IPM STRATEGIES: INDEXING DIFFICULT TO MONITOR POPULATIONS OF PEST SPECIES

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ABSTRACT: Monitoring populations of problem species is an essential component for integrated damage reduction programs. Tracking population size through time and space helps define the potential magnitude and geographical extent of damage. Population size at an early stage of a crop cycle can serve as a predictor of damage levels later on, indicating whether control is necessary or what forms would be economically optimal. The ability to monitor for population change also permits assessment of the efficacy of the control methods for reducing numbers of a pest species. Methods for quantifying population levels can be as diverse as the number of subject species, the objectives of an IPM program, and whether direct estimates or indices of population parameters are required. Often, indirect methods involving counts of tracks, burrows, droppings, or food removal are used. We review methods used for a variety of wildlife species, examine the desirable characteristics for useful monitoring methods, and describe some of our current research on indexing methods.

KEY WORDS: activity indices, animal damage, carnivores, fossorial mammals, indirect observations, wildlife management

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INTRODUCTION

Actions to successfully reduce animal damage in an economically prudent manner usually involve some assessment of animal numbers. A great variety of methods have been developed to estimate the density of animal populations (e.g., Seber 1994; Thompson et al. 1998). However, estimates of population density for many species of animals are often difficult to implement, expensive to obtain, or require difficult-to-meet analytical assumptions. Besides that, population density estimates frequently are unnecessary for research or management purposes (Caughley 1977). Instead, researchers and managers may rely on indirect observation methods to produce useful indices. The methods vary greatly among species and assessment objectives, but the assessment must fit within management practicalities. An index should be simple and quickly applied in the field, while providing sensitivity to reflect population changes over time or space. Such an index can provide the necessary comparative information to make management decisions. The use of tracking tiles for rats (*Rattus* spp.) (e.g., Fiedler 1994), scent post surveys for coyotes (*Canis latrans*) (Roughton and Sweeney 1982), and the open hole method for pocket gophers (*Thomomys* spp.) (Richens 1967) are examples of population indexing methods that are used to supplant more theoretically and technically rigorous density estimation procedures.

We begin this paper by reviewing concepts for monitoring animal populations as part of an integrated pest management (IPM) program for damage reduction. We describe the characteristics for which to look when selecting or developing an indexing method. Restricting ourselves to select groups of mammals, we describe situations where indices are highly valuable and look at some examples of their application. Finally, we suggest areas needing further research in indexing methods.

WHY MONITOR PEST SPECIES

Animal populations, in general, are monitored for a wide spectrum of research and management reasons, including setting harvest management parameters, assessing biodiversity, tracking threatened or endangered species, disease surveillance, and the general accumulation of knowledge. When an animal species conflicts with human interests, the rationale for monitoring their population numbers would seem self-evident. However, the objectives for monitoring pest animals within an IPM program are varied, and often different monitoring objectives are accompanied by different sampling methodologies.

The most obvious application for pest animal monitoring within a damage reduction program is for comparative purposes to determine the efficacy of population reduction efforts. This could be before and after control within an area, or simultaneously between otherwise similar controlled and uncontrolled areas. The distribution of a pest species is another factor affecting levels of damage. Depending on the species and habitat, pest animal populations, and consequently damage, can be highly variable and localized. Indexing population distributions in a region, or even in a field, provides managers insight on the potential for damage patterns, key points for placement of control tools, and the cost-effectiveness of damage reduction methods. The relative abundance of a pest species at a particular point in an annual, or other, crop cycle often can be used to predict future damage levels and aids in the selection and timing of damage control approaches (Cantrill 1992; Cantrill and Ramsey 1991; Brown et al. 1998). Managers can optimally time implementation of damage reduction strategies to minimize the impact of the species, or they can avoid unnecessary expenditures by not implementing control measures when they are not predicted to be

cost-effective. Frequently, damage is inflicted within a system by more than one pest species and simultaneous monitoring of the relative activities of each offending species permits optimal application of damage reduction methods so that the combined damage inflicted by all species is minimized. Otherwise, the methods leading to the reduction or elimination of damage by one species may increase total damage due to the response by another species (e.g., Molsher 1998; Risbey et al. 1999).

DESIRABLE CHARACTERISTICS OF MONITORING METHODS

Prior to the application of a method to index or estimate the abundance of a pest species (or a suite of pest species), consideration should be given to its qualities for meeting management objectives and its suitability for use in a particular situation (summarized in Table 1). Often, a number of methods may be available, from which the most appropriate method, or set of methods, must be selected (e.g., Tables 2, 3). On the other hand, a tested indexing method may not be available. A method used successfully on a similar species or in a similar situation would be a good candidate method to apply, but it should have been developed and tested to meet management needs. Without such validation, index results and consequent management decisions are highly speculative.

One of the most essential characteristics of a successful indexing method is that it is practical to apply. A method that is too difficult, too inefficient, or too expensive to apply will ultimately result in poor data and an inability to make lucid management decisions. Inefficient or uneconomical procedures usually will result in the collection of too little data from which to base management decisions. Related to this, the index method should be user-friendly, with the procedures and concepts for recording information easily understood. It should not require excessive manpower and the potential for observation bias should be minimal. The observer should be readily able to identify and measure the observation of interest for the target species, with little chance for confusion with other species. The method should be as robust as possible to environmental variables, for example, cloud cover, humidity, rain, and wind. Indices requiring expensive equipment that can malfunction, be damaged by animals, or be stolen or easily vandalized are of limited use in many areas. While holding the potential for high quality data, "high-tech" methods also often are more difficult to universally apply due to the start up and maintenance expenses required. Methods must impose minimal inconvenience on landowners and managers for them to be acceptable and implemented. All of these concepts are compounded in situations where the monitoring must take place multiple times per year.

As with density estimation, indices result in quantitative information being collected and synthesized into a format from which inferences can be made. The index value should be sensitive to relative (proportional) changes or differences in the target species' population(s). Thus, 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). It follows that an index value should have an associated estimate of its variance, without requiring subjective subdivisions of the data. The calculated index and associated variance should be burdened with as few assumptions as possible about the data structure and distribution of the observations, which makes for the most robust management inferences.

Perhaps most importantly, the method should be appropriate for the objectives and validated for the circumstances to which it will be applied. For example, evaluating efficacy of control may require a different method than for determining the distribution of a species. The method should have been tested on the target species in similar circumstances (habitat, time of year, etc.). If not, a new method for the species should be applied concurrently with another proven (but perhaps more difficult) method, or otherwise validated on the target species before being used exclusively for making management or research inferences.

Table 1. Desirable properties for an animal population indexing method.

Planning Stage:
- Appropriate for objectives (e.g., evaluating efficacy of control may require different method than determining distribution of species)
- Practical to apply (efficient, cost-efficient)
- Tested on target species

In-Field:
- User-friendly (simple)
- Minimal observation bias
- Robust to the environment
- Target species identifiable
- Minimal manpower
- Inexpensive equipment/low maintenance
- Low level of inconvenience to landowner/manager

Analytical:
- Minimal assumptions
- Sensitive to change
- Good statistical properties: variance estimate available, minimal subjectivity

Table 2. Examples of indexing methods applied to various fossorial mammal pest species.

Species	Method	References
Pocket Gophers	Plot Occupancy	Anthony and Barnes 1984; Engeman et al. 1993
	Open Hole	Engeman et al. 1993, 1999b; Matschke et al. 1994; Richens 1967
Mountain Beaver	Swordfern Bundles	Engeman et al. 1991
	Knockdowns	Engeman et al. 1991
Prairie Dogs and Ground Squirrels	Visual Counts	Fagerstone and Biggins 1986; Menkens et al. 1990; O'Connell and Clark 1992; Powell et al. 1994; Severson and Plumb 1998
	Closed Hole	Engeman et al. In Press-a; Jackson 1979; O'Connell and Clark 1992
	Burrow Counts	Powell et al. 1994; Severson and Plumb 1998
	Alarm Calls	Lishak 1977
Voles	Apple Slice	Byers 1975; Tobin et al. 1992
	Runway Counts	Tobin et al. 1992

Table 3. Examples of indexing methods applied to various mammalian carnivores.

Method	References
Scent Stations	Henke and Knowlton 1995; Linhart and Knowlton 1975; Robson and Humphrey 1985: Roughton and Sweeney 1982
Catch/Effort	Henke and Knowlton 1995
Buried Meat Plots	Allen et al. 1989; Allen et al. 1996
Howling Response (canids)	Alcorn 1946; Harrington and Mech 1982; Laundre 1981; Okoniewski and Chambers 1984; Wenger and Cringan 1978
Track Plots	Allen et al. 1996; Allen and Engeman 1995; Engeman et al. 1999; Engeman et al. In Press-b; Mahon et al. 1998
Track Plates	Barrett 1983; Zielinski and Kucera 1995
Tracks/Distance	Beasom 1974; Fleming et al. 1996; Henke and Knowlton 1995; Mahon et al. 1998; Van Dyke et al. 1986; Van Sickle and Lindzey 1992
Scat Counts	Andelt and Andelt 1984; Davison 1980
Snow Track	Todd and Keith 1976
Road Kill	Case 1978; Rolley and Lehman 1992
Spotlight Counts	Mahon et al. 1998
Cameras	Cutler and Swann 1999

DIFFICULT MAMMALIAN CASES

Carnivores and fossorial animals, while including many species often in conflict with human interests (e.g., Hygnstrom et al. 1994), pose particular difficulties for assessing population status. The difficulties in making observations on animals that live and carry out much of their behavior below ground is obvious, while the difficulties in assessing carnivore populations arise for a variety of reasons (e.g., Pelton and Marcum 1977; Witmer et al. 1998; Zielinski and Kucera 1995), including relatively sparse populations, territorial with large home ranges and movement patterns of individual animals, secretive behavior (often nocturnal or crepuscular), occurrence in rough terrain, and difficulties in capture and observation or recapture and re-observation. This is in sharp contrast to monitoring other large land mammals, such as ungulates, which often can be observed in daylight, provide readily observable sign (tracks, droppings), and often occur at relatively high densities.

Observations used for indexing populations of fossorial animals usually take advantage of some aspect of the animal's burrowing behavior. This could be the density or distributions of burrows, cleaning of burrows, maintenance of a closed burrow system, maintenance of open entrances, or the time spent above ground. Indexes for some fossorial species have been highly successful, while other species have proven very difficult to observe without high variability or bias. More than one index method may be needed to meet multiple objectives, such as assessing spatial distribution versus control efficacy. An index that works well for a particular species, can only be considered a starting point for testing on another species, even if this species is closely related. For example, the open hole method for assessing activity for northern pocket gophers (*T. talpoides*) (Richens 1967; Engeman et al. 1993) has been a disappointment when applied to its close relative, Townsend's pocket gopher (*T. townsendii*) (Matschke et al. 1994). The quality of an index for describing a fossorial population is affected by such factors as the number of animals per burrow system, changes in seasonal activity (including hibernation and estivation), seasonal changes in characteristics of the ground where burrowing occurs, weather conditions, food availability, etc. Examples of indexing methods applied to various fossorial mammals are given in Table 2.

Many carnivore indices are based on observations of active responses by the animals resulting from their predatory, investigatory, or territorial behaviors. These include the use of scent stations or bait stations to elicit tracks or snag hair samples, and the use of sirens to induce a howling response in canids (Table 3). Other indexing methods are passive in that they are not seeking a response to the observer's activities, but rather are observations made on the routine behaviors of the animals. Scat deposition rates and tracking rates not incorporating attractants are examples of passively obtained observations for producing indices. Nighttime searching by spotlight takes advantage of the nocturnal behavior of many carnivores. Catch-per-effort surveys also actively seek the animals, but usually modify the population being studied. Many of the problems common to indexing other animals also apply for predators. Weather can dramatically affect animal behavior, the ability to elicit and observe a response, observability of tracks, the decomposition rate of scat, etc. Some methods induce differential response rates by different members of a social hierarchy or status, such as territorial and nonterritorial responses of canids to scent stations (Allen et al. 1996; Windberg and Knowlton 1990).

EXAMPLES OF INDEX APPLICATIONS

Here we give examples of how indirect monitoring methods can be applied to achieve a variety of objectives: determination of presence or absence, spatial distribution, index population abundance/activity, and evaluation of control efficacy. We include examples of tested methods for fossorial mammals and for carnivores.

The first example we consider is directed at northern pocket gophers on reforestation sites. Pocket gophers likely account for more damage to natural regeneration and artificially planted conifers in the western U.S. than all other animals combined (Crouch 1986). All four of the above monitoring objectives are important for forest managers. The existence of pocket gophers on a site is a key predictor of damage potential and their distribution is used to decide whether control is needed (e.g., Engeman and Witmer, In Press). One prominent approach for monitoring gopher presence and distribution in a reforestation site is to establish a transect through the site, along which a number of plots are placed. The plots, usually 1/100th acre and accounting for up to 5% of the area in the site (Marsh and Steele 1992), are observed for gopher sign. The need for control is judged on the proportion of the plots showing gopher activity and the age of the seedlings (if already planted). The same procedure can be used to assess control method efficacy, or other temporal changes in gopher activity, but because northern pocket gophers are usually solitary and they maintain closed burrow systems, the open-hole method (Richens 1967) is usually a more sensitive measure of efficacy (Engeman et al. 1993). Active (occupied) burrow systems are identified by opening two or three holes into the burrows. If a hole is closed upon recheck 24 to 48 hours later, the system is considered active. The process is repeated on the same burrow systems after control to yield a high-quality estimate of control efficacy. The same method can also be used to measure reinvasion into a controlled site. We reiterate here that, while the open-hole method has been applied to a variety of pocket gopher species, it has been validated on but a few, and appears inappropriate for some species (Matschke et al. 1994).

The carnivore monitoring method that we highlight uses the same observational method to monitor presence or absence as it does to index abundance and control efficacy. Passive tracking plots are placed at regular intervals on lightly used dirt roads or trails. The spacing of the plots is dependent on the species of interest and the size of the area to be indexed. Each plot is observed on consecutive days, not for presence or absence of tracks, but for the number of track intrusions by each species into the plot (Allen et al. 1996; Engeman et al. 1999a). This measure contains more information than the binary observation and has been shown to be much more sensitive for indexing animal abundance. The passive nature of the tracking plots not only avoids the behavioral

biases, such as conditioning or neophobia, potentially associated with attractant based tracking plot methods, but by not targeting a particular species with an attractant, it permits the simultaneous monitoring of a variety of species (Allen et al. 1996; Allen and Engeman 1995; Engeman et al. In Press-b). In Queensland, Australia, this method was used successfully to index the abundance of dingoes (*Canis lupus dingo*), some of their prey species, and other animals living in the area, including the documentation of the presence of koalas (*Phascolarctos cinereus*), which had not been observed for 15 years (Allen and Engeman 1995). The same versatility held true in Texas, where coyotes were indexed along with ungulates, a variety of prey species, and also competing predators, such as bobcats (*Felis rufus*) and raccoons (*Procyon lotor*) (Engeman et al. In Press-b; Engeman Unpubl. data). One of the strongest points of the method is that the statistical properties inherent to its data structure permit calculation of standard errors, confidence intervals, and statistical tests, without subjectively subdividing the data, and without making unjustified assumptions about the independence of plots or days. Thus, efficacy of control was easily tested and the dynamic of removing a large proportion of one predator population on another predator population was examined (Engeman et al. 1999a). The observations from the plots were also used to spatially optimize the location of control devices.

CURRENT RESEARCH

We are currently conducting research in a number of areas relative to monitoring various species of pest animals. In some cases, we are extending and validating existing methods on new species or new habitats. In others, we are refining existing methods or optimizing their application, as well as developing new methods. Additionally, we are deriving the quantitative theory to maximize the utility and information gained from index methods. To encourage the development of relevant and practical indexing methods, we describe below some of the research efforts at the National Wildlife Research Center relative to indexing pest animal populations.

Chew cards were developed in Australia as a mouse population index for use in predicting mouse plagues (Caughley et al. 1998). We are currently experimenting with card designs and materials for application to North American rodents, specifically voles (*Microtus* spp.) (Witmer Unpubl. data). Our experiments also involve relating the average proportion of cards missing to population density and correlating chew card results with the apple slice index (Tobin et al. 1992) as the standard method. We are looking into computerized means to rapidly and accurately measure consumption on each card, and we are deriving the covariance structure for the data to produce precise variance estimates, confidence intervals, and statistical tests.

Tracking tiles have long been used for obtaining binary observations on the presence of rodents (e.g., Mayer 1957). We are currently developing continuous, rather than binary, measurements from tracking tiles for producing a more sensitive abundance index. We also are testing computerized measurement methods so that multiple species may be observed simultaneously, and we are deriving the appropriate covariance structure for this method, too.

We recently completed a study to optimize the application parameters for using the open-hole method to assess northern pocket gopher activity (Engeman et al. 1999b). We continue to evaluate ways to make the method more practical to apply in the field, while retaining its sensitivity for assessing activity. We also have been assessing this method for indexing other species of pocket gophers.

We have been researching a variety of possibilities for applying the passive tracking plot method described in the previous section. We recently compared off-road plot placements to placement on dirt roads, and found that off-road placements were far less likely to obtain enough intrusions to produce an index, were less sensitive to population changes, required greater effort to implement, and were more prone to methodology-induced observation biases (Engeman Unpubl. data). We currently are testing applications for new species in new habitats. Because feral pigs (*Sus scrofa*) were indexed as ancillary species in Queensland (Allen, pers. comm.) and Texas (Engeman Unpubl. data), the passive tracking index was selected for application to a palmetto/scrub pine habitat in Florida to evaluate the efficacy of a control program. At the same time, the plots will be used to monitor for coyote population expansion into the area. An even further reaching application is underway at a nearby wildlife refuge in Florida. For a variety of objectives, the passive tracking plots will be used along the beach to monitor the activities of the two primary predators of sea turtle nests, raccoons and armadillos (*Dasypus novemcinctus*). The first objective is to monitor the movement of the predators to the beach as turtle nesting season commences. The index will then be used to determine when to implement predator control, and the plots will be used to optimally locate traps for maximal effect. After completion of a control contract, the index will be used to evaluate the efficacy of control. Continued monitoring will provide information on whether a subsequent control contract is needed during turtle nesting season.

Occasionally only binary observations can be made at a plot or a station. For those situations we have been deriving the appropriate covariance structure for the data without making unreasonable assumptions of independence among stations or over time. If the application parameters can be optimized for the purpose, an index for brown tree snake (*Boiga irregularis*) abundance might be based on their take of dead neonate mice from bait stations.

Because many of the indices we have been examining possess useful statistical properties, and because many can be used in conjunction with control programs where a known number of animals is removed, another one of our research aims is evaluate whether a change-in-ratio estimator of population density can be derived. We also would evaluate the quality of the estimates in a variety of situations. Depending on those results, a link between a simple-to-apply index and an estimate of population density could be produced when efficacy of control is evaluated using the index.

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