The causes and prognoses of different types of fractures in wild koalas submitted to wildlife hospitals

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\section*{A B S T R A C T}
Fractures are a major problem in wild koalas of great veterinary and conservation importance as their occurrence in different locations of the body might result in varying healing success. The aim of this study was to determine the fracture types (defined by location of the fracture) occurring in wild koalas, temporal patterns, possible causes and risk factors of fracture types, and the prognosis for successfully releasing koalas with healed fracture types into the wild. Data from a total of 2031 wild koalas submitted to wildlife hospitals in South-East Queensland, Australia, over a period of 13 years were analysed. Approximately 56.7\% of koalas experienced head fractures, 13.4\% had torso fractures, 14.9\% had limb fractures and 15\% had combination fractures. A total of 84.1\% of fractures were caused by vehicle collisions, 9.1\% by dog attacks, 3.3\% by falls from trees, 1.3\% by train collisions, 0.2\% by livestock trampling and 1.8\% due to unknown causes. Multinomial logistic regression was used to identify risk factors (cause of fracture, age category, sex, year, three-year admission period and season of fracture event) by fracture type. The type of fracture was associated with both the cause of the fracture and the season when it occurred: for example torso fractures (compared to combination fractures) were associated with dog attacks (OR $= 10.98$; 95\% CI $= 3.03, 20.01$) and falls from trees (OR $= 4.79$; 95\% CI $= 2.26, 10.19$) relative to vehicle collisions. More submissions of koalas with head fractures due to vehicle collisions occurred in spring compared to autumn and winter, coinciding with the breeding season of koalas and increased animal movement. Prognosis for koalas with fractures was poor, with approximately 63.8\% of koalas admitted dead on arrival, 34.2\% euthanised, and only 2.0\% of koalas able to be released. Given this data, further research into mitigation strategies to decrease the risk of fractures and to increase the observed low recovery rate should be considered.

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\section*{1. Introduction}
The koala, \textit{Phascolarctos cinereus}, a tree-dwelling, medium-sized marsupial, is an iconic wildlife species in Australia. Koalas are currently experiencing a drastic population decline in South-East Queensland and were listed of vulnerable conservation status by the Queensland State Government in June 2015. Their decline estimated at 54\%, from greater than 10,000 animals in the South-East Queensland region in 1995 to less than 5000 by 2011, is driven by the consequences of koala habitat loss and diseases such as Chlamydia infection (Department of Environment, Australian Government, 2011; de Oliveira et al., 2014; Dique et al., 2003; McAlpine et al., 2006; Rhodes et al., 2014). Habitat loss or its fragmentation through the establishment of new roads are a result of urban expansion for both residential and commercial development, associated with rapid population increases in South-East Queensland (Department of Environment and Heritage Protection, Queensland Government 2011; McAlpine et al., 2006; Rhodes et al., 2014). Major threats to koalas associated with this infrastructure changes and increased human activity are vehicle collisions and dog attacks (Department of Environment and Heritage Protection, Queensland Government 2014; Griffith et al., 2013; McAlpine et al., 2006; Preece, 2007; Rhodes et al., 2014). A 1983 study of wild southern koalas admitted for hospital treatment in Victoria reported traumatic injury as ‘the most common presentation’, with motor vehicle collisions as the leading cause (Obendorf, 1983). However, the types or locations of traumatic injuries in koalas have not yet been described in detail. Understanding fractures types and their risk factors may aid...
veterinarians in the clinical management of these cases and guide the use of limited rehabilitation resources towards animals with a more favourable prognosis. Previous research has shown that where the fracture is located has a great bearing on whether wild animals coming into care will be successfully released—for example humerus fractures in wild birds resulted only in the release of 1.3% of cases, while radius fractures had release rates of 20% (Mason, 2004; Frowler, 2014). However, release rates of fracture cases in koalas have never been formally investigated. As the survival of individual koalas of breeding potential is of ever-growing significance, the rehabilitation of fracture cases plays an important role in conservation efforts.

Given the impact of traumatic injury on the koala population, the objectives of this study were to (1) describe fracture types occurring in wild koalas and determine their prognosis, (2) describe seasonal and temporal patterns of fractures (3) summarize the causes of fractures, (4) examine if variables, such as cause of fracture, age category, sex, year, three-year admission period and season were associated with fracture types.

2. Materials and methods

2.1. Study design

The Queensland Government Department of Environment and Heritage Protection Moggill Koala Hospital (MKH) maintains a Microsoft Access 2007 database of koalas that are found injured or deceased and that are submitted to veterinary clinics and wildlife hospitals. The MKH database is made up of koala admissions to the MKH, the Australia Zoo Wildlife Hospital (AZWH), the Currumbin Sanctuary Wildlife Hospital (CSWH) and various other veterinary clinics in South-East Queensland. At admission, a mandatory koala paper record sheet is completed describing the signalment and general health of the koala, including sex, weight and cause of admission. Depending on the veterinary assessment, koalas are then retained for treatment, euthanised or instantly released. Cause of trauma is recorded as it was observed by the submitter, who is generally a member of the public (e.g. a member of the public might observe a koala being involved in a vehicle collision or dog attack), or is logically deduced from the presentation during clinical or post-mortem examination. For example, a koala found on the side of a road with massive blunt force trauma may be presumed to have been hit by a motor vehicle. Euthanised and dead-on-arrival koalas receive a postmortem examination. Additional information such as postmortem results are entered in a free text field in the database.

2.2. Statistical analysis

A search in the free-text field section of the MKH database for the words ‘fractured’, ‘crushed’ or ‘broken’ was performed to create the dataset used in this study. The dataset was further refined by removing cases that did not involve fractured bones or were duplicates. Only definite findings were included, and all potentially misleading descriptions were cross-checked (and corrected if necessary) by referring to the original paper records.

Clinical fracture outcomes were defined as dead-on-arrival, euthanased or released. Dead-on-arrival describes an individual that was found deceased, or died shortly after rescue, or in some cases shortly after the commencement of treatment. Fracture locations were cross tabulated with clinical fracture outcomes and the prevalence and the 95% Jeffrey’s confidence interval for the prevalence of fracture locations was calculated. Fracture locations were then summarized into four fracture types: (1) Head only, (2) Torso only, (3) Limbs only (including hindlimb, forelimb, or both), and (4) combination of fracture locations.

Fracture causes were summarised into the following categories: vehicle collisions, dog attacks, falls from trees, train collisions, livestock trampling and unknown. Koala age groups were defined by weight: adults >4 kg, young adults 2–4 kg, juvenile <2 kg. Season was coded in accordance with the Southern Hemisphere (spring: September–November; summer: December–February; autumn: March–May; winter: June–August). To analyse the long-term trend, years of admission between 1997 and 2008 were categorized into three-year intervals as these intervals largely represented the temporal increasing, decreasing or plateauing changes in admission numbers. The chi-square statistic for homogeneity of a sample was used to explore the pattern of seasonal fracture submissions and the frequency of clinical outcomes observed. Multinomial logistic regression was then used to analyse the association of clinical fracture outcomes and of fracture causes with the individual koala risk factors sex and age category.

Fractures caused by livestock trampling, train collisions or unknown causes were sparse and these cases were therefore excluded from further analysis. Multinomial logistic regression analysis was utilized to analyse univariable associations between risk factor variables (cause of fracture, age category, sex, year, three-year admission period and season) and the dependent variable, fracture type. Combination fractures were considered as the base category to which the other three categories of fracture types were compared to. For the explanatory risk factor variables we chose the following reference groups: spring for season, adult for age group, female for sex. A multiple Wald test was computed to evaluate the statistical significance of all categories together for any

<table>
<thead>
<tr>
<th>Fracture location</th>
<th>N Dead-on-arrival</th>
<th>N Euthanised</th>
<th>N Released</th>
<th>N Total</th>
<th>% (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head</td>
<td>855</td>
<td>292</td>
<td>4</td>
<td>1151</td>
<td>56.7 (54.0, 58.8)</td>
</tr>
<tr>
<td>Torso</td>
<td>123</td>
<td>142</td>
<td>8</td>
<td>273</td>
<td>13.4 (12.0, 15.0)</td>
</tr>
<tr>
<td>Hindlimb</td>
<td>108</td>
<td>65</td>
<td>16</td>
<td>189</td>
<td>9.3 (8.1, 10.6)</td>
</tr>
<tr>
<td>Forelimb</td>
<td>33</td>
<td>70</td>
<td>10</td>
<td>113</td>
<td>5.6 (4.6, 6.6)</td>
</tr>
<tr>
<td>Head torso</td>
<td>57</td>
<td>37</td>
<td>0</td>
<td>94</td>
<td>4.6 (3.8, 5.6)</td>
</tr>
<tr>
<td>Head forelimb</td>
<td>38</td>
<td>25</td>
<td>0</td>
<td>63</td>
<td>3.1 (2.4, 3.9)</td>
</tr>
<tr>
<td>Head hindlimb</td>
<td>40</td>
<td>8</td>
<td>2</td>
<td>50</td>
<td>2.5 (1.9, 3.2)</td>
</tr>
<tr>
<td>Torso hindlimb</td>
<td>9</td>
<td>21</td>
<td>0</td>
<td>30</td>
<td>1.5 (1.0, 2.1)</td>
</tr>
<tr>
<td>Torso forelimb</td>
<td>6</td>
<td>14</td>
<td>0</td>
<td>20</td>
<td>1.0 (0.6, 1.5)</td>
</tr>
<tr>
<td>Both limbs</td>
<td>6</td>
<td>10</td>
<td>0</td>
<td>16</td>
<td>0.8 (0.5, 1.3)</td>
</tr>
<tr>
<td>Head torso hindlimb</td>
<td>9</td>
<td>1</td>
<td>0</td>
<td>10</td>
<td>0.5 (0.3, 0.9)</td>
</tr>
<tr>
<td>Head both limbs</td>
<td>4</td>
<td>4</td>
<td>0</td>
<td>8</td>
<td>0.4 (0.2, 0.7)</td>
</tr>
<tr>
<td>Head torso forelimb</td>
<td>4</td>
<td>1</td>
<td>0</td>
<td>5</td>
<td>0.3 (0.1, 0.5)</td>
</tr>
<tr>
<td>Torso both limbs</td>
<td>2</td>
<td>3</td>
<td>0</td>
<td>5</td>
<td>0.3 (0.1, 0.5)</td>
</tr>
<tr>
<td>Torso both limbs</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>4</td>
<td>0.2 (0.1, 0.5)</td>
</tr>
</tbody>
</table>
categorical risk factor variable (Dohoo et al., 2009). Variables for which Wald's $p < 0.10$ were considered for multivariable analysis. Backward and forward model selection procedures were run and the overall $p$-values, as well as odds ratios (OR) with 95% confidence intervals (CI) for explanatory variables, were recorded. The stepwise selection process was stopped once all covariates were significantly ($p < 0.05$) contributing to the model. First order interactions between explanatory variables were also explored.

Any variable not selected for the original multivariable model was added back one at a time, with significant variables retained. Using this approach we were able to identify variables that, by themselves, were not significantly related to the outcome but make an important significant contribution in the presence of other variables (Bursac et al., 2008).

The Hausman–McFadden Test was used to test the assumption that the model odds ratios for each level of the response variable were independent of the other levels (Hausman and McFadden, 1984).

Several approaches were used to conduct regression diagnostics. At first, three binary logistic regression models were created from the final multivariable model (head fracture/torso fracture, head fracture/limb fracture, head fracture/combination fracture) and regression diagnostics were carried out on each model as described in Dohoo et al. (2009). Thus covariate patterns with outlying standardised Pearson residual and delta–beta values were identified and the models were then rerun excluding individuals from within these patterns and the changes in the resulting coefficients were examined. Model fit was then assessed using the Hosmer–Lemeshow goodness-of-fit test. Secondly, a recently developed overall goodness-of-fit-test for multinomial logistic regression models (Fagerland et al., 2008) was applied using the −mlogitgof−command in STATA.

Predicted probabilities were calculated from the multinomial model using the−margins−command in STATA, where the predicted probability of each fracture type was calculated at each level of the risk factor, while all other variables in the model were at their means.

Stata 12.0 (Stata Statistical Software, Stata Corporation, College Station, TX, USA) was used for all statistical analyses.

### 3. Results

A total of 2045 koalas were admitted between 13 January 1997 and 29 December 2010 with reported fractures. Koalas with missing information regarding the type of fracture ($N = 12$), sex ($N = 1$) and outcome ($N = 2$) were excluded, resulting in a dataset of 2031 individual koalas with fractures to be analysed. This represents 40.7% of all koala cases submitted during this observation period with traumatic injuries ($N = 4982$).

Approximately 70% of koalas submitted with fractures were found in local government areas of South-East Queensland (Fig. 1). The majority of fracture cases were found in the Redland City Council area ($N = 720$), a coastal region of Greater Brisbane with extensive native bushland providing good habitat for koala populations, in the Moreton Bay Regional Council area ($N = 455$), which also comprises of large native forest areas and in the Brisbane City region ($N = 243$), a stronger urbanised and densely populated area with fragmented native bush land.

A total of 59.8% ($N = 1214$) of koalas submitted with fractures were male and 40.2% ($N = 817$) were female. Approximately 89.7% ($N = 1821$) of koalas submitted with fractures were mature adults, 6.8% ($N = 139$) were young adults and 3.5% ($N = 72$) were juveniles.

Fractures were overwhelmingly associated with poor clinical outcomes, with a majority of fractures, 63.8% ($N = 1296$) resulting in koalas being dead-on-arrival at the hospital, 34.2% ($N = 695$) of fractures in koalas resulted in euthanasia, while only 2.0% ($N = 40$) of koalas with fractures were released after hospitalisation ($X = 1165.8$, df = 2, $p < 0.001$). Using dead-on-arrival as reference category, koalas were more likely successfully rehabilitated and released when they were young adults (OR = 2.96, 95% CI 1.19, 7.36) or juveniles (OR = 6.14, 95% CI 2.55, 14.78) (Supplementary Table 1). There was no statistical difference for sex between the three clinical outcomes (Supplementary Table 1).

More than half of the fractures occurred to the head of the koalas, followed by torso and either hindlimb or forelimb; these fractures totalled 85% of all fractures reported during the study period. The remaining reported fractures were combinations of various fracture types (Table 1). By assessing the frequency of fracture types within each clinical outcome, hindlimb or forelimb fractures were the only injuries with a higher frequency of release of koalas into the wild (approximately 8.6%). Head injuries were more likely to result in being dead-on-arrival (approximately 74.3%), whilst torso fractures mostly resulted in the euthanasia after veterinary assessment (approximately 52.0%) (Table 2).

The cause of the fracture by sex is listed in Table 3. A total of 84.1% of fractures were caused by vehicle collisions, 9.1% by dog attacks, 3.3% by falls from trees, 1.3% by train collisions, 0.2% livestock trampling and 1.8% were due to unknown causes. Using unknown causes as a base category, a larger proportion of male koalas was involved in vehicle and train collisions compared to females (OR = 1.94, 95% CI 1.00, 3.79 and OR = 3.57, 95% CI 1.21, 10.55 respectively) (Supplementary Table 2).

The seasonal pattern of fracture admissions (number of submissions per month across all years) by cause is displayed in Fig. 2. There is a strong temporal pattern for vehicle collisions ($X = 498.45$, df = 11, $p < 0.001$) and dog attacks ($X = 42.35$, df = 11, $p < 0.001$) across months, with most submissions from these two causes occurring from July to November, with a peak in September.

Head fracture submissions increased 5 times between 1997 and 2000, remained high until a sharp drop in 2005 and then increased again to another lower plateau between 2006 and 2008 and declined to around 50 animals in 2009 and 2010 (Fig. 3). As the total admissions number for other fracture types were lower, the fluctuation between years was less dominant compared to head trauma.

In the univariable analysis, the three-year admission interval ($X = 24.65$, df = 12, $p = 0.017$), fracture cause ($X = 236.64$, df = 6, $p < 0.001$) and season ($X = 27.38$, df = 9, $p = 0.001$) were associated

### Table 2
Outcome of admission (dead-on-arrival, euthanised, released) by age group (mature adult, young adult, juvenile) for koalas with fractures submitted to wildlife hospitals in South-East Queensland between 1997 and 2010.

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Mature adult% (N)</th>
<th>Young adult% (N)</th>
<th>Juvenile% (N)</th>
<th>Total N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dead-on-arrival</td>
<td>63.7 (1160)</td>
<td>63.0 (87)</td>
<td>68.1 (49)</td>
<td>1296</td>
</tr>
<tr>
<td>Euthanised</td>
<td>34.8 (634)</td>
<td>32.6 (45)</td>
<td>22.2 (16)</td>
<td>695</td>
</tr>
<tr>
<td>Released</td>
<td>1.5 (27)</td>
<td>4.4 (6)</td>
<td>9.7 (7)</td>
<td>40</td>
</tr>
<tr>
<td>Total</td>
<td>100 (1821)</td>
<td>100 (138)</td>
<td>100 (72)</td>
<td>2031</td>
</tr>
</tbody>
</table>

### Table 3
Cause of fracture (vehicle collision, dog attack, fall from tree, livestock trampling, train collision, unknown) by sex (female, male) for koalas submitted to wildlife hospitals in South-East Queensland between 1997 and 2010.

<table>
<thead>
<tr>
<th>Cause of fracture</th>
<th>Female% (N)</th>
<th>Male% (N)</th>
<th>Total N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Car accident</td>
<td>81.8 (668)</td>
<td>85.8 (1041)</td>
<td>1709</td>
</tr>
<tr>
<td>Dog attack</td>
<td>11.0 (90)</td>
<td>7.8 (59)</td>
<td>185</td>
</tr>
<tr>
<td>Fall from tree</td>
<td>3.4 (28)</td>
<td>3.4 (41)</td>
<td>69</td>
</tr>
<tr>
<td>Livestock trampling</td>
<td>0.5 (4)</td>
<td>0.1 (1)</td>
<td>5</td>
</tr>
<tr>
<td>Train collision</td>
<td>0.9 (7)</td>
<td>1.6 (20)</td>
<td>27</td>
</tr>
<tr>
<td>Unknown</td>
<td>2.4 (20)</td>
<td>1.3 (16)</td>
<td>36</td>
</tr>
<tr>
<td>Total</td>
<td>100 (817)</td>
<td>100 (1214)</td>
<td>2031</td>
</tr>
</tbody>
</table>
with fracture type. However, age group ($X^2 = 5.53, df = 6, p = 0.478$) and sex ($X^2 = 3.15, df = 3, p = 0.369$) had no significant association with fracture type. Details of the univariable analysis are summarized in Supplementary Table 3.

In the final multivariable model, cause of the fracture ($X^2 = 234.26, df = 6, p < 0.001$) and the season ($X^2 = 25.04, df = 9, p = 0.003$) when the fracture occurred were associated with fracture type (Table 4). The three-year admission interval and also a tested interaction between season and cause of fracture did not improve the final multivariable model. Overall, the model appeared to fit the observed data very well.

Thus, torso fractures (compared to combination fractures) were positively associated with dog attacks ($OR = 10.98, 95\% CI 6.03, 20.01$) and falls from trees ($OR = 4.79, 95\% CI 2.26, 10.19$) relative to vehicle collisions. Similarly, limb fractures (compared to combination fractures) were positively associated with dog attacks ($OR = 3.52, 95\% CI 1.88, 6.60$) relative to vehicle collisions, while head fractures were less common (compared to combination fractures) for fall from trees ($OR = 0.31, 95\% CI 0.13, 0.71$) relative to vehicle collisions (Table 4). The results of the expected adjusted probabilities for the four different fracture types (with 95\% CIs) by season and cause of fracture are shown in Figs. 4 and 5. Expected probabilities of head fractures (compared to combination fractures) indicated a strong positive association with vehicle collisions ($OR = 3.28, 95\% CI 1.42, 7.59$) and a negative association with autumn ($OR = 0.58, 95\% CI 0.40, 0.86$) and winter periods ($OR = 0.71,$

**Fig. 1.** (A) Administrative map of Queensland with study area circled, (B) Chloropleth map indicating the number of koalas submitted to wildlife hospitals by council area in South-East Queensland between 1997 and 2010.

**Fig. 2.** Number of koalas submitted to wildlife hospitals in South-East Queensland between 1997 and 2010 by cause of fracture (vehicle collision, dog attack, fall from tree, livestock trampling, train collision, unknown) and month of submission.
Table 4
Results of the final multivariable multinomial logistic regression model showing risk factors associated with fracture type (head only, torso only, limbs only, and combination fracture with combination fracture used as reference category) of koalas submitted to wildlife hospitals in South-East Queensland between 1997 and 2010.

<table>
<thead>
<tr>
<th>Risk factor</th>
<th>Head only</th>
<th>Torso only</th>
<th>Limbs only</th>
<th>P</th>
<th>Head only</th>
<th>Torso only</th>
<th>Limbs only</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cause of fracture</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vehicle collision</td>
<td>1</td>
<td>0.012</td>
<td>1</td>
<td>&lt;0.001</td>
<td>1</td>
<td>0.799</td>
<td>1</td>
<td>0.622</td>
</tr>
<tr>
<td>Dog attack</td>
<td>0.69</td>
<td>0.37, 1.29</td>
<td>10.98</td>
<td>6.03, 20.01</td>
<td>3.52</td>
<td>1.88, 6.60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fall from tree</td>
<td>0.31</td>
<td>0.13, 0.71</td>
<td>4.79</td>
<td>2.26, 10.19</td>
<td>2.06</td>
<td>0.93, 4.58</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Season of fracture</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spring</td>
<td>1</td>
<td>0.012</td>
<td>1</td>
<td>0.799</td>
<td>1</td>
<td>0.98</td>
<td>1</td>
<td>0.51, 1.51</td>
</tr>
<tr>
<td>Summer</td>
<td>1.04</td>
<td>0.69, 1.58</td>
<td>1.28</td>
<td>0.74, 2.19</td>
<td>0.88</td>
<td>0.51, 1.51</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Autumn</td>
<td>0.58</td>
<td>0.40, 0.86</td>
<td>1.01</td>
<td>0.61, 1.68</td>
<td>0.86</td>
<td>0.53, 1.40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Winter</td>
<td>0.71</td>
<td>0.52, 0.97</td>
<td>0.97</td>
<td>0.63, 1.51</td>
<td>1.15</td>
<td>0.76, 1.70</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fig. 3. Number of koalas submitted to wildlife hospitals in South-East Queensland between 1997 and 2010 by fracture type (head only, torso only, limbs only, and combination fracture) and year of submission.

Fig. 4. Predicted probabilities and 95% confidence intervals for occurrence of fracture types type (head only, torso only, limbs only, and combination fracture) by cause of fracture (vehicle collision, dog attack, fall from tree) for koalas submitted to wildlife hospitals in South-East Queensland between 1997 and 2010.
95% CI 0.52, 0.97) (but not for summer periods) compared to spring. A similar seasonal pattern was not identified for other fracture types.

4. Discussion

Traumatic injury refers to physical injuries or wounds to the body, produced by external causes such as blunt or penetrating force, or burns. In koalas, a large proportion of traumatic injuries will result in fractures, in our study at least 40%, although the correct figure is likely to be higher as many koalas suffering trauma had no detailed information on the type of injuries recorded in the database.

The majority of trauma causes in South-East Queensland koalas were vehicle collisions and dog attacks. Other less common causes were koalas falling out of trees, train collisions and livestock trampling. This is consistent with previous reports of koala mortalities in Victoria and New South Wales, where vehicle collisions were found to be the leading cause of traumatic injury and death (Canfield, 1991; Griffith et al., 2013; Obendorf, 1983). Vehicle collisions are probably a result of urbanisation and subsequent fragmentation of koala habitat with major roadways forcing koalas to cross highways and other busy roads in order to carry out normal social behaviours or to forage for suitable browse (de Oliveira et al., 2014; McAlpine et al., 2006). In addition, ground movement associated with moving between forage trees in fragmented habitat gives dogs a predatory advantage, and makes koalas more vulnerable to attack (McAlpine et al., 2006).

Vehicle collisions were found to cause high numbers of head fractures, in particular skull and jaw fractures, followed by combination and limb fractures. Again, this correlates with a previous report that found vehicle collisions result most frequently in head injuries (Canfield, 1991). Canfield (1991) speculated that the koala gait and conformation, particularly skull height in relation to the ground clearance of a car, predisposes koalas to head trauma during collisions with vehicles. This author also indicated that the increased movement of koalas at night, particularly at dusk, when vehicles are using their headlights, may startle the animals, resulting in head injuries when these animals face oncoming vehicles (Canfield, 1991).

Dog attacks, in comparison, are more likely to involve the ribs and the torso. This can be explained by the fragility of the ribs, and the possible canine predispisition to maul the abdominal and thoracic regions (Wong et al., 1999). Limb involvement may reflect the defence reaction of the koala, as in human dog attack victims (Wong et al., 1999). These attacks might originate from either domestic or feral dogs, or even dingos. Feral dogs are common in peri-urban areas of Queensland (Department of Employment Economic Development and Innovation, Biosecurity Queensland, 2014), but the relative contribution of domestic versus feral dogs in koala attacks is unknown.

More fractures due to vehicle collisions were found in male koalas. This may correlate to the larger home range of males (Ellis et al., 2002), leading to increased contact with traffic. Also the majority of head fractures and vehicle collision were observed in spring, which represents the peak of the breeding season of koalas (Martin and Handasyde, 1999). Predominantly parturition in free-ranging female koalas in Queensland occurs between December and March, but the peak period of births can vary between different populations (Canfield, 1991; Ellis et al., 2010; Martin and Handasyde, 1999). Male koalas also tend to enter breeding condition earlier than females, with blood testosterone levels rising sharply in early spring (August), which results in a higher level of activity (Martin and Handasyde, 1999). Thus, increased koala activity during the breeding season would expose them to greater risk of vehicle collisions as they move about on the ground.

Fractures caused by koalas falling out of trees represented 3.3% of all incidents and generally included torso and limb fractures. Although not a major cause, tree fall injuries might be related to intraspecific fighting, which might account for the higher incidence of tree fall fractures in males compared to females (although not significant at p < 0.05). In addition males are heavier than females which might result in falls when trying to browse leaves at the end of rotten or thin branches.
The peak period of head injuries between 1999 and 2003 resulting from vehicle collisions might reflect a period of intensified infrastructure changes destroying koala habitats, particularly new housing developments (de Oliveira et al., 2014; Dique et al., 2003). Disturbingly, the use of reduced speed limits in koala habitat in South-East Queensland found no reduction in the number of koalas hit by vehicles during a 5-year trial period, though importantly there were not any significant differences in actual vehicle speeds measured between trial sites and control sites (Dique et al., 2003). A recent study indicated that accommodating growth in traffic through increases in volume of cars on existing roads has a lower impact on koalas than building new roads (Rhodes et al., 2014). Other factors such as environmental conditions like reduced rainfall causing nutritional stress leading to increased foraging and movement of koalas might also play a role in the temporal patterns observed (although this was beyond the scope of the current analysis). Further still, the reduction in total numbers of recorded head injuries following the peak period might reflect the rapid decline in koala populations during the 1990s into the 2000s (Dique et al., 2003). In fact the ‘Koala Coast’ located 20 km South-East of Brisbane experienced a koala population decline of 26% between 1996 and 2005, with an overall estimated decline of 54% in the South East Queensland region (Department of Environment and Resource Management, Queensland Government, 2012; Department of Environment, Australian Government, 2011). Nevertheless, the majority of koalas with fractures were recorded in local government areas with good koala habitat and therefore higher koala density; although a large proportion of cases were also found in the inner City of Brisbane, where a lower koala density is present and a stronger urbanisation is providing less coherent habitat resulting in more frequent exposure of koalas to traffic and dogs.

Adult koalas had a higher rate of fracture injury than juveniles. Again, this may be explained by the increased activity and home range of a reproductively active koala. Juvenile koalas were barely represented, assumedly because they are protected by their mothers’ bodies during vehicle impacts and dog attacks and because they form a smaller proportion of the wild population. A confounding factor may be the limited number of postmortem assessments in this age group, particularly in pouch young koalas.

The release rates for fracture injuries were very low, so their prognosis is poor. It is important to distinguish between the cause of the injury or fracture (as it was recorded by the public or the examining veterinarian) and the cause of the death (as determined by the pathological examination). The experience of the authors as koala veterinarians (AM and RL) or as veterinary pathologists (RA) is that a majority of animals in this dataset had concurrent injuries and/or diseases that lead to their deaths or euthanasia. Canfield (1991) also reported that traumatic injuries from motor vehicle accidents in koalas included in addition to head injuries also haemoperitoneum, limb injuries, haemorrhage, spinal injuries. Unfortunately, the rates of co-morbid injuries were not captured in this dataset, but will be explored in a large prospective study currently conducted by the authors. Furthermore, fractures at sites in close association with vital organs, for example the skull, spine and pelvis, have also a poor prognosis. In addition, fractures of the jaw have also low release rates as they are often associated with cranial trauma, and importantly, may cause misalignment of the molar teeth, which are known to lie in a close and specific arrangement in koalas (which is important for the mastication of folivore diet) (Crompton et al., 2010). Dental misalignment and malocclusion can severely affect the koala’s ability to maintain sufficient energy intake, because Eucalyptus leaves are an energy poor diet, and koalas have no visceral fat reserve, so disturbances in energy intake rapidly result in poor body condition and debilitation (Logan and Sanson, 2002). It is also the experience of the authors as koala veterinarians (AM and RL) that damage to the gingival junction in most cases leads to intractable infection as oral micro-organisms and vegetation lodge in the gap and are refractory to treatment, particularly as koalas must eat continuously. Veterinarians dealing with koala admissions are aware of this and are likely to euthanise a koala with tearing and other damage to the gingival junction or a fractured jaw, unless it is a simple fracture at the maxillary symphysis with no gingival tearing. Only limb fractures had a reasonable prognosis, with a higher chance of release compared to other fracture locations. In fact, hindlimb fractures are more likely to have a positive outcome – including amputations – as a koala carries most of its weight on its forelimbs when climbing and therefore euthanasia of a koala with a forelimb fracture is more likely than euthanasia of koala with a hindlimb fracture.

This retrospective epidemiological study should be interpreted within its limitations. Non-severe fractures in the wild could potentially heal and these koalas will not be admitted to wildlife hospitals and will not be included in the MKH database. Incidental healed fractures have been observed in koalas submitted for other reasons. Further, the original purpose of the MKH database was a clinical reference data set and not a database for scientific research. Thus some case information was incomplete. For example, sometimes a traumatic injury was recorded, but no details were documented on the injuries obtained. These inconsistencies may be explained by the often unavoidable variances in personnel conducting clinical and postmortem examinations, written descriptions and database entries. Currently a new research project, called ‘KoalaBASE’, has been established to standardise nomenclature of autopsy recordings and data entry to allow a more comprehensive analysis and improved surveillance of koala cases (School of Veterinary Science, University of Queensland, 2013).

Overall, the findings presented here will provide wildlife management agencies with information about causes of koala fractures and clinicians with probabilities of fracture types occurring (including their prognosis), which will ultimately guide their clinical decision making.

Conflict of interest

None of the authors of this paper has a financial or personal relationship with other people or organisations that could inappropriately influence or bias the content of the paper.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.prevetmed.2015.10.015.

References


Department of Environment, Australian Government 2011. *Assessment of the sensitivity of estimates of the trend in the national koala population to uncertainty in estimates of the populations at state level*. (accessed 5.06.15.).


