



Minerva Access is the Institutional Repository of The University of Melbourne

Author/s:

Bennett, A;Haydon, S;Stevens, M;Coulson, G

Title:

Culling reduces fecal pellet deposition by introduced sambar (Rusa unicolor) in a protected water catchment

Date:

2015-06-01

Citation:

Bennett, A., Haydon, S., Stevens, M. & Coulson, G. (2015). Culling reduces fecal pellet deposition by introduced sambar (Rusa unicolor) in a protected water catchment. *Wildlife Society Bulletin*, 39 (2), pp.268-275. <https://doi.org/10.1002/wsb.522>.

Persistent Link:

<https://hdl.handle.net/11343/115977>

REVISED 17 SEPTEMBER 2014

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

AMI BENNETT,¹² *Department of Zoology, The University of Melbourne, Victoria 3010, Australia*

SHANE HAYDON, *Melbourne Water, Victoria 3008, Australia*

MELITA STEVENS, *Melbourne Water, Victoria 3008, Australia*

GRAEME COULSON, *Department of Zoology, The University of Melbourne, Victoria 3010, Australia*

¹E-mail: bea@unimelb.edu.au

²Present address: *Department of Zoology, The University of Melbourne, Victoria 3010, Australia*

KEYWORDS *Cervus unicolor*, density, exotic deer, population control, water catchment, water quality, zoonotic pathogens.

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

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

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

85 **STUDY AREA**

86 The Upper Yarra Catchment, located approximately 100 km north east of Melbourne,
87 Victoria (Figure 1), is 1 of 3 catchments that encompass the majority 84% (64 500 ha) of the
88 Yarra Ranges National Park. Together with the O'Shannassy and Maroondah catchments,
89 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

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

117 **METHODS**

118 **Distribution and density**

119 Deer pellet counts are positively related to deer density and are frequently used as an index of
120 deer abundance (Forsyth et al. 2007). Therefore, to investigate the population density of
121 sambar in forests at varying distance from The Flats, standing crop counts of sambar fecal
122 pellets were conducted in 2007, with 15 transects located in forest < 1 km and 15 transects
123 > 5 km from The Flats (Bennett 2008). This survey was repeated during 2009 (Bennett and
124 Coulson 2012). We used these data to investigate changes in sambar density in forest at
125 varying distance from The Flats between 2007 and 2009 following sambar control that
126 commenced in 2008 (see sambar control and monitoring). We positioned triangular-shaped
127 transects 210 m long around exclusion units constructed in forest to investigate sambar
128 browsing impacts. We attached a rope to a central peg and searched 12.56-m² ($r = 2$ m)
129 circular plots located at 10-m intervals along the transects for sambar fecal pellets, and
130 recorded the number of groups and pellets within each group to examine which measure was
131 the most informative. For analysis, we categorized 29 transects into 3 distance classes from
132 The Flats: 1 – 250 m ($n = 9$), 251 – 500 m ($n = 4$) and > 1000 m ($n = 16$, including 2 at 1000
133 m and 14 located > 5 km). We omitted 1 transect located > 5 km from analyses because it had
134 been burnt by a spot fire prior to the 2009 survey. We normalized data using a log
135 transformation and tested differences in fecal pellet counts between distance categories over
136 time using Repeated Measures Analysis of Variance.

137 To examine longer-term trends of sambar density on The Flats, we collated data from
138 Houston (2003) and Whelan (2005), and from our surveys in 2008, 2011 and 2012. All of
139 these surveys used the fecal pellet accumulation method (Campbell et al. 2004) where pellet
140 groups are removed from within marked plots and the plots surveyed following a set time
141 interval when the number of pellet groups are counted. A pellet group is classified as being
142 defecated at the same time based on their appearance including size, shape, color and texture
143 (Welch et al. 1990; Forsyth et al. 2003). All pellets are then removed and plots resurveyed
144 again at the same time interval. Houston (2003) and Whelan (2005) alternately classified
145 pellet groups that were deposited on plot boundaries as in or out of plots, while we included
146 all pellet groups that had > 50% of pellets within the plot boundary. In all five surveys,
147 circular plots were placed a random number of paces along or adjacent to parallel transect
148 lines that covered the survey area at a random (Whelan 2005), semi-random (Houston 2003)
149 or systematic (this study) distance apart. The centre of each plot was discretely marked with
150 fluorescent flagging tape attached to a peg pushed into the ground. However plot size,
151 definition of a fecal pellet group (minimum number of pellets) and accumulation time varied
152 among these studies. Despite these limitations, we were able to standardize the definition of a
153 pellet group (one pellet group > 10 pellets), accumulation length (month) and survey area
154 (m²) to allow comparison. Fecal pellet decay in this habitat type was estimated at 226 days by
155 Houston (2003), substantially more than the longest accumulation time of 30 days used in
156 these surveys, so we assumed that decay was negligible. Surveys in 2003 – 2008 were all
157 from the Open Herb-rich Zone, while surveys in 2011 – 2012 were from the Grassy Rush and
158 Rush-sedge zones (Figure 1).

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

162 could survey only about 35 ha of it because the dense vegetation of the Rush-sedge Zone
163 (Figure 1) obscured sambar from view. During March – September 2005 we conducted
164 evening observations ($n = 20$) using a spotting telescope, with wide-angle or zoom lens. We
165 conducted observations on average 3 times per month for 2.25 hours duration, and made less
166 frequent observations in Summer – Autumn 2006 ($n = 3$) and 2007 ($n = 4$). In each
167 observation session we recorded the sex-age class of each individual: mature (> 2 years old)
168 males and females, yearlings (1 – 2 years old) and juveniles (< 1 year old). We used Analysis
169 of Variance to examine differences in the number of deer present within each sex-age class,
170 and with season. To count sambar during hours of darkness, we used a forward-looking
171 infrared (FLIR) Agema 570 camera (AGEMA Infrared Systems AB, Stockholm, Sweden),
172 with an additional Agema lens for a total of 12° field of view, mounted on a tripod. Given
173 constraints on image storage limit and battery life, we filmed at 1-hour intervals from dusk to
174 dawn on two nights, recording a series of overlapping still images from the blind in a 180°
175 arc, then analyzed each image for presence of deer using the program ThermaCAM Explorer
176 99 (FLIR Systems, Inc., <http://www.flir.com>). We used a Kolmogorov-Smirnov test to
177 examine variation in activity pattern between the 2 nights.

178 **Sambar control and monitoring**

179 The initial cull was conducted in the Upper Yarra Catchment from May 2008 to November
180 2009. A team of 4 people operated from a 4×4 vehicle once or twice weekly, depending on
181 weather conditions. Effort was mainly concentrated on open grassy flats beside the reservoir,
182 including The Flats, Aldermans Creek Flat and Walshs Creek Flat, where sambar were shot
183 by experienced hunters concealed on the edge of forest. Otherwise vehicles were driven
184 slowly along access tracks, searching for sambar with the aid of a spotlight during hours of
185 darkness. Once sighted, sambar were shot from beside the vehicle. Culling was continued
186 January – February 2010, October – November 2011 and May – November 2012 by a team

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

197 To assess the effectiveness of the cull in reducing sambar fecal pellets on The Flats, we
198 established 20 fecal pellet accumulation plots during 2008. We located plots at a random
199 number of paces (30 – 80) along 6 parallel transects 100 m apart in the Open Herb-rich Zone
200 (Figure 1). We discretely marked the circular plots (area 40 m^2 , $r = 3.6 \text{ m}$) with flagging tape
201 on a central peg pushed into the ground, and systematically searched for fecal pellets and
202 fecal pellet groups in plots delineated by a rope anchored to the central peg as before. We
203 surveyed plots every 14 days for 3 months (May – July) in conjunction with a cull, such that
204 shooting occurred in the first month, ceased in the second and resumed in the third. We log-
205 transformed data and examined the effect of the cull on fecal pellet groups and fecal pellets
206 using Analysis of Variance. We again monitored the density of sambar pellets on The Flats in
207 July – November 2011 (11 surveys) and April – August 2012 (10 surveys) using fecal
208 accumulation. Due to a persistent rise in reservoir level, we surveyed only the Grassy Rush
209 and Rush-sedge Zones (Figure 1), using 62 plots located a random distance (10 – 30 m) along
210 18 parallel transects 20 m apart. We reduced plot size to an area of 12.56 m^2 ($r = 2 \text{ m}$) to
211 accommodate the smaller survey area, and surveyed for fecal pellets and fecal pellet groups

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

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

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

230 **RESULTS**

231 **Distribution and density**

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

236 78.34, $P < 0.001$, pellets: $F_{2,26} = 62.42$, $P < 0.001$). While the counts of fecal pellet groups
237 and pellets demonstrated a similar reduction over time, the magnitude of change was greater
238 in pellets: the quantity of pellets within 1 km of The Flats was more than halved in 2009
239 (Figure 2). There was no interaction between year and distance from The Flats for pellets
240 ($F_{2,26} = 2.32$, $P = 0.118$). In contrast, pellet group density in 2009 was lower than 2007
241 within 500 m of The Flats, but was unchanged at locations ≥ 1 km ($F_{2,26} = 8.40$, $P = 0.002$).
242 Accumulation of fecal pellet groups on The Flats was highest in 2005, but was above 20
243 groups $\text{ha}^{-1} \text{day}^{-1}$ in 4 of the 5 years surveyed (Figure 3). In 2012, fecal pellet group
244 accumulation fell below 10 groups $\text{ha}^{-1} \text{day}^{-1}$ (Figure 3).

245 The vantage point counts showed that several sambar fed on The Flats during the day, but the
246 greatest abundance of sambar occurred at dusk. The maximum number observed on each
247 survey ranged from 10 to 70, with a mean of 39 (Figure 4). The number of sambar observed
248 each evening was not influenced by season ($F_{3,28} = 1.12$, $P = 0.357$). There were 3 – 4 times
249 as many mature females present at each observation than any other sex-age class ($F_{4,155} =$
250 18.34, $P < 0.001$, Figure 4), but no difference was observed in the number of individuals of
251 the other sex-age classes observed. The images obtained using the infrared camera were
252 effective in identifying sambar on The Flats at night, but not their sex-age class. The hourly
253 activity pattern of sambar on The Flats during the 2 night trials were not significantly
254 different (Kolmogorov-Smirnov test, $\chi^2 = 1.0$, d.f. = 2, $P = 0.607$), indicating sambar were
255 most active 16:00 – 20:00 h (15 – 40 individuals), with a reduced presence (< 15 individuals)
256 throughout the rest of the night until they left The Flats following sunrise.

257 **Sambar control and monitoring**

258 Almost half (44 %) of sambar culled were mature females (Figure 5). The initial cull (2008 –
259 2009) closely reflected the population structure observed on The Flats during vantage point

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

263 The number of fecal pellet groups (Wald₁ = 10.44, $P = 0.002$) and pellets (Wald₁ = 15.16, $P <$
264 0.001) were significantly lower in the Grassy Rush and Rush-sedge Zones of The Flats
265 during 2012 in comparison to 2011 (Figure 3). Fecal pellets were monitored for
266 approximately 5 months in each year, but culling coincided with just one month of
267 monitoring in 2011 compared with 4 months in 2012. The number of pellet groups was not
268 significantly affected by the cull on The Flats during 2008 ($F_{1,5} = 0.02$, $P = 0.90$). However
269 the number of pellets was significantly lower when culling was being conducted ($F_{1,5} = 8.91$,
270 $P = 0.03$), with a reduction in the fecal pellet load by approximately half. Both pellet groups
271 and pellets generally decreased during culling and increased when culling had ceased, except
272 for an increase in pellet groups from weeks 10 to 12 (Figure 6) while culling was being
273 conducted. Deer produced 0.21 fecal pellets m⁻² day⁻¹ during June 2008 which was reduced to
274 0.11 fecal pellets m⁻² day⁻¹ when culling was conducted during May and July. Mean dry pellet
275 weight was 0.59 g, so the fecal pellet load on the Open Herb-rich Zone of The Flats over a 6
276 month accumulation time (with no decomposition) was 7.4 t, which was reduced to 3.9 t during
277 culling.

278 **DISCUSSION**

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

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

286 Our studies in the Upper Yarra Catchment have advanced our understanding of how sambar
287 use the catchment from a landscape scale to the scale of the small area of The Flats adjacent
288 to the reservoir. Forsyth et al. (2009) previously used GIS modeling of sambar pellet density
289 and environmental variables in the Upper Yarra Catchment, and concluded that the most
290 important predictors of sambar habitat use were distance to water (gullies), aspect (east- and
291 south-facing) and elevation (lower). Surprisingly, The Flats did not emerge as an important
292 feature for sambar in their analysis, despite the high pellet density recorded in this small area.

293 Our pellet surveys of a more restricted area of the catchment, centered on The Flats, showed
294 that the density of sambar pellets in adjacent forested areas was highest in proximity (< 500
295 m) to The Flats. This suggested that the local population of sambar was attracted to the
296 abundant forage on these open grassy areas beside the water body, thus increasing the risk to
297 water quality from fecal contamination.

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

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

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

314 Counts of pellet groups are commonly used to estimate deer abundance (e.g. Campbell et al.
315 2004), but we also counted individual pellets. Although the two measures largely showed
316 similar patterns, we found that pellet group counts failed to detect short-term effects, whereas
317 counts of individual pellets were more sensitive to subtle changes in deer activity. Initially,
318 fecal pellet density on The Flats decreased with shooting in May 2008, but quickly returned
319 to pre-cull levels when shooting paused in June, suggesting that the primary effect of control
320 activities was short-term deterrence rather than a significant reduction of the population.
321 Nevertheless, shooting was effective in reducing use of The Flats by sambar as shown by a
322 reduction of fecal pellets. Continued control of sambar achieved a further decrease of pellet
323 density on The Flats by 2012, and had the desired effect of reducing fecal deposition adjacent
324 to the water supply.

325 **MANAGEMENT IMPLICATIONS**

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

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

337 **ACKNOWLEDGMENTS**

338 This research was funded by Melbourne Water. Many thanks to Melbourne Water staff N.
339 Rattray, M. Tucker, J. Rogers, H. Gooren, K. Reynolds, J. Tite, M. Malovic, R. Gray, and
340 staff at Parks Victoria Woori Yallock for co-operation during the cull. M. Tucker collated
341 sambar sex and age data, A. Whelan contributed to the collection of vantage point count data,
342 G. Hepworth, The University of Melbourne, provided statistical advice, and N. Davis, S.
343 Garnick, J. Cripps and several reviewers provided helpful comments on the draft manuscript.

344 **LITERATURE CITED**

- 345 Bennett, A. 2008. The impacts of sambar (*Cervus unicolor*) in the Yarra Ranges National
346 Park. Dissertation, The University of Melbourne, Melbourne, Australia.
- 347 Bennett, A. and G. Coulson. 2012. The Seedling Ratio Method for determining ungulate
348 impacts on forest understoreys: Utility in an Australian ecosystem. *Ecological
349 Management & Restoration* 13:198-201.
- 350 Bennett, L. J., P. F. English and R. McCain. 1940. A study of deer populations by use of
351 pellet-group counts. *Journal of Wildlife Management* 4:398-403.
- 352 Bentley, A. 1998. An introduction to the deer of Australia with special reference to Victoria.
353 Australian Deer Research Foundation, Croydon, Victoria, Australia.

- 354 Bilney, R. J. 2008. Sambar. 12 Pages 777-778 in S. Van Dyck and R. Strahan, editors. The
355 Mammals of Australia. New Holland Publishers (Australia) Pty Ltd, Chatswood, New
356 South Wales, Australia.
- 357 Biondi, K. M., J. L. Belant, J. A. Martin, T. L. DeVault and G. Wang. 2011. White-tailed
358 deer incidents with U.S. civil aircraft. *Wildlife Society Bulletin* 35:303-309.
- 359 Bleier, N., R. Lehoczki, D. Újváry, L. Szemethy and S. Csányi. 2012. Relationships between
360 wild ungulates density and crop damage in Hungary. *Acta Theriologica* 57:351-359.
- 361 Böhm, M., P. C. L. White, J. Chambers, L. Smith and M. R. Hutchings. 2007. Wild deer as a
362 source of infection for livestock and humans in the UK. *The Veterinary Journal*
363 174:260-276.
- 364 Burke, P. 1982. Food plants utilized by sambar. *Australian Deer* 7:7-12.
- 365 Campbell, D., G. M. Swanson and J. Sales. 2004. Comparing the precision and cost-
366 effectiveness of faecal pellet group count methods. *Journal of Applied Ecology*
367 41:1185-1196.
- 368 Caughley, G. and A. R. E. Sinclair. 1994. *Wildlife ecology and management*. Blackwell
369 Scientific Publications, Boston, Massachusetts, USA.
- 370 Cinque, K., M. A. Stevens, S. R. Haydon, A. R. Jex, R. B. Gasser and B. E. Campbell. 2008.
371 Investigating public health impacts of deer in a protected drinking water supply
372 watershed. *Water Science & Technology* 58:127-132.
- 373 Cleveland, S. M., M. Hebblewhite, M. Thompson and R. Henderson. 2012. Linking elk
374 movement and resource selection to hunting pressure in a heterogeneous landscape.
375 *Wildlife Society Bulletin* 36:658-668.
- 376 Cromsigt, J. P. G. M., D. P. J. Kuijper, M. Adam, R. L. Beschta, M. Churski, A. Eycott, G. I.
377 H. Kerley, A. Mysterud, K. Schmidt and K. West. 2013. Hunting for fear: innovating
378 management of human–wildlife conflicts. *Journal of Applied Ecology* 50:544-549.

- 379 Department of Sustainability and Environment. 2008. Reduction in biodiversity of native
380 vegetation by Sambar (*Cervus unicolor*), Draft Flora and Fauna Guarantee Action
381 Statement. Department of Sustainability and Environment, Melbourne, Victoria,
382 Australia.
- 383 Downes, M. C. 1983. The Forest Deer Project 1982: a report to the Forests Commission
384 Victoria. Australian Deer Research Foundation, Melbourne, Victoria, Australia.
- 385 Dudley, N. and S. Stolton (2003). Running Pure: The importance of forest protected areas to
386 drinking water. A research report for World Bank / WWF Alliance for Forest
387 Conservation and Sustainable Use. Oakland, California, USA, World Bank/WWF
388 Alliance for Forest Conservation and Sustainable Use.
- 389 DuPont, H. L., C. L. Chappell, C. R. Sterling, P. C. Okhuysen, J. B. Rose and W.
390 Jakubowski. 1995. The infectivity of *Cryptosporidium parvum* in healthy volunteers.
391 New England Journal of Medicine 332:855-859.
- 392 Ferguson, C. M., K. Charles and D. A. Deere. 2009. Quantification of microbial sources in
393 drinking-water catchments. Critical Reviews in Environmental Science and
394 Technology 39:1-40.
- 395 Forsyth, D. M., R. J. Barker, G. Morriss and M. P. Scroggie. 2007. Modeling the
396 relationships between fecal pellet indices and deer density. The Journal of Wildlife
397 Management 71:964-970.
- 398 Forsyth, D. M. and N. E. Davis. 2011. Diets of non-native deer in Australia estimated by
399 macroscopic versus microhistological rumen analysis. Journal of Wildlife
400 Management 75:1488-1497.
- 401 Forsyth, D. M., S. R. McLeod, M. P. Scroggie and M. D. White. 2009. Modelling the
402 abundance of wildlife using field surveys and GIS: non-native sambar deer (*Cervus*
403 *unicolor*) in the Yarra Ranges, south-eastern Australia. Wildlife Research 36:231-241.

- 404 Forsyth, D. M., D. S. L. Ramsey, C. J. Veltman, R. B. Allen, W. J. Allen, R. J. Barker, C. L.
405 Jacobson, S. J. Nicol, S. J. Richardson and C. R. Todd. 2013. When deer must die:
406 large uncertainty surrounds changes in deer abundance achieved by helicopter- and
407 ground-based hunting in New Zealand forests. *Wildlife Research* 40:447-458.
- 408 Forsyth, D. M., M. P. Scroggie and B. Reddiex. 2003. Review of methods to estimate the
409 density of deer. Unpublished contract report (LC0304/015). Landcare Research,
410 Lincoln, New Zealand.
- 411 Gheysen, T., Y. Brostaux, J. Hébert, G. Ligot, J. Rondeux and P. Lejeune. 2011. A regional
412 inventory and monitoring setup to evaluate bark peeling damage by red deer (*Cervus*
413 *elaphus*) in coniferous plantations in Southern Belgium. *Environmental Monitoring*
414 *and Assessment* 181:335-345.
- 415 Gormley, A. M., D. M. Forsyth, P. Griffioen, M. Lindeman, D. S. L. Ramsey, M. P. Scroggie
416 and L. Woodford. 2011. Using presence-only and presence-absence data to estimate
417 the current and potential distributions of established invasive species. *Journal of*
418 *Applied Ecology* 48:25-34.
- 419 Hothorn, T., R. Brandl and J. Müller. 2012. Large-scale model-based assessment of deer-
420 vehicle collision risk. *PLoS ONE* 7:e29510.
- 421 Houston, E. 2003. The use of faecal counts to estimate sambar deer (*Cervus unicolor*)
422 population abundance in Victoria. Thesis, Monash University, Melbourne, Australia.
- 423 Kistemann, T., F. Dangendorf and M. Exner. 2001. A Geographical Information System
424 (GIS) as a tool for microbial risk assessment in catchment areas of drinking water
425 reservoirs. *International Journal of Hygiene and Environmental Health* 203:225-233.
- 426 Korich, D. G., J. R. Mead, M. S. Madore, N. A. Sinclair and C. R. Sterling. 1990. Effects of
427 ozone, chlorine dioxide, chlorine, and monochloramine on *Cryptosporidium parvum*
428 oocyst viability. *Applied and Environmental Microbiology* 56:1423-1428.

- 429 Leslie, D. M. 2011. *Rusa unicolor* (Artiodactyla: Cervidae). Mammalian Species 43:1-30.
- 430 Mason, E. 2006. Secrets of the Sambar. Shikari Press, Bairnsdale, Victoria, Australia.
- 431 McClellan, P. (1998). Sydney Water Inquiry. Final Report Volume 2. New South Wales
432 Premier's Department, Sydney, Australia.
- 433 Menkhorst, P. and F. Knight. 2011. A field guide to the mammals of Australia. Oxford
434 University Press, South Melbourne, Victoria, Australia.
- 435 Messmer, T. A. 2000. The emergence of human-wildlife conflict management: turning
436 challenges into opportunities. International Biodeterioration & Biodegradation 45:97-
437 102.
- 438 Nolan, M. J., A. R. Jex, A. V. Koehler, S. R. Haydon, M. A. Stevens and R. B. Gasser. 2013.
439 Molecular-based investigation of *Cryptosporidium* and *Giardia* from animals in water
440 catchments in southeastern Australia. Water Research 47:1726-1740.
- 441 Parker, I. D., R. R. Lopez, R. Padia, M. Gallagher, R. Karthikeyan, J. C. Cathey, N. J. Silvy
442 and D. S. Davis. 2013. Role of free-ranging mammals in the deposition of
443 *Escherichia coli* into a Texas floodplain. Wildlife Research 40:570-577.
- 444 Proffitt, K. M., J. L. Grigg, K. L. Hamlin and R. A. Garrott. 2009. Contrasting effects of
445 wolves and human hunters on elk behavioral responses to predation risk. The Journal
446 of Wildlife Management 73:345-356.
- 447 Putman, R. J. and N. P. Moore. 1998. Impact of deer in lowland Britain on agriculture,
448 forestry and conservation habitats. Mammal Review 28:141-164.
- 449 Ratcliffe, P. R. 1987. Red deer population changes and the independent assessment of
450 population size. Symposia of the Zoological Society of London 58:153-165.
- 451 Rendtorff, R. C. 1954. The experimental transmission of human intestinal protozoan
452 parasites. II. *Giardia lamblia* cysts given in capsules. American Journal of Hygiene
453 59:209-220.

- 454 Robertson, L. J., A. T. Campbell and H. V. Smith. 1992. Survival of *Cryptosporidium*
455 *parvum* oocysts under various environmental pressures. Applied and Environmental
456 Microbiology 58:3494-3500.
- 457 Robinson, G., R. M. Chalmers, C. Stapleton, S. R. Palmer, J. Watkins, C. Francis and D.
458 Kay. 2011. A whole water catchment approach to investigating the origin and
459 distribution of *Cryptosporidium* species. Journal of Applied Microbiology 111:717-
460 730.
- 461 Scientific Advisory Committee. 2007. Final Recommendation on a nomination for listing:
462 Reduction in biodiversity of native vegetation by sambar (*Cervus unicolor*)
463 (Nomination No. 756). Department of Sustainability and Environment, Melbourne,
464 Victoria, Australia.
- 465 Viggers, J. I., H. J. Weaver and D. B. Lindenmayer. 2013. Melbourne's water catchments:
466 Perspectives on a world-class water supply. CSIRO Publishing, Collingwood,
467 Victoria, Australia.
- 468 Walter, W. D., M. J. Lavelle, J. W. Fischer, T. L. Johnson, S. E. Hygnstrom and K. C.
469 VerCauteren. 2010. Management of damage by elk (*Cervus elaphus*) in North
470 America: a review. Wildlife Research 37:630-646.
- 471 Welch, D., B. W. Staines, D. C. Catt and D. Scott. 1990. Habitat usage by red (*Cervus*
472 *elaphus*) and roe (*Capreolus capreolus*) deer in a Scottish Sitka spruce plantation.
473 Journal of Zoology 221:453-476.
- 474 Whelan, A. 2005. Determining the output and decomposition rates of faecal pellets of free-
475 ranging sambar deer (*Cervus unicolor*). Thesis, The University of Melbourne,
476 Melbourne, Australia.

- 477 Wilson, C. J., A. Britton and R. Symes. 2009. An assessment of agricultural damage caused
478 by red deer (*Cervus elaphus* L.) and fallow deer (*Dama dama* L.) in southwest
479 England. *Wildlife Biology in Practice* 5:104-114.

For Review Only

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.

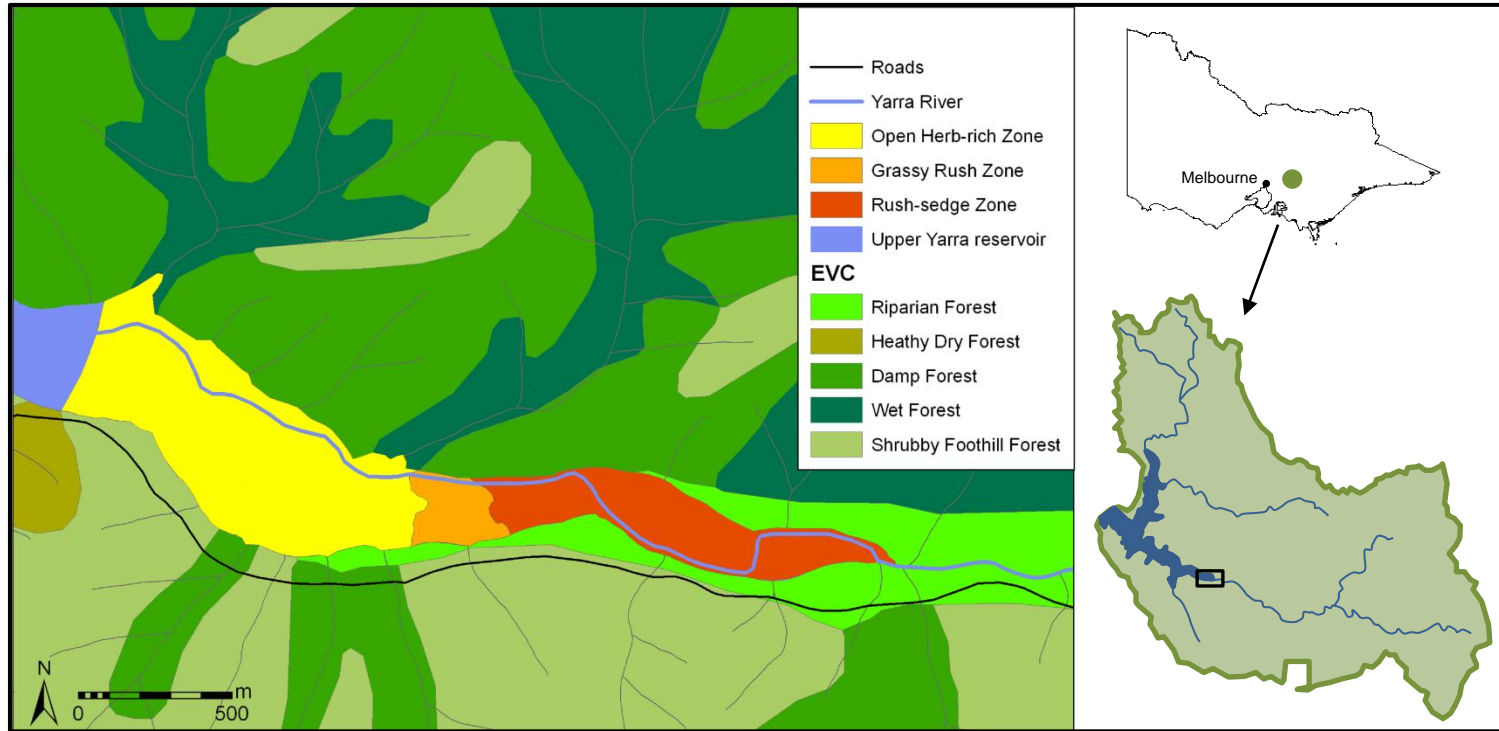
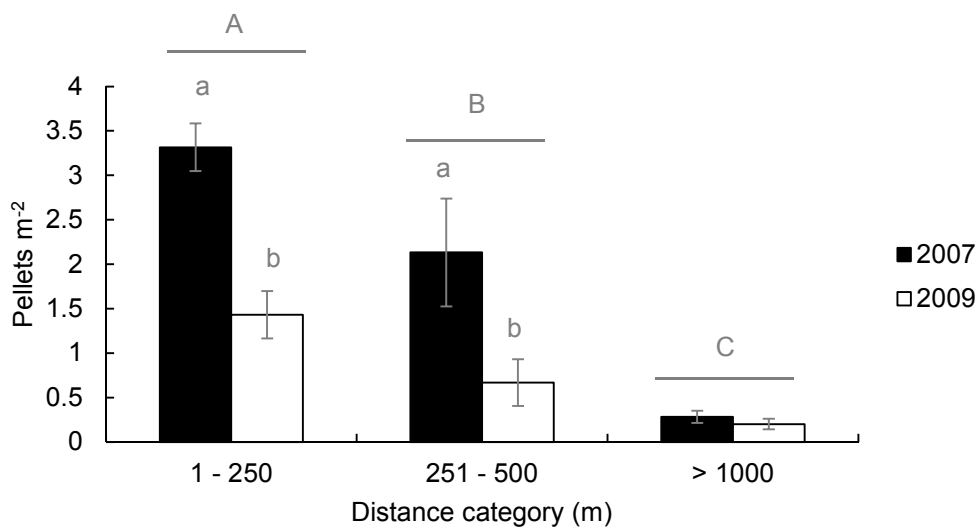
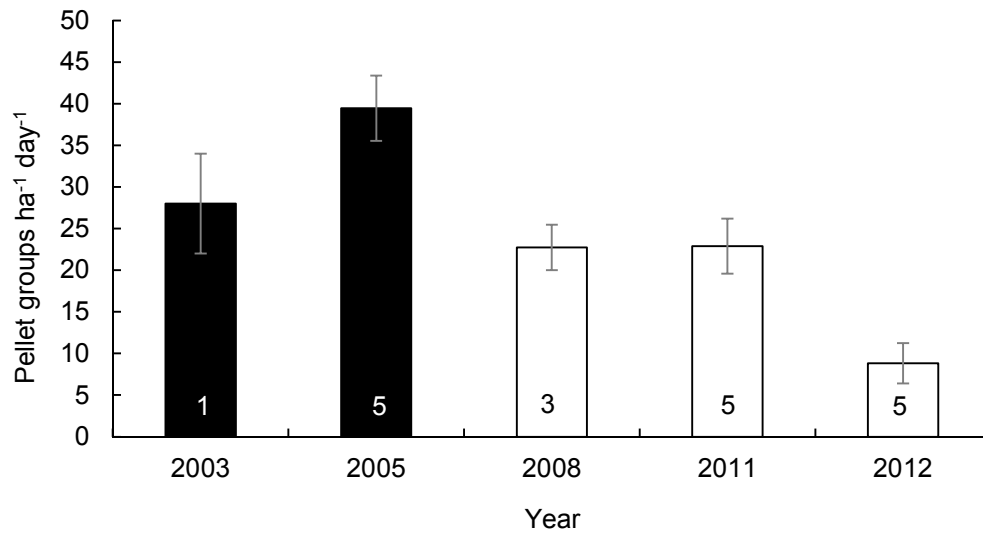


Figure 2



Review Only

Figure 3



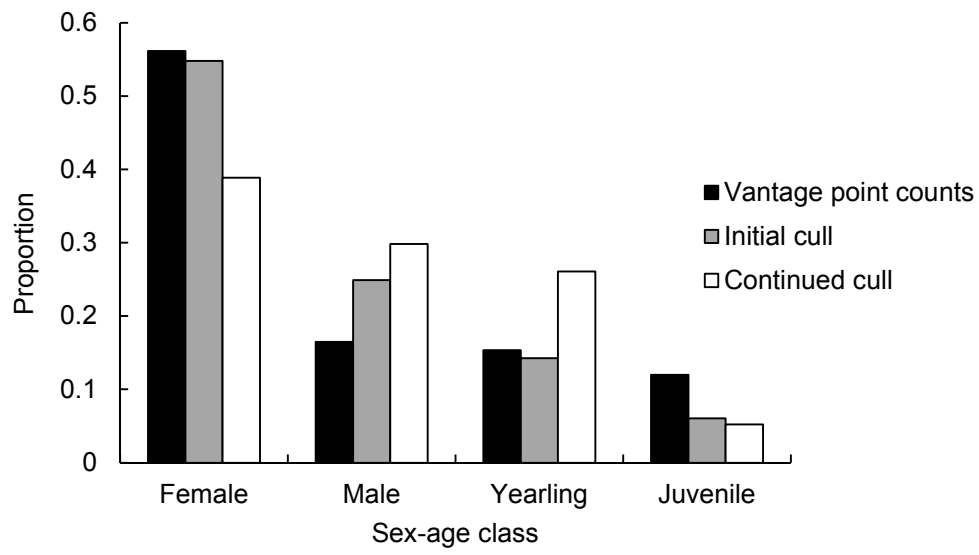
Review Only

Figure 4



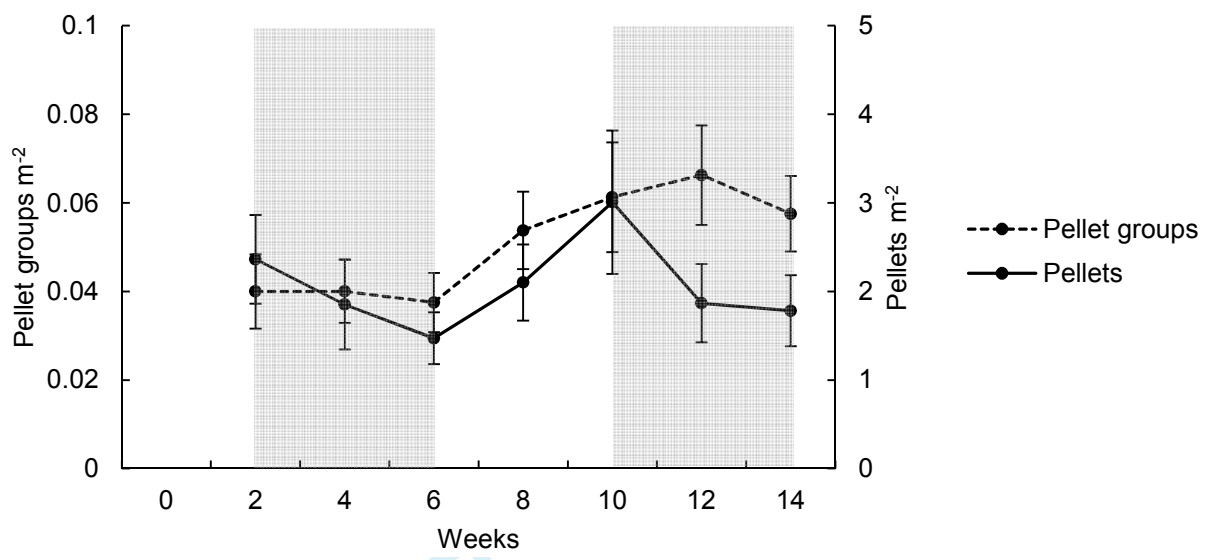
Review Only

Figure 5



Review Only

Figure 6



Review Only

For Review Only