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Science deficiency in conservation practice: the monitoring of tiger populations in India

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Abstract

Conservation practices are supposed to get refined by advancing scientific knowledge. We study this phenomenon in the context of monitoring tiger populations in India, by evaluating the 'pugmark census method' employed by wildlife managers for three decades. We use an analytical framework of modern animal population sampling to test the efficacy of the pugmark censuses using scientific data on tigers and our field observations. We identify three critical goals for monitoring tiger populations, in order of increasing sophistication: (1) distribution mapping, (2) tracking relative abundance, (3) estimation of absolute abundance. We demonstrate that the present census-based paradigm does not work because it ignores the first two simpler goals, and targets, but fails to achieve, the most difficult third goal. We point out the utility and ready availability of alternative monitoring paradigms that deal with the central problems of spatial sampling and observability. We propose an alternative sampling-based approach that can be tailored to meet practical needs of tiger monitoring at different levels of refinement.

INTRODUCTION

Conservationists generally agree with the proposition that conservation practices should be based on sound science. For example, understanding the population dynamics of a species in decline is known to be central to implementing appropriate recovery practices (Burgman, Ferson & Akçakaya, 1993; Lancia, Nichols & Pollock, 1994). In reality, however, conservation measures are often initiated on the basis of sparse data and incomplete knowledge. Theoretically, these lacunae are subsequently addressed through the absorption of advancing scientific knowledge into conservation practice. Methods, data and practices of conservation are all supposed to get continually refined through an adaptive feedback process that involves the process of scientific peer-review and publication (Walters, 1986; Nichols, Johnson & Williams, 1995; Pulliam, 1995). However, in practice, the pace at which conservation practitioners absorb new scientific knowledge may be too slow to assist species recovery.

In this paper, we examine the above issue in the context of the conservation of the tiger (*Panthera tigris*) in India. Reliable estimation and effective monitoring of demographic parameters in wild tiger populations are of central concern to conservationists (Karanth & Nichols, 1998, 2002; Seidensticker, Christie & Jackson, 1999). Indian tiger monitoring efforts provide a unique opportunity to examine to what extent new scientific advances influence conservation practices, for the following reasons. First, Indian tiger conservation has involved 30 years of serious official commitment leading to sporadic recovery of tiger populations (Mountfort, 1981; Thapar, 1999; Karanth, 2001). Second, Indian officials have used a single approach called the 'pugmark census method' to monitor tiger populations throughout the above period (Choudhury, 1970, 1972; Panwar, 1980; Singh, 1999). Third, new knowledge about tiger ecology (Schaller, 1967; Sunquist, 1981; Seidensticker & McDougal, 1993; Smith, 1993; Karanth & Sunquist, 1995, 2000; Karanth & Nichols, 1998, 2000; Chundawat, Gogate & Johnsingh, 1999; Miquelle *et al*., 1999), as well

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as development of new methodologies of animal population monitoring (Seber 1982; Thompson, 1992; Lancia *et al*., 1994; Thompson, White & Gowan, 1998; Williams, Nichols & Conroy, 2002), both advanced greatly during the same period.

In this paper, we describe a statistical framework that underpins modern animal population sampling methods (Thompson, 1992; Lancia *et al*., 1994; Thompson *et al*., 1998; Williams *et al*., 2002). We then evaluate the biological and statistical bases of the pugmark census method. Based on our analysis, we propose an array of alternative tiger monitoring methods within the statistical framework described by us.

A REVIEW OF TIGER POPULATION MONITORING ISSUES

The analytical framework

Most modern methods of animal population sampling/estimation come under a general statistical framework that deals with two central concerns: spatial sampling and observability (Thompson, 1992; Lancia *et al*., 1994; Thompson *et al*., 1998; Williams *et al*., 2002). Spatial sampling concerns the frequent inability of animal survey methods to cover the entire area of interest. In such cases, we representatively survey some subset of that area, and then use these results to draw inferences about the entire area. Observability concerns the typical inability to detect and count all animals (or their sign) in the surveyed area, requiring us to estimate the underlying detection probabilities from our sample counts. Using this framework, Lancia *et al*. (1994) described the following general estimator for the number of animals in a population: $\hat{N} = C / \hat{\alpha}\ \hat{p}$, where $\hat{N}$ = estimated number of animals in the population within the total area of interest, C = count statistic, or the number of animals counted during the survey, $\hat{\alpha}$ = estimated proportion of the total area which was actually covered during the survey, $\hat{p}$ = estimated proportion of animals occurring in the surveyed area that were counted.

In a true animal census, by definition, the entire area of interest is *assumed* to be covered by the survey, and *all* animals in the area are *assumed* to be counted. There are strong assumptions in a census that $\alpha = 1$ and $p = 1$, so that $C = N$ in the above general estimator. If either of these major assumptions is invalid, the survey cannot be considered a true 'census' (Lancia *et al*., 1994; Thompson *et al*., 1998).

However, because biologists realize that true 'censuses' that ensure $\alpha = p = 1$ are rarely feasible in the field, they employ 'sample surveys' in which α and p are modelled, estimated and then combined with the count statistic C to derive estimates of population size ($\hat{N}$) (Thompson *et al*., 1998; Williams *et al*., 2002). Under this approach, several plausible models that generated the sample can be tested against the field data, to select the most appropriate model using objective criteria (Burnham & Anderson, 1998). Even when estimates of absolute animal abundance $\hat{N}$ cannot be derived because of practical constraints, the above sampling framework can be used to generate indices for comparing the relative abundances of animals at two points in time or space. In such cases, the investigator hopes to establish at least a monotonic relationship between count C and true animal abundance N by standardizing the survey protocols to ensure that values of α and p are similar between surveys. Even where direct counting of animals is not feasible, and only their sign, such as tracks or scats can be recorded, this sampling framework can still be employed to estimate probabilities of detecting sign, thereby enabling the investigator to estimate relative abundance or habitat occupancy with greater rigour (Thompson *et al*., 1998; Mackenzie *et al*., 2002; Williams *et al*., 2002).

The pugmark census approach to monitoring tigers

The 'pugmark census' was invented in 1966 by Indian forester S. R. Choudhury (Choudhury, 1970, 1972). In this census, during a 1–2-week period, thousands of forestry department personnel simultaneously fan out across India to search for tiger tracks. They are expected to locate the tracks and obtain plaster casts (or tracings) of the imprints of the left hind paws of nearly all the tigers in the entire country. The 'pugmarks' collected are later compared to identify individual tigers relying on perceived differences in shape, other measurements and ancillary local knowledge. These 'individual tiger identifications' are then refined through cross-comparisons among census blocks, reserves and larger regions to obtain what are claimed to be reliable estimates of wild tiger numbers in India. The protocol for conducting pugmark censuses has been described repeatedly in the grey literature but not in peer-reviewed journals (Choudhury, 1970, 1972; Panwar, 1980; Singh, 1999). In this paper we examine only this particular method and not the general use of tiger track surveys for monitoring.

For 30 years, this method has been exclusively used to derive tiger numbers in individual parks and larger regions, and on a country-wide basis. It is claimed that the pugmark censuses yield accurate results in a cost-effective and practical manner (Panwar, 1980; Singh, 1999). However, because the objective is 'censusing' rather than 'sampling' tiger populations, the practitioners do not record the field effort invested or try to derive estimates of α and p within any kind of estimation framework. Instead, they assume, without any evidence, that $\alpha = p = 1$.

Biological basis of the pugmark census

The pugmark census method assumes that adult female and male tigers spatially exclude same-sex conspecifics. Choudhury (1970, 1972) even suggests that tigers live in pairs. Panwar (1979) opines that transient tigers reside in marginal habitats away from core breeding areas. Singh (1999) adds that tiger populations at higher densities have a relatively lower proportion of transient tigers. On the basis of such conjectures, the census method assumes that probability of tracks of the same individual being found in different counting units is negligible, thus avoiding multiple counts (Singh, 1999).

The above premises can be examined in light of scientific data on tiger ecology (Schaller, 1967; Sunquist, 1981; Karanth & Nichols, 1998). These data show that tigers are polygynous animals that do not form pair bonds (Smith, McDougal & Sunquist, 1987; Smith, 1993). Although breeding tigers may occupy exclusive ranges in some high-density areas, same travel routes are intensively used by neighbours (Sunquist, 1981; Smith, 1993). In other areas, the overlap between individuals is considerable (Karanth & Sunquist, 2000). In low tiger density areas, even breeder ranges show large overlaps (Miquelle *et al.*, 1999). More importantly, adult male ranges spatially overlap ranges of two to six breeding females (Sunquist, 1981; Smith *et al.*, 1987; Smith, 1993; Chundawat *et al.*, 1999). Both male and female transient 'floaters' also move back and forth across breeding territories (Smith, 1993; Karanth & Sunquist, 2000). Tiger populations at higher densities have higher proportions of transient individuals (Karanth & Nichols, 1998, 2000). Karanth (1987, 1988) has pointed out additional inconsistencies in census results: the lack of correlation between reported prey densities and tiger densities, as well as unrealistic long-term population growth rates over large regions. Thus, ecological data on tigers from field studies do not support the major biological assumptions as well as results generated from pugmark censuses.

Statistical basis of the pugmark census

Choudhury (1970, 1972) and Panwar (1980) claim that a total (or nearly total) count of all tigers in an area can be reliably obtained by the census. Singh (1999) concedes the possibility of some undercounts, but not of any overcounts. This means the term $\alpha p \leq 1$, but never > 1. Therefore, the following assumptions must hold true for the pugmark method to be statistically valid:

1. The entire potential tiger habitat in India is effectively covered during the pugmark census.
2. All the four paw prints of every individual tiger in the surveyed area are detected during the censuses.
3. The same hind pugmark of each one of these individual tigers is lifted from suitable and comparable substrates or from standardized soil track-plots.
4. The shape of each pugmark lifted is recorded without distortion by thousands of census personnel involved in the operation.
5. Supervisory officials are subsequently able to segregate the pugmarks of each individual tiger correctly, based on footprint shape, track measurements, and prior local knowledge. They are expected to do so using either subjective skills (Singh, 1999) or multivariate statistical approaches (Sharma, 2001).

We note that all the above conditions must be satisfied if the pugmark census is to work at all. Furthermore, failure of assumptions 1 and 2 would lead to under-counts ($\alpha p < 1$), failure of assumptions 3 and 4 would lead to overcounts ($\alpha p > 1$), and failure of assumption 5 could lead to either undercounts or overcounts.

Therefore, the pugmark census depends on several complex, unstated statistical assumptions. Failure of these assumptions can potentially influence the magnitude of both α and p to vary from 0 to > 1, with the result that the count C may have no predictable relationship with the true tiger population size N.

In the following section, using ecological data, experimental evidence and our own field observations, we show how several underlying assumptions are violated during pugmark censuses.

Violations of the assumptions

Surveying the entire area

Potential tiger habitat in India extends over 300,000 km^2 area (Wikramanayake *et al.*, 1998). In reality, only an unknown fraction of this area is searched intensively during censuses (Karanth, 1999). For example, about 300 km^2 out of the total 3000 km^2 Namdapha Tiger Reserve were covered in the 1996 census. In reserves like Nagarahole and Bandipur, census teams of three to four persons who walk about 15–20 km/day are unrealistically assumed fully to search blocks of 10–15 km^2. In reality, logistical constraints (e.g. in Namdapha, Sundarban), security concerns (e.g. in Nagarjuna Sagar, Indravati and Manas reserves) or staff shortages (almost everywhere) restrict the proportion of the area covered by field teams (Karanth, 1999).

Locating the tracks of every individual tiger

The probabilities of finding the tracks of each individual tiger in the surveyed area are low, except in a few reserves with high road density and suitable substrates. Over most of India, particularly in the Western Ghats and Northeastern hills, difficult substrate conditions and terrain hinder the finding of tiger tracks. For example, in Nagarahole reserve, which has a high tiger density of 12 tigers/100 km^2 (Karanth & Nichols, 1998), tracks were impossible to detect along many tiger travel routes because of inappropriate substrates although radiotelemetry and camera trapping showed intensive tiger movements along them.

Selecting the appropriate footprint

Lifting footprints from a firm substrate overlaid with dust or sand is an essential precondition to obtaining accurate pugmarks. Admittedly, prints lifted from loose or muddy soil invalidate the identifications by distorting track shapes (Choudhury, 1972; Panwar, 1980; Singh, 1999). However, such ideal soil conditions do not occur in most areas, thereby forcing census personnel to lift prints from inappropriate substrates (Karanth, 1987, 1988).

Laying down artificial track-plots (called 'Pug Impression Pad's), is advocated as a solution to the problem of unsuitable substrates (Panwar, 1980; Singh, 1999). However, track-plots often do not work because of practical problems: lack of suitable soil in the vicinity, logistical problems in transporting soil, and the effects of rain, wind or animal movement. For example, the track-plots observed in Namdapha during the 1996 pugmark census were made from the wrong soil type. Although the 2600 km^2 delta of Sundarban Tiger Reserve obviously lacks the appropriate substrate, track-plots are not employed because of logistical difficulties (K. U. Karanth, pers. obs.)

Unless clear impressions of all the four paws on the right substrate are detected for *each individual tiger*, it is impossible to pick the *same hind pugmark* of each individual for comparisons, as prescribed by the pugmark method (Choudhury, 1970, 1972; Panwar, 1980; Singh, 1999). In reality, census personnel often do not find clear prints of all four paws, and consequently lift prints of the different paws of the same animal from different localities.

Recording and recognizing tiger tracks

The shape of the same tiger footprint traced by different persons may vary considerably (Choudhury, 1972; Sharma, 2001). This variation can be reduced by using well-trained persons in controlled trials (Sharma, 2001), but not in field censuses involving thousands of personnel with varying levels of skills.

The pugmark method assumes that supervisory officials can identify and segregate tracks of each individual tiger from the pugmarks brought in by field teams. However, Karanth (1987) demonstrated through a blind test involving footprints from captive tigers obtained from varying substrates that even experienced census personnel failed to segregate individual animals correctly. More recent validation tests done in captivity on standardized substrates (Riordan, 1998; Sharma, 2001) suggest that the ability of 'experts' (or multivariate statistical tests) to discriminate individual tracks improves somewhat if there are less than 12 individual tigers involved in the comparisons.

The crucial point at issue here is not whether the prints of the same paw obtained from standard substrates and compared among a small number (< 12~17) of individual tigers can lead to the correct identification of a high proportion of individuals (Riordan, 1998; Sharma, 2001). Such controlled studies simply do not address other serious problems with large-scale field 'censuses' we have described above. Moreover, how the probabilistic 'individual tiger identifications' derived from statistical track-discrimination can be used for population estimation in a general sampling framework (Thompson *et al.*, 1998; Williams *et al.*, 2002) remains unexplored.

CONSERVATION IMPLICATIONS

Utility of pugmark census for monitoring tiger populations

We emphasize that while tiger monitoring methods must be practical, they should also be scientifically defensible. Invalid data inhibit progress towards potential solutions, whereas lack of data might actually encourage such progress (Karanth, 1999).

We identify the following three critical goals (Karanth, 1999; Karanth & Nichols, 2002) relevant for monitoring wild tiger populations in India: (1) periodic measures of the expansion or contraction of distribution of tiger populations based on geo-referenced habitat occupancy data on a country-wide basis; (2) annually derived indices of relative abundance that reflect changes in tiger numbers in important reserves, at least in terms of detecting increases, declines or stability; (3) measures of absolute abundance or densities of tigers at high-priority sites.

Although an elaborate record-keeping protocol has been prescribed for the pugmark censuses (Choudhury, 1972; Panwar, 1980; Singh, 1999), this protocol essentially ignores the fundamental need for mapping and geo-referencing the tiger signs that are detected by field personnel. As a result, even after 30 years of pugmark censuses, large-scale, country-wide maps of tiger spatial distribution are not available.

Because the effort expended by the field teams in terms of search routes, distances covered and time spent looking for tiger tracks has not been recorded or replicated over successive pugmark censuses in the past, it is not possible now to use the raw counts of tracks obtained even to derive simple indices that can possibly detect changes in tiger abundance or habitat occupancy over time.

In fact, the pugmark census method (Choudhury, 1970; Panwar, 1979; Singh, 1999) does not even consider the above two simple monitoring goals that are adequate for most management purposes. It primarily addresses the third and most difficult goal, that of measuring the absolute abundance of tigers, on a country-wide basis. Because the pugmark census fails to attain its unrealistic goal, three decades of tiger monitoring has basically failed in India, despite being backed by massive investments and the best of intentions.

This failure has, inevitably, led to poor conservation practices. For example, field managers initially reported an increase in tiger population in 1994, despite mounting evidence of deteriorating reserve protection and increasing poaching pressure (Thapar, 1999; Karanth, 2001). In response, the authorities of Project Tiger arbitrarily reduced census tally by 750 tigers, to instil a sense of 'crisis' among field officials. Although the situation has not improved greatly thereafter, recent pugmark censuses are once again reporting increasing 'tiger numbers'.

Possible alternative approaches to monitoring tigers

In a brief review of this nature, it is not possible to describe all possible approaches to monitoring tigers based on the sampling framework we proposed earlier. Some of us, and other workers, have tried to do so elsewhere (Karanth, 1988, 1999; Karanth & Nichols, 1998, 2002; McDougal, 1999; Miquelle *et al.*, 1999). We briefly reiterate below a few alternative approaches that can meet tiger monitoring needs at different levels of resolution.

(1) As tiger habitats become fragmented and degraded

local populations may be extirpated. On the other hand, if conservation measures are successful, habitats may get reconnected or restored, establishing new or larger populations. Therefore, at the national level (> 300,000 km^2 of tiger habitat) it is critical to document annually the spatial distribution (presence or absence) of tigers. This goal can be met by modifying the present large-scale, labour-intensive pugmark censuses into surveys of tiger sign that involve merely recording the presence of tiger tracks and other signs under a statistically rigorous sampling design. Such surveys will necessarily involve recording the sampling effort and proper geo-referencing of survey data, but they will not involve the impossible task of individually trying to identify all wild tigers from track prints under field conditions.

(2) At the level of individual reserves, managers need to keep track of annual population trends of tigers to evaluate the effectiveness of conservation interventions. Although desirable, it may not always be possible to obtain rigorous estimates of tiger densities because of lack of material resources or skills. However, even under resource constraints, indices of relative densities of tigers can be derived annually using encounter rates of tiger sign (e.g. number of tiger track sets or scats encountered per 10 km walked, the proportion of 1 km trail segments in which tiger tracks were detected, number of fresh tiger tracks crossing the path of a boat or vehicle). Although such quantitative indices of tiger abundance may not necessarily calibrate accurately to absolute tiger abundance (Karanth & Nichols, 2002), with sufficient survey effort, establishing a monotonic relationship between the index value and tiger abundance may be still feasible. Such standardized, quantitative index surveys of tiger signs will be non-subjective and replicable.

(3) At a few priority sites ecological parameters such as absolute densities of prey and tigers may need to be estimated. In such cases, there is no escape from employing advanced equipment and techniques, and skilled personnel. Such techniques will include line transect surveys of prey densities and camera-trap capture–recapture surveys of tigers (Karanth & Nichols, 1998, 2000, 2002).

The central challenge involves identification of the relevant level of resolution required for tiger monitoring, and then deploying available material and manpower resources within the rigorous population-sampling framework we elaborated earlier. We estimate that during 1999 alone, the central and state governments in India spent about 10 million dollars on tiger-related conservation measures, with non-governmental donors contributing an additional 1.75 million dollars (Thapar, 1999). In the absence of reliable tiger population monitoring, it is impossible to judge the effectiveness of such conservation investments, thus highlighting the urgent need for addressing the deficiencies pointed out in this paper.

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