A MONITORING PROGRAM FOR THE AMUR TIGER

TWELVE-YEAR REPORT: 1998-2009

In accordance with the Russian National Strategy for Tiger Conservation

A cooperative project conducted by representatives of:

Wildlife Conservation Society
All Russia Research Institute of Wildlife Management, Hunting, and Farming
Institute of Geography, Far Eastern Branch of the Russian Academy of Sciences
Institute of Biology and Soils, Far Eastern Branch of the Russian Academy of Sciences
Sikhote-Alin State Biosphere State Zapovednik
Lazovski State Zapovednik
Ussuriski State Zapovednik
Botchinski State Zapovednik
Bolshe-Khekhtsirski State Zapovednik
Institute for Sustainable Use of Renewable Resources
World Wide Fund for Nature

FUNDING FOR YEAR 12 PROVIDED WITH SUPPORT FROM

THE SAVE-THE-TIGER FUND, NATIONAL FISH AND WILDLIFE FOUNDATION, EXXON CORPORATION
WORLD WIDE FUND FOR NATURE (WWF)
DVO RAN (Far Eastern Branch of the Russian Academy of Sciences)
THE WILDLIFE CONSERVATION SOCIETY

Previous Sponsors include:

Save the Tiger Fund
The Tiger Rhinoceros Conservation Fund, U.S. Fish and Wildlife Service
World Wide Fund For Nature, U.S.
PIN MATRA

PROJECT COORDINATORS:

Overall Coordinator:

Miquelle, D. G., Wildlife Conservation Society, Russian Far East Program

Khabarovski Krai Coordinator

Dunishenko, Yu. M. A, All Russia Research Institute of Wildlife Management, Hunting, and Wildlife Farming (VNIIOZ)
Zvyagintsev, D. A. VNIIOZ
Darensky, A.A. VNIIOZ
Golyb, A. M. VNIIOZ
Dolinin, V. V. VNIIOZ
Shvetx, V. G., VNIIOZ
Kostomarov, S. V., Botchinski Zapovednik

Primorski Krai Coordinators:

Aramilev, V. V., Institute of Geography, Far Eastern Branch of the Russian Academy of Sciences
Fomenko, P. V., WWF, Russian Far East
Litvinov, M. N., Ussuriski State Zapovednik
Nikolaev, I. G., Institute of Biology and Soils, Far Eastern Branch Russian Academy of Sciences
Pikunov, D. G., Institute of Geography, Far Eastern Branch of the Russian Academy of Sciences
Salkina, G. P., Lazovski State Zapovednik
Zaumyslova, O. Yu. Sikhote-Alin Biosphere State Zapovednik
Kozichev, R. P., Agricultural Dept. of Control and Management, Vladivostok.

Data entry, Translations, Report Editing, and Project Management

Nikolaeva, E. I., Wildlife Conservation Society, Russian Far East Program

TABLE OF CONTENTS

A MONITORING PROGRAM FOR THE AMUR TIGER

TWELTH-YEAR REPORT: 2009 WINTER

Executive Summary

Evidence from 12 years of the Amur Tiger Monitoring Program suggests that both key prey species and tiger numbers themselves are declining in the Russian Far East. There is strong evidence that both red deer and roe deer are declining across many of the 16 monitoring sites. Both species appeared to increase during the early years of the monitoring program, and then beginning in 2001 to 2003, populations of prey began to decrease. Evidence for declines in wild boar populations is not as strong, but numbers appear to have dropped in many sites. Even sika deer, which are believed to be expanding across southern Russian Far East, are declining in half of the monitoring sites.

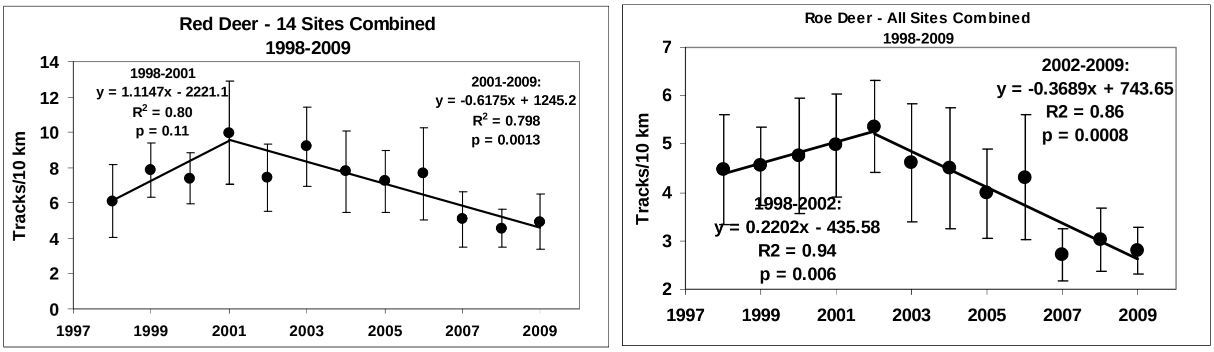

Figure i. Relative abundance of red deer and roe deer, based on track counts, averaged across all sites where they occur on the 16 monitoring units of the Amur Tiger Monitoring Program, 1998 through 2009. For both species, it appears that numbers were slightly increasing or stable from 1998 through 2001 or 2002, when numbers started to decline. Values from 2007-2009 represent the lowest of the 12 years of monitoring.

Both indicators of tiger abundance – track densities and expert assessments of tiger numbers, suggest that tiger numbers are decreasing across the Russian Far East. Tiger track densities in 2008 and 2009 were the lowest reported in the Amur Tiger Monitoring Program.

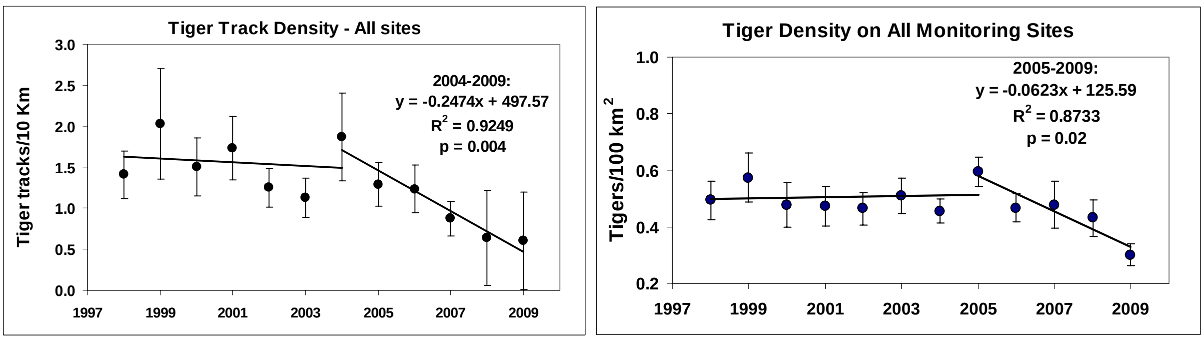

Figure ii. Tiger track densities and expert assessments of tiger numbers averaged across all 16 sites of the Amur Tiger Monitoring Program, 1998-2009.

In 2009, the total number of tigers reported on monitoring sites was only 56 individuals, which represents a 41% decline from the 12-year average (95.2 individuals). Deep snows in some parts of tiger range no doubt reduced movements of tigers, decreasing the chances of detecting many individuals. However, deep snows were not a factor in most monitoring sites, which nonetheless are reporting decreases in tiger numbers.

While the exact magnitude is difficult to define, the overall results indicate that significant declines are underway:

In 11 of 15 sites (73%) red deer numbers appear to be in decline;
In 12 of 16 sites (75%) roe deer numbers appear to be in decline;
In 8 of 16 sites (50%) wild boar numbers appear to be in decline;
In 4 of 8 sites (50%) where sika deer occur, numbers appear to be in decline;
In 13 of 16 sites (81%) tiger track densities indicate tigers are in decline
In 13 of 16 sites (81%0 tiger numbers, based on expert assessments, are in decline.

Any one of these indicators is subject to debate as to their accuracy, but collectively they provide powerful evidence that the situation for tigers and their prey is deteriorating in the Russian Far East. We provide a list of recommendations that represent the key steps to recovering tigers and their prey in the Russian Federation. These recommendations have been reviewed and agreed upon by Russian scientists and non-governmental agencies. We are hopeful that these recommendations can provide a basis for action to reverse the alarming trends in tiger numbers in the Russian Far East.

I. INTRODUCTION

At the international level, the Amur tiger (*Panthera tigris altaica*) is considered in danger of extinction. With only a few individuals remaining in China and an unknown number in North Korea, preservation of this animal has become primarily the responsibility of the Russian government and the Russian people. Accordingly, Russia has taken many steps to conserve this animal, starting with a ban of hunting in 1947. The Russian Federal government has since listed the animal as endangered (Russian Red Data Book), and has developed a National Strategy for Conservation of the Amur Tiger in Russia.

The recovery of the tiger after near extinction in the first half of this century (following the 1947 ban) has been fairly well documented through a series of surveys (Kaplanov 1947, Abramov 1962, Kudzin 1966, Yudakov and Nikolaev 1970, Kucherenko, 1977, Pikunov et al. 1983, Kazarinov 1979, and Pikunov 1990). A range-wide survey in 1996 indicated that 415-476 individuals resided in the Russian Far East (Matyushkin et al. 1996). The most recent survey, conducted in winter 2005, reported 428-502 tigers were in Primorski and Khabarovski Krai (Miquelle et al. 2005). The slight difference between these two surveys was considered a result of more intensive survey effort in 2005, thus suggesting that the Amur tiger population had been stable during this 10-year interval.

Although these full range surveys provide fairly reliable information on tiger numbers, the logistical and financial levels of commitment make them infeasible to conduct on a regular basis. Therefore, despite the wealth of information provided by full range surveys in Russia, there remains a long standing need for a reliable and efficient means for monitoring changes in the tiger population on a yearly basis.

Such a monitoring program should serve a number of functions, including:

1. A monitoring program should act as an "early warning system" that can indicate dramatic changes in tiger abundance. Range-wide surveys, usually conducted between long intervals with no information, may come too late to allow a rapid response to a decline in numbers. Yearly surveys should serve to provide notice so that immediate conservation actions can be initiated.

2. Tiger numbers, or at least trends in the tiger population, should be used as a basis to determine the effectiveness of conservation/management programs. In Russia, there have been tremendous efforts and significant support from regional, Krai-wide, federal, and international levels for implementation of tiger conservation efforts that range from anti-poaching programs to conservation education. All these efforts are aimed at protecting the existing Amur tiger population in Russia, yet without an accurate monitoring program that can determine trends in tiger numbers with statistical accuracy, the ultimate effectiveness of these conservation programs will remain unknown.

3. Among other indicators, a monitoring program should provide information on reproductive rate of the population, which may act most effectively as a predictor, or early indication of imminent changes even before there are dramatic changes in actual tiger numbers.

4. Changes in ungulate populations, as primary prey for tigers, may also provide important clues to potential impacts on tiger numbers.

5. Other indicators that might influence the tiger population, including records of tiger poaching and natural deaths, as well as changes in habitat due to human and natural disturbances.

The tiger is a rare, sparsely distributed, and secretive animal that is distributed across at least 180,000 km^2 of Primorski and Khabarovski Krais in southern Russian Far East. This combination of attributes make it a particularly difficult animal to count reliably, and the financial burden and logistical problems associated with range-wide surveys make it practically impossible to conduct full-range surveys with sufficient frequency to track changes in tiger abundance.

In an attempt to address these needs and constraints, coordinators of the 1996 tiger survey worked in concert with government representatives to develop a reliable and effective monitoring program for Amur tigers. The task is a huge one, given the area involved and the logistics of working in a northern environment. The derived methodology has been tested over 5 years (1997-1998 winter through 2001-2002 winter season) and the results, as provided in the yearly reports, provides an indicator of the value of this program. .

II. GOALS AND OBJECTIVES

The ultimate goal of this program is the yearly implementation of a standardized system for collecting data that can be used to monitor changes in tiger abundance, and factors potentially affecting tiger abundance, across their present range in the Russian Far East. The intent is to provide a mechanism that will assess changes in the density of tigers, as well as other potential indicators of population status, within their current range over long periods of time. This methodology should provide a means of assessing the effectiveness of current management programs, provide a means of assessing new programs, and provide an “early warning system” in the event of rapid decreases in tiger numbers.

Objectives

Specifically, the objectives of this monitoring program are to:

1. 2. Develop a standardized, statistically rigorous estimate of track density within count units as an indicator of trends in tiger numbers over time, and trends in differences in tiger abundance among survey units in the Russian Far East.

2. Develop an expert assessment of actual tiger numbers within count units as a second indicator of population trends over time.

3. Record presence of female tigers with young on count units across the range of tigers to monitor reproduction rates over time and identify areas of high/low productivity, and changes in reproduction over time.

4. Monitor trends over time in the prey base (large ungulates) of tigers within count units.

5. Record and monitor instances of tiger mortality within and in close proximity to count units.

6. Monitor changes in habitat quality.

III. METHODOLOGY

We emphasize that any survey design has limitations, and it is therefore the responsibility of program authors to clearly define their goals and objectives, and the methodology used to obtain those goals and achieve those objectives. The methodology as presented here is intended to address the goals and objectives as stated above.

1. Measures as indices of tiger abundance

All tiger surveys conducted in Russia since the 1940's have either relied on interview data of hunters and forest guards (Kudzin 1966, Kucherenko, 1977, Kazarinov 1979) or have relied on track information collected in winter (specifically track numbers, distribution, size, and age) to develop an "expert assessment" of tiger numbers (Kaplanov 1947, Abramov 1962, Yudakov and Nikolaev 1970, Pikunov et al. 1983, and Pikunov 1990, Matyuskin et al. 1996, Miquelle et al. 2005). Of these two approaches, it is clear that expert assessments provide a more precise estimate of tiger numbers than questionnaires, but even this approach has its drawbacks: different experts interpret data in different ways, providing the possibility for the same data set to be interpreted in different ways (e.g., compare Pikunov 1985 and Bragin and Gaponov 1989, Kucherenko 2001).

Because reliance on a single methodology may lead to mistakes or misinterpretation of data, we developed a methodology that relies on three indicators of tiger abundance: 1) track density on routes; 2) expert assessments of number of tigers in each count unit; and 3) a standardized algorithm that uses the same principles as delineated for expert assessment, but are estimated through a computerized algorithm. These three indicators use the same basic data (as described below to derive indicators of tiger abundance, but because the approaches all exploit that data differently they provide distinct and separate indicators of trends in tiger numbers.

1.1. Tiger track densities

An index of tiger abundance, based on track counts measured on sampling units well dispersed across the total range of tigers, should provide an index of relative abundance of tiger numbers that can be used to monitor trends.

Tiger track densities are expressed as a function of number of tracks recorded along each survey route adjusted by the length of the survey route, and the time since last snow (the greater the interval since the last snow, the more time for tiger tracks to accumulate). The number of tracks is first divided by the length of each route for each survey unit, providing an estimate of tracks/km for each survey route separately. Tracks/km is then divided by the number of days since the last snowfall, providing an estimate of tracks/day/km, which is arbitrarily multiplied by 100 to provide an estimate of tracks/day/100 km. The mean derived from this value for both surveys in each winter is taken as the track density estimator for each separate route.

There are two problems using days since last snow to adjust the track density estimator. First, in a few cases, the date of last snow is unknown, or not reported. Secondly, degradation/elimination of tracks can occur between snowfalls when the interval is large, resulting in an underestimation of track densities. Based on a preliminary assessment in Sikhote-Alin Zapovednik, nearly all tracks become immeasurable after 7-8 days. However, many of these can still be identified as tiger tracks. By approximately 14 days, however, most tiger tracks are fairly well obliterated.

Based on these considerations, we used the following standards for adjusting the track density estimator for days since last snowfall:

1. We set the maximum time interval between snows as 14 for adjusting track abundance, assuming that tiger tracks will deteriorate beyond recognition by that time;
2. I either date of last snow or date route was traveled is unreported, we use 14 days as the interval since last snow.

1.2. Expert assessment of tiger numbers

Coordinators for each site develop an estimate of the number of tigers present on each monitoring site during the winter period (December-February). Their source of data for these expert assessments are threefold: 1) track data from the survey routes, as described above; 2) additional records of tracks on monitoring sites that are not recorded on survey routes during the 2-stage survey (see below); 3) interview information that is collected from local informants. Based on these sources, by comparing track sizes, distances of tracks from each other, dates tracks were created, and the coordinator's understanding of tiger social structure and behavior in relationship to the local physical environment, each coordinator derives an estimate of the likely number of tigers on the study site, and provides an estimate of age (adult, sub-adult, cub, unknown) and sex (male, female, unknown). If evidence of a particular tiger is recorded in only one of the survey periods (i.e., it may have been a transient, may have died, or was simply missed in one of the counts), that animal is nonetheless included in the total count for the study period as a measure of the total number of tigers that were present at some time on the monitoring site during the monitoring period. Details of the criteria used for defining numbers of individuals are provided in Appendix III of Miquelle et al. (2006). While the way in which different experts interpret track data undoubtedly varies, these expert assessments, conducted by the same coordinators on the same sites over extended periods of time, provide a valuable indicator of changes in tiger numbers on that site.

For analyses, we combined all age classes except cubs (adults, sub-adults, and unknown) to form an estimate of number of "independent tigers" (i.e., independent of their mother) existing on a monitoring site during the survey periods. The number of independent tigers is used to estimate tiger density (number of independent tigers/area of monitoring unit x 100 km^2), which provides a basis for comparisons among sites. As with track density estimates, we conduct a trend analysis for all sites combined, and each site separately to assess changes over time.

1.3. Standardized algorithm estimate of tiger numbers

1. In past surveys (prior to 2005) strict and standardized criteria for converting track data into estimates of tiger abundance were never defined. Because of this lack of standardization, comparisons among surveys was difficult, as there was no clear understanding of the potential biases in each survey.. To address this issue, Matyushkin worked with coordinators of the 1996 tiger survey to develop strict criteria to standardize the expert assessment process (these criteria are published in Miquelle et al. 2006), but these criteria were not implemented until the 2005 survey, and even then, expert assessments still included some degree of personal interpretation of track data in assessing tiger numbers. To avoid these problems, we developed an algorithm to estimate the minimum number of tigers in a region based on criteria associated with track size, age of the track, and daily travel distances of tigers estimated from radio-collared tigers. Details of this approach, and sensitivity analyses that indicate how variation in parameters affects results, are available in Miquelle et al. (2006).

Analyses of all three tiger abundance estimators. Variations in all three indicators of tiger abundance can be measured across at least 3 types of parameters:

i. overall trends in tiger numbers (by measuring changes across all count units);

ii. regional variation (assuming the population may be changing differently among regions, by looking for differences in:-

northern, middle, and southern monitoring sites;

-coastal versus inland monitoring sites;

-protected versus unprotected monitoring sites;

iii. variation among sites is likely due to a number of factors, and an assessment of the impacts and conditions within each site may reveal reasons for this variation.

2. Location, Size, and Number of Monitoring Units

Sampling only a portion of the entire distribution of tigers provides a more efficient and cost-effective means of monitoring tigers than an entire count. However, location of sampling units should be well dispersed across the total range of tigers. Changes in count estimates over time within each count unit should provide an indication of changes across the entire range. Furthermore, by creating several count units represented in each key geographic region, it may be possible to detect changes that may be regional or localized.

We delineated a set of count units based on criteria outlined below, and then developed a sampling scheme within each count unit that provides an estimates of tiger and prey abundance.

2.1. Location of count units

Count units should be dispersed across tiger range to represent the full range of conditions in which tigers occur. Both high quality and marginal areas should be monitored. It is important that protected areas be monitoring using the same methodology as in unprotected areas to provide a comparison of the impacts of human activities on tiger populations. We also sought to create "parallel" monitoring units within and adjacent to the larger zapovedniks (Sikhote-Alin, Lazovski, and Ussuriski) to act as paired comparisons of protected and unprotected areas that share nearly all features except protected status. These paired comparisons may act as sensitive indicators of the effect of human impacts.

We determined that the following parameters may be important in determining location of count units:

i. Protected status: protected (as zapovednik)/unprotected areas;
ii. Latitude: northern, central, or southern; and,
iii. Geographic location: inland or coastal.

We defined protected areas only as those areas with zapovednik status. Although some sites are partially or wholly protected as zakazniks (or wildlife refuges) (such as Borisovskoe Plateau and Matai), these designations do not provide the same level of protection afforded to zapovedniks. It is commonly assumed that latitude is an important factor affecting tiger density, and that density decreases at the northern limits of its range. Therefore sites in Khabarovski Krai should theoretically retain lower tiger densities than sites to the south. We assigned all count units to one of three latitudinal sections: *northern*, which includes all of Khabarovski Krai; *central*, which includes the northern half of Primorski Krai; and, *southern*, which includes the southern half of Primorski Krai. Finally, there are important habitat differences between *coastal* areas (i.e., those drainages that flow into the Sea of Japan) and *inland* sites (all drainages that flow into the Ussuri and/or the Amur River). Because forest types and weather varies between coastal and inland sites, it is possible that ungulate densities, and ultimately tiger densities, also vary. In all cases except for Borisovskoe Plateau, this designation represents the west and east sides of the Sikhote-Alin Mountains, respectively.

2.2. Number of count units

The number and location of count units should be determined by a number of factors:

i. Representation: there should be adequate representation of the environmental variables as defined above; and

ii. the sample size should be sufficient to allow statistical analyses for overall trends in population and differences due to environmental variables (e.g., protected/unprotected);

iii. Infrastructure support: there should be personnel and an infrastructure that will insure long-term monitoring will be consistently carried out on all designated sites;

iv. financial constraints will largely limit the number of sites that can be consistently funded.

2.3. Size of count units

Our criteria for determining size of count units were as follows:

i) potential for variability in tiger numbers. To detect changes in tiger density, a count unit must be sufficiently large to detect fluctuations over time, hopefully reflecting the conditions for tigers in the representative region. In other words, count units should be large enough to have a low probability of tigers being completely absent from the area during the survey period (if tigers are perennially absent from a count area, it is impossible to detect changes in population density), and large enough so that several or more tigers might be present. Hence, a monitoring unit should, at a minimum, should be large enough to contain 2-3 female territories.

ii) minimum size to provide variability but keep expenses low. Given that units must be large enough to contain several potential female home ranges; count units should be as small as possible to minimize the expenses of monitoring.

iv) natural or predefined boundaries. Count units should have natural boundaries reflecting geographic constraints on tiger movements (e.g., high ridgetops, large rivers) or predefined boundaries (e.g., protected areas boundaries, county or krai boundaries).

In good tiger habitat, assuming that female home ranges average 400-500 km^2 (Miquelle et al. 1999) 100,000 - 150,000 ha may contain 2-3 adult resident females, at least 1 adult male, transients, dispersers, and cubs. Therefore, we sought to create count units of approximately this size. Some exceptions were inevitable. For instance, the size of existing protected areas is obviously fixed (although with larger protected areas we sought to sample only a portion of the region). In general, we sought to keep count units with the range of 1000 - 1500 km^2.

Table 1. Monitoring sites selected for the Amur tiger monitoring program in the Russian Far East.

#	Name	Size of unit (km^2)	Krai	Status	Latitude	Geographic location
1	Lazovski Zapovednik	1192.1	Primorye	Zapovednik	southern	coastal
2	Lazovski Raion	987.5	Primorye	unprotected	southern	coastal
3	Ussuriski Zapovednik	408.7	Primorye	Zapovednik	southern	inland
13	Ussuriski Raion	1414.3	Primorye	unprotected	southern	inland
6	Borisovkoe Plateau	1472.9	Primorye	Zakaznik (partially)	southern	coastal
7	Sandagoy (Olginski Raion)	975.8	Primorye	unprotected	southern	coastal
4	Vaksee (Iman)	1394.3	Primorye	unprotected	central	inland
5	Bikin River	1027.1	Primorye	unprotected	central	inland
14	Sikhote-Alin Zapovednik	2372.9	Primorye	Zapovednik	central	coastal
15	Sineya (Chuguevski Raion)	1165.4	Primorye	unprotected	central	inland
16	Terney Hunting lease	1716.5	Primorye	unprotected	central	coastal
8	Khor	1343.8	Khabarovsk	unprotected	northern	inland
9	Botchinski Zapovednik	3051	Khabarovsk	Zapovednik	northern	coastal
10	Bolshe Khekhtsirski Zapovednik	475.6	Khabarovsk	Zapovednik	northern	inland
11	Tigrini Dom	2069.6	Khabarovsk	unprotected	northern	inland
12	Matai River Basin (Zakaznik)	2487.6	Khabarovsk	new zakaznik	northern	inland

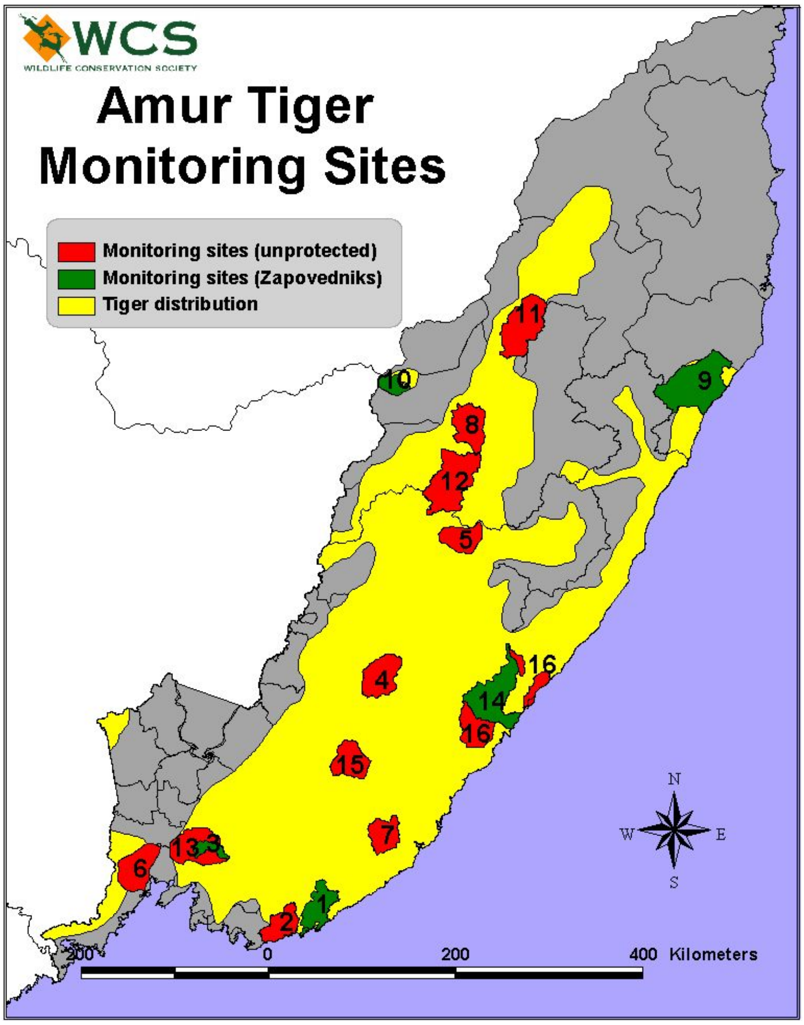

Figure 1. Location of the 16 sites used for monitoring Amur tigers in the Russian Far East. Numbers referenced in Table 1 and most other tables throughout text.

Table 2. Characteristics of monitoring units for tiger monintoring program.

	Protected (zapovednik)		Unprotected		
	Inland	Coastal	Inland	Coastal	Total
Southern	1	1	1	3	6
Central	0	1	3	1	5
Northern	1	1	3	0	5
Total	2	3	7	4	16

Given these constraints and requirements, sixteen permanent monitoring units were created to be representative of the range of conditions across the present distribution of tigers (Figure 1, Table 1).

Summarizing the count units on the basis of the environmental variables outlined above shows that the resulting distribution of sites is well dispersed in a north-south gradient (6 southern, 5 central, and 5 northern) and the inland versus coastal gradient (9 inland, 7 coastal).

Included as monitoring units are all 5 zapovedniks that have potential tiger habitat. Obviously, location, size, and number of protected areas were not variables we could determine or randomize, limiting the extent to which we could develop a balanced design (Table 2). An imbalance of this design also exists in the distribution of unprotected sites in inland versus coastal areas (7 versus 4), but we were constrained here by personnel and infrastructure capacities in selecting sites. In Khabarovsk (northern section), there is little coastal habitat for tigers, and access is very difficult. Hence, except for Botchinski Zapovednik, no effort has been made to monitor the northern coastal region.

3. Data be collected within Monitoring sites

3.1. Use of survey routes

Forty years of experience surveying tigers in the Russian Far East has demonstrated that counting tracks encountered while snow is on the ground along well-placed routes can be an effective means of describing the distribution and numbers of tigers in a region. Unlike other tiger range, in the Russian Far East the snow cover afforded in the winter season provides a continuous medium which reveals presence of tigers, and usually retains that evidence for an extended period.

3.2. Location of survey routes

Two potential approaches exist for positioning routes: either distribute them randomly throughout a given count unit as a non-biased indicator of the presence of tigers within the region, or place them along routes that have the highest probability of encountering tiger tracks. Because our interests lay maximizing probability of detecting changes over time, it is more important that there be a high probability of tiger tracks being encountered along routes. If a large percentage of routes are devoid of tracks, there is no means of detecting changes in tiger numbers. Therefore, we sought to position routes to maximize the chance of intersecting tiger tracks, and to minimize the number of zero counts. Maximum efficiency of encountering tracks can be achieved by positioning routes along trails, ridgetops, roads, or natural travel corridors where tigers are most likely to travel (Matyushkin 1990).

3.3. Route length

Routes should be sufficiently long so as to have a high probability of encountering tracks, and should be of a length sufficient to reduce the variability of tracks encountered per route. However, determination of appropriate length is always a trade-off between the appropriate length for statistical rigor, the financial cost of conducting surveys with different route lengths, and the amount of time (money) that can be invested in covering routes. Ideally, we should select the shortest route length that will result in only a small percentage of routes without tiger tracks, and that is sufficiently long enough to reduce the variability in number of tiger tracks per route. When variability in track density among routes is high, our ability to statistically detect changes in tiger abundance decreases.

To attempt to determine the optimal route length, we used data developed in an initial experimental stage of this program at Sikhote-Alin Zapovednik (Hayward et al. 2002), and conducted a set of tests to determine effect of route length first on the presence/absence of tiger tracks (i.e., to determine how changing route length changes the proportion of routes with zero counts), and secondly on track density data (i.e., to determine how changing route length affects the variance associated with track density data).

Effect of route length on 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 x 60 km 'landscape'. For each computer simulation, two 'tiger trails' were randomly placed in each 10 x 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 x 20 km grid squares. Intersection of simulated tiger trails and survey routes were counted to determine the number of tiger detections for 2000 iterations for each of 25 route lengths to generate the function relating proportion of zeroes to route length.

Simulated track counts demonstrated that the proportion of zero counts should decline as a negative exponential as route length increases. The parameters for the function would be situation-dependent but clearly the probability of obtaining a count of zero will tend to be smaller when route length is longer and the shape of the function is similar to a negative exponential.

Analysis of field data. We also examined field data from survey routes to determine the relationship between zero counts and both route 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. route 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 reflect the same theoretical distribution.

Based on data from surveys, the relationship between zero counts and route length was not similar to the pattern observed with simulated data. As expected, increases in route length resulted in fewer routes with no tiger tracks (Table 3). However, the proportion of zero counts from field data for route length demonstrated 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 when the independent variable was log-transformed (a negative exponential model) (proportion zero counts to route length for linear model, $R^2 = 0.945$, $F = 34.312$, $P = 0.028$; and for exponential model $R^2 = 0.753$, $F = 6.095$, $P = 0.132$).

Table 3. Relationship between proportion of zero counts and route length for surveys conducted on foot from 1995-1999 in Sikhote-Alin Zapovednik

Route length (km)	n	Proportion of zero counts
0-5	207	0.652
5-10	220	0.573
10-15	87	0.494
>15	19	0.211

Relationship between route length and variance of track density data. We explored the relationship between variance in the track density index and route length in two ways. Based on a direct analysis of 427 routes surveyed in Sikhote-Alin Zapovednik, we evaluated variation in the track index in relationship to route length. Using this approach, sample size differed greatly among distance categories (for instance there were 172 foot surveys 0-5 km long but 66 foot routes 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 = 5000) by randomly combining up to 5 routes from field data to create new routes that fell within one of 6 length categories (0-2.9, 3-5.9, 6-11.9, 12-23.9, 24-47.9, 48-96 km). Variability in counts of tiger crossings was examined for both the original and artificial data set by calculating the standard deviation and coefficient of variation in the track index for each length category.

As expected, variability in the track index, as measured by its coefficient of variation, declined with longer routes (Table 4). However, the standard deviation did not decline with increasing route length. The simulated data combining individual survey routes further demonstrated the pattern of decline in variance as route length increased (Table 5). These simulations suggest a dramatic decrease in variability between the first two distance categories with a negative exponential decline in variability thereafter. The pattern suggests only marginal reductions in variance could be realized from the extreme effort necessary to produce long survey routes.

Table 4. Relationship between variability in the tiger track index with route length based on field surveys of Amur tigers in Sikhote-Alin Zapovednik. Variability in the track index is represented by the standard deviation and coefficient of variation from a sample of 427 foot routes conducted from 1995-1999.

Route length (km)	Standard deviation	Coefficient of variation
0-5	0.0435	2.376
5-10	0.0589	2.293
10-15	0.045	1.983
>15	0.0511	1.357

Summary of analysis of route length. Longer route lengths result 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. It is clear from the above analyses that short routes should be avoided. If each route represents a sample unit, it will be imperative to successfully conduct counts on each route each year, independent of weather conditions. In deep snow years, there are situations where it is unlikely that a field worker can cover more than 15 km. Therefore, we recommend route lengths average 10 to 15 km in length.

Table 5. Relationship between route length and variability in the track index from 30,000 simulated track count surveys developed from actual field data.

	Track index		
Route length (km)	Mean	SD	CV
0-3	0.198	0.7141	3.59
3-6	0.162	0.3181	1.95
6-12	0.15	0.2828	1.88
12-24	0.151	0.2121	1.4
24-48	0.153	0.1484	0.97
48-96	0.154	0.1061	0.69

3.4. Number of routes per site

The number of routes per site should be based on the following considerations: 1) there should be sufficient number of routes to have a high probability of encountering tracks of all tigers within the count unit (to allow for expert assessments of number of tigers); and, 2) there should be sufficient number of routes to provide a statistical basis for comparisons among count units and within a count unit over years.

We examined the statistical power of a monitoring program with different numbers of routes (see section below), and determined that with 10 routes per count unit there is a 90% chance of statistically detecting a 10% decrease in population size (using density of tiger tracks as an indicator of tiger abundance) (see Table 9). Chances of detecting a 5% change are decidedly less with 10 routes (45%). Increasing the number of routes to 20 increases the chance detecting a 10% decrease to 98%, but would represent a doubling of effort for a relatively modest gain. Therefore, we decided that our goal would be to establish 10-20 routes/count unit.

3.5. Method of transportation

Initial analysis of data from Sikhote-Alin (Miquelle and Smirnov 1995) indicated that there may be differences in detection rate of tiger and ungulate tracks dependent on the mode of transportation. Because we are primarily interested in monitoring changes in track density along each route for each year, variation in detection rate is acceptable between routes, but not in one route over years. Therefore, it is preferable that for each route the same mode of transportation (on foot, snowmobile, or vehicle) be used every year, for each survey, under all conditions.

3.6. Continuity of Personnel

People selected for the monitoring program should be selected on the basis of their experience in the region, their knowledge of tigers, and the probability of their continuing to participate in the monitoring program in the future. Stability in track counts will depend on retaining the same personnel over many years. Therefore, every effort has been made to retain the same coordinators and fieldworkers in each monitoring unit. Changes in personnel have been necessary due to deaths and movements of people, but we have striven to maintain consistency in personnel.

4. Timing of monitoring

Timing of a monitoring program is vitally important. We consider three temporal issues in determining timing of the monitoring program.

4.1. Yearly surveys

Because statistically rigorous detection of trends in wildlife populations is difficult, the more often sampling is conducted, the greater the probability of detecting trends. Monitoring should be conducted every year, with the exact same protocol, to collect sufficient information to recognize trends in tiger numbers, prey numbers, and/or reproduction rates of tigers.

4.2. Repetition in survey counts

It is well known that counts of rare, secretive animals that occur in low numbers across a large area result in great variability because there are many parameters that affect the probability of encountering any one animal. Given these constraints, it is nearly impossible to count the entire population with a single simultaneous survey of all routes. An analysis of repeated surveys in Sikhote-Alin Zapovednik, where it is possible to check if radio-collared animals were included in a count, indicated that in a single, simultaneous count, as few as 20%, and up to 100%, of the tracks of known animals were encountered along routes. This variability in simultaneous counts makes it particularly difficult to monitor changes in tiger numbers between years, because it is impossible to determine whether differences in survey results reflect real changes in tiger numbers or simply fluctuations in ability to detect presence of animals.

Two ways to reduce the amount of variation between years are: 1) to saturate a count unit with greater numbers of routes for a single simultaneous survey in the hope that there will be more consistent detection of tigers. This approach may be helpful, but there are at least two reasons why a saturation approach may prove ineffective in reducing variability. First, because tigers are so mobile, part of the variation is due to the fact that some percentage of tigers is simply not present on the count unit during any single survey. Secondly, because tigers can stay on kill sites for up to a week, moving less than 100 meters, even with a very large number of routes some tigers could be missed in a single survey.

The second possible approach is to repeat a survey of a count unit within a given year. This process greatly increases the cost of the survey, but should also greatly increase the probability of encountering all tigers that use a count unit in the course of a winter, and should therefore greatly decrease inter-year variation in count accuracy.

We initially conducted surveys in separate months, with the first survey conducted in December or early January, and the second survey in February. However, if we are trying to develop a point estimate of the population, this approach violates the assumption that the population is "closed," that is, that no animals die, or move into or out of the study area during the period of study. Although it is impossible to be sure these assumptions are met, the chances are greater the closer the repeated counts are made to each other. Therefore, starting in 2007, our protocols changed, and we now strive to conduct two surveys within two weeks of each other, preferably in February.

4.3 Timing of surveys in relation to snowfall

We used the same approach for analyzing zero counts for presence/absence data and variance in track density data as for assessing the effect of route length. As expected, increases in days since snow resulted in fewer routes with no tiger tracks (Table 6). However, the proportion of zero counts from field data resulted in a convex declining function rather than the concave function of the negative exponential. A linear model fit the data better than a model when the independent variable was log-transformed (a negative exponential model) ($R^2 = 0.969$, $F = 63.315$, $P = 0.015$ for a linear model and $R^2 = 0.815$, $F = 8.787$, $P = 0.0975$ for the negative exponential model).

Table 6. Relationship between proportion of zero counts and days since snow for surveys conducted on foot from 1995-1999 in Sikhote-Alin Zapovednik.

Days since last snow	n	Proportion of zeros
1-4	147	0.68
5-8	90	0.633
9-12	110	0.527
$\geq$13	90	0.411

Table 7. 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. Variability in the track index is represented by the standard deviation and coefficient of variation from a sample of 427 foot routes conducted from 1995-1999.

Days since last snow	Standard variation	Coefficient of variation
1-4	0.0755	2.227
5-8	0.0374	2.143
9-12	0.0285	1.802
$\geq$13	0.0275	1.478

Variability in the track index, as measured by its coefficient of variation, declined with greater intervals since snowfall (Table 7). Standard deviation also declined in relation to days since snow (Table 7).

Results of these analyses demonstrate that conducting surveys immediately following snowfall results in a higher proportion of sample routes with no tiger tracks, and a higher variance of track density estimates, making it more difficult to detect real trends in the tiger population. Standard deviation of track density estimators decline dramatically if counts are conducted at least 5 days after snow. While the coefficient of variation shows its greatest drop when 9 days have passed since snowfall, at least in some years, when snows are common, waiting 9 days after a snowfall to initiate survey work may be difficult. Surveys conducted 9-12 days after snowfall may be ideal in terms of encounter rate, but this bonus must be weighed against track disintegration (see above). Therefore, we recommend that surveys be conducted 5-10 days after snowfall, whenever possible. This time frame strikes a balance between reducing the proportion of zero counts, and reducing variance estimates, and the loss of information due to track disintegration.

5. Tiger Population Productivity

Data on number of litters, number of cubs, and litter size are reported for each site as part of the estimate of tiger numbers by coordinators. We summarize this data across all sites to develop an estimate of productivity for the year. There are four types of information that can be derived as indicators of tiger productivity:

Number of litters. We compare the total number of litters produced across all sites combined over time, and compare number of litters produced within each site over time.

Number of cubs. We compare the total number of cubs produced across all sites combined over time, and compare number of cubs produced within each site over time.

Cub density. Because count units vary in size, it is better to use a standardized variable, such as cub density, to compare productivity of different monitoring units. This variable provides a basis for determining trends and allows for statistical testing.

Litter size. Litter size is often an indicator of the nutritional status of the mother, and is an important variable affecting overall productivity. Changes in litter size over time are an indicator of shifts in productivity. However, because litter size varies dramatically with the age of the litter (with much mortality occurring in the first 3 months) interpretation of this data must be done carefully.

6. Prey Abundance

Good estimates of actual prey abundance require extensive work to acquire, and would become a major expense of a tiger monitoring program. Instead of trying to estimate actual density, we decided to use track density as an indicator of relative abundance of ungulates. We report "fresh" (< 24 hours old) tracks, as we know that fresh ungulate track density has a direct linear relationship to actual ungulate density (Chelintsev, 1995, Miquelle et al. 2006, Stephens et al. 2005), but acquiring the extra data to convert track density to actual animal density is difficult, time consuming, and requires added expenses. Therefore, changes in track density, over time, can act as an adequate indicator of changes in population numbers over time. Actual track densities show great variability over a season, and among routes covered within any single count unit. Therefore, we believe that double sampling (conducted primarily to reduce variability in tiger numbers) will also assist in reducing variability of ungulate tracks as well. We use the average number of tracks for both the first and second surveys for each survey route as an independent estimate of abundance for each species of prey on a monitoring unit. That estimate, averaged for all survey routes, provides an estimate of statistical error for each site, and provides a means of comparing sites and trends within sites over multiple years.

7. Tiger mortality

Each coordinator is responsible for collecting information on deaths of tigers in or in proximity to count units. In many cases, these reports cannot be confirmed, as coordinators often have to assure confidentiality to obtain the data. Because coordinators usually have a long history at a monitoring unit, they are able to obtain information on poaching that outsiders could not. Nonetheless, it is clear that coordinators do not acquire information on all cases of poaching. Thus, there are no doubt errors associated with these reports, but they nonetheless act as a "barometer" of tiger mortalities - usually human-caused - that are occurring in and around monitoring units within a given year. As such, they provide valuable information on the impacts of humans on tigers, and on the mortality rates for a given region. These data provide a different and very valuable perspective on tiger mortalities in comparison to official reports, and likely provide an estimate closer to actual mortality rates than official reports.

8. Changes in Habitat Quality

We collect a standard set of measurements on each monitoring unit to assess changes in habitat quality. Yearly monitoring is focused not so much in specifying exact conditions on count units, which would be a time consuming and difficult process, but identifying changes occurring on the unit. Therefore, nearly all questions seek to determine if changes have occurred, whether than to specify exactly what conditions exist. The questions relate to logging, fire, hunting, livestock use, and overall human use of the monitoring units. Most questions that seek to quantify the level of activity require only categorical responses (e.g. we have 5 categories as potential responses to the question "How much logging has occurred on the count unit this past year?" ranging from none to greater than 1000 ha.). The questions are formulated as follows:

1. Have any new roads been built in the count unit this year? If so, how many kilometers?
2. Has there been repairs/reopening of any roads in the past year (e.g. asphalt)?
3. Have any roads been closed in the count unit this year?
4. Has logging occurred on the count unit this year? If so, what types and how many hectares
5. How many villages are there within 30 km of the count unit?
6: How many people are living within 30 km of the count unit?
7: Has there been a change in the number of people within 30 km of the count unit in the past year?
8. Specify type of fires (grass fire, crown fire) and area burned within your count unit this past year.
9: Report the number of livestock that have pastured on the count unit in the past year (total number of animals – not total number of days grazed).
10. Has the number of livestock using the count unit changed from last year?
11: Number of reports of depredation by tigers on livestock within the monitoring site, by species.
12. Provide an estimate of the human disturbance factor on the count unit (number of person days on the count unit per month, for the months during which the monitoring program was conducted.
13. How many hunting licenses were provided for the count unit this year?
14. In your opinion, has the number of illegal shootings of ungulates increased or decreased from last year?
15. Estimate the number of illegal shootings of ungulates on your count unit this year.

16. In your opinion, has the number of illegal killings of tigers increased or decreased from last year?

17. In your opinion, has the status of tiger habitat on your count unit increased or decreased from last year.

18. Have there been any other changes on your count unit that may have an impact on the tiger population or tiger habitat?

These data are tabulated, and over years provide an indication of trends in exploitation of monitoring units.

9. Data Storage

A key component of creating a reliable, long-term monitoring program is the development of a means of storing and analyzing data. We have invested substantial finances and energy into developing a spatially explicit database in a standardized format that will insure long-term protection of the database, and at the same time provide relatively easy access for analysis. We have developed the database in Microsoft ACCESS that linked to a specially edited version of ArcView (ESRI Corp.) that contains all data collected by fieldworkers on every tiger track and individual, tiger deaths, route information (ungulate densities are reported by route), and count unit. The first two years of the program were spent in developing the database, and creating ArcView interface that spatially links the attribute data. Each count unit is defined by a series of "coverages" that includes: boundaries of count unit (and boundaries of protected areas), the river system, for most count units a forest cover map, location of survey routes, tiger tracks (coded by sex and age when possible) location of females with cubs, and sites of mortality. The MS ACCESS database exists as a series of linked tables, making analysis relatively easy, and the ArcView interface provides the opportunity to quickly visually assess the data and obtain necessary information. The ArcView project exists in two scales: 1) 1:500,000 for general reference to the entire range of tigers; and 2) 1:100,000, which is the scale used for recording and entering data on specific count units. The database now exists in a specially designed format (using AVENUE) so that data entry is possible without technical expertise in ARCINFO, or the need for digitizing data.

10. Data Analysis

While an approach based on sampling provides the benefits of lower cost, more frequent implementation, and better measures of accuracy, there are problems. Counts of rare objects generally result in estimates with large variances. This leads to the potential for estimates that lack the level of precision necessary to make critical management decisions. Therefore, careful attention needs to be paid to how data can and should be analyzed.

We sought to determine trends in tiger populations and their key prey resources by assessing spatial and temporal variation in the following parameters:

10.1. Relative tiger abundance

We use three indices of relative tiger abundance: track density, adjusted for number of days since last snow; "independent tiger" density based on expert assessment, and "independent tiger density, based on a standardized algorithm. The mean and standard deviation of the first index for each site can be derived using each route as a subsample for the site. The expert assessment and standardized algorithms of number of tigers exist as a single value (expressed as density of "independent tigers" with no error term. These three sets of data can then be used to make the following comparisons:

Changes over time in tiger abundance across the entire range, and changes in tiger abundance indices over time for each count unit separately. *W*e conduct linear regression analyses for all sites combined (to give an indication of trends for the entire Amur tiger population) and each site separately (to look for trends within each site). The same types of trend analyses are conducted for tiger track density, expert assessments of tiger density, and track data for ungulates (see below). The intent of the regression analyses is to identify trends over time in the population across the whole region, and within each of the monitoring sites. We have defined sites as "areas of concern" if the trend analyses demonstrates a negative slope for at least 4 years which the statistical probability was greater than 80% (i.e. $P < 0.2$) that the population was decreasing (i.e. that the slope of the line did not equal zero, i.e., $\beta \neq 0$). We have used the same criteria for defining sites as "areas with positive growth indicators" if the slope is positive.

This is a very conservative approach, as most statisticians use a P value of 0.05. By increasing the P-value to 0.2, we dramatically increase the probability of defining a site as an "area of concern" or an "area with positive growth" when in fact such may not be the case. We use this more conservative approach because we argue that we must have a mechanism for identifying areas early, so that remedial action can take place: a more liberal approach (with a smaller P value) would result in fewer "false alarms" but may not identify all areas in time to respond on an appropriate time scale. We balance this conservative approach by using a suite of indicators (3 for tigers, and one for each species of prey). We consider trends to be occurring in the tiger population (for the entire population or for any individual site) if two of the three indicators demonstrate a similar pattern (i.e., decline, growth, or stability in population status).

By assessing a host of variables, we believe the approach provides a balance between being overly alarmist and overly complacent.

Differences in tiger abundance among sites in any given year (or over all years). To assess whether variation in tiger abundance (for any of the three indicators) exists among sites in any given year (or all years combined), we employ a non-parametric analysis of variance using the ranks of each indicator. In most cases we use a non-parametric approach because the indicator values are not normally distributed. The results of the ANOVA F-test will determine if there are significant overall differences among sites, but will not provide a means of determining which sites are different from each other. To do that requires a "multiple comparison" test. We employ either protected LSD test – conducting the Fishers Least Significant Difference test (LSD test) only if the overall ANOVA is significant, or conducting a Tukey's "honestly significant difference" pair wise comparison test (as defined in SAS 1985)

The effect of environmental/geographic parameters on tiger abundance indicators. We assess the importance of environmental parameters in explaining variation in tiger abundance indicators by conducting a 3-way unbalanced factorial ANOVA, with protected status, latitude, and proximity to coast as independent variables. If the distribution of the tiger abundance indicator data is not normal, we first rank the values of the indicator for each count unit, and then conduct the same factorial analysis of variance on those ranked values. If the overall ANOVA is significant, we use one of the multiple comparison tests described above to test for differences within any one of the three parameters.

Paired comparisons of zapovedniks and adjacent unprotected territories. Paired comparisons of the 3 zapovedniks with adjacent monitoring sites (i.e., Ussuriski Zapovednik versus Ussuriski Raion, Lazovski Zapovednik versus Lazovski Raion, and Sikhote-Alin Zapovednik versus Terney Hunting Society) provide a means of comparing adjacent sites that retain similar characteristics, with the only major difference being protected status. Using these three pairs provides a clear demonstration of the importance of protected status and its impact on tiger and ungulate abundance indices.

The relationship of these three tiger abundance indices to each other. We compare how well the three tiger abundance estimators (algorithm, track densities, tiger densities) correlate with each by ranking each site by its relative value for each of the estimators, and estimating Spearman's rho (Conover 1980) on those ranks.

10.2. Changes in the tiger productivity

Data on number of litters, number of cubs, and litter size are reported for each site as part of the estimate of tiger numbers by coordinators. We summarize this data across all sites to develop an estimate of productivity for the year. However, because sites vary greatly in size, we cannot simply use the total number of cubs or litters as a parameter for comparison across years and sites. We instead use cub density (number of cubs divided by area of the monitoring site) as a measure of productivity to compare among sites and as a constant that can be used for analyses of trends across years.

10.3. Changes in prey populations

Relative abundance of the 4 primary prey species of tigers (red deer, wild boar, roe deer, and sika deer) is estimated on the basis of number of fresh (< 24 hours old) tracks intersecting survey routes. Estimates from both surveys in each winter (early and later winter surveys) are averaged to derive an estimate of mean number of tracks, for each species, for each route for the winter. Each route acts as a sampling unit to develop a mean for the monitoring site. That mean value is used to conduct a trend analysis similar to that conducted for the tiger abundance indices (see above) for each site separately and for all combined.

Statistical Probability of Detecting Trends in the Population index

Power analysis

Our analysis assumes 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 $B_1 < 0$ (Gibbs 1995, Gerrodette 1987, 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).

We used Monte Carlo simulations to determine how route length, number of routes, and alpha (probability of a Type I error) influence 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 tiger track index of +10%, +5%, no change, -5%, or -10%. The analyses assume 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. (1998:160) and chose to model exponential, rather than linear population growth (or decline) because this model is expected to most closely approximate demographic processes of tiger populations.

Input values for the simulations were based on statistical summaries of surveys from Sikhote-Alin Zapovednik from 1995-1999. The simulations require a mean track index and standard deviation for each simulated route. A specified trend (say 5% decrease) is 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 are drawn from a normal distribution whose mean is 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 trend would be expected to vary among sites within a region, we assumed that the standard deviation describing trend variation among sites would equal 0.015. This value is based on the standard deviation of the mean track index from 16 survey areas sampled in our field surveys. Because power to detect regional declines will be higher if one-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 one-tailed tests assuming α = 0.20.. Input parameters for route length, number of routes, and alpha are described below.

Route length. The mean and standard deviation for the track index from survey routes were used for each of five length categories (0-5, 5-10, 10-15, 15-20 and 20-25 km). Each simulation examined index values over five years from a single route sampled twice each year.

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, α = 0.20, and a one-tailed test.

Alpha, probability of type I error. We examined the extent to which power increased as α is increased by comparing α = 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 of power analysis to detect trends in tiger tracks

Route length. Power increased with route length (Table 8). Based on the variance structure of data from survey routes, the most substantial improvements in power are realized by extending route length from 17.5 to 22.5 km.

Table 8. 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 wishes to detect. Analysis is based on mean track index and standard deviation calculated from 427 foot surveys conducted from 1995-1999 in Sikhote-Alin Zapovednik. Mean and STD refer to the mean index for each route length and the standard deviation of that value calculated from the field surveys.

Trend (proportional change in population)	Route length				
	2.5 km	7.5 km	12.5 km	17.5 km	22.5 km
-0.1	0.409	0.407	0.404	0.421	0.503
-0.05	0.292	0.301	0.293	0.295	0.337
0	0.2	0.188	0.201	0.197	0.197
0.05	0.305	0.302	0.299	0.304	0.348
0.1	0.415	0.415	0.4	0.434	0.528
Mean	0.0187	0.0213	0.0177	0.0196	0.015
STD	0.0379	0.04148	0.038	0.02988	0.01126

Number of routes. Results demonstrate that it is difficult to detect a significant change in tiger tracks based on a single route (Table 8). Results also illustrate that it will 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 9). However, given a 10% annual trend, adequate power is achieved with a sample of 10 routes. The most substantial gains in power are achieved by increasing sample size from 3 to 10 routes. Monitoring more routes results in relatively modest increases in power if seeking to detect a trend of ± 10%.

Table 9. Relationship between number of routes monitored and probability of detecting a trend in tiger track index based on foot surveys. See table 8 and text for further details.

Trend (proportional change in population)	Number of Routes			
	3	5	10	20
-0.1	0.593	0.724	0.892	0.984
-0.05	0.391	0.456	0.583	0.753
0	0.194	0.197	0.2	0.196
0.05	0.382	0.458	0.592	0.756
0.1	0.608	0.737	0.908	0.988

Alpha, probability of type I error. Results demonstrate that a significance level (α) below 0.15 will achieve unacceptable power for all effect sizes (Table 10). Decisions regarding choice of (α) will depend on judgment regarding the effect size to monitor and the perceived consequences of Type I error vs. Type II error.

Table 10. 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. See table 8 and text for details.

Trend (proportional change in population)	Alpha (α)			
	0.05	0.1	0.15	0.2
-0.1	0.624	0.771	0.847	0.887
-0.05	0.258	0.399	0.504	0.586
0	0.048	0.096	0.156	0.199
0.05	0.266	0.406	0.503	0.586
0.1	0.653	0.793	0.855	0.901

This power analysis provides additional support for the design of this monitoring program. We have selected the number of routes per monitoring unit, and the length of those routes to increase the power to detect changes in tiger numbers, as well as prey. The power analysis further suggests that we have an 89% probability of detecting 10% changes (but not 5% changes) in tiger numbers if we accept an alpha level of 0.2. which is what we have done for our trend analyses (see above). This approach provides a fairly conservative approach to detecting trends, and we acknowledge that there is a greater chance of "false alarms," that is, claiming there to be declines in tiger numbers when in fact there are not. Nonetheless, given the quickly changing landscape in the Russian Far East today, such a conservative approach seems appropriate.

Additional information

Additionally, it is worth noting that in 2006 we published a monograph "Theoretical basis for surveys of tigers and their prey in the Russian Far East" which provides much of the background, history, and development of survey approaches in the Russian Far East. This monograph is presently only available in Russia, but is obtainable by contacting the WCS Russia Office (dalemiq@vlad.ru, nika1204@mail.ru, or call to the Vladivostok office at: 7-4232-41-00-33).

IV. RESULTS OF THE 2009 WINTER MONITORING PROGRAM

SUMMARY DATA ON COUNT UNITS AND ROUTES

As in previous years, in the 2009 winter the total area included in monitoring units was 23,555 km^2, or approximately 15-18% of the total area considered suitable tiger habitat, assuming either 156,571 (Matyushkin et al. Table 4) or 127,693 km^2 (Miquelle et al. 1999, Table 19.3) of suitable habitat.

A total of 246 survey routes were sampled twice representing a total of 6114 km traversed (each route covered twice) (Table 11).

Table 11. Characteristics of sites surveyed for Amur tiger monitoring program, 2009.

	Monitoring Site	Coordinator	Size of unit (km^2)	# survey routes	Total length of survey routes (km)	Average length of survey routes (km)	Survey route density (km/10 km2)
1	Lasovski Zapovednik	Salkina, G. P.	1192.1	12	121.4	10.1	1.02
2	Laso Raion	Salkina, G. P.	987.5	11	138.9	12.6	1.41
3	Ussuriski. Zapovednik	Litvinov, M. N.	408.7	11	104.4	9.5	2.55
4	Iman	Nikolaev. I. G.	1394.3	12	176.9	14.7	1.27
5	Bikin	Pikunov, D. G.	1027.1	15	188.4	12.6	1.83
6	Borisovkoe Plateau	Pikunov, D. G.	1472.9	14	216.8	15.5	1.47
7	Sandago	Aramilev, V. V.	975.8	16	218.5	13.7	2.24
8	Khor	Dunishenko, Yu. M.	1343.8	19	190.3	10	1.42
9	Botchinski Zapovednik	Dunishenko, Yu. M.	3051	14	164.7	11.8	0.54
10	Zapovednik	Dunishenko, Yu. M.	475.6	7	82.9	11.8	1.74
11	Tigrini Dom	Dunishenko, Yu. M.	2069.6	14	181.8	12	0.88
12	Matai	Dunishenko, Yu. M.	2487.6	24	372	15.5	1.50
13	Ussuriski Raion	Litvinov, M. N.	1414.3	12	178.2	14.9	1.26
14	Sikhote Alin Zapovednik	Zaumyslova, O. Yu.	2372.9	26	277.7	10.7	1.17
15	Sineya	Fomenko, P. V.	1165.4	15	207.2	13.8	1.78
16	Terney Hunting Society	Kozichev, R. P.	1716.5	24	247.2	10.3	1.44
	Totals		23555.1	246	3057.3	12.42805	1.30

MEASURES OF TIGER ABUNDANCE

Tiger Track Counts on Survey Routes

Mean track density, adjusted for the number of days since the last snowfall (see Methods), provides an indication of relative abundance of tigers on monitoring sites (Table 12). Averaged across all 12 years, Ussuriski Zapovednik consistently reports the highest track density of all 16 monitoring units, followed by Lazovski Zapovednik and then the Bikin Basin (Table 12). No tracks were reported in Sandagoy or Bolshekhekhtsirski Zapovednik on survey routes in 2009 – the first time no tracks were reported in any site other than Bolshekhekhtsirski Zapovednik, where tigers seemingly disappeared in 2007. As would be expected, tiger track densities are significantly higher within zapovedniks ($x = 2.0 \pm 1.6$ tracks/10 km) than in unprotected monitoring units ($x = 1.0 \pm 0.4$ tracks/10 km), a difference that is statistically significant ($t = 2.07$, $df=14$, $p = 0.05$). As might also be expected, tiger track density varies with latitude: tiger track densities are, on average, highest in the southern monitoring units (1.65 tracks/10 km), and lowest in the northernmost units in Khabarovsk (1.03 tracks/10 km), although this difference is not statistically significant (one-way ANOVA, $df = 15$, $F = 0.64$, $p = 0.54$).

Table 12. Tiger track densities in relation to latitude, based on 16 monitoring units of the Amur Tiger Monitoring Program 1998-2009

	Tiger tracks/10 km		
Latitude	n	Mean	SD
Southern	6	1.65	1.36
Central	5	1.13	0.92
Northern	5	1.03	0.18
Overall	16	1.3	0.99

Observations from the past six years (from 2004 onwards) provide a strong indication that, averaged across all sites, tiger track densities are decreasing (Figure 2). Track densities in 2008 and 2009 represent the lowest reported over the 12 years of the monitoring program: overall average track densities for all 12 years has averaged 1.3 tracks/10 km, but in 2008 and 2009 track density was dramatically lower (0.68 and 0.60 tracks/10 km). A visual inspection of the data (Figure 2) suggests that over the first seven years of the program, track densities fluctuated, but there was no significant trend, suggesting that tiger numbers were relatively stable. However, beginning in 2004, there has been a significant negative linear trend. In fact, over all 12 years combined there is also a statistically significant downward trend ($Y=193.04 -0.0957X$, $P=0.004$, $r^2 = 0.58$), but the strength of this correlation is much stronger since 2004 ($Y=497.6 -0.247X$, $P=0.002$, $r^2 = 0.92$). If these data can be assumed to be representative of the entire Amur tiger population in the Russian Far East, and if it is assumed that track density is an adequate and linear indicator of tiger density itself, these data provide strong evidence that the tiger population may be decreasing in the Russian Far East.

Because monitoring units are scattered across a vast area, it is not expected that all units would demonstrate the exact same pattern. Each site has a unique set of variables that will affect measurements and trends. Therefore, it is important to consider the variation that is occurring at each unit.

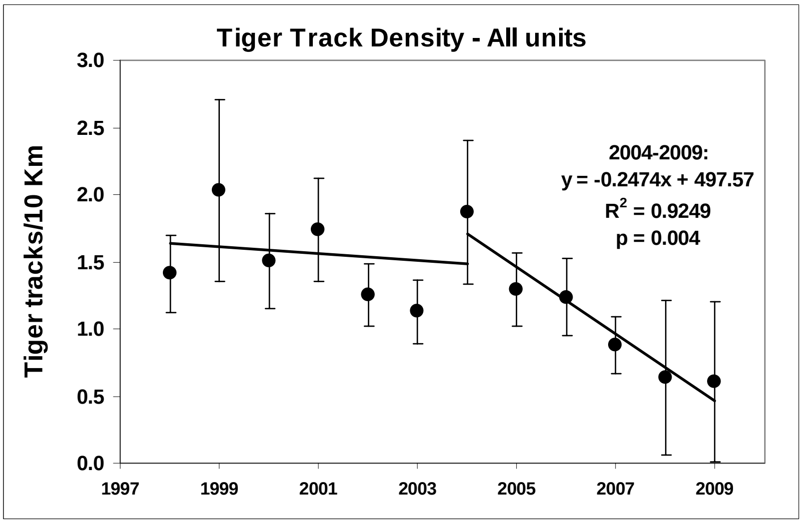

Figure 2. Density of tiger tracks (tracks/10 km/days since last snow) as an indicator of relative tiger abundance averaged across 16 sites included in the Amur Tiger Monitoring Program, winter 1998 through 2009.

Thirteen of the 16 monitoring units (81%) show significantly negative trends ($p \leq 0.2$) for at least the past fours years (Figure 3). For about half the sites (6), the downward trend began around 2004 or 2005, but for the other half (7), the decline has been ongoing for much longer: seven, since at least 2000. While not all sites have strongly significant downward trends (only 8 of the 13 have p-values ≤ 0.05) it is important to note that there is not one site where there is any evidence of an increase in tiger track densities. If the overall population of tigers were generally stable, we would expect an equal percentage of monitoring sites to show increasing, decreasing, and stable patterns of population dynamics. The fact that there are no sites where there is any indication of an increase in tiger track densities is alarming. Also alarming is the fact that there are downward trends in all 5 zapovedniks, suggesting that zapovedniks are not effectively protecting tigers any better than non-protected monitoring units.

Table 13. Track densities (tracks/10 km/last snowfall) based on two winter surveys per year, 1998-2009 on monitoring sites of the Amur Tiger Monitoring Program.

	Year												
Unit	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	Average
Lazovski Zapovednik	3.620	2.193	3.011	3.570	2.515	3.498	4.152	2.132	3.445	3.472	2.636	2.605	3.071
Lazovski Raion	1.436	0.670	0.990	1.018	1.617	0.929	1.344	0.445	1.321	1.646	0.826	0.499	1.062
Ussurisk Zapovednik	3.281	9.663	6.211	6.149	3.485	2.619	2.115	2.713	4.202	0.257	0.823	2.742	3.688
Iman	0.959	2.810	0.865	0.761	0.808	0.647	0.505	0.639	0.630	0.295	0.219	0.186	0.777
Bikin	3.612	7.710	0.949	3.704	2.307	2.635	6.336	0.607	2.203	1.243	1.016	0.451	2.731
Borisovskoe Plateau	0.501	0.848	1.448	0.601	0.514	1.174	0.715	0.736	1.228	0.286	0.788	0.709	0.796
Sandagoy	0.479	0.661	0.344	0.410	0.233	0.831	0.398	0.388	0.670	1.221	0.198	0.000	0.486
Khor	0.435	0.798	1.672	1.500	1.352	0.453	1.049	4.167	0.260	1.205	0.534	0.079	1.125
Botchinski Zapovednik	0.876	0.736	1.197	1.295	1.043	0.458	0.578	0.768	0.808	0.658	0.545	0.335	0.775
Bolshekhekhtsirki Zapovednik	1.986	0.866	0.842	0.714	0.714	0.422	7.143	1.810	0.262	0.000	0.000	0.000	1.230
Tigrini Dom	0.671	1.471	1.127	1.511	1.657	1.265	2.206	1.506	0.314	0.946	0.426	0.095	1.100
Mataiski Zakaznik	0.627	1.177	0.733	2.417	0.381	0.390	0.593	2.459	0.531	0.522	0.702	0.357	0.908
Ussuriski Raion	1.007	0.611	1.933	1.438	1.697	0.524	0.723	0.463	0.962	0.176	0.221	0.308	0.838
Sikhote Alin Zapovednik	1.986	1.283	1.516	1.178	0.912	1.037	1.062	0.907	0.927	1.175	0.585	0.503	1.089
Sineya	0.242	0.334	0.472	0.580	0.382	0.576	0.862	0.568	1.765	0.695	0.215	0.511	0.600
Terney Hunting Lease	0.833	0.644	0.731	0.904	0.392	0.613	0.152	0.401	0.265	0.247	0.461	0.297	0.495
Average	1.409	2.030	1.503	1.734	1.251	1.130	1.871	1.294	1.237	0.878	0.637	0.605	1.298

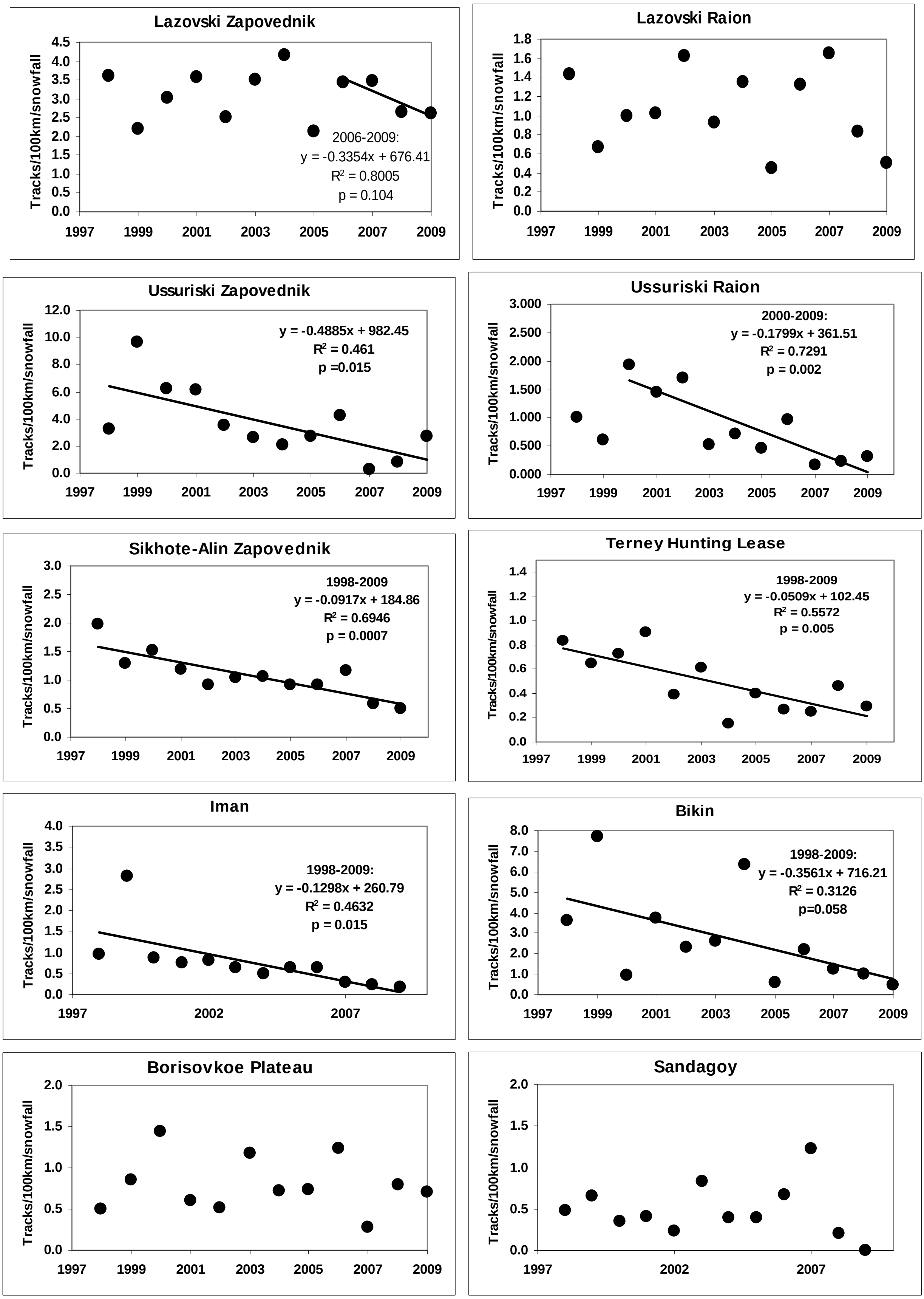

Figure 3. Track density (tracks/10 km/days since last snow) and trends for all 16 sites of the Amur Tiger Monitoring Program. Linear regressions are shown for those sites where the regression for the selected years is statistically significant (where $p \leq 0.2$). R-squared values (r^2) indicate the strength of the correlation (0 = low correlation, 1 = perfect correlation).

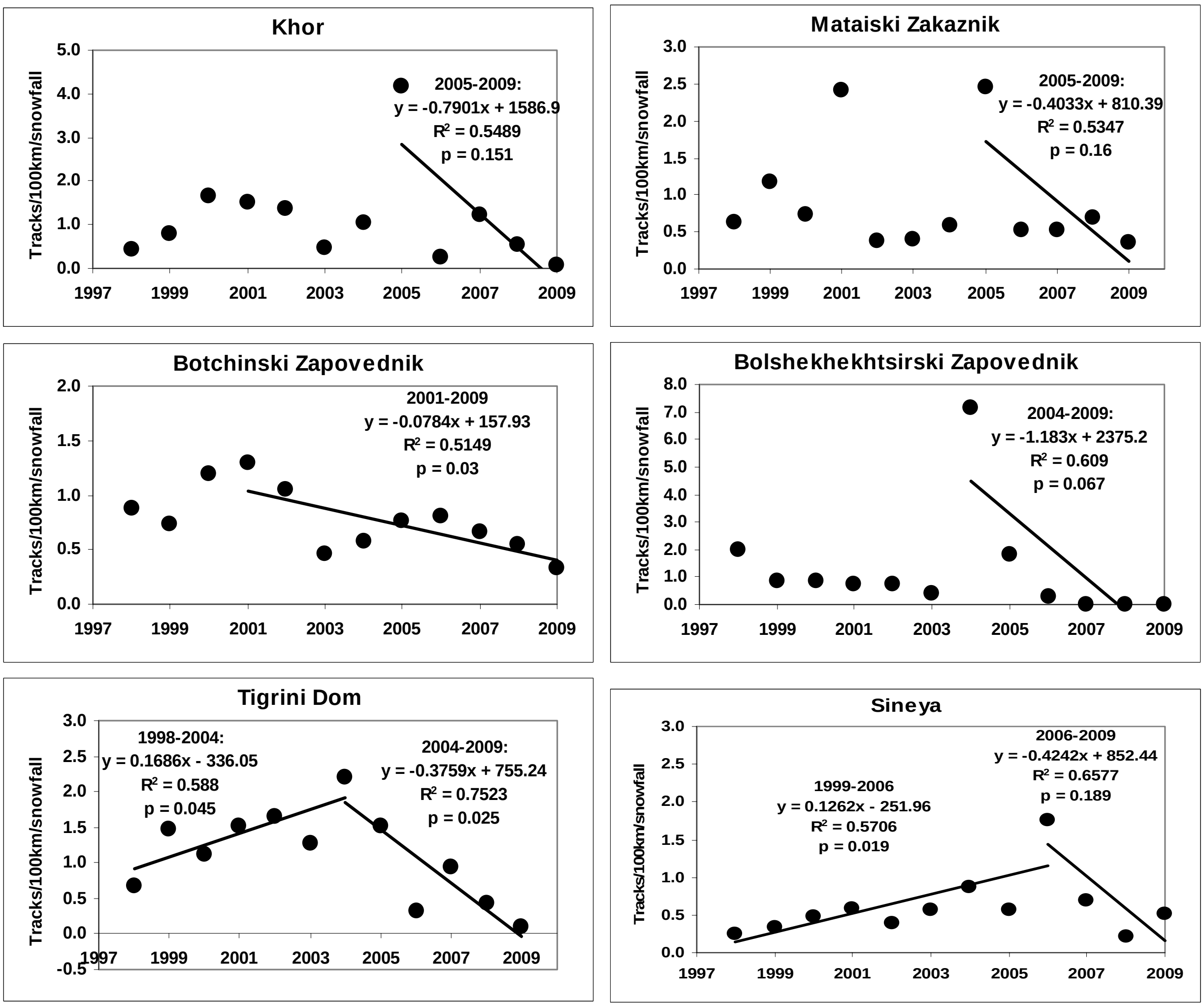

Figure 3 (continued). Track density (tracks/10 km/days since last snow) and trends for all 16 sites of the Amur Tiger Monitoring Program. Linear regressions are shown for those sites where the regression for the selected years is statistically significant (where $p \leq 0.2$). R-squared values (r^2) indicate the strength of the correlation (0 = low correlation, 1 = perfect correlation).

Expert Assessment of Tiger Numbers on Monitoring Sites

We try to maintain consistency in having a single coordinator make expert assessments on each of the 16 monitoring units across the range of Amur tigers in the Russian Far East. In 2004 V.K. Abramov passed away, and two monitoring units (Ussuriski Zapovednik and Ussuriski raion) have since been coordinated by his former assistant, M. Litvinov. In Sikhote-Alin Zapovednik E.N. Smirnov retired in 2006, and passed away in 2008, so responsibilities for monitoring tigers were shifted over to O. Yu. Zaumyslova in the Zapovednik, and R. P. Kozhichev in the adjacent Terney Hunting Lease. By retaining consistency in personnel, we believe that the year to year estimates within any given unit are likely to be consistent, assuming coordinators interpret track data in the same manner each year. While the variation among coordinators (and therefore among sites) is more difficult to account for, we assess that variation through the use of a standardized algorithm (see below) that is consistent in how track data is interpreted, Thus the two approaches combined provide a basis for making relative comparisons for each site over time, as well as for comparing tiger density across sites.

As with tiger track densities, the monitoring sites with highest tiger densities based on expert assessments were Ussuriski Zapovednik, Lazovski Zapovednik, Sikhote-Alin Zapovednik, and the Bikin site (Table 15). Monitoring sites in Khabarovsk had lower tiger densities than in southern sites (Table 15), and Botchinski Zapovednik has the lowest tiger density averaged over all 12 years (0.13 tigers/100 km^2).

Prior to 2009, the average number of independent tigers (independent tigers = adults + subadults) reported on all monitoring units combined was 98.7 (Table 14). In 2005 115 adult/subadult tigers were recorded on all 16 sites combined, representing the highest number of tigers reported for the entire 12-year period (Table 14). For two of the following three years (2006-2008) numbers of tigers dropped below the 11-year average. Then, in 2009, we recorded a dramatic decline in numbers of tigers: only 56 individuals were reported on all sites combined (Table 14). This represents a 41% decline from the 12-year average. If this estimate is correct, overall tiger density on monitoring sites dropped from an average of the previous 11 years of nearly 0.5 tigers/100 km^2, to a 12-year low of 0.3 tigers/100 km^2, again representing a 41% decline in total numbers from the 12-year average.

The patterns of decline are similar to those suggested by tiger track densities, but there are some differences. As with tiger track densities, 13 of the 16 (81%) sites showed significant ($p < 0.2$) downward trends in tiger numbers, either from 2005 through 2009, or for a longer period (Figure 5). All zapovedniks except Sikhote-Alin showed negative declines: in Sikhote-Alin Zapovednik tiger numbers appeared to decline from 1998 through 2004, and then increase through 2008, but in 2009 there was again a dramatic drop in numbers of tigers reported (however, extremely deep snows in Terney Raion likely contributed to this low count by reducing movements of tigers – see below). Aside from Sikhote-Alin Zapovednik, there was no evidence of increasing tiger numbers in any monitoring site. As with tiger track densities, there appeared to be three patterns at monitoring sites: 1) no apparent change over time (two sites); 2) downward trends starting around 2005 (10 sites); and 3) downward trends starting much earlier in the monitoring period (3 sites). Only one site (Sikhote-Alin) had evidence of an increase in tiger numbers since 2005 (which contradicts the tiger track data – see Figure 3). Some sites, such as the Iman, showed both long-term and short-term declines (Figure 5). Eight of the 13 sites with downward trends had statistically significant downward correlations with p-values equal to or less than 0.05, indicated a strong evidence that the negative is very real.

Table 14. Number of "independent" tigers (adults and subadults) on monitoring sites of the Amur Tiger Monitoring Program, based on expert assessments, 1998-2009.

	Number of independent tigers												
Monitoring Unit	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	Average
Lazovski Zapovednik	6	9	10	11	12	9	10	12	11	12	9	8	9.9
Lazovski Raion	8	4	5	4	6	5	4	7	6	5	5	4	5.3
Ussurisk Zapovednik	6	10	4	5	4	6	7	9	5	5	5	5	5.9
Iman	8	6	5	6	6	4	5	8	5	4	4	3	5.3
Bikin	3	10	7	6	7	8	5	5	4	6	5	3	5.8
Borisovskoe Plateau	4	5	4	3	3	5	3	2	3	3	2	2	3.3
Sandagoy	6	6	5	7	3	7	5	5	6	6	5	1	5.2
Khor	3	4	4	4	4	5	5	5	6	4	4	4	4.3
Botchinski Zapovednik	3	3	4	4	6	4	2	5	4	3	4	1	3.6
Bolshekhekhtsirki Zapovednik	2	1	2	1	1	1	2	2	1	1	0	0	1.2
Tigrini Dom	4	6	4	4	5	6	5	7	4	5	5	1	4.7
Mataiski Zakaznik	3	5	4	4	5	5	5	8	7	4	6	3	4.9
Ussuriski Raion	6	1	2	2	9	6	5	7	5	3	5	3	4.5
Sikhote Alin Zapovednik	21	21	23	17	17	16	12	19	16	26	20	8	18.0
Sineya	5	6	5	7	5	7	5	6	6	7	5	5	5.8
Terney Hunting Lease	10	11	13	11	5	7	3	8	6	5	8	5	7.7
Total	98	108	101	96	98	101	83	115	95	99	92	56	95.2

Table 15. Density of independent tigers (adults, subadults, and unknown tigers/100 km2) based on expert assessments of tiger tracks on 16 sites in the Russian Far East Amur Tiger Monitoring Program, 1998-2008

	Tigers/100 km2												
Monitoring Unit	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	Average
Lazovski Zapovednik	0.50	0.75	0.84	0.92	1.01	0.75	0.84	1.01	0.92	1.01	0.75	0.67	0.85
Lazovski Raion	0.81	0.41	0.51	0.41	0.61	0.51	0.41	0.71	0.61	0.51	0.51	0.41	0.54
Ussurisk Zapovednik	1.47	2.45	0.98	1.22	0.98	1.47	1.71	2.20	1.22	1.22	1.22	1.22	1.47
Iman	0.57	0.43	0.36	0.43	0.43	0.29	0.36	0.57	0.36	0.29	0.29	0.22	0.40
Bikin	0.29	0.97	0.68	0.58	0.68	0.78	0.49	0.49	0.39	0.58	0.49	0.29	0.58
Borisovskoe Plateau	0.27	0.34	0.27	0.20	0.20	0.34	0.20	0.14	0.20	0.20	0.14	0.14	0.23
Sandagoy	0.61	0.61	0.51	0.72	0.31	0.72	0.51	0.51	0.61	0.61	0.51	0.10	0.57
Khor	0.22	0.30	0.30	0.30	0.30	0.37	0.37	0.37	0.45	0.30	0.30	0.30	0.32
Botchinski Zapovednik	0.10	0.10	0.13	0.13	0.20	0.13	0.07	0.16	0.13	0.10	0.13	0.03	0.13
Bolshekhekhtsirki Zapovednik	0.42	0.21	0.42	0.21	0.21	0.21	0.42	0.42	0.21	0.21	0.00	0.00	0.27
Tigrini Dom	0.19	0.29	0.19	0.19	0.24	0.29	0.24	0.34	0.19	0.24	0.24	0.05	0.24
Mataiski Zakaznik	0.12	0.20	0.16	0.16	0.20	0.20	0.20	0.32	0.28	0.16	0.24	0.12	0.20
Ussuriski Raion	0.42	0.07	0.14	0.14	0.64	0.42	0.35	0.49	0.35	0.21	0.35	0.21	0.33
Sikhote Alin Zapovednik	0.88	0.88	0.97	0.72	0.72	0.67	0.51	0.80	0.67	1.10	0.84	0.34	0.80
Sineya	0.43	0.51	0.43	0.60	0.43	0.60	0.43	0.51	0.51	0.60	0.43	0.43	0.50
Terney Hunting Lease	0.58	0.64	0.76	0.64	0.29	0.41	0.17	0.47	0.35	0.29	0.47	0.29	0.46
Average	0.49	0.57	0.48	0.47	0.46	0.51	0.46	0.59	0.47	0.48	0.43	0.30	0.48

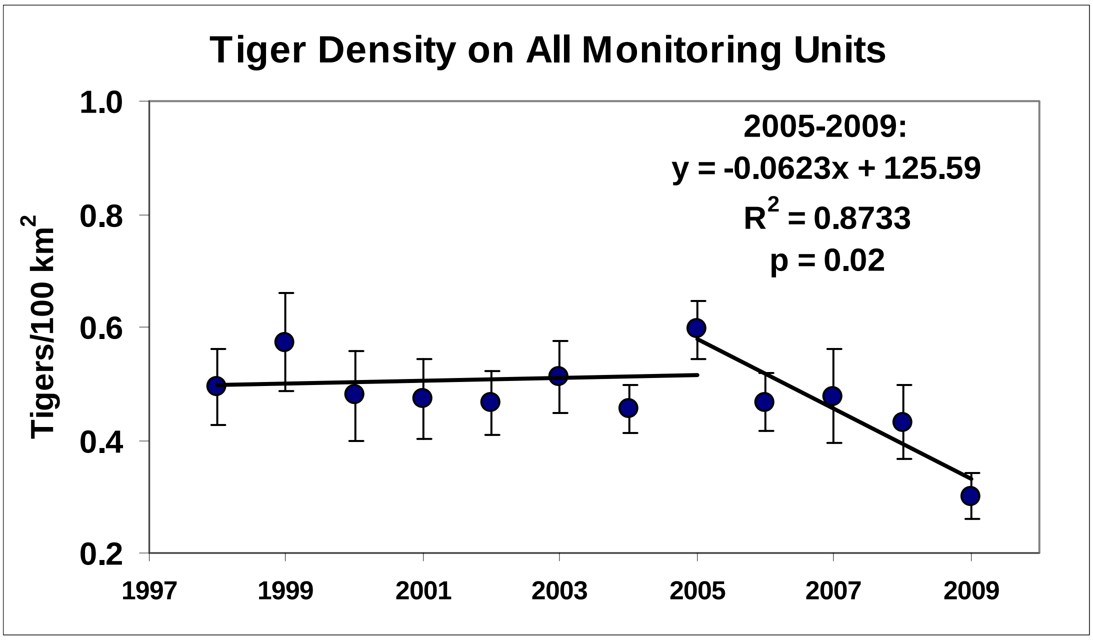

Figure 4. Density of independent tigers (adults, and subadults) counted on monitoring units, based on expert assessments for 16 sites in the Amur Tiger Monitoring Program, 1998 through 2009 winter seasons.

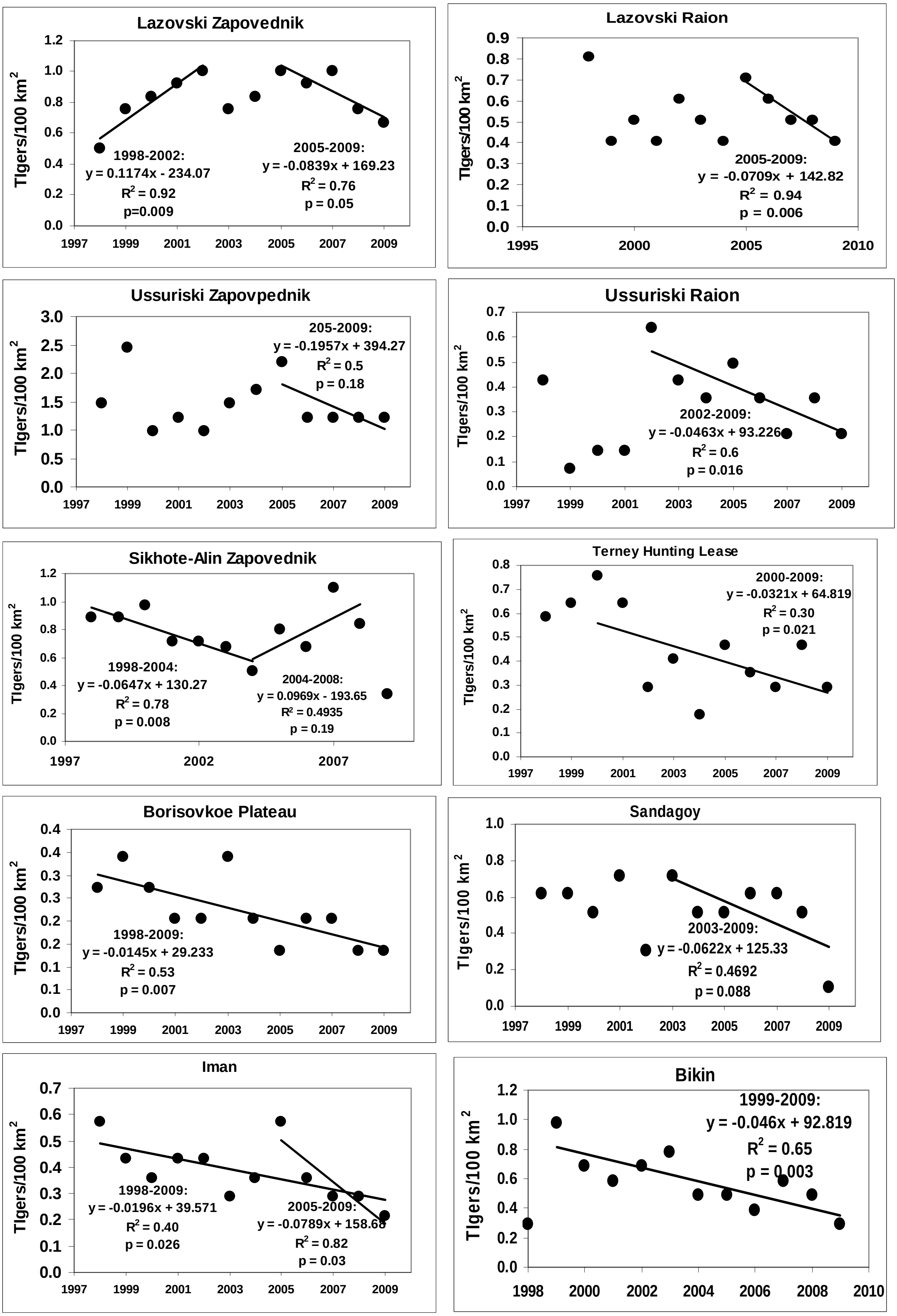

Figure 5. Tiger densities (adult tigers/100 km^2) in six of the 16 monitoring units of the Amur Tiger Monitoring Program, winters 1998 through 2009.

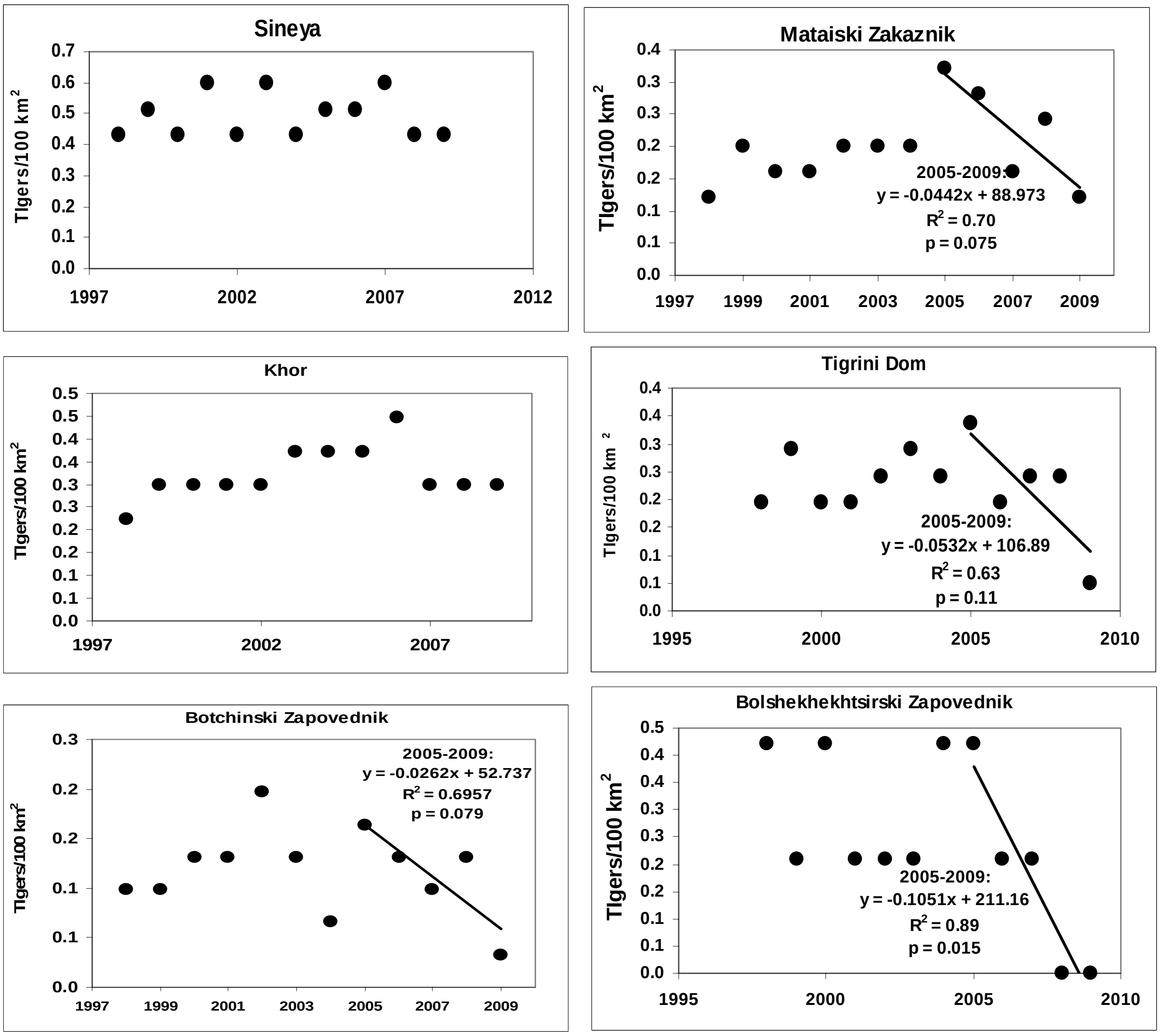

Figure 5 (continued). Tiger densities (adult tigers/100 km^2) in six of the 16 monitoring units of the Amur Tiger Monitoring Program, winters 1998 through 2009.

UNGULATE POPULATIONS ON MONITORING SITES

Red deer, wild boar, and sika deer are the primary prey of Amur tigers. Roe deer are taken relatively infrequently, and may be considered secondary prey. On occasion, even musk deer and moose are taken. Of these 6 species, only wild boar and roe deer are relatively common across most of tiger habitat in the Russian Far East. Moose occur only in the northern half of tiger range (and rarely show up in monitoring sites), and red deer are rare in the southern third of tiger range and now absent from Southwest Primorski Krai. Sika deer occur mostly in the southern third where red deer are uncommon, and in fact there appears to be an inverse relationship in the relative abundance of red deer, roe deer, and sika deer (see below). The distribution boundaries of all species are shifting quite remarkably, with the entire ecosystem "shifting" north: moose are becoming uncommon in the central Sikhote-Alin; sika deer are expanding rapidly to the north, and red deer also appear to be retreating in the face of sika deer expansion, especially along the eastern slopes of the Sikhote-Alin Range. These fluctuations may be related to global climate change. But whatever the reason, these fluctuations make interpretation of trends for ungulate populations more difficult. For instance, if red deer numbers are decreasing in a southern monitoring unit, is this the result of high illegal harvest, or does it represent a response to increasing sika deer numbers? Thus we should be aware of changes in ungulate numbers, but at the same time be careful in making assumptions about the causes of those changes.

We use fresh track (< 24 hours old) density as an indicator of ungulate abundance on Amur tiger monitoring units because there is a clear linear relationship to absolute ungulate density (Chelintsev, 2000, Miquelle et al. 2006, Stephens et al. 2005), but is much easier to measure than true density itself.

As in previous years, prey numbers varied greatly among sites (Table 16). In general, those sites where sika deer occur have much higher overall track densities than sites without sika deer, suggesting that prey biomass for tigers will also be greater where sika deer are present (Table 16). Sika deer track densities reach levels that are not reported for other species. Since tiger densities tend to be greater in zapovedniks, it would be expected that ungulate densities are also greater. In general, this is the case: 4 of the 6 monitoring units with the highest overall track densities are zapovedniks (Table 16).

Table 16. Mean track densities (fresh tracks/10 km) and 95% confidence intervals of primary ungulate prey species for tigers on monitoring sites of the Amur Tiger Monitoring Program.

		Tracks/10 km								
		Red deer		Roe deer		Wild boar		Sika deer		Total track
Monitoring Unit	n	mean	95% ci	mean	95% ci	mean	95% ci	mean	95% ci	density
Lazovski Zapovednik	12	1.10	1.08	1.28	2.21	17.87	23.57	99.34	39.52	119.59
Ussurisk Zapovednik	11	7.05	3.92	3.90	2.25	7.86	5.04	24.23	14.00	43.05
Lazovski Raion	11	0.00		4.37	5.97	1.18	1.26	36.60	31.58	42.15
Bolshekhekhtsirki Zapovednik	7	25.43	17.44	2.00	1.71	3.21	4.47	0.00		30.64
Borisovskoe Plateau	14	0.00		2.42	1.74	0.37	0.59	21.74	10.33	24.53
Sikhote Alin Zapovednik	25	8.20	2.41	4.33	1.18	1.98	2.99	3.68	3.54	18.19
Ussuriski Raion	12	4.45	3.21	5.46	3.05	4.42	2.81	1.53	1.08	15.86
Bikin	16	3.96	1.26	5.87	1.95	4.47	3.07	0.00		14.31
Botchinski Zapovednik	14	6.47	1.91	6.02	2.19	0.00		0.00		12.49
Iman	12	3.20	2.95	2.70	1.49	1.14	1.47	0.00		7.04
Khor	19	2.59	1.42	0.62	0.41	3.73	2.03	0.00		6.95
Sandagoy	16	2.78	1.51	2.44	1.54	0.28	0.34	1.27	1.29	6.77
Mataiski Zakaznik	24	1.82	0.52	0.73	0.39	2.28	0.64	0.00		4.84
Terney Hunting Lease	24	0.88	0.60	1.47	0.69	0.23	0.24	0.42	0.82	3.00
Sineya	15	0.41	0.25	0.74	0.34	0.37	0.26	0.00		1.51
Tigrini Dom	14	0.83	0.83	0.37	0.60	0.20	0.40	0.00		1.41

To attempt to understand how density estimates vary across time, we conduct a regression analysis to look for trends, looking first at trends for all sites combined, and then separately for each site and each species. We conducted trend analyses for the entire twelve years, or a subset of those years where a visual inspection suggested a significant trend might exist. We report all sites where the p-values are is less than 0.2 (suggesting that the slope of the line is not zero, thereby indicating either an increase or decrease in animal abundance) with the understanding that we are looking for general trends and potential early warning signs across the region and within each monitoring site. While we use a relatively large p-value to increase our chances of detecting changes (and recognizing that some of these changes may be false alarms) we also look at how large the p-values are, as well as the correlation coefficient (r^2) to assess the strength of the trends we are assessing. Similar patterns across multiple sites, along with low p-values and high correlation coefficients, should increase the reliability that the patterns we are seeing are real.

Red deer

As in past years, red deer track densities varied greatly among monitoring sites, from 23 tracks/10 km in Bolshekhekhtsirski Zapovednik to 0 in Borisovskoe Plateau (where red deer have not been reported for many years) and Lazovski Raion (Table 17). In the 2009 winter the average red deer track density was 4.94 $\pm$ 3.1 tracks/10 km of survey route (Table 17). This estimate is quite a bit less than the 12-year average (7.10 $\pm$ 3.60) but similar to estimates of the past two years, which also suggested a marked decrease in red deer numbers has occurred (Table 17).

It appears that red deer have largely disappeared in Lazovski Raion (no records of red deer on monitoring routes for the past two years) (Table 17). Although Lazovski Zapovednik is still reporting red deer, they are declining there as well (Figure 7), suggesting that we may be witnessing the disappearance of red deer in this region. And as in past years, track count densities of red deer were highest in Bolshe-Khekhtsirski Zapovednik, and secondly, in Sikhote-Alin Zapovednik although red deer numbers appear to have dropped dramatically in Sikhote-Alin in the past two years, according to monitoring data (Table 17). Red deer track densities in Sikhote-Alin Zapovednik are now similar to those found in Ussuriski Zapovednik which is the only site, along with neighboring Ussuriski Raion, where red deer numbers appear to be increasing. (Figure 7).

In our twelfth year of monitoring we are detecting disturbing trends for red deer. Overall, the pattern for red deer on monitoring sites as a whole appears to be represented by a slight increase in numbers between the beginning of monitoring and 2001, followed by a steady decline since that time (Figure 6). The past three years indicate consistently lower red deer track densities, all well below the 12-year average (Table 17, Figure 6). Overall the decline in red deer should be of serious concern, as they represent the primary prey for tigers over much of their range in Russia.

While, as mentioned above, two sites appear to be supporting an increase in red deer numbers, but 11 of the 15 sites (73%) where red deer exist are undergoing significant declines with all but one of these sites having high regression coefficients and small p-values (below 0.03), indicating very strong trends. A twelfth site, Bolshekhekhtsirski Zapovednik, appears to be undergoing a decline in red deer numbers as well, but is as yet not significant (Figure 7). The pattern of decline varies. Some sites, such as the Matai, Khor, and Iman showed an increase in the early years of the monitoring program followed by the decline after 2002. Others, such as Sikhote-Alin and Terney Hunting Lease, appear to have undergone steady declines during the entire course of the monitoring program.

In many sites in southern Primorye, red deer numbers are disappearing or have already disappeared (Borisovskoe Plateau, Lazovski Raion, and Sineya). In some cases, as in Borisovskoe Plateau, it is possible that sika deer have been responsible for the decline in red deer numbers (see below for a discussion of this factor) but red deer are also declining in areas where sika deer are absent or very rare (Bikin, Matai, Khor, and Terney Hunting Lease). In these areas where sika deer are not a factor, declines in red deer numbers are more likely due to uncontrolled harvest by humans.

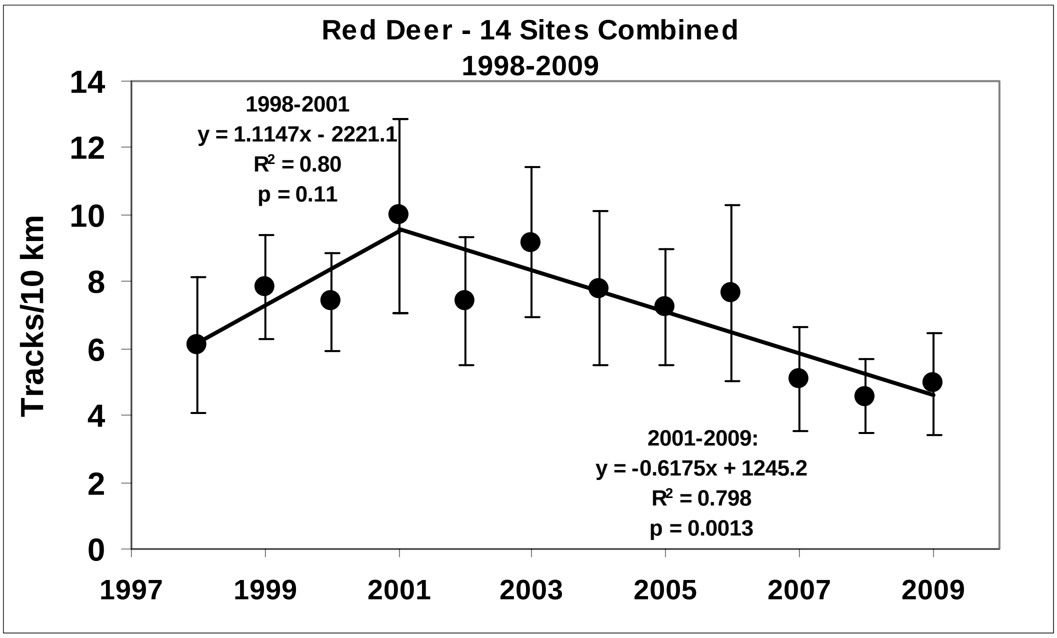

Figure 6. Average red deer track density and standard errors across 14 sites for all twelve years of the Amur Tiger Monitoring Program, 1998 though 2009. Two sites were not included because red deer are rare or completely absent (Borisovskoe Plateau and Lazovski Raion.

Table 17. Red deer track densities (tracks/10 km) on routes surveyed on 16 sites for the Amur Tiger Monitoring Program 1998-2009.

	Fresh tracks/10 km												
Unit	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	Average
Lazovski Zapovednik	1,36	1,49	6,62	9,16	3,92	1,14	5,53	4,30	4,67	3,71	2,28	1,10	3,77
Ussurisk Zapovednik	5,87	7,03	7,06	5,11	3,43	4,79	3,64	5,13	3,08	7,21	7,05	7,05	5,54
Iman	1,83	6,33	5,33	5,56	8,10	5,29	4,61	6,66	4,57	3,04	3,35	3,20	4,82
Bikin	1,47	11,24	7,14	9,53	5,32	10,37	4,52	6,91	4,13	6,85	2,86	3,96	6,19
Sandagoy	1,74	3,84	9,90	7,41	9,87	6,87	5,07	4,67	4,08	2,30	6,41	2,78	5,41
Khor	5,35	6,82	3,98	3,66	4,19	11,72	5,64	7,82	7,73	3,30	4,89	2,59	5,64
Botchinski Zapovednik	1,82	6,87	4,33	2,84	4,73	5,40	11,61	4,72	5,44	0,79	1,11	6,47	4,68
Bolshekhekhtsirski Zapovednik	11,01	16,29	13,63	40,57	29,00	34,79	35,93	24,50	41,66	26,07	17,21	25,43	26,34
Tigrini Dom	3,00	5,06	1,38	1,38	2,29	2,38	1,58	0,72	1,73	1,41	1,34	0,83	1,93
Mataiski Zakaznik	1,74	4,85	3,76	2,23	4,67	9,54	3,43	5,34	3,05	1,98	2,64	1,82	3,76
Ussuriski Raion	2,28	2,02	4,30	1,85	1,43	2,78	1,50	2,84	0,94	3,48	3,54	4,45	2,62
Sikhote Alin Zapovednik	32,55	23,98	23,98	32,82	19,41	21,29	20,35	21,74	20,48	8,35	8,86	8,20	20,17
Sineya	1,67	4,00	2,77	3,49	1,55	2,31	1,79	1,62	0,57	0,67	0,59	0,41	1,79
Terney Hunting Lease	13,69	10,11	9,27	13,94	6,16	9,87	3,96	4,26	5,15	1,94	1,77	0,88	6,75
Lazovski Raion	0,83	0,25	1,18	0,18	0,14	0,36	0,18	0,00	0,08	0,04	0,00	0,00	0,27
Borisovskoe Plateau	0,02	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Average (without last two units)	6,10	7,85	7,39	9,97	7,43	9,18	7,80	7,23	7,66	5,08	4,56	4,94	7,10

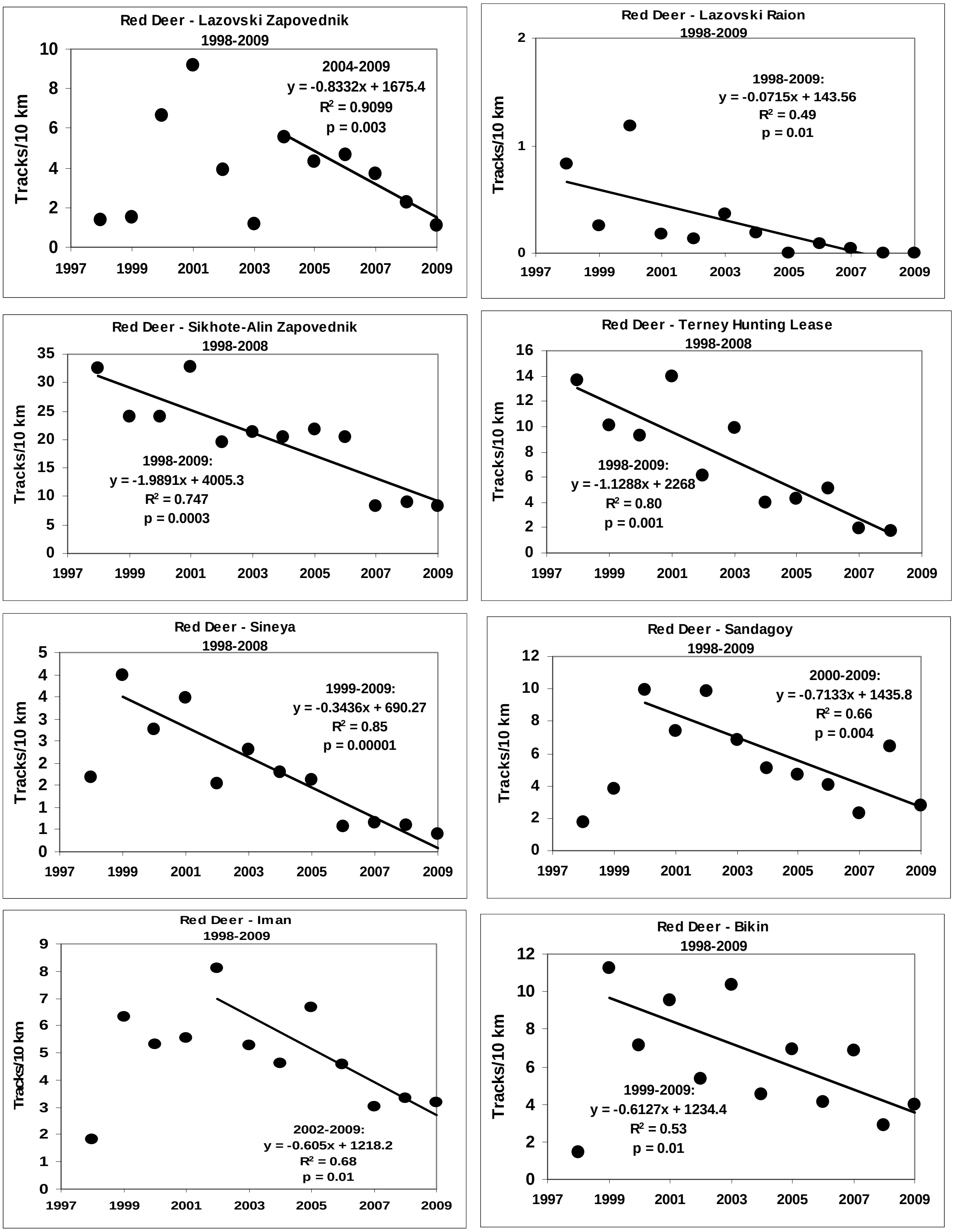

Figure 7. Trends (where $p < 0.2$) in red deer densities, as measured by fresh tracks/10 km along routes in 15 of the 16 monitoring sites of the Amur Tiger Monitoring Program (One site – Borisovskoe Plateau - has no red deer).

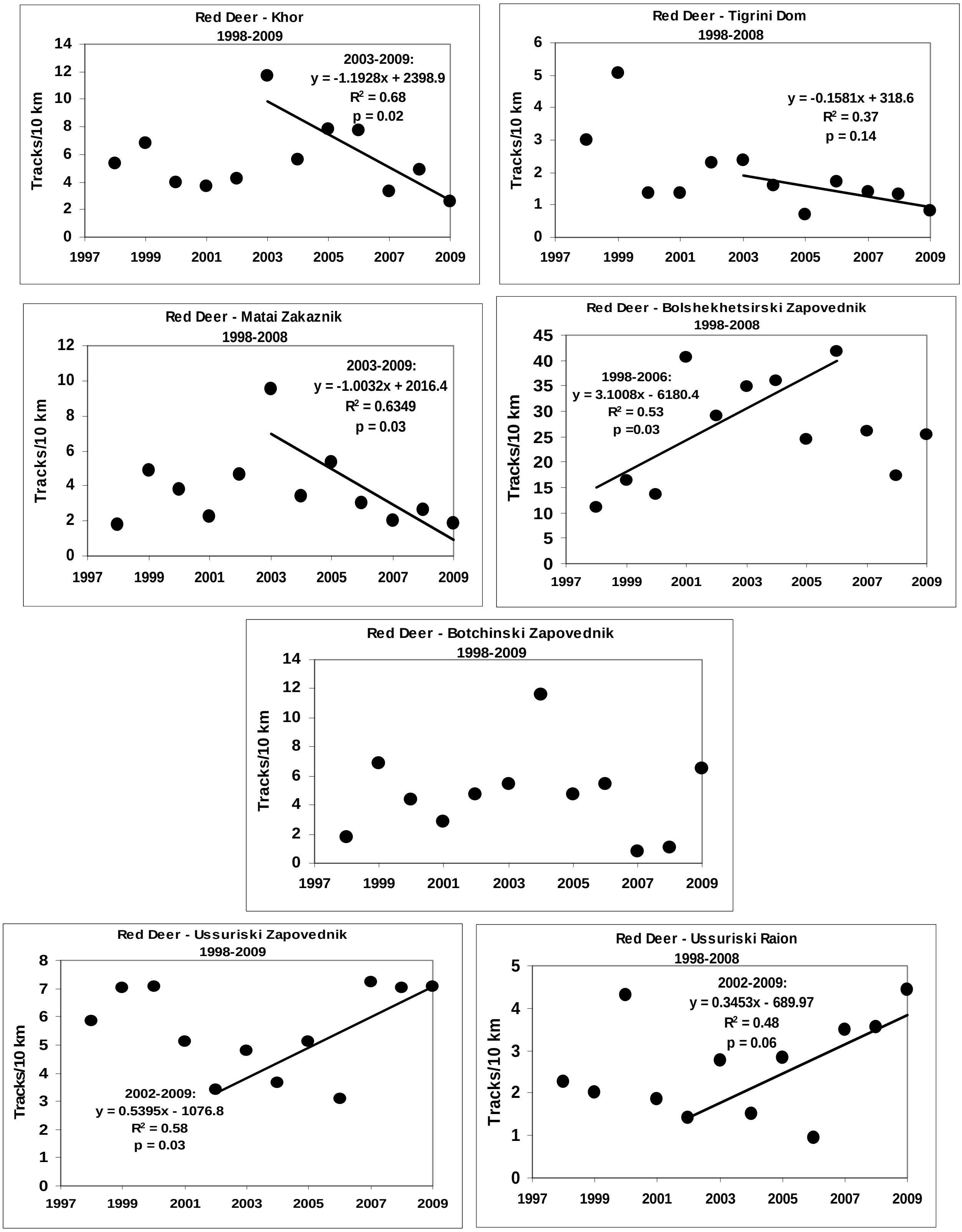

Figure 7 (Continued). Trends (where $p < 0.2$) in red deer densities, as measured by fresh tracks/10 km along routes in 15 of the 16 monitoring sites of the Amur Tiger Monitoring Program (One site – Borisovskoe Plateau - has no red deer). Eleven of 15 sites show significant downward trends in red deer densities over 4 to 12 years, and two (Ussuriski Raion and Zapovednik) show a resurgence of red deer track densities since 2002.

Wild boar

Wild boar populations are known to fluctuate more dramatically than most deer populations due to disease and other factors. This natural tendency for greater fluctuations, along with the fact that they are commonly found in large groups, makes accurate estimating wild boar population numbers and trends more problematic than other ungulate species.

Since 2005, overall wild boar numbers appeared to drop over the next three years, but in 2009, numbers appeared to have increased slightly. However, given the large error associated with counts of wild boar, there is no significant difference in wild boar numbers from the previous three years when all sites are combined. Numbers still appear to be low, but there is no clear significant downward trend, although a visual assessment of Figure 8 suggests that there may have been a drop in numbers since 2005.

Wild boar track densities are generally lower than those of red deer (wild boar track density at all sites over 12 years = 3.1 $\pm$ 1.2 tracks/10 km, versus 7.1 $\pm$ 3.0 tracks/10 km for red deer) but fluctuate more from site to site than those of red deer, apparently because they have the capacity to move large distances in search of winter forage. In 2009 winter, wild boar densities averaged 3.1 $\pm$ 2.3 tracks/10 km, essentially the same as the 12-year average (Table 18).

In contrast to the overall pattern of no change, there are clear trends in many individual sites. In fact half of the 16 monitoring sites have downward trends over the 5 past years or more (Figure 9). Only one site – Khor in Khabarovsk – has demonstrated a positive growth during the 12-year monitoring period. As with red deer, the disparity in the number of sites showing declines (8) versus the number showing increases (1) provides strong evidence that wild boar populations are declining in at least in some regions of tiger range in the Russian Far East.

Table 18. Wild boar track densities (fresh tracks/10 km) on routes surveyed on 16 sites for the Amur Tiger Monitoring Program 1998-2009.

	Wild boar track density/10 km												
Unit	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	Average
Lazovski Zapovednik	1.51	2.52	5.49	5.08	8.04	7.82	11.18	5.96	2.57	6.17	3.04	17.87	6.44
Lazovski Raion	3.38	0.30	0.35	0.27	1.87	1.99	3.48	0.75	1.00	0.94	2.16	1.18	1.47
Ussurisk Zapovednik	13.60	29.56	4.24	25.63	5.33	0.99	4.13	7.79	8.90	3.27	2.26	7.86	9.46
Iman	4.17	1.55	0.22	0.66	2.51	1.14	5.32	3.97	1.68	1.03	1.72	1.14	2.09
Bikin	15.94	4.00	0.29	3.97	1.69	3.20	5.09	8.46	3.96	7.31	7.21	4.47	5.47
Borisovskoe Plateau		0.26	5.53	7.47	1.38	6.65	5.42	16.90	11.16	1.35	1.32	0.37	5.25
Sandagoy	0.42	2.76	2.68	0.54	1.04	2.42	5.40	1.83	1.74	0.66	1.41	0.28	1.77
Khor	1.17	0.66	0.37	2.27	1.71	2.13	1.68	6.34	2.93	4.57	2.92	3.73	2.54
Botchinski Zapovednik	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bolshekhekhtsirki Zapov	1.36	3.16	0.61	3.36	2.29	26.43	4.57	2.14	4.46	2.07	4.00	3.21	4.80
Tigrini Dom	0.54	0.94	1.00	0.46	0.08	0.15	0.35	0.30	0.18	0.17	0.90	0.20	0.44
Mataiski Zakaznik	0.63	1.11	2.05	1.95	0.48	5.56	1.00	4.20	1.54	0.48	2.21	2.28	1.96
Ussuriski Raion	3.30	2.19	2.22	1.84	2.74	1.25	1.61	2.26	2.83	4.44	1.46	4.42	2.55
Sikhote Alin Zapovednik	4.47	4.21	2.69	3.64	1.91	1.91	2.61	11.31	5.63	1.62	2.46	1.98	3.70
Sineya	1.53	1.23	0.61	0.56	1.26	0.88	0.53	0.61	0.61	0.51	0.94	0.37	0.80
Terney Hunting Lease	4.76	0.75	1.22	0.20	0.18	0.72	1.37	1.57	1.75	0.38	0.76	0.23	1.16
Average	3.79	3.45	1.85	3.62	2.03	3.95	3.36	4.65	3.18	2.18	2.17	3.10	3.11

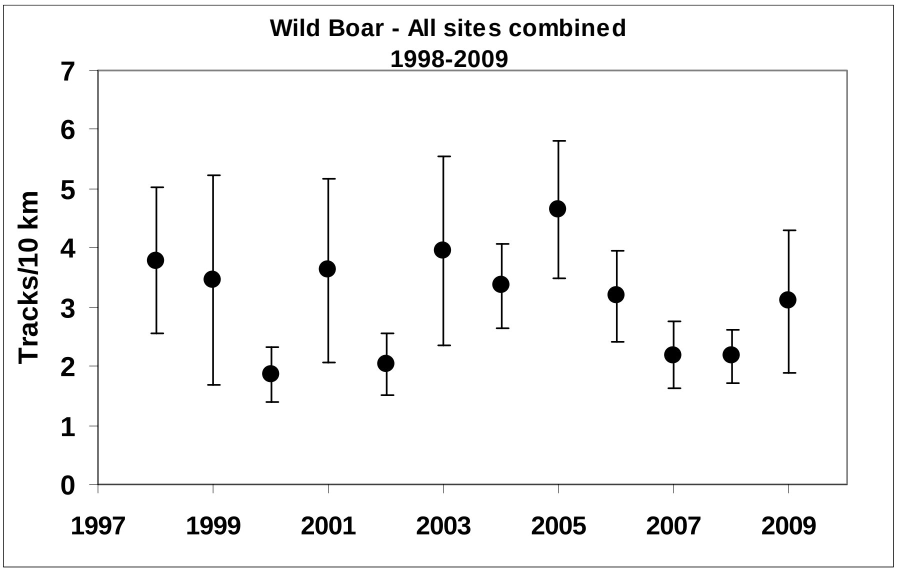

Figure 8. Average wild boar track density and standard errors for all sites, for each of the nine years of the Amur Tiger Monitoring Program, 1998 though 2009.

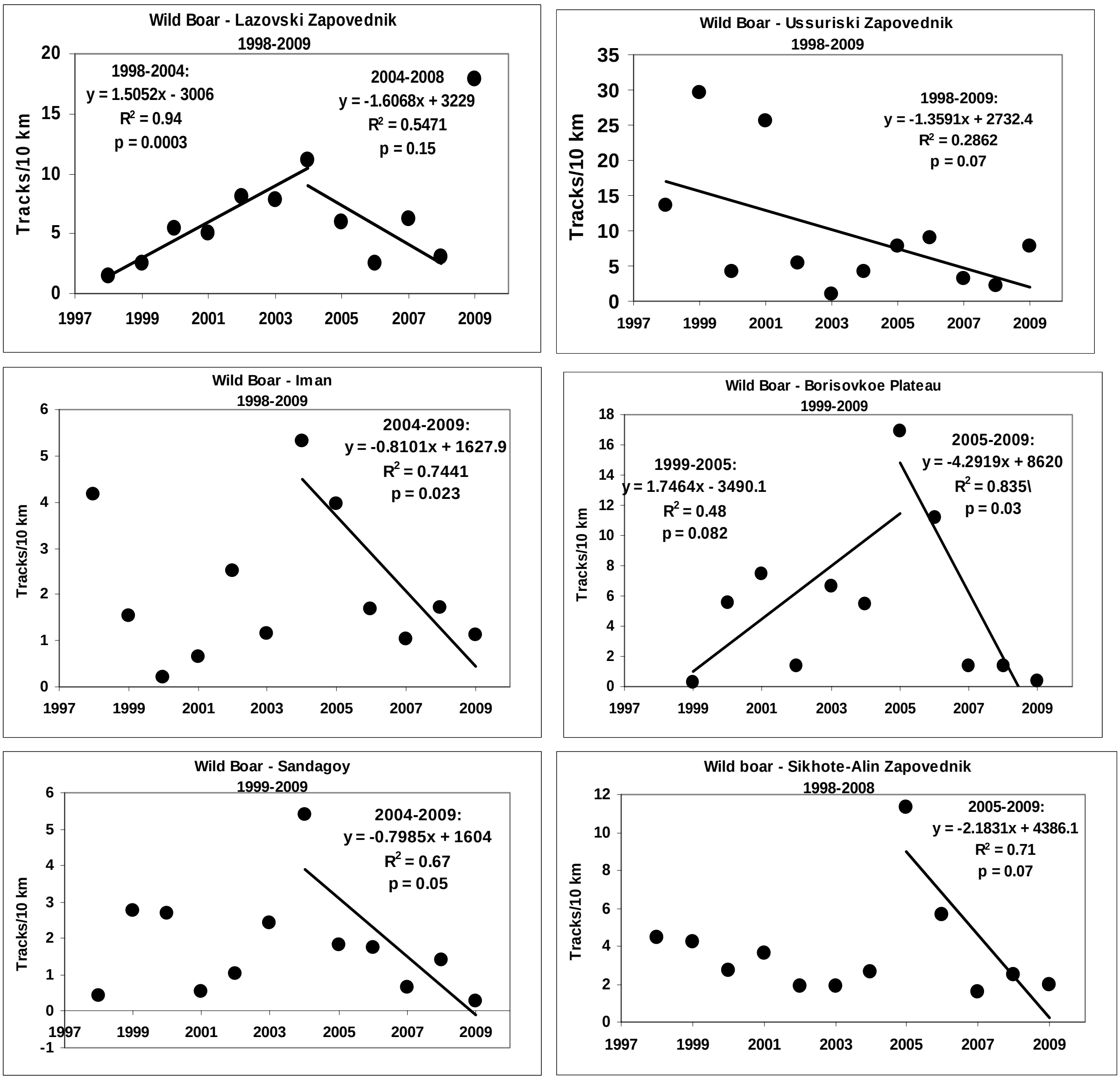

Figure 9. Changes in wild boar densities, as measured by fresh tracks/10 km along routes in 9 of the 16 monitoring sites of the Amur Tiger Monitoring Program.

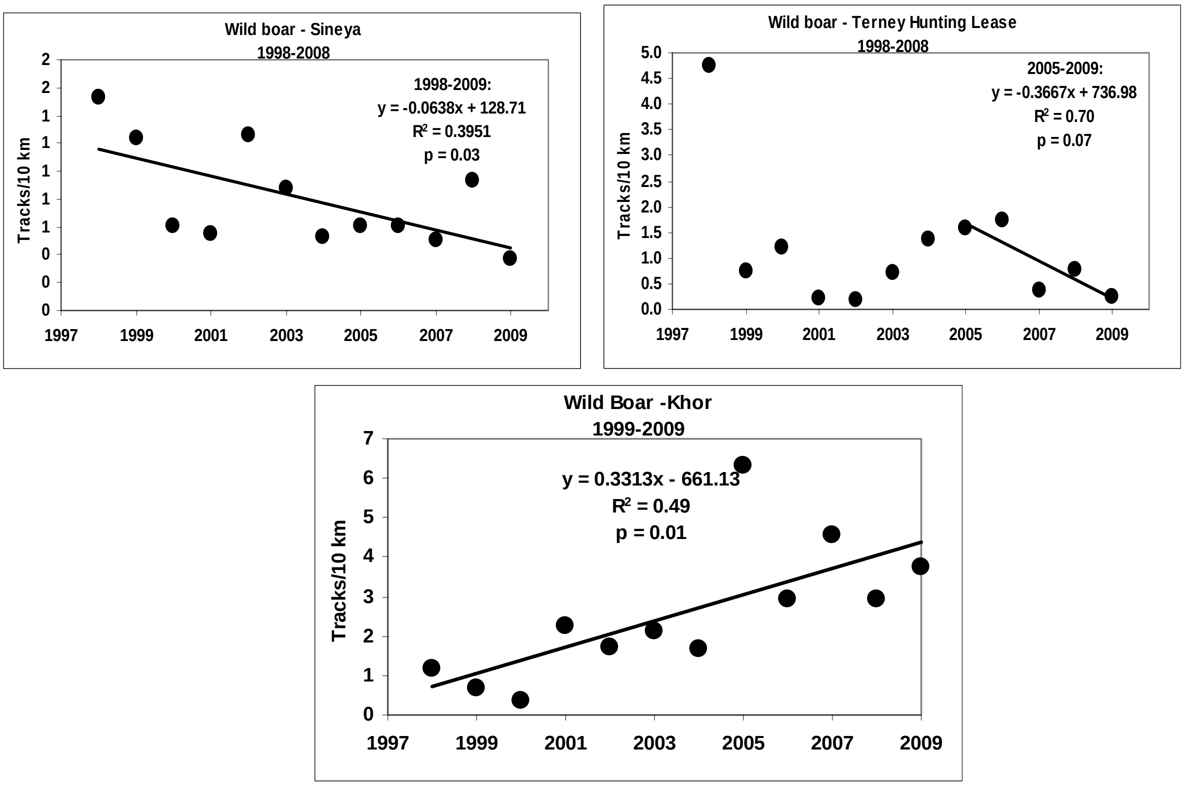

Figure 9 (continue). Changes in wild boar densities, as measured by fresh tracks/10 km along routes in 9 of the 16 monitoring sites of the Amur Tiger Monitoring Program.

Roe deer

Roe deer are the only ungulate species that is found on all 16 monitoring sites. In the 2009 winter the average roe deer track index was 2.80 $\pm$ 0.96 tracks/10 km of survey route (Table 19). This estimate is significantly less than the 12-year average (4.17 $\pm$ 0.80) but at a similar level as the past two years (Table 19), strengthening the evidence that roe deer numbers are in decline.

As with red deer, there is evidence that roe deer densities increased during the early years of the monitoring program through 2002 or 2003, but have since been in steady decline (Figure 10). Patterns within individual monitoring units generally support this overall picture, but there are varying patterns, as noted for red deer and wild boar In three cases (Ussuriski and Lazovski Zapovedniks and Tigrini Dom)), there has been a steady decline during much of the monitoring period (Figure 11), but more commonly (in nine cases) the pattern is similar to the overall pattern seen in Figure 11) – a peak and then decline staring around 2003 or 2004 is evident (e.g. Sandagoy, Iman, Sineya Sikhote-Alin Zapovednik, and others) (Figure 11). Twelve of the 16 sites (75%) show downward trends in the last 5 years of more of monitoring, while only two (Ussuriski Raion and Bikin) show positive trends: two sites show no trends at all (Lazovski Raion and Bolshekhekhtsirski Zapovednik). In the Tigrini Dom there is a downward trend with the exceptional year of 2006.

Table 19. Roe deer track densities (tracks/10 km) counted along survey routes within all 16 monitoring sites of the Amur Tiger Monitoring Program, 1998-2009.

	Year												
Unit	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	Average
Lazovski Zapovednik	4.49	2.40	4.35	2.73	4.07	0.62	0.97	2.47	1.29	0.67	2.80	1.28	2.34
Lazovski Raion	4.18	1.01	1.04	0.11	1.40	0.10	0.97	0.35	0.41	0.09	3.12	4.37	1.43
Ussurisk Zapovednik	13.08	8.61	10.53	6.62	6.31	2.19	1.60	2.03	2.44	1.81	3.04	3.90	5.18
Iman	3.83	2.68	3.16	4.45	4.29	5.50	3.50	5.04	4.18	3.46	3.39	2.70	3.85
Bikin	1.61	4.96	1.39	2.88	4.49	3.41	4.73	5.43	3.95	5.35	5.60	5.87	4.14
Borisovskoe Plateau	3.38	8.48	4.58	6.22	11.27	2.69	4.36	3.78	2.26	5.00	2.97	2.42	4.78
Sandagoy	2.37	2.44	6.70	8.98	11.94	6.39	3.26	3.94	4.39	2.55	4.09	2.44	4.96
Khor	2.42	7.60	2.73	2.85	5.25	4.05	5.62	6.45	5.48	1.80	1.23	0.62	3.84
Botchinski Zapovednik	0.43	2.99	2.69	4.59	3.91	6.55	7.51	2.44	1.82	0.60	0.81	6.02	3.36
Bolshekhekhtsirki Zapov	0.64	1.27	0.16	1.36	4.86	0.64	4.36	1.57	3.34	4.86	1.00	2.00	2.17
Tigrini Dom	0.65	1.04	0.36	0.28	0.59	0.08	0.45	0.15	1.88	0.13	0.06	0.37	0.51
Mataiski Zakaznik	1.46	2.62	2.10	1.49	1.39	4.02	1.46	1.45	1.27	1.03	0.89	0.73	1.66
Ussuriski Raion	7.79	7.92	11.73	7.93	4.68	2.03	2.55	2.58	4.53	4.84	4.34	5.46	5.53
Sikhote Alin Zapovednik	16.24	11.50	17.53	16.94	13.69	19.17	21.45	15.64	22.50	7.06	11.02	4.33	14.76
Sineya	2.39	2.59	2.37	3.77	3.01	5.55	2.12	4.27	1.73	1.04	1.75	0.74	2.61
Terney Hunting Lease	6.61	4.58	4.67	8.33	4.63	10.87	7.25	6.02	7.48	2.95	2.29	1.47	5.60
Average	4.47	4.54	4.76	4.97	5.36	4.61	4.51	3.98	4.31	2.70	3.03	2.80	4.17

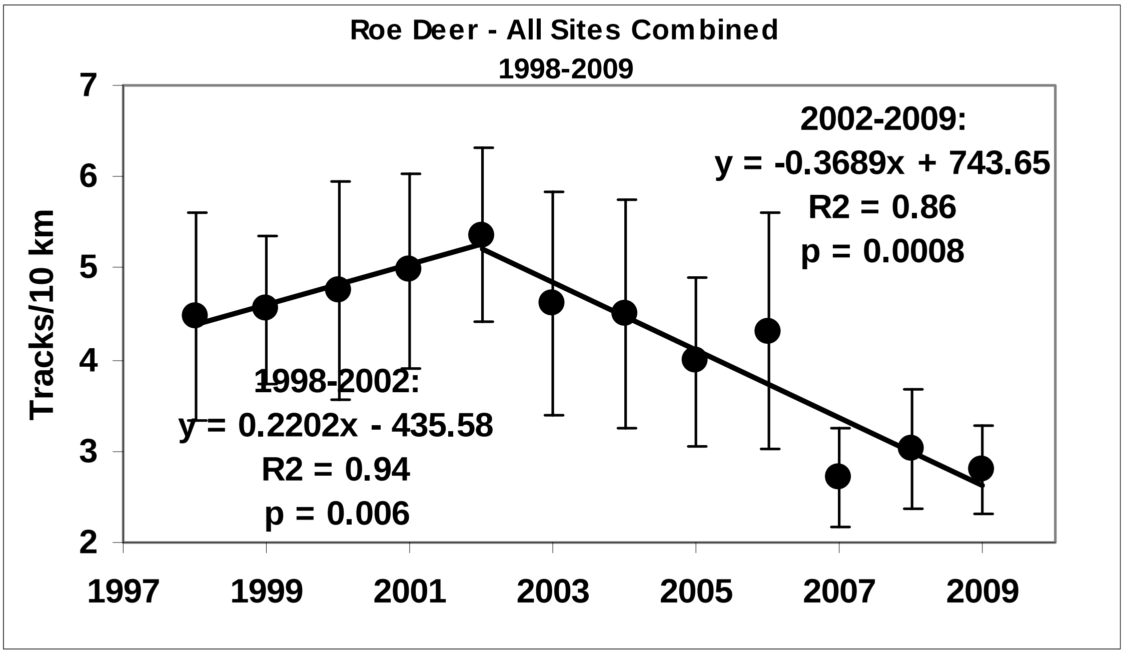

Figure 10. Roe deer track density averaged across all study sites, for twelve years of the Amur Tiger Monitoring Program, 1998 though 2009.

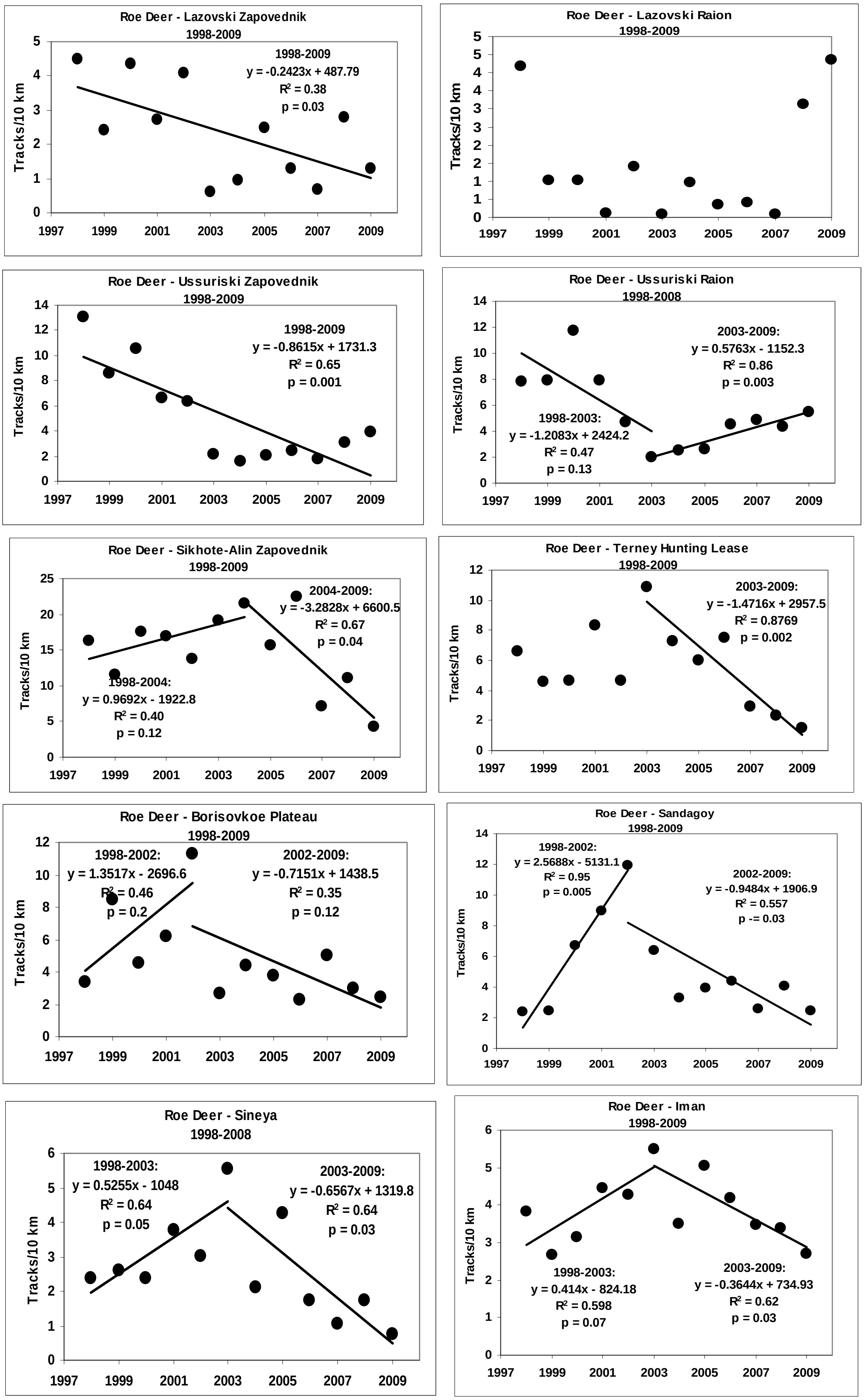

Figure 11. Changes in roe deer densities, as measured by tracks/10 km along routes all sixteen monitoring sites in the Amur Tiger Monitoring Program, 1998 through 2009.

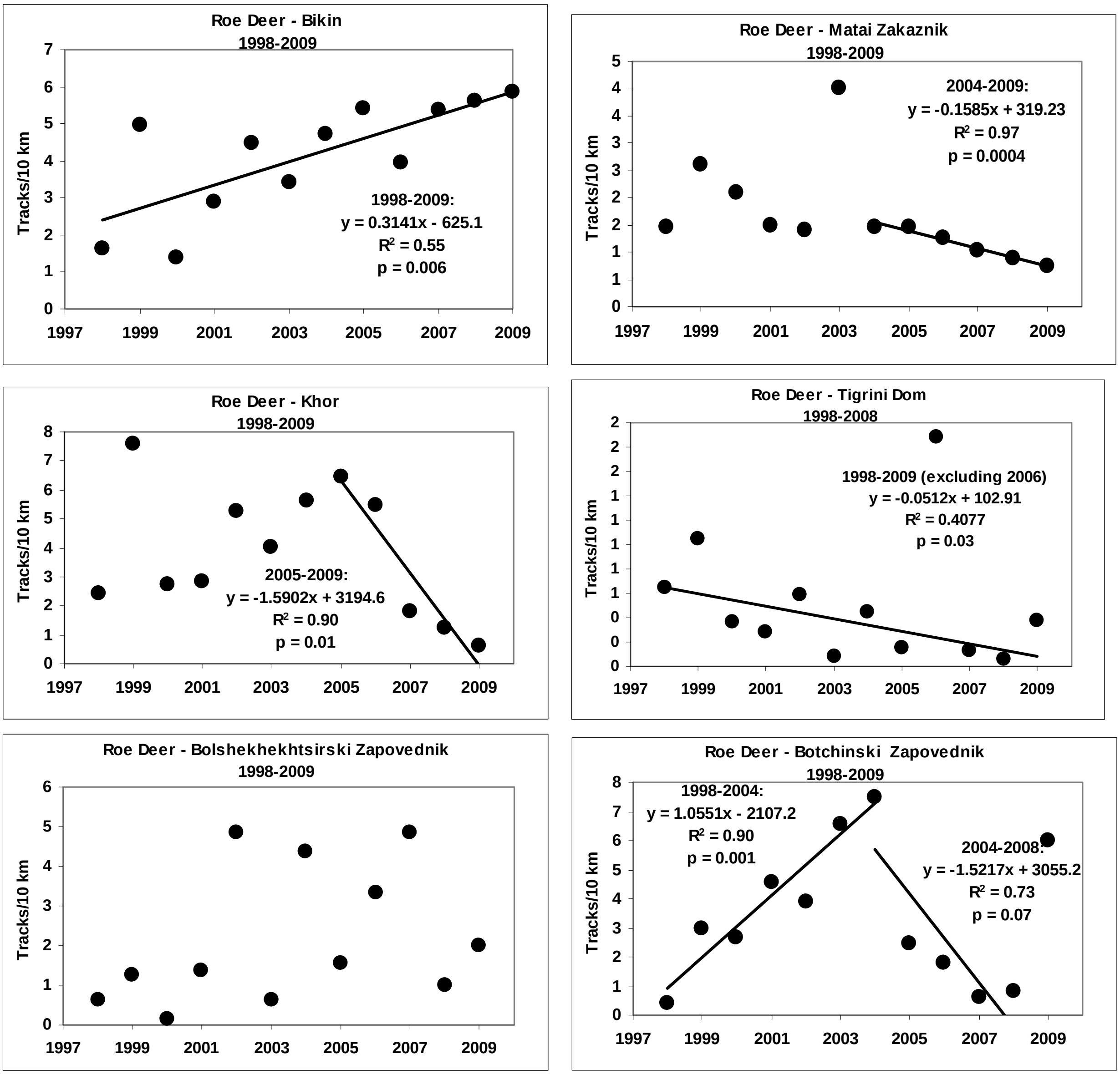

Figure 11(continue). Changes in roe deer densities, as measured by tracks/10 km along routes all sixteen monitoring sites in the Amur Tiger Monitoring Program, 1998 through 2009.

Sika deer

Sika deer reach their highest densities in southern Primorski Krai, but also occur regularly in some of the central Amur tiger monitoring sites. Although there are reports of a few sika deer in Khabarovsk, they are mostly absent from this region. Sika deer are found regularly in only eight of the monitoring units, including all 6 in the south, and 2 of the central monitoring sites (Table 20). However, in the two central units where they occur (Sikhote-Alin Zapovednik and Terney Hunting Lease) they exist in localized pockets, and are not uniformly distributed throughout the monitoring units. Sika deer appear to be increasing in the coastal areas of Terney Raion, and appear to be extending their range to the north, as more reports of sika deer are coming in from Khabarovsk and northern Terney Raion.

Track densities (and hence presumably animal densities) are generally much higher for sika deer than other ungulate species, consistently reaching their highest levels in Lazovski Zapovednik (Table 20). Track densities average 26.2 $\pm$ 19.7 /10 km across all 8 sites for all years (Table 20), with the large confidence interval a reflection of the great variability in sika deer densities across sites, ranging from less than 2 tracks/10 km in Terney Hunting Lease to 100/10 km in Lazovski Zapovednik.

Sika deer are highly gregarious, and there is great variation in track counts dependent on the number of groups encountered along transects. Greater sampling is probably required to obtain more accurate estimates of track densities, with smaller confidence intervals.

There are no trends that appear consistent across all 8 southern sites combined for the 12 years of monitoring (Figure 12), but there are important and opposing trends for some of the individual sites (Figure 13).

Table 20. Sika deer track densities (fresh tracks/10 km) on routes surveyed on 8 sites of the Amur Tiger Monitoring Program 1998-2009. (Sika deer are absent or extremely rare in the other 8 monitoring sites.)

Monitoring Site	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	Average
Lazovski Zapovednik	47.4	43.9	107.0	123.4	92.5	42.7	83.7	183.8	120.4	67.9	211.0	99.3	101.9
Lazovski Raion	9.7	11.4	51.3	51.6	47.8	28.8	30.3	37.4	36.3	56.8	39.0	36.6	36.4
Ussurisk Zapovednik	21.2	16.1	31.2	27.6	24.7	12.0	22.7	18.0	19.9	14.8	26.4	24.2	21.6
Borisovskoe Plateau	116.2	42.9	65.7	20.8	34.1	18.6	28.3	19.9	20.7	24.5	20.7	21.7	36.2
Sandagoy	0.8	2.5	4.1	7.9	4.3	2.9	1.3	1.3	1.4	1.7	2.4	1.3	2.6
Ussuriski Raion	0.6	0.3	2.7	2.0	1.2	1.1	0.6	1.3	2.5	1.0	1.0	1.5	1.3
Sikhote Alin Zapovednik	9.9	5.2	3.7	8.4	9.7	11.8	14.7	6.6	9.1	7.2	7.7	3.7	8.1
Terney Hunting Lease	6.6	1.6	2.0	0.5	1.3	3.4	1.4	0.5	1.4	0.1	1.0	0.4	1.7
Average of Tracks/10 km	26.6	15.5	33.5	30.3	26.9	15.1	22.9	33.6	26.5	21.7	38.6	23.6	26.2

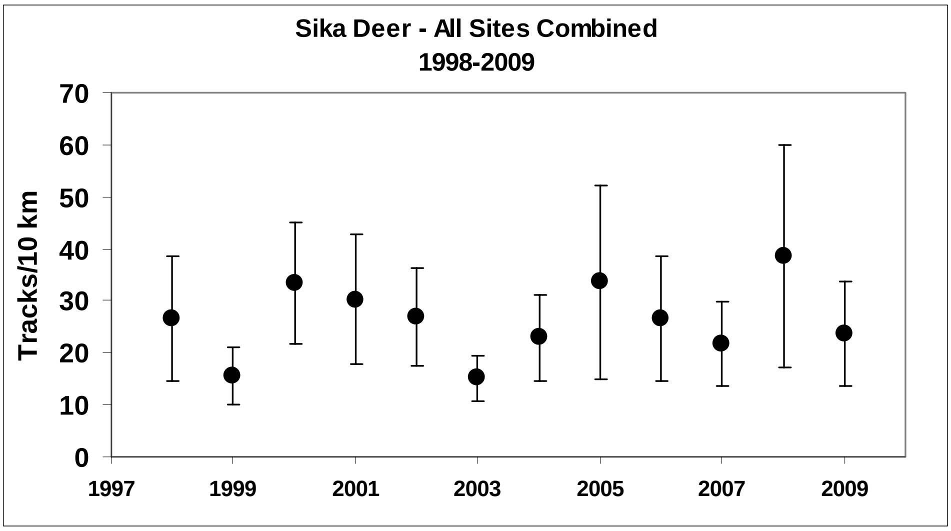

Figure 12. Average sika deer track density and standard errors averaged across eight sites where sika regularly occur, for twelve years of the Amur Tiger Monitoring Program, 1998 though 2009.

Despite this apparent trend of range extension, the data across all 8 sites where sika deer normally occur does not suggest that, overall, sika deer numbers are increasing at those sites (Figure 13), but rather, suggests a variety of dynamics in different regions. In the Lazo area (Lazovski Zapovednik and Lazo Raion) there are marginally significant upward trends in population indices (Figure 13) suggesting that the population there may be increasing (though low R^2 values and large p-values make this conclusion tentative). Dramatic differences in the track counts between those adjacent units reflect the importance of protected areas in protecting even populations on the Russian Red Data Book – track densities in the zapovednik are 2-4 times higher than adjacent hunted lands. Nonetheless, the general pattern in the Lazo region appears to be upward or stable.

Track count indices in Borisovskoe Plateau and Terney Hunting lease suggest sika deer numbers have been decreasing during the entire period of monitoring (Figure 13). Sika deer are legally hunted only in Nezhinskoe Military Hunting lease (part of the Borisovskoe Plateau monitoring site, but the downward trends in both sites may reflects the low level of protection provided by these two hunting leases.

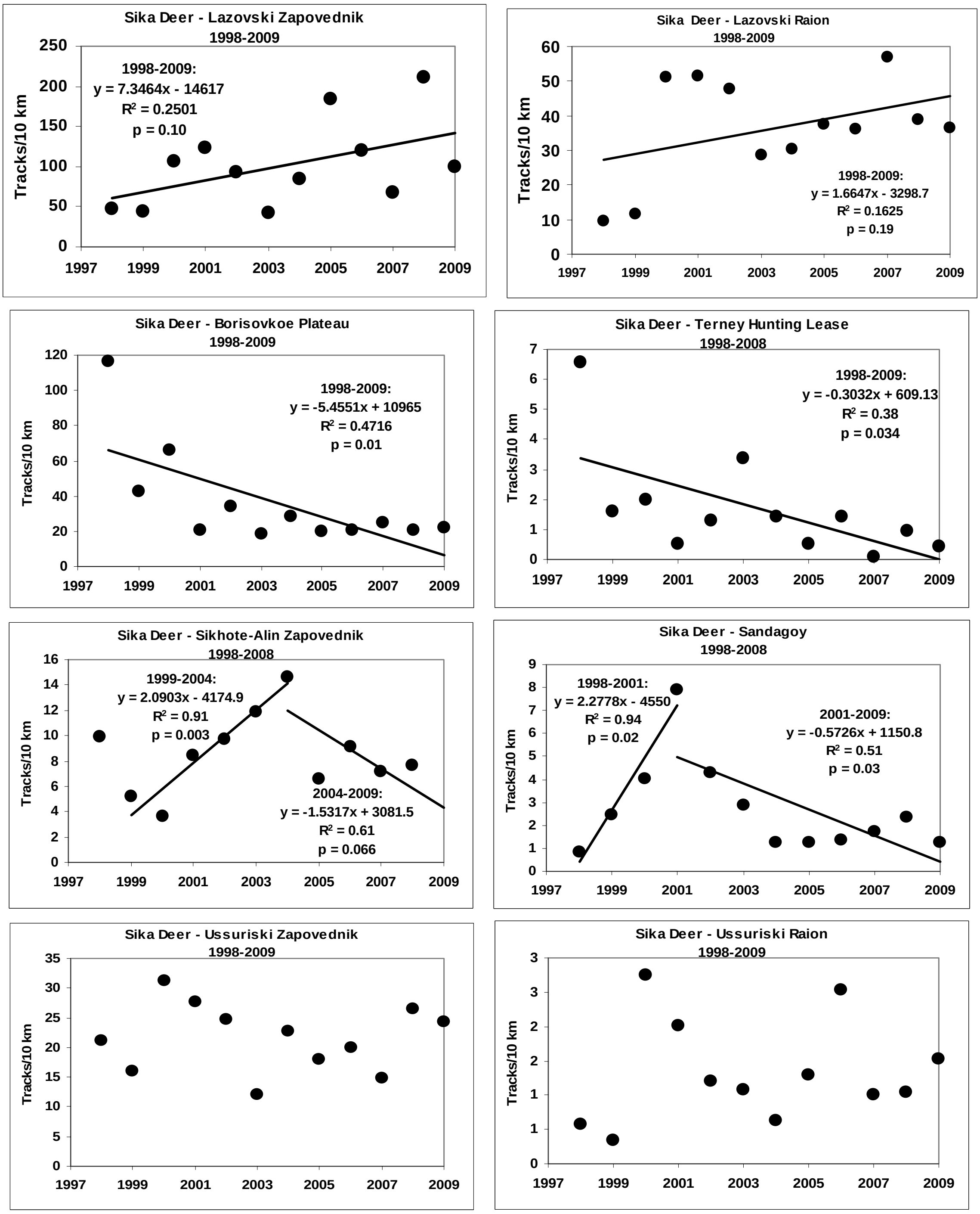

Figure 13. Changes in sika deer densities, as measured by tracks/10 km along routes in all 8 monitoring sites where this species occurs in the Amur Tiger Monitoring Program, 1998 through 2009.

Track density patterns of two other units – Sikhote-Alin Zapovednik and Sandagoy – that suggest population numbers increased in the first half of our monitoring program, and have since decreased. The timing of the decline, however, varies. In Sandagoy, the beginning of the decline coincides with declines in red deer and roe deer across the region (2001-2002), while in Sikhote-Alin the population appears to have peaked in 2004.

Only in two of the eight count – Ussuriski Zapovednik and Raion – do track count indices show no clear trends, suggesting that population numbers there may be relatively stable.

Collectively, these analyses suggest that sika deer have declined in half of the monitoring sites where they commonly occur, have increased in only two sites, and remain stable in the other two. Again, as the primary prey of tigers in the southern Sikhote-Alin, declining numbers of sika deer in half the monitoring sites is a reason for concern.

STATUS OF AMUR TIGERS IN THE RUSSIAN FAR EAST

We use two indicators to assess changes in the status of the Amur tiger population in the Russian Far East over the past twelve years: track density, and expert estimates of tiger density. Because any single measurement has its inherent biases and errors associated with it, we believe that using a system that compares these three estimators will give a more balanced assessment of the status of tigers at any given point of time and in any given monitoring unit. Our monitoring program is designed not to provide an assessment of the absolute numbers of tigers in either Primorski or Khabarovski Krai, but to detect changes in numbers. We believe that such a monitoring system, if sufficiently accurate, should act as an “early warning signal” which will allow the appropriate governmental agencies to react with this information. Based on an assessment of the trends identified above, we believe there are a number of important conclusions that can be drawn.

Because we are most concerned about detecting changes in population levels, our assessment of the status of tigers and their prey is based on trend analyses. To be conservative, we set $p = 0.20$ as level at which we should be concerned about trends in a population of tigers or prey at any of the monitoring sites. Setting p at such a high level raises the probability that we will identify areas of concern (evidence of downward trends) but at the same time increases the probability that we will detect changes in population trends in time to take action to correct situations. But where analysis show a stronger correlation (lower p-values) we should be even more concerned. Therefore, in scoring the status of the sixteen monitoring sites, we took the following steps.

For Tigers:

1. If trend analyses of tiger track densities showed that there has been a negative trend for at least 4 years, and the p-value confirming that trend is less than 0.05, that site received a score of -2. Similarly, if the trend was positive, and $p < 0.05$, that site received a score of +2.

2. If trend analyses of tiger track densities showed that there has been a negative trend for at least 4 years, and the p-value confirming that trend is greater than 0.05, but less than 0.20. that site received a score of -1. Similarly, if the trend was positive, and $0.05 < p < 0.2$, that site received a score of +1.

3. The exact same scoring was used for trends in tiger numbers based on expert assessments, and for each ungulate population.

4. To combine the two scores on tiger trends into a meaningful indicator of potential trends, we summed the two scores, and converted them to a scale from -1 to +1, with the lower the number, the greater the concern that a site was experiencing a decline in tiger numbers. With this scoring system, a value of -1 would indicate that trend analyses of both the track density estimator and the expert assessment for tigers indicated there were significant downward trends at that site for at least the past 4 years, both with a p-value ≤ 0.05. in the same vein, a value of -0.75 would indicate that one trend was significant at $p \leq 0.05$, and the second was significant at $p \leq 0.20$. Similarly, we summed scores for all ungulate populations, and converted that value to a scale of -1 to +1, which is intended to represent the extent to which the prey base in each site is increasing or decreasing.

5. We also summed the number of sites that are experienced downward trends, upward trends, or no trends at all for at least the past four years of the Amur Tiger Monitoring Program, as an indication of patterns across the range of tigers.

The results of this assessment are in Table 21. Trend analyses for both indicators of tiger abundance provided strong evidence of declines in tiger numbers ($p < 0.05$) for four sites (Lazovski Zapovednik Iman, Ussuriski Raion, and Terney Hunting Lease), and for another 5 sites (Ussuriski Zapovednik, Bikin, Botchinski Zapovednik, Bolshekhekhtsirski Zapovednik, and Tigrini Dom) both trend analyses indicated a decline in tiger numbers, but one of the indicators was not as strong (0.05

< p < 0.2). Looking at the scaled combination of tiger tracks and expert assessments, all 16 sites show some evidence of a decline in the tiger population, and nowhere is there evidence that the tiger population is increasing, or even stable.

A similarly dismal picture exists for the prey base of tigers. For three sites (Iman, Sandagoy, and Sineya), evidence suggests that all prey species at those sites are declining. For half of the monitoring sites, at least half of the ungulate populations are also in decline. There are only two sites (Bikin and Bolshekhekhtsirski Zapovednik) where evidence suggests that overall prey numbers are relatively stable (or even numbers of species are in decline and increase) and only one site (Ussuriski Raion) where the overall situation for prey may be improving.

To provide a visual representative of the situation, we plotted the scaled tiger and ungulate trend data (Figure 14) on an x-y scale. If both tiger and prey numbers were increasing, a site would be located in the upper right quadrant of the graph. On the other hand, if both ungulates and tigers were decreasing, a site would be located in the lower left quadrant. In this graph, 15 of the 16 monitoring sites are in the lower left quadrant, indicating that both ungulate and tiger populations are on the decline.

Of significance is the fact that there is no clear direct relationship between declining tiger numbers and declining ungulate numbers, suggesting that something other than the decline in ungulate numbers is driving the decline in tigers.

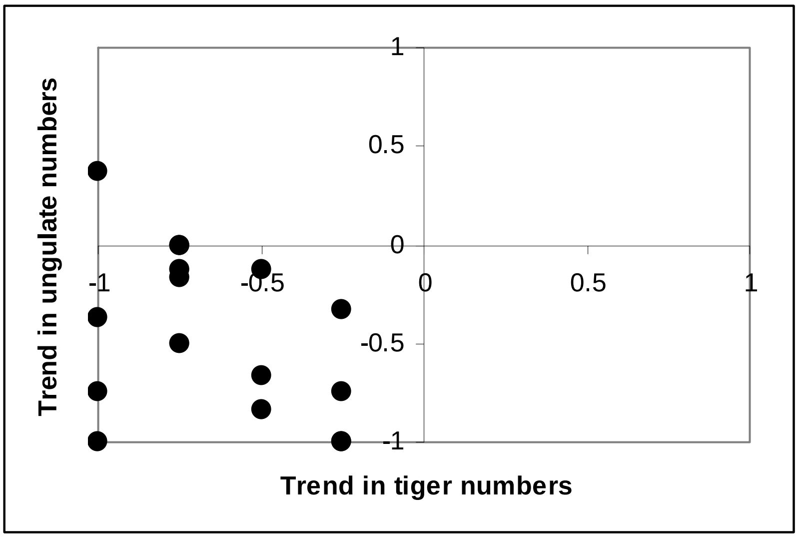

Figure 14. Trends in tiger numbers and ungulate numbers for 16 sites of the Amur Tiger Monitoring Program. Values less than 0 indicate negative trends in tiger and ungulate populations. For the majority of monitoring sites, both tiger and ungulate numbers are situated in the lower left quadrant of the graph, indicating both are in decline.

If we look at the difference between the 12-year average number of tigers reported on monitoring sites (95.2 adults/subadults) the number of tigers reported in 2009 (56 individuals) suggests that there has been a 41% decline in numbers. However, there is no doubt a number of mitigating factors that would suggest that a decline of such severity has not yet occurred. First, extremely deep snows in northeastern Primorye, and probably parts of Khabarovsk, limited movements of tigers, thereby reducing the probability of encountering their tracks. Yet deep snows were not a factor across much of the region, where decreases in tiger numbers were nonetheless being reported. The extremely low numbers of tigers reported in 2009 may be an anomaly, and it is likely that in 2010, if monitoring is conducted, that we will see at least a slightly higher value.

Presently, we cannot say with great certainty the extent to which numbers have dropped, but the overwhelming evidence suggests that both tiger and prey populations are declining in the Russian Far East. This evidence includes:

In 11 of 15 sites (73%) red deer numbers appear to be in decline;
In 12 of 16 sites (75%) roe deer numbers appear to be in decline;
In 8 of 16 sites (50%) wild boar numbers appear to be in decline;
In 4 of 8 sites (50%) where sika deer occur, numbers appear to be in decline;
In 13 of 16 sites (81%) tiger track densities indicate tigers are in decline
In 13 of 16 sites (81%0 tiger numbers, based on expert assessments, are in decline

Any one of these indicators is subject to debate as to their accuracy, but collectively they provide powerful evidence that the situation for tigers and their prey is deteriorating in the Russian Far East.

The primary intent of this monitoring program is to act as an early warning signal so that appropriate responses can be developed before numbers decline excessively or catastrophically. Hence the program appears successful in providing evidence that warns us of potential danger in conserving tigers. Below, we make recommendations that can assist in the recovery of prey and tigers in Russia.

Table 21. Status of conditions on the 16 monitoring sites of the Amur Tiger Monitoring Program for tigers are compared indicators of tiger abundance (track density and animal density based on expert assessments) and indicators of ungulate abundance based on track densities. Scores for each site represent trends. Trends with p-values < 0.05 are weighted twice the value of trends with p-values between 0.05 and 0.20. Positive trends recieve positive values, and negatrive trends recieve negative values. A site is considered as having no trend if regression analysis revealed no trend with p-value less than 0.2 for the past 4 years. The two scores for tigers are summed (Scaled Tiger Trend) as are the scores for ungulates, and rescaled from -1 to + 1 . Sites are ranked from areas of greatest concern (where all summed score of tiger trends are lowest, indicating the most likely areas where tiger numbers have declined) to areas of least concern (where all indicators are not as strong that tiger numbers are decreasing). Based on data from 12 monitoring years (1998 through 2009).

		Trends in population levels								
#	Monitoring site	Tiger track density	Tiger density	Scaled Tiger Trend	Red deer trend	Wild Boar trend	Sika deer trend	Roe deer	Scaled Ungulate trend	Scale of Concern
4	Iman	-2	-2	-1	-2	-2	-	-2	-1	
16	Terney Hunting lease	-2	-2	-1	-2	-1	-1	-2	-0.75	
1	Lazovski Zapovednik	-2	-2	-1	-2	-1	1	-1	-0.38	
13	Ussuriski Raion	-2	-2	-1	1	0	0	2	0.38	
11	Tigrini Dom	-2	-1	-0.75	-1	0	-	-2	-0.50	
9	Botchinski Zapovednik	-2	-1	-0.75	0	0	-	-1	-0.17	
3	Ussuriski Zapovednik	-2	-1	-0.75	2	-1	0	-2	-0.13	
5	Bikin River	-1	-2	-0.75	-2	0	-	2	0	
10	Bolshe Khekhtsirski Zapovednik	-1	-2	-0.75	0	0	-	0	0	
6	Borisovkoe Plateau	0	-2	-0.5	-	-2	-2	-1	-0.83	
12	Matai Zakaznik	-1	-1	-0.5	-2	0	-	-2	-0.67	
2	Lazovski Raion	0	-2	-0.5	-2	0	1	0	-0.13	
7	Sandagoy (Olginski Raion)	0	-1	-0.25	-2	-2	-2	-2	-1	
15	Sineya (Chuguevski Raion)	-1	0	-0.25	-2	-2	-	-2	-1	
14	Sikhote-Alin Zapovednik	-2	1	-0.25	-2	-1	-1	-2	-0.75	
8	Khor	-1	0	-0.25	-2	2	-	-2	-0.33	
	Average across sites	-1.31	-1.25	-0.64	-1.20	-0.63	-0.50	-0.50	-0.50	
	# Negative trends	13	13	16	11	8	4	12	13	
	# Positive trends	0	1	0	2	1	2	2	1	
	# with no trends	3	2	0	2	7	2	2	2	
	Total # sites	16	16	16	15	16	8	16	16	

V. RECOMMENDATIONS TO REVERSE TRENDS IN THE AMUR TIGER POPULATION

Introduction

The wild population of tigers, estimated at 100,000 tigers around 1900, has declined to as few as 3,000 individuals today, with four of the eight originally designated tiger subspecies having become extinct in the wild. While numbers plummeted almost everywhere else in the vast range of tigers in Asia, the Russian population showed a remarkable opposite trend. At the start of the 1940's the Amur tiger had been almost hunted to extinction in Russia with as few as 30 animals remaining. At this critical juncture the situation changed for the better when in 1947 Russia became the first country in the world to ban hunting of tigers. Hunting of the main prey species – ungulates – became restricted by an annual quota system. As a result of effective law enforcement, poaching of tigers became relatively rare and the Amur tiger made a remarkable recovery. In 2005 a full-range survey in Russia showed that the population had recovered to between 428 and 502 individuals (up from 415 to 476 in the previous 1996 count). Moreover, approximately 95% of the Amur tigers are part of one contiguous population, probably the largest in the world.

Amur tiger monitoring results

Due to the Amur tiger's extensive distribution, it is impossible to conduct range-wide surveys with sufficient frequency to effectively monitor changes in tiger abundance. Therefore a standardized annual monitoring program was designed, which is intended to act as an "early warning system" to signal rapid changes in population numbers.

This monitoring program includes 16 sample sites dispersed across the entire range of tiger habitat in Primorsky and Khabarovsky Provinces, totaling 23,555 km^2 (approximately 15-18% of suitable tiger habitat). Twice each winter 246 routes with a total length of 3,057 km are surveyed to assess changes in tiger numbers, cub production and relative prey densities. The program provides a statistical basis to assess trends in populations of both tigers and their prey.

Since the last full range count in 2005, the results of the annual monitoring program show alarming downward trends for both tigers and prey that can be summarized as follows:

- *11 of 15 (73%) sites show declining trends for red deer.*
- *12 of 16 (75%) sites show declining trends for roe deer.*
- *13 of 16 (81%) sites show declining tiger track densities.*
- *13 of 16 (81%) sites show declining tiger densities based on expert assessments.*

Factors leading to the decline in tiger numbers

Tiger and prey numbers are declining simultaneously and this indicates that shortage of prey is not the main factor driving the drop in the tiger numbers. Most likely both ungulates and tigers suffer directly from the same factor; increased poaching. Research over the past 15 years in Sikhote-Alin Nature Reserve has shown that natural deaths are rare among Amur tigers and that in fact approximately 60% - 85% are killed by poachers. It appears that poaching levels have now reached a point where tiger reproduction is no longer able to compensate for the losses.

Another threat to the stability of the population is the reduction in size and quality of habitat for tigers and their prey. This is largely due to logging in forests with high conservation value, and to fires and development projects, such as the construction of oil and gas pipelines.

The Amur tiger population reached its peak in the mid-1980s when all suitable habitat was occupied. A die-off of wild boar due to disease in 1983 and a fall in red deer and roe deer numbers due to exceptional snowfalls in 1985-1987 led to food shortages for tigers, forcing them into settlements in search of food, and of course also into confrontation with humans (according to official data alone 48 conflict tigers were shot). The population quickly began to recover, but opening of the border with China (1989-1991) led to intensive poaching to satisfy the demand for tiger parts in traditional Asian medicines (approximately 60 tiger skins and skeletons were confiscated during this period). Establishment of the anti-poaching brigade “Inspection Tiger” and provision of massive funding by conservation NGOs resulted in a stabilization of the population at 450-500 individuals.

During this time law enforcement agencies received a percentage of the fines and damage payments that resulted from their work from the State Ecology Funds, thus providing an effective incentive for good performance. Unfortunately, these State Ecology Funds were abolished in 2002.

Inspection Tiger lost its enforcement function in 2003 and in 2005 the Hunting Department was closed, resulting again in epidemic poaching in the forests.

Harsh winters with deep snow led to high ungulate mortality in south Khabarovsky Krai in 2006 and in northeast Primorye in 2009, resulting in increased human-tiger conflicts, more frequent poaching of tigers and even tiger mortality as a result of collisions with vehicle traffic. Annually up to 10 cases of human-caused tiger deaths or orphaned tiger cubs are being recorded.

In 2002 more than 1400 people were directly or indirectly involved in the protection of Amur tigers, their habitat and prey base. The provincial branch of the federal Ministry of Natural Resources employed 35 inspectors and Nature Reserves (zapovedniks) employed 100 inspectors. The Wildlife Management Agency of the Ministry of Agriculture employed 240 inspectors who were assisted by 200 game wardens from private hunting leases. In addition there were more than 1000 forest service inspectors and police officers assisted in forest patrols.

In 2009 funding and the number of inspectors was almost reduced by half – to 760 inspectors. In the Wildlife Management Agency 140 inspectors remained, including enforcement staff of provincial wildlife refuges. Game wardens of privatized hunting leases lost their enforcements rights, including the right to write up citations. Forest service field staff was reduced to 480 people – without the right to carry weapons or enforce the law.

Government wildlife management agencies suffered from three reforms with a peak in 2007-2008 when no more than 10-15 inspectors remained for the protection of wildlife in the Amur tiger’s range, an area 20 million ha.

In 2009 the situation started to improve, but a new hunting law coming about to come into effect will lead to a prolonged period of reorganisation of wildlife management.

Logging rates in the Amur tiger’s range have increased from 3 to 7 million cubic meters between 2000 and 2008. Control of logging operations by government agents is almost completely absent after 7 years of continuous forestry reforms, resulting in an increase of illegal logging 50%-60% above legal levels. “Sanitary” logging operations have been turned into massive commercial logging that destroys some of the forests most valuable in terms of biodiversity and watershed protection.

New demands have resulted in intensive logging of oak trees, depriving wild boar and sika deer of their staple food - acorns. The past 5 years have also shown an increase in logging of Korean pine (with official exports growing from 130,000 to 186,000 cubic meters), because logging of this species is not prohibited and the limitations that were imposed in 1989 have been reversed by new forest management guidelines. Moreover, it is estimated that in reality more than 500,000 cubic meters of Korean pine is being logged annually, resulting in a decrease of the remaining volume by 27%. Because pine nuts are a primary food resource for many species of wildlife, including key prey species of tigers such as wild boar, these changes are of great concern.

Recommendations

To reverse the negative trends in tigers, their prey, and in habitat quality in the Russian Far East, a number of actions are recommended:

1. Resolve organizational and funding issues related to Amur tiger conservation
    - Speed-up the revision of the federal Amur Tiger Conservation Strategy and develop a federal program for its implementation.
    - The Administrations of the Primorsky and Khabarovsky provinces should develop concrete plans for the conservation of the Amur tiger and its habitat.
    - Solve organisational and financial issues that frustrate adequate functioning of Inspection Tiger, establish under Inspection Tiger a governmental Amur tiger monitoring center and allocate annual government funding for monitoring.
    - Funding by the Primorsky and Khabarovsky provinces for the conservation of Red Book species should be increased from the present hundred thousand roubles to a level required (millions of roubles).
    - Initiate talks for the development of a Russian-Chinese Amur tiger conservation program, including the establishment of a transboundary nature reserve in the Strelnikov Mountain Range in Russia and nearby Wandashan Mountains in China.

2. Facilitate the protection of Amur tiger habitat
    - Immediately return Korean pine to the list of tree species for which logging is prohibited.
    - Limit logging of mature oak stands.
    - Federal agencies should strictly supervise planning and implementation of sanitary logging in Amur tiger habitat, with a full logging ban in protected forests, especially in pine nut production zones.
    - Logging plans should include a road management plan and after logging operations have been discontinued the logging companies should be obliged to close logging roads that do not connect villages or towns.
    - Establish a full logging ban in wildlife refuges (zakazniks) in Amur tiger range (namely the Birskiy, Mataiskiy, Taezjniy, Upper-Bikin and Leopard Wildlife Refuges).

3. Complete the development of a network of protected areas in Amur tiger range
    - Establish a federal territory for traditional resource use on the Bikin river and provide UNESCO *World Heritage* status to the system of protected areas on the Bikin and Khor rivers in the Primorsky and Khabarovsky Provinces.
    - Create a protected buffer zone along the border of Ussuriisk Nature Reserve that includes the adjacent multiple-use area "Orlinoe" and the Scientific-Experimental Forestry area of the Russian Ministry of Agriculture and obtain UNESCO Biosphere status for the reserve and this buffer zone.
    - Establish a wildlife refuge (zakaznik) in the Strelnikov Mountain Range in Primorsky Krai as compensation for construction of the East-Siberian–Atlantic Ocean oil pipeline and the Khabarovsk-Vladivostok gas pipeline, and use the refuge as a starting point for an agreement with China on the foundation of a transboundary protected area.
    - Urgently facilitate adequate functioning of the combined protected area that consists of the Kedrovaya Pad Nature Reserve and the federal Leopard Wildlife Refuge, and subsequently use it as a basis for development of a Russian-Chinese-Korean transboundary reserve.

4. Make the following modifications to Russia's federal legislation in order to strengthen the fight against poaching:

- Make possession and transport of tiger derivatives illegal and punishable (i.e. add to article 8.35 of the Administrative Code of the Russian Federation "Destruction of rare and endangered fauna and flora" after "or capturing, collecting, keeping, obtaining" the words "possession and transport").
- Develop and approve regulations that stipulate that illegal storage and transport of skins and other parts of tigers in the territory of Russia will be treated the same as illegal hunting of species in the Red Data Book of the Russian Federation
- Make the illegal export of wildlife derivatives a criminal offense. (Expand paragraph 2 of article 188 of the Criminal Code of the Russian Federation on Contraband and include derivatives of Red Book species in the contraband list presently consisting of weapons, narcotics, and goods of strategic importance and cultural value).
- Increase the administrative punishments for poaching of Red Book species. (Make amendments in article 8.35 of Administrative Code of the Russian Federation "Destruction of rare and endangered fauna and flora", to increase the maximum fine for private citizens from 200,000 to 500,000 roubles and also add a provision for the confiscation of transport means (vehicles) used for transport of illegal goods).
- Increase to the level of criminal offense illegal hunting of rare and endangered species. Include this change and add to article 258 of the Criminal Code of the Russian Federation "Illegal hunting" as a separate adequate cause for increasing fines for illegal hunting of birds and animals, including illegal hunting on protected territories, and during periods of ecological catastrophes.
- Return to game wardens of hunting leases the right to draw-up citations for hunting violations. .
- Institute a buffer zone of no less than 1 km. around nature reserves (zapovedniks) within the range of Amur tiger's and restrict natural resource use in this zone.
- The minimum fine for poaching of ungulates should be considerably increased.
- Firearms (including registered ones) that are used for poaching ungulates, rare and endangered species, as well as firearms that are illegally carried into protected areas, should be confiscated permanently.
- Institute strict measures for multiple violations of hunting regulations, including rescinding permits for hunting and possession of firearms. Maintain a database of poaching that is effectively exchanged between appropriate governmental agencies to assist in apprehending offenders with multiple violations

Note: These recommendations have been developed and agreed upon by the following organizations and individuals:

World Wide Fund For Nature (WWF)
Wildlife Conservation Society (WCS)
Phoenix Fund
International Fund for Animal Welfare (IFAW)
Zoological Society of London (ZSL)

VI. LITERATURE CITED

Abramov, V.K. 1962. On the biology of the Amur tiger, Panthera tigris longipilis Fitzinger, 1868. Vestn. Ceskoslov, Spolecnosti Zool. T. 26 No. 2. pp. 189-2002.

Abramov, K. G. 1965. Amur tiger and relic fauna of the Far East. Notes of the Primorski Branch of the Geographical Society, USSR. 1(24).

Bragin, A.P., & Gaponov, V.V. Problems of the Amur Tiger. *Okhota i Okhotnichie Khozyaistvo* 10:12-15 (1989). (In Russian).

Chelintsev, N.G. (1995) Mathematical principles of winter censuses of mammals. Byulleten Moskovskogo Obschestva Ispytatelei Prirody, 100, 3-19(in Russian).

Chelintsev, N.G. 2000, The mathematical basis of animal censuses. Moscow: CentroKhotcontrol (in Russian)

Hayward, G. D., D. G. Miquelle, E. N. Smirnov, and C. Nations. 2002. Monitoring Amur tiger populations: characteristics of track surveys in snow. Wildlife Society Bulletin 30(4):1150-1159.

Kaplanov, L. G. (1948). Tigers in Sikhote-Alin. In *Tiger, red deer, and moose*, Materialy k poznaniyu fauny i flory SSSR. Moscow: Izd. Mosk. Obschestva Ispytateley Prirody. Novaya seria. Otdel zool., 14, 18-49. (in Russian).

Kazarinov, A. P. 1972. Status, distribution, and numbers of tigers in the Far East. Pp. 401-402 in: Zoological problems in Siberia. Siberian Branch of the Institute of Biology, USSR Academy of Sciences. Nauka, Moscow.

Kucherenko, S.P. 1977. The impact of the Amur tiger on the population of its prey. Redkie vidy mlekopitaiuschikh I ikh okhrana. Materilay 2 Vseoiuznogo soveshcania, pp. 133-134. Nauka, Moscow

Kucherenko, S. P. (2001). Amur tigers at the turn of the century. *Okhota i okhotnichie khozyaistvo*, 4: 20-24. (in Russian).

Kudzin, K. F. 1966. Tigers of Primorye. Pp. 8-53 in Agricultural production in Siberia and the Far East.MSK USSR

Matyushkin, E. N. 1977. The choice of route and territory used by the Amur tiger (according to winter tracking data). Mammals' behaviour, USSR Academy of Sciences. Nauka, Moscow.

Matyushkin, E. N., Pikunov, D. G., Dunishenko, Y. M., Miquelle , D. G., Nikolaev, I. G., Smirnov, E. N., Salkina, G. P., Abramov, V. K., Bazylnikov, V. I., Yudin, V. G., & Korkishko, V. G. (1996). Numbers, Distribution, and Habitat Status of the Amur Tiger in the Russian Far East: 'Express-report'. Final report to the USAID Russian Far East Environmental Policy and Technology Project.

Matyushkin, E. N. , D. G. Pikunov, Y. M. Dunishenko, D. G. Miquelle, I. G. Nikolaev, E. N. Smirnov, G. P. Salkina, V. K. Abramov, B. I. Bazilnikov, V. G. Yudin, and V. G. Korkiskho. (1999). Distribution and numbers of Amur tigers in the Russian Far East in the mid-1990's. In *Rare mammal species of Russia and neighboring territories*, ed Aristova, A. A., pp. 242-271. Moscow: Russian Academy of Sciences Therological Society,. (in Russian).

Mescheryakov, V. S., and S. P. Kucherenko. 1990. Number of tigers and ungulates in Primorsky Krai; recommendations for protection and rational use. Final report. All Soviet Scientific Research Institute of Hunting Management, Far East Division of Primorye Commercial Hunting, and Primorsky Cooperative for Commercial Hunting.

Miquelle, D.G., E.N. Smirnov, and J.M. Goodrich (eds.). 2005. Tigers in Sikhote-Alin Zapovednik: Ecology and Conservation. PSP, Vladivostok (in Russian).

Miquelle, D.G., D.G. Pikunov, Yu.M. Dunishenko, V.V. Aramilev, I.G. Nikolaev, V.K. Abramov, E.N. Smirnov, G.P. Salkina, and A.A. Murzoin. 2006. A theoretical basis for surveys of Amur tigers and their prey base in the Russian Far East). DalNauka, Vladivostok.

Pikunov, D. G., V. N. Basilnikov, V. N. Rebachuk, and V. K. Abramov. (1983). Present area, number, structure, and distribution of tigers in Primorski Krai. Pp. 130-131 in Rare Mammals of USSR Nauka, Moscow. (in Russian)

Pikunov, D. G., and A. P. Bragin. 1987. Organization and census methods for the Amur tiger. Organization and methods of surveying commercial and rare species of mammals and birds in the Far East. DVNT AN USSR, Vladivostok.

Pikunov, D. G. 1990. Number of tigers in the Far East USSR. 5th Meeting of the All-Soviet Theriological Society.

Yudakov, A. G., and I. G. Nikolaev. 1973. Status of the Amur tiger (Panthera tigris altaica) in Primorsky Krai. Zool. J. 52(6):909-919.

Yudakov, A. G., and I. G. Nikolaev. 1987. Ecology of the Amur tiger. Nauka, Moscow. 152 pp. (in Russian).