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A RETROSPECTIVE STUDY OF ADMISSION TRENDS OF KOALAS TO A REHABILITATION FACILITY OVER 30 YEARS

Joanna E. Griffith,[1,2] Navneet K. Dhand,[1] Mark B. Krockenberger,[1] and Damien P. Higgins[1]
[1] McMaster Building, B14, Faculty of Veterinary Science, The University of Sydney, Camperdown, New South Wales, Australia 2006
[2] Corresponding author (email: jgri7031@sydney.edu.au)

ABSTRACT: To identify threats to the survival of koalas (*Phascolarctos cinereus*) in coastal New South Wales, Australia, we compared 3,781 admission records of koalas, admitted between 1 January 1975 and 31 December 2004 to a koala rehabilitation facility on the midnorthern coast of New South Wales, against local wild population demographics, with the use of multinomial logistic regression and chi-square analyses. Trauma, the most frequent reason for admission, affected young and male animals more frequently than other groups. Seasonal differences in the probability of males presenting as trauma cases suggest behavioral factors as an important risk factor for this group. An increasing probability of koalas presenting as a result of motor vehicle accident since 1985 strongly supports the enhanced action of local authorities to pursue traffic-calming strategies if urban koala populations are to be maintained in this area. Koalas with clinical signs of chlamydiosis made up the second most frequent admission group, and these animals were more likely to be aged. This study highlights the potential usefulness of wildlife rehabilitation centers in detailing threats to local wildlife populations, provided record keeping is efficient and focused, and the role of such studies in providing evidence for focusing threat-mitigation efforts. Continual community engagement by koala researchers is important to ensure that maximum benefit is obtained from activities of special interest groups.
Key words: Koala, *Phascolarctos cinereus*, New South Wales, threats, wildlife rehabilitation.

INTRODUCTION

Identification and mitigation of threats to biodiversity are likely to become more important, given rapidly changing ecosystems in the face of rising human populations, shrinkage and fragmentation of wildlife habitat, introduction of exotic species and pathogens, and the effects of climate change. The study of wildlife health often provides an indication of ecosystem health and the understanding of host–pathogen–environment interactions that aids in the prediction of disease emergence with environmental change (Daszak et al., 2000, 2001). However, studies of threats to wild populations may be limited by logistic difficulties. In particular, longitudinal studies with large sample sizes are rare. These difficulties may be partly overcome through effective collaboration between wildlife rehabilitation centers and researchers (Shine and Koenig, 2001; Mazaris et al., 2008). With careful consideration of biases, such studies can be a useful adjunct to more traditional ecologic surveys. Use of large data sets often kept by these organizations allows detailed statistical analyses with high power, and the polychomotous analysis of multiple threats simultaneously assists in extrication of the relative impact of threats where the decline of a species is often multifactorial. Such studies may provide a sound evidence base for mitigation efforts (Kalpakis et al., 2009).

Populations of koalas (*Phascolarctos cinereus*) in southeast Queensland, Australia have declined sharply in recent years (Department of Environment and Resource Management, 2009). Should these trends apply to populations in New South Wales, local extinction may occur (Department of Environment and Climate Change–NSW, 2008). Current proposed threats to the survival of koala populations in other regions of Australia include loss of habitat (Melzer et al., 2000), predation by dogs (Lunney et al., 2007), motor vehicle collision (Dique et al., 2003b), loss of genetic diversity (Sherwin et al., 2000), bushfire (Lunney et al., 2007), climate change (Clifton et al., 2007), and disease

(Canfield, 1987; Tarlinton et al., 2005). Many of these reported threats relate to habitat fragmentation due to human impact on the natural environment but have not been well documented temporally, nor examined in relation to each other.

We analyzed the case records of the Koala Preservation Society of New South Wales (NSW) Koala Hospital (the Koala Hospital) over a 30-yr period (1975–2004) to identify 1) the numbers and characteristics of koalas admitted to a major NSW Koala Hospital during a 30-yr period; 2) to document the most common reasons for presentation in an urban koala population; 3) to describe seasonal or temporal patterns in the numbers of, and reasons for, koala presentations; and 4) to examine whether age class and sex influences the impact of specific threats; and thus better inform decision making aimed to mitigate threats to urban koala populations.

MATERIALS AND METHODS

Admission records in this study were those of koalas drawn from the district and surroundings of Port Macquarie (31°26′S, 152°54′E) encompassing a catchment area of approximately 8,300 km^2, on the midnorth coast of NSW. The koalas were reported as sick, injured, misplaced in areas perceived as dangerous (e.g., in a yard with a dog), or dead, by members of the public, to the Koala Hospital between 1 January 1975 and 31 December 2004. On admission, trained paraveterinary supervisors or veterinarians examined koalas and recorded age class, sex, reason for admission, and date of admission, in paper medical records. Age class was estimated by assessment of tooth wear (Martin, 1981), or previous admissions where animals were permanently identified (ear tags and subcutaneous passive transponder microchips). Information was transcribed into a computer database (Microsoft® Access 2003, Microsoft, North Ryde, NSW, Australia). Data used in the current study were imported from that database into SAS® statistical software for analysis (release 9.1, 2002–2003, SAS Institute Inc., Cary, North Carolina, USA).

Reasons for admission was used as a nominal outcome variable with 10 categories: 1) *motor vehicle accident* (MVA), 2) *dog attack*, 3) *healthy*, 4) *wet bottom*, 5) *eye disease*, 6) *debilitated*, 7) *fire*, 8) *undiagnosed*, 9) *orphaned joey* (*joey*), *and* 10) *all other*. *Healthy* included animals perceived by people to be in dangerous areas, healthy joeys with mothers, and animals presented for a health check and subsequently found with no clinical signs of disease. *Wet bottom* described clinical signs typical of urogenital chlamydiosis, such as rump pelage staining, dysuria, stranguria, and incontinence (Blanshard and Bodley, 2008) and *eye disease* described clinical signs of ocular chlamydiosis such as conjunctivitis and keratitis (Kempster et al., 1996). Fifty-eight animals were coded as having both wet bottom and eye disease between 1977 and 2000 and were included in analysis for *wet bottom* due to the small number involved and the inconsistent use of this category. Four explanatory variables were evaluated for their association with the outcome: sex (male; female); age class (juvenile, <2 years; young adult, 2–5 yr; mature adult, 5–8 yr; aged adult, <8 yr). Age classes corresponded to tooth-wear classes I–II, III, IV, V–VII, respectively (Martin, 1981); admission year in 5-yr intervals (1975–1979, 1980–1984, 1985–1989, 1990–1994, 1995–1999, and 2000–2004); and season (spring, September–November; summer, December–February; autumn, March–May; and winter, June–August). We studied the ages coded for abandoned joeys to estimate the translational errors in the data set.

Multinomial logistic regression analyses

A contingency table was created to assess the distribution of explanatory variables (sex, age class, season, and 5-yr interval) and their associations with the multicategory outcome variable (reasons for admission outlined above). To assess risk factors for presentation within the hospital population, we performed univariable multinomial logistic regression analyses for each explanatory variable to examine their unadjusted association with the outcome with the use of the SAS LOGISTIC procedure (Stokes et al., 2000). Variables significant in the univariable analyses ($P<0.10$) were used to build a multivariable multinomial logistic regression model by a manual forward stepwise approach to quantify risk factors for admission reason after adjusting for each other. Decision on inclusion or exclusion of a variable at each step was based on the individual contribution of each variable to the model, with the use of a likelihood-ratio chi-square test and retaining variables with $P\leq0.05$. We tested first-order interaction terms among variables in the final model and retained those significant ($P\leq0.05$).

Probabilities for each outcome category were calculated with the use of SAS statistical program and were plotted with Graphpad Prism® 5 for Windows (Graphpad Software, La Jolla, California, USA). We arbitrarily chose the following reference groups for explanatory variables: female, aged adults, autumn, and 1975–1979, and the arbitrarily chosen reference group for the outcome variable was *eye disease*.

Chi-square analyses

To test the hypothesis that some groups were at greater risk of presenting for different reasons, we assumed a population structure of a 1:1 sex ratio and age classes of 6.3% juveniles, 43.8% young adults, 40.6% mature adults, and 9.4% aged adults for the entire wild koala population of Port Macquarie, based on combined results from two field studies of 33 koalas from periurban subpopulations in 2005 (Biolink, 2005) and 2008 (Biolink, 2008). We used initial chi-square goodness-of-fit tests to compare observed frequencies with expected frequencies to determine whether the population structure of hospital admissions approximated that of the wild population in each admission category, and to test the hypothesis that the number of koalas received per season was uniform year round, and that koala admissions had not changed in each 5-yr interval compared to the preceding one. If significant ($P \leq 0.05$) by a chi-square goodness-of-fit test, we compared the observed values to the expected values within each category with the use of a z test or, where sample sizes were small, with a Fisher's exact test.

RESULTS

Descriptive statistics of koalas admitted to the Koala Hospital

There were 3,781 individual admissions from 2,674 individual koalas between 1 January 1975 and 31 December 2004 (Table 1). Six hundred thirty-five koalas presented more than once (mean admissions 2.75±1.50 SD) and 2,044 animals presented once only. Forty-one percent of admissions were for trauma (*MVA*, *dog attack*), 20.4% of koalas were admitted with clinical signs associated with chlamydial disease (*wet bottom*, *eye disease*), and 15.8% were admitted *healthy*. *All other* comprised animals admitted due to misadventure (fallen [19], drowned [13], electrocuted [2], neurologic signs [11], injured by animals other than dogs [11], musculoskeletal disease [8], dead on arrival with no identified cause [6], skin disease [2], diarrhea [1], neoplasia [1], and severe parasitism by ticks [1]).

Animals were two and three times more frequently admitted in spring than in winter ($P \leq 0.001$; Table 1) and autumn ($P = 0.002$), respectively. Admissions per 5-yr interval increased in each 5-yr interval, relative to the previous 5-yr interval ($P \leq 0.004$), with the exceptions of 1980–1984 ($P = 0.107$) and 1995–1999 ($P = 0.956$). Translational errors were low (<2% of joeys coded in an age group other than juvenile).

At-risk cohorts in comparison with the wild population

Males ($P \leq 0.001$), aged adults ($P \leq 0.001$), and juveniles ($P \leq 0.001$) were overrepresented in the hospital presentations, relative to the assumed demographics of the entire wild population. On examining data with respect to age and sex, we found that juveniles were overrepresented in the categories *healthy* ($P \leq 0.001$) and *debilitated* ($P \leq 0.001$) and those associated with trauma, predation, and misadventure (*dog attack*: $P \leq 0.001$, *fire*: $P \leq 0.001$, *motor vehicle accidents*: $P = 0.003$, *all other*: $P = 0.02$), and aged animals were overrepresented in admission categories associated with chlamydial disease (*eye disease*: $P \leq 0.001$, *wet bottom*: $P \leq 0.001$) and *debilitated* ($P \leq 0.001$). Females were overrepresented for *wet bottom* ($P \leq 0.001$) and males for admission as *motor vehicle accidents* ($P \leq 0.001$), *eye disease* ($P \leq 0.001$), and *healthy* ($P = 0.02$).

Statistical models of the Koala Hospital population

All the explanatory variables were significant in univariable and multivariable analyses (multivariable P values: age class, $P \leq 0.001$; sex, $P = 0.007$; season, $P \leq 0.001$; 5-yr interval, $P \leq 0.001$), indicating that all explanatory variables significantly affected the reasons for admission. In addition, an

TABLE 1. Contingency table of explanatory variables (age, sex, season, and 5-yr interval) for cohorts according to admission categories for koalas (*Phascolarctos cinereus*) admitted to the Koala Hospital, Port Macquarie, New South Wales, Australia, 1 January 1975–31 December 2004.[a]

Explanatory variable	Dog attack	MVA[b]	Fire	Eye disease	Wet bottom	Debilitated	Healthy	Joey	Undiagnosed	All other	Overall
Juvenile[c]	138	82	44	15	21	41	116	64	44	14	579
Young	327	286	44	85	137	50	215	6	82	16	1,248
Mature	201	335	62	182	184	90	179	2	117	28	1,380
Aged	79	76	7	66	78	72	77	0	54	3	512
Female	373	288	90	121	289	132	278	28	127	26	1,752
Male	373	510	68	228	133	127	318	44	178	36	2,015
Autumn	88	120	2	52	96	53	49	6	53	5	524
Winter	170	208	6	64	100	48	130	13	76	16	831
Summer	124	150	43	113	132	87	130	32	75	17	903
Spring	367	324	108	121	94	71	289	21	103	25	1,523
1979[d]	45	24	4	26	23	24	54	7	27	1	235
1984	50	40	2	26	28	25	65	7	26	1	270
1989	113	104	12	49	92	29	85	9	64	3	560
1994	157	158	106	75	90	51	150	9	69	6	871
1999	219	212	1	80	85	51	144	8	55	14	869
2004	165	264	34	94	104	79	100	32	66	38	976
Overall	749	802	159	350	422	259	598	72	307	63	3,781

[a] Data missing from 14 records of gender; 62 records of age class.

[b] MVA = motor vehicle accident.

[c] Age classes according to tooth-wear class (TWC; Martin, 1981): Juvenile = TWC I–II; young = TWC III; mature = TWC IV; aged = TWC V–VII.

[d] Year denotes final year of each 5-yr interval.

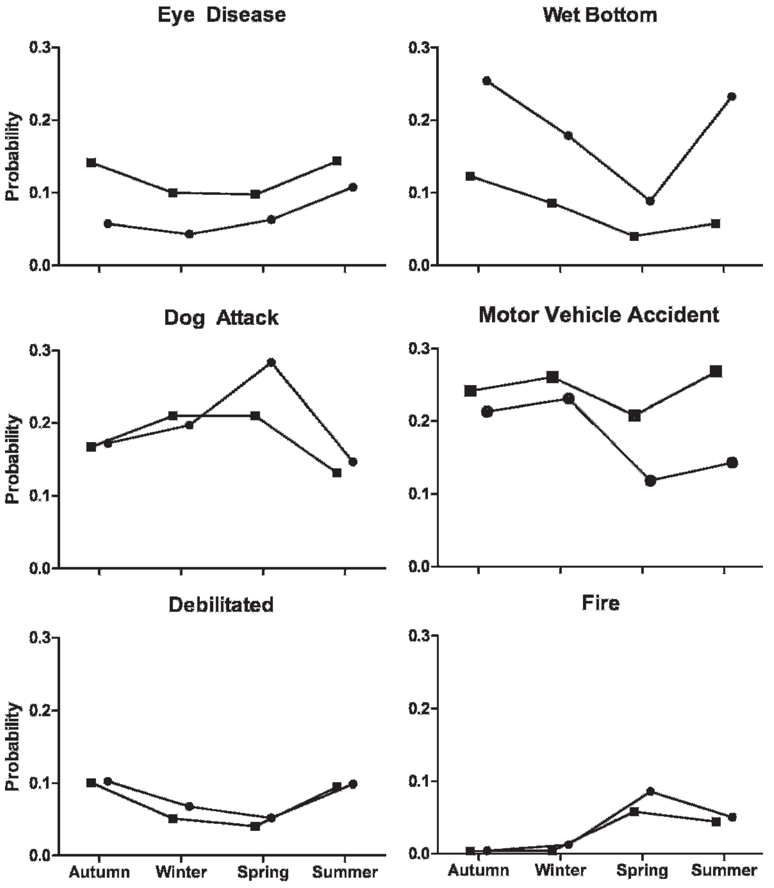

FIGURE 1. Relative probabilities of admission outcomes for koalas admitted to a rehabilitation facility in Port Macquarie, New South Wales, Australia, 1 January 1975–31 December 2004, where sex or season was a significant risk factor. Circles = female; squares = male. With the use of the multivariable multinomial model the only significant interaction ($P<0.05$) was between sex and season for MVA, where *eye disease* and *autumn* were reference categories.

interaction between season and sex was significant in the multivariable model: males were at increased risk of *motor vehicle accident*, relative to references, in spring and summer, but females were at decreased risk in these seasons (Fig. 1; $P=0.036$). Findings from the multivariable model are presented as probabilities (Figs. 1–3). Analysis using a multivariable model found similar results to that comparing the hospital population to that of the wild population: there was an increased risk of younger animals presenting for traumatic reasons (*dog attacks*, *fire*) or *healthy*; and older animals presenting as admissions associated with disease (*eye disease*, *wet bottom*, and *debilitated*) (Fig. 2); females were more likely to present with *wet bottom*; and males with *eye disease* or as *motor vehicle accidents* (Fig. 1); diseased animals (*wet bottom*, *debilitated*) were more likely to present in autumn (Fig. 1); risk of *motor vehicle accidents* increased after 1985 relative to the reference group (Fig. 3), and warmer months increased risk of presentations resulting from *fire* (Fig. 1).

DISCUSSION

The study of medical records is a common and attractive area of research

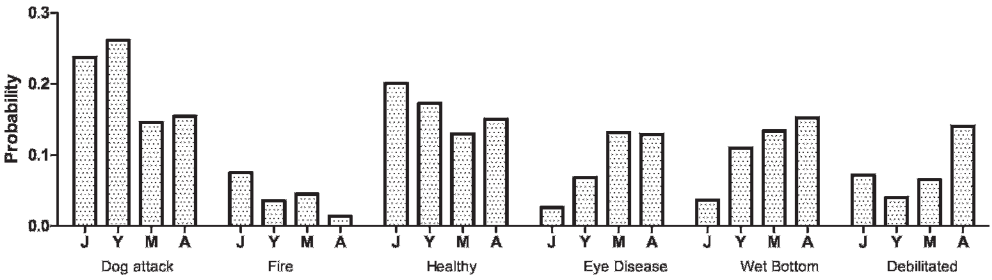

FIGURE 2. Relative probabilities of admission outcomes for koalas admitted to a rehabilitation facility in Port Macquarie, New South Wales, Australia, 1 January 1975–31 December 2004, where age class was a significant risk factor. J = juvenile; Y = young; M = mature; A = aged.

in the human and veterinary literature and their use in wildlife research is increasingly being recognized (Shine and Koenig, 2001; Dique et al., 2003b). The large number of records available, relatively long study period (30 yr), demonstrated high accuracy of data input from paper records (few translational errors as demonstrated by the study of ages in animals coded as *joey*), and the use of objective terms (sex, age class, date) for much of the data examined here, indicate that, with care, useful conclusions can be made from the our data set.

The strength of the conclusions based on comparison of the population demographics of the hospital and wild populations are dependent on the accuracy of assumptions of the wild population structure. Although a larger sample size of wild koalas from Port Macquarie would be useful to confirm the validity of assumptions in this study, other surveys of urban koala populations in southeast Queensland with greater numbers (up to 79), likely to be under comparable selection pressures to those of Port Macquarie due to climatic and geographic similarity, have found similar population demographics (Dique et al., 2003a; Thompson, 2006; Biolink, 2007). Without knowledge of the temporal dynamics of the local koala population, it is difficult to draw definitive conclusions as to why koala admissions change; for example, human population increase and associated development may increase likelihood of anthropogenic admissions to the hospital, but may also increase risks of koalas being admitted simply because more people are looking for sick or iconic animals. Regular accurate local population surveys, including demographic information, are vital to assess whether conservation efforts by rehabilitation groups are effective and

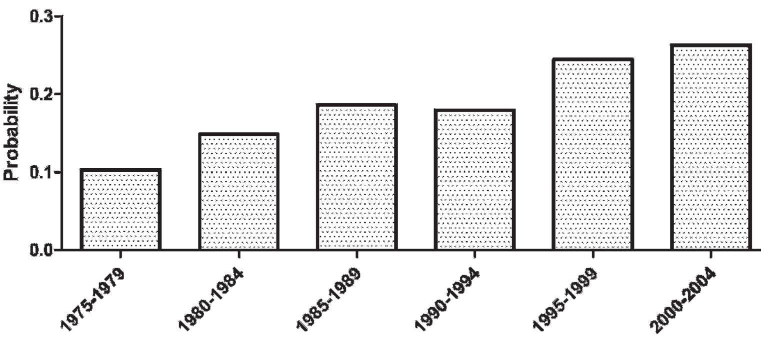

FIGURE 3. Relative probabilities of koalas admitted to a rehabilitation facility in Port Macquarie, New South Wales, Australia, 1 January 1975–31 December 2004 presenting as a motor vehicle accident where 5-yr interval was a significant risk factor.

would be a valuable addition to interpreting rehabilitators' temporal data. In addition, a further study examining only animals re-presenting would be valuable to examine possible trends within this group; however, our statistical model could not accommodate this analysis, probably as a result of the relatively low number of animals re-presenting. To determine whether each re-presentation is independent of past presentation would require detailed analysis of spatial data (for example, vicinity to roads for *motor vehicle accident*, dogs for *dog attack*, vicinity to the public might increase reporting for all), knowledge of koalas' home ranges and, in the case of chlamydial reinfection vs. recrudescence, highly discriminatory sequence analysis of chlamydial isolates from both occasions—data that were not available in this study.

The polychomatous statistical analysis used in this study allowed analysis of the relative influence of different temporal and animal variables on reasons for presentation, a technique not previously used to our knowledge with a data set from a wildlife organization. In this study we found males and younger animals were more likely to present because of trauma or misadventure and older animals because of disease. These findings are in agreement with speculation from previous authors (Martin and Handasyde, 1999) and studies examining the demographics of koalas presenting for one reason only (motor vehicle accident [Canfield, 1991; Dique et al., 2003b] or chlamydial disease [McLean, 2003]). The demographics of trauma could be explained logically by behavioral factors: koalas spending more time on the ground travelling, that is males in breeding season or dispersing juveniles (Mitchell, 1990b; Logan and Sanson, 2002b), are more likely to encounter motor vehicles or dogs. In addition, males may be more inclined to fall from trees during fights and inexperienced juveniles may fall whilst climbing. The demographics of disease could be explained by factors relating to age: older animals are more likely to have been exposed to infectious agents during their life and still exhibit permanent structural changes or ongoing disease associated with persistent organisms such as *Chlamydia*, and are more likely to succumb to infectious diseases because of geriatric degeneration and nutritional stress resulting from worn teeth (Lanyon and Sanson, 1986).

The observed patterns of motor vehicle accident presentations in this work are closely associated with a combination of seasonal male behavioral factors, longitudinal and annual seasonal changes in motor vehicle numbers, and increasing habitat fragmentation. We found that male koalas were at increased risk of motor vehicle accident during summer, a season when the human population of Port Macquarie approximately doubles (W. Beverley, Project support officer, Port Macquarie-Hastings Council, pers. comm.). In addition, the increased risk of koalas presenting as a result of motor vehicle accidents since 1985 (Fig. 3) coincides with a period of fragmentation of bush habitat and reduction of the number of suitable trees within urban habitat as a result of development: During the study period the human population of the Port Macquarie–Hastings area increased from 25,323 (Australian Bureau of Statistics, 1978) to 71,284 (Australian Bureau of Statistics, 2006). Radiotracking of urban koalas has demonstrated that provision of habitat corridors and patches are less important than total area and connectivity of habitat, and koalas may make frequent, long-range movements (>2 km) among patches of suitable habitat, without using corridors (White, 1999); behavior likely to increase their exposure to trauma. Studies of radio-collared koalas would be useful to define their movement patterns in developed and undeveloped areas of Port Macquarie better, thus informing habitat preservation, rehabilitation of developed areas, and sensitive development plans.

The fatality rate of motor vehicle strike has been estimated as up to 83% (Dique et al., 2003a). Its frequent occurrence in this study, in the cohort most likely to be dispersing, supports a likely impact on gene flow and/or contribution to koala population decline, as predicted by modeling (Caneris and Jones, 2004) and observations in Victoria (Martin and Handasyde, 1999). Although, in this study, spatial data were insufficient for the analysis necessary to identify or predict high-risk areas for threat mitigation (Preece, 2007), the cohort identified highlights the importance of considering behavior and habitat use by the target species (Roger and Ramp, 2009), rather than concentrating only on current efforts to deter animals from roadsides and/or reduce speed of vehicles (Magnus et al., 2004). Reduction of time koalas spend on the ground by providing a mosaic of more viable habitat, including trees within urban areas, appears worthy of investigation as an alternative or addition to funneling koalas into habitat corridors, wildlife underpasses, or traffic-calming efforts.

The finding that the risk of presenting following *dog attack* has not changed since the 1970s suggests that the increasing practice of responsible pet ownership and the legal requirements to do so (Government of New South Wales, 1998) may have mitigated the potentially increased risk of predation occurring consequent to habitat fragmentation. The change in numbers of dogs in Port Macquarie is not known, as many animals are not routinely registered, but presumably has increased along with the human population.

That older animals were more likely to present with signs of chlamydiosis (*wet bottom* and *eye disease*) or *debilitation* was not surprising. As the main route of transmission of chlamydiosis is sexual (White and Timms, 1994) and the disease is often chronic, and repeated chlamydial infections or recrudescence may result in more overt clinical signs, as for *C. trachomatis* in people (Grayston et al., 1985), clinical chlamydiosis is expected to be more prevalent in older animals. In addition, nutritional stress through worn teeth in aged animals (Lanyon and Sanson, 1986) may result in the clinical expression of previously subclinical infections. That such animals were more likely to present in autumn is consistent with seasonal disease expression attributed to cold stress in captive marsupials (Canfield and Cunningham, 1993) and seasonal factors are important in explaining disease presentation in *Chlamydia trachomatis* in people (fly transmission [Da Cruz et al., 2002] and seasonal sexual activity [Schroeder et al., 2001]): Any of these factors, or a combination, could explain the seasonality found in this study, as such interactions can be complex and frequently poorly understood (Grassly and Fraser, 2006). The demise of such animals may have less impact on population viability than traumatic deaths, as aged females in Chlamydiaceae-positive populations generally have a fecundity of $<20\%$ (McLean, 2003) and older males have behavioral changes that could reduce breeding success (Logan and Sanson, 2002a, b). Removal of older animals may even be advantageous by freeing home ranges for other animals (Mitchell, 1990a), though population modeling has indicated that the demise of aged animals likely had little impact on the survival of one population of koalas (Caneris and Jones, 2004) and it is possible that the same occurs in Port Macquarie.

Significant differences between the sexes suggest that both anatomic and behavioral factors are important in the expression of clinical signs associated with chlamydiosis. In line with the findings of other researchers using postmortem series (Obendorf, 1983; Stalder, 2003) or epidemiologic surveys (Weigler et al., 1988; McLean, 2003), we found that females were overrepresented as *wet bottom* admissions, and males as *eye disease* admissions. Although the female predisposition to clinical *wet bottom* might be explained by urogenital anatomical differences (Obendorf, 1981), the overrepresentation of males as *eye disease*, also observed in ecologic surveys in Victoria (McLean, 2003), is more difficult to understand; but has been attributed to traumatic injuries sustained by males while fighting, contributing to clinical disease (McLean, 2003).

Risks of admissions as a result of *eye disease* or *wet bottom* have not changed over the last 30 yr, and this study does not, therefore, support the suggestion by other researchers (Canfield, 1989; Jackson et al., 1999) that urbanization increases the expression of clinical signs of chlamydiosis. Although it is possible that a stable host–parasite relationship exists, as subclinical chlamydiosis is a frequent occurrence in koalas (Jackson et al., 1999), conclusions based on external clinical signs run the risk of underestimating the true incidence of disease and its impacts on the population. A study examining incidence of chlamydial infection and disease, including subclinical changes to the reproductive tract of females and impacts on the fertility of the wild population, would be extremely useful in studying the evolving host–pathogen–environment relationship.

This study is the first of its kind in a koala hospital. It has the advantages of a large data set, both in terms of total numbers and in the time span covered. This study highlights the potential of research using wildlife rehabilitation data bases to identify risks to wild populations, and provides information that may be useful for rehabilitation centers to plan logistics, allocate resources, and plan better record-keeping systems. In most cases, differences in the likely behavior among the cohorts examined was considered the most important contributor to risk in each admission category and effective mitigation of threat must take this into account. A significant and increasing threat to survival of the Port Macquarie koala population is suggested by increasing relative risk of koalas presenting as a result of motor vehicle accident since 1985. A regular, scientifically rigorous ecologic survey of the koala population in Port Macquarie is vital to assess whether the significant efforts of rehabilitators, the local council, and residents to preserve the wild koala population are effective.

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