Overview of a passive tracking index for monitoring wild canids and associated species

Richard M. Engeman
USDA-APHIS-Wildlife Services, s_r100@yahoo.com

Lee Allen
Robert Wicks Research Centre, Australia

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Richard M. Engeman[1,*] & Lee Allen[2]
[1]*USDA/Wildlife Services, National Wildlife Research Center, 4101 LaPorte Ave, Fort Collins, CO 80521-2154, U.S.A.;* [2]*Robert Wicks Research Centre, P.O. Box 318, Toowoomba, Qld 4350, Australia*
**Author for correspondence (e-mail: richard.m.engeman@usda.gov)*

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Abstract

Population density estimates for many animal species are often difficult or expensive to obtain, and they rely on assumptions that, if violated, result in unmeasurable estimation errors. Density estimates also may be unnecessary for research or management purposes, because an index that tracks changes in a population within appropriate time and geographic constraints could provide the information necessary to make management decisions or to evaluate the impact of a control program. We review research on a passive tracking index where observations are made on a series of tracking plots placed on lightly used dirt roads. The number of sets of tracks (individual intrusions) are recorded for each species of interest on each plot on consecutive days. The mean number of intrusions over the plots is calculated for each day for each species. The index is the mean of the daily means. These design and measurement methods present valuable advantages over most traditional tracking plot methods. Because no scents or baits are used as attractants, no conditioning of animals to the plots biases the results. This also permits multiple species, predator and prey alike, to be simultaneously monitored. Using the number of animal intrusions as observations produces results that are far more sensitive to change than tracking surveys where only presence or absence of spoor are recorded for each plot. Of particular importance, the statistical properties inherent to this data structure permit calculation of standard errors, confidence intervals and statistical tests, without subjectively subdividing the data.

Introduction

A frequent problem in wildlife biology occurs when the population and/or density of the animal of interest is impossible to accurately assess with current methods, or the economic or logistical costs of doing such an assessment are prohibitive. In addition, the statistical theory used to produce density estimates usually requires fulfillment of assumptions that, when violated, result in estimates of questionable quality (see Leidloff (1998) for an excellent examination of potential problems with capture–recapture methods and Burnham *et al.* (1980) for a similar discussion on line transect methods). Carnivores pose particular difficulties for assessing population status, as they are characterized by: relatively sparse populations; large home ranges and movement patterns of individual animals; secretive behavior; occurrence in rough terrain; and difficulties in capture and observation (Pelton & Marcum 1977). Frequently, density estimates are unnecessary for research or management purposes, because an index that tracks changes in a population within appropriate time and geographic constraints can provide the information necessary to make management decisions or to evaluate the impact of a control program (Caughley 1977). Such an index should be simple and quickly applied in the field, while providing sensitivity to reflect population changes over time or space.

We have developed and refined a passive tracking index (PTI) that has been applied for monitoring wild canid populations in Australia and North America. The index may have applications for monitoring canid species worldwide. Canids such as coyotes (*Canis latrans*), foxes (*Vulpes* spp.), dingoes (*Canis lupus dingo*), wolf (*C. lupus*), jackals (*C.* spp.) and wild dogs (*C. familiaris*) often conflict with human interests throughout the world, primarily because of depredations on livestock, but also due to transmission of diseases such as rabies, and unwanted predation on other species (e.g., waterfowl or endangered species). In addition, the PTI has been effective not only for canids, but also for simultaneously monitoring a variety of other animal species, including other carnivores. Its versatility for monitoring multiple species at the same time also holds potential for extensive application. Here, we give an overview of the method and the findings to date concerning its application.

Passive tracking index methodology

Plot placement. Tracking plots are placed on transects along low-use dirt roads (usually at 0.5–1.0 km intervals). Plots are raked and smoothed with soil to span the road width (only one-lane roads have been used). Plot width remains constant over all plots, with 1–1.5 m adequate. Fine soil of the same type, preferably from the immediate vicinity, is added as needed to prepare the tracking surface while keeping the visual impact of the plot at a minimum. After 24 hours, the plots are examined for spoor and the plots resurfaced (tracks erased and soil smoothed) for the next day's observation. At each plot, the number of track sets (number of intrusions) by each animal species are recorded. Each plot is observed for several consecutive days. Trials have tested up to 6 consecutive days of plot monitoring, but variance components analyses and percent changes in index values when consecutive days of observation are increased have consistently indicated that 4 days almost invariably suffices and that as few as 2 consecutive days may be adequate, given constant climatic conditions (Allen *et al.* 1996; Engeman *et al.* 1998; Engeman *et al.* 2000). The number of plots to place in an area is less explicit, because it must be balanced with the size of area to be monitored, a minimal spacing relative to movement patterns of the target animal, desired precision of the index, and experimental logistics.

Calculation of index and statistics. The PTI is calculated according to the following formula (Engeman *et al.* 1998) after using a mixed linear model (e.g., McLean *et al.* 1991; Wolfinger *et al.* 1991) to describe the number of intrusions on each plot each day:

$$\mathrm{PTI} = \frac{1}{d}\sum_{j=1}^{d}\frac{1}{p_j}\sum_{i=1}^{p_j}X_{ij},$$

where the X_{ij} values represent the number of intrusions by a given species on the ith plot on the jth day, d is the number of days of observation, and p_j is the number of plots contributing data on the jth day. The variance formula for the PTI, also calculated according to Engeman *et al.* (1998), is

$$\mathrm{var(PTI)} = \frac{\sigma_\mathrm{p}^2}{d}\sum_{j=1}^{d}\frac{1}{p_j} + \frac{\sigma_\mathrm{d}^2}{d} + \frac{\sigma_\mathrm{e}^2}{d^2}\sum_{j=1}^{d}\frac{1}{p_j},$$

where the σ_p^2, σ_d^2, and σ_e^2 are, respectively, the components for plot-to-plot variability, daily variability, and random observational noise associated with each plot each day. Estimation of var(PTI) requires variance component estimates for σ_p^2, σ_d^2, σ_e^2, which can be produced using software such as SAS PROC VARCOMP, with a restricted maximum likelihood estimation procedure (REML) (SAS Institute 1996). Confidence intervals are calculated using the standard normal approximation, and *Z*-tests can compare population index values.

Applications summary

Australia. Beginning in 1993, the index has been used in investigations on large cattle stations in Queensland to examine the effects of 1080 baiting of dingoes for reducing calf losses to predation (Allen *et al.* 1996; Allen & Gonzales 1998), and to evaluate the impact of dingo predation on other vertebrate pest populations (Allen & Engeman 1995). The cattle stations were divided into two areas separated by large buffers. One area on each station received 1080 baiting to control dingoes, while the other area served as an untreated control. The index demonstrated that dingoes were maintained at low numbers in the treated areas, and the index provided an excellent opportunity to simultaneously monitor multiple species. It was demonstrated that severe dingo predation on calves corresponded to depressed populations of their staple prey, usually during drought conditions.

Because dingo predation potentially can be beneficial to graziers and the environment by controlling pest species of wildlife, the index also was used to simultaneously monitor multiple species to evaluate the long-term impacts that dingo predation and dingo control have on other wildlife populations. Specific attention was focused on feral swine (*Sus scrofa*), rabbit (*Oryctolagus cuniculus*) and kangaroo (*Macropodidae*) populations, but the whole suite of wildlife species was of interest. Index results indicated that predation did not strongly influence most mammalian species by itself, as it is only one of the many factors which influence activity. Correlation coefficients between dingo indices and those of the other species never achieved an absolute magnitude >0.4 (Allen & Engeman 1995).

U.S.A. Based on the success of the index for monitoring dingoes in Australia, the PTI was initially tested in Texas in conjunction with trap testing studies. Trials were conducted on two large ranches in 1998 (Engeman *et al.* 2000) and a third trial was conducted at another ranch site in 1999 (Engeman unpublished data). We applied the index before and after trapping to determine how sensitive index values were to the known reductions in coyote populations.

The PTI proved very sensitive in all three trials for statistically detecting known reductions in coyote population density from 0.85 to 1.14 animals/km^2 (Engeman *et al.* 2000 Engeman unpublished data). Simultaneously, the tracking plots produced index values for white-tailed deer (*Odocoileus hemionus*), a potential prey species from which ranches in Texas derive considerable hunting income. Indices also were produced for two other carnivore species at the same time (Engeman *et al.* 2000; Engeman unpublished data): bobcats (*Felis rufus*) and raccoons (*Procyon lotor*). Other mammals for which index values were calculated included feral swine, javelina (*Tayassu tajacu*), rabbits and rodents.

In some cases, the effect of a trapping program on coyotes could be seen on other species, but interpretation of results required care (Engeman *et al.* 2000). For example, in 1998 bobcat activity appeared to increase with the extensive removal of coyotes. Small increases in index values post-trapping were detectable statistically, even though some bobcats also were removed incidentally by trapping. This seemingly contradictory result was probably due to increased bobcat activity in response to density reductions of a competing predator species (coyote), a canid–felid interaction observed for feral house cats (*Felis catus*) when red foxes (*Vulpes vulpes*) were removed in two Australian states (Molsher 1998; Risbey & Calver 1998; Risbey *et al.* 1999).

Another example of the care needed in interpreting indices also occurred in 1998 where a large decrease in index values was seen for deer post-trapping on one ranch, while remaining constant on the other ranch (no deer were removed from either ranch). This result probably pointed to differences in land use patterns between the ranches. Deer on the first ranch were very extensively hunted, with much of the hunting conducted from vehicles. Studies began on that ranch the week after deer-hunting season. The coyote trapping conducted between the two index assessments on this ranch increased vehicle traffic throughout the area of assessment and had the shooting to euthanize trapped coyotes associated with it. The deer, conditioned to avoid roads when shooting is associated with vehicle traffic, probably responded to coyote control activities. As no shooting took place during pre-trapping observations, they were unlikely to have been affected. However, after 40 coyotes had been shot in 12 days, the post-trapping observations recorded reduced activity. The other ranch, however, did not receive the same order of magnitude of hunting pressure as the first ranch. In addition, the trapping program on the second ranch was another two weeks removed from the deer season. Thus, PTI results for deer most likely indicated deer hunting pressure differences between the two ranches, and differences in timing of the trials relative to hunting season (Engeman *et al.* 2000).

Comparisons to plots with attractants

When first developing and applying the PTI in Australia, five trials in 1993 and 1994 were used to simultaneously compare it to the two most frequently used tracking plot methods for assessing canid populations (Allen *et al.* 1996). These methods used a scent or food as an attractant to draw animals to the plots.

Fatty acid scent (FAS) index. The scent station or FAS index was used for many years to monitor coyote populations in the western U.S.A. (Linhart & Knowlton 1975; Roughton & Sweeny 1982). The visitation rate of dingoes to tracking stations (each 1 m^2 of raked earth), located every 500 m on alternate sides <3 m from the dirt road, was monitored (Allen *et al.* 1996). A plaster scent-impregnated disc

(20 mm diameter × 5 mm thick) was placed in the plot center. Discs were prepared in the laboratory prior to the field trial. Residual odors were removed from the plaster by placing them in a glass chamber that was continuously evacuated for 30 min. Then they were soaked in FAS for 60 min, removed, drained and sealed in bottles to await placement in the plots using tweezers or plastic gloves. Tracking plots were checked daily. Dingo responses to FAS (and buried meat plots, below) made it impractical to separate superimposed tracks (dingoes scratched, rolled, urinated and often wrecked the tracking plot), so no attempt was made to identify the number of intrusions by dingoes onto the plots. Plots were recorded as a positive or negative response for dingo activity.

Buried meat (BM) index. One piece (50–100 g) of fresh, boneless kangaroo meat was buried (5–10 cm) in the center of 1 m^2 of raked earth every 500 m on alternate sides of the road and 250 m from the nearest FAS plot. Burying the baits did not reduce the probability of discovery by dingoes, but deterred removal by birds and other non-target animals (Allen *et al.* 1989). Plot activity was assessed as for the FAS index, above (Allen *et al.* 1996).

Comparisons. The PTI (taken from plots spaced at 1 km on the same roads to which the FAS and BM plots were adjacent) resulted in substantially higher proportions of positive readings than for the FAS or BM indices (Allen *et al.* 1996). The BM index tended to have a response rate 2–3 times that for the FAS index, and the passive index had a response rate about 1.5 times that for the BM index and 3 times that for the FAS index. Correlation coefficients among the three indices were each >0.85, indicating that the three methods maintained their relative response rates through time. The FAS disc appeared to attract to the plots only a small proportion of the dingo population potentially exposed. This comparatively low response rate for dingoes to the novel FAS attractant is consistent with the response reported for coyotes in the U.S.A. (Harris 1983) and suggests that dingoes exhibit a similar neophobic behavior inside their territories. Discounting any differences in magnitudes of odor plumes from the two attractants, and their respective presentation differences, the dingoes response to FAS and BM indicated they may be more likely to investigate a familiar food (kangaroo) than an unfamiliar odor.

Variations tested for the passive tracking index

Comparison of binary responses to measuring number of intrusions. Analyses of tracking plot data as a binary response (positive or negative) reduced sensitivity for detecting differences in dingo activity (Allen *et al.* 1996). Numbers of dingo intrusions on the plots were recorded, rather than just a positive or negative result, but with binary data it is possible that control could reduce the population, but surviving animals could provide no fewer positive responses. Theoretically, if the number of animals visiting the FAS and BM stations could have been recorded, then the sensitivity of the methods could have been improved. This loss of sensitivity is expected when information is reduced from a greater continuum to two options. (e.g., Engeman *et al.* 1989).

To specifically examine the sensitivity of this index versus using binary observations for each plot where only presence or absence of spoor are recorded, the Texas data from 1998 were used to conduct additional statistical tests for comparing pre-trapping data to post-trapping data (Engeman *et al.* 2000). First, mean daily proportions of plots positive for spoor pre- and post-trapping were compared. Pre- and post-trapping differences were still detected for both ranches, but not to the same degree of confidence (*p*-values increased by factors from 5 to 1500). Next, we considered what the result would have been if only the first day of data had been collected as presence–absence (binary) observations, pre- and post-trapping. The use of binary observations with only a single day of observation resulted in a further loss of sensitivity to change, with only one of the two ranches trapped in 1998 showing differences statistically (Engeman *et al.* 2000).

Alternative plot placement test. We examined the influence on index results of road usage or non-usage by the animals being monitored (Engeman unpublished data). This could have a bearing on the index values themselves, as well as on interpretations of the effects of population changes by one species on the populations of another species, especially when the two may use roads differently. In the Texas trial in 1999, paired tracking plots were created to examine how indices calculated from off-road plots compared to indices calculated from tracking plots placed as usual in the roads. At each road plot, another same-sized plot was located ≥30 m from the road on naturally occurring bare ground in natural habitat. The underbrush in that part of Texas is dense and dominated by dense stands of woody (and thorny) shrubs and cacti. It appeared that most species used the dirt roads as travel ways, as only deer produced comparable index values from off-road plots. Most species for which indices were calculated from on-road plots produced too few observations off-road for indices to be calculated. We concluded that plots placed on lightly used dirt roads in similar habitats permit indices to be calculated that allow the best inferences on animal populations.

Discussion

The PTI, being based on counting daily movements of animals across tracking stations, is unlikely to influence normal animal behavior. We found no track evidence that the species we monitored in the U.S.A. and Australia avoided tracking plots. An advantage of a passive tracking plot is that it can detect less common or neophobic species (or individuals) and simultaneously can capture (observe) a suite of wildlife species using a relatively simple, yet sensitive, method. Table 1 summarizes the diversity of species monitored in Queensland, Australia and Texas, U.S.A. by calculating index values. Had we considered targeting them as well as the mammals, we could have produced indices for a number of bird species in both Australia and Texas (Table 2) (we even contemplated applications for monitoring illegal immigration into Texas from Mexico (Engeman *et al.* 2000)). To detect presence or to index populations with alternative methods could require a major effort using perhaps a combination of methods such as pitfall trapping, spotlight counts, pellet or scat counts, line transect counts or aerial surveys.

Table 1. Mammals successfully monitored with the passive tracking plot index in Queensland, Australia and Texas, U.S.A.

Queensland	
Dingo	*Canis lupus dingo*
Macropods	Family *Macropodidae*
Fat-tailed dunnarts	*Sminthopsis crassicadata*
Feral cats	*Felis catus*
Brush-tailed possums	*Trichosurus vulpecula*
Rabbits	*Oryctolagus cuniculus*
Rodents	Order *Rodentia*
Feral pigs	*Sus scrofa*
Texas	
Coyote	*Canis latrans*
Bobcat	*Felis rufus*
White-tailed deer	*Odocoileus hemionus*
Rodents	Order *Rodentia*
Rabbits	Family *Leporidae*
Javelina	*Tayassu tajacu*
Feral pigs	*Sus scrofa*
Raccoon	*Procyon lotor*

Table 2. Birds that we could have targeted for indexing with the passive tracking plot index in Queensland, Australia and Texas, U.S.A.

Queensland	
Emu	*Dromaius novaehollandiae*
Bustard	*Ardeotus australis*
Bush thick-knee	*Burhinus grallarius*
Cranes	*Grus* spp.
Crows/ravens	*Corvidae*
Doves	*Columbidae*
Parrots	*Psittacidae*
Lapwings	*Charadriidae*
Texas	
Roadrunners	*Geococcyx californianus*
Quail (primarily scaled quail)	*Callipepla squamata*

An obvious question in the PTI approach is how well species' tracking rates relate to abundance. Several factors affect activity at tracking plots other than population density. However, Bider (1968), in a comprehensive study that produced 182 000 observations in sand transects, evaluated population density as the most important factor affecting activity on tracking plots. He showed seasonal activity related to reproduction, seasonal differences in food availability, seasonal migration, dispersal of young, and of lesser importance, weather at the time of assessment and climatic events may influence activity and affect the index of abundance. While seasonal changes in activity do not necessarily compromise the value of the index, studies which involve comparisons of treatment effect based on population responses should be made during comparable seasons.

Because the PTI is an indirect measure of animal abundance, inferences about changes in index values are best made with an understanding of the system being observed. Earlier we saw how an increase in PTI for bobcats actually was not an increase, and a decrease for white-tailed deer did not represent a true decrease in populations. However, understanding the system not only prevented false inferences, but also allowed the PTI to provide additional insight about the interactions and behaviors of the animals monitored in addition to coyotes.

While the PTI produces few methodology-induced changes to animal behavior that might influence results, the daily inspection of tracking plots encompasses a time aspect that some assessment methods do not reflect. Methods can be sensitive to the time of day at which they are conducted, relative to each species' peak period of activity. Different species may be active at different times of day, and these peaks may be influenced by events such as cloud cover, temperature, wind speed, etc. (Bider 1968). The methods used to assess population abundance can have profound effects on species behavior or activity, resulting in biased results. This is well documented for line transect observations (e.g., Burnham *et al.* 1980) and is further validated by other examples such as feral pigs acting dead during aerial surveys for helicopter-shot pigs (Saunders & Bryant 1988). Caughley (1977) further discusses how individual and species behavior relative to trapping devices and survey methods affects data quality.

The PTI relies on the detection and correct identification of spoor left on the plots and the ability to distinguish the number of individual intrusions within a plot. Spoor might be missed if the tracking plot is inadequately prepared or if the observers are not trained. Rain, wind and traffic might further obscure or obliterate tracks. Although we have experienced no problems with superimposed tracks when more than one animal crossed the plots, this could pose a problem for monitoring some species in some situations. Loss of information cannot be prevented entirely, but careful attention to plot preparation reduces the loss of data. The loss of some data do not seriously affect calculations of the index and its variance, as each species' index is averaged over many stations and over multiple days.

Implementation of the PTI defines a data structure which is described by a linear mixed model and permits calculation of its variance. This facilitates calculation of confidence intervals and use of hypothesis tests. The variance components calculated for use in the variance formula also provide the investigator with helpful information for planning future studies (e.g., Searle *et al.* 1992), as the relative contributions of plot-to-plot variation and day-to-day variation can be examined to optimize the combination of days and plots.

That the PTI has successfully been used to monitor (simultaneously) multiple species of animals on both continents implies the potential for much broader application than for monitoring wild canids. Based on the success with which white-tailed deer were monitored during the coyote trap tests in Texas, the index is now being applied specifically to target white-tailed deer populations damaging corn in Iowa. Another potential application relates to deer hunting, which is big business in the part of Texas where our studies took place. Landowners could use the index to track deer abundance to make management decisions regarding the optimal number of hunters to allow each season. Raccoon populations, which were monitored with the PTI in Texas, recently have suffered a rabies epidemic along the east coast of the U.S. (Winkler & Jenkins 1991), and relative abundance could be monitored to plan delivery of oral vaccines in baits (Linhart *et al.* 1991). Raccoons are also major predators of sea turtle nests (Bergh 1999; Stancyk 1995), and populations could be indexed to evaluate the necessity, timing and efficacy of management actions. Research is currently underway at a national wildlife refuge and a state park in Florida where the PTI is being used to monitor activity of raccoons and armadillos along a turtle nesting beach. The role of the index is expanded there because the information is being used to optimize timing of control, measure efficacy of control, and identify locations for placement of control devices (Engeman *et al.* accepted). Feral swine have caused habitat and conservation problems worldwide, and the PTI could be used to assist managers in controlling swine populations. It also was applied in another Florida state park to monitor the feral swine causing significant habitat destruction. The PTI is now incorporated in a quarterly monitoring program to determine the necessity for control, efficacy of control and rates of re-invasion, locations of control devices, and swine spatial distribution patterns (Engeman unpublished data).

References cited

Allen, L. and Engeman, R.M. (1995) Assessing the impact of dingo predation on wildlife populations. *Australian Vertebrate Pest Control Conference*, Hobart, Tasmania, Vol. 10, pp. 72–79.

Allen, L. and Gonzales, A. (1998) Baiting reduces dingo numbers, changes age structures yet often increases calf losses. *Australian Vertebrate Pest Control Conference*, Bunbury, Western Australia, Vol. 11, pp. 421–428.

Allen, L., Fleming, P.J.S., Thompson, J.A. and Strong, K. (1989) Effect of presentation on the attractiveness and palatability to wild dogs and other wildlife of two unpoisoned wild dog bait types. *Australian Wildlife Research* **16**, 593–598.

Allen, L., Engeman, R.M. and Krupa, H.W. (1996) Evaluation of three relative abundance indices for assessing dingo populations. *Wildlife Research* **23**, 197–206.

Bergh, B. (1999) Hobe Sound National Wildlife Refuge 1998 Sea Turtle Nesting Report. Ecological Associates, Jensen Beach, FL, 27pp.

Bider, J.R. (1968) Animal activity in uncontrolled terrestrial communities as determined by a sand transect technique. *Ecological Monographs* **38**(4), 269–308.

Burnham, K.P., Anderson, D.R. and Laake, J.L. (1980) Estimation of density from line transect sampling of biological populations. *Wildlife Monographs*, No. 72.

Caughley, G. (1977) *Analysis of Vertebrate Populations*. New York: Wiley & Sons.

Engeman, R.M., Otis, D.L., Bromaghin, J.F. and Dusenberry, W.E. (1989) On the use of the R_{50}. In K. Fagerstone and R. Curnow (eds), *Vertebrate Pest Control and Management Materials*, Vol. 6, STP1055, Monterey, California, pp. 13–18. American Society for Testing and Materials.

Engeman, R.M., Allen, L. and Zerbe, G.O. (1998) Variance estimate for the Allen activity index. *Wildlife Research* **25**, 643–648.

Engeman, R.M., Pipas, M.J., Gruver, K.S. and Allen, L. (2000) Monitoring coyote populations with a passive activity index. *Wildlife Research* **27**, 553–557.

Engeman, R.M., Constantin, B., Noel R. and Woolard, J. Monitoring raccoon populations to maximize efficacy from a fixed-cost control budget for reducing predation on sea turtle nests. *Australian Vertebrate Pest Control Conference* (accepted).

Harris, C.E. (1983) Differential behavior of coyotes with regard to home range limits. Ph.D. Thesis, Utah State University, Logan, Utah.

Leidloff, A.C. (1998) Habitat utilisation by the Grassland Melomys (*Melomys burtoni*) and the swamp rat (*Rattus lutrelus*) in a coastal heathland of Bribie Island, South-East Queensland. Ph.D. Dissertation, Queensland University of Technology.

Linhart, S.B. and Knowlton, F.F. (1975) Determining the relative abundance of coyotes by scent station lines. *Wildlife Society Bulletin* **3**, 119–124.

Linhart, S.B., Blom, F.S., Dasch, G.J., Roberts, J.D., Engeman, R.M., Esposito, J.J., Shaddock, J.H. and Baer, G.M. 1991) Formulation and evaluation of baits for oral rabies vaccination of raccoons (*Procyon lotor*). *Journal of Wildlife Diseases* **27**, 21–33.

McLean, R.A., Sanders, W.L. and Stroup, W.W. (1991) A unified approach to mixed linear models.*The American Statistician* **45**, 54–64.

Molsher, R. (1998) Interactions between feral cat and red foxes in NSW: Evidence for competition? *Australian Vertebrate Pest Control Conference*, Bunbury, Western Australia, Vol. 11, pp. 227–231.

Pelton, M.R. and Marcum, L.C. (1977) The potential use of radioisotopes for determining densities of black bears and other carnivores. In R.L. Phillips and C. Jonkel (eds) *Proceedings of 1975 Predator Symposium*, p. 268. Missoula: Montana Forest and Conservation Experimental Station.

Risbey, D.A. and Calver, M.C. (1998) Can current control strategies against introduced predators endanger native mammals? *Australian Vertebrate Pest Control Conference*, Bunbury, Western Australia, Vol. 11, p. 233.

Risbey, D.A., Calver, M.C. and Short, J. (1999) The impact of cats and foxes on the small vertebrate fauna of Heirisson Prong, Western Australia. I. Exploring potential impact using diet analysis. *Wildlife Research* **26** 621–630.

Roughton, R.D. and Sweeney, M.W. (1982) Refinements in scent-station methodology for assessing carnivore populations. *Journal of Wildlife Management* **46**, 217–229.

SAS Institute (1996) *SAS/STAT User's Guide.* Carey, North Carolina: SAS Institute.

Saunders, G. and Bryant, H. (1988) The evaluation of a feral pig eradication program during a simulated exotic disease outbreak. *Australian Wildlife Research*. **15** 73–81.

Searle, S.R., Casella, G. and McCulloch, C.E. (1992) *Variance Components*. New York: Wiley & Sons.

Stancyk, S.E. (1995) *Non-Human Predators of Sea Turtles and Their Control. Biology and Conservation of Sea Turtles*, Revised Edition K.A. Bjorndal, (ed) pp. 139–152. Washington, DC: Smithsonian Institution Press.

Winkler, W.G. and Jenkins S.R. (1991) Raccoon rabies. G.M. Baer (ed.) *The Natural History of Rabies*, 2nd edn, pp. 325–340. Boca Raton, FL: CRC Press.

Wolfinger, R.D., Tobias, R.D and Sall, J. (1991) Mixed models: A future direction. In *16th SAS Users Group Conference*, New Orleans, Louisiana, pp. 1380–1388.