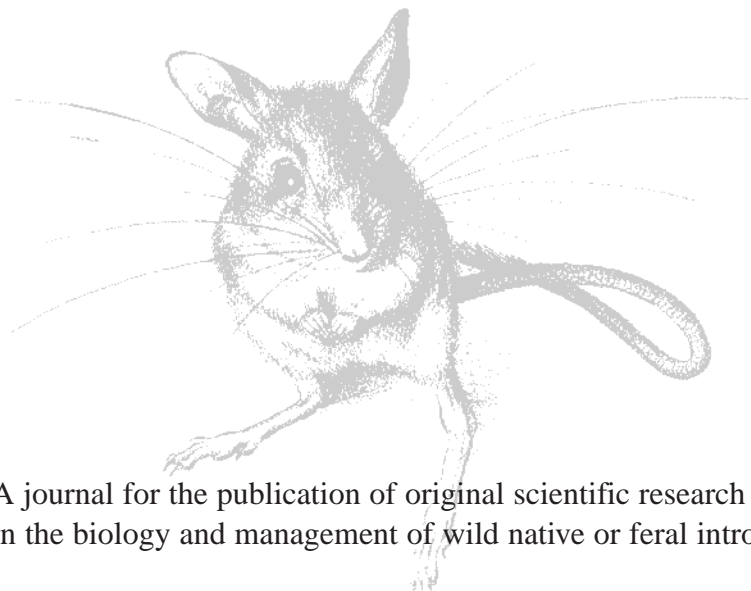

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Monitoring coyote population changes with a passive activity index

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Abstract. A passive tracking index method that has been successfully applied to dingoes (*Canis lupus dingo*) in Australia was shown to have more general applicability to wild canids by monitoring coyote (*Canis latrans*) populations in southern Texas. The index was calculated simultaneously for multiple species of animals from observations on the number of intrusions onto a series of tracking plots over several days. We found that the index reflected changes in coyote activity before and after a trapping program on each of 2 ranches. We also were able to simultaneously monitor bobcat (*Felis rufus*) and white-tailed deer (*Odocoileus virginianus*) populations, producing some interesting (and unexpected) insights. In our study area, we found it difficult to distinguish the number of rabbit and rodent intrusions into the plots, but these animals might be indexed in other habitats. Analyses of the data as binary responses (presence or absence of spoor on each tracking plot), as has been done in scent-post surveys, reduced the sensitivity and accuracy of inferences.

Introduction

Estimates of population density for many animal species are often difficult and/or expensive to obtain, and density estimates are frequently unnecessary for research or management purposes (Caughley 1977). Carnivore populations tend to be particularly challenging to assess, with the primary difficulties summarised by Pelton and Marcum (1977): relatively sparse populations; large home ranges and movement patterns of individual animals; secretive behavior; occurrence in rough terrain; and difficulties in capture and observation or recapture and re-observation. Researchers and managers often must rely on indirect observation methods and activity indices, and 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. Such an index should be simple and quickly applied in the field, while providing sensitivity to reflect population changes over time or space.

Recently, Allen *et al.* (1996) successfully used a passive activity index (PAI) to assess the activity of dingo (*Canis lupus dingo*) populations. This index was effective not only for dingoes, but simultaneously allowed monitoring of a variety of other animal species (Allen and Engeman 1995), such as macropods (Macropodidae), fat-tailed dunnarts (*Sminthopsis crassicaudata*), feral cats (*Felis catus*), brush-tailed possums (*Trichosurus vulpecula*), and rabbits (*Oryctolagus cuniculus*).

Canid species are often the focus of management or research attention and the value of the PAI for monitoring dingoes may have applications on canid species worldwide. Canids such as coyote, foxes (*Vulpes* spp.), dingoes, wolf (*C. lupus*), jackals (*Canis* spp.) and wild dogs (*C. familiaris*) often conflict with human interests throughout the world, primarily because of depredations on livestock, but also because of transmission of diseases such as rabies, and unwanted predation on other species (e.g. waterfowl or endangered species).

In North America, interest in indirect methods of monitoring coyote (*Canis latrans*) populations has been strong for many years. Scent-post surveys (Linhart and Knowlton 1975; Roughton and Sweeny 1982) have been most commonly used and were applied for 10 consecutive years in a west-wide coyote survey in the U.S. (Roughton and Sweeney 1982), despite some important drawbacks (Henke and Knowlton 1995). For example, use of attractants to bring coyotes to tracking plots can be biased by neophobic behavior. Harris (1983) found that individual coyotes were less likely to visit novel Fatty Acid Scent (FAS) stations encountered in their territories than those encountered on the periphery. Differences in vulnerability of coyotes to capture devices relative to device location within their territories have been reported by Windberg and Knowlton (1990). Similarly, Allen *et al.* (1996) found increased potential for bias in monitoring dingo populations when using either a scent or a meat attractant rather than a passive plot.

Here, we applied and evaluated the PAI in North America for a species of particular concern, the coyote. We did this in conjunction with a coyote trap-testing program where we would know the number of animals removed. We simultaneously evaluated whether the AI also could monitor other species, and how these species might respond to the coyote-removal program.

Methods

This study was conducted on 2 ranches in Webb County, Texas, in February and March 1998. Study sites included a 47-km² area on Ranch 1 and a 29-km² area on Ranch 2. Habitat on both ranches was similar and representative of the South Texas Plains ecoregion (Gould 1975; Taylor *et al.* 1997). Each ranch had a network of primary dirt roads that were criss-crossed with low-use, one-lane dirt roads/tracks. Vegetation communities were dominated by dense stands of woody shrubs, primarily honey mesquite (*Prosopis glandulosa*), blackbush acacia (*Acacia rigidula*), sweet acacia (*A. minuta*) and prickly pear (*Opuntia* spp.). Extensive brush control by landowners resulted in varying stages of secondary plant succession. The topography was level to rolling, with drainages that flowed toward the Rio Grande River. Upland sites, which were predominant in this study, were characterised by variable soils that ranged from fine sandy loam to clay (Windberg *et al.* 1985). This region of Texas has consistently supported high-density coyote populations (Windberg 1995). Windberg and Knowlton (1988) reported densities of 2 coyotes km⁻² and Knowlton (1972) reported 1.5–2.3 coyotes km⁻² throughout southern Texas.

To examine the sensitivity of the PAI for detecting coyote population changes, we planned the study to coincide with coyote-trap-testing investigations on each ranch. Tracking plots were established and observed prior to commencement of trapping. After trapping on a ranch was completed, the same plots were re-used to observe post-trapping coyote population activity. Tracking plots were placed on transects along the low-use dirt roads, spaced at ≥ 0.8 -km intervals. Plots were 1.5 m long, raked and smoothed soil spanning the road-width (only one-lane roads were used). Fine soil of the same type from the immediate vicinity was added as needed to prepare the tracking surface. After 24 h, the plots were 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 was recorded. Ranch 1 had 41 tracking plots, and 35 plots were established at Ranch 2. We observed each plot for 2–4 consecutive days pre- and post-trapping.

The PAIs and associated variances were calculated according to Engeman *et al.* (1999), where a mixed linear model (e.g. McLean *et al.* 1991; Wolfinger *et al.* 1991) is used to describe the number of intrusions on each plot each day, without assumptions of independence among plots or days. SAS PROC VARCOMP, with a restricted maximum-likelihood estimation procedure (REML) (SAS Institute 1992, 1996, 1997) was used to calculate the variance components needed in the PAI variance-estimation formula (Engeman *et al.* 1999). We calculated confidence intervals using the standard normal approximation and we conducted Z-tests to compare pre- and post-trapping population index levels of coyotes (and other species) for each ranch. We applied analysis of variance to compare the mean daily proportion of plots positive for spoor before and after trapping on each ranch. Because scent-post surveys often have recorded only presence or absence of spoor overnight, we examined the loss in sensitivity of the PAI if these data were considered similarly. Thus, McNemar's test (Sokal and Rohlf 1995) was applied to compare the proportion of plots active on Day 1, pre- and post-trapping on each ranch.

Results

Tracking plots were placed on Ranch 1 for 4 days of monitoring prior to coyote trapping. However, on Days 2 and 3 plots could not be read because of heavy overnight rains, but even with only 2 days of observations the PAI and its variance still can be calculated (Allen *et al.* 1996; Engeman *et al.* 1999). We observed plots for 4 days post-trapping on Ranch 1, and 4 days each of pre- and post-trapping on Ranch 2. A variety of animals left identifiable tracks (Table 1). We calculated the PAI, its variance estimate, and confidence intervals (Table 2) for coyotes, bobcats (*Felis rufus*) and white-tailed deer (*Odocoileus virginianus*), species whose spoor always could be identified and intrusions to the plot separated. Rodent and lagomorph tracks were regularly found on the plots, but in these plots their activity usually was so intense that the number of individual intrusions could not be identified. Very soft, dry sand soil conditions frequently made some rabbit tracks and rodent tracks difficult to distinguish. Thus, these common prey species were not included in our calculations, but probably could be indexed in other habitats.

Trapping was carried out on each ranch for 12 nights. On Ranch 1, 40 coyotes and 6 bobcats were removed. On Ranch 2, 26 coyotes and 6 bobcats were removed. Animals removed during the trap-testing studies would represent reductions in densities of 0.85 and 0.90 coyotes km⁻² for Ranches 1 and 2, respectively (40 coyotes per 47 km² and 26 coyotes per 29 km², respectively, for Ranches 1 and 2). The reductions in coyote populations are reflected in the resulting PAIs (Table 2). The PAI for Ranch 1 dropped from 0.559 pre-trapping to 0.182 post-trapping, a 67% decrease in PAI value. The PAI for Ranch 2 dropped from 0.749 to 0.321, a 57% decrease.

We calculated Z-tests to compare pre- and post-trapping values of the PAI for both ranches. In both cases, differences

Table 1. Animals detected on tracking plots in southern Texas

Wildlife:	
Coyote	<i>Canis latrans</i>
Bobcat	<i>Felis rufus</i>
White-tailed deer	<i>Odocoileus virginianus</i>
Rodents	Rodentia
Rabbits	Leporidae
Javelina	<i>Tayassu tajacu</i>
Feral pigs	<i>Sus scrofa</i>
Foxes	<i>Vulpes</i> spp.
Turkeys	<i>Meleagris gallopavo</i>
Snakes	Serpentes
Domestic livestock:	
Cattle	<i>Bos taurus</i>
Goats	<i>Capra hircus</i>
Horses	<i>Equus caballus</i>
Other:	
Human ^A	<i>Homo sapiens</i>

^ARanch 1 was in a corridor for immigration from Mexico.

Table 2. Passive activity index (PAI) values, variances and 95% confidence limits for 3 species on each of 2 ranches in Webb County, Texas

Species	Ranch	Period	PAI value	Variance	95% confidence limits
Coyote	1	Pre-trapping	0.559	0.026	0.242–0.876
	1	Post-trapping	0.182	3×10^{-5}	0.172–0.193
	2	Pre-trapping	0.749	7.2×10^{-4}	0.696–0.801
	2	Post-trapping	0.321	1.2×10^{-4}	0.299–0.342
Bobcat	1	Pre-trapping	0.105	6.4×10^{-4}	0.056–0.155
	1	Post-trapping	0.182	1.0×10^{-4}	0.090–0.129
	2	Pre-trapping	0.021	5×10^{-7}	0.020–0.023
	2	Post-trapping	0.059	3×10^{-6}	0.055–0.063
Deer	1	Pre-trapping	0.406	0.005	0.274–0.537
	1	Post-trapping	0.060	3×10^{-7}	0.056–0.063
	2	Pre-trapping	0.453	3×10^{-4}	0.419–0.487
	2	Post-trapping	0.484	7.9×10^{-4}	0.429–0.539

were strongly indicated (Ranch 1: $Z = 2.329$, $P = 0.0099$; Ranch 2: $Z = 14.788$, $P < 0.00001$). We also compared the ranches to each other pre- and post-trapping. A difference in PAI value was not detected pre-trapping ($Z = 1.163$, $P = 0.2450$), but a difference was indicated post-trapping ($Z = 11.284$, $P < 0.00001$). To examine the sensitivity of this index versus using binary observations for each plot where only presence or absence of spoor are recorded, we conducted the two additional statistical tests for comparing pre-trapping data to post-trapping data. First, we compared mean daily proportions of plots positive for spoor pre- and post-trapping. Differences were still detected for both ranches, but not to the same degree of confidence (Ranch 1: $F = 7.83$, d.f. = 1,4, $P = 0.0489$; Ranch 2: $F = 11.42$, d.f. = 1,6, $P = 0.0149$). 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. Not surprisingly, the use of binary observations with only a single day of observation resulted in a further loss of sensitivity to change. Ranch 1 still showed a difference pre- and post-trapping ($\chi^2 = 6.368$, d.f. = 1, $P = 0.0116$), but Ranch 2 did not ($\chi^2 = 0.077$, d.f. = 1, $P = 0.7814$).

The PAI holds potential for simultaneously monitoring other predators (Table 2). On Ranch 1 we calculated an index for bobcats pre- and post-coyote trapping. Although 6 bobcats were taken from the ranch during the coyote-trapping program, the PAI value increased post-trapping (Table 2), and differed statistically from the pre-trapping value ($Z = 2.831$, $P = 0.0046$). A similar phenomenon occurred on Ranch 2 (Table 2) where a post-trapping increase in PAI value also was detected ($Z = 15.021$, $P < 0.00001$).

The PAI values for white-tailed deer pre-trapping on Ranch 1, and for pre- and post-trapping on Ranch 2 were of similar magnitudes (Table 2). The post-trapping values on Ranch 1 were substantially less than the pre-trapping values ($Z = 4.893$, $P < 0.00001$), but a difference was not found on Ranch 2 ($Z = 0.939$, $P = 0.3477$).

Discussion

The PAI proved sensitive for detecting reductions in coyote populations on both ranches. Analyses of activity plots with binary responses (positive or negative) reduced sensitivity for detecting differences, as was also demonstrated for dingoes (Allen *et al.* 1996). This loss of sensitivity is expected when information is discarded by reducing continuous (or more extensive discrete data) to 2 options (e.g. Engeman *et al.* 1989). Unfortunately, most scent-post surveys or bait-attractant surveys have recorded only binary data, in part because the active responses generated in these plots often result in the obliteration of the plot by rolling, scratching, and urinating, thus eliminating the possibility of counting intrusions.

Bobcat PAI values were smaller than those for coyotes (Table 2). Nonetheless, bobcat activity appeared to increase with the extensive removal of coyotes. Although the proportional magnitudes of increase in PAI were high for both ranches, only small increases in frequency of less common events produce large proportional increases. Even so, the small absolute increases in the PAI post-trapping were still detectable statistically. The greater PAI values for bobcats post-trapping might indicate increased bobcat activity in response to density reductions of a competing predator species (coyote), a canid–felid interaction observed for feral house cats when red foxes (*Vulpes vulpes*) were removed (Molsher 1998; Risbey and Calver 1998).

The large decrease in the PAI for deer post-trapping on Ranch 1, while remaining constant on Ranch 2, may point to differences in land-use patterns between the ranches. Deer on Ranch 1 are extensively hunted, with much of the hunting conducted from vehicles. Our studies began on Ranch 1 the week after deer-hunting season. The coyote trapping conducted between the two PAI assessments on this ranch produced daily vehicle traffic throughout the area of assessment, with associated shooting to euthanise trapped coyotes. The

deer on Ranch 1 probably had been conditioned to avoid the roads during times when shooting is associated with vehicle traffic. Such conditioning would not have affected PAI observations pre-trapping when no shooting took place, but could have been a concern post-trapping, after 40 coyotes had been shot in 12 days. Ranch 2, however, does not receive the same order of magnitude of hunting pressure as Ranch 1. In addition, the trapping program on Ranch 2 was another two weeks removed from deer season and fewer coyotes were removed (less shooting than on Ranch 1). Thus, our PAI results for deer may indicate differing behavioral responses to different deer-hunting circumstances on the two ranches, and corresponding to different time lags from the end of hunting season.

The PAI, being based on counting daily movements of animals across tracking stations, is unlikely to influence normal animal activity. We found no track evidence that any species we monitored either avoided or was attracted to activity 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. To detect presence or to index activity with alternative assessment 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.

While the PAI produces few methodology-induced changes to animal behaviour or activity that might influence results, the daily inspection of tracking plots permits a time dimension that some assessment methods do not reflect. Methods can be sensitive to the time of day when they are conducted, relative to each species' peak period of activity. Each wildlife species will 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 behaviour 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 of pigs shot from helicopters (Saunders and Bryant 1988). Caughley (1977) further discusses individual and species' behaviour relative to trapping devices and survey methods affecting the quality of data.

The PAI 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 found no problems with superimposed tracks when more than one coyote 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 of activity is averaged over many stations and over multiple days.

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 optimise the combination of days and plots. In south Texas, the component of variance for plot-to-plot variation was larger than the other sources of variation, except for the pre-trapping assessment on Ranch 1, where the daily variation contributed the most variability (probably due to changing weather). Thus, if the outlook is for consistent good weather during data collection, then the emphasis should be placed on the number of plots. However, if the weather could change during the assessment period, then the number of observation days should be increased, or the assessment delayed. Nonetheless, the reality of wildlife research often is that experimental logistics and resources are often the most important influences on sampling design. Because of the data structure for the PAI, the index, variance and associated statistics will still be calculable, but the variability will reflect the changing circumstances and will be higher, thus decreasing sensitivity for detecting differences between PAI values.

On two continents, the AI successfully has been applied to monitor wild canid species that are often in conflict with humans for livestock depredations. In each case, other animals were simultaneously monitored, providing general population information on other species and insights into possible interactions with canids. Applications could be worldwide for canid species, but we also now are considering the method for monitoring two other species often in conflict with human interests: deer and feral pigs.

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