), and the introduced European rabbit. There are similar but smaller grassy flats above the upper reaches of the reservoir, including Aldermans Creek and Walshs Creek flats.

METHODS

Distribution and density

Deer pellet counts are positively related to deer density and are frequently used as an index of deer abundance (Forsyth et al. 2007). Therefore, to investigate the population density of sambar in forests at varying distance from The Flats, standing crop counts of sambar fecal pellets were conducted in 2007, with 15 transects located in forest < 1 km and 15 transects > 5 km from The Flats (Bennett 2008). This survey was repeated during 2009 (Bennett and Coulson 2012). We used these data to investigate changes in sambar density in forest at varying distance from The Flats between 2007 and 2009 following sambar control that commenced in 2008 (see sambar control and monitoring). We positioned triangular-shaped transects 210 m long around exclusion units constructed in forest to investigate sambar browsing impacts. We attached a rope to a central peg and searched 12.56-m² ($r = 2$ m) circular plots located at 10-m intervals along the transects for sambar fecal pellets, and recorded the number of groups and pellets within each group to examine which measure was the most informative. For analysis, we categorized 29 transects into 3 distance classes from The Flats: 1 – 250 m ($n = 9$), 251 – 500 m ($n = 4$) and > 1000 m ($n = 16$, including 2 at 1000 m and 14 located > 5 km). We omitted 1 transect located > 5 km from analyses because it had been burnt by a spot fire prior to the 2009 survey. We normalized data using a log transformation and tested differences in fecal pellet counts between distance categories over time using Repeated Measures Analysis of Variance.

To examine longer-term trends of sambar density on The Flats, we collated data from Houston (2003) and Whelan (2005), and from our surveys in 2008, 2011 and 2012. All of these surveys used the fecal pellet accumulation method (Campbell et al. 2004) where pellet groups are removed from within marked plots and the plots surveyed following a set time interval when the number of pellet groups are counted. A pellet group is classified as being defecated at the same time based on their appearance including size, shape, color and texture (Welch et al. 1990; Forsyth et al. 2003). All pellets are then removed and plots resurveyed again at the same time interval. Houston (2003) and Whelan (2005) alternately classified pellet groups that were deposited on plot boundaries as in or out of plots, while we included all pellet groups that had > 50% of pellets within the plot boundary. In all five surveys, circular plots were placed a random number of paces along or adjacent to parallel transect lines that covered the survey area at a random (Whelan 2005), semi-random (Houston 2003) or systematic (this study) distance apart. The centre of each plot was discretely marked with fluorescent flagging tape attached to a peg pushed into the ground. However plot size, definition of a fecal pellet group (minimum number of pellets) and accumulation time varied among these studies. Despite these limitations, we were able to standardize the definition of a pellet group (one pellet group > 10 pellets), accumulation length (month) and survey area (m^2) to allow comparison. Fecal pellet decay in this habitat type was estimated at 226 days by Houston (2003), substantially more than the longest accumulation time of 30 days used in these surveys, so we assumed that decay was negligible. Surveys in 2003 – 2008 were all from the Open Herb-rich Zone, while surveys in 2011 – 2012 were from the Grassy Rush and Rush-sedge zones (Figure 1).

To examine the abundance and demographic structure of the sambar population on The Flats, we conducted vantage point counts (Ratcliffe 1987) from a blind constructed above The Flats. Although The Flats was estimated to cover 50 ha during the majority of surveys, we

could survey only about 35 ha of it because the dense vegetation of the Rush-sedge Zone (Figure 1) obscured sambar from view. During March – September 2005 we conducted evening observations ($n = 20$) using a spotting telescope, with wide-angle or zoom lens. We conducted observations on average 3 times per month for 2.25 hours duration, and made less frequent observations in Summer – Autumn 2006 ($n = 3$) and 2007 ($n = 4$). In each observation session we recorded the sex-age class of each individual: mature (> 2 years old) males and females, yearlings (1 – 2 years old) and juveniles (< 1 year old). We used Analysis of Variance to examine differences in the number of deer present within each sex-age class, and with season. To count sambar during hours of darkness, we used a forward-looking infrared (FLIR) Agema 570 camera (AGEMA Infrared Systems AB, Stockholm, Sweden), with an additional Agema lens for a total of 12° field of view, mounted on a tripod. Given constraints on image storage limit and battery life, we filmed at 1-hour intervals from dusk to dawn on two nights, recording a series of overlapping still images from the blind in a 180° arc, then analyzed each image for presence of deer using the program ThermaCAM Explorer 99 (FLIR Systems, Inc., <http://www.flir.com>). We used a Kolmogorov-Smirnov test to examine variation in activity pattern between the 2 nights.

Sambar control and monitoring

The initial cull was conducted in the Upper Yarra Catchment from May 2008 to November 2009. A team of 4 people operated from a 4×4 vehicle once or twice weekly, depending on weather conditions. Effort was mainly concentrated on open grassy flats beside the reservoir, including The Flats, Aldermans Creek Flat and Walshs Creek Flat, where sambar were shot by experienced hunters concealed on the edge of forest. Otherwise vehicles were driven slowly along access tracks, searching for sambar with the aid of a spotlight during hours of darkness. Once sighted, sambar were shot from beside the vehicle. Culling was continued January – February 2010, October – November 2011 and May – November 2012 by a team

of 3 or 4 hunters who operated once or twice weekly from a 4×4 vehicle, but shooting was largely restricted to access tracks because most of The Flats (Open Herb-rich Zone) was inundated. The hunters classified and recorded the sex and age of all deer, and carcasses were removed from the catchment the following day and buried in a pit. Hunter effort was on average 7 h day^{-1} over a total of 115 days (805 h). In total, 273 sambar were culled from the catchment: 125 in 2008 (including 21 shot on The Flats in May and July 2008), 51 in 2009, 3 in 2010, 45 in 2011 and 49 in 2012. We compared the number of deer observed in each sex-age class during vantage point counts on The Flats (2005 – 2007) to the sex-age classes of deer shot in the initial cull (2008 – 2009) and continuing cull (2010 – 2012) using G-tests of goodness-of-fit.

To assess the effectiveness of the cull in reducing sambar fecal pellets on The Flats, we established 20 fecal pellet accumulation plots during 2008. We located plots at a random number of paces (30 – 80) along 6 parallel transects 100 m apart in the Open Herb-rich Zone (Figure 1). We discretely marked the circular plots (area 40 m^2 , $r = 3.6 \text{ m}$) with flagging tape on a central peg pushed into the ground, and systematically searched for fecal pellets and fecal pellet groups in plots delineated by a rope anchored to the central peg as before. We surveyed plots every 14 days for 3 months (May – July) in conjunction with a cull, such that shooting occurred in the first month, ceased in the second and resumed in the third. We log-transformed data and examined the effect of the cull on fecal pellet groups and fecal pellets using Analysis of Variance. We again monitored the density of sambar pellets on The Flats in July – November 2011 (11 surveys) and April – August 2012 (10 surveys) using fecal accumulation. Due to a persistent rise in reservoir level, we surveyed only the Grassy Rush and Rush-sedge Zones (Figure 1), using 62 plots located a random distance (10 – 30 m) along 18 parallel transects 20 m apart. We reduced plot size to an area of 12.56 m^2 ($r = 2 \text{ m}$) to accommodate the smaller survey area, and surveyed for fecal pellets and fecal pellet groups

every 14 days. Small fluctuations in reservoir level occasionally covered some plots, which were omitted from the survey then cleared of pellets again once the water level had receded, so counts resumed on the following survey. We continued these surveys until a further rise in reservoir level prevented access. We log-transformed these data and used a Generalized Linear Mixed Model framework with Restricted Maximum Likelihood to estimate parameters due to an uneven sample size to examine variation in the number of pellet groups and pellets between the 2 years.

To estimate the biomass of fecal pellets deposited on The Flats during 2008, we collected 10 pellets from each of 15 fresh fecal pellet groups in a plastic bag, oven dried them in a paper bag for 5 days at 70°C and weighed them on an electronic balance to obtain dry weight. We combined results of fecal accumulation surveys with dry pellet weight to estimate fecal load over the Open Herb-rich Zone (32.7 ha) (Figure 1) during 2008, allowing comparison between cull and no-cull periods. Given the 226-day decay time of fecal pellets at this location (Houston 2003), we assumed that all pellets deposited on The Flats over the 6-month interval The Flats were exposed in 2008 would enter the water supply following a rise in reservoir level.

We used the statistical program GenStat 14 (VSN International, <http://www.vsn.co.uk>) for all analyses, and assessed significance at a *P*-value of 0.05.

RESULTS

Distribution and density

Sambar fecal pellet density was lower at greater distance from The Flats during both 2007 (pellet groups: $F_{2,26} = 45.22$, $P < 0.001$, pellets: $F_{2,26} = 26.93$, $P < 0.001$) and 2009 (pellet groups: $F_{2,26} = 23.08$, $P < 0.001$, pellets: $F_{2,26} = 23.22$, $P < 0.001$) (Figure 2). Fecal pellet density declined between 2007 and 2009 after culling began in 2008 (pellet groups: $F_{2,26} =$

78.34, $P < 0.001$, pellets: $F_{2,26} = 62.42$, $P < 0.001$). While the counts of fecal pellet groups and pellets demonstrated a similar reduction over time, the magnitude of change was greater in pellets: the quantity of pellets within 1 km of The Flats was more than halved in 2009 (Figure 2). There was no interaction between year and distance from The Flats for pellets ($F_{2,26} = 2.32$, $P = 0.118$). In contrast, pellet group density in 2009 was lower than 2007 within 500 m of The Flats, but was unchanged at locations ≥ 1 km ($F_{2,26} = 8.40$, $P = 0.002$). Accumulation of fecal pellet groups on The Flats was highest in 2005, but was above 20 groups $\text{ha}^{-1} \text{ day}^{-1}$ in 4 of the 5 years surveyed (Figure 3). In 2012, fecal pellet group accumulation fell below 10 groups $\text{ha}^{-1} \text{ day}^{-1}$ (Figure 3).

The vantage point counts showed that several sambar fed on The Flats during the day, but the greatest abundance of sambar occurred at dusk. The maximum number observed on each survey ranged from 10 to 70, with a mean of 39 (Figure 4). The number of sambar observed each evening was not influenced by season ($F_{3,28} = 1.12$, $P = 0.357$). There were 3 – 4 times as many mature females present at each observation than any other sex-age class ($F_{4,155} = 18.34$, $P < 0.001$, Figure 4), but no difference was observed in the number of individuals of the other sex-age classes observed. The images obtained using the infrared camera were effective in identifying sambar on The Flats at night, but not their sex-age class. The hourly activity pattern of sambar on The Flats during the 2 night trials were not significantly different (Kolmogorov-Smirnov test, $\chi^2 = 1.0$, d.f. = 2, $P = 0.607$), indicating sambar were most active 16:00 – 20:00 h (15 – 40 individuals), with a reduced presence (< 15 individuals) throughout the rest of the night until they left The Flats following sunrise.

Sambar control and monitoring

Almost half (44 %) of sambar culled were mature females (Figure 5). The initial cull (2008 – 2009) closely reflected the population structure observed on The Flats during vantage point

counts in 2005 – 2007 ($G_3 = 5.81$, $P > 0.10$), whereas there was a lower proportion of adult females and a higher proportion of yearling males ($G_3 = 99.81$, $P < 0.001$) in the continued cull (2010 – 2012) (Figure 5).

The number of fecal pellet groups (Wald₁ = 10.44, $P = 0.002$) and pellets (Wald₁ = 15.16, $P < 0.001$) were significantly lower in the Grassy Rush and Rush-sedge Zones of The Flats during 2012 in comparison to 2011 (Figure 3). Fecal pellets were monitored for approximately 5 months in each year, but culling coincided with just one month of monitoring in 2011 compared with 4 months in 2012. The number of pellet groups was not significantly affected by the cull on The Flats during 2008 ($F_{1,5} = 0.02$, $P = 0.90$). However the number of pellets was significantly lower when culling was being conducted ($F_{1,5} = 8.91$, $P = 0.03$), with a reduction in the fecal pellet load by approximately half. Both pellet groups and pellets generally decreased during culling and increased when culling had ceased, except for an increase in pellet groups from weeks 10 to 12 (Figure 6) while culling was being conducted. Deer produced 0.21 fecal pellets m⁻² day⁻¹ during June 2008 which was reduced to 0.11 fecal pellets m⁻² day⁻¹ when culling was conducted during May and July. Mean dry pellet weight was 0.59 g, so the fecal pellet load on the Open Herb-rich Zone of The Flats over a 6 month accumulation time (with no decomposition) was 7.4 t, which was reduced to 3.9 t during culling.

DISCUSSION

Natural, forested watershed areas are used throughout the world to provide high quality water containing few pollutants, and can have the added benefit of preserving native flora and fauna and ecological associations in their natural form (Dudley and Stolton 2003). However, these watersheds may also protect introduced pest species such as sambar, which has become well established in the Upper Yarra Catchment. Accumulation of sambar fecal pellets adjacent to

the Upper Yarra Reservoir increases the risk of zoonotic pathogens entering the water body (Ferguson et al. 2009), so could result in a dramatic reduction in the supply of potable water.

Our studies in the Upper Yarra Catchment have advanced our understanding of how sambar use the catchment from a landscape scale to the scale of the small area of The Flats adjacent to the reservoir. Forsyth et al. (2009) previously used GIS modeling of sambar pellet density and environmental variables in the Upper Yarra Catchment, and concluded that the most important predictors of sambar habitat use were distance to water (gullies), aspect (east- and south-facing) and elevation (lower). Surprisingly, The Flats did not emerge as an important feature for sambar in their analysis, despite the high pellet density recorded in this small area. Our pellet surveys of a more restricted area of the catchment, centered on The Flats, showed that the density of sambar pellets in adjacent forested areas was highest in proximity (< 500 m) to The Flats. This suggested that the local population of sambar was attracted to the abundant forage on these open grassy areas beside the water body, thus increasing the risk to water quality from fecal contamination.

The majority of sambar were observed at dusk, although sambar fed on The Flats throughout the night, and at times during the day. The aggregations of up to 70 sambar attracted to food resources at The Flats are the largest documented for this species anywhere in the world (Leslie 2011). Given that the majority of these animals are mature females, The Flats are likely to play an important role in the dynamics of the sambar population in the Upper Yarra Catchment.

Culling is a common management technique used to control deer populations where conflicts occur (Walter et al. 2010), although culling does not necessarily achieve a reduction in population density (Forsyth et al. 2013). Almost half of the sambar culled in the Upper Yarra Catchment were mature females, the sex-age class that should be targeted for effective,

overall population reduction (Caughley and Sinclair 1994). However, even if culling in the Upper Yarra Catchment had reduced the overall population density of sambar, their use of the attractive grassy flats adjacent to the reservoir may not have decreased. Studies have shown that deer can alter their behavior and decrease their use of habitats associated with human hunting (Proffitt et al. 2009; Cleveland et al. 2012), which offers a more effective solution to human-wildlife conflicts at a local scale (Cromsigt et al. 2013).

Counts of pellet groups are commonly used to estimate deer abundance (e.g. Campbell et al. 2004), but we also counted individual pellets. Although the two measures largely showed similar patterns, we found that pellet group counts failed to detect short-term effects, whereas counts of individual pellets were more sensitive to subtle changes in deer activity. Initially, fecal pellet density on The Flats decreased with shooting in May 2008, but quickly returned to pre-cull levels when shooting paused in June, suggesting that the primary effect of control activities was short-term deterrence rather than a significant reduction of the population. Nevertheless, shooting was effective in reducing use of The Flats by sambar as shown by a reduction of fecal pellets. Continued control of sambar achieved a further decrease of pellet density on The Flats by 2012, and had the desired effect of reducing fecal deposition adjacent to the water supply.

MANAGEMENT IMPLICATIONS

Melbourne Water has spent approximately AUD \$400 000 on control of sambar in the Upper Yarra Catchment between 2008 and 2012. Other potentially less costly deterrents, such as propane cannons to simulate shooting, are unlikely to be effective beyond the short term (Walter et al. 2010). At The Flats, hunting was immediately effective for reducing use by sambar and the consequent fecal load adjacent to the water body of the reservoir. Deterring sambar from The Flats over 6 months represented a 3.5-t reduction of fecal pellets entering

the reservoir in 2008. Although sambar are unable to use the Flats when it is inundated, maintaining a consistently high water level in the reservoir is not possible due to water management constraints. The use of culling as a technique would therefore be of greatest benefit at times when the water level is low and large areas of forage are exposed on The Flats.

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480 **Figure 1.** Location of The Flats within the Upper Yarra Catchment, Victoria, Australia,
481 showing the forest types (Ecological Vegetation Classes) and floristic zones of The Flats.

482 **Figure 2.** Mean ($\pm$ standard error) standing crop of fecal pellets of sambar (*Rusa unicolor*) at
483 exclusion units in forest of the Upper Yarra Catchment, Victoria, Australia, during 2007 and
484 2009. Significant differences are shown between distance categories where $A > B > C$, and
485 between years where $a > b$.

486 **Figure 3.** Mean ($\pm$ standard error) sambar (*Rusa unicolor*) fecal pellet group accumulation
487 on The Flats, Victoria, Australia, between 2003 and 2012, showing pre-control (black bars)
488 and post-control (white bars) and the number of surveys (n) conducted in each year are
489 shown within bars. Control activities commenced May 2008 – Nov 2009 and continued Jan –
490 Feb 2010, Oct – Nov 2011 and May – Nov 2012. Data for 2003 and 2005 were obtained from
491 Houston (2003) and Whelan (2005), respectively.

492 **Figure 4.** Mean ($\pm$ standard error) number of sambar (*Rusa unicolor*) at each vantage point
493 survey conducted from the blind at The Flats, Upper Yarra Catchment, Victoria, Australia,
494 Mar 2005 - Feb 2007. Significant differences are shown between sex-age classes where $a > b$.

495 **Figure 5.** Proportion of sambar (*Rusa unicolor*) in each sex-age class observed in vantage
496 point counts on The Flats (2005 – 2007), initial cull (May 2008 – Nov 2009) and continued
497 cull (Jan – Feb 2010, Oct – Nov 2011 and May – Nov 2012) Upper Yarra Catchment,
498 Victoria, Australia.

499 **Figure 6.** Mean ($\pm$ standard error) accumulation of sambar (*Rusa unicolor*) fecal pellet
500 groups and fecal pellets on The Flats, Upper Yarra Catchment, Victoria, Australia, May – Jul
501 2008. Culling (grey shading) occurred in May at weeks 2 – 6 and July weeks 10 – 14.

Figure 2

Figure 3

Figure 4

Figure 5

Figure 6

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