Demonstrating stewardship of the environment and ecologically sustainable forestry

Use of plantations by Tasmanian devils and Eastern Quolls

Final report
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By

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Executive summary

The Tasmanian forest practices system has a wide range of management strategies in place to mitigate negative impacts of forest practices on important values, including threatened species. The objective of the current project was to assess the effectiveness of current management for maintaining populations of the threatened Tasmanian devils and eastern quolls in plantation landscapes. The specific aims of the project were:

1. To identify the drivers of devil and eastern quoll abundance in production forest landscapes (landscape study); and
2. To identify devil movements, habitat selection and den sites within a plantation landscape (tracking study).

For the landscape component of the study a network of camera traps was deployed across three production forest landscapes, one pine plantation dominated, one eucalypt plantation dominated, and one dominated by native forest with a history of partial harvesting. Results indicated that devil and quoll abundance increased with the extent of timber plantations within production forest landscapes. Overall, devils were positively associated with higher tree density and eastern quolls with indicators of open habitat. Within plantations, devil abundance increased with the volume of windrows (linear piles of logging residue), as did eastern quoll abundance in pine plantations. Neither species showed a strong response to logging-related features in native forest such as time since harvest.

For the tracking component of the study GPS collars were attached to 12 female and 3 male devils in a landscape dominated by eucalypt plantation. Data retrieved from the collars were used to classify each locality fix into one of three behavioural states that correspond approximately to stationary (sleeping or feeding), tortuous movement (e.g. foraging), or directional travel. Results indicated that devils did not show preferences for any of native forest, native grassland, or plantation. Within plantations, devils preferred a plantation age of 4–7 years and slightly avoided older plantations. Devils preferred roads and plantation edges in all behavioural states, and moved faster on roads and edges than away from them indicating they use them for foraging and travel.

Data from the GPS collars were used to determine the approximate location of denning sites used by the devils being tracked. Active searching and camera traps were then used to confirm the exact location of denning sites. One confirmed maternal den was located in a windrow in 6-year-old plantation. Four non-maternal dens were confirmed, two in windrows and two in native forest remnants.

This research found that devils and eastern quolls are highly adaptable to production forest landscapes, as has been found for other generalist carnivores. The use of windrows for denning by devils indicates that the current approach to managing this species is appropriate.

This research was done as part of the PhD research conducted by Evie Jones (Jones 2023a) and will be published in peer-reviewed scientific articles.

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Introduction

While plantations generally have reduced biodiversity value compared to native vegetation, they can support a wide variety of native species and help maintain biodiversity in many landscapes (Kanowski et al., 2005). The areas utilised by native fauna include both the planted stands and the areas of native vegetation retained in plantation landscapes for non-wood values (e.g. streamside reserves).

Tasmania has an extensive forest estate, of which 9% is covered by plantation (FPA 2022). Forestry activities in Tasmania are regulated via the forest practices system, which is administered by the Forest Practices Authority (FPA). The objective of the Tasmanian forest practices system is to achieve sustainable management of Crown and private forests with due care for the environment and taking into account social, economic and environmental outcomes. To achieve this, a number of planning tools are made available to forest planners to help manage the variety of values found in Tasmanian forests. Threatened species are one of the values managed under the system, with management recommendations delivered via an online planning tool known as the 'Threatened Species Adviser'.

Three large carnivore species are native to Tasmania and all are listed as threatened; Tasmanian devils (*Sarcophilus harrisii*), eastern quolls (*Dasyurus viverrinus*) and spotted-tailed quolls (*Dasyurus maculatus*). Conservation of carnivores is particularly important as carnivores play an important ecological role in helping stabilise the abundance of other species and improving ecosystem resilience (Ritchie et al., 2012; Ritchie and Johnson, 2009). Management of these three carnivorous species in areas subject to forest practices has two to three key elements.

- Manage den sites. This requires that the FPA be contacted if a suspected or known den site occurs within or in proximity of the harvest footprint. The advice provided by the FPA often requires a 50 m harvest-exclusion buffer to be placed around all entrances.
- Manage potential denning habitat in native forest. In areas of native forest, small patches of vegetation should be retained intact in areas that have potential refuge or den sites.
- Manage potential denning habitat in plantations (devils only). In plantation areas it is recommended that a subset of windrows (linear piles of logging residue) be retained undisturbed to provide denning habitat, particularly in landscapes where potential denning habitat is rare. It is also recommended that structural alteration of high-quality windrows and burning of retained windrows be avoided where practical.

Aims

The current project is part of a broader project assessing the effectiveness of current management of several iconic threatened species in Tasmania. The specific aim of this sub-project was to assess the effectiveness of current management for maintaining devil populations in plantation landscapes. Of particular interest was the attributes of active den sites that make them attractive to devils. During the course of the project data were also collected on the occurrence of eastern quolls in production forest landscapes.

Thus the specific aims of this study were:

1. To identify the drivers of devil and eastern quoll abundance in production forest landscapes (landscape study); and

2. To identify devil movements, habitat selection and den sites within a plantation landscape (tracking study).

This research was done as part of the PhD research conducted by Evie Jones

Jones, E. (2023) *The response of marsupial carnivores to production forest landscapes and operations,* PhD thesis, University of Tasmania.

Detailed accounts of the research will be published in peer-reviewed scientific journals, but a summary is provided below.

Methodology

Study sites

Three different landscapes were used in this study, with only one of these (Surrey Hills) used for the tracking component of the study (Figure 1).

1. Eucalypt plantation dominated landscape: Surrey Hills is an intensively managed forestry region, containing a mosaic of *Eucalyptus nitens* plantations, remnant native forest and native grasslands.

2. Pine plantation dominated landscape: Moogara is dominated by *Pinus radiata* plantations established on pasture or converted native wet eucalypt forest, surrounded by predominately harvested native forest to the south and west and agricultural land to the north.

3. Harvested native forest dominated landscape: Roses Tier is a landscape dominated by partially harvested wet and dry native eucalypt forest (periodically harvested at 15–35 year intervals) containing smaller patches of remnant unharvested forest and timber plantations (eucalypt and pine).

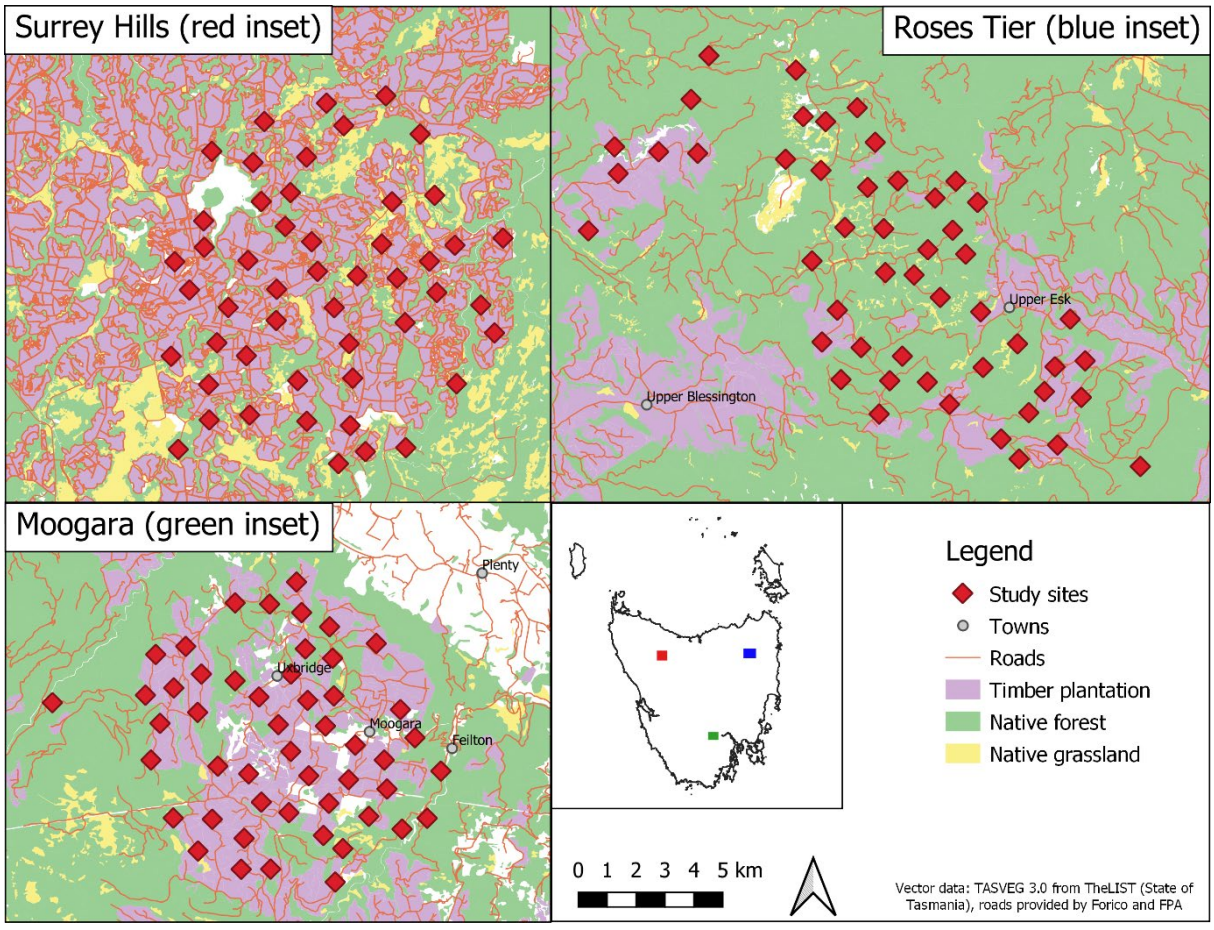

Figure 1. Location of study sites. Reprinted from Jones et al. (2023b).

Landscape study

Data collection

In each of the three 100–200 km^2 landscapes, a camera trap was deployed at 50 sites. Sites were chosen to encompass a range of stand types and ages, were at least 1 km apart and > 50 m from roads. Cameras were deployed for 28 days between November 2020 and March 2021. At the time of deployment a lure of fish oil was poured in a 1 m diameter circle 5 m in front of the camera. Nineteen of the cameras failed before the 28 days, with one of these being excluded from any data analysis.

For each night of data collected, individual animals (devils, eastern quolls, spotted-tailed quolls and feral cats) were identified using coat patterns. The majority of individuals could be distinguished and the minimum number of individuals that could be reliably distinguished was used in the analyses.

Data analysis

The only species that had enough data to model separately were devils and eastern quolls. N-mixture modelling was used to examine the factors that corresponded to changes in the abundance of devils and eastern quolls, an approach that accounts for missing data. The analysis was conducted in two steps.

The first step involved establishing the detection probability. The detection probability of devils and eastern quolls on a given camera and night was modelled using covariates that vary with night and are considered to influence carnivore behaviour (lure age and moon phase for both species, and also predator activity for the eastern quoll model). The covariates in the best fitting (lowest AIC value) model were used as detection predictors.

The second step involved running three sets of models for both devils and eastern quolls.

1. The 'whole-of-landscape' model included both plantation and native forest sites (149 sites) and investigated the effects of attributes present at all sites.
2. The 'plantation-only' model included only the plantation sites (86 sites: 40 at Moogara, 39 at Surrey Hills, 7 at Roses Tier) and examined the effects of plantation-specific features. For eastern quolls, initial modelling indicated a strong influence of landscape on the results, so eastern quoll models were subsequently split into 'pine-plantation-only' using sites from Moogara and 'eucalypt-plantation-only' using sites from Surrey Hills to account for differences between these sites.
3. The 'native-forest-only' model included only the native forest sites at Roses Tier (43 sites) and investigated the attributes specific to harvested native forest.

'Landscape' was included as a predictor in all whole-of-landscape and plantation-only models to account for differences in species abundance among the three study landscapes. Models were constructed using predictors that represented hypotheses about environmental influences on devil and eastern quoll abundance (Table 1). Models were ranked using multi-model inference and AIC values (Burnham et al., 2011; Burnham and Anderson, 2002; Richards, 2008). Analyses were conducted in the R programming environment using the 'pcount', 'predict' and 'modSel' functions of the *unmarked* package (Fiske and Chandler, 2011).

Table 1. Description of covariates for devil and eastern quoll abundance models at three scales: whole-of-landscape, including all sites considered in the study; plantation-only, including only sites located in plantation; and native-forest-only, including only sites located in native forest at Roses Tier. FPA = Forest Practices Authority, STT = Sustainable Timber Tasmania.

COVARIATE	DESCRIPTION	DATA SOURCE
Whole-of-landscape models		
Landscape level environmental parameters		
Landscape	Landscape of camera site: Surrey Hills, Moogara or Roses Tier.	
Extent of vegetation type	Proportion of native forest, grassland (including scrub and moorland), and plantation forest cover within 500 m (eastern quolls) and 1 km (devils) of the camera (6 variables).	TasVeg 3.0 (DPIPWE, 2017)
Road density	Total length of roads within 1 km of the camera (m).	Forico Pty Ltd and LIST (DPIPWE, 2018)
Site level environmental parameters		
Canopy height	Height of canopy (m).	Vegetation survey
Canopy cover	Visual estimate of % canopy cover.	Vegetation survey
Understorey cover	Visual estimate of % cover of understorey vegetation 10-100 cm high within 20 m of camera.	Vegetation survey
Large stem density	Number of live stems >10 cm diameter at chest height within 5 m of the camera.	Vegetation survey
Small stem density	Number of live stems 2-10 cm diameter at chest height within 5 m of the camera.	Vegetation survey
Windrow presence	Presence or absence of windrows within 50 m of the camera.	Vegetation survey
Plantation-only models		
Windrow attributes		
Volume	Mean of 3 measures of max width x height of the nearest windrow, taken 5 m apart.	Vegetation survey
Burnt/unburnt	Nearest windrow burnt or unburnt.	Vegetation survey
Windrow composition	Composition of nearest windrow material: eucalypt plantation debris, pine plantation debris, native forest debris, or combined plantation debris/native forest debris.	Vegetation survey
CWD amount	Volume of coarse woody debris (CWD) in the nearest windrow (m^3), defined as the summed basal areas of all CWD >10 cm DBH in 4 transects across the width of the windrow taken 5 m apart.	Vegetation survey
Plantation attributes		
Rotation number	First or second rotation of plantation in coupe.	Forico Pty Ltd, SFM, STT

Prior land use	Land use prior to establishment of plantation: pasture or native forest.	Forico Pty Ltd, SFM, STT
Plantation age	Years since establishment of current plantation coupe.	Forico Pty Ltd, SFM, STT
Native-forest-only models		
Log cover	Visual estimate of percentage cover of logs >10 cm DBH within 20 m of camera.	Vegetation survey
Time since logging	Years since most recent logging activity, stratified as follows: 0-2, 3-5, 6-20 and 20+. These age classes roughly conform to changes in the structure of the native forest areas.	STT
First logged	Years since first harvest.	STT
Harvested?	Remnant unharvested forest or harvested forest.	STT
Forest type	Wet or dry eucalypt forest.	TasVeg 3.0 (DPIPWE, 2017)
Detection covariates		
Lure age	Age of scent lure in days.	
Moon phase	Full moon ± 3 days, new moon ± 3 days, waxing and waning.	
Predator activity (eastern quoll only)	Total devil, feral cat and spotted-tailed quoll detections per night (3 variables).	

Tracking study

Data collection

Adult devils greater than two years old were captured in custom-built traps (Figure 2b) and fitted with GPS radio-collars between April–October 2021. Devils are primarily nocturnal (Jones et al., 1997) so collars were set to take 15-minute fixes every second night from approximately sunset until sunrise and were turned off during the day to conserve batteries.

To account for errors in animal locations acquired by the GPS, fixes with less than 3 satellites, horizontal dilution of precision (HDOP) > 7 (as in Andersen et al. 2017b), or unrealistic step lengths (> 4000 m) were removed from the analysis. The successful fix rate was low (23%) so tests were conducted for any bias in the success rate of GPS fixes due to vegetation type or plantation age, but none was found. The data were also assessed to determine the proportion of failed fixes likely to be a result of animals resting in a den, which increased the fix success rate to 52%.

Each of the GPS fixes for each animal was attributed the following:

- a velocity (the difference in time and distance between 2 consecutive points);
- a distance to road or edge (< 20 m, 20–50 m or > 50 m);
- a habitat type (plantation, native forest, or native grassland, moorland and scrub);
- a plantation age class (if applicable) (< 1, 1–3, 4–7, 8–13 and 14+ years); and
- a behavioural state (using Hidden Markov Models (HMMs) via the 'moveHMM' package in R, Michelot et al., 2019).
    - State 1: stationary (e.g., resting and/or feeding at carcass).
    - State 2: characterized by short step lengths and variable turning angles indicating tortuous movement (e.g., foraging).
    - State 3: characterized by long step lengths and relatively constant turning angles indicating directional movement (e.g., travel).

To account for temporal autocorrelation in the tracking data, the GPS data were subsampled by a time threshold specific to each behavioural state (the time threshold was determined using variograms to determine when the variance stabilised and each location could be considered independent using 'track_resample' in R package 'amt' [Signer et al., 2019]). There were insufficient data to do this for plantations so instead the data were subsampled by the time threshold for all combined states. These subsampled data were used for habitat selection analyses, but the full data set was used for home range analyses.

Data from the GPS collars were used to determine the approximate location of denning sites used by the devils being tracked. The exact location of denning sites was confirmed using active searching, the VHF unit on the GPS collar and camera traps.

Data analysis

The home range of each devil was calculated using 100% minimum convex polygons (MCPs) (Mohr, 1947) and biased random bridges which quantify an animal's utilization distribution (UD) based on movement paths rather than just the density of individual fixes (Benhamou, 2011). To examine if the size of a devil's home range varied with habitat variables, linear models were constructed using home range size as a response variable (95% UDs) and sex, proportions of different habitat types and plantation ages within each devil's home range as predictors. Habitat variables were included in separate models due to correlation among the variables. Final candidate models were selected using Akaike's Information Criterion values

adjusted for small sample size (AICc) (Burnham and Anderson, 2002). The percentage of each devil's home range that was logged during the collaring period and in the 12 months preceding it was determined.

To investigate habitat selection by female devils in each behavioural state, differences in used versus available habitat were examined using Manly's selection ratios (Manly et al., 2007). A selection ratio (wi) > 1 indicates that a habitat type was used proportionally more than expected based on availability and < 1 proportionally less. The percentages of habitat attributes within the home range (95% MCP buffered by 5%) represented available habitat, while the locations of GPS points within the buffered MCPs represented used habitat. Univariate models were run for each behavioural state with the predictors of habitat type, plantation age, and distance to roads and plantation edges. Analyses were undertaken using the 'adehabitatHS' package in R (Calenge, 2011).

To investigate if devils move at different speeds in different habitats, we constructed linear mixed effects models using 'velocity' as a response variable and distance to road, distance to edge, habitat type, and plantation age as predictors. Animal ID was included as a random effect. We ran two sets of models: 'whole-of-landscape' models, including all successful GPS fixes and all predictors except plantation age; and 'plantation-only' models, including only GPS fixes inside plantations, and all predictors except habitat type (to investigate the influence of plantation age). Final candidate models were selected using AIC for whole-of-landscape models and AICc for plantation-only models.

(a)

(b)

Figure 2 (a) The study landscape, Surrey Hills eucalypt plantation in Tasmania and (b) a Tasmanian devil caught in a pipe trap. Photos: Evie Jones.

Results

Landscape study

Data from 3,884 trap nights were obtained from 149 cameras and used for analyses. Devils were detected most frequently at Surrey Hills (69 detections), followed by Moogara (66) and Roses Tier (38), while eastern quolls were detected most at Moogara (198), then at Surrey Hills (165) and Roses Tier (54).

Species detection probability

For both devils and eastern quolls the detection probabilities decreased linearly with lure age in all models. Detection of eastern quolls also increased linearly with increasing devil presence in whole-of-landscape, eucalypt-plantation-only and native-forest-only models and decreased with increasing cat presence in the whole of landscape models (showing a weak negative effect with large confidence intervals), and moon phase in the eucalypt plantation and pine plantation models.

Devil abundance models

For the whole-of-landscape analyses, predicted devil abundance ranged from 0.46 to 4.19 (average 1.27 ± 0.38 SE) individuals per camera site, increasing linearly with extent of plantation within 1 km and with small stem density (Figure 3). Six models remained in the final candidate set (Table 2). The top model carried 32% of the AIC weight, and included extent of plantation within 1 km, large stem density and small stem density. Large stem density was absent from the second ranking model, which was almost equivalent, so it was considered less important.

For the plantation-only analyses, predicted devil abundance ranged from 0.39 to 3.96 (1.59 ± 0.62) individuals per site and increased with windrow volume. Three models remained in the final candidate list (Table 2). The top model, carrying 39% of the AIC weight, included a positive linear relationship with windrow volume and plantation age. However, the second model was almost equivalent and included only windrow volume, so plantation age was considered unimportant. The third model was the null model and was less influential at 0.22 AIC weight.

For the native-forest-only analyses, the average predicted devil abundance was 0.76 ± 0.25 individuals per site. Only the null model remained in the final candidate list, indicating none of the parameters considered were important (Table 2).

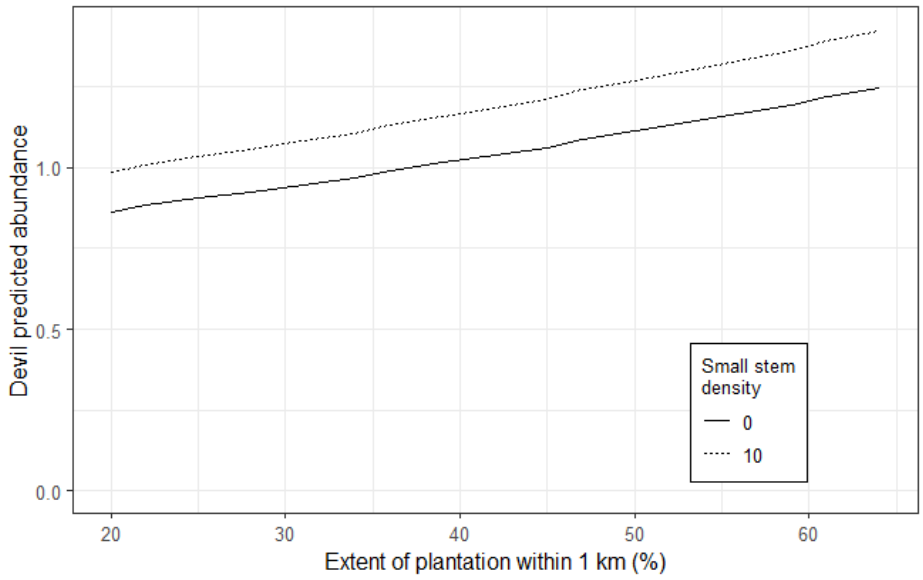

Figure 3. Modelled relationship at whole-of-landscape sites between predicted devil abundance and extent of plantation, which is the percentage of plantation cover within 1 km of the camera, and small stem density, which is the number of stems 2-10 cm DBH within 5 m of the camera. Lower and upper values for each parameter were selected based on first and third quartiles of the data.

Table 2. Final candidate models for predicting devil abundance in forestry landscapes, showing parameter estimates and [95% confidence intervals]. RIV describes the relative importance of variables, derived from the summed AIC weights (AICwt) of models containing each parameter. m=Moogara, sh=Surrey Hills, rt=Roses Tier, *z transformed.

	Parameter estimates					**Abundance (ψ)**		
Whole-of-landscape models								
Model	Intercept	Landscape	Plantation extent 1 km (%)*	Small stem density*	Large stem density*	K	ΔAIC	AICwt
1	-0.10 [-0.64 to 0.44] (rt)	m: 0.39 [-0.24 to 1.01] sh: 0.38 [-0.22 to 0.98]	0.23 [-0.04 to 0.50]	0.22 [0.06 to 0.38]	0.15 [-0.05 to 0.35]	8	0	0.32
2	-0.13 [-0.67 to 0.40] (rt)	m: 0.43 [-0.19 to 1.05] sh: 0.42 [-0.18 to 1.02]	0.23 [-0.04 to 0.50]	0.24 [0.09 to 0.40]	x	7	0.12	0.3
3	-0.28 [-0.78 to 0.22] (rt)	m: 0.65 [0.10 to 1.19] sh: 0.63 [0.09 to 1.16]	x	0.18 [0.02 to 0.34]	0.15 [-0.05 to 0.35]	7	0.85	0.21
4	-0.11 [-0.64 to 0.42] (rt)	m: 0.31 [-0.32 to 0.93] sh: 0.33 [-0.29 to 0.95]	0.16 [-0.10 to 0.42]	x	0.19 [-0.02 to 0.39]	7	2.84	0.08
5	-0.28 [-0.76 to 0.20] (rt)	m: 0.54 [0.02 to 1.07] sh: 0.59 [0.06 to 1.11]	x	x	x	5	3.26	0.06
6	0.07 [-0.26 to 0.40]	x	x	x	x	3	5.2	0.02
RIV	x	x	0.78	0.84	0.61			
Plantation-only models								
Model	Intercept	Landscape	Windrow volume (m^3)*	Plantation age*		K	ΔAIC	AICwt
1	-0.46 [-1.81 to 0.89] (rt)	m: 1.11 [-0.20 to 2.42] sh: 0.71 [-0.69 to 2.11]	0.25 [0.003 to 0.49]	0.22 [-0.08 to 0.51]		7	0	0.39
2	-0.07 [-1.27 to 1.13] (rt)	m: 0.73 [-0.46 to 1.92] sh: 0.24 [-0.99 to 1.48]	0.29 [0.06 to 0.52]	x		6	0.02	0.39
3	0.32 [-0.19 to 0.82]	x	x	x		3	1.18	0.22
RIV	x	x	0.78	0.39				
Native-forest-only models								
Model	Intercept					K	ΔAIC	AICwt
1	-0.29 [-0.93 to 0.35]					3	0	1

Eastern quoll abundance models

For the whole-of-landscape analyses, predicted eastern quoll abundance ranged from 0.04 to 25.28 (1.64 ± 0.38) individuals per camera site, decreasing with increasing canopy height, small stem density and understorey cover and increasing with extent of both plantation and grassland within 500 m (Figure 4A, B). Two models were included in the final candidate list (Table 3). The top model had an AIC weight of 0.88 and included all the above parameters.

For the eucalypt-plantation-only analyses, predicted eastern quoll abundance ranged from 0.93 to 2.78 (1.62 ± 0.41) individuals per site and was greatest in plantations when windrows were comprised of eucalypt plantation logging debris, least when comprised of native forest debris, with combinations of those intermediate (Figure 5A). Three models remained in the final candidate list (Table 3). The top model carried 72% of the AIC weight and included only windrow composition.

For the pine-plantation-only analyses, predicted eastern quoll abundance ranged from 1.01 to 8.38 (3.10 ± 1.01) individuals per site, was greater in plantations where the prior land use was pasture rather than native forest, and increased with volume of retained windrows (Figure 5B). Two models remained in the final candidate list (Table 3). The top model carried 55% of the AIC weight and included prior land use, windrow volume, and windrow composition. Windrow composition was missing from the second model, which was almost equivalent, so this parameter was considered less important.

For the native-forest-only analyses, predicted eastern quoll abundance ranged from 0.18 to 0.78 (0.32 ± 0.13) individuals per site, with abundance increasing linearly with log cover, although this effect was not strong because the final model set included the null model. Two models remained in the final candidate list (Table 3). The top model carried 66% of the AIC weight and included only log cover. The second model was the null model.

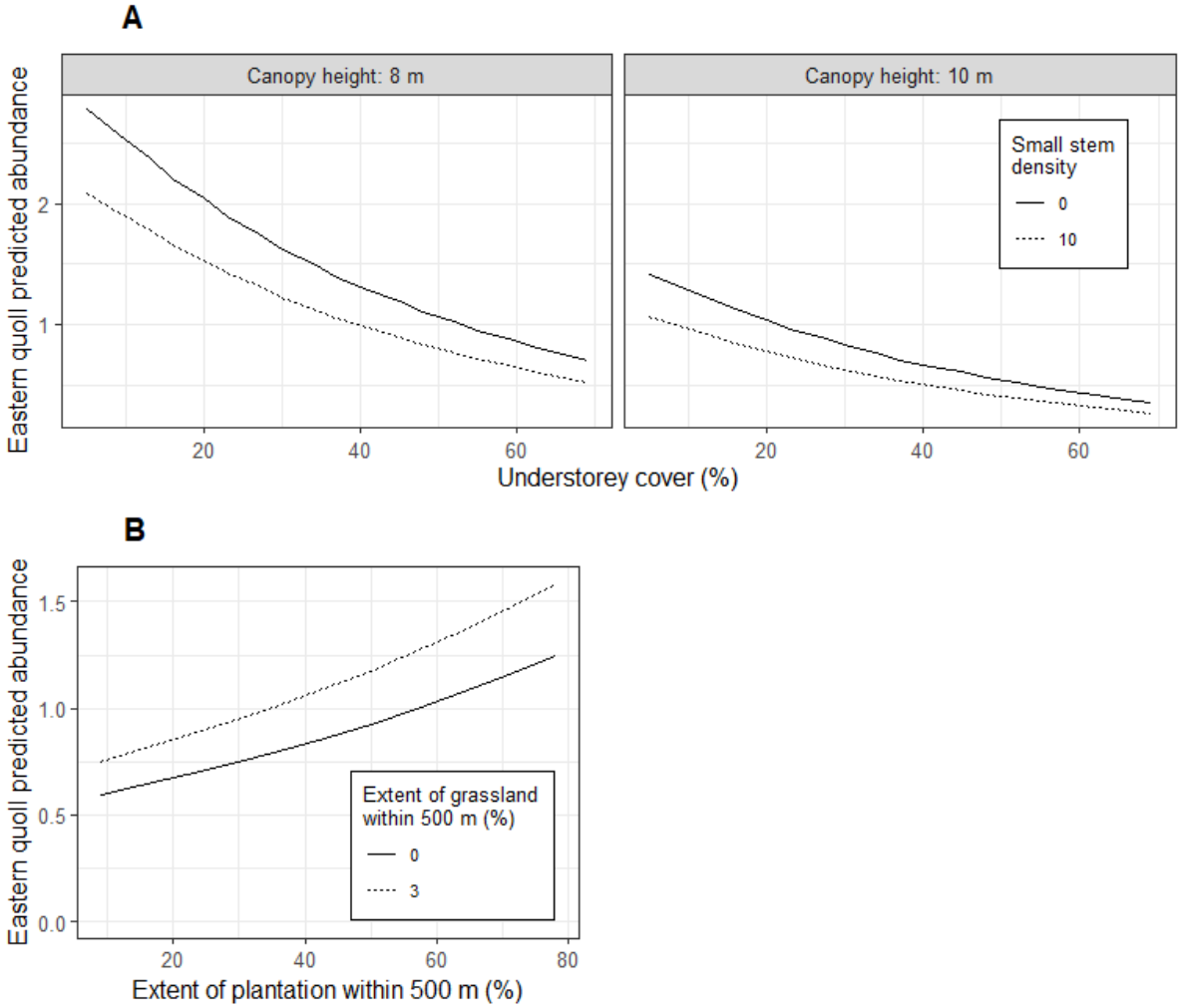

Figure 4. Modelled relationship at whole-of-landscape sites between predicted eastern quoll abundance and extent of grassland/plantation, which is the percentage cover of each vegetation type within 500 m of the camera. Lower and upper values for each parameter were selected based on first and third quartiles of the data.

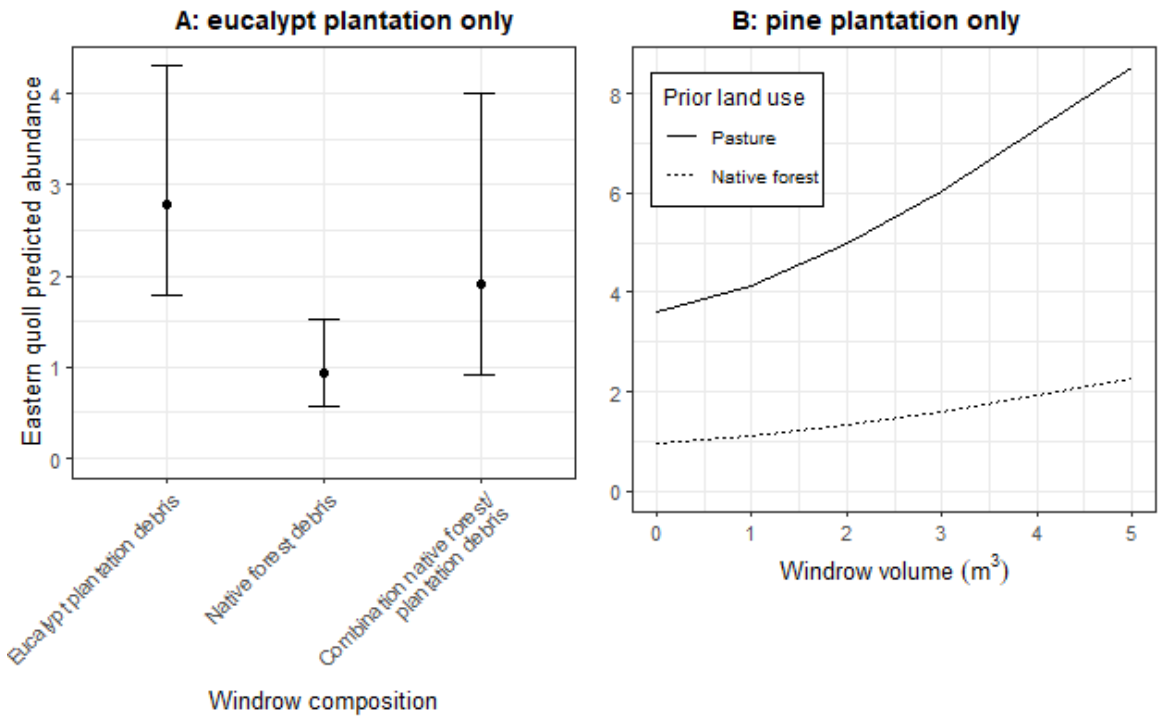

Figure 5. Modelled relationship at eucalypt-plantation-only sites between predicted eastern quoll abundance and windrow composition, which is the logging debris material that comprises the windrow; and at pine-plantation-only sites between predicted eastern quoll abundance and windrow volume, which is the mean w x h of the windrow, and prior land use, which is the land cover type prior to plantation establishment. Error bars indicate 95% confidence intervals. Lower and upper values for each parameter were selected based on first and third quartiles of the data.

Table 3. Final candidate models for predicting eastern quoll abundance in forestry landscapes, showing parameter estimates and [95% confidence intervals]. RIV describes the relative importance of variables, derived from the summed AIC weights (AICwt) of models containing each parameter. m=Moogara, sh=Surrey Hills, rt=Roses Tier, pa=pasture, nf=native forest, e=eucalypt plantation debris, p=pine plantation debris, n=native forest debris, np=combination native forest/plantation debris, nw=no windrow, *z transformed.

	Parameter estimates							**Abundance (ψ)**		
Whole-of-landscape models										
Model	Intercept	Landscape	Canopy height (m)*	Small stem density*	Understorey cover (%)*	Grassland extent 500 m (%)*	Plantation extent 500 m (%)*	K	ΔAIC	AICwt
1	-0.18 [-0.65 to 0.29] (rt)	m: 0.04 [-0.51 to 0.60] sh: -0.21 [-0.77 to 0.35]	-0.52 [-0.71 to -0.34]	-0.48 [-0.89 to -0.06]	-0.77 [-1.03 to -0.51]	0.40 [0.27 to 0.52]	0.37 [0.07 to 0.67]	12	0	0.88
2	-0.28 [-0.75 to 0.20] (rt)	m: 0.23 [-0.33 to 0.78] sh: -0.07 [-0.63 to 0.49]	-0.58 [-0.76 to -0.41]	-0.74 [-1.14 to -0.34]	-0.87 [-1.12 to -0.63]	0.33 [0.22 to 0.44]	x	11	4	0.12
RIV	x	x	1	1	1	1	0.88			
Eucalypt-plantation-only models										
Model	Intercept	Windrow composition		Plantation age (years)*		Rotation number		K	ΔAIC	AICwt
1	-0.07 [-0.57 to 0.42] (n)	np: 0.72 [-0.14 to 1.58] e: 1.10 [0.48 to 1.71]		x		x		9	0	0.72
2	0.35 [0.003 to 0.69]	x		-0.48 [-0.82 to -0.13]		x		8	2.31	0.23
3	-0.30 [-1.11 to 0.50] (r1)	x		x		r2: 0.88 [0.04 to 1.72]		8	5.28	0.05
RIV	x	0.72		0.23		0.05				
Pine-plantation-only models										
Model	Intercept	Prior land use		Windrow volume (m^3)*		Windrow composition		K	ΔAIC	AICwt
1	0.22 [-0.42 to 0.86] (n, nf)	pa: 1.32 [0.48 to 2.17]		0.63 [0.30 to 0.97]		nw: 0.73 [-0.44 to 1.90] p: 0.03 [-1.10 to 1.15]		12	0	0.55
2	0.44 [-0.02 to 0.90] (nf)	pa: 1.23 [0.59 to 1.86]		0.45 [0.17 to 0.73]		x		9	0.44	0.45
RIV	x	1		1		0.55				
Native-forest-only models										
Model	Intercept	Log cover (%)*						K	ΔAIC	AICwt
1	-1.29 [-1.92 to -0.65]	0.48 [-0.001 to 0.97]						4	0	0.65
2	-1.22 [-1.82 to -0.62]	x						3	1.26	0.35
RIV	x	0.65								

Tracking study

We deployed GPS radio-collars on 15 adult devils (12 females, 3 males) between April and October 2021. One collar was unable to be retrieved at the end of the study, although some data were downloaded when the animal was recaptured during the study. A total of 7406 successful GPS fixes remained after removal of GPS errors. Data were retrieved from between 24 and 164 days per animal (mean 77 ± 49 SD), with 152 to 1452 successful fixes per individual (494 ± 384). A total of 7066 points were used for analysis, following removal of points outside each animal's buffered 95% MCP.

After subsampling by state-specific time thresholds for the habitat selection analysis, there were 338 observations for state 1, 469 for state 2, 712 for state 3, and 859 for combined states.

Landscape-scale habitat selection and home ranges

At a landscape scale, behaviour-specific habitat selection ratios for female devils showed that devils did not select among habitat types (plantation, native forest, and native grassland/scrub) in any behavioural state (Figure 6a).

The mean home range size was 1849 (416 SE) ha for female devils and 3343 (1388 SE) ha for males. Core use areas (50% UDs) were 318 (66 SE) ha for females and 467 (102 SE) ha for males. A single model remained in the final candidate set for predictors of devil home range size and included only sex, with males having larger home ranges (Table 4), although male home range results should be treated with caution as there were only 3 male devils in the study.

The average recently logged area within each devil's home range was 3.46% (0–9.15%).

Plantation-specific habitat selection

Within plantations, female devils selected for plantations aged 4–7 years, slightly avoiding older age classes 8–13 and 14+ years and neither selecting nor avoiding young age classes < 4 years (Figure 6b).

Devil movements in plantation landscapes

Female devils used areas < 20 m from plantation edges and roads more than twice as often as expected for all behavioural states. To a lesser extent, they selected for areas 20–50 m from plantation edges and roads for state 2 only. They avoided areas > 50 m from edges and roads in all states, particularly edges.

The single remaining model from the whole-of-landscape analysis predicting devil velocity included both distance to roads and plantation edges (Table 4), and indicated devils moved faster on roads and edges (< 20 m) than away from them (Figure 7). In the plantation-only models, only distance to plantation edges remained in the final candidate list.

Table 4. Final candidate models with parameter estimates for predicting devil home range size and velocity in plantations (95% confidence intervals in square brackets).

Home range size (ha)

Fixed effects		Model description	
Intercept	Sex	df	AICc
1849 [1433 to 2264] (female)	1494 [566 to 2421] (male)	3	234.6

Velocity (m.sec^{-1}) (whole-of-landscape)

Fixed effects			Random effects		Model description	
Intercept (m)	Distance to road (m)	Distance to plantation edge (m)	Intercept (animal ID)	Residual	df	AIC
0.41 [0.38 to 0.44] (< 20)	-0.09 [-0.12 to -0.06] (20–50) -0.06 [-0.09 to -0.04] (> 50)	-0.07 [-0.09 to 0.05] (20–50) -0.08 [-0.10 to -0.06] (> 50)	0.002 (0.04 SD)	0.09 (0.30 SD)	5	2511.3

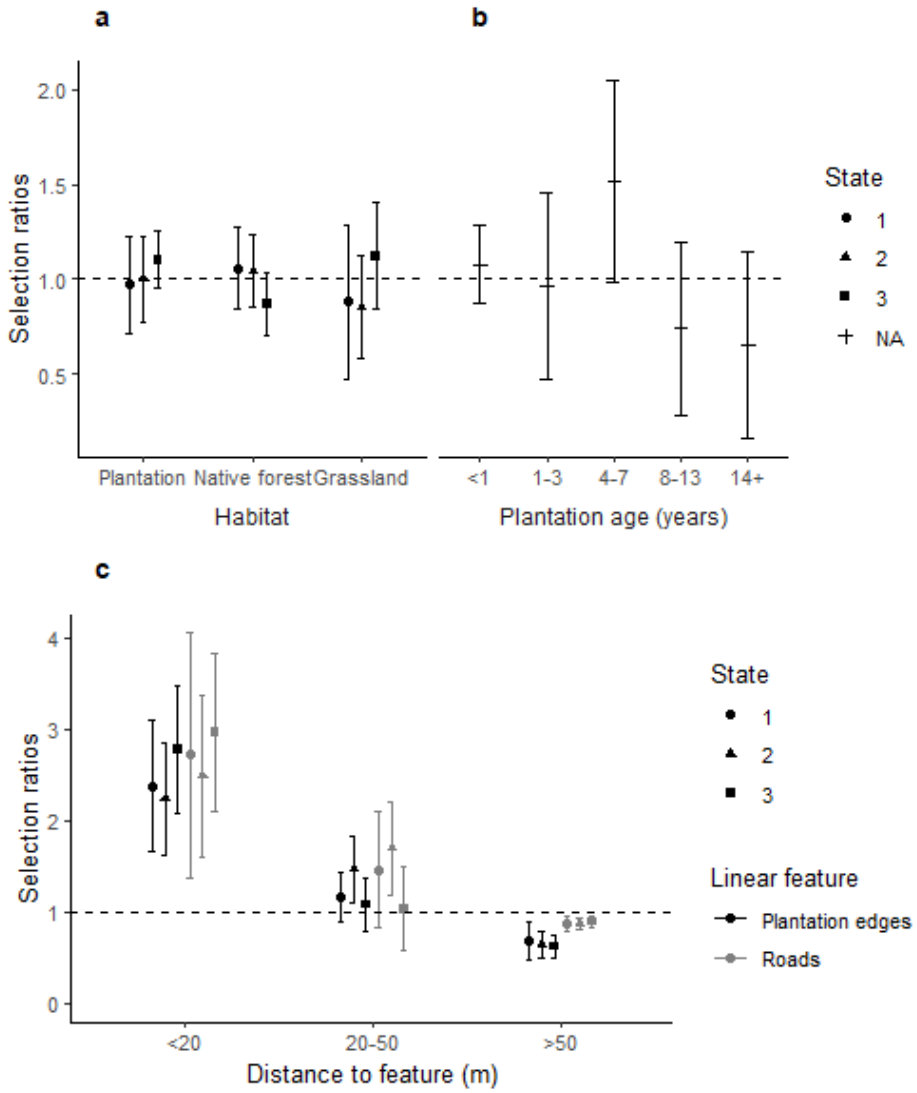

Figure 6. Habitat selection by adult female devils regarding habitat type (a), plantation age (b) and distance to roads/edges (c) in three behavioural states. Behavioural states were not considered for plantation ages due to limited data. Error bars show 95% confidence intervals. A selection ratio of 1 indicates attributes were selected in proportion to availability; 0.5 indicates they were used half as often as expected; and 2 indicates they were used twice as often as expected, based on availability within buffered 95% MCPs.

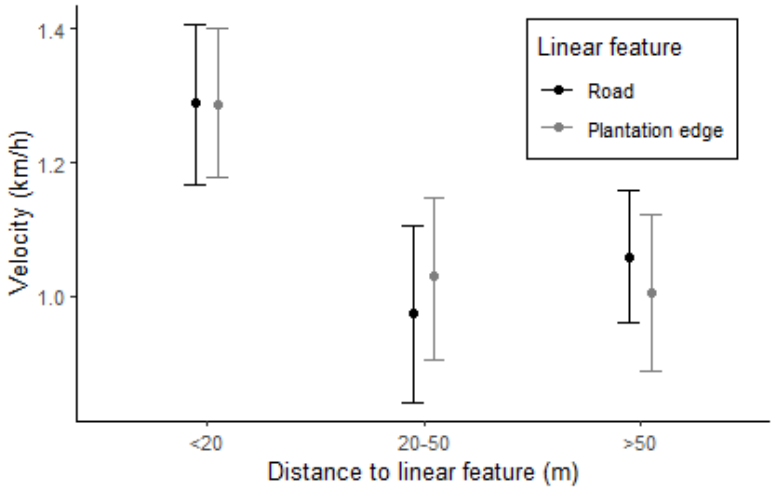

Figure 7. Predicted velocity of devils with distance to roads and plantation edges using whole-of-landscape data. Error bars represent 95% confidence intervals.

Den sites

One maternal den site was confirmed, located in a wombat burrow in a windrow in 6-year-old plantation (Figure 8). From when the remote camera was placed in October, the mother devil appeared to successfully raise all four of her joeys until they left the den in January, the normal time for juvenile dispersal (Pemberton, 1990). The den was located 200 m from the nearest road and active logging occurred in a coupe < 1 km from the den for most of the denning period (15/9/22 to 28/12/22). The den was not used the following year, confirmed by a remote camera placed on the den for a week in September 2022.

Four non-maternal dens were located, two in native forest streamside remnants and two in windrows in plantation (Table 5). Four of the five located dens were in wombat burrows, including the maternal den. Cameras on non-maternal dens were set for between 193 and 243 days and visited on 7–22 days by devils, although for most visits devils did not appear to enter the den (Table 5). Other species recorded using non-maternal dens were pademelons (*Thylogale billardierii*), Bennet's wallabies (*Macropus rufogriseus*), wombats (*Vombatus ursinus*), eastern quolls (*Dasyurus viverrinus*), brushtail possums (*Trichosurus vulpeca*), feral cats (*Felis catus*), echidnas (*Tachyglossus aculeatus*) and unidentified small mammals.

Figure 8. Devil mother rests outside her maternal den with three of her four joeys. This den was located inside a wombat burrow in a plantation windrow.

Table 5. Details of located female devil dens. 'Visits' denotes number of days each den was visited by devils during the period monitored by the camera.

Den ID	Camera set	Camera days	Visits	Habitat	Windrow volume (w × h) (m^2)	Windrow composition material
D1	26/05/2021	243	14	Streamside native forest remnant, wombat burrow	NA	NA
D2	31/05/2021	238	7	Windrow, wombat burrow	6.4	Plantation and native slash, unburnt
D4	28/05/2021	242	22	Streamside native forest remnant, wombat burrow	NA	NA
D10	17/07/2021	193	10	Windrow, under log	9.8	Plantation slash, unburnt
D15*	31/10/2021	86	Continuously occupied	Windrow, wombat burrow	4.4	Native slash, unburnt

**maternal den*

Discussion

The results of this study indicate that devils and eastern quolls can survive and thrive in production forests. The abundance of both devils and eastern quolls was found to increase with plantation extent in the landscapes studied, and neither species showed a strong response to attributes of partially harvested native forest such as time since logging or logged vs. remnant forest. Devils did not actively select among native forest, native grassland and plantation in a plantation-dominated landscape, and within plantations they appear to prefer mid-stage regrowth and avoid older age classes.

While devils and quolls are generally regarded as being generalist carnivores (Ferreira et al., 2018), the published literature provides mixed results with regards to how willing devils and quolls are to use human-modified landscapes. Thalmann et al. (2016) found that translocated devils preferred agricultural habitats over wet eucalypt forest, while Lyall (2017) found devil abundance was lower in plantations than native forest. When taking the range of studies into account it seems clear that devils are sufficiently adaptable that they can take advantage of modified landscape features. Their use of roads and habitat edges as shown in the current study and by Andersen et al. (2017a) are evidence of this.

The high use of plantations by devils found in the current study may be a result of the high abundance of prey in the area, and the configuration of dense vegetation alongside open areas (forestry tracks, logged coupes and grassland) which provide good opportunities for hunting and ambushing these prey (Andersen et al., 2017a). Some primary prey of devils, such as pademelons, wallabies and brushtail possums (Andersen et al., 2017b), are at sufficiently high densities in Tasmanian plantations that they are regarded as pests and regularly culled (Forest Practices Authority, 2017). Culling combined with roadkill from vehicle collisions on forestry roads would also provide abundant carrion and opportunities for scavenging for this morphologically specialised scavenger (Cunningham et al., 2018; Jones, 2003b).

The abundance of devils and eastern quolls was positively associated with windrows. These linear piles of logging residue can provide shelter and denning habitat for wildlife (Scrafford et al., 2017) including devils (Mann, 2016, 2014). This study provides the first confirmed case of a devil using a windrow as a maternal den. The mother devil successfully raised all four of her joeys to independence and did not abandon the den despite active logging occurring in a coupe < 1 km away. The frequency of this denning behaviour is unknown and requires further investigation. While we did not find enough dens to analyse the habitat preferences of devils in relation to den use, some broad patterns were found. Wombat burrows appear to be important devil denning habitat (4 of 5 located dens), as do windrows (3 of 5) and streamside forest remnants (2 of 5). Non-maternal dens were visited seldom and irregularly. This could indicate devils have low fidelity to non-maternal dens, using den sites opportunistically, though due to the low number of dens found it is also possible that we did not locate other dens that devils returned to more frequently. Den sites seem to be hubs of communication as well as shelter, as devils often visited, sniffed and scent marked but did not appear to use the den.

Management conclusions

The objective of the current project was to determine the effectiveness of current management of devils (and quolls) in a production forest landscape.

The value of plantations to Tasmanian devils is already recognised, with the current definition of potential habitat for devils being “all terrestrial native habitats, forestry plantations and

pasture". Within the forest practices system current management recommendations focus on protecting known den sites and retaining high quality windrows as potential denning habitat. The current research has shown that devils do use windrows for denning, and even as maternal den sites and therefore this management approach is appropriate. Maternal den sites are particularly important to manage because when joeys are dropped at a den site they have little ability to change dens until they are large enough to travel, and so are vulnerable if these windrows get destroyed. The abundance of devils found in the areas studied, which were all areas heavily used for timber extraction, indicate that the species can thrive in production forest landscapes. No negative responses to forestry were detected. From this we conclude that if denning sites continue to be managed effectively, that current management of devils in this landscape is effective. The main improvement to management that may result from this study is improving the description of 'high quality windrows'. FPA Fauna Technical Note No. 10 helps practitioners identify Tasmanian devil (and spotted-tailed quoll) habitat and mentions "large piles of coarse woody debris" but does not specifically mention windrows so there is currently minimal guidance on how to identify 'high quality windrows'.

Tracking data were not collected for eastern quolls, so the only insight into habitat selection by quolls was obtained from the camera data. The definition of potential habitat for eastern quolls does not currently include plantation areas, yet it is clear from the current research that eastern quolls can thrive in production landscapes. Therefore, a review of the current habitat definition for eastern quolls may be warranted. It is, however, interesting that eastern quolls are currently thriving in plantation areas despite the lack of active management. This may be due to management strategies put in place for Tasmanian devils, or for other values (e.g. streams). While no den sites for eastern quolls were located during the current study, the landscape component of the research suggests that the type of windrow preferred by eastern quolls may be different to that preferred by Tasmanian devils – with eastern quolls seeming to prefer windrows constructed from plantation debris which is presumably smaller in diameter than windrows constructed from native timber harvesting. Eastern quolls are smaller than Tasmanian devils so the space they would require for a den site would be smaller. Windrows constructed from plantation debris are likely to degrade more quickly than those constructed from larger stems, and so if plantation-derived windrows are used as a resource they're likely to be constructed and degrade on a much shorter timescale than the larger windrows used by devils. Little is known about the denning behaviour of eastern quolls and whether they exhibit high fidelity to maternal dens. It is possible that the destruction of plantation-derived windrows (outside of the breeding period) may have lesser implications on eastern quolls than would be found for devils that prefer the larger windrows. Strong conclusions are difficult to draw from the current study but more research on the den sites used by eastern quolls is recommended.

Overall, this study has found that current management of Tasmanian devils in production forest areas appears to be effective. But improvements could be made via

1. Providing a description of 'high quality' windrows in Fauna Tech Note 10
2. Including plantation areas in the description of potential habitat for eastern quolls.

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A more detailed account of this research is published in the thesis below and will soon be published in peer-reviewed scientific journals.

> Jones, E. (2023) *The response of marsupial carnivores to production forest landscapes and operations,* PhD thesis, University of Tasmania.

Researcher's Disclaimer
This research was done in fulfilment of the requirements for the degree of Doctor of Philosophy at the University of Tasmania. The research abides by the Australian Code of Practice for the Care and Use of Animals for Scientific Purposes, 7th edition, 2004 and the University of Tasmanian Animal Ethics Guidelines. The research was carried out under University of Tasmania Animal Ethics Approval A23211 and the Tasmanian Department of Primary Industries, Parks, Water, and the Environment Permits TFA21284, TFA21021, and TFA20218.