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# Plot placement when using a passive tracking index to simultaneously monitor multiple species of animals

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*Abstract.* We evaluated a passive tracking index (PTI) when plots were placed on lightly used dirt roads *versus* placement on naturally occurring bare ground in natural habitat. PTIs were calculated before and after removal of coyotes and some non-target species during another study that evaluated capture devices. Six mammals were simultaneously monitored with the PTI: coyotes, raccoons, white-tailed deer, feral swine, javelina, and rabbits. PTIs from road plots were significantly higher than from off-road plots, except for deer and javelina, for which no differences were detected. After removal of coyotes, PTIs were significantly lower, both from on- and off-road plots. For coyotes and raccoons, the decline in index values primarily reflected population reductions. For animals hunted for sport (deer, swine, javelina), population reductions were minor compared with coyotes, and their declines in index values likely reflected conditioned responses to the activity and shooting that accompanied evaluations of the capture devices. We conclude that the PTI is sensitive to changes in population or changes in activity in response to an event for a variety of species, and it is most useful when placed on lightly used dirt roads.

## Introduction

Researchers and managers often rely on indirect observation methods to produce indices of animal abundance because population density estimates frequently are unnecessary for research or management purposes (e.g. Caughley 1977), or because the economic or logistical costs of doing a density assessment are prohibitive. Moreover, the statistical theory used to produce density estimates usually requires fulfillment of assumptions that, when violated, result in estimates of questionable quality (see for example, Leidloff (2000) for an excellent overview of potential problems with capture–recapture methods and Burnham *et al.* (1980) for potential hazards with line-transect estimation). The methods vary greatly among species and assessment objectives, but the assessment must fit within management practicalities. Among the more important of the desirable characteristics for an indexing method is that it should be simple and quickly applied in the field, while providing sensitivity to reflect population changes over time or space (Engeman and Witmer 2000).

As with density estimation, indices result in the collection of quantitative information that is synthesised into a format from which inferences are made. In contrast to density estimation, where there is a premium on accuracy, precision is of the utmost importance for an index (e.g. Caughley and Sinclair 1994; Engeman and Witmer 2000). It follows that an index value should have an associated estimate of its variance, without requiring subdivisions of the data into subjective units. The calculated index and associated variance achieve greatest robustness for inferences if burdened with as few assumptions as possible about the data structure and distribution of the observations.

Interest in indirect methods of monitoring coyote populations has been strong for many years (Linhart and Knowlton 1975; Roughton and Sweeny 1982; Henke and Knowlton 1995). Recently, a passive tracking index (PTI) was successfully applied for monitoring changes in coyote (*Canis latrans*) abundance, while avoiding many of the drawbacks and biases associated with attractant-based tracking plot methods (Henke and Knowlton 1995; Allen *et al.* 1996; Engeman *et al.* 2000). The PTI also simultaneously monitored bobcat (*Felis rufus*) and white-tailed deer (*Odocoileus virginianus*) populations in Texas (Engeman *et al.* 2000), and earlier versions of the index had been applied to dingoes and coexisting species in Queensland, Australia (Allen and Engeman 1995; Allen *et al.* 1996).

All previous applications of the PTI have been on low-use dirt roads or tracks, but because roads are not samples of the habitat through which they pass (Caughley and Sinclair 1994), we were interested in whether an off-road (natural

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habitat) based index method would be more effective for monitoring animal populations (e.g. Mahon *et al.* 1998; Westcott 1999). Although roads or other runways have been successfully used for tracking indices for canids worldwide (e.g. Engeman and Witmer 2000), some have felt that aversions to open habitat cause other species to not be well monitored by road surveys (Mahon *et al.* 1998). Despite this, secretive animals have been successfully monitored from tracks on roads: the relative abundance of mountain lions (*Felis concolor*) has been successfully monitored from a roadway tracking index (Van Dyke *et al.* 1986), as has bobcat abundance (Engeman *et al.* 2000). In light of this, we felt it important to understand the effect on the index of placing tracking plots on roads *versus* placing plots in natural habitat for a suite of species.

Our interest in simultaneously monitoring multiple species was not to compare index values across species, but to examine relative index values within each species. Even though we do not presume index values to be comparable across species, relative changes within species over time (and events) can give insight into species interactions (Engeman *et al.* 2000). Because south Texas is rich in species of general interest, we also wanted to understand how broadly applicable the PTI might be for multiple species of mammals.

## Materials and Methods

This study was conducted in a 42-km$^2$ area on a ranch in Webb County, Texas in February and March 1999. Habitat on the ranch was representative of the South Texas Plains ecoregion (Gould 1975; Taylor *et al.* 1997). The 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 shrubs, primarily honey mesquite (*Prosopis glandulosa*), blackbush acacia (*Acacia rigidula*), sweet acacia (*A. minuta*) and pricklypear (*Opuntia* spp.). 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).

To examine the sensitivity of the PTI for detecting coyote population changes, we planned the study to coincide with a separate study on the same ranch that evaluated devices for capturing coyotes (Shivik *et al.* 2000) (This region of Texas has consistently supported high densities of coyotes: Knowlton 1972; Windberg and Knowlton 1988; Windberg 1995.) Tracking plots were established and observed prior to commencement of evaluation of the capture devices. After the evaluations were completed, the same tracking plots were re-used to observe whether the population changes could be detected. The evaluations of capture devices were conducted in an area almost 3 times as large (118 km$^2$) as the area where our indexing observations were made, and totally encompassed the area where indexing took place.

Forty tracking plots were randomly located along low-use, single-lane dirt roads, with a minimum inter-plot spacing of 0.8 km. Plots (1.5 m long) were raked and smoothed to produce a good tracking base that spanned the road width (approximately 3 m on average). At each location of a plot in a road, another same-sized plot was located ≥30 m from the road on naturally occurring bare ground in natural habitat. The side of the road from which this plot was placed was randomised. (In some locations, natural topography or property boundaries permitted consideration of only one side of the road.) The locations of all plots were recorded using a Global Positioning System unit. Fine soil of the same type from the immediate vicinity was added as needed to prepare the tracking surface of both on-road and off-road plots (few plots required supplemental soil). After 24 h, the plots were examined for spoor and resurfaced (tracks erased and soil smoothed) for the next day's observations. At each plot, the number of track sets (number of intrusions) by each animal species was recorded. We observed each plot for 4 consecutive days prior to the evaluations of the capture devices and for 3 consecutive days after the evaluations (A rainstorm eliminated the potential fourth day of post-evaluation observations.) The occasional destruction of a day's observation on some plots by vehicular traffic or livestock occurred, as was our expectation. The unequal number of observation days before and after the evaluations of the capture devices posed no problem for our purposes as equal numbers of observations are not required to calculate the PTI and its variance for comparative purposes (Engeman *et al.*1998).

The PTIs and associated variances were calculated according to Engeman *et al.* (1998), where a 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, and no assumptions of independence among plots or days are made. The mean number of track intrusions on each plot by each species is calculated for each day. The index values are the means of the daily means for each species:

$$PTI = \frac{1}{d}\sum_{j=1}^{d}\frac{1}{p_j}\sum_{i=1}^{p_j}x_{ij}$$

where the $x_{ij}$ represent the number of intrusions by a given species on the *i*th plot on the *j*th day, *d* is the number of days of observation, and $p_j$ is the number of plots contributing data on the *j*th day. SAS PROC VARCOMP, with a restricted maximum-likelihood estimation procedure (REML) (SAS Institute 1996) was used to calculate the variance components (Searle *et al.* 1992) needed in the PTI variance-estimation formula (Engeman *et al.* 1998):

$$var(PTI) = \frac{\sigma_p^2}{d}\sum_{j=1}^{d}\frac{1}{p_j} + \frac{\sigma_d^2}{d} + \frac{\sigma_e^2}{d}\sum_{j=1}^{d}\frac{1}{p_j}$$

where the $\sigma_p^2$, $\sigma_d^2$, and $\sigma_e^2$ are, respectively, the components for plot-to-plot variability, daily variability, and random observational variability associated with each plot each day. We calculated confidence intervals using the standard normal approximation. Calculations were done separately for on-road and off-road data. We conducted *Z*-tests to compare pre- and post-trapping population index levels of species monitored. Plot locations were mapped, and distances and areas were calculated using ArcView and Atlas GIS software.

## Results

A variety of mammal species left identifiable tracks at least once. Less than 1% of the plots were erased by vehicular traffic or livestock trampling (data from those plots on those days were not available as observations for the analyses). The PTI, its variance estimate, and confidence intervals (Table 1) were calculated for coyotes, white-tailed deer, rabbits (Family Leporidae), javelina (*Tayassu tajacu*), feral swine (*Sus scrofa*), and raccoons (*Procyon lotor*). The tracks from these species were readily distinguished, and the number of intrusions by each these species was straightforward to

**Table 1. Passive tracking index values calculated for six south Texas mammals using plots on two different habitats, and in two different trapping periods**
The two habitats were lightly used dirt roads (on-road) and natural habitat (off-road). The two trapping periods were before and after the evaluation of the capture devices. Data are shown ± 95% confidence intervals

| Species | Trapping period | Habitat | Index value | Percentage of plots tracked |
|---|---|---|---|---|
| Coyote | Before | On-road | 0.790 ± 0.086 | 38.5 ± 7.4 |
| | | Off-road | 0.069 ± 0.004 | 5.0 ± 3.3 |
| | After | On-road | 0.212 ± 0.011 | 17.8 ± 6.9 |
| | | Off-road | 0.110 ± 0.006 | 8.5 ± 5.0 |
| Deer | Before | On-road | 0.755 ± 0.077 | 33.6 ± 7.2 |
| | | Off-road | 0.819 ± 0.069 | 33.8 ± 7.3 |
| | After | On-road | 0.128 ± 0.013 | 8.5 ± 5.0 |
| | | Off-road | 0.298 ± 0.013 | 17.0 ± 6.7 |
| Feral swine | Before | On-road | 0.253 ± 0.020 | 15.8 ± 5.6 |
| | | Off-road | 0.100 ± 0.007 | 6.3 ± 3.7 |
| | After | On-road | 0.042 ± 0.003 | 3.4 ± 3.2 |
| | | Off-road | 0.017 ± <0.001 | 1.7 ± 2.3 |
| Rabbit | Before | On-road | 0.568 ± 0.051 | 37.9 ± 7.4 |
| | | Off-road | 0.313 ± 0.021 | 20.0 ± 6.2 |
| | After | On-road | 0.187 ± 0.013 | 12.8 ± 6.0 |
| | | Off-road | 0.110 ± 0.011 | 8.5 ± 4.9 |
| Raccoon | Before | On-road | 0.215 ± 0.012 | 13.9 ± 5.4 |
| | | Off-road | 0.006 ± <0.001 | 0.6 ± 1.2 |
| | After | On-road | 0.042 ± 0.001 | 4.2 ± 3.6 |
| | | Off-road | 0.000 ± 0.000 | 0.0 ± 0.0 |
| Javelina | Before | On-road | 0.110 ± 0.008 | 7.0 ± 3.9 |
| | | Off-road | 0.100 ± 0.008 | 5.6 ± 3.5 |
| | After | On-road | 0.050 ± 0.004 | 3.4 ± 3.2 |
| | | Off-road | 0.010 ± <0.001 | 0.8 ± 1.6 |

determine with careful inspection of the plots. We found no problems with superimposed tracks when multiple animals crossed the plots, although this might pose a problem for monitoring large groups in some situations. Rodent tracks were regularly found on the plots, but their activity often was so intense that the number of individual intrusions could not be identified, and we do not present index results for rodents. We could have produced indices for at least two birds, roadrunners (*Geococcyx californianus*) and quail (primarily scaled quail, *Callipepla squamata*). However, when we implemented the study we did not expect this and we did not attempt to differentiate among bird species producing tracks on the plots.

Nineteen days elapsed between data collection for before and after the evaluations of the capture devices. During that interim, 90 coyotes were captured and removed. In addition, varying numbers of the other species we monitored were captured as non-target species during the device evaluations: 10 raccoons, 1 javelina, 1 deer, 2 swine, 2 rabbits. Predator control was ongoing at the ranch, and additional coyotes and other predators may have been removed in the same period. Also, during the time between the indexing periods, we observed the hunting of javelina and black-tailed jackrabbits (*Lepus californicus*) on the ranch, with an unknown number of animals being removed.

Because many plot-based indexing methods use only binary information from each plot about whether or not at least one track was present, we incorporated a column in Table 1 to indicate the percentage of plots that were tracked and their corresponding 95% confidence limits. In some cases the proportional differences between on- and off-road plots, and between pre- and post-evaluations of capture devices, were similar to those for the PTI. However, as would be expected when reducing broader data to binary format (e.g. Engeman *et al.* 1989), sensitivity to change or differences was also reduced, as has been demonstrated previously (Allen *et al.* 1996; Engeman *et al.* 2000). As particular examples among those instances where sensitivity for detecting differences was lost by considering only the percentage of plots tracked, the post-evaluation off-road and on-road results would no longer be distinguishable for coyotes, swine and rabbits (Table 1).

Plots placed off-road generally were not as proficient at producing tracking observations as were plots on the roads. For coyotes, feral swine, raccoons and rabbits there were substantially larger index values for the road plots than for the off-road plots ($Z \geq 9.1$, $P < 0.00001$), but not for deer and javelinas ($Z = 1.21$, $P = 0.23$; $Z = 1.69$, $P = 0.09$, respectively). Index values for all species declined substantially after the evaluations of the capture devices, both for plots on the roads and off ($Z > 12.5$, $P < 0.00001$), except for coyotes using off-road plots, where the tracking rate already was low before removals. No off-road plots were observed with raccoon tracks after the evaluations of the capture devices. For all species except deer, the post-evaluation index values were substantially higher from plots on the roads than from off-road plots ($Z > 8.9$, $P < 0.00001$ for all cases). For deer, the opposite occurred: the index value from the off-road plots was higher than that from the plots on the road ($Z = 18.3$, $P < 0.00001$).

## Discussion

The underbrush in Texas where our study was conducted is dense and dominated by dense stands of thorny shrubs and cacti. It appeared that most of the larger mammalian species used the dirt roads as travel ways, as only deer produced comparable index values from off-road plots. Roads may not be a representation of available habitat, but if the indexing objective is to reference the abundance of a species in an area, then plot placement on the roads provides a reflection of population abundance, because of, rather than despite, any preferential usage of roads as travel ways by animals. Thus, an index would best reflect the animal populations in an area if the observation sites (tracking plots in our case) were placed in predictable travel routes of the species of interest. This is especially true for a passive system such as ours, but also would be true when placing observation sites employing an attractant to obtain observations.

As with any other aspect of sampling, potential confounding effects must be identified and avoided. Thus, the PTI should not be used to compare different species, because the index values could be confounded with differential usage of roads and different species' home-range sizes relative to plot spacing. Similarly, comparative inferences from index values taken from the same species in markedly different environments could be confounded with differences in road usage by the same species. Some habitats may change substantially between seasons and the same cautions apply that road usage may vary accordingly, and possibly may be confounded, or confused, with changes in abundance. The most accurate population-assessment solution might be a passive mark–recapture system. Such an approach would require an investment in sophisticated equipment to detect animals without affecting behaviour, and it would be labor-intensive to obtain sufficient animals and to distinguish among recorded individuals to identify recaptures. Presently, such methodology is used for some research applications (M. Jaeger, personal communication), but is not practical for general management applications.

Undoubtedly, the removal of at least 90 coyotes affected the coyote index value. Similarly, the removal of 10 raccoons likely affected the raccoon index value; however, a behavioral component associated with the evaluations of the capture devices between PTI assessments evidently influenced index values beyond the removal of animals. The consistent vehicular traffic, combined with the shooting and other activities, could have suppressed or otherwise altered the activities of the other species monitored, especially the species hunted as game.

The decrease in the PTI for deer after trapping may relate to activity changes due to hunting, and has been observed previously (Engeman *et al.* 2000). Deer are extensively hunted from the roads on the ranch, and our studies began shortly after the end of deer-hunting season. The evaluations of the coyote capture devices between the two PTI assessments produced daily vehicular traffic throughout the area of assessment, with associated shooting to euthanise trapped coyotes. The deer probably had been conditioned to avoid the roads during times when shooting is associated with vehicular traffic. Our off-road plots may have given an indication of this effect, as the off-road post-trapping index value for deer was higher than the road index, although both were substantially smaller than the pre-trapping values. Perhaps if the off-road plots had been more remote, no change in pre- and post-trapping PTIs would have been detected. However, the dense and thorny nature of the underbrush made that impractical for our study without cutting trails, and cutting trails would have defeated the purpose of the off-road plots.

While not producing the same income potential as deer to landowners, feral swine and javelina are also hunted on ranches in this part of Texas. The removal of two swine and a javelina during the device evaluations may have had some impact on their populations, as did the javelina hunting we observed between assessments. However, as with deer, the greater impact on the PTI likely resulted from a conditioned response during the capture-device evaluation period similar to that for deer. This may be especially true when considering the learning capabilities of swine, as exemplified by feral swine acting dead during aerial surveys for swine shot from helicopters (Saunders and Bryant 1988). A small behavioural component may also be evident in the coyote results. We have already noted that the index values from on-road plots were more proficient at tracking coyotes than were the off-road plots, and the road plots showed a dramatic decrease in magnitude from the period prior to the testing of the capture devices to that following the testing. However, the small off-road index value before testing increased a small but statistically detectable amount after testing, possibly indicating an aversion by surviving coyotes to the coyote-removal activity along the roads.

The investigator should be clear on the monitoring objectives when choosing to apply an index to monitor animal populations. While reflecting population changes, indices are not estimates of numerical abundance. To attempt to infer an abundance or density estimate from an index requires additional study where known densities (not density estimates) are related to index values with a statistical model.

This is difficult to validly achieve, and it is inappropriate to assume that the same functional relationship would hold true over changes in time and space. Thus, if estimates of absolute population numbers are essential, then the additional labor and expense for validly carrying out a density estimation procedure should be applied.

Statistically detectable changes or differences in index values permit inferences and management decisions when applied to comparable circumstances. Our results reflected changes in animal behaviour due to the activity associated with the evaluations of the capture devices between index assessments, but not due to the assessment method. Situations such as this are informative about animal activity, but require understanding and care in interpreting index results. When monitoring for the effects of a treatment that could affect populations, interpretation might be facilitated by monitoring the same species in a nearby untreated site.

Finally, our results support applications for the PTI on other species than canids. For example, deer hunting is big business in the part of Texas where our study was conducted, and landowners could use the index to track deer abundance to make management decisions regarding the optimal number of hunters to allow each season. Feral swine have caused habitat and conservation problems worldwide, and we are currently experimenting with the PTI in a tropical habitat to monitor relative abundance of swine and the efficacy of removal programs. Raccoon populations recently have suffered a rabies epidemic along the east coast of the USA (Winkler and Jenkins 1991), and relative abundance could be monitored to plan delivery of oral vaccines in baits (Linhart *et al.*1991). In addition, raccoons are major predators of sea turtle nests (Stancyk 1995; Bergh 1999), and we are experimenting with PTI application methods on beaches to evaluate the necessity, timing and efficacy of management actions (Engeman *et al.* 2001). The study site in Texas was just across the Rio Grande River from Mexico, and appeared to be in a corridor of (often illegal) immigration from Mexico. On the basis of our regular observations of overnight deposition of human tracks on our plots, perhaps the most novel application for the method might be to quantitatively index such movements.

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