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Germination of native and introduced plants from scats of Fallow Deer (*Dama dama*) and Eastern Grey Kangaroo (*Macropus giganteus*) in a south-eastern Australian woodland landscape

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Summary Introduced deer occur in many forests and woodlands in Australia and potentially play an important role in influencing the floristics and structure of these landscapes through eating plants and disseminating seeds. In a glasshouse trial, we tested whether field-collected scats of Fallow Deer (*Dama dama*) contained viable plant seeds. Scats of deer obtained from a woodland study area in Kosciuszko National Park, New South Wales, produced seedlings from a range of native and introduced plant species. Forbs and herbs were dominant in these samples, confirming the grazing behaviour of deer at the time scats were collected. Samples of scats from Eastern Grey Kangaroos (*Macropus giganteus*), collected contemporaneously from the same sites as deer scats, also produced plant germinants. By volume, deer scats produced a greater diversity of plant germinants, including native and weed species, than did kangaroo scats. Although no weed species emanating from deer or kangaroo scats were of national significance, several species were of regional environmental significance, including Common Mullein (*Verbascum thapsis*), which was only found germinating out of deer scat, Stinkgrass (*Eragrostis cilianensis*) and Purpletop (*Verbena bonariensis*). In addition to dispersing viable seeds, Fallow Deer may also influence vegetation structure through their browsing. Further research is necessary to elucidate their respective role in dispersing native and introduced plants as well as any impacts that foraging behaviour might be having on woodland landscapes, to better inform management of the resident deer population.

Key words: *Australia, deer, forests, grazing, kangaroo, seed dispersal.*

Introduction

Introduced deer are a commonly seen and sometimes locally abundant component of the fauna of Australian forest and woodland landscapes. Since European human settlement, many different species of deer have been deliberately brought to the country, primarily for farming but also for game hunting (Moriarty 2004a). Of these, at least two species, the Asian Sambar Deer (*Cervus unicolor*) and the European Fallow Deer (*Dama dama*), have become widespread, particularly in south-eastern mainland Australia and in the case of the latter species, also Tasmania (Potts *et al.* 2014). As herbivores with a potentially broad-ranging palate, deer are known to browse and graze on a diversity of plants, such as in New Zealand where they sometimes impose great and negative changes on both the floristics and structure of native vegetation communities through their feeding behaviour (Nugent 1990; Coomes *et al.* 2003; Forsyth *et al.* 2010). In Australia, the potential as well as realised environmental damage that introduced deer can do has been recognised at state level by way of key-threatening process listings in legislations such as the New South Wales *Threatened Species Conservation Act* 1995 (TSC Act) and the Victorian *Flora and Fauna and Guarantee Act* 1988 (NSW Scientific Committee 2004; Department of Primary Industries and Environment 2012). Among the listed threats that deer may and sometimes do pose to the Australian environment is the browsing and grazing of native plants, including several species threatened with extinction. Through their feeding activities, deer can also alter vegetation structures important for fauna, including endangered species, and in severe cases, the loss of vegetation may lead to soil erosion and sedimentation. Unfortunately, the environmental impacts of deer in Australia have been far less studied than in other countries where they have been introduced, being limited to a few investigations of diet and feeding behaviour (Duncan 1992; Moriarty 2004b; Davis *et al.* 2008; Bee *et al.* 2010), together with browsing and other impacts (Moriarty 2004b; Keith & Pellow 2005; Peel *et al.* 2005; Bennett & Coulson 2008; Bilney 2013; Bailey *et al.* 2014).

The Fallow Deer successfully colonised a range of habitats after being introduced in the early nineteenth century (Mulley

2008). An increase in their wild distribution has been exacerbated by escapees from farms and illicit releases (Moriarty 2004a). Fallow Deer prefer woodland opening onto grassland and forest edges. As ruminants they are well adapted for the efficient digestion of fibre from grazing, but are also known to consume browse (Nugent 1990). In the Tasmanian midlands, Duncan (1992) found that grasses such as Yorkshire Fog (*Holcus lanatus*) and a Danthonia (*Austrodanthonia* sp.) made up most of the diet of Fallow Deer together with low-fibre herbs such as clovers (*Trifolium* spp.) and geraniums (*Geranium* spp.) and high-fibre browse species such as *Acacia* spp. and *Banksia* spp. Given these wide-ranging food habits, Fallow Deer potentially can alter native vegetation communities and, in turn, the habitat for associated fauna.

In southern New South Wales, Fallow Deer are becoming commonplace in box gum eucalypt woodlands and eucalypt forest margins abutting cleared agricultural lands in and adjacent to Kosciuszko National Park (NSW Office of Environment and Heritage, unpublished data). From a management perspective, it is imperative to characterise what plant species Fallow Deer are consuming, because at least part of the landscape in which they occur includes representative patches of the endangered 'White Box (*Eucalyptus albens*), Yellow Box (*E. melliodora*) Blakely's Red Gum (*E. blakelyi*) Woodland Community', listed under both the TSC Act and the Commonwealth *Environment and Biodiversity Protection Act* 1999 (NSW Department of Environment, Climate Change and Water 2010). In addition, Fallow Deer might influence vegetation composition through ingesting seeds and dispersing them in these environments. This potentially includes native plants and environmentally significant weeds. The role of deer as plant dispersers in the Australian environment has been examined for the Hog Deer (*Axis porcinus*; Davis *et al.* 2010) in coastal Victoria and the Sambar deer in Alpine Victoria (Eyles 2002). Those studies highlight that while deer are capable of dispersing weeds, they can equally disperse native plant species. In isolation from browsing and grazing effects, this dual dispersal role raises an interesting management conundrum. Extending our knowledge of plant dispersal to include Fallow Deer is necessary as different deer species have different browsing behaviours and food preferences and thus impacts on the environment may vary.

In this study, we examined the potential role of Fallow Deer in dispersing native plants and weeds in the woodland landscapes of southern New South Wales. This was performed by collecting fresh deer scats in the field and using them as a potential propagule source in a controlled glasshouse setting. For comparison, we also tested what plants germinated from scats of the Eastern Grey Kangaroo (*Macropus giganteus*), the largest native ground-dwelling herbivore in the same landscape. This preliminary investigation forms part of a larger study examining ecological impacts of deer on fauna and flora across the Australian Alps.

Methods

Study area

Fallow Deer and Eastern Grey Kangaroo (*Macropus giganteus*) scats (hereafter deer and kangaroo scats) were collected within the catchment of Snowy River in the Byadbo Wilderness Area of Kosciuszko National Park ~40 km south of the township of Jindabyne in southern New South Wales, Australia (hereafter Byadbo). The predominantly hilly study area receives less than 600 mm of rainfall on average per annum. The predominant vegetation reflects this low rainfall, mainly containing a dry White Box (*Eucalyptus albens*) and White Cypress Pine (*Callitris glaucophylla*) community below 650 m (Pulsford 1991) with strips of Ribbon Gum (*E. viminalis*) in riparian sites. Above 650 m in elevation, a grassy or shrubby Yellow Box woodland occurs, grading through Long-leaved Box (*E. nortonii*) woodland to Mountain Gum (*E. dalrympleana*) forest with increasing elevation. Common understorey and mid-storey shrubs include several species of *Acacia*, as well as Sweet Bursaria (*Bursaria spinosa*), while grasses, sedges and herbs dominate the generally sparse ground layer. Fallow Deer and Eastern Grey Kangaroo are widespread throughout the study area.

Seedling germination trials

We collected fresh scats at discrete locations across the elevational gradient of the study area in autumn (late May) 2010 to see what germinated out of them. As deer are easily capable of moving between vegetation communities across this gradient, and depositing scats well away from places at which plants were browsed, there was no point separating scat collections by site. Instead, in our analyses, seedlings germinating from deer scats were considered to be a representation of what might be being dispersed across the entire landscape. The same was considered true of kangaroo scats. Irrespective, fresh scats were those that still retained a moist outer surface and otherwise were dark black in colour. Although the study area is also known to support low numbers of another deer species, the Sambar Deer, scats of Fallow Deer, were discriminated by their cylindrical shape with a point at one end and dimple at the other. For comparison, we also simultaneously collected fresh scats from the Eastern Grey Kangaroo, the largest local native herbivore. Scats from both species were collected from each of six sites, with each site separated by at least one kilometre from the next nearest site so as to collect samples from a range of different animals. Within each site, six separate and random collections of 12 scats each from deer and six separate and random collections of six scats each from kangaroos were made to provide a series of replicate samples (each sample consisting of the bulked 12 or 6 scats for deer and kangaroo, respectively). Although the number of scats from each species differed, the volume of scats per collection was approximately the same. So far as was practicable, a 12 scat collection from deer came from the same deposit, as did the six scat collection from kangaroo. Each collection from the same species at the same site was at least 10 metres apart. Despite this sampling arrangement, it is possible that collections made from the same site were from the same individual animals but this is considered unlikely due to the amount of sign.

Scats were stored in appropriately labelled paper soil sampling bags (10 × 15 cm) in a well-ventilated shed until they were prepared for the glasshouse trials in July 2010. As per Davis *et al.* (2010), we used the seedling emergence method to quantify germination from deer and kangaroo scats. Each sample of 12 deer scats or six kangaroo scats was first broken into coarse fragments using a mortar and pestle and then spread evenly over a *ca*. 50-mm layer of seed raising mix in an 85 × 140 mm plastic growing tray. In each case, the resultant layer of fragmented scats was <5 mm deep, such that ample light was available for germination of seeds. Had we used any more scats, the volume of prepared material would not have fit comfortably in the growing trays. Prepared trays were placed in a greenhouse under a set of controlled conditions to promote maximum germination of different plant species and individual seedlings: 16 h at 25°C and 8 h at 18°C and watered *ad libitum*. Humidity was not constant but generally at least >50%. We recognise here that some plant species held in scats may not have germinated under the growing conditions provided, so in this respect our trials likely underestimate the diversity of viable seed material present.

Resulting germinants from each sample were checked at least monthly for 12 months after preparation and the number of new germinants noted. Germinants were mostly left to grow long enough to allow for species identification and then removed from their trays to allow new germinants to flourish (as per Gross 1990). The exceptions to this were the sedge *Carex* sp., a species of clover (*Trifolium* sp.) and an unidentified species of Verbena. In these cases, flowering enabling species identification had not yet occurred but germinants were crowding the respective tray. Similarly, some samples gave rise to a species of lichen which was not identified taxonomically. Irrespective, for each sample, the number of germinants of different plant species and taxa was counted. We also noted whether those species or taxa were exotic or native, together with the functional group that they belonged to (i.e. grasses, herbs, ferns, lichens).

Data analysis

A series of descriptive and formal statistical comparisons were made between seedling germinants emerging from deer and kangaroo scats. For both species, the number of samples from which plant germinants arose was recorded and expressed as a percentage of the total number of samples collected (n = 36). Similarly, the percentage representation of different plant species in scats of deer and kangaroos was also calculated. For further statistical analysis, the 36 samples of deer scats were considered as one 'population', despite having been collected at six separate sites across the study area. Kangaroo scat samples were similarly combined. This was justified since the origin of the plant material in relation to the scat collection sites was unknown, the habitat in the sites in which the scats were collected was largely uniform, and, finally, was necessary given the relatively low number of germinants that emerged from scats. More formally, we also examined whether there were differences in the average number of germinants emerging from deer scats compared to that emerging from kangaroo scats. The same comparison was made for the diversity of plant species emerging from deer and kangaroo scats. In both cases, we used a simple two-sample t-test, assuming unequal variances, in the statistical program R (R Core Team 2014). Finally, we also tested whether there were proportional differences in the representation of introduced plant germinants emerging from deer versus kangaroo scats. This was statistically evaluated in R using a one-tailed z-test for population proportions.

Results

Seedling germination trials

In total, at least 22 different species of plants and one species of lichen germinated from Fallow Deer and Eastern Grey

Table 1. Species of plants and lichens germinating out of Fallow Deer and Eastern Grey Kangaroo scats collected from the Byadbo Wilderness Area of Kosciuszko National Park, New South Wales

Species name	Common name	Life form	Eastern grey kangaroo scat (n = 36)	Fallow deer scat (n = 36)
Adiantum formosum	Maidenhair Fern	Fern		2.8
Alternantha denticulata	Lesser Joyweed	Herb		5.6
Carex sp.	Sedge	Herb	5.6	2.8
Cheilanthes seiberi	Poison Rock Fern	Fern		5.6
Chenopodium album	**Fat Hen**	**Herb**		**11.1**
Chenopodium carinatum	Keeled Goosefoot	Herb	2.8	5.6
Chenopodium pumilie	Small Crumbweed	Herb	2.8	13.9
Crassula helmsii	Swamp Stonecrop	Herb	2.8	5.6
Crassula seiberiana	Australian Stonecrop	Herb		2.8
Cyperus eragrostis	**Tall Flatsedge**	**Herb**	**5.6**	
Cynodon dactylon	Couch Grass	Grass	2.8	
Eragrostis cilianensis	**Stinkgrass**	**Grass**		**2.8**
Eragrostis parviflora	Weeping Lovegrass	Grass		2.8
Modiola caroliniana	**Red-flowered Mallow**	**Herb**		**2.8**
Papaver somniferum	**Poppy**	**Herb**		**2.8**
Portulaca oleracea	Pigweed	Herb		5.6
***Trifolium* sp.**	**Clover**	**Herb**	**16.7**	**19.4**
Unidentified Lichen		Lichen	5.6	5.6
Urtica incisa	Stinging Nettle	Herb	36.1	33.3
Verbascum thapsis	**Common Mullein**	**Forb**		**2.8**
Verbena bonariensis	**Purpletop**	**Forb**	**5.6**	**5.6**
***Verbena* sp.**		**Forb**	**2.8**	**5.6**
Wahlenbergia communis	Tufted Bluebell	Herb		2.8

The number represents the percentage of the total number of samples of scats in which a given plant or lichen species germinated (n = 36). Introduced plant species are indicated in bold type.

Kangaroo scats (Table 1). These species comprised a roughly equal mix of native herbs and the sedge *Carex* sp. and introduced herbs and forbs. For both deer and kangaroo scats, the number of germinants found emerging from samples essentially stopped approximately 10 months after initial preparation, with very few new germinants arising thereafter from scat samples. In effect, the 12-month growing period of this glasshouse-based study was sufficiently long to determine what species of plants deer and kangaroos were capable of dispersing at the time scats were collected (Fig. 1).

Overall, the number of plant germinants emerging from deer scats was 114, considerably greater than the 65 plant germinants from kangaroo scats. Similarly, the percentage of separate samples of deer scats from which germinants arose was higher (26 of 36 samples or 72%) than for samples of kangaroo scats (19 of 36 or 53%). On average, deer scat collections produced a higher mean number of germinants than did kangaroo scat collections (Fig. 2a), and this difference was statistically significant (t = 1.69, d.f. = 57, P = 0.048).

The range of plant species found to germinate out of deer scats was also greater than for kangaroo scats, with deer producing germinants from 20 different plant taxa, while kangaroos only produced 10 plant taxa. On average, deer scat collections produced a higher mean diversity of plant taxa than kangaroo scat collections (Fig. 2b), and this difference was also statistically significant (t = 1.93, d.f. = 65, P = 0.029).

At least 10 species of introduced weeds were found in either deer or kangaroo scats. For deer, weeds found to germinate from scats included Clover. Common Mullein (*Verbascum thapsis*), Fat Hen (*Chenopodium album*), Poppy (*Papaver somniferum*), Purpletop (*Verbena bonariensis*), Red-flowered Mallow (*Modiola caroliniana*) and Stinkgrass (*Eragrostis cilianensis*). In contrast, weeds germinating from kangaroo scats only included Clover, Purpletop and Tall Flatsedge (*Cyperus eragrostis*) (Table 1). Clover was by far the most common introduced species germinating from both deer and kangaroo scats, being represented in nearly 17% of

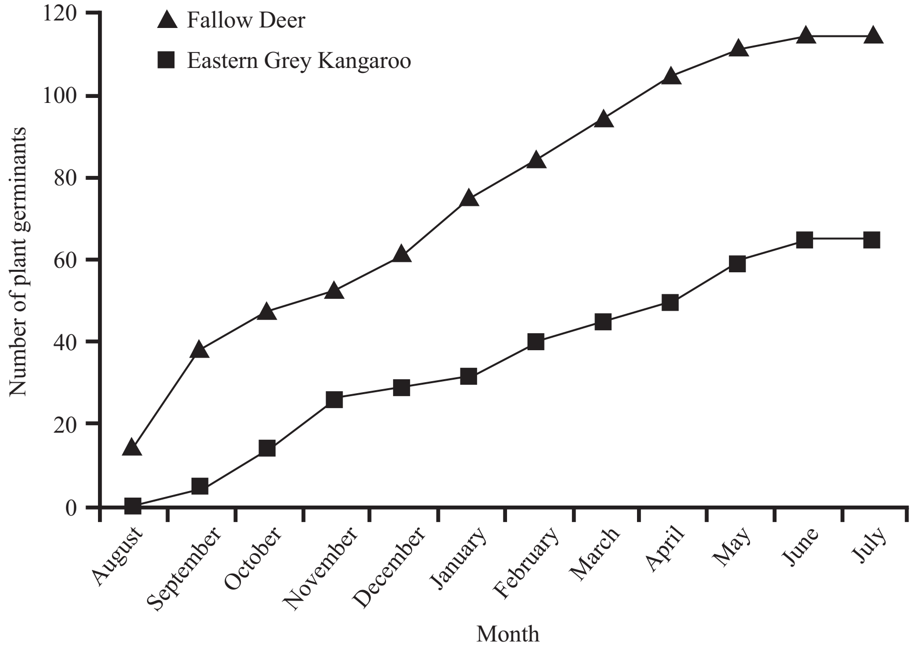

Figure 1. The number of plant germinants arising out of Fallow Deer and Eastern Grey Kangaroo scats over a 12-month period. The monthly figure projections represent the cumulative number of germinants across all samples for each mammal species.

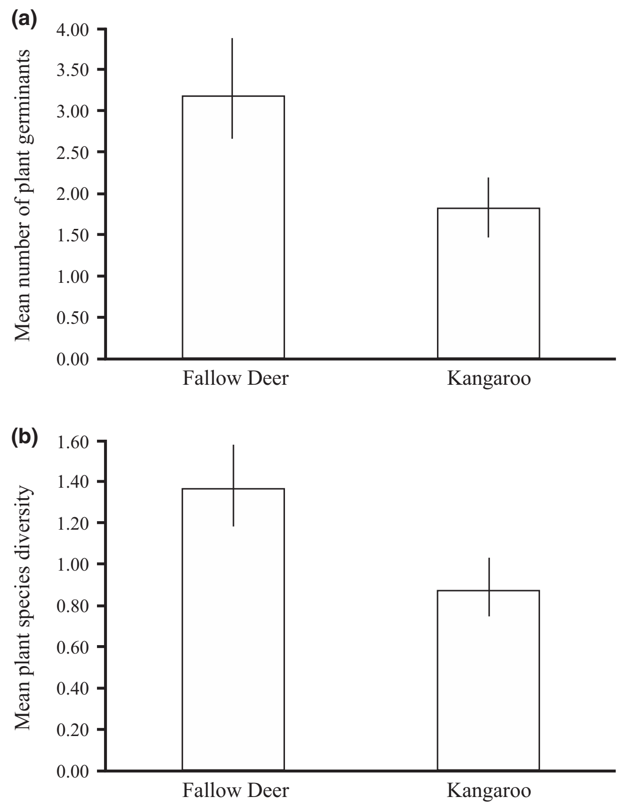

Figure 2. The mean number of plant germinants emerging from Fallow Deer and Eastern Grey Kangaroo scat samples (a), and mean diversity of plant species emerging from scat samples of both mammal species (b).

deer scat collections and over 19% of kangaroo scat collections. Fat Hen was also well represented in deer scats, occurring in over 11% of collections. Other than those two plant taxa, Purpletop also occurred in multiple deer scat collections. Although deer scats produced a greater diversity of germinants from introduced plant species, this trend did not extend to the proportional representation of such plants relative to native plant germinants. Deer scats produced a total of 22 germinants from introduced plants out of a total germinant population of 114 plants. In contrast, kangaroo scats produced 25 germinants from introduced plants from an overall germinant population of 65 plants. The resultant proportional representation of introduced plant germinants emerging from deer versus kangaroo scats was statistically significant ($z = -2.80$, $P = 0.003$).

Of the native plant species found in deer scat collections, Stinging Nettle (*Urtica incisa*) was by far the most common germinant, followed by herbs such as Small Crumbweed (*Chenopodium pumilie*), Lesser Joyweed (*Alternantha denticulata*), Swamp Stonecrop (*Crassula seiberiana*) and Pigweed (*Portulaca oleraceae*), together with Poison Rock Fern (*Cheilanthes seiberi*) (Table 1). Stinging Nettle was similarly the most common germinant arising out of kangaroo scat collections, followed by the sedge *Carex* sp. All other native plant species found to germinate out of scats were rarer.

Discussion

Our preliminary seedling germination trial illustrated that Fallow Deer are capable of dispersing a range of native and introduced plant species. Of the plants found to germinate from deer scats, the vast majority were herbs and grasses, confirming that in the Byadbo study area, Fallow Deer were predominantly grazing low ground cover plants. In Tasmania, Duncan (1992) also found that Fallow Deer in open woodland and grassland predominantly grazed on grasses and low-fibre herbs, although woody shrubs such as *Acacia* and *Banksia* were also browsed. Where we worked, Fallow Deer also browse on a variety of shrubs including *Acacia*, but it could be that at the time we were collecting scats they were not ingesting viable seed material from those shrubs. Notably, scat samples collected by us were made in late autumn, when many shrubs had already shed seed. Given the observations of feeding on shrubs by Fallow Deer in Tasmania by Duncan (1992) were in late winter through early spring, it would seem prudent to repeat our germination experiment using scats collected in other seasons before concluding that deer do not spread viable seeds of woody shrubs at Byadbo. We did not do this in the first instance because it would have extended the duration of fieldwork by a further six months and, by definition, the glasshouse experiment too; however, this extension is recommended in any future investigations.

In other germination studies using deer scats, albeit from different deer species at different times of the year, seedlings from a variety of woody shrubs have been found to emerge (i.e. Davis *et al.* 2010). Collecting Fallow Deer scats from our study area at other times of the year and seeing what germinates out of them would undoubtedly increase the plant list we have so far established, and potentially also change the relative abundance of different species that emerge. Regardless, the mix of native and introduced plants identified as growing from Fallow deer scats at Byadbo highlights both a partially positive as well as negative role for the species in the woodland landscapes it inhabits. In coastal Victoria, Davis *et al.* (2008, 2010) similarly found that on the positive side, Hog Deer potentially spread viable seed of a range of native species, while on the negative side, they potentially spread environmental weeds and aggressively growing native plants that might dominate vegetation communities. At Byadbo, Eastern Grey Kangaroo scats also contained a mix of (predominantly) native as well as introduced plants, from a smaller range of species than fallow deer. Irrespective of what deer and native macropods are eating and subsequently dispersing, untangling the net effect of their behaviours on the floristics and structure of the vegetated landscape is a complicated task (see Davis *et al.* 2010). The real question is what does the outcome of their behaviour mean for the landscape of Byadbo, which is otherwise designated wilderness, and its subsequent management? Firstly, deer and kangaroos both seem to have a role in dispersing viable seeds of native plant species, potentially contributing to the persistence of those in the local forests and woodlands. However, most native plant species found to germinate from scats were common and widespread grasses and herbs, with none being listed as threatened species. From the point of view of the wilderness aesthetic and value of the area, the impact on those plants from deer and kangaroos may be benign. But what of other plants, including weeds? In relation to weed management, none of the introduced plant species found to germinate from Fallow Deer or Eastern Grey Kangaroo scats are recognised as nationally significant (Thorp & Lynch 2000), nor are they listed noxious weeds at the New South Wales State level (NSW Department of Primary Industries 2014). Nevertheless, the spread of any weed species in the Wilderness area in which we worked is a major negative. Kosciusko National Park is known to host the nationally significant Blackberry (*Rubus fruticosus* aggregate), Serrated Tussock (*Nassella trichotoma*) and various willows (*Salix* spp.). Where we collected scats both Blackberry and willow do occur but have been controlled extensively. No scats were collected in direct proximity to fruiting Blackberry plants, although the time of year in which they were obtained (May) is consistent with the end of fruiting by that plant (NSW Department of Primary Industries Weed Management Unit 2009). Targeted collection of deer and kangaroo scats in and adjacent to fruiting Blackberry would need to occur to establish whether they can disperse that weed. For willow, neither deer nor kangaroos would play a role in its dispersal because it is mainly dispersed by wind and water (Holland Clift & Davies 2007). Similarly, serrated tussock mainly spreads through wind dispersal of seeds and is otherwise generally unpalatable to most herbivores unless they are food stressed (Osmond *et al.* 2008).

Of the weeds that did germinate from deer scats, Common Mullein is declared as noxious in Victoria, being classified as a regionally controlled and restricted weed across the State under the *Catchment and Lands Protection Act* 1994. At Byadbo, common mullein is widespread, particularly along minor drainage lines, creeks and rivers where deer frequent (NSW Office of Environment and Heritage, unpublished data). Indeed, deer browsing on mature plants is often noted in such locations. Given our study area incorporates the major catchment of the Snowy River, which is contiguous across the New South Wales–Victorian border, deer might be playing a role in the movement of this weed species across State boundaries. Other weed species of potential concern that were found to germinate only from deer scats include Stinkgrass and Purpletop. In damp and wet areas, Stinkgrass has been found to become at least a locally significant weed issue, across several landscapes on the eastern seaboard of Australia (University of Queensland 2011b). At Byadbo, Stinkgrass occurs mostly along drainages so future monitoring of it in such areas with and without deer would be useful. Purpletop too has the potential to become an aggressive weed given that it self-seeds readily once established (Royal Botanic Gardens of Sydney 2015), although presently it is patchily distributed across our study area.

Fallow Deer and Eastern Grey Kangaroos are not the only potential vectors for environmental weeds at Byadbo. Native invertebrates, other mammals and birds of both native and introduced origin might also play a role (e.g. Whitney 2002; Murphy *et al.* 2005; Twigg *et al.* 2009). However, the large body size, mobility and local population numbers of deer, in particular, necessarily means that they consume much plant material over a big area. In short, deer are capable of exerting a dominant effect on the local vegetation and sometimes not just through acting as a dispersal vector for native plants and weeds. A case in point is the browsing effect they are having on a Sweet Bursaria, a dominant understorey shrub in Byadbo. Although germinants of this native plant were not recorded from fallow deer scat in our study, they do eat the flowering heads from bursaria, consuming much leaf and stem material. Further investigation measuring the impact deer are having on the biomass of bursaria is warranted, perhaps using exclosure plots (see Bennett & Coulson 2008). Eastern Grey Kangaroo scats also contained viable weeds, including some species that grew from deer scat as well as unique species such as Tall Flatsedge (*Cyperus eragrostis*). Overall, however, kangaroo scats produced half as many species of weeds as deer scats. Tall Flatsedge is not a noxious weed in most jurisdictions in Australia, but it can be invasive in disturbed sites and wet places such as drainages (University of Queensland 2011a). Across the study area, it is mostly confined to major rivers and creeks.

In summary, our preliminary seedling germination trials demonstrate that Fallow Deer likely play a role in the dispersal of native and introduced plant species in woodland environments of the southern section of Kosciuszko National Park. This role is similar to that found for the introduced hog deer in coastal Victoria, which ingests and subsequently disperses a wide diversity of native and introduced plants (Davis *et al.* 2008, 2010). Like Hog Deer, Fallow Deer might also influence the floristics and structure of the vegetation they utilise for forage. Further studies are necessary to better tease apart these effects. Any such studies will need to clearly differentiate between the relative impacts of deer on vegetation and that caused by native herbivores. Meanwhile, the benefits of active management of the resident deer population (or other non-native herbivores) might simply be to reduce the spread of weeds in the landscape (see Coomes *et al.* 2003; Bee *et al.* 2010).

Implications for Managers

Introduced deer are fast becoming a common and sometimes locally abundant component of the fauna of forests and woodlands in south-eastern mainland Australia. As herbivores with a broad-ranging palate, they may have a profound impact on plant communities, both through browsing and through dispersal of seeds. In a glasshouse trial, we found that fallow deer scats contained viable seeds of a range of native plants as well as environmental weeds. A similar suite of plants were found to germinate from scats of kangaroos collected from the same study area. Understanding the relative impacts of deer and native herbivores on the composition of vegetation communities will require further detailed investigation.

References

Bailey T. G., Gauli A., Tilyard P., Davidson N. J. and Potts B. M. (2014) Feral deer damage in Tasmanian restoration plantings. *Australasian Plant Conservation* **23**, 10–12.

Bee J. N., Wright D. M., Tanentzap A. J. *et al.* (2010) Spatio-temporal feeding selection of red deer in a mountainous landscape. *Austral Ecology* **35**, 752–764.

Bennett A. and Coulson G. (2008) Evaluation of an exclusion plot design for determining the impacts of native and exotic herbivores on forest understoreys. *Australian Mammalogy* **30**, 83–87.

Bilney R. (2013) Antler rubbing of yellow-wood by sambar in East Gippsland, Victoria. *The Victorian Naturalist* **130**, 68–74.

Coomes D. A., Allen R., Forsyth D. M. and Lee W. G. (2003) How reversible are the impacts of introduced deer in New Zealand forests? *Conservation Biology* **17**, 450–459.

Core Team R. (2014) *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing, Vienna.

Davis N. E., Coulson G. and Forsyth D. M. (2008) Diets of native and introduced mammalian herbivores in shrub-encroached grassy woodland, south-eastern Australia. *Wildlife Research* **35**, 684–694.

Davis N. E., Forsyth D. M. and Coulson G. (2010) Facilitative interactions between an exotic mammal and native and exotic plants: hog deer (*Axis porcinus*) as seed dispersers in south-eastern Australia. *Biological Invasions* **12**, 1079–1092.

Department of Primary Industries and Environment (2012) Reduction in biodiversity of native vegetation by Sambar (*Cervus unicolor*), [Accessed 17 April 2015]. Available from URL: http://www.depi.vic.gov.au/__data/assets/pdf_file/0019/251515/201207-FFG-processes-list.pdf.

Duncan A. (1992) The winter diets of fallow deer (*Dama dama*) and forester kangaroos (*Macropus giganteus*) in the midlands of

Tasmania. *The Tasmanian Naturalist* **110**, 1–6.

Eyles D. (2002) Sambar Deer (*Cervus unicolor*) as a potential seed vector for the spread of the environmental weed Himalayan Honeysuckle (*Leycesteria formosa*) at Mount Buffalo National Park (Honours thesis). The University of Melbourne, Melbourne, Vic.

Forsyth D. M., McLeod S. R., Scroggie M. P. and White M. D. (2009) Modelling the abundance of wildlife using field surveys and GIS: non-native sambar deer (*Cervus unicolor*) in the Yarra Ranges, south-eastern Australia. *Wildlife Research* **36**, 231–241.

Forsyth D. M., Wilmshurst J. M., Allen R. B. and Coomes D. A. (2010) Impacts of introduced deer and extinct moa on New Zealand ecosystems. *New Zealand Journal of Ecology* **34**, 48–65.

Gross K. L. (1990) A comparison of methods for estimating seed numbers in soil. *Journal of Ecology* **78**, 1079–1093.

Holland Clift S. and Davies J. (2007) *Willows National Management Guide: Current Management and Control Options for Willows (Salix spp.) in Australia*. Victorian Department of Primary Industries, Geelong, Vic.

Keith D. and Pellow B. (2005) Effects of Javan rusa deer (*Cervus timorensis*) on native plant species in the Jibbon-Bundeena area, Royal National Park, New South Wales. *Proceedings of the Linnean Society of New South Wales* **126**, 99–110.

Moriarty A. J. (2004a) The liberation, distribution, abundance and management of wild deer in Australia. *Wildlife Research* **31**, 291–299.

Moriarty A.J. (2004b) The environmental impacts of Rusa deer in the Royal National Park (PhD thesis). University of Western Sydney, Richmond, NSW.

Mulley R. C. (2008) Fallow deer *Dama dama*. In: *The Mammals of Australia*, 3rd edn (eds S. Van Dyk and R. Strahan) pp. 770–772. Reed New Holland, Sydney, NSW.

Murphy M. T., Garkaklis M. J., St J. and Hardy G. E. (2005) Seed caching by woylies *Bettongia penicillata* can increase sandalwood *Santalum spicatum* regeneration in Western Australia. *Austral Ecology* **30**, 747–755.

NSW Department of Environment, Climate Change and Water (2010) *National Recovery Plan for White Box – Yellow Box – Blakely's Red Gum Grassy Woodland and Derived Native Grassland*. Department of Environment, Climate Change and Water NSW, Sydney, NSW.

NSW Department of Primary Industries (2014) *Noxious and Environmental Weed Control Handbook – A Guide to Weed Control in Non-Crop, Aquatic and Bushland Situations*, 6th edn. NSW Department of Primary Industries, Sydney, NSW.

NSW Department of Primary Industries Weed Management Unit (2009) *Blackberry Control Manual: Management and Control Options for Blackberry (Rubus spp.) in Australia*. Department of Primary Industries (Victoria), Melbourne, Vic.

NSW Scientific Committee (2004) Herbivory and environmental degradation caused by feral deer [Accessed 17 April 2015]. Available from URL: http://www.environment.nsw.gov.au/determinations/FeralDeerKtp.htm.

Nugent G. (1990) Forage availability and the diet of fallow deer (*Dama dama*) in the Blue Mountains, Otago. *New Zealand Journal of Ecology* **13**, 83–95.

Osmond R., Veebeck M., McLaren D. A. *et al.* (2008) *Serrated Tussock – National Best Practice Manual*. Victorian Department of Primary Industries, Melbourne, Vic.

Peel B., Bilney R. J. and Bilney R. J. (2005) Observations of the ecological impacts of Sambar *Cervus unicolor* in East Gippsland, Victoria, with reference to destruction of rainforest communities. *The Victorian Naturalist* **122**, 189–200.

Potts J. M., Beeton N. J., Bowman D. J. M. S., Williamson G. J., Lefroy E. C. and Johnson C. N. (2014) Predicting the future range and abundance of fallow deer in Tasmania, Australia. *Wildlife Research* **41**, 633–640.

Pulsford I. F. (1991) History of disturbances in the white cypress pine (Callitris glaucophylla) forests of the Lower Snowy River valley, Kosciuszko National Park (MSc Thesis). The Australian National University, Canberra, ACT.

Royal Botanic Gardens of Sydney (2015) New South Wales Flora Online. PlantNET. *Verbena bonariensis* L [Accessed 11 May 2015]. Available from URL: http://plantnet.rbgsyd.nsw.-gov.au/cgi-bin/NSWfl.pl?page=n-swfl&lvl=sp&name=Verbena~bonariensis.

Thorp J.R. and Lynch R. (2000) *The Determination of Weeds of National Significance*. National Weeds Strategy Executive Committee, Launceston.

Twigg L. E., Lowe T. J., Taylor C. M. *et al.* (2009) The potential of seed-eating birds to spread viable seeds of weeds and other undesirable plants. *Austral Ecology* **34**, 805–820.

University of Queensland (2011a) Drain flat sedge, cyperus eragrostis. [Accessed 21 May 2015]. Available from URL: http://key-server.lucidcentral.org/weeds/data/0303 0800-0b07-490a-8d04-0605030c0f01/media/Html/Cyperus_eragrostis.htm.

University of Queensland (2011b) Drain flat sedge, cyperus eragrostis. [Accessed 8 May 2015]. Available from URL: http://key-server.lucidcentral.org/weeds/data/0303 0800-0b07-490a-8d04-0605030c0f01/media/Html/Eragrostis_cilianensis.htm.

Whitney K. D. (2002) Dispersal for distance? *Acacia ligulata* seeds and meat ants *Iridomyrmex viridiaeneus*. *Austral Ecology* **27**, 589–595.

