Response of the tiger quoll *Dasyurus maculatus* to disturbance from selective logging

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Summary

Data from a trapping and radio-tracking study were used to analyse use of selectively logged and unlogged forest by tiger quolls in moist tableland forest in south-eastern New South Wales. Both male and female tiger quolls were found to use unlogged and some age classes of logged forest significantly more than would be expected from the availability of those classes, and to avoid or use some age classes of logged forest significantly less than their availability would indicate. The use of different age classes of logged forest is discussed in relation to habitat use, ecological requirements and previous logging practices. The results are compared with the response to logging of ecologically similar species, such as American martens (*Martes americana*), fishers (*M. pennanti*) and pine martens (*M. martes*). Forest management implications are discussed in relation to conservation of the tiger quoll and their prey.

Keywords: habitat selection; logging effects; territory; tiger quoll; *Dasyurus maculatus*

Introduction

The tiger quoll (*Dasyurus maculatus*) is a forest-dependent marsupial carnivore found in a range of forested habitats in eastern Australia from Queensland to Tasmania (Edgar and Belcher 1995). Female tiger quolls are territorial, occupying exclusive home ranges (μ = 496 ha minimum convex polygon (MCP)) while male home ranges (μ = 1755 ha MCP) overlap extensively with both females and other males (Belcher 2000; Belcher and Darrant 2004). The species is considered to be rare and threatened throughout its range, and nationally (EPBC Act 1999) is listed as ‘endangered’. Mansergh (1984) found that since European settlement in Victoria, the tiger quoll’s range had been reduced by about 50% and is now disjunct, primarily due to clearing for agriculture. From European settlement to 1980, the area of Victoria covered by forest and dense woodland had declined from 74% to about 33% (Kile *et al.* 1980). Maxwell *et al.* (1996) suggested that the tiger quoll had undergone a range contraction exceeding 30% between 1970 and 1995 in south-eastern Queensland and had become extinct in South Australia, and that the total range reduction could be as high as 50%. Lunney and Leary (1988) thought the range of the tiger quoll had declined by 26–50% since European settlement in NSW.

The continued decline of the species has been attributed to a number of factors including continued habitat loss and fragmentation, logging, trapping and poisoning, disease and competition with introduced predators (Settle 1978; Mansergh 1984; Mansergh and Belcher 1992; Watt 1993; Belcher 1994, 1998; Edgar and Belcher 1995; Maxwell *et al.* 1996; Long and Nelson 2007). Clearfell logging and related land use practices such as post-logging slash burning, the development of even-aged regrowth, changes in forest tree species composition, and fragmentation and alienation of habitat in forested areas have caused concern for the survival of the tiger quoll (Pattemore 1977; Recher *et al.* 1980; Green and Scarborough 1990).

Habitat requirements of the tiger quoll include old-growth forest elements such as hollows, logs, ≥50% canopy cover and structurally complex vegetation (Belcher 2000; Belcher and Darrant 2006a). Tiger quolls use hollow logs, tree hollows, burrows and rock crevices for denning (Belcher 2000; Belcher and Darrant 2006b). Timber harvesting may remove the habitat elements required by the tiger quoll, rendering the habitat unsuitable. Timber harvesting may also reduce or eliminate arboreal marsupials through the removal of shelter (tree hollows) and the foraging strata (Tyndale-Biscoe and Smith 1969; Recher *et al.* 1980; Ambrose 1982; Lunney 1987; Lindenmayer *et al.* 1991; Wilson and Friend 1999). Arboreal marsupials are a major dietary component of the tiger quoll (Belcher 1994, 1995, 2000; Jones and Barmuta 1998; Belcher *et al.* 2007) and their reduction or elimination may reduce the suitability of habitat for the species. Medium-sized mammals (500–5000 g) form 75% and large mammals taken as carrion form 17% of the biomass of tiger quoll’s diet (Belcher 1995). Small mammals make up less than 2% of the biomass of the species’ diet (Belcher 1995).

The main silvicultural techniques used in Australia are clearfell logging and selective logging. Clearfell logging involves the felling of all trees in a compartment except for where prescriptions require their retention (e.g. seed trees and habitat trees). Selective logging removes selected merchantable trees while retaining other trees. Trees may be removed in groups — creating small gaps and clusters of trees — or individually throughout a compartment. Regeneration after logging is usually promoted through burning logging slash and or mechanical soil disturbance. Logging cycles vary from 20 to 80 y depending on the silvicultural system employed, growth rates and the market for the timber (Anon. 1995).

This study investigated the use of selectively logged and unlogged tableland moist forest by a population of tiger quolls in south-eastern New South Wales and assessed the impact of selective logging on the population. The results are discussed in relation to the likely impact of clearfell logging on the species.

The results are also compared with research on the impact of logging on martens in North America and Europe. Martens are forest-dependent carnivores of a similar size, body shape and ecology to the tiger quoll. Like quolls, martens are intrasexually territorial, occupy similar sized home ranges and are dependent on prey of similar size (Powell 1994; Martin 1994). The impact of logging has been studied on American martens (*Martes americana*), fishers (*M. pennanti*) and pine martens (*M. martes*) (Soutiere 1979; Steventon and Major1982; Spencer *et al.* 1983; Bissonette *et al.* 1989; Brainerd *et al.* 1994; Buck *et al.* 1994; Jones and Garton 1994; Thompson and Harestad 1994; Paragi *et al.*1996; Sturtevant *et al.* 1996).

Methods

Study area

The study was conducted in Badja and Tallaganda State Forests in southern New South Wales. Badja and Tallaganda State Forests are adjoined and run north-south along the Great Dividing Range in south-eastern New South Wales. The study site was near Pikes Saddle and is about 3.5 km north-east of Big Badja (35°59′32″S, 149°33′20″E), in tableland forest on the western fall of the escarpment. Altitude ranges from about 800 to 1400 m. The climate is characterised by short mild summers and long cold winters, with frosts and snowfalls common in winter. Rainfall is highest in summer and lowest in July and varies from 900 to 1200 mm y^{-1} (Anon. 1995). Forest types range from snow gum (*Eucalyptus pauciflora*), mountain gum (*E. dalrympleana*) and white ash (*E. fraxinoides*) on the higher slopes; brown barrel (*E. fastigata*), manna gum (*E. viminalis*), shining gum (*E. nitens*) and broad-leaved peppermint (*E. dives*) on deep soils with high moisture; to sivertop ash (*E. sieberi*) and narrow-leaved peppermint (*E. radiata*) on the drier sites. The understorey varies from a dense to open shrub layer with a fern- or grass-dominated ground-cover.

Logging history

Early logging was for fencing timber but by the 1860s there were a number of sawmills (Anon. 1995). Early logging was very selective and caused minimal disturbance, but since the 1950s logging intensity has increased. Current harvesting is selective, removing about 17 m^2 basal area and retaining 22 m^2 in compartments of around 350 ha (Anon. 1995).

Use of logged and unlogged forest

Tiger quolls were trapped between May 1996 and July 1998 in large wire cage traps (Mascot Wire Works, Sydney). Each tiger quoll trapped was transferred from the cage trap to a cloth catch-bag, weighed with 10 kg Salter scales, injected intramuscularly with the sedative Zoletil (at a dose rate of 5 mg kg^{-1} body weight) and held until the sedative had acted. The animal was then removed from the catch-bag, its sex and reproductive status (if female) were recorded, and photographed for later identification. Spot patterns unique to each animal were used to identify individuals. Teeth were examined for wear as a guide to the animal's age (Belcher 2000), and a radio-transmitter was fitted. The animal was held in the trap until it had fully recovered from the effects of the sedative, then was released at the point of capture.

The transmitters were manufactured by Faunatech (Faunatech Pty Ltd, Bairnsdale Victoria), using Sirtrack transmitter bases — two-stage VHF 150 megahertz band with 3-volt lithium batteries. The transmitters were sealed in a moulded epoxy resin case with either silicon rubber or suede leather straps that formed a collar for attaching around the animal's neck. Transmitters had a whip antenna covered with heat-shrunk plastic. The transmitters had a range of 5–10 km, with a battery life of 4–6 months. Transmitters weighed between 35 g (silicon rubber collar) and 25 g (leather collar), and were less than 2.5% of body weight.

Between May 1996 and September 1998 individual tiger quolls were radio-tracked for periods of up to nine months and locations plotted. Radio-tracking was undertaken during the day and at night, but most activity was recorded during the day and most locations were subsequently recorded during the day. An attempt was made to locate each animal each day, but some individuals were located less frequently. Most locations were derived from radio-tracking to the animal, rather than triangulating to determine the animal's position. The locations were then compared with a forestry map containing compartment boundaries and logging histories.

Forest compartments were grouped into time-since-logging strata of 0–5, 6–10, 11–15, 16–20, 21–50 y and unlogged, although there were no compartments that fell within the 11–15-y-since-logging category. To determine whether quolls were using each age class in proportion to its availability, the area of each compartment, in each age class, was summed and the percentage area for each age class was calculated. The number of locations for each individual quoll in each logging age class was summed and the percentage use of each age class was calculated.

The statistical approach presented by Neu *et al*. (1974) was applied to test the hypothesis that tiger quolls were exhibiting preference for a particular age-class of forest. A χ^2 test was performed for each individual quoll for the goodness-of-fit of utilised age class to available age class. Two null hypotheses were tested, as described by Alldredge and Ratti (1986). These were: H_{01}, in which forest age class utilisation occurred in proportion to availability, considering all forest age classes simultaneously, with the option of testing the second hypothesis, H_{02}, that usage occurred in proportion to availability, considering each forest age class separately.

If the null hypotheses were rejected, that is individuals were showing preference, the methodology of Neu *et al.* (1974) was followed to determine which specific forest age classes were avoided or preferred. Confidence intervals for the proportion of times an animal used each age class were:

$$p_i - z_{\alpha/2k}\left(\frac{p_i(l-p_i)}{n}\right)^{1/2} \leq p_i \leq p_i + z_{\alpha/2k}\left(\frac{p_i(l-p_i)}{n}\right)^{1/2}$$

where p_i is the proportion of locations in forest age class i, and $z_{\alpha/2k}$ is the upper standard normal variate corresponding to a probability tail area of $\alpha/2k$. The $2k$ denominator under α is used because multiple confidence intervals are being computed simultaneously (White and Garrott 1990). Bonferroni normal statistics were used to keep the Type 1 error level low, with k = the number of forest age classes. The Z statistic is computed for $\alpha = 0.10$. The confidence interval is checked for overlap with the availability proportion of the corresponding habitat to determine whether a habitat is avoided or preferred. If the confidence interval includes the availability proportion then the hypothesis of no preference or avoidance cannot be rejected. If, however, the lower bound of the interval exceeds the availability proportion, then the animal has shown preference.

To determine habitat preferences for a population, χ^2 statistics and their degrees of freedom can be summed. The χ^2 test of preference requires that the observations of an animal's locations are independent, that is, not auto-correlated. Lack of independence will result in too many Type 1 errors. All locations for each individual quoll were taken at least two hours apart and in the majority of cases 24 hours or more apart, to avoid auto-correlation. However, where a few observations are taken on many animals, pooling of the data is appropriate (White and Garrott 1990).

Results

Use of logged and unlogged forest

Tiger quolls use of logged and unlogged forest was significantly different to availability (Table 1).

Female quolls used recently logged compartments (0–5 y) significantly less than proportional availability, 6–10 y post-logging compartments in proportion to availability, and 16–20 y post-logging and unlogged compartments significantly more than proportional availability. They did not use 21–50 y post-logging compartments (Table 1).

Male tiger quolls used recently logged compartments (0–10 y) significantly less, unlogged and 16–20 y post-logging compartments significantly more than proportional availability while 21–50 y post-logging compartments were used in proportion to availability (Table 1).

Preference in logged and unlogged forest

The Bonferroni–Z confidence interval test showed differences in the preferences of tiger quolls for post-logging stand age classes. Male and female tiger quolls avoided the 0–5 y post-logging forest age class to a significant extent, and females avoided the 21–50 y age class. Male 2 showed preference for the 16–20 y age class and avoided the 21–50 y age class. Male 3 avoided the 0–10 y age class. Female 1 showed preference for the 16–20 y age class and avoided the 21–50 y age class. Female 2 and 3 avoided the 0–5 and 21–50 y age classes, and female 2 showed preference for unlogged forest (Table 2).

Discussion

Tiger quolls in this study used unlogged forest significantly more than its proportional availability, but they also used some age classes of selectively logged forest significantly more than their proportional availability. Recently (0–10 y) selectively logged forest was used significantly less by male tiger quolls, while females used 0–5 y forest significantly less. The understorey and ground cover are removed by mechanical disturbance during logging operations. Regeneration of *E. fastigata*, the

Table 1. Chi-squared analysis of use of logged and unlogged forest compartments in Badja and Tallaganda State Forests, south-eastern New South Wales, by male and female tiger quolls between 1996 and 1998

Portion of quoll population and time since logging (y)	Area (fraction of total)	Use[A]		χ^2	Significance[B]
		Observed	Expected		
Female tiger quolls					
0–5	0.15	7	22.2	10.41	**
6–10	0.36	53	55.7	0.13	
16–20	0.25	55	37.6	8.05	**
21–50	0.10	0	16.0	16.00	
Unlogged	0.14	38	22.0	11.64	**
Overall (4 df)				46.23	$P < 0.01$
Male tiger quolls					
0–5	0.15	1	14.4	12.47	*
6–10	0.36	8	36.1	21.47	**
16–20	0.25	57	24.3	44.00	**
21–50	0.10	7	10.4	1.11	
Unlogged	0.14	26	14.3	9.57	*
Overall (4 df)				89.02	$P < 0.01$

[A] Use = the number of times (days) a quoll was recorded by radiotracking in a particular post-logging age class or unlogged are
[B] * = $P < 0.05$, ** = $P < 0.01$

Table 2. Preference for or avoidance of various forest age classes by male and female tiger quolls at Badja and Tallaganda State Forests, NSW

Individual	Forest age class (y)	N^A	p_i^B	Confidence interval	Available area (fraction of total)	Preference or avoidance
Female 1	0–5	7	0.167	–0.16 to 0.49	0.15	–
	6–10	11	0.262	–0.05 to 0.57	0.36	–
	16–20	23	0.444	0.55 to 0.65	0.25	Prefer
	21–50	0	0	0	0.10	Avoid
	Unlogged	1	0.024	–0.33 to 0.38	0.14	–
Female 2	0–5	0	0	0	0.15	Avoid
	6–10	3	0.115	–0.31 to 0.54	0.36	–
	16–20	9	0.346	–0.02 to 0.71	0.25	–
	21–50	0	0	0	0.10	Avoid
	Unlogged	14	0.538	0.29 to 0.85	0.14	Prefer
Female 3	0–5	0	0	0	0.15	Avoid
	6–10	32	0.405	0.20 to 0.607	0.36	–
	16–20	23	0.290	0.09 to 0.486	0.25	–
	21–50	0	0	0	0.10	Avoid
	Unlogged	24	0.304	0.09 to 0.52	0.14	–
Male 1	0–5	0	0	0	0.15	Avoid
	6–10	2	0.080	–0.37 to 0.53	0.36	–
	16–20	15	0.600	0.19 to 1.01	0.25	–
	21–50	3	0.120	–0.49 to 0.73	0.10	–
	Unlogged	5	0.200	–0.38 to 0.78	0.14	–
Male 2	0–5	0	0	0	0.15	Avoid
	6–10	1	0.067	–0.51 to 0.65	0.36	–
	16–20	12	0.800	0.53 to 1.07	0.25	Prefer
	21–50	0	0	0	0.10	Avoid
	Unlogged	2	0.133	–0.43 to 0.69	0.14	–
Male 3	0–5	0	0	0	0.15	Avoid
	6–10	0	0	0	0.36	Avoid
	16–20	9	0.333	–0.03 to 0.67	0.25	–
	21–50	6	0.222	–0.17 to 0.62	0.10	–
	Unlogged	12	0.444	0.11 to 0.78	0.14	–

[A]N = number of locations in each age class
[B]p_i is the proportion of locations in forest age class i $\alpha = 0.10$

dominant commercial tree species in the study area, is dependent on disturbance caused by fire or mechanical soil disturbance. Regeneration of many of the logged compartments has relied on mechanical disturbance, but in recent times post-logging burning has also been used to promote regeneration. The removal of the understorey and ground cover is probably a factor in the avoidance of recently (0–5 y) logged forest. In a previous study, habitat analysis (Belcher 2000; Belcher and Darrant 2006a) revealed the importance of both cover (overstorey and understorey) and structural complexity for the tiger quoll. Logs are important for den sites, while cover is likely to be important for cover from predators and as foraging strata (Belcher 2000). Hot slash-burns usually remove the understorey and burn logs, removing denning and foraging habitat.

Female use of 6–10 y forest was in proportion to the availability of that age class. A factor that may be relevant in the species' use of this age class is the presence of a dense understorey and ground cover. As timber harvesting in this age class had been for sawlogs only, defective logs were left in situ rather than being removed for pulp (Anon. 1995). One of the three females had a number of dens and two maternal dens in a 6–10 y post-logging compartment. Many defective sawlogs were present in the compartment, providing abundant potential den sites. The compartment covers a broad flat adjacent to Jinden Creek and adjoins unlogged forest. Belcher (2000) found riparian flats had the highest prey densities, which is consistent with the presence of a maternal den. Female tiger quolls leave their young in a maternal den at about seven weeks of age, at a stage when they are too young to be able to thermoregulate properly (Settle 1978). The females are therefore restricted in the time they can spend away from the den, and would be expected to select maternal dens in prey-rich areas.

Both male and female quolls used 16–20 y post-logging forest significantly more than would be expected on the basis of its availability alone. As selective logging during this period was for sawlogs only (Anon. 1995), logging intensity may have been low and any defective logs left on the ground, providing more potential den sites.

The intensity of logging of each compartment has varied over time, which may have a direct bearing on the current utilisation of individual compartments and different forest age-classes by tiger quolls. Female quolls were not recorded in 21–50 y post-logging forest, which may have been an artifact of the position of their territories in relation to forest in this category, or it may have been because this forest age-class provides fewer resources. Male quolls used 21–50 y post-logging forest slightly less than would be expected on the basis of its availability. Logging intensity was higher during this period (21–50 y) — due to the demand for mining timbers, the post-war building material shortage and the housing boom in Canberra (Anon. 1995) — which may help explain the lower use of this age class. The silvicultural practice at the time would have been closer to clearfelling than selective logging, resulting in dense stands of forest regrowth in which trees are still too small to provide quota-quality sawlogs (Anon. 1995). These stands are less likely to contain sufficient hollows for arboreal prey at densities high enough to support resident quolls, particularly breeding females.

Both male and female quolls used unlogged forest significantly more than would be expected on the basis of its availability. All the studied quolls used unlogged forest and five out of six used it either in proportion to availability or significantly more than its availability, suggesting that it was an important component of their habitat. The major item of prey of tiger quolls in the study area was the greater glider *Petauroides volans* (Belcher 2000), which is dependent on the presence of suitable tree hollows and foraging strata (Tyndale-Biscoe and Smith 1969; Recher *et al.* 1980; Ambrose 1982; Lunney 1987; Lindenmayer *et al.* 1991). Greater glider populations can be substantially depleted by clearfelling (Loyn *et al.* 1980), and densities of greater gliders decline in approximate proportion to the amount of biomass removed during logging, i.e. the density of populations of greater gliders is correlated negatively with logging intensity and positively with standing biomass (Stockwell *et al.* 1990; Davey and Stockwell 1991; Howarth 1992). Compared to logged forest, unlogged forest provides optimal denning and feeding habitat for the greater glider due to the abundance of tree hollows.

The tiger quolls congeners, the eastern (*D. viverrinus*), western (*D. geoffroi*) and northern (*D. hallucatus*) quolls, are not dependent on forests used for commercial timber harvesting, although the western quoll is now found only in the south-west of Western Australia and some of its habitat may be logged, while fire frequency has been found to affect the northern quoll (Oakwood 2002).

Martens are forest-dependent carnivores of similar size, body shape and ecology to the tiger quoll. Governor Phillip described the tiger quoll as a spotted marten (Phillip 1789), suggesting the close similarities between the two genera. Studies have been undertaken on the impact of logging in North America on American martens (*Martes Americana*), fishers (*M. pennanti*) and in Europe on pine martens (*M. martes*) (Soutiere 1979; Steventon and Major 1982; Spencer *et al.* 1983; Bissonette *et al.* 1989; Brainerd *et al.* 1994; Buck *et al.* 1994; Jones and Garton 1994; Thompson and Harestad 1994; Paragi *et al.* 1996; Sturtevant *et al.* 1996).

Martens prefer old-growth forest, but will use logged forest that contains the structural characteristics associated with old-growth forest that provide the habitat characteristics that they require. These habitat features include cover for predator avoidance, coarse woody debris and large-diameter trees for shelter and prey abundance (Thompson and Harestad 1994; Sturtevant *et al.* 1996)). Soutiere (1979) and Steventon and Major (1982) found that American marten habitat could be maintained by selective logging. Buck *et al.* (1994) found that the effect of selective logging was less apparent than the effect of clear cutting on fishers.

Marten habitat could be maintained by selective logging if a basal area of 20–25 m^2 ha^{-1} (Soutiere 1979) and a minimum canopy cover of 30–50% (Spencer *et al.* 1983; Buck *et al.* 1994; Thompson and Harestad 1994) was retained.

In a study of the impact of logging on the Eurasian pine marten, Brainerd *et al.* (1994) found that martens preferred old-growth forest, which provides a greater degree of structural diversity; that they generally avoided 0–8-y-old clear cuts; and that the scale of cutting was important. They found that clear cuts of less than 10 ha interspersed in a mosaic of older forest had a limited impact on marten densities, whereas large-scale clear cuts may adversely affect those populations (Grakov 1972; Thompson and Colgan 1987; Thompson 1991; Thompson and Harestad 1994).

Research on the impact of logging on martens and fishers has concluded that forest management must be planned at the landscape level to ensure an adequate supply of all age classes of all types of ecosystems and communities. This entails maintaining sufficient old-growth forest to enable species that are dependent on it to survive (Buck *et al.* 1994; Thompson and Harestad 1994; Sturtevant *et al.* 1996).

Selective sawlog-only logging in Tallaganda and Badja State Forests removed an average basal area of 17 m^2 ha^{-1} and retained an average basal area of 22 m^2 ha^{-1} (Anon 1995). This resulted in the retention of about 40–60% of canopy cover.

The habitat requirements of the tiger quoll appear to be similar to those of martens and fishers in that they require canopy cover, hollow logs of sufficient diameter to provide suitable dens, mature trees with hollows for arboreal prey species, and structural complexity — presumably to provide cover from predators and suitable hunting strata (Belcher 2000; Belcher and Darrant 2006a). The results of this study suggest that the tiger quoll is dependent on the maintenance of these habitat features of old-growth or unlogged forest, which are not necessarily completely removed by sawlog-only selective logging or are removed for a short period (0–10 or 0–15 y).

As the tiger quoll appears to have habitat requirements, home range size and responses to logging similar to those of martens and fishers, forest management within the tiger quoll's range should similarly be planned at a landscape level to ensure that adequate suitable habitat and a matrix of forest age-classes are available to maintain and conserve a viable tiger quoll population. As the average compartment size is close to three-quarters of the size of a female territory, harvesting of compartments should be dispersed throughout the forest rather than clumped.

The results of this study suggest that selectively logged forest with a mosaic of age classes including unlogged forest can maintain tiger quoll habitat, or minimise the period in which the logged forest is alienated. It is, however, imperative that prescriptions protecting riparian zones, rocky outcrops and areas of high prey densities are implemented (Belcher 2000).

The results also provide some insights into the impact of different logging regimes — they suggest that clearfell logging is likely to result in habitat unsuitable for the tiger quoll for a much longer time than selective logging, due to the removal of habitat features important for the tiger quoll (such as tree hollows, hollow logs and structural complexity) and the time required for those features to redevelop. Loyn *et al.* (1980) reported such an impact of clearfell logging on the tiger quoll, which failed to persist in regrowth forest in eastern Victoria after clearfell logging. Similarly the tiger quoll's main prey species, the greater glider, is significantly reduced after clearfelling and population re-establishment suffers significant delays (Davey and Stockwell 1991). In Tasmania only transient male and non-breeding females were recorded in even-aged regrowth forest (Long and Nelson 2007).

The results also suggest that the matrix of logged and unlogged forest present in the study area provided habitat suitable for the tiger quoll. A reduction in the ratio of unlogged to logged forest and or an increase in logging intensity may reduce the carrying capacity or suitability of the forest for tiger quolls.

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