Monitoring Amur tiger populations: characteristics of track surveys in snow

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Abstract We examined the efficacy of employing a track-count index to monitor trends in abundance of the Amur tiger (*Panthera tigris altaica*) in the Russian Far East. Conservation of the Amur tiger depends upon region-specific information regarding population trends. A traditional tiger census technique has inherent logistical and theoretic constraints, but a logistically feasible and statistically rigorous alternative compatible with the historic tradition of winter track counts has not yet been developed. We used data collected during 434 surveys of foot routes conducted from 1995–1999 to examine characteristics of track counts that will influence monitoring design. Longevity of tiger tracks in snow was 7–8 days in January and February but only an average of 2 days in March. Route length and days since last snow were the 2 most significant design variables explaining variability in detection rate of tracks on survey routes. Variation in track counts observed from foot surveys 0.5 to 28 km long suggested that an efficient survey design would employ routes 10 to 15 km in length. Results of simulations examining power suggested that track counts could be employed as part of a system to monitor Amur tiger abundance given the critical assumption that changes in track counts reflected changes in tiger population size. A monitoring system employing 10 to 20 routes 12 to 15 km long, sampled twice each year, could provide over 80% power to detect a 10% annual decline in tiger tracks with a 20% chance of type I errors ($\alpha=0.20$). Approaches to monitoring large carnivores with track counts usually have employed presence–absence surveys. The greater power to detect population declines that may be achieved through counts of tracks (rather than a presence–absence survey) led us to favor use of track counts to monitor tigers in the Russian Far East.

Key words Amur tiger, conservation, monitoring, *Panthera tigris altaica*, power, Russian Far East, Sikhote-Alin Zapovednik, survey design, trend

The traditional method for monitoring Amur tiger (*Panthera tigris altaica*) populations in the Russian Far East, in use for the past 50 years, employs a series of extensive track surveys designed to represent a complete census, with tiger numbers derived from expert interpretation of track numbers and distribution (Kaplanov 1948, Matyushkin and Zhivotchenko 1979, Pikunov and Bragin 1987, Matyushkin et al. 1996). Employing a number of variations on this standard methodology, Russian biologists reported an apparent bottleneck of 20-30 individuals in the 1930s and 1940s (Kaplanov 1948) and subsequent recovery following protective legislation and restrictions on capture of cubs (Abramov 1961, Yudakov and Nikolaev 1973, Pikunov 1990, Matyushkin et al. 1996,

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Smirnov and Miquelle 1999). However, in the more recent past, these same track data have been interpreted in a variety of ways, resulting in vociferous debate on actual tiger numbers (Bragin and Gaponov 1989, Mescheryankov and Kucherenko 1990, Pikunov 1990, Kucherenko 2001). Because none of these surveys employed a standardized method for defining tiger numbers, or a statistical estimate of error associated with them, conclusions concerning trends in tiger numbers in the Russian Far East remain largely speculative.

As part of ongoing efforts to assist in implementation of the Federal Target Program "Conservation of the Amur Tiger" (enabling legislation, Russian Federation Act No. 795), we designed field studies to test a monitoring program to better assess trends in Amur tiger abundance. Although a variety of methods have been proposed and developed for surveying large carnivore populations including mark-recapture (Karanth and Nichols 1998), probability sampling via aerial surveys (Van Sickle and Lindzey 1991), and feces or hair sampling (Morin and Woodruff 1996), most of these approaches are poorly suited for the low-density Amur tiger population (estimated at 0.1-1.0/100 km^2, Smirnov and Miquelle 1999) spread across a vast territory largely covered with coniferous forests (Miquelle et al. 1999). Additionally, we sought a monitoring program that would complement existing traditional methodologies and associated databases generally accepted by Russian biologists and administrators.

Track surveys have been identified as a potential method to monitor population trends for large felids (Beier and Cunningham 1996) and other carnivores (Kendall et al. 1992) and have a long history of use in counting Amur tigers (e.g., Kaplanov 1948, Abramov 1961, Smirnov and Miquelle 1999). Unlike other subspecies of tigers, the Amur tiger exists in a temperate region where snow provides a continuous tracking medium for several months of the year. However, a rigorous assessment of error and power of traditional Russian methodologies has never been conducted. Therefore, we designed a pilot monitoring program to examine characteristics of tracks in snow and track counts. The pilot program sought to evaluate the efficacy of employing track-count indices as part of a long-term, range-wide monitoring scheme for Amur tigers. The pilot program was partially based on traditional survey techniques in that it relied on an extensive system of transects or routes that were positioned to sample a region for tiger tracks. Using each route as a sample unit, repeated samples over years could indicate trends. The effectiveness of this approach would depend on constraints related to characteristics of tracks and characteristics of track indices. Because our objective was to evaluate these constraints, we structured our analysis around 5 questions that would provide a basis for design of a long-term monitoring program: 1) How long do tiger tracks in snow remain distinguishable and what factors influence track deterioration rates? 2) What survey characteristics influence the number of tiger tracks counted on a route? 3) How does variability in encounter rates of tiger tracks change with increasing route length? 4) How does the proportion of zero counts change with route length? and 5) How does the probability of detecting a change in abundance (power) change as key design features change? Based on this analysis, we evaluated the efficacy of monitoring with track counts and suggest design criteria for a monitoring program.

Study area

To develop a database to assess constraints and precision of tiger track counts in snow, we conducted a series of surveys within and adjacent to Sikhote-Alin State Biosphere Zapovednik, Russia. Zapovedniks are a form of highly protected reserves with mandated management plans to protect and maintain the land in a natural state with virtually no disturbance by humans.

The central features of Sikhote-Alin Zapovednik are the Sikhote-Alin Mountains, a low range that parallels the coast of the Sea of Japan. We restricted our work to the coastal side of the Sikhote-Alin Divide, which, due to a series of fires over the past century, is dominated by deciduous forests, predominantly Mongolian oak (*Quercus mongolica*). More inland, and at higher elevations on the coastal side, a mixture of deciduous and conifer forests is characterized by Korean pine (*Pinus koraiensis*), larch (*Larix komarovii*), birches (*Betula costata*, *B. lanata*, and others), basswood (*Tilia amurensis*), Khingan fir (*Abies nephrolepis*), and Jeddo spruce (*Picea ajanensis*).

Methods

Characteristics of track degradation

We traveled prescribed routes every second day during the winter (January, February, and March)

1995-1999 to locate and monitor changes in individual tiger tracks in snow. We measured width of the front pad, which is a standard measurement used for Amur tigers (Abramov 1961, Matyushkin et al. 1996, Smirnov and Miquelle 1999). We recorded "track longevity" as the length of time it was possible to measure pad width of the front paw. We also recorded date of last measurement and primary cause for track degradation (fresh snowfall, wind, ice overflow, melt-out). We examined track longevity and cause of degradation for 3 months (January, February, and March) to assess variation in track longevity through the winter season, an important feature in protocol design.

Field surveys

We conducted repeated track surveys by walking prescribed routes in and near Sikhote-Alin Zapovednik, employing 5-20 field observers at a time. Routes were chosen to provide thorough coverage of the region within limitations of the trail network and locations of winter shelter. For each survey, field observers recorded date, route length, time since snow, snow depth, primary forest type, and number of tiger tracks that crossed the route. For each tiger trail that crossed the route, the observer measured front pad width, freshness of the sign (estimated to the closest 24-hr interval), and aspect on which the track crossed the survey route.

Track index

Number of tiger tracks encountered on a transect should be related to the abundance of tigers using the area and a number of other variables. Route length, the number of days since snow, forest type along the route, aspect along the route, snow depth, weather conditions following snowfall, and abundance of prey tracks all could influence the number of tiger tracks counted, regardless of the actual abundance of tigers. Preliminary evaluation of these variables suggested that only route length and days since last snow were significantly related to detection of tracks on survey routes. Therefore, we developed an index of tiger abundance from winter track surveys:

$$\text{Track index} = \frac{\text{tiger crossings}}{(\text{route length})(\text{days since snow})}$$

We used this index to examine the influence of survey design criteria on a program to monitor trend in tiger abundance based on track counts. Throughout this paper we assumed that survey routes represented sample units and multiple routes sampled in any region provided an estimate of trend. Evaluations described below standardize track counts using both variables except for some simulations that examined only the influence of route length on the track index.

Analysis

Relationship between route length and variance

We explored the relationship between variance in the track index and route length in 2 ways. Based on a direct analysis of 427 surveys, we evaluated variation in track index in relationship to route length and days since snow. We eliminated 7 of 434 survey records because the recorded number of tiger crossings (and snow trail of the tiger) suggested that a single animal had repeatedly crossed the trail, weaving on and off the path. Observations not included in this analysis were defined as those with a track index value >4 standard deviations from the mean of all observations where tiger tracks were observed. Using this approach, sample size differed greatly among distance categories (for instance, there were 172 foot surveys 0-5 km long but 66 foot surveys 10-15 km) and long survey routes were rare, making it difficult to estimate variation of longer routes.

To examine variability in the track index without the constraints of sample size imposed by the field data, we created a simulation data set with equal samples sizes ($n = 5{,}000$) by randomly combining up to 5 routes from field data to create new routes that fell within 1 of 6 length categories (0-2.9, 3-5.9, 6-11.9, 12-23.9, 24-47.9, 48-96 km). We examined variability in counts of tiger crossings for both the original and artificial data sets by calculating standard deviation and coefficient of variation in the track index for each length category.

Zero counts

Trend analysis procedures using linear regression do not perform well when the proportion of zero counts is high. Therefore, we employed both field and simulated data to examine the relationship between zero counts and route length.

Null model. To determine the functional form (e.g., linear or exponential decrease) of the relationship between zero counts and route length, we simulated surveys in a model 60 × 60-km "landscape." For each computer simulation, 2 "tiger trails" were randomly placed in each 10 × 10-km grid and 4 survey routes of a designated length (from 1 to 35 km long) were placed in the landscape with a random starting point and random direction. To avoid surveying "outside" the landscape, route starting points were constrained to begin within the inner 20 × 20-km grid squares. We counted the intersection of simulated tiger trails and survey routes to determine the number of tiger detections for 2,000 iterations for each of 25 route lengths to generate the function relating proportion of zeroes to route length.

Analysis of field data. We examined field data from survey routes to determine the relationship between zero counts and both survey length and days since snow. We also compared the empirical data to the relationship developed in the simulation model. Patterns were compared qualitatively (visual inspection of plots of proportion zero counts vs. survey length) rather than formally testing the similarity of the distributions because we were interested in whether the patterns were similar in shape rather than whether they reflected the same theoretical distribution.

Influence of survey design on power

Our analysis assumed that trend will be examined using regression methods by testing for a significant slope coefficient based on a *t*-test of the null hypothesis that $B_1 < 0$ (Gerrodette 1987, Gibbs 1995, Thompson et al. 1998). Although other statistical approaches could be employed, we based our analysis on this method because its applicability for monitoring vertebrate populations has been thoroughly assessed in recent literature (see review in Thompson et al. 1998). Other approaches, such as dividing the time series into 2 or 3 intervals and testing for differences using a Wilcoxon signed rank test or employing graphical methods, also might have been useful. However, examining statistical power and other features of the pilot data employing regression provided a focus for analysis to assist in field protocol design.

We used Monte Carlo simulations to determine how route length, number of routes, and alpha (probability of a Type I error) influenced power. Using the program MONITOR 6.2 (Gibbs 1995), we generated 10,000 simulations of track indices over a 5-year monitoring horizon to estimate power to detect an annual change in track index of +10%, +5%, no change, -5%, or -10%. The analyses assumed that tiger tracks will be counted on routes for 5 years and trends assessed with a linear regression model of log-transformed track indices. We followed Thompson et al. (1998) and chose to model exponential rather than linear population growth (or decline) because this model was expected to most closely approximate demographic processes of monitored tiger populations.

We based input values for the simulations on statistical summaries of surveys from Sikhote-Alin Zapovednik from 1995-1999. The simulations required a mean track index and standard deviation for each simulated route. A specified trend (e.g., 5% decrease) was simulated by extrapolating an annual 5% decline, beginning with the specified mean index and then generating random index values each year for five years. The generated indices were drawn from a normal distribution whose mean was equal to the deterministic projection for a particular year and standard deviation based on the estimated value from our field studies. Most simulations assumed sampling from multiple routes to determine trend. Because we expected trend to vary among sites within a region, we assumed that the standard deviation describing trend variation among sites would equal 0.015. This value was based on the standard deviation of the mean track index from 15 survey areas sampled in our field surveys. Because power to detect regional declines will be higher if 1-tailed tests are employed and because ability to detect declines is of paramount importance, we examined the influence of monitoring design criteria on power for 1-tailed tests assuming $\alpha=0.20$. Input parameters for route length, number of routes, and alpha are described below.

Route length. We used mean and standard deviation for the track index from survey routes for each of 5 length categories (0-5, 5-10, 10-15, 15-20 and 20-25 km). Each simulation examined index values over 5 years from a single route sampled twice each year. We focused on a sampling design that surveyed each route twice per year because this provides a link to information collected in the past from the traditional census.

Number of routes. We examined the power of a monitoring system to detect a trend based on 3, 5, 10, and 20 routes. We used track index values corresponding to a mean route length of 8 km from the field surveys, $\alpha=0.20$, and a 1-tailed test.

Alpha or probability of type I error. We examined the extent to which power increased as α was

Table 1. Average duration tiger tracks could be measured after initial location and the cause for degradation of tracks in snow in Sikhote-Alin Zapovednik, Russia, 1995–1999.

	Track duration (days)			Cause for degradation			
	n	$\bar{x}$	95% bound	Melted	Overflow	Snow	Wind
January	59	8.7	0.9	8	4	44	3
February	37	7.8	1.4	2	2	30	3
March	18	2.1*	0.8	14	2	2	0
Total	114	7.4	0.8	24	8	76	6

increased by comparing $\alpha = 0.05$, 0.10, 0.15 and 0.20. For these analyses we simulated a monitoring design employing 10 routes monitored twice each year for five years.

Results

Between 1995 and 1999, we conducted 538 surveys in 13 river basins. Survey routes were walked during periods of complete snow cover (average 7.7±0.456 days after snow) and averaged 7.4± 0.344 km long. We could not use a portion of the surveys due to missing values for some variables. We recorded tiger tracks on 42.2% of the survey routes. For those surveys with at least one set of tiger tracks, we recorded only a single set of tracks on 51% of the surveys and 3 or fewer tracks on 75% of the routes.

Characteristics of track degradation

We measured tiger tracks observed in January and February for an average 7-8 days, but tracks created in March degraded faster ($F = 25.33$; df=2, 111; $P = 0.0001$), lasting on average 2.1 days (Table 1). Warm weather resulted in higher rates of track meltout in March, while in January and February, snowfall was the most common cause (82%) of track degradation (Table 1). Wind played a minor role in track degradation (Table 1) but was more important prior to March when cold snow was prone to blowing.

Factors influencing track counts and variability in track index

Variability in track index relative to survey design. Variability in the track index, as measured by its coefficient of variation, declined with both longer routes and greater intervals since snowfall (Table 2). Standard deviation also declined in relation to days since snow but not in relation to route length.

The simulated data combining individual survey routes further demonstrated the pattern of decline in variance as route length increased (Table 3). These simulations suggested a dramatic decrease in variability between the first 2 distance categories with a negative exponential decline in variability thereafter. The pattern suggested that only marginal reductions in variance could be realized from the extreme effort necessary to produce long survey routes.

Influence of design on zero counts. Simulated track counts demonstrated that the proportion of zero counts should decline as a negative exponential as route length increased. The parameters for the function would be situation-dependent, but

Table 2. Relationship between variability in the tiger track index with route length and days since snow based on field surveys for Amur tiger in Sikhote-Alin Zapovednik, Russia. Variability in the track index is represented by the standard deviation (SD) and coefficient of variation (CV) from a sample of 427 foot surveys conducted from 1995–1999. Distance is expressed as route length categories and time is examined as categories of time since snowfall.

Route length (km)	Time since snow (days)	SD	CV
0–5		0.0435	2.376
5–10		0.0589	2.293
10–15		0.0450	1.983
>15		0.0511	1.357
	1–4	0.0755	2.227
	5–8	0.0374	2.143
	9–12	0.0285	1.802
	≥13	0.0275	1.478

Table 3. Relationship between route length and variability in the track index (Mean, Standard deviation [SD], and coefficient of variation [CV]) from 30,000 simulated track count surveys developed from field data collected from the Sikhote-Alin Zapovednik, Russia, 1995-1999.

	Track index		
Route length	$\bar{x}$	SD	CV
0–3	0.198	0.7141	3.59
3–6	0.162	0.3181	1.95
6–12	0.150	0.2828	1.88
12–24	0.151	0.2121	1.40
24–48	0.153	0.1484	0.97
48–96	0.154	0.1061	0.69

Table 4. Relationship between proportion of zero counts and both route length and time since snowfall for 434 foot surveys conducted from 1995–1999 in Sikhote-Alin Zapovednik, Russia.

Route length (km)	Time since snow (days)	*n*	Proportion zero counts
0–5	1–4	55	0.818
0–5	5–8	43	0.674
0–5	9–12	50	0.600
0–5	≥13	26	0.500
5–10	1–4	68	0.618
5–10	5–8	30	0.700
5–10	9–12	42	0.548
5–10	≥13	37	0.432
10–15	1–4	17	0.529
10–15	5–8	12	0.583
10–15	9–12	16	0.313
10–15	≥13	23	0.348
>15	1–4	7	0.571
>15	5–8	3	0.000
>15	9–12	2	0.000
>15	≥13	4	0.000

clearly the probability of obtaining a count of zero would tend to be smaller when route length was longer and the shape of the function was similar to a negative exponential.

Based on data from surveys, the relationship between zero counts and both route length and days since snow was not similar to the pattern observed with simulated data (comparing Tables 4, 5). As expected, increases in route length or in days since snow both resulted in fewer routes with no tiger tracks. However, the proportion of zero counts from field data for both route length and days since snow resulted in a convex declining function rather than the concave function of the negative exponential. For both variables, a linear model fit the data better than a model in which the independent variable was log-transformed (i.e., a negative exponential model) (proportion zero counts to route length for linear model $R^2=0.945$, $F=34.312$, $P=0.028$; exponential model $R^2=0.753$, $F=6.095$, $P=0.132$). Similarly, regression models relating proportion zero counts to time since snow resulted in $R^2=0.969$, $F=63.315$, $P=0.015$ for a linear model and $R^2=0.815$, $F=8.787$, $P=0.0975$ for the negative exponential model.

Table 5. Relationship between proportion of zero counts and both route length and days since snow for surveys conducted on foot from 1995–1999 in Sikhote-Alin Zapovednik, Russia. Values for route length and time since snow represent the center of respective categories.

Route length (km)	*n*	Proportion zero	Time since snow (days)	*n*	Proportion zero
0–5	207	0.652	1–4	147	0.680
5–10	220	0.573	5–8	90	0.633
10–15	87	0.494	9–12	110	0.527
>15	19	0.211	≥13	90	0.411

Table 6. Relationship between route length and probability of detecting a trend (power) using regression analysis of tiger track index from a single monitoring route. Trend refers to the annual proportional change in the track index (effect size) that the monitoring program is designed to detect. Analysis is based on mean track index and standard deviation (SD) calculated from 427 foot surveys conducted from 1995–1999 in Sikhote-Alin Zapovednik, Russia. Mean and SD refer to the mean index for each route length and the standard deviation of that value calculated from the field surveys.

	Route length (km)				
Trend	2.5	7.5	12.5	17.5	22.5
–0.10	0.409	0.407	0.404	0.421	0.503
–0.05	0.292	0.301	0.293	0.295	0.337
0.00	0.200	0.188	0.201	0.197	0.197
0.05	0.305	0.302	0.299	0.304	0.348
0.10	0.415	0.415	0.400	0.434	0.528
$\bar{x}$	0.0187	0.0213	0.0177	0.0196	0.0150
SD	0.03790	0.04148	0.03800	0.02988	0.01126

Power to detect trends in tiger tracks

Route length. Power increased with route length (Table 6). Based on the variance structure of data from survey routes, the most substantial improvements in power were realized by extending route length from 17.5 to 22.5 km.

Number of routes. Results demonstrated that it is difficult to detect a significant change in tiger tracks based on a single route (Table 6). Results also illustrated that it would be difficult to achieve sufficient power to detect a 5% annual change in tiger track counts even with a sample of 20 routes monitored within any region (Table 7). However, given a 10% annual trend, adequate power was achieved with a sample of 10 routes. The most substantial gains in power were achieved by increasing sample size from 3 to 10 routes. Monitoring more routes resulted in relatively modest increases in power if seeking to detect a trend of ±10%.

Alpha or probability of type I error. Results demonstrated that a significance level (α) below 0.15 would achieve unacceptable power for all effect sizes (Table 8). Decisions regarding choice of (α) would

Table 7. Relationship between number of routes monitored and probability of detecting a trend in tiger track index based on foot surveys. Trend refers to the annual proportional change in the track index (effect size) that the monitoring program is designed to detect. Analysis is based on mean track index and standard deviation (SD) calculated from 427 foot surveys conducted from 1995–1999 in Sikhote-Alin Zapovednik, Russia.

	Number of routes			
Trend	3	5	10	20
-0.10	0.593	0.724	0.892	0.984
-0.05	0.391	0.456	0.583	0.753
0.00	0.194	0.197	0.200	0.196
0.05	0.382	0.458	0.592	0.756
0.10	0.608	0.737	0.908	0.988

depend on judgment regarding the effect size to monitor and the perceived consequences of type I versus type II errors.

Discussion

Is monitoring Amur tigers with track counts feasible?

Our results suggested that track counts could be employed as part of a system to monitor Amur tiger abundance, given the critical assumption that changes in track counts reflect changes in tiger population size. A monitoring system employing 10 to 20 routes 12 to 15 km long, sampled twice each year, could provide over 80% power to detect a 10% annual decline in tiger tracks with a 20% chance of "false alarms" ($\alpha = 0.20$). Achieving this level of power, however, required 1-tailed tests, forcing a manager to look for either a decline or an increase, but not both.

Employing track counts to monitor tiger populations assumes there is a direct relationship between numbers of tracks encountered on a system of sample routes and abundance of tigers. This critical relationship between an index and population abundance has not been tested, and application of an unvalidated index requires careful consideration of potential errors (Thompson et al. 1998). However, Caughley (1977) argued strongly that an index frequently provides the information needed for management. Thorough validation of our index would be extremely difficult because of significant problems encountered in executing the preferred alternative, estimating abundance of Amur tigers.

Table 8. Influence of alpha (level of significance) on power in a test of trend in a tiger track index based on 10 routes surveyed twice each year for 5 years. Trend refers to the annual proportional change in the track index (effect size) that the monitoring program is designed to detect. Analysis is based on mean track index and standard deviation (SD) calculated from 427 foot surveys conducted from 1995–1999 in Sikhote-Alin Zapovednik, Russia.

	Alpha (α)			
Trend	0.05	0.10	0.15	0.20
-0.10	0.624	0.771	0.847	0.887
-0.05	0.258	0.399	0.504	0.586
0.00	0.048	0.096	0.156	0.199
0.05	0.266	0.406	0.503	0.586
0.10	0.653	0.793	0.855	0.901

Probability sampling (Becker 1991, Van Sickle and Lindzey 1991) and mark-recapture using genetic analysis of hair samples or camera traps represent alternative methods for directly monitoring tiger abundance (Karanth 1995, Hornocker Wildlife Institute 1998). These methods avoid the problems encountered with an index. Logistical constraints related to aircraft availability and an inability to detect tiger tracks in forest habitats from aircraft (especially mixed coniferous forests) have inhibited development of probability sampling with aerial surveys. Similarly, low probability of "recapture" with low-density populations might limit usefulness of mark-recapture procedures. The logistical constraints of sampling a rare animal across a vast landscape (nearly 200,000 km^2) will remain for any system employed, but large home ranges and long daily movements (Yudakov and Nikolaev 1979) of Amur tigers make probability of encountering tracks of any given animal during periods of snow cover relatively high. Use of a track index can provide statistical rigor and act as a suitable link to the institutionalized and politically acceptable tiger counts conducted in the past. Therefore, given the theoretical support for a track index to monitor other carnivores (Kendall et al. 1992, Beier and Cunningham 1996), we suggest that this index offers an acceptable monitoring tool.

If the track index represents the most feasible monitoring tool for Amur tigers, can implementation of a monitoring program using the index be defended, given the realistic constraints of power, type I error rates, and the field effort? We feel the design criteria that emerged from our analysis of foot surveys from 1995–1999 support pursuing a program based on the track index. Based on recommendations of this work (as well as other data), monitoring has been initiated in 16 count units (averaging over 1,600 km^2 in size) distributed across tiger range in Russia. This approach provides the opportunity to monitor tiger abundance with a track index as well as to conduct other components of the traditional monitoring program (e.g., indices of reproduction, prey abundance, human impact, and tiger mortality).

Constraints associated with track degradation, in concert with variance associated with route length and time since snow, helped define many of the parameters for designing the monitoring program. Increasing the time since snow will decrease variance (Tables 2, 4, and 5), but this factor must be weighed against the probability of track degradation due to recurrent snow, wind, or melt-out (Table 1). We suggest that surveys conducted 6-8 days after snow during January and February will incur relatively little loss of tracks due to degradation and benefit from reduced variance due to extended time since last snow.

Longer routes resulted in decreased variance and smaller percentages of routes with zero counts. However, feasible route length is limited by the realities of travel time and human endurance. If each route represents a sample unit, counts must be successfully conducted on each route each year, independent of weather conditions. In deep-snow years, a field worker likely will encounter situations that preclude covering more than 15 km. Therefore, we recommend that route lengths average 10-15 km.

Larger numbers of routes per count unit provided a greater probability of detecting trends. Based on the power analysis, we recommend that no fewer than 10 routes be located within each count unit.

A reduced sampling effort would not permit detection of declines of 10%, which we feel is an effect size sufficient to invite a conservation response. Kendall et al. (1992) used statistical methods appropriate for beta-binomial data and examined power of track and scat surveys to detect an effect size of 20%. However, if 350 adult tigers exist in the Russian Far East, a 10% annual decline in abundance would lead to a population of about 200 tigers after 5 years, a change warranting immediate action. Therefore, given the precarious status of the Amur tiger, we feel uncomfortable recommending that a smaller sample effort be employed with the goal of detecting a larger effect size (such as the 20% examined by Kendall et al. 1992). The system we recommend ($\alpha=0.20$) would lead to a relatively high rate of false inferences that tigers are declining when, in fact, they are not. Allowing a type-I error rate of 20% has been defended as a reasonable compromise in endangered-species monitoring (Kendall et al. 1992, Beier and Cunningham 1996). Reducing the frequency of false alarms would lead directly to reduced ability to detect declines, delaying the initiation of further conservation management.

Contrast with presence-absence surveys

The presence-absence approach avoids some problems encountered in our design. Individual tigers might cross a trail repeatedly. Although we measured the size of tiger tracks in an effort to distinguish the number of different individuals crossing the route, we could not be certain of the identity of separate tracks and used the number of crossings rather than number of different individuals encountered. Repeated crossings grossly inflate the track index on a few routes, increasing variance estimates across routes. Future field protocol must have a standardized method of addressing this dilemma.

Despite these problems, we favor a track abundance index over presence-absence data because of the low power of presence-absence surveys. Strayer (1999:1037) recently examined the power of presence-absence data to detect population declines and, like Beier and Cunningham (1996) and Kendall et al. (1992), concluded that power of these designs was "low, especially if population declines are modest (<20-50%)." For large, long-lived vertebrates, a 20-50% annual decline in abundance is alarming. Our analysis suggests that a track index (from track counts) provides a more informative database than presence-absence surveys and significantly improves power to detect declines that are of interest to conservation managers. Analysis methods outlined by Kendall et al. (1992) could be used with such a data base, however, because the presence-absence data are easily extracted from the records.

Management implications

Our analysis suggests that track counts represent a feasible monitoring tool; however, incorporating track counts into a monitoring program for tigers in the Russian Far East will require a sophisticated sampling scheme, which the results of this work will help to delineate. Concurrent with establishing the monitoring program, we suggest initiating a program to test the relationship between track counts and tiger abundance. As methods to directly estimate tiger abundance are tested (e.g., probability sampling) we suggest conducting concurrent track counts based on the design criteria developed in this paper. If a strong relationship can be established between track counts and tiger abundance, confidence in the index will increase and management decisions based on the index can be implemented with greater confidence.

Analysis of trend data from Amur tiger track counts should be conducted with care. In this paper we examined design criteria based on the assumption that trend will be examined through regression analysis; this provided a focus for our analysis of sample size, route length, and days since snow. However, other methods to examine trends are available (Thompson et al. 1998). Critical assumptions of the regression model should be examined with monitoring data. If model assumptions are violated, particularly assumptions of random distribution of residuals and form of the trend, we suggest that permutation or randomization tests be considered (Manly 1997). Design criteria developed in this paper should provide suitable estimates of sample size for the alternative analysis (Thompson et al. 1998). However, randomization methods and nonparametric methods often are less efficient than parametric methods (when assumptions of the parametric method are met). Therefore, sample sizes developed here should be considered minimal and larger samples gathered from the most important regions for tiger conservation.

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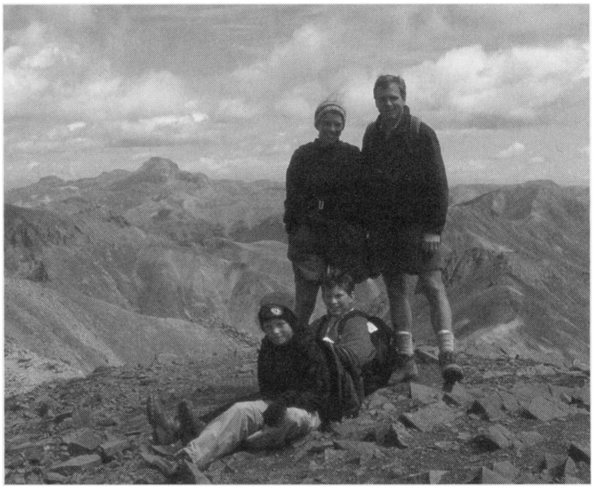

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