

A SURVEY OF AMUR (SIBERIAN) TIGERS IN THE RUSSIAN FAR EAST, 2004-2005

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SUMMARY. The “Strategy for Conservation of the Amur Tiger in Russia” calls for a full range survey of tigers every 5-10 years. Since the last survey was conducted in 1996-1996, a survey was long overdue.

The 2004-2005 survey represented the most comprehensive census ever conducted on tigers in the Russian Far East, with 1096 survey units, which encompassed nearly all potential tiger habitat (Map 8). In total, tracks of tigers were reported in 614 of 763 survey units (80%) where people an average of 50 days during the winter season. A total of 977 fieldworkers covered 1537 routes totaling 26,031 km during the simultaneous survey (Table 7, Map 9), which represented 8000 km (31%) more effort than the 1996 survey.

A total of 5267 tracks were reported for the total survey period: 3949 from the seasonal winter survey and 1318 during the simultaneous survey (Table 8, Map 10). Of these total, 79% were reported within Primorski Krai (1107 simultaneous, 3061 seasonal winter) and 21% in Khabarovsk (211 simultaneous, 888 seasonal winter).

A total of 352,740 km² were defined as suitable habitat for tigers. Korean pine and oak forests are the two key habitat types for tigers and their prey, representing 58 and 30% of preferred habitat respectively. Protection and/or well defined management restrictions on all Korean pine and oak forests would go a long ways towards securing a future for tigers in the Russian Far East. Although riverine forests are not as common as Korean pine or oak forests, they are also critical habitat, and represent areas heavily impacted by humans. Map 13 provides a first attempt at explicitly defining suitable habitat for Amur tigers, and provides a basis for use in environmental impact assessments and for defining conservation priorities.

Based on expert assessment, the 2004-2005 survey indicated that there were 331-393 adult/subadult tigers and 97-109 cubs. In total then, there were an estimated 428-502 tigers in the Russian Far East. Tigers were reported north of the Amur River for the first time in the past 30 years, reinforcing indications that tiger distribution is expanding northward. An algorithm derived to rigorously employ the same criteria as those used by experts generally resulted in higher estimates, but there was a strong correlation between the two approaches.

In general, the available evidence suggests that the tiger population in the Russian Far East has been relatively stable for the past 10 years, based both on a comparison of surveys conducted in 1995-1996 and 2004-2005, and monitoring that has been conducted yearly in defined survey areas for the entire period. An analysis of track densities does raise concerns, as those results indicated that track densities were significantly higher in 1996 than 2005. In determining appropriate conservation actions for endangered species, it is wise to be conservative in assessing their status. Analyses of factors affecting results of the tiger survey indicated that a variety of parameters can significantly influence results, and therefore, caution should be used in interpreting the results of this survey and in developing appropriate conservation plans.

Table 11. Number of tigers estimated in the Russian Far East, 1996 and 2005, based on expert assessments of tiger tracks.

	Cubs		Adults/Subadults		Total	
	1996	2005	1996	2005	1996	2005
Khabarovsk	16-18	19-20	48-53	52-57	64-71	71-77
Primorye	69-87	78-89	282-318	279-336	351-405	357-425
Total	85-105	97-109	330-371	331-393	415-476	428-502

I. INTRODUCTION

As the 21st century begins, Russia has the only remaining population of Amur (Siberian) tigers (*Panthera tigris altaica*) in the world, and therefore has primary responsibility for their conservation. Recent surveys in Heilongjiang and Jilin Provinces of China (Yang et al. 1998, Sun et al. 1998) suggest that no more than 15-20 Amur tigers reside in China, mostly along the Russian border. Recent reports have not confirmed that tigers still occur in Korea (Institute of Geography 1998), but if some individuals still survive, numbers are undoubtedly small. Therefore, it appears that no less than 95% of the world-wide population of Amur tigers resides in the Russian Far East.

Although this species is not immediately threatened with extinction, its future has still been a cause for serious concern. With the exceptions of zapovedniks (IUCN Category 1 reserves) and other protected areas, most forest lands within the range of tigers have been subjected to logging operations. There is evidence that ungulate numbers have decreased across its range over the past 10 years, resulting in an obvious imbalance between populations of key prey species and the tiger itself. A dramatic increase in poaching occurred in the beginning of the 1990's, which was largely a result of new opportunities for selling tiger bones. Tiger products, believed to have powerful medicinal properties, are still sold in the majority of East-Asian countries (Mills and Jackson 1994). In the early 1990s it was believed that as many as 60 tigers/year were being poached (Galster and Vaud Elliot 1999). With the creation of Inspection Tiger, and special anti-poaching teams of the Krai Hunting Departments, it is believed that poaching levels have decreased in the late 1990s (WWF 2000). While the exact magnitude of poaching is not known, information on radio collared tigers suggests that even today, the majority of tigers are killed by poachers or in human-related events (Goodrich et al. 2005). Analyses of population dynamics of tigers suggests that low population growth rates, even in comparison to other large felids, make this species especially vulnerable to poaching (Chapron et al. 2005). Over the past decade, changes in logging practices, increases in illegal logging activities, new pressures to exploit natural resources to boost economic productivity, and new incentives to poach all have had impacts on tiger habitat, tiger prey, and directly on the tiger population itself.

Additionally, there is the question of population size itself. Population geneticists warn that small populations run the risk of extinction from a variety of causes associated with low genetic diversity. What constitutes a "viable" population has been open to debate, yet it is clear that populations with less than 1000 breeding individuals is certainly at risk (Franklin 1980, Frankel and Soule 1981, Allendorf and Ryman, 2002). Thus the Amur tiger population, estimated to have 330-371 adults in 1995, certainly falls into the category of populations at risk due to small size. Information on the status of the entire population obtained at regular intervals is important to understand the impacts of these pressures.

Russia's commitment to tiger conservation in the Russian Far East was evident as far back as 1947, when protective legislation outlawed hunting of tigers. Control of and eventual elimination of the capture of cubs for the world's zoos, beginning in 1952, also played a key role in the recovery of tiger populations. Since that time conservation of this subspecies has become a key priority in regional and federal ecological policies. In 1996 the Russian Federation's Resolution #795, "On the conservation of Amur tigers and other rare and endangered species of wild flora and fauna on the territory of Primorski and Khabarovski Krai," (approved in July,

1996 by the Russian Federation Ministry of Environmental and Natural Resources Protection) provided a basis for development of a "Strategy for Amur Tiger Conservation in Russia". This step in turn, led to the implementation of Federal Target Program for Conservation of Amur Tigers. The newly developed Strategy for "Conservation of Rare and Endangered Species of Animals, Plants, and Mushrooms" is a policy expansion away from a single species approach to a document and policy that covers all endangered species in the Russian Federation, including the Amur tiger.

To conserve a species, there are a number of fundamental questions that must be addressed, including: what is the distribution of the species, how is the species distributed across its range, what numbers of the population exist currently, what are the trends for this population, what is the sex-age structure of the population, and what is the status of the food resources required for survival of the species. Answers to these questions provide a foundation for defining future conservation actions.

The "Strategy for conservation of the Amur tiger in Russia" calls for full range surveys to be conducted every 5-10 years. As the last Amur tiger survey was conducted in 1995, it was clear that a survey was needed. The first call for a full range survey came with recommendations stemming from the 2003 Khabarovsk Conference on Conservation of Amur tigers. Further discussions in Primorye, Khabarovsk, and Moscow, led to a protocol developed at a meeting of interested parties on 17 June 2004. Planning, fund-raising, and organizational details were conducted throughout much of 2004, with the field work conducted in winter 2005 (December 2004 through March 2005). The Ministry of Natural Resources officially approved the methodology for the survey in fall of 2005, ensuring that the results would be considered "official" by the Russian government. Data collation, GIS database development occurred from November 2004 through December 2005. Analyses of data began in January 2006.

This report is the result of extensive cooperative effort amongst a large number of individuals, and organizations, international in scope. This is no doubt the largest, most intensive survey of tigers to have occurred in Russia, with more fieldworkers involved, more routes covered, and more intensive efforts put into estimating prey abundance. At the same time, the international conservation community played a large role as well, providing the majority of funding for this effort. Thus, the cooperation between Russian governmental bodies, with guidance by the Ministry of Natural Resources, non-governmental organizations, and international funding agencies makes this project one of the largest and impressive conservation events in recent history. We are very hopeful that the results of this work will contribute to the conservation of the Amur tiger in the Russian Far East.

II. NEED TO CONDUCT A SURVEY

Viability of large carnivore populations is dependent upon large tracts of relatively undisturbed habitat where natural ecosystem processes are preserved. In the face of ever increasing human demands on the landscape, this requirement for large intact ecosystems, as well as unavoidable direct and indirect conflicts with humans, has resulted in large carnivores being threatened world-wide. The Amur tiger is of special concern because, living as it does in the northernmost habitat of the species, it must survive in an ecosystem where productivity, and hence prey densities, are naturally low. Consequently, the Amur tiger probably has the largest

land area requirements of any subspecies. A survey provides an opportunity to compare present status with past surveys and to assess the effectiveness of conservation efforts. Hence survey work is essential to determine appropriate future conservation actions.

The need for a tiger census, as well as other endangered and threatened species, has been stated in several key state documents that concern conservation of endangered species in the Russian Federation. The Strategy for Conservation of the Amur Tiger in Russia recommended that monitoring be conducted on a yearly basis, but that full-range surveys should be conducted at 5 year intervals. In the Federal Amur Tiger Program, it was emphasized that “accurate and current information about the condition of the Amur tiger population and about threats to its habitat is fundamental for the evaluation of population viability and for the practical realization of a conservation plan”. At the International symposium “Conservation of the Amur tiger” (Khabarovsk, 2003), the recommendations of the research and monitoring subgroup call for a full range survey in 2004-2005. Finally the federal “Strategy for Conservation of Rare and Endangered Species of Animals, Plants, And Mushrooms” calls for regular monitoring of endangered species to assess status of the population and their habitat.

III. HISTORY OF SURVEYS AND POPULATION STATUS OF THE AMUR TIGER

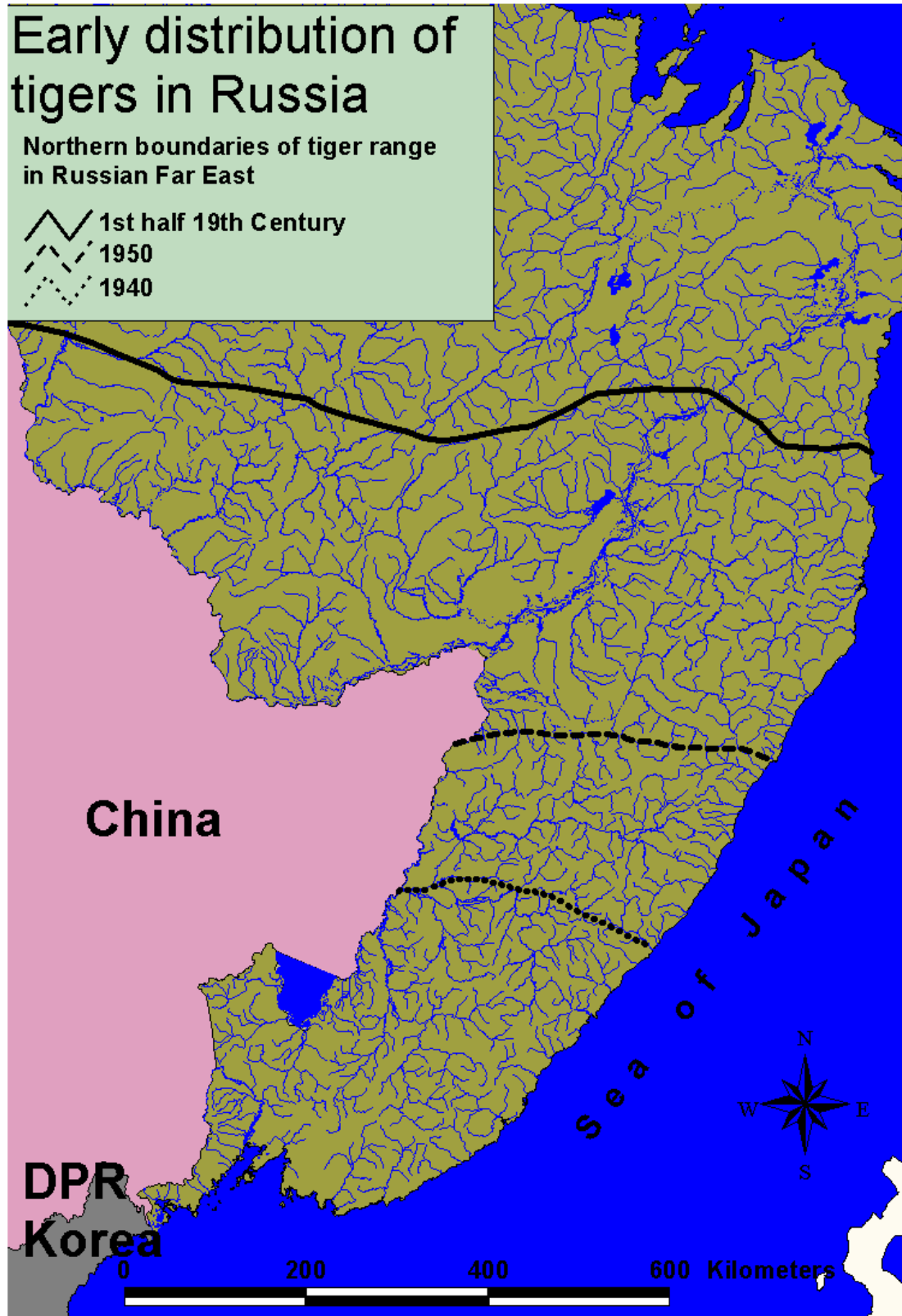
Heptner and Sludski (1972) attempted to reconstruct the original range of Amur tigers in the Russian Far East in the first half of the nineteenth century (Map 1). They suggested that tigers occurred permanently in a region extending from above the lower reaches of the Zeya River in Amur Oblast across what is now the Jewish Autonomous Region and across the Amur River at the confluence with the Gorin River, and from here, towards the Straits of Tartar along the northern sector of the Sikhote-Alin Mountains (Map 1). They suggest that the range of tigers dramatically decreased in the first half of the 20th century as a result mainly of direct persecution, and in part due to extensive logging and reduction of prey, particularly wild boar (Heptner and Sludski 1972). By 1940, the northern boundary of tiger range had been pushed dramatically south, extending generally along the Iman River and down towards the Sea of Japan in what is now southern Terneiski Raion (county) (Map 1; see Map 5 for location of raions). Prior to the 1940s, there are no reliable estimates of tiger numbers in the Russian Far East. However, from this point on, a series of surveys are being conducted in Russia that accurately delineate the changes in distribution of tigers, and reflect changes in tiger numbers.

The first survey of Amur tigers in the Russian Far East was organized by L. G. Kaplanov at the end of the 1930s (Kaplanov 1948). Kaplanov relied on a combination of field work by himself and his assistants, along with questionnaires to local residents and hunters. Intensive fieldwork was conducted in Sikhote Alin Zapovednik (then 1 million ha) and its subsidiary Lazovski Zapovednik (then called Sudzukhinski Zapovednik), while information was collected elsewhere from professional hunters, forest guards, inspectors, and managers of hunting organizations.

Kaplanov (1948) reported that 20-30 tigers remained in the Russian Far East. Although Kaplanov's estimate may be conservative, it is likely that the population at this time amounted to no more than 50 (Matyuskin et al. 1996). At the very least, a second survey conducted by Kuznetsov in 1952 indicated a population of 40-45 animals existed. Kaplanov's great contribution was his ability to bring attention to the plight of Amur tigers, leading to a 1947 repeal of legal hunting on this species. This was the critical first step in recovery of the Amur tiger population.

In 1957 A. E. Florov conducted a survey of hunters in Khabarovski Krai (Dunishenko and Kulikov 1999), which indicated 23 animals resided in that northern province in two subpopulations; one of the western slopes of the Sikhote-Alin mountains, and a second population to the west in the Mali Khingan range (in what is now Jewish Autonomous Region). It is significant to note that at that time, no tigers were observed along the coastal region of Khabarovski Krai, an area that has since been "colonized" and where tigers now appear to be expanding.

One year later (the 1958-1959 winter), K. G. Abramov conducted a major survey of tigers that was important for a number of reasons. First, he employed well-know tiger "catchers" (men employed by the state to capture cubs to supply to the world's zoo populations) and was able to use their knowledge about identifying sex and age of tigers based on relative size of tracks in the snow (these specialists ability to safely capture cubs was dependent on their interpretation of body size based on track size, and they therefore had a good understanding for the size of animals in relation to track size). Thus, Abramov was able to propose a survey method that



Map 1. Distribution of tigers in Russia in: 1) the middle of the 19th century; 2) in 1940; and, 3) in 1950, based on a reconstruction of tiger distribution by Heptner and Sludski (1972).

Table 1. Distribution and numbers of Amur tigers in the Russian Far East based on previous surveys.

Year	Primorski Krai	Khabarovski Krai	Total	Source of Information
1940	20	No data	20-30	Kaplanov 1947
1952	40-45	No data		Kuzentsov, 1952
1954	48	No data		Kuzentsov, 1954
1957	35	23	58	Bromley, 1957; Florov, 1957
1959	55-65	35	90-100	Abramov, 1962
1965	70	No data		Kudzin, 1966
1970	129-131	20	149-151	Yudakov & Nikolaev, 1973; Kazarinov, 1979
1976			160-170	Bromley, 1977; Kucherenko, 1977
1979	172-195	34	206-229	Pikunov et al., 1983; Kazarinov, 1979
1985	200-210	68-69	240-250	Pikunov, 1990
1986	No data	91		Kazarinov, 1986
1989	275-295	No data		Mesheryakov, 1989
1990	No data	64	349	Mesheryakov, Kucherenko, 1990
1993	No data	54-56		Dunishenko, 1993
1994	No data	57-58		Dunishenko et al., 1994
1996	351-405	64-71	415-476	Matyushkin et al., 1996

Note: The decrease in tiger numbers in Khabarovski Krai in the 1970s was apparently due to the extinction of a subpopulation of tigers in what is now called the Jewish Autonomous Region.

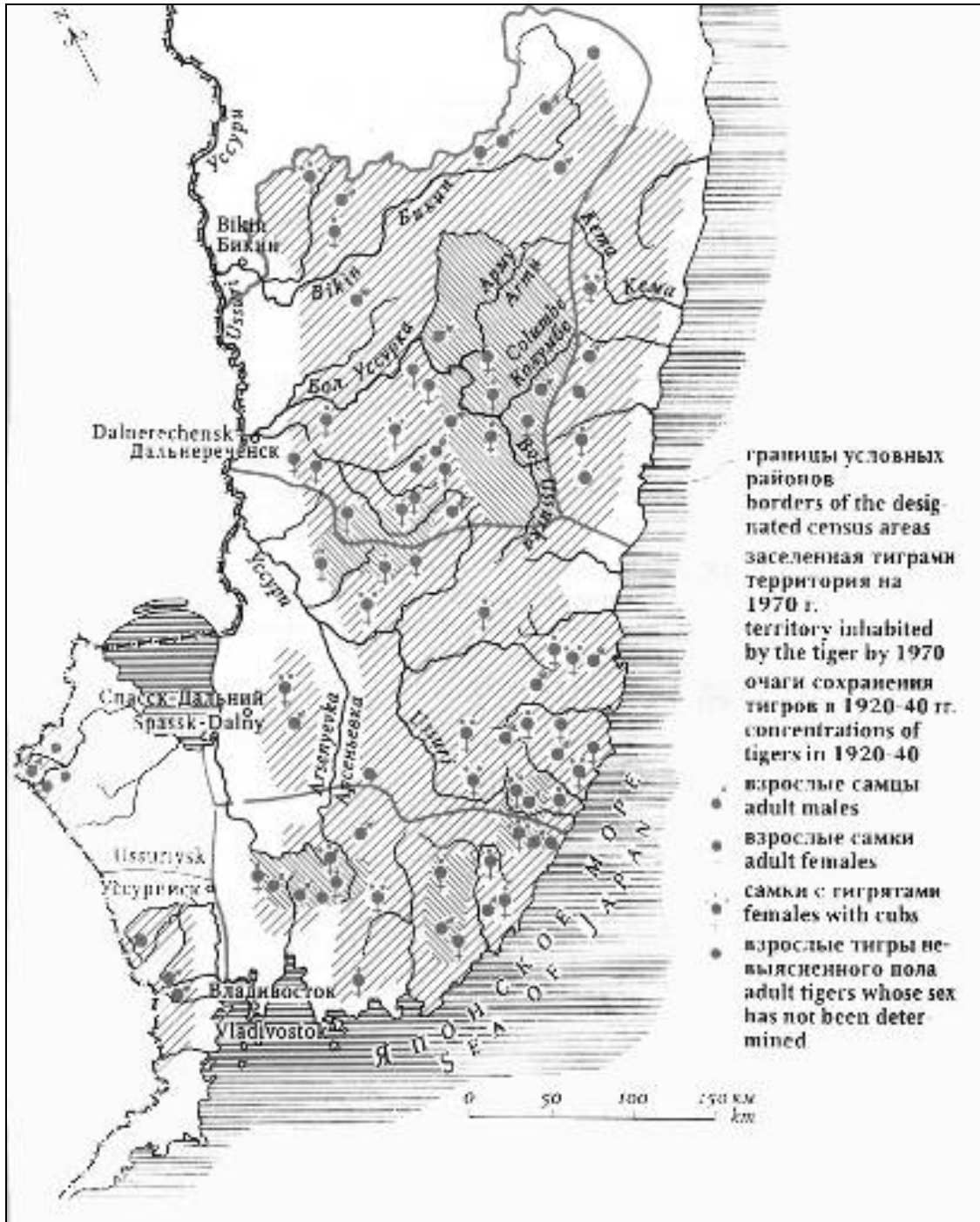
employed identification of sex and age classes based on the relative size of the front paw, a formula that has been modified slightly, but employed to the present in Russia.

Abramov's was also the first survey to cover the entirety of tiger habitat in the Russian Far East. His results indicated that there were 90-100 tigers inhabiting Primorye and Khabarovsk (Abramov 1965). Abramov was primarily responsible for halting the capture of cubs in the 1950s, a factor he considered was chiefly responsible for the slow recovery of the population. With the population apparently back from the brink of extinction, carefully controlled permission to capture cubs for the world's zoos began again.

In 1965 a survey of tigers in Primorski Krai was organized by the Primorye Wildlife Management Department and led by K. F. Kudzin, using a questionnaire to survey local wildlife biologists and hunters. Results indicated that 70 tigers existed in Primorski Krai, and that tigers had expanded their range into Chernigovski, Spasski, Skhotovski, and Nadeshenski Raions (see Map 5 for locations of raions, or counties), areas where tigers had not recently occurred. Tracks were noted within 50-60 km of Vladivostok. Kudzin emphasized the need for a full survey of tigers across their entire range.

The first survey that was based primarily on direct field observations (versus using questionnaires sent out to hunters) over a vast area occurred in 1970, when Yudakov and Nikolaev (1973) surveyed the entirety of Primorski Krai, and A. P. Kazarinov (1979) led a survey of Khabarovsk territory. In Primorye, Yudakov and Nikolaev assigned regional coordinators who were responsible for collection of data from 6 regions of Primorye (with boundaries coinciding with specific raions and/or hunting leases - an approach that has been adopted in all subsequent tiger surveys). Data from surveys in zapovedniks, and specially designed "field diaries" completed by 130 professional hunters who spent the entire winter in the forest were used.

Yudakov and Nikolaev (1972) reported 129-131 tigers in Primorski Krai in 1970, including 29 adult males, 46 adult females, 47-49 cubs, with the rest representing animals of unknown sex-age classes (Map 2). In Khabarovsk Kazarinov (1979) estimated another 20 tigers existed, noting that that decline in numbers there was largely due to the extinction of tigers in the Jewish Autonomous Region. This was an important finding, as it marked the



Map 2. Tiger distribution and areas of concentration in Primorski Krai in 1970, from the results of the survey conducted by Yudakov and Nikolaev (1973).

loss of the western subpopulation of Amur tigers, which had clearly been dependent on connectivity to a population that was being eliminated in China at the same time. In Primorye, Yudakov and Nikolaev also noted some alarming trends, including a decrease in ungulate numbers in a number of raions, and consequently an increase in tiger attacks on domestic livestock. In association with this trend, not surprisingly, was an increase in illegal shooting of tigers. Yudakov and Nikolaev estimated that 70 animals had been illegally killed between 1965 and 1970, noting that the legislation making tiger hunting illegal had lost its effectiveness in reducing human-caused mortality.

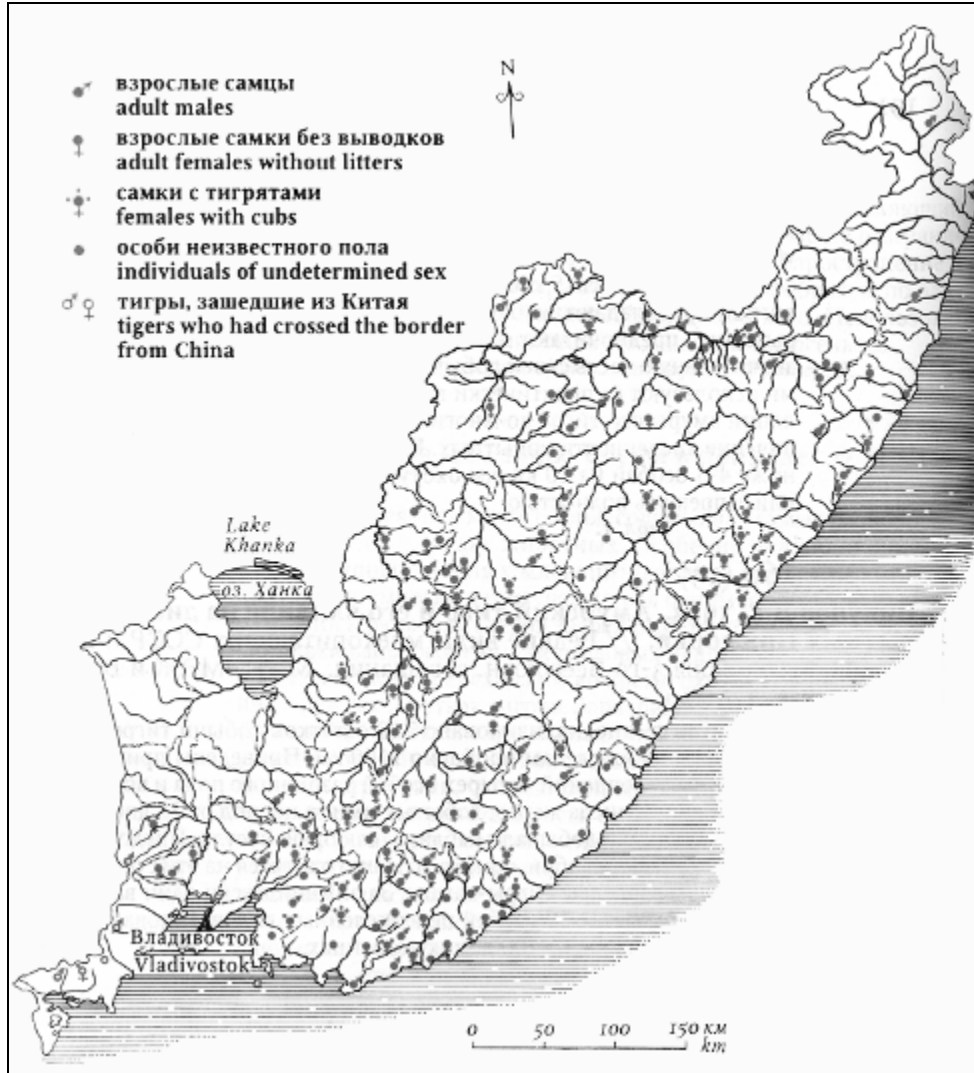
In 1978-1979 a tiger survey in Primorski Krai was organized by the provincial wildlife department, with V. K. Abramov, D. G. Pikunov, and V. I. Bazilnikov responsible for implementation. They developed a field "diary" that standardized data collection for fieldworkers (mostly hunters) in all hunting leases, zapovedniks, and zakazniks (Pikunov et al 1983). In addition to data collected throughout the winter by wildlife biologists and professional hunters, this survey was also the first to employ a "simultaneous survey" in which routes were covered within a short time frame to minimize probability of multiple counts of individual tigers. In the survey, an attempt was made to develop "geo-referenced" data by recording all locations of tracks on maps. Publications detailing the methodology for full surveys, published in a various formats (Pikunov et al. 1983, 1985, and Pikunov and Bragin 1987), provided a standardized framework for future surveys.

The 1978-1979 survey reported 179-195 tigers occurred across 97,150 km² of habitat in Primorski Krai, including 43-50 adult males, 64-75 adult females (including 36 females with 53 cubs), and 10-15 tigers of unknown sex-age class. Average density of tigers across their range was 0.22-0.25 animals/100 km². Maximum densities of tigers occurred in Pojarski Raion (in the Bikin River Basin), Olginski, Lazovski, and Yakovlevski Raions (Abramov et al. 1979, Pikunov et al. 1983).

The next full range survey across Primorski Krai took place in the 1984-1985 winter and was organized by D. G. Pikunov and A. P. Bragin. A total of 528 fieldworkers covered nearly the entire territory of the western slopes of the Sikhote-Alin, while on the eastern, coastal side fieldwork was conducted only around Lazovski and Sikhote-Alin Zapovedniks, with results then extrapolated to the rest of the coastal region. Primorski Krai. Results of this survey suggested that 200-210 tigers occurred in Primorye, and extrapolations suggested 240-250 in the entire Russian Far East (Pikunov and Bragin 1985, Pikunov 1990). Tigers were distributed across 86,648 km², and occurred at an average 2.4-2.5 animals/1000 km², a density similar to the results of 1979 (Map 3).

On the basis of this survey, Pikunov and Bragin recommended creation of two special protection zones (one in the north and one in the south) with zapovedniks (Sikhote-Alin and Lazovski) at their core. Within these special protection zones no commercial logging and no hunting on ungulates would be allowed. Furthermore, within the rest of tiger habitat in Primorski and Khabarovski Krai they recommended a ban on all ungulate hunting for the 1986-87 and 1987-88 seasons. Opening of hunting seasons after that period on wild boar, red deer, and sika deer would be on a case by case basis for hunting leases that demonstrated ungulate densities at a minimum of 5-7 animals/10 km². In response to these recommendations, hunting of ungulates was banned for two years, but the rest of their recommendations went unheeded.

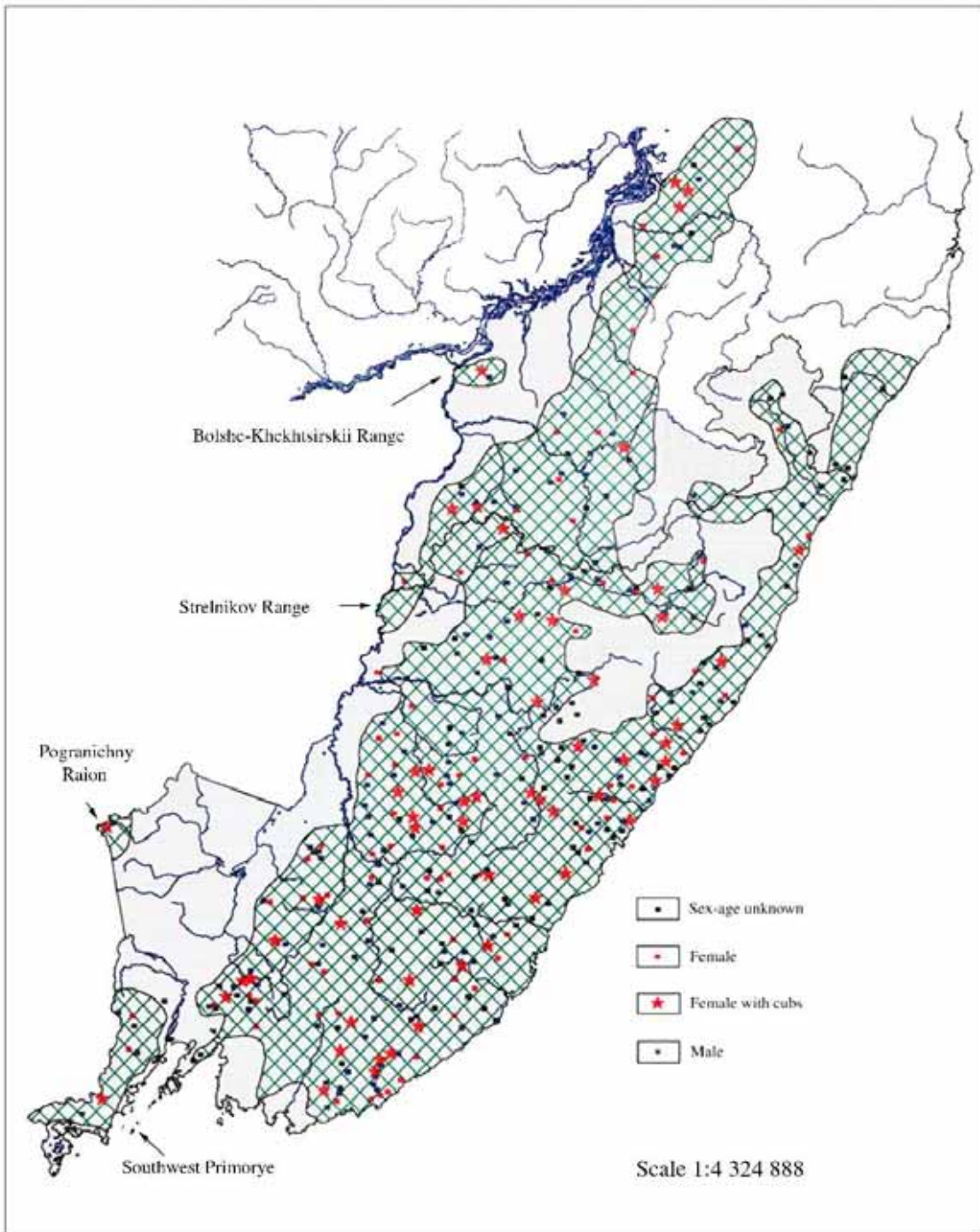
A series of surveys based solely on questionnaires, with no fieldwork, were conducted between 1986 and 1994. In Primorski Krai, disputes over the results of the 1985 survey led to two questionnaire surveys conducted in 1989 and 1990, which suggested that tiger numbers were



Map 3. Distribution of tigers in Primorski Krai in the 1984-1985 winter, based on data from the survey of Pikunov and Bragin (Pikunov 1990)

higher than the 1985 survey indicated, but differences in methodology make it difficult to compare results (Table 1). For the two surveys conducted in Khabarovsk in 1993 and 1994, organizers recognized the limitations of such surveys, but no funds for more comprehensive fieldwork were available. Nonetheless, there was widespread concern about the status of tigers as poaching pressures increased markedly with the collapse of the Soviet Union.

The last major survey of Amur tigers was conducted across the entirety of tiger range in Primorski and Khabarovski Krai under the direction of E. N. Matyushkin. This survey was unique by including nearly all local scientists engaged in the study and survey of tigers to assist in organizing the census, each responsible for specific regions (Matyushkin et al. 1996). A total of 655 fieldworkers were employed, and data was collected as in the previous survey, using both “seasonal winter” correspondents (hunters who reported on tracks during the entire hunting/trapping season) and a simultaneous count in which fieldworkers walked prescribed routes across the entire area within a 5-day period, February 10-15 1996. For the first time, an



Map 4. Tiger distribution in the Russian Far East in the 1995-1996 winter, based on the full range survey conducted by Matyushkin et al. (1996, 1999).

attempt was made to standardize criteria for determining number of individual tigers based on the size of tracks, date they were created, daily travel distances of tigers, and maximum distances between tracks of a single individual (see Miquelle et al. in press).

The 1996 survey reported a total population of 415-476 animals, including 108-121 males, 132-143 females (including 52-58 females with a total of 85-100 cubs), and 90-107 animals of unknown sex-age classes. Total area inhabited by tigers encompassed 156,500 km² (Map 4). Tigers were distributed across nearly all forested areas of Primorye and southern Khabarovsk, with the Sikhote-Alin population intact as a single continuous population. In contrast to previous surveys, tigers had colonized the coastal region of Khabarovsk, extending as far north as the newly created Botchinski Zapovednik. However, there were regions where fragmentation had occurred, or was likely to occur, including Southwest Primorye, Pogranichny Raion, and BolsheKheksirski Range.

With long-term support provided by the National Fish and Wildlife Foundation's Save-the-Tiger Fund, since 1997 an Amur Tiger Monitoring Program has been developed whose goal is to determine trends in the population of tigers and their prey base (Miquelle et al. 2003). 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 provides a means of assessing the effectiveness of current management programs, provides a means of assessing new conservation initiatives, and provides an "early warning system" in the event of rapid decreases in tiger numbers. Sixteen monitoring sites are distributed across the range of Amur tigers to ensure representation of parameters relevant to tiger abundance (protected status, north-south and east-west gradients). Results from the first six years suggest changes are occurring in the Amur tiger population. While expert assessments of tiger numbers suggest changes within monitoring units are minimal (Figure 13, the standardized track density estimate suggests a decrease in tiger abundance (Figure 2).

Cub production continues to be an area of concern. Although the total number of cubs produced in 2003 on all sites combined (23) is very close to the 6-year average (23.8), the number of litters being produced appears to be declining (Figure 3). Total cub production remains stable because litter size appears to be increasing. The reason for this increase in litter size is not clear, but the results indicate that fewer and fewer monitoring sites are producing cubs; 61% of the cubs reported over the 6 years of monitoring have been produced on 5 sites (31% of sites), and there is a trend towards fewer and fewer sites producing cubs (Figure 4). Further increases in litter size are unlikely, and therefore continued decline in cub production on many sites suggests that recruitment in the future may not be able to compensate for total mortality, in which case we would anticipate a decline in tiger numbers. Concern over the results of the monitoring program, along with other indicators, provided additional support for the need to conduct a full range survey.

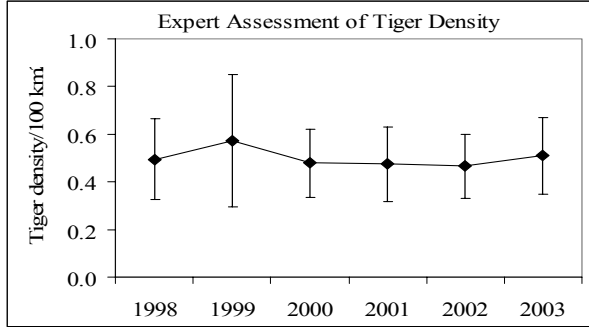


Figure 1. Trend in density of independent tigers (/100 km²), based on expert assessments, for 16 sites in the Amur Tiger Monitoring Program, 1997-1998 through 2002-2003 winter seasons.

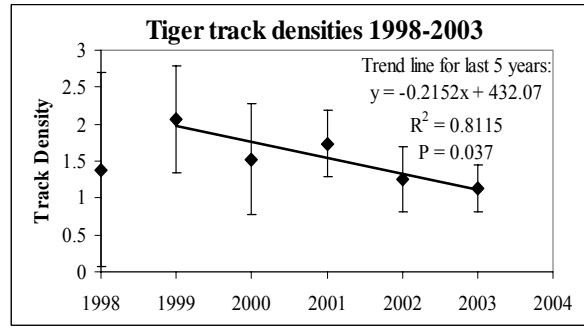


Figure 2. Density of tiger tracks (tracks/100 km/days since last snow) as indicators of tiger abundance averaged across 16 sites included in the Amur Tiger Monitoring Program; trend line estimated for past 5 years.

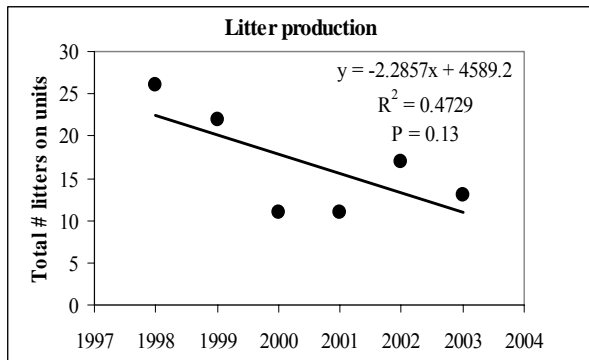


Figure 3. Litter production (total number of litters produced) on all 16 units combined for the Amur Tiger Monitoring Program appears to be decreasing.

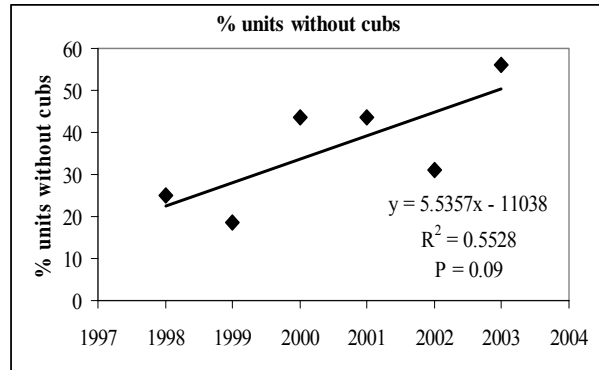


Figure 4. Percent of sites without cubs appears to be increasing over time in the Amur Tiger Monitoring Program, based on 6 years of monitoring, winter 1997-1998 through 2002-2003.

Although methods have varied in how censuses were conducted, the overall trend from these works suggests that from Kaplanov's first work in the late 1930s, the Amur tiger population was in a recovery phase through the early 1990s (Figure 5). Kucherenko (2000) has reviewed this literature, and suggests that the peak in population size may have come in the late 1980s or early 1990s. Monitoring work conducted since 1997 does not allow us to extrapolate across the entirety of tiger habitat, but the results support the idea that the population may have been declining in the late 1990s and early 2000s. Consequently, a survey provides the only means to assess whether this was indeed the case.

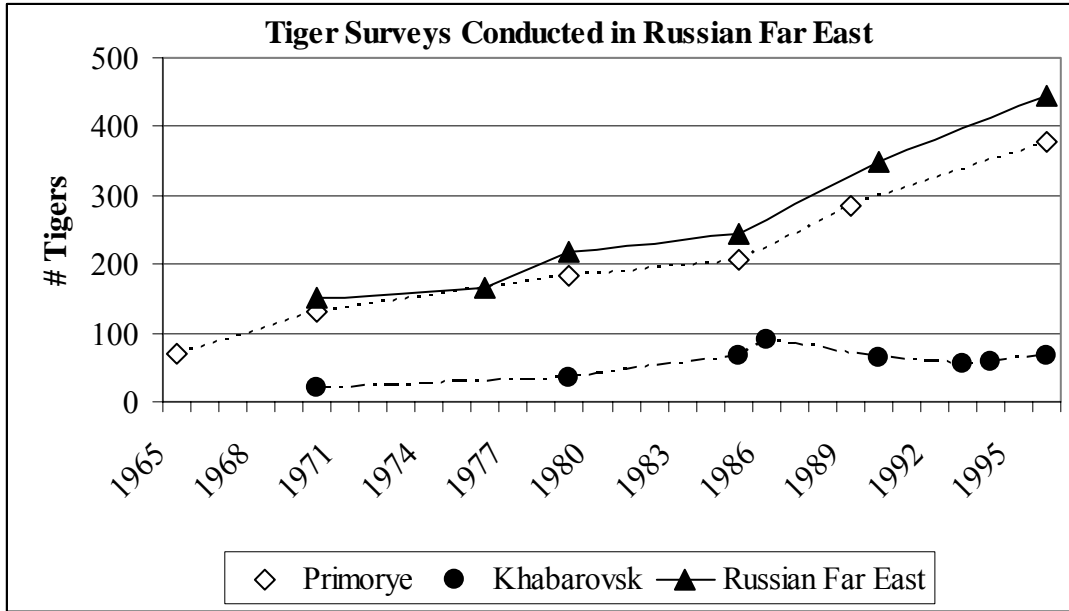


Figure 5. Results of tiger surveys conducted in Primorye, Khabarovsk, and across the Russian Far East, 1965-1996.

IV. GOALS AND OBJECTIVES

The goal of a 2004-2005 winter survey of Amur tigers was to assess the current status of Amur tiger subspecies across its entire existent range in the Russian Far East. The methodology used should provide a means of comparing new information with past surveys, provide a means of assessing the success of existing conservation programs, and provide an indication of changes in tiger numbers, distribution, reproduction, and status of its prey base. Specifically, this survey should achieve the following objectives:

1. ASSESS HABITAT SELECTION BY AMUR TIGERS.

An important component of conserving tigers is understanding their habitat requirements, and hence it is important to assess habitat preferences. Defining suitable habitat, relative importance of habitat types, and defining density of tigers (based on available habitat) as well as determining appropriate management regimes (as they related to specific forest types) all depend on a clear understanding of tiger habitat preferences. Defining habitat preferences is a necessary precursor to defining distribution, relative abundance across the region, in defining prey densities.

2. DEFINE PRESENT DISTRIBUTION OF THE AMUR TIGER POPULATION IN RUSSIA.

Population numbers can shift as a response to changes in densities within an area, or changes in overall distribution (total area inhabited) of a species. As the northernmost representative of the species, Amur tigers live at the very edge of natural conditions that allow for their survival. This biogeographic characteristic, in addition to the multiple anthropogenic impacts, make regular definition of the tiger distribution critical to understanding the status of this population. There is evidence from Khabarovsk, and parts of Primorye (Dunishenko, Pikunov, unpubl. data) that suggest that boundaries of the tiger population may have shifted since the 1996 survey. Careful assessment and delineation of those boundaries is needed.

3. DETERMINE NUMBERS OF TIGERS BASED ON AN EXPERT ASSESSMENT.

An expert assessment of tiger numbers, conducted with the same methodology as in previous surveys, will provide an estimate comparable to nearly all previous surveys. While all survey methods have their limitations and biases, using the same methodology as in past surveys provides a higher probability of detecting changes in the tiger population. However, because of potential biases in this approach, we recommend combining this information with other indicators (track abundance and track algorithm – see below) to interpret the status of the Amur tiger population.

4. DETERMINE TRACK ABUNDANCE AS AN INDICATOR OF TIGER ABUNDANCE.

The Amur Tiger Monitoring Program relies on track abundance (expressed as “tracks/100 km route/days since last snow”) as a standardized measurement to compare relative abundance of Amur tigers across their range. Using this metric it is possible to compare relative abundance of tigers in a standardized format across the entire range of tigers (including China and any other potential tiger range). This measurement provides a relatively stable indicator of tiger abundance, but does not specifically define the number of tigers.

5. DETERMINE NUMBERS OF TIGERS BASED ON A STANDARDIZED “ALGORITHM.”

One of the problems with expert assessments is the difficulty of interpreting differences between assessments by various experts. Because in the past there has been no rigorous, standardized method to interpret track data, results of expert assessments are difficult to compare unless the same experts conduct subsequent surveys. Changes in personnel bring unknown and immeasurable changes to the results. Therefore, development of a standardized mechanism for interpreting abundance and distribution of tracks that is compatible with expert assessment techniques will provide structure and standardization to the process. Perhaps more importantly, use of an algorithm provides an opportunity to assess how changes in key parameters used to define tiger abundance in Russia can influence the results.

6. CHARACTERIZE THE SEX-AGE STRUCTURE OF THE AMUR TIGER POPULATION; IN PARTICULAR TO DEFINE THE NUMBER AND DISTRIBUTION OF REPRODUCTIVE FEMALES.

Existing information from the Amur tiger monitoring program has demonstrated the importance of careful analyses of sex-age parameters (Dunishenko 2003). While track data is not always easy to convert into sex-age classes, at a minimum they can usually provide clear indications of where and how much reproduction is occurring in the population. Recording the presence of female tigers with young on count units across the range of tigers will provide a clear indication of the number of reproducing females, and where reproduction is occurring. This information can help to define important centers of recruitment and where potential problem sites are (“sink” areas).

7. RECORD INSTANCES OF TIGER MORTALITY ACROSS ITS RANGE TO DETERMINE THE RELATIVE IMPACT PRIMARILY OF HUMAN-CAUSED DEATHS.

Existing data suggests that human-caused mortality (mostly poaching) is the primary cause of death for tigers in the Russian Far East (Nikolaev and Yudin 1993, Goodrich et al. 2005, Miquelle et al. 2005) and that poaching rates may (or could) be the primary factor limiting the Amur tiger population (Chapron et al. 2005). Development of a standardized way of characterizing mortality in the Amur tiger population is one mechanism for gaining an understanding of the magnitude of this problem. Reports of tiger mortalities are highly skewed towards instances of human-caused deaths, because these are most likely to be reported. Nonetheless, such information can provide an indication of the extent of poaching, and the relative levels of poaching across tiger range. By conducting a standardized survey of people across tiger range, we can develop a geographic depiction of the relative frequency and causes of tiger mortality.

8. ASSESS ABUNDANCE OF KEY PREY SPECIES.

An understanding of prey distribution and abundance, and the ratio of prey to predator is critical to understanding the status tiger populations. Changes in ungulate densities, which are the primary prey of tigers, provides the potential to predict future changes in the population, and where potential problem areas may exist. Because the majority of tiger habitat in the Russian Far East occurs in Federal Forest Lands (GosLesFund) where hunting leases are active, the situation is even more complicated by the need to understand the relationship of not only tigers and prey, but of the needs of the hunting community as well. While an index of prey abundance is useful, it is preferable to derive estimates of absolute abundance of prey to clearly understand the complexities of the predator-hunter-prey relationship.

9. DETERMINE THE RELATIVE ABUNDANCE OF OTHER LARGE CARNIVORES IN TIGER RANGE.

Large scale surveys across large areas provide an opportunity to collect additional data of potential value. Understanding the distribution and relative abundance of other large carnivores can provide several important benefits. First, because other large carnivores are competitors to tigers, understanding where the relationship between the two is important (e.g., Miquelle et al. 2005). Secondly, because most other large carnivores are also hunted species, any information on their abundance and distribution is useful to those organizations responsible for their management. And finally, because other large predators also rely on some of the same prey species as tigers, an understanding of their abundance and distribution also assists in understanding all mortality pressures on prey populations.

10. DETERMINE PRIORITY CONSERVATION ACTIONS BASED ON THE RESULTS OF THE SURVEY.

Every survey provides a new picture of the status of the Amur tiger population in Russia. Data derived from the survey will provide new insights into the status of the Amur tiger population in Russia, where potential fragmentation points exist, what conservation actions are needed for both the tiger itself and its prey base. Therefore, an important responsibility of those organizations and people who implement surveys is the determination of necessary actions to ensure long term security and survival of this endangered population

This report provides information on the first 5 objectives of the survey program, as well as defining priority conservation actions recommended by the authors...

V. METHODS

Details and rationale explaining the theoretical basis for most of the methodology for surveying tigers in the Russian Far East have been discussed in Miquelle et al. (in press). Here we provide a brief synopsis of the methodologies employed for the 2004-2005 winter survey.

DEFINING THE STUDY AREA

We focused survey efforts on the Southern region of the Russian Far East, including all territory south of the Amur River except for Ulschi raion in Khabarovski Krai. We surveyed forested regions of all raions (counties) of Primorye and Khabarovsk which were included in recent previous surveys (since 1985) and included any raions (counties) where new information suggested that tigers may occur. The list of raions included in this survey, along with the coordinator responsible for organizing survey work in that region, is shown in Table 2 and Map 5. Additional information outside this region (especially along the northern and western boundaries of tiger range in Khabarovski Krai) was obtained by from hunters, professional wildlife biologists, and foresters (people active in the forest).

Although tigers have been recently reported in Amur Oblast, and other regions to the west, there is no evidence of a breeding population of tigers. Individuals that disperse long distances from the core population have been consistently reported in the past (Sludski and Heptner 1988). These infrequent sightings do not merit intensive surveys of such areas, but such areas should be monitored by local wildlife biologists to determine whether such occurrences represent lone individuals, or possibly represent colonization by more than a single animal. Evidence of breeding (females with cubs) would be especially important.

To avoid errors in defining current distribution of tigers, the study area should include potential habitat along the boundary of the known existing distribution, with survey effort to determine whether tigers are present or absent in these marginal zones. To collect such information economically, we relied on “winter seasonal data” (to be defined below) collected by local people exclusively in these regions. This approach provides a fairly accurate means of determining presence/absence, but does not provide sufficient data to estimate numbers accurately. However, since animals will generally be sparsely distributed in such regions, the loss of accuracy in these marginal regions is minimal.

STRATIFICATION OF SURVEY AREA INTO SURVEY ZONES

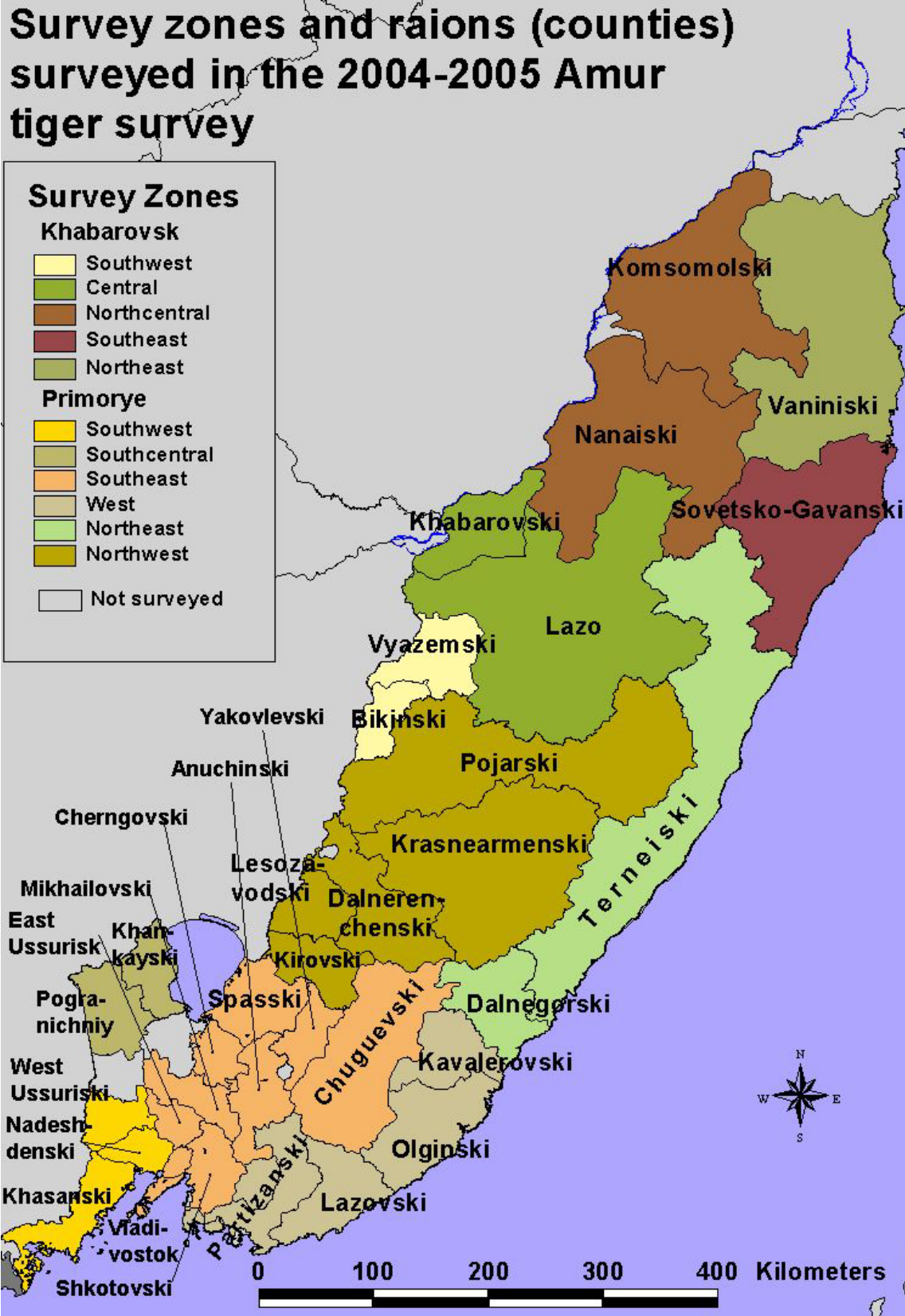
Because the vast area in which tigers occur across the Russian Far East varies greatly in habitat characteristics important to tigers and their prey, it is useful to divide the area to be surveyed into smaller survey zones. Zones should be delineated so that generally similar climatic and topographic characteristics exist within each zone, with greater variation among zones than within any single survey zone. The delineation of survey zones used in the 2004-2005 survey (presented in Table 2 and Map 5) is virtually identical to that used in the last survey (1996) except we have added a new zone in northeast Khabarovski Krai, where new survey effort was allocated.

Table 2. Division of Tiger habitat in Russian Far East by Raion (county) and coordinators, for 2005 Amur tiger survey

Krai (Province)	Region	Raion (county)	Coordinator
Primorye	1 Southwest	Khasanski	Korkishko/Pikunov
		Nadesdinski	Pikunov
		Ussuriski (western half)	Pikunov
	2 West	Pogranichniy	Nikolaev
		Khankaiski	Nikolaev
	3 Southcentral	Spasski	Yudin
		Chernogovski	Yudin
		Mikhailovski	Litvinov/Seryodkin
		Vladivostok (outer city limit:	Litvinov/Seryodkin
		Shkotovski	Litvinov/Seryodkin
		Ussuriski (eastern half)	Litvinov/Seryodkin
		Anuchinski	Litvinov/Seryodkin
		Chuguevski	Gaponov
		Yakolevski	Gaponov
	4 Southeast	Kaverlovski	Aramilev
		Olginski	Aramilev
		Partizanski	Salkina
		Partizanski City	Salkina
		Lazovski	Salkina
5 Northeast	Terneiski	Smirnov	
	Dalnegorski	Kostyria	
6 Northwest	Pojarski	Seryodkin	
	Krasnearmenski	Fomenko	
	Dalnerechenski	Nikolaev	
	Lesozavodski	Nikolaev	
	Kirovski	Nikolaev	
Khabarovsk	7 Southwest	Bikinski	Dunishenko
		Vyasemski	Zvyagentsev
	8 Central	in-the-name-of Lazo	Dunishenko
		Khabarovski	Darenski
	9 Northwest	Komsomolski	Golub
		Nanaiski	Darenski
	10 East (Coastal)	Sovgavanski	Dolinin
	11 Northeast	Vaninski	Dolinin

DEFINITION OF TIGER HABITAT

We attempted to survey the entirety of tiger habitat in the Russian Far East, but to do so, it was first necessary to define “tiger habitat.” We used a landcover map derived by Ermoshin et al (2003) based on interpretation of Landsat satellite imagery that categorized Primorski Krai and Khabarovski Krai south of the Amur River into 52 landcover types (Map 6). Minimum polygon size used in interpreting imagery was 10 km², and minimum polygon width was 1 km².



Map. 5. Raions (counties) and survey zones included in the 2004-2005 winter survey of Amur tigers in the Russian Far East.

Classification of landcover types was based on dominant vegetative cover, and topographic characteristics. To define tiger habitat, we simplified the classification into 12 habitat types and then ranked each of these categories as potential tiger habitat (i.e. habitats where tigers could survive for extended periods of time) (Table 3). Our criteria for this designation were derived largely from previous studies, including previous surveys (Matyushkin et al. 1999, Abramov, Yudakov and Nikolaev, Pikunov) and habitat analyses (Miquelle et al. 1999, Carroll and Miquelle 2006) that had assessed habitat quality for Amur tigers. In general, forests of oak, birch, Korean pine, and mixed valley forests were considered high quality habitat. Larch forests and young forests (usually the result of either fire or intensive logging) were considered of moderate quality. Both of these types often appear on the landscape as relatively small polygons amidst high quality habitats, and therefore have a reasonably high probability of being used because of adjacent quality habitat. Spruce-fir forests tend to occur at high elevations or higher latitudes where deeper snows and lower prey densities make them low quality habitat for tigers. Similarly, “sparse forests” were usually associated with human-dominated landscapes, where prey densities are low and mortality risk for tigers is high. Agricultural fields, swamps, and alpine environments were all considered extremely poor tiger habitat. The resulting classification provides a map of potential habitat for tigers and areas that should be surveyed for tigers. In total, we identified 171,520 km² as high quality habitat, 32,721 km² as moderate quality, and 150,422 km² as low or extremely low quality habitat. We assumed “suitable habitat” included high and moderate quality habitat, and hence, our goal was to survey 204,242 km² (high and moderate habitat) of the 354,664 km² in the region.

In past surveys (e.g. Matyushkin et al. 1996) it has been assumed that tigers do not use high elevation areas due to deep snows and low prey densities. Our definition of suitable habitat also inherently includes this fact, as the vast majority of habitat types above 700 m were categorized as unsuitable (mostly spruce-fir and alpine habitat types).

This *a priori* definition of suitable and unsuitable habitat was necessary to prioritize and define sampling units, but was largely subjective, based on general assessments of extensive surveys across the region by coordinators. However, because sampling units and survey routes inevitably included some unsuitable habitat during our survey, we used the data obtained from the simultaneous survey to test these assumptions using Neu’s habitat preference test (Neu et al. 1974), which has been found to be one of the most consistent in evaluating habitat preferences (McClellan et al. 1998). For each of the 11 regional zones defined above (Figure 4) for which there were sufficient numbers of tiger tracks (three zones could not be included in separate tests due to limited numbers of tracks), we summed the total number of tiger tracks reported in each habitat type, and the total kilometers of routes covered within each habitat type. We used the total kilometers sampled to estimate the expected number of tiger tracks that should be found along routes in each habitat type for each zone, and for the total area surveyed, and compared this value to the actual number of tracks in each habitat type using a chi-square log-likelihood test. If significant differences were found, we derived Bonferroni confidence intervals for each habitat type for each zone (and for all zones combined) to determine in which cases habitat types were significantly preferred or avoided by tigers. We also derived a “preference ratio” defined as the proportion of tracks found in a specific habitat type divided by the proportion of routes that covered that habitat type within each zone, and for the entire area. A preference ratio greater than 1 was an indication of preference by tigers, whereas a preference ratio less than 1 indicated avoidance of that habitat by tigers.

Table 3. Habitat types used to define potential tiger habitat.

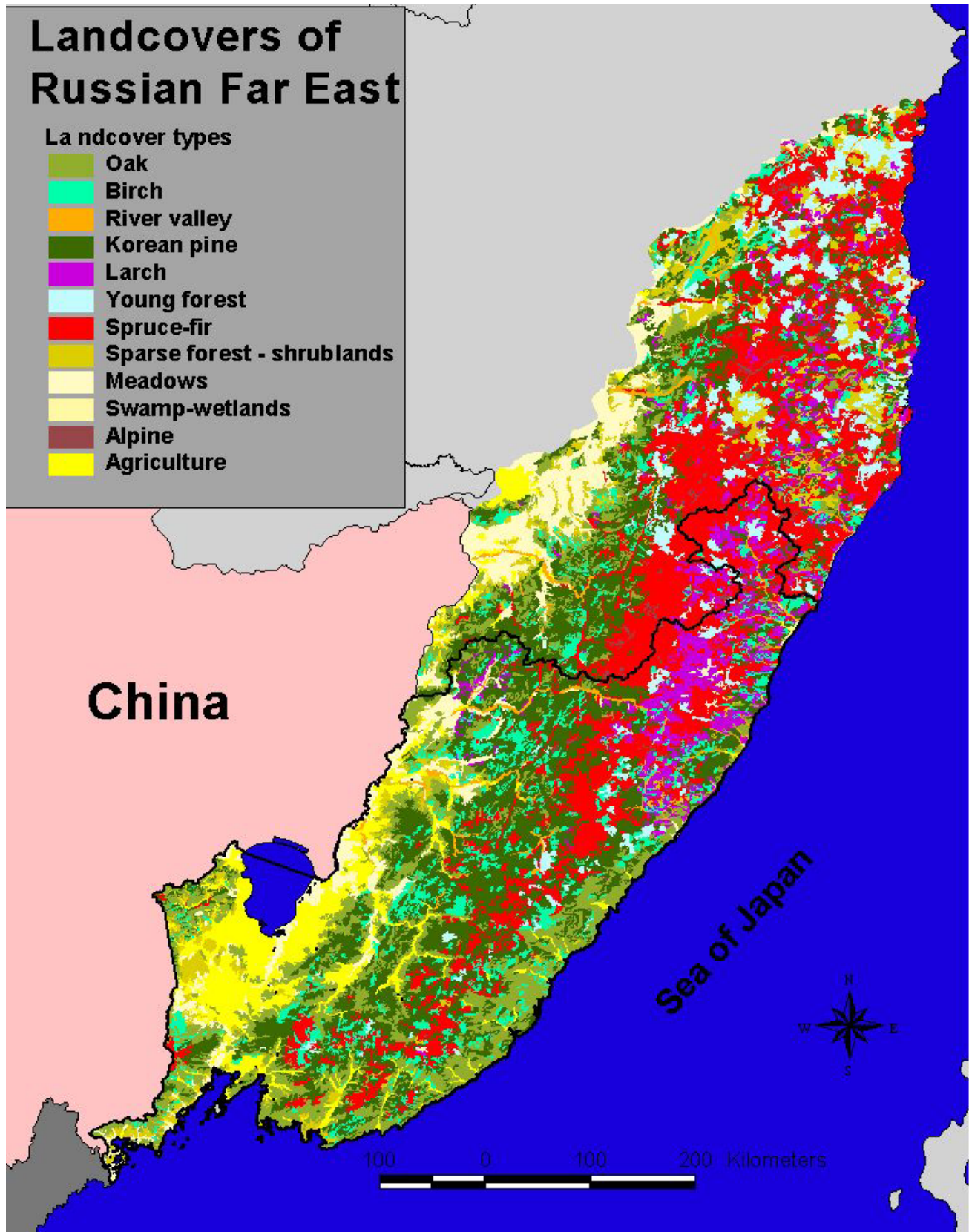
#	Landcover type	A priori expectation of tiger habitat preference	Post hoc assessment of tiger habitat preference	Area (km ²)
1	Deciduous broad-leaved (Oak)	High	High	51,836
2	Deciduous small-leaved (Birch)	High	High	30,929
3	Riverine forests (includes deciduous, mixed, and coniferous)	High	High	4,071
4	Korean pine forests (mixed with deciduous and coniferous species)	High	High	84,684
5	Larch forests (mixed with deciduous and coniferous species)	Moderate	Moderate	16,198
6	Young forest (fire, extensive logging, or pests in past 30 years)	Moderate	Low	16,524
7	Spruce fir forests	Low	Low	73,852
8	Sparse forest (shrublands, mixed forest/ag fields)	Low	Moderate	21,909
9	Meadows	Low	Low	22,872
10	Swamp-coastal wetlands-peatlands	Extremely low	Moderate	201
11	High elevation stunted forest/alpine	Extremely low	Extremely low	2,809
12	Agricultural fields	Extremely low	Extremely low	28,780
	Total			354,664

DELINEATION OF SURVEY UNITS WITHIN ZONES

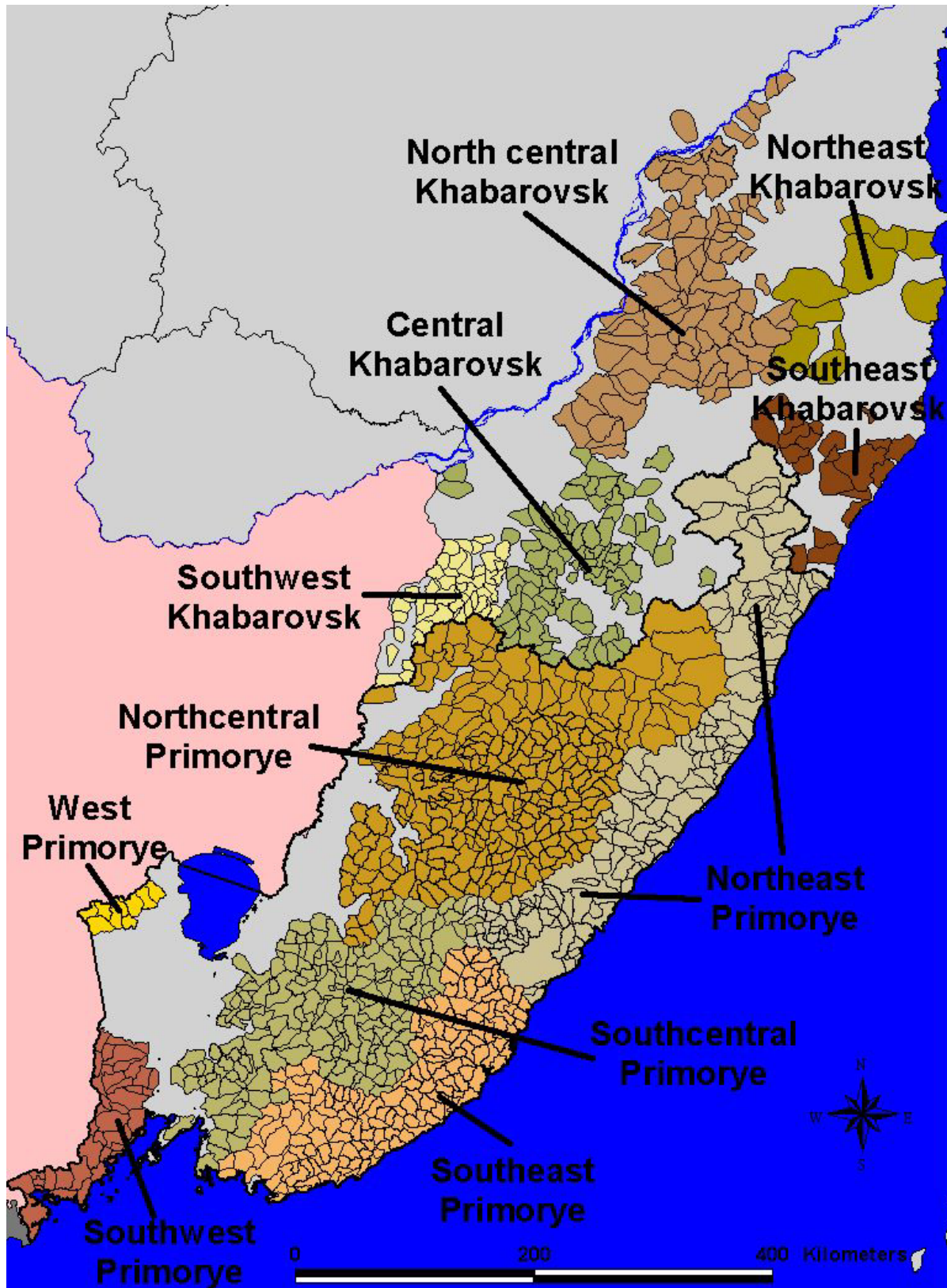
Over the past three surveys each survey zone was divided into survey units of 10,000-15,000 ha (100-150 km²). We also used the approach, and with each unit further delineated by landcover types (Map 6) they represented the fundamental units for measuring tiger distribution and abundance. For the 2004-2005 tiger survey a total of 1096 survey units were created (Map 6). As in previous surveys, survey units were laid out with the intention to cover all high quality and moderate quality habitat. Some low and extremely low habitat was unavoidably included in survey unit boundaries, but these lower categories were not targeted as part of our survey area. Additionally, some survey effort was made on the “left bank” (north side) of the Amur River. Two routes were placed in Komsolmoski Zapovednik, and information (seasonal winter data) was obtained from other sites where tracks of tigers were reported.

On every survey unit coordinators defined 1-3 survey routes that should be covered during the “simultaneous: survey (defined below). Additionally, coordinators identified 1-2 people who would be responsible for collecting “winter seasonal data.” In most cases, people responsible for winter seasonal data and for covering survey routes during the simultaneous survey were the same.

Boundaries of survey units were traditionally defined to coincide with boundaries of hunting units (in which one or a few hunters have exclusive rights to hunt and/or trap). This system has



Map 6. Landcovers in the southern Russian Far East (Table 3).



Map 7. Eleven survey zones of the 2005 Amur tiger survey, and survey units delineated within each zone.

largely been abandoned in southern Primorye, but because trapping is still an important economic activity in northern Primorye and Khabarovsk, boundaries of survey units still largely coincide with these previously existing delineations. In all cases, survey units were defined by the beginning of the winter season to ensure full and even coverage of tiger range. It was assumed that each survey unit includes potential tiger habitat. Therefore, estimates of tiger density, derived from expert assessments, are based on the total area that was surveyed, as represented by the sum of these survey units.

DATA COLLECTION WITHIN SURVEY UNITS

Two forms of data collection occurred on survey units: 1) one or two local residents who spend extended periods of time on survey units (usually hunters/trappers who have permits to hunt/trap on that survey unit) have the opportunity to report information over an extended period (“winter seasonal” information); and 2) specified survey routes were covered during the “simultaneous” count period and collect specific information on tracks of tigers and ungulates.

WINTER SEASONAL DATA

As with previous surveys, the 2004-2005 survey relied on the fact that over the vast majority of tiger habitat there exists a network of hunters who were active much of the winter hunting/trapping on their hunting territory (which in many cases coincides with boundaries of survey units). This vast network of people can provide a rich supply of information on distribution of tigers. Although they are not requested to travel any special routes, during their daily routine on their survey units hunters can collect valuable information. We requested hunters, conservation officers, or foresters who spent extended periods of time on specific survey units to collect 4 types of data: 1) information on presence/absence of tigers (reporting date, location, and size of every tiger track {pad width in cm} encountered; 2) especially important are observations of females with young; 3) answers to a questionnaire developed to derive additional information on tiger mortality, trends in tiger numbers and prey, and changes in habitat within the survey unit. Information collected by local hunters will begin in November with first snow fall and continue through the end of February. All season data was reported in a standardized field notebook (Appendix I).

Seasonal winter data collection began in November 2004 with first snow fall and continued through the end of February, 2005. Some information was even collected in March 2005. Probability of a hunter encountering tracks of tigers will be dependent partially on how often he is traveling in the forest. We therefore requested that hunters report the number of days they are active in the forest as a measure of survey effort.

Winter seasonal data is intended to provide a means of determining presence/absence of tigers on survey units, with the assumption that large survey effort (represented as the number of days a person was present on the survey unit) with no evidence of tigers would be strong indication that tigers are not present on that unit. Secondly, because the tigers can be missed during the simultaneous count (see below) the winter seasonal data provide a second opportunity to “capture” resident tigers within the scope of the.

This portion of the survey design was derived when there existed a network of “professional” hunters who spent the majority of the winter on their survey units. This system has changed largely with “privatization” of hunting leases in the early 1990s. Especially in the southern portion of Primorski Krai, there are relatively few people who spent large amounts of time in the forest, and therefore, the effectiveness of this portion of the survey has probably somewhat diminished in comparison to previous surveys. ;

SIMULTANEOUS SURVEY ROUTES

During a specified period (February 10-15th), a predefined set of survey routes (no less than 20-30 km per survey unity) were covered within each survey unit. Routes were placed to achieve two goals: 1) estimate tiger distribution and abundance; and 2) estimate ungulate distribution and abundance. To achieve these somewhat conflicting goals, two types of routes were placed within survey units.

At least one route was placed within survey units to maximize probability of encountered tiger tracks. Repeated surveys in the Russian Far East since the 1940s have provided extensive information on likely travel corridors of tigers in the region. Local knowledge is particularly important in identifying areas where probability of encounter is greater. In most cases, these survey routes will be placed along river bottoms, where travel is easiest for survey workers, and where there is a high probability that tigers will travel (Matyushkin 1977).

For ungulates, placement of all survey routes along river bottoms will bias results, because distribution of ungulates is dependent on snow conditions and food availability that vary between river bottoms and north and south-facing slopes. To reduce this bias, we sought to add survey routes that included the dominant habitat types within a survey unit, and a full representation of slopes and aspects. Although logistical constraints prevented random placement of transects (preferred for statistical extrapolation), routes were placed to sample a representative set of habitat types within a survey unit (see below).

Along survey routes the following data were collected: location of tiger tracks, size of tiger tracks (measured as the width of the front pad) age of tracks (reported as an estimate of how many days ago tracks were created), location of other large carnivores (wolves, bears, and lynx), location and number of ungulate tracks, and snow depth at 4 interspersed locations along survey routes. Data from each route were recorded in special field “diary,” with two copies of a map of the region (1:100,000 scale) on which the route was drawn. On the first map locations of tiger tracks other large carnivores were noted. Every intersection with a set of tiger tracks was allocated a unique number, with pad with reported as the average of at least 4 measurements of different tracks at a single crossing. Fieldworkers were requested to estimate sex of the tiger (see below). On the second map locations of ungulate tracks were noted. Only ungulate tracks estimated to be less than 24-hours old were reported (whereas tiger tracks of any age were reported). For each intersection with ungulate tracks on the table in the field diary the species, the number of crossings, and an estimate by the counter of the number of ungulates that crossed the route at each location (see below) was reported.

Wherever possible, routes were at least 12 km in length to reduce variance in tiger track abundance. Efforts were made to maintain a route density of 1.5 km/km² within survey units (Miquelle et al. in press).

Tiger track abundance of tigers is obviously be dependent on how recently snow has fallen (assuming no snow had fallen in the past 24 hours, there is no similar problem with

ungulate tracks). Based on analyses of track abundance and the trade-off in effectiveness in survey implementation (Miquelle et al. in press), we requested that simultaneous routes be covered at least 5 days after a snowfall of more than 5 cm. This limitation resulted in some disruption of the goal to implement survey routes simultaneously across the entire range of tigers, but inasmuch as snowfall affects large areas, adjacent survey units were mostly still covered simultaneously.

ESTIMATING NUMBERS OF TIGERS

EXPERT ASSESSMENT

Regional coordinators organized and summarized data from fieldworker diaries in the following manner:

- A summary map (scale 1:100,000) was prepared that included all tiger tracks encountered during the simultaneous census;
- An analogous map was developed for tracks reported from the seasonal winter data set;
- Identification of individuals was based on: an analysis of track size, track age, daily travel distances, maximum travel distance (home range diameter) of sex-age classes, and potential barriers to movement. Each of these five factors is reviewed below.

1. Track size. Data from wild Amur tigers indicate that subadult (greater than 1.5 years) and adult males are easily differentiated from subadult and adult females based on the width of the front pad, as pad width of subadult and adult male tigers is always greater than or equal to 10.5 cm, a width never attained by females (Table 4). (Yudin 2006, Kerley et al. 2005) The only potential confusion is with young males (< 1.5 years), but males less than 1.5 years are usually in association with a liter, and can thus be identified. Hence the only potential confusing situation is in which a female has a single male cub, a relatively rare event.

Differences in the size of tracks made by a single tiger can be due to differences in surface conditions/snow depths, errors or differences in measurements made by two or more fieldworkers, and degradation of a track with age. Specialists from the 1996 survey agreed that tracks with pad width measurements within 1 cm of each other could likely represent a single individual. We also applied this criterion for interpretation of tracks, even though recent data suggest that errors in pad width measurements may be as great as 2 cm. (Yudin 2006). We have attempted to assess the potential impact of greater error in measuring pad width (see section on Algorithm).

Table 4. Front pad width measurements of wild Amur tigers, from Kerley et al. 2005.

	Front pad width of females				Front pad width of males			
	<i>n</i>	mean	SD	Range	<i>n</i>	mean	SD	Range
Cubs (1.0-1.5 yrs)	5	8.5	0.5	8.0 - 9.0	5	10.3	0.7	9.5 - 11.0
Subadults (1.5-3.0 yrs)	5	9	0.3	8.6 - 9.5	4	10.6	0.3	10.4 - 11.0
Adults (> 3 yrs)	10	9.2	0.4	8.5 - 10.0	12	11.4	0.6	10.5 - 12.8

2. Track age. “Freshness” of tracks is an important variable in distinguishing individual tigers within a specific region because the probability that tracks were created by one individual is dependent on the daily travel distance of tigers, multiplied by the number of days separating when tracks were created. However, as tracks get older, the precision with which their age can be determined diminishes greatly. It is generally believed that tracks less than 24 hours old can be reliably identified. Tracks of 1-3 days can be reasonably accurately identified based on melt-out patterns and granular characteristics of snow in the track in relation to frost-thaw patterns in that time period, but accuracy already diminishes at this age. Based on likely travel distances, tracks older than 4 days are of less significance because most tigers have the capacity to travel across their entire home range in that period, making distances greater than that walked within a 4-day period unimportant. It was assumed that an error of 1 day is possible in calculating track age between 1 and 4 days.

3. Average daily travel distance. Whether two tracks could have been created by a single individual (assuming track size is similar) is dependent on the distance between tracks and the probability that a tiger could have covered the distance between those tracks within the timeframe in which the tracks were created. Yudakov and Nikolaev reported that adult male tigers travel, on average, 9.6 km (maximum = 41 km) per day when not at a kill, and adult female tigers travel on average, 7 km (maximum = 22 km) per day. This is the actual distance traveled. Linear distance between two sets of tracks, which is the variable that will be assessed in the track data, will be less than actual travel distance.

In Sikhote-Alin, distances between locations of radio-collared tigers on sequential days were measured to provide an indication of the average, median, and quartile estimates of daily distances moved by radio-collared tigers on sequential days (Miquelle et al. in press). Separate summaries are provided for females, females with cubs, and males, with days when tigers were on kills (and moved very little) not included. When not on kills, females with cubs travel slightly shorter distances than females without cubs, and males travel greatest distances (Table 5). Use of a mean daily travel distance would include only half of the daily travel distances for any sex-age class. To be more conservative, we used the 75% quartile. Thus daily average travel distance used in distinguishing tracks was 4.7 km for females with cubs, 7.1 km for females without cubs, and 9.6 km for males.

4. Maximum distance between tracks of an individual tiger. Tigers typically confine their movements to well-defined home ranges (Goodrich et al. 2005, Sunquist 1981), and therefore the likely distance between two tracks that could have been made by one individual reaches a threshold that is dependent on the size (diameter) of an animal’s home range. For

Table 5. Daily straight-line distance traveled by tigers, based on radio locations of individual tigers on consecutive days. Data from the Russian-American Siberian Tiger Project, 1992-2002 (Miquelle et al. in

Sex	Cubs	# tigers	n	Means	SD	Straight-line distance between locations on two consecutive days (m)				
						20% quartile	25% quartile	75% Median quartile	80% quartile	
Females	cubs	9	731	3236	3321	526	744	2113	4717	5468
	no cubs	13	582	5015	3931	1669	1925	4053	7078	8324
Males		7	163	6699	4960	2061	2672	5573	9660	10786

female tigers radio-collared in and near Sikhote-Alin Zapovednik the average home range size of 14 adult females was 402 km² (minimum convex polygon) and 1379 km² for 6 males (Goodrich et al. 2005). Assuming that home ranges can be represented in the abstract by a circle, the diameter of these home ranges would average approximately 24 km for females, and 43 km for males. Yudakov and Nikolaev (1986) reported maximum home range diameters of 35 and 27 km for two females and 45 km for a male. Our estimate from Sikhote-Alin is an abstraction, and is no doubt lower than the maximum diameter of any single home range, which are not in actuality circular. Based on these measurements, no matter how many days separate the age of neighboring tracks, if those tracks were created by animals with the same size track, but are greater than 25 km apart for females, or 43 km for males, we considered them to be created by different animals.

Of course, not all members of a tiger population are residents who remain in a well-defined area. Dispersing young animals travel unknown but large distances, and Russian literature is filled with discussions of “rogue” tigers that have no home range, or have abandoned their home range. Nonetheless, the majority of a tiger population will be comprised of resident animals and their offspring. Our data from dispersing animals, though fragmentary, suggests that they spend large blocks of time in relatively well defined spaces; therefore, these criteria are appropriate for the limited duration of the survey. Therefore, for the data from the simultaneous survey, these criteria can still be applied.

5. Barriers that prevent movement of tigers. Three physiographic features are assumed to present barriers to movement of tigers in winter.

i. Elevation. Due to deep snow conditions, it is assumed that elevations greater than 700 m will be effective barriers to travel for tigers. Therefore, tracks of the same size but which are separated by such elevation gradients, will be considered separate animals. If snow depth is particularly low in a particular region, then this geographic barrier is not enforced.

ii Open fields. Open, unforested (and generally free of vegetation (e.g., plowed fields) greater than 3 km wide and 10 km long represent effective barriers to travel for tigers, irrespective of snow depth.

ii. Settlements. We assume that tigers will generally not travel through settlements, but usually travel along their edge and around them. Therefore distance between two tracks, if there is a settlement between them, is the distance it takes to travel around the settlement.

E.N. Matyushkin and coordinators of the 1996 Amur tiger survey derived a set of criteria, based on the above factors, to be used as standards for interpreting track data and derived estimates of tiger numbers. They developed two sets of criteria are derived: a “relaxed” set of criteria, whose application results in larger estimates of tiger numbers, and a “conservative” set of criteria, whose application results in a smaller, more conservative estimate of tiger numbers. Details of these criteria are provided in Appendix 1. The range of values between “relaxed” and “conservative” criteria are intended to represent the likely error in estimating tiger numbers. Although these criteria were formerly adopted and applied to the data by coordinators of the 2005 tiger survey, each coordinator reserved the right to “interpret” data that did not, in the view of the coordinator, fit exactly into the prescribed criteria. Therefore, this approach is still

considered an “expert assessment” but the variation between coordinators should be diminished in comparison to earlier surveys (e.g., 1996) because criteria were clearly defined.

To ensure standardization in implementing these criteria, a small committee of coordinators, including the krai-level coordinators, reviewed the expert assessment of every coordinator.

ALGORITHM TO ESTIMATE TIGER NUMBERS

In past full range surveys the specific criteria for distinguishing individual tigers has never been specifically delineated, or, as in the case of 1996 and 2005, the criteria were defined, but coordinators had the right to stray from these criteria. Because there has been no rigorous, standardized method to interpret data, results of expert assessments are difficult to compare unless the same experts conduct subsequent surveys. Changes in personnel bring unknown and immeasurable changes to the results. Therefore, development of a standardized mechanism for interpreting abundance and distribution of tracks that is compatible with expert assessment techniques will provide structure and standardization to the process. The parameters for such an algorithm have been largely defined already (above and Appendix I)

A supplemental approach to estimating tiger numbers is to standardize interpretation of track data by using set criteria applied to all data across the entire region. The advantages of applying such a standardized set of criteria are:

1. Standardized criteria are not subject to individual interpretation, and therefore data gathered across the entire region can be processed in the same way, and direct comparisons of tiger numbers are possible.

2. By varying criteria (e.g. relaxed and conservative criteria), it is possible to define a range of abundance estimates that represent a more reasonable estimate of tiger numbers.

3. By varying key criteria, it is possible to conduct a “sensitivity analysis” that can specifically define the impact of errors in measurement, or changes (errors) in the criteria used. Such a sensitivity analysis provides a mechanism to determine the likely range of errors that can be derived from the interpretation of track data.

Developing a standardized means of interpreting track data does not necessarily make the results any closer to the true number of tigers, but it does provide a means of determining real trends when the same approach is used to estimate relative densities of tigers.

The parameters used in developing the algorithm have already been defined above, and in Appendix I, with the exception that barriers were not applied to this data, due to technical constraints.

The algorithm was defined to develop a minimum estimate of tiger numbers, using criteria defined by Matyushkin et al. (1996, see Appendix 1).). Application of the algorithm required development of a diagonal matrix, D , with normalized parameters of distance between pairs of tracks, using the following formula:

$$\text{NormDist} = (\text{Distance} / \text{MaxDist}) * 100$$

where:

NormDist – normalized degree of proximity between two tracks,

Distance – distance between tracks,

MaxDist - maximum allowable distance between tracks of a single individual (home range diameter) of a sex-age class given the difference in time when tracks were created.

A second matrix, *W*, was then created based on the degree of similarity between tracks based on track size, again normalized as follows:

$$\mathbf{NDSizePad} = (\mathbf{DifSize} / \mathbf{LW_Pad}) * 100$$

where:

NDSizePad – normalized similarity in tracks size,

DifSize – difference in size of a pair of tracks,

LW_Pad - maximal allowable difference between tracks of a single individual.

These two estimates were considered to be of equal weight in determining whether two tracks represented a single individual, and so the overall estimate of similarity between pairs of tracks can be formulated in a third matrix, *M*, as follows:

$$\mathbf{Mtr} = \text{Sqrt}(\mathbf{NDSizePad} * \mathbf{NDSizePad} + \mathbf{NormDist} * \mathbf{NormDist}) * 100 / \text{Sqrt}(20000)$$

where:

Mtr – normalized estimate of similarity between two tracks,

Using this matrix *M* the task was to group tracks to provide a minimum estimate of tigers. This was done using a nearest neighbor approach that first selected the closest track (based on matrix *M*) from a selected starting track, and then selecting the next closest track, again based on *M* values, from that pair. This approach was repeated using each track as a starting point, resulting in a number of estimates of individuals equal to the number of tracks. From this point each tracks was assigned a value (US_t) representing the number of groups in which it occurred. Using this value, uniqueness/overlap of each group was assessed using the formula

$$US_{c(k)} = \text{Sum} (US_{t(ik)}) / N_k,$$

where:

$US_{t(ik)}$ – coefficient of overlap for track *i* in group *k*,

N_k – number of tracks in group *k*,

$i = 1 \dots N_k, k = 1 \dots K$; where *K* = total number of groups.

When every track in a group is unique to that group alone, $US_{c(k)} = 1$, and the larger the value of $US_{c(k)}$ the greater the overlap. To derive a minimum estimate of tigers, the group with the largest value was deleted, and then tracks of that group were reassigned according to the above process, and the $US_{c(k)}$ values again estimated, and the process repeated, until every group had at least one tracks that was unique to that group. Details of this process are available in Miquelle et al. (in press).

The database was created in ArcInfo/ArcView with MS Access. The model itself was written in Basic. PathMatrix V.1.1, developed by Nicolas Ray, was used to estimate minimum distance between tracks.

Comparison of results from expert assessment and algorithm. To compare results of the expert assessment and the algorithm, we applied the same parameters (as defined in the

“conservative” and “relaxed” criteria, Appendix I) used in the expert assessment to the algorithm and compared the two results by survey zone. When one animal occurred in two zones, the expert assessment coordinators determined among themselves who would report the animal based on where it was most commonly found. Similarly, with output of the algorithm, we assigned animals to zones where the most number of tracks assigned to that animal were found, and in the 6 cases in which the number of tracks were even between zones, we assigned animals to that zone with the set of tracks furthest from the boundary. We compared the results of the two approaches by looking at the ratio derived as the estimate made by coordinators for each zone (with few exceptions, one coordinator was responsible for each zone) divided by the estimate made by the algorithm for each zone, for both “conservative” and “relaxed” criteria. A value of one therefore represented no difference in estimates. We also plotted estimates made by coordinators versus estimates derived from the algorithm, assuming that a linear relationship would indicate good correlation between the two approaches, even if the absolute values differed (i.e., ratios did not equal one).

Sensitivity Analysis of factors affecting estimates of tiger numbers. In order to test the capacity of variation in parameters to affect estimates of the size of the tiger population, we conducted a sensitivity analysis on the three key parameters used in both expert assessments and in the algorithm to estimate tiger numbers are: 1) variation in pad width measurements (meaning both variation in size of different tracks of the same animal, and variation in measurement by various fieldworkers); 2) diameter of home range, which has only been measured accurately in one small region of Amur tiger range, but which could vary significantly across their range; and 3) daily travel distance, which has been estimated in two areas (Yudakov and Nikolaev 1974, Miquelle et al. in press) but which may also vary over time and space, in relation to prey density and other factors. To assess how changes in these variables might affect estimations of tiger numbers in both the expert assessment and the algorithm, we conducted a “sensitivity” analysis by varying values of these three parameters within the algorithm. We attempted to select values that are reflective of the true potential variation of these variables (Table 12). For example, tiger surveys in Russia have generally assumed that error in pad width measurements between tracks of the same individual will be no more than 1 cm, yet recent observations suggest this error may be as great as 2 cm (Yudin 2007), so values of 1, 1.5, and 2 were used. The values used for each parameter in the sensitivity analysis were not necessarily centered on a mean “expected: value, so the actual results, in terms of numbers of tigers, are less important than assessing the impact of variation in specific values. The sensitivity analysis does not necessarily allow a more accurate estimate of actual tiger numbers, but will provide reasonable insight to how much variation in key parameters can affect the outcome of the estimate.

DETERMINING TRENDS IN THE AMUR TIGER POPULATION BASED ON TRACK DENSITY ESTIMATES

An index of tiger abundance, based on track counts on sampling units dispersed across the total range of tigers, provides an index of relative abundance of tigers that can be used to compare relative density across the region and monitor changes over time (by comparison to earlier surveys), assuming that there is a positive correlation between track abundance and tiger abundance that is constant across the entire study area and constant over time.

To provide a standardized, repeatable estimate of relative abundance, we relied on track abundance as reported on routes traveled during the simultaneous survey effort. This estimate, expressed as tiger tracks/100 km of routes traveled, also has to be adjusted by the number of days since snow fell, since the probability of encountering tiger tracks increases linearly as the number of days since the last snowfall increases (Miquelle et al. in press). Tiger track densities were estimated for each survey unit by dividing the total number of tracks counted within a given unit by the total length of those routes within the unit and then dividing by the number of days since the last snow. This value is arbitrarily multiplied by 100 to provide an estimate of tiger tracks/snowday/100 km. When the value for number of days since snow varied between routes in one survey unit, we used the average number of days.

One problem with using days since snow to adjust the track density estimator is that degradation/elimination of tracks can occur between snowfalls when the interval is large, resulting in an underestimation of track densities. Previous research (Miquelle et al. in press) indicated that by approximately 14 days, most tiger tracks are fairly well obliterated due to wind, sun, and frost/thaw patterns. Therefore, we used a maximum value of 14 to adjust for interval since snow, even if the true interval between when the route was covered and when snow last fell was greater.

Differences in track densities across raions (counties) (Map 5), survey zones (Map 7) and krajs (provinces) were estimated separately with one-way ANOVAs, followed by Fisher's least significant difference (LSD) test to assess where differences occurred.

To compare relative abundance over time, we compared track density estimates between the 1996 and 2005 surveys, by Krai and raion, using the same track density estimator adjusted for time since snow. We conducted this analysis using a 2-way factorial ANOVA, excluding those raions for which there was little or incomplete data (e.g. data collected in only one of the years).

VI. RESULTS AND DISCUSSION

GENERAL

SURVEY EFFORT

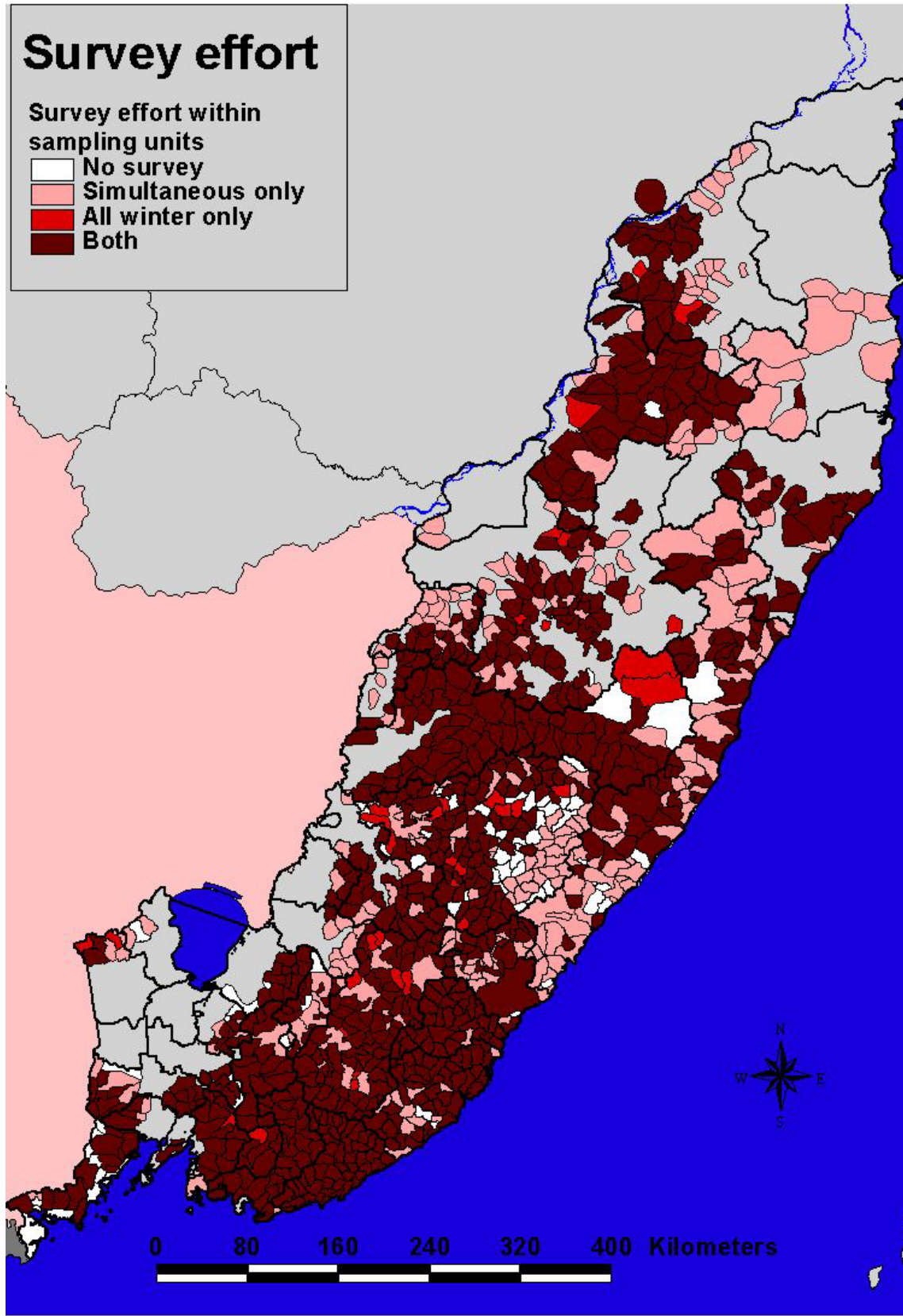
The 2004-2005 survey represents that largest and most comprehensive effort to survey tigers in the Russian Far East. A total of 1096 survey units (846 in Primorye, 250 in Khabarovsk) were tentatively delineated to include suitable tiger habitat (Map 8). Of these, data for either the all-winter or simultaneous survey (or both) were collected on 1026 survey units (94%) (Table 6). On 70 survey units no data were collected either because these units were later deemed low quality tiger habitat, or because people could not be found to reliably collect data for the survey period. Average size of survey units where data was collected was $180 \pm 10 \text{ km}^2$, but survey units were smaller in Primorye ($163 \pm 10 \text{ km}^2$) than Khabarovsk ($233 \pm 24 \text{ km}^2$). Both seasonal winter and simultaneous survey data were collected on 66% of all survey units (Table 6, Map 8).

To maximize information on current distribution, seasonal winter data were collected across a broad area, even beyond the region assumed to be inhabited by tigers. Consequently, there were more survey units in which seasonal winter data were collected than simultaneous data (990 versus 763) (Table 6).

For the 763 units for which we have estimates of survey effort during the seasonal winter period, people remained on survey units collecting data for periods that ranged from 2 to 180 days, averaging 49.2 ± 2.2 . However, this estimate is likely highly inaccurate, as many hunters appeared to overestimate the total time actually in the forest. The fact that there appears to be no clear relationship between number of tiger tracks found and length of stay in the forest (not considering those units where no tiger tracks were found) also casts doubt on the reliability of these data (Figure 6). Nonetheless, as a result of the seasonal winter data collection effort, 3955 tiger tracks were reported in 614 of the 763 units (80%) of the units surveyed (3072 in Primorye, 855 in Khabarovsk) during the winter period.

Table 6. Percentage of survey units in which data was collected during the seasonal winter and simultaneous survey efforts, for the 2004-2005 Amur tiger survey.

Survey effort	n	% survey units		
		Primorye	Khabarovsk	Total
No survey	70	8.0	0.8	6.4
Simultaneous only	263	20.8	34.8	24.0
All winter only	35	3.2	3.2	3.2
Both	728	68.0	61.2	66.4
Total	1096	100.0	100.0	100.0



Map 8. Survey effort allocated within survey units of the 2004-2005 Amur tiger winter survey.

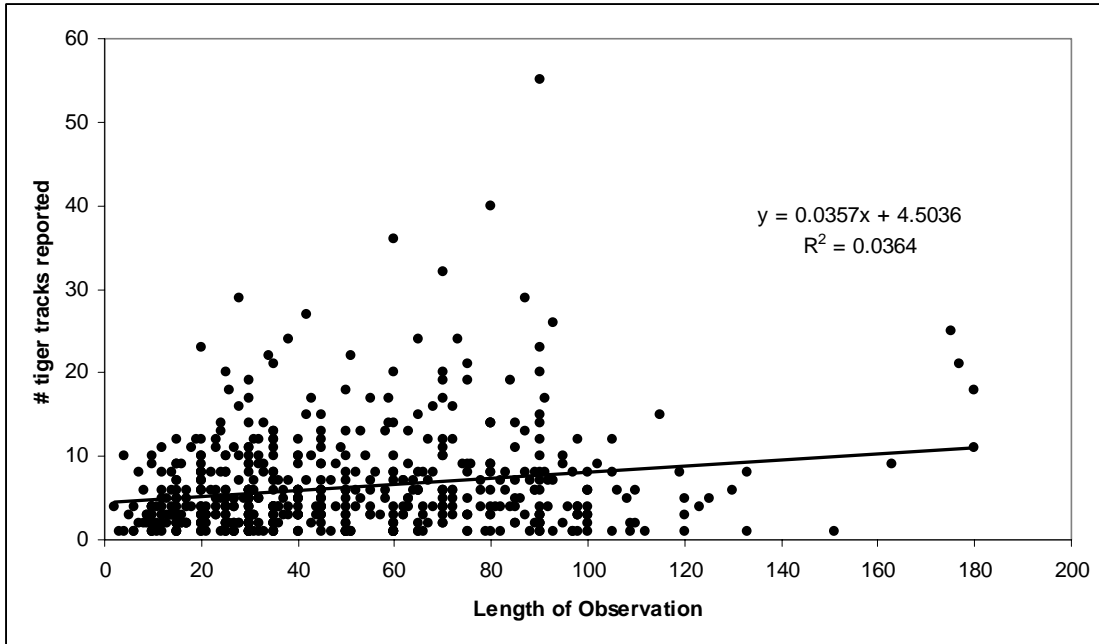
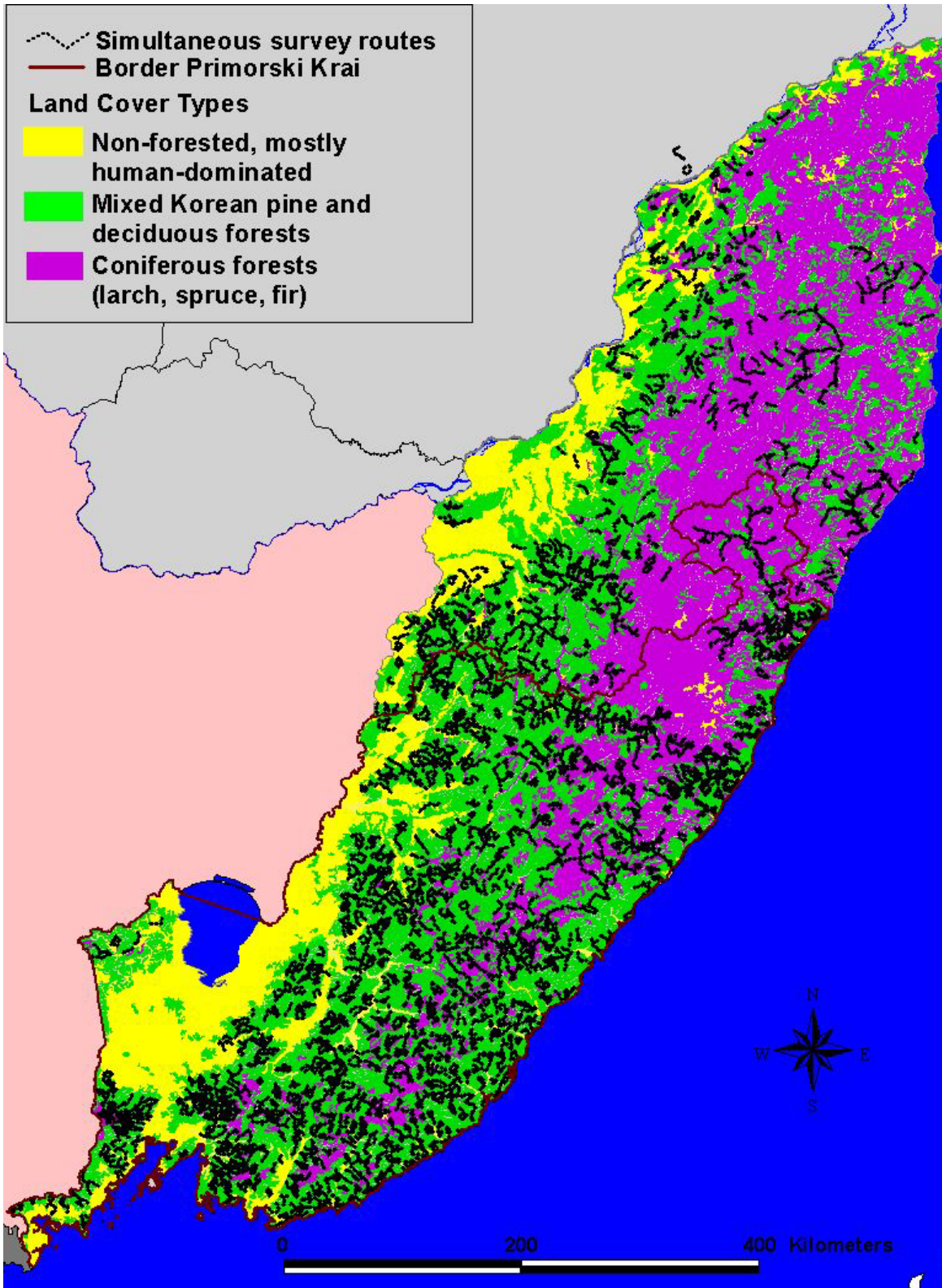


Figure 6. Relationship between number of days spent in the forest, and number of tiger tracks reported, for the “all-winter” portion of the 2005 Amur tiger winter survey.

A total of 977 fieldworker covered 1537 routes totaling 26,031 km were covered during the simultaneous survey (Table 7, Map 9), which represents 8000 km (31%) more survey effort than the 1996 simultaneous survey. Simultaneous survey routes were covered on foot, on skis, on snowmobile, and by vehicle. Approximately half (53%) of all routes were covered either on foot or skis, and about 23% of routes were a combination of transportation modes (usually vehicle and skis) (Table 7). The average length of each route was 16.9 ± 0.5 km.

Table 7. Number of kilometers traveled by various modes of transportation for 1537 routes covered during the simultaneous survey of tigers, 2005.

Mode of transportation	Kilometers traveled		
	Primorye	Khabarovsk	Total
on foot/skis	10,429	3,265	13,693
by vehicle	2,783	670	3,453
by snowmobile	1,318	1,341	2,659
mixed	5,508	519	6,026
unknown	189	11	200
Total	20,227	5,805	26,031



Map 9. Routes covered during the simultaneous survey of the Amur Tiger Survey, 2005. With routes overlaying general land cover types, it is clear to see that routes were fairly evenly distributed across non-coniferous forest types throughout all of Primorski and southern Khabarovsk Krai.

TIGER TRACKS: LOCATIONS, NUMBERS AND DATES REPORTED

A total of 5267 tracks were reported for the total survey period: 3949 from the seasonal winter survey, and 1318 during the simultaneous survey (Table 8, Map 10). Of these total, 79% were reported within Primorski Krai (1107 simultaneous, 3061 seasonal winter) and 21% in Khabarovsk (211 simultaneous, 888 seasonal winter).

Given the variation in size, and amount of tiger habitat in each zone, it is not surprising that survey zones varied greatly in the number of tracks reported (Table 8, Map 10). Interestingly, for the first time since the 1970s, persistent records of tracks were reported north of the Amur River (Map 10, Figure 7, and Table 8).

The majority (64%) of the seasonal-winter data was reported, not surprisingly, during the peak of the hunting season, in December 2004 and January 2005, when most hunters are active in the forest (Figure 8). The usefulness of seasonal data collected in October, November, and March is marginal in estimating tiger numbers because it is difficult to assume that the population was closed for that period of time (i.e., no births, deaths, immigration, or emigration). However, these data are still valuable in defining the distribution of tigers, and in defining habitat preferences.

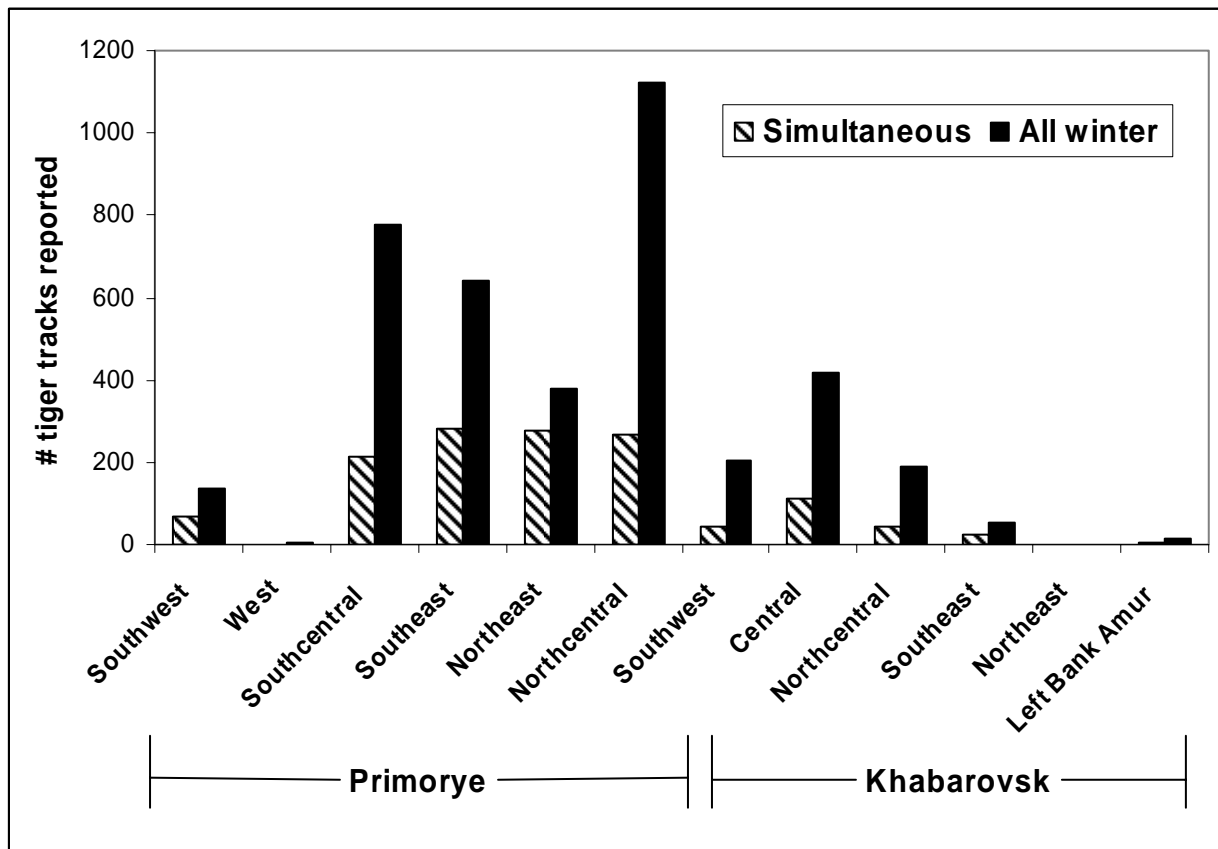
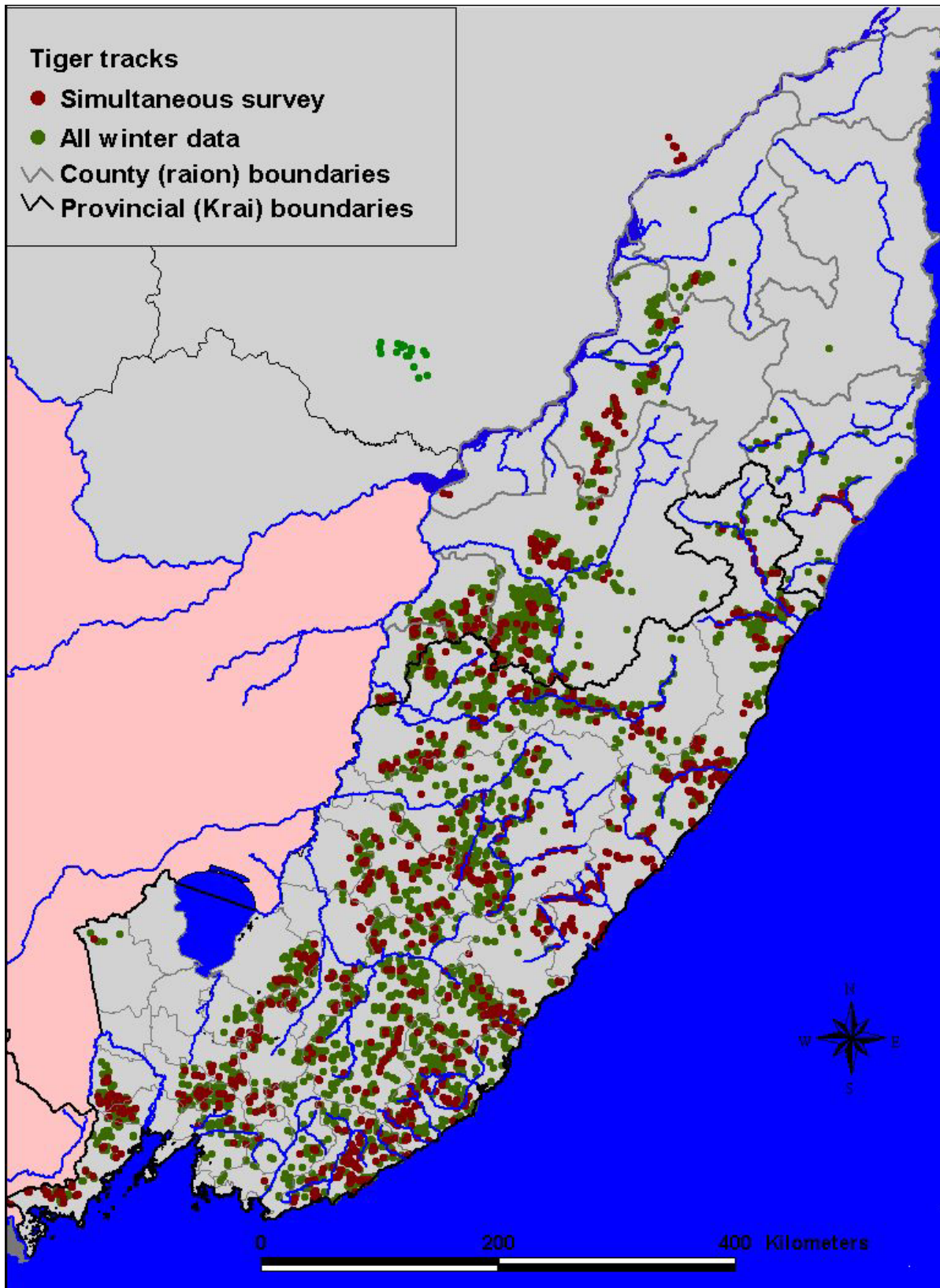


Figure 7. Number of tiger tracks reported in the simultaneous and seasonal winter data sets for 11 zones in the Russian Far East. Data collected from October 2004 through March 2005 for the Amur tiger survey.



Map 10. Location of all tracks reported for the seasonal (“all winter”) and the simultaneous survey of the 2004-2005 Amur Tiger winter survey.

Table 8. Number of tiger tracks reported by raion (county), for the all winter and simultaneous components of the 2005 winter survey, with number of routes, total distance of routes, and an estimate of tiger track density for the simultaneous survey for each raion

Krai	Raion	Number of tiger tracks reported			Routes for Simultaneous survey		
		Simultaneous	All winter	Total # tiger tracks	Total # routes	Total km	Tiger track density on routes (tracks/100 km)
Primorye							
	Anychinski	27	61	88	23	482.9	5.59
	Dalnerechinski	54	132	186	62	1069.8	5.05
	Dalnegorski	25	37	62	62	990.2	2.52
	Kavalerovski	64	176	240	58	686.7	9.32
	Kirovski	9	8	17	18	342.7	2.63
	Krasnoarmski	90	415	505	137	2757.5	3.26
	Lasovski	122	196	318	95	1161.5	10.50
	Lesozavodski	10	35	45	8	175.6	5.70
	Mikhailovski	13	29	42	20	215.2	6.04
	Nadeshdinski	11	42	53	14	186.8	5.89
	Oktyabrski	0	0	0	1	46.8	0.00
	Olginski	82	190	272	89	1071.1	7.66
	Partinzanski (city & raion)	12	79	91	64	980.7	1.22
	Pogranichny	1	4	5	6	74.8	1.34
	Pojarski	106	534	640	128	2531.4	4.19
	Spasski	47	66	113	12	242.9	19.35
	Terneiski	252	342	594	93	2772.5	9.09
	Ussuriski	37	103	140	40	590.7	6.26
	Khankhinski	0	0	0	2	24.8	0.00
	Khasanski	38	67	105	27	413.1	9.20
	Khorolski	0	0	0	0	0.0	0.00
	Chernigovski	11	23	34	12	180.5	6.09
	Chuguevski	65	381	446	76	1927.3	3.37
	Shkotovski	12	90	102	31	858.0	1.40
	Yakolevski	19	51	70	22	443.2	4.29
	City of Artyom	0	0	0	0	0.0	0.00
	City of Vladivostok	0	0	0	0	0.0	0.00
Khabarovsk							
	Bikinsky	18	52	70	20	273.6	6.58
	Vyazemsky	12	148	160	40	632.9	1.90
	Lazo em	108	410	518	140	1847.3	5.85
	khabarovsk	2	0	2	7	59.3	3.37
	Nanaisky	47	178	225	83	1095.9	4.29
	Komsomolsky	2	20	22	54	729.0	0.27
	Sovetsko-Gavansky	22	55	77	51	648.5	3.39
	Vaninsky	0	1	1	42	518.1	0.00
	Left Bank Amur	0	24	24	0	0.0	-
Primorski Krai Total		1107	3061	4168	1100	20226.6	5.47
Khabarovski Krai Total		211	888	1099	437	5804.6	3.64
Total		1318	3949	5267	1537	26031.3	5.06

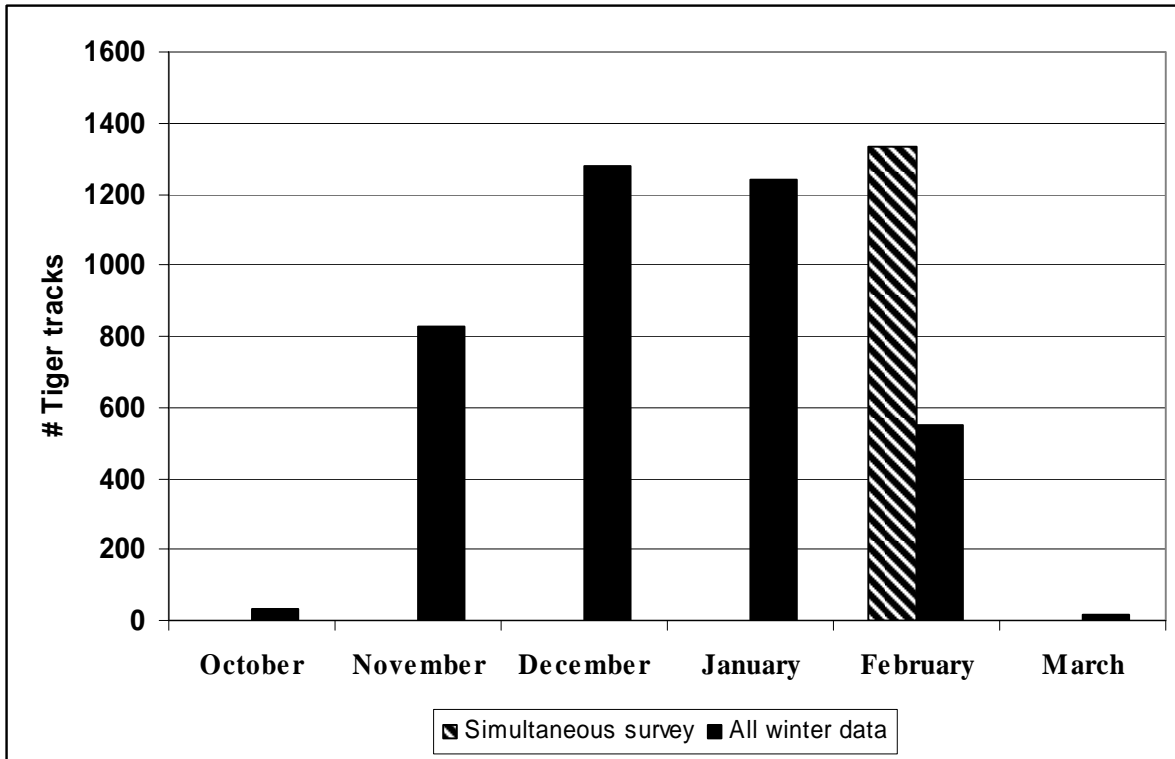


Figure 8. Total number of tiger tracks reported, by month, for the seasonal winter and simultaneous survey data of the 2004-2005 winter Amur tiger survey.

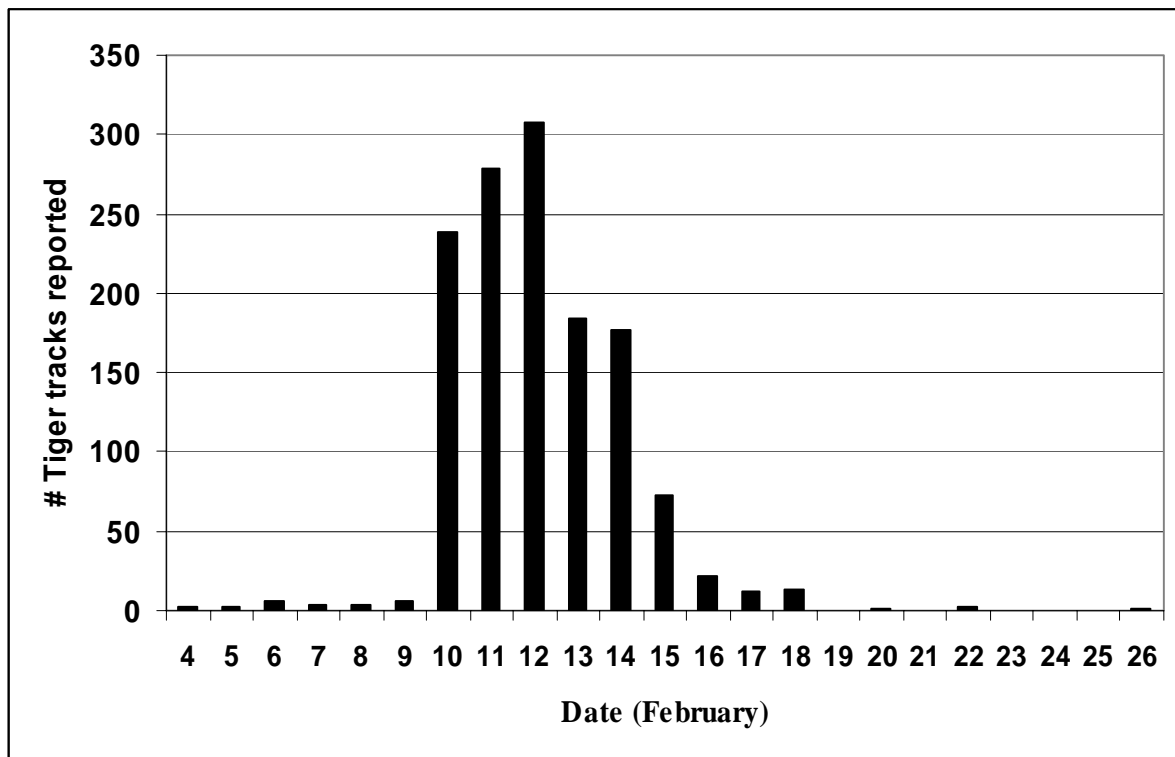


Figure 9. Dates on which tiger tracks were reported for the simultaneous survey.

The effectiveness of the simultaneous survey is dependent on routes being counted in an extremely short-period of time to reduce the probability of double counting individual tigers. An examination of the timeframe in which tracks were reported for the simultaneous survey demonstrates that the vast majority of tracks (94%) were reported in a 6-day window from - February 10-15 (Figure 9). Although there were a few tracks reported quite late (including even one track reported in March), the vast majority of counters were able to conduct their work in the time specified by coordinators.

HABITAT SELECTION BY AMUR TIGERS

We selected survey units, and placed routes within survey units based on existing understanding of habitat preferences of tigers, including an *a priori* definition of suitable habitat types (Table 3). However, because survey routes included nearly all landcover types, and tiger tracks were found in all but high elevation/alpine habitats, it is possible to assess habitat preferences of tigers based on results of the survey, and use this information to better describe their distribution and abundance.

We conducted habitat preference analyses using log-likelihood chi-square analyses to look for overall indications of selection within each zone, and across all zones combined. In two zones (West Primorye and Northeast Khabarovsk) there were insufficient numbers of tracks to conduct statistical tests. Because no tiger tracks were reported in high elevation/alpine habitat, this habitat was dropped from all analyses. Additionally, for each zone, specific habitat types were deleted from the analyses if less than 10 km of routes had been sampled.

Overall, we found significant differences in preferences for the 11 habitat types tested ($\chi^2 = 60.4$, $df = 10$, $P < 0.0001$) (Table 9). We found significant differences in 8 of the 9 zones tested – only in Southeast Primorye was there no clear indication that tigers prefer specific habitat types. In many instances, specific habitat types could not be sampled within zones due either to the fact that they did not exist in the region, or were so rare that they were inadequately sampled: this was especially true for Larch forests, Swamps-peatlands, and Riverine forests. In specific zones Korean pine, Riverine, Oak, and Birch forests were used in greater proportion than their abundance by tigers, but across their entire range, only Korean pine and Oak forests were significantly preferred. In contrast, all other habitat types were significantly avoided in at least one zone by tigers. Across both Primorye and Khabarovsk however, only Meadows, Young disturbed forests, and Spruce-fir forests were avoided by tigers.

The preference index provides further insight (Table 9). Riverine forests had the highest preference index, and only four habitat types (Riverine, Oak, Birch, and Korean pine) had positive indexes (indicating preference for these types). Swamps-coastal wetlands and peatlands were used in approximate proportion to their availability. Larch and Sparse forests had preference indices about the same (0.79) suggesting that they were used in lower proportions to their availability, but not strongly avoided. All other habitat types had considerably smaller preference indices, suggesting they were more strongly avoided by tigers. The fact that agricultural fields appeared to be no more strongly avoided than Spruce-fir forests is probably an artifact of sampling the edges of agricultural fields in close proximity to forest lands.

Based on the preference ratios and Bonferoni confidence intervals, these results largely coincide with the *a priori* assessment of habitat types made in planning for the survey (Table 3), Riverine, Oak, Birch, and Korean pine forests were all preferred, as expected, although only

Table 9. Habitat preferences of Amur tigers, based on the proportion of tracks reported from the simultaneous survey in 10 habitat types versus the proportion available (based on km surveyed during the simultaneous survey), from the 2004-2005 Amur Tiger

Habitat type	Total # tracks reported (n)	Zones											Total All combined	Combined preference ratio
		1	2	3	4	5	6	7	8	9	10	11		
		Southwest Primorye	West Primorye ¹	South- central Primorye	South- east Primorye	North- east Primorye	North central Primorye	Southwest Khabarovsk	Central Khabarovsk	North- central Khabarovsk	South- east Khabarovsk ¹	Northeast Khabarovsk ¹		
River Valley	107	nt ²	nt	nt	nt	-	-	nt	-	nt	positive	nt	-	1.267
Oak	303	-	nt	-	-	-	-	-	-	positive	nt	nt	positive	1.172
Korean pine	539	-	nt	-	-	positive	-	positive	-	-	-	nt	positive	1.120
Birch	157	-	nt	-	-	-	-	nt	-	-	nt	nt	-	1.078
Swamp-coastal wetlands-peatlands	51	nt	nt	negative	nt	-	-	-	nt	-	nt	nt	-	0.949
Larch	52	nt	nt	nt	nt	-	-	nt	nt	-	negative	nt	-	0.797
Sparse forest	15	-	nt	-	nt	-	-	nt	nt	-	nt	nt	-	0.793
Meadows	16	-	nt	negative	-	-	nt	nt	nt	nt	nt	nt	negative	0.578
Agricultural fields	9	nt	nt	-	-	-	-	-	nt	nt	nt	nt	-	0.524
Young (disturbed) forest	41	nt	nt	-	-	negative	-	-	nt	-	nt	nt	negative	0.493
Spruce-fir	41	-	nt	-	-	negative	negative	nt	nt	nt	negative	nt	negative	0.432
High elevation stunted forest/alpine		nt	nt	nt	nt	-	nt	nt	nt	nt	nt	nt	-	0.000
Chi square test for each zone:						-		-						
Log-likelihood ratio (chi square)		31.16	-	31.88	3.49	52.69	30.91	16.40	46.73	21.28	22.76	-	60.40	
df		5	-	8	6	6	11	3	7	5	3	-	10	
P value		P < 0.001	-	P < 0.001	P = 0.75	P < 0.0001	P < 0.0001	P < 0.001	P < 0.0001	P < 0.001	P < 0.001	-	P < 0.0001	

¹In two zones (West Primorye and Northeast Khabarovsk) there were insufficient numbers of tracks to conduct chi-square log-likelihood tests.

²nt = not included in test due either to insufficient sample size (less than 10 km total routes) or small expected values for log-likelihood test

Korean pine and Oak forests had overall significantly positive relationships. Larch forests were probably correctly categorized as “moderate” quality tiger habitat, and agricultural fields, alpine and high elevation forests, and meadows are largely avoided. However, three adjustments are needed to correct our a priori assessment of habitat use by tigers: 1) we expected that Young forests with some anthropogenic impacts (fire, logging, etc.) would be used in approximately equal proportions to availability, but they appear to be avoided. This may be partially due to the fact that many areas highly impacted by humans (both by clear-cutting and fires) are high elevation Spruce-fir and Larch forests (non-preferred prior to disturbance) (Map 5), where deep snows with no forest cover make these habitats even less preferred by tigers. 2) We predicted that sparsely forested lands would be seldom used by tigers, but their use was similar to that of Larch forests, suggesting that they should be categorized as “moderately” preferred. 3) We expected that Swamps, coastal wetlands, and peatlands would be little used, but our data suggest they were used in proportion to availability, again suggesting moderate preference. These adjustments are noted in Table 3. We will use the seven habitats that have been rated “high” or “moderate” quality (Oak, Birch, Riverine, Korean Pine, Larch, Sparsely forested, and swamp-coastal wetlands-peatlands) based on the results of the habitat preference analysis to define suitable tiger habitat. We will exclude from analyses Young disturbed forests, Spruce-fir forests, Meadows, High elevation-alpine, and Agricultural zones.

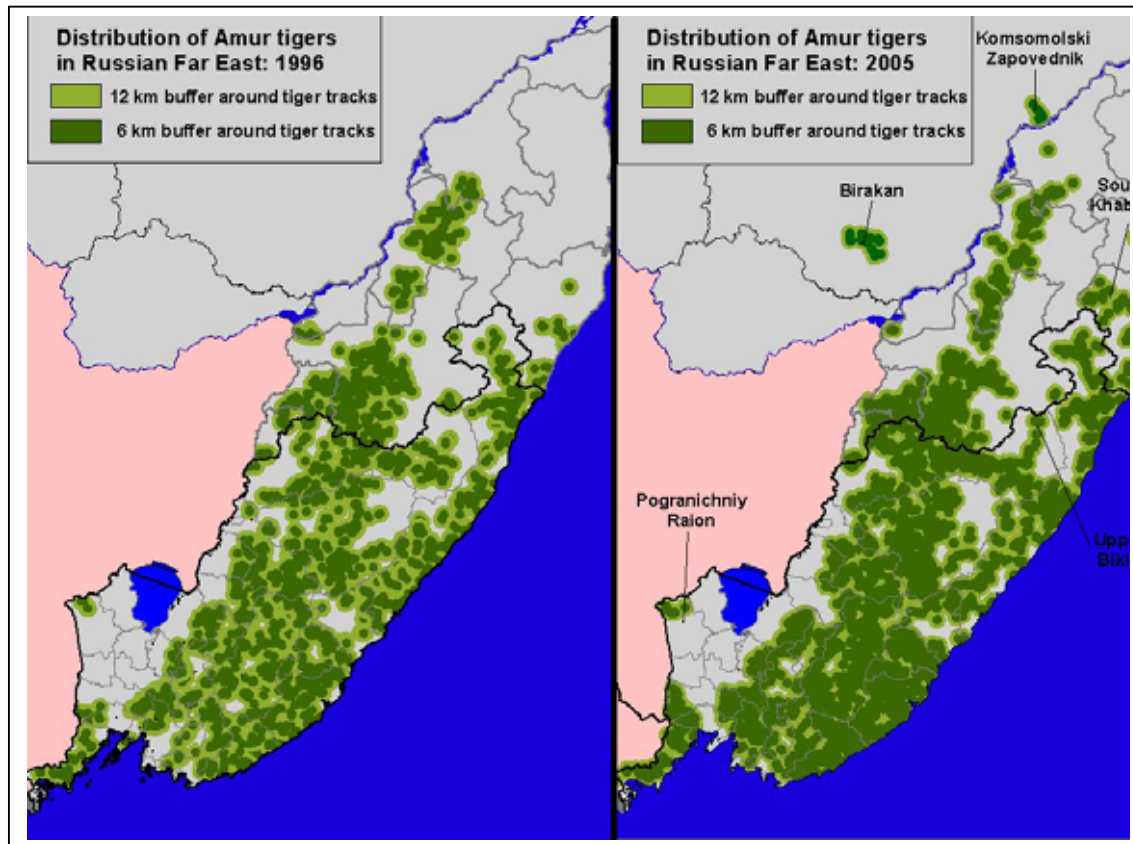
This definition of suitable tiger habitat is supported by the distribution of tracks across these habitat types in both the simultaneous and seasonal winter datasets: 92% of all tracks reported during the simultaneous survey were found in habitats defined as suitable for tigers, and 91% for tracks reported over the course of the entire winter.

CURRENT DISTRIBUTION OF AMUR TIGERS IN RUSSIA

To define the current distribution of tigers in the Russian Far East, we created buffers of 6 and 12 km around each track that was reported in the 2005 survey period. We selected 12 km because it represents the radius of the average size of an adult female home range (Goodrich et al. 2005). Therefore, a 12-km radius from each track represents an area likely inhabited by tigers. However, because any one tiger is probably represented by multiple tracks, a distribution map using a 12-km radius on all tracks represents the maximum likely area where tigers might occur in the region (assuming no animals have been missed in the count). To provide a more conservative estimate we also included a representation of distribution based on a 6-km radius. For comparison we derived a distribution map for tigers from the 1995-1996 survey using the same approach (Maps 11a-b).

Across Primorski Krai, the distribution of tigers appeared remarkably stable between 1995 and 2006 (Maps 11a-b). The larger area covered by the 12-km buffer in 2005 is simply a reflection of the greater sampling effort (and hence more tracks) in this most recent survey. Only two notable differences appear in comparing distribution of tigers in Primorski Krai between the two most recent surveys. First, more tracks were reported in Pogranichny Raion in 1995 than 2005. This appears to be at least partly a sampling issue: in 2005 it was not possible to survey within the KSP zone (the region between a boundary fence and the actual border of Russia), which is considered some of the best tiger habitat in this region. The second difference was the appearance of tigers in the uppermost regions of the Bikin River, where they have not been present in recent history.

More dramatic changes have occurred in Khabarovski Krai, where tigers appear to be expanding dramatically to the north on both sides of the Sikhote-Alin Divide (Map 11b). On there have not been permanent resident tigers since the early part of the 19th century (Map 1).



Map 11a-b. A comparison of the distribution of Amur tigers in the Russian Far East from 1996 (11a) and 2005 (11b). Distribution defined by 6- and 12-km buffers for all tracks (both seasonal winter and simultaneous) reported in surveys in both years.

the east side of the Sikhote-Alin, the distribution of tigers has expanded dramatically into the upper reaches of many basins in SovGavanski Raion, and even into Vaninski Raion (Map 11b), where tigers have occurred only as transients in the past.

For the first time in recent history, there were multiple reports of tigers residing on the left bank (north) of the Amur River. In the region around Birkaan, Ologoni, Ilgi, and Pochegoni Basins there were multiple reports of what appeared to be a female and male. Those reports began in April of 2004 and continued through February 2005, lending credence to the idea that they are permanent residents there. The presence of wild boar, red deer, and an abundance of roe deer (based on field reports) suggest that the region is suitable for tigers. This is a very significant development as these results suggest that tigers are dispersing quite some distance from the Sikhote-Alin Mountains, and establishing themselves in places where

Further to the north, at least one animal was reported north of the Amur in the region of Komsomolski Zapovednik, where one male tiger was reported multiple times along routes during the simultaneous survey. Additionally, tiger distribution has moved northward in Komsomolski Raion south of the Amur, where, according to local wildlife biologists and hunters, tigers periodically appeared in the past, but are now permanently residing in basins such as Gur, Chermal, Dunchinka, and Khoso. These observations are also important because they clearly demonstrate, in comparison to the 1995 survey data, that tigers are moving north and establishing residence in places formerly unoccupied. Dunishenko attributes the increase in tiger numbers and the northern movement of tigers to a reduction in weather severity, which has allowed an increase in roe deer and wild boar.

DISPERSALS

Several significant reports of tiger dispersal from the core range (as represented in Map 11b) were noted in this and the previous winter. First, as part of this survey tiger tracks were reported along the international border on the Khabarovsk side of the Strelnikov Range, whose ridgeline forms the eastern boundary between Primorye and Khabarovsk, and provides a linkage to the Wandashan Mountains of eastern Heilongjiang Province, China. Tracks of a female with young were reported moving across the international boundary (the Ussuri River) into the Wandashan Mountains of China. Such movements have been noted in the past, and collectively they demonstrate the importance of the Strelnikov Range as an international ecological corridor for tigers. This is the only remaining habitat that allows for movement of tigers across the international border between the Sikhote-Alin Mountains of Russia and the Wandashan Mountains of China. The Strelnikov Range is a narrow finger of habitat, infringed upon on both sides (in both Primorye and Khabarovsk) and partially blocked from the Sikhote-Alin Mountains by the main Vladivostok-Khabarovsk road. The importance in retaining the integrity of this range to ensure connectivity between China and Russia cannot be overemphasized.

In the previous winter (2003-2004) tracks of an adult male were reported in Amur Oblast, suggesting that the animal apparently dispersed from Khabarovsk Krai. The tiger traveled back and forth between Zeivski and Norski Zapovedniks before being killed west of Norski Zapovednik (Map 12). This record of dispersal is significant first because it was well documented, and secondly because it demonstrates that tigers have the capacity for long distance dispersals. This animal traveled more than 700 km from the closest record of tigers in 2005 (and more than 800 if we use the 1995 distribution map). But it also demonstrates the difficulties of reestablishing tigers in their former range – this animal was killed because it was considered a threat to human safety, even though it had apparently done nothing to suggest it was a dangerous animal.

DEFINING CURRENT DISTRIBUTION OF TIGERS IN THE RUSSIAN FAR EAST BASED ON HABITAT PREFERENCES

The map produced above (Map 11b) to describe tiger distribution is a very “coarse grain” indication of where tigers occur today in the Russian Far East. Using the information we have gained concerning habitat preferences (Table 9), we created a map of suitable habitat that restricts the 12-km buffer of all tiger locations to the seven most preferred habitat types based on our habitat analyses (Table 3). We have excluded spruce-fir, meadows, young forests, sparse forests, agricultural fields, and alpine zones as areas rarely used by tigers. Although tiger tracks were found in all these habitat types except high elevation areas, tracks were more likely to be found at the edge of these zones, close to more highly preferred habitat. This more restricted definition of suitable habitat for tigers includes 92% of tracks reported (Map 13), and is more representative of “suitable habitat” for tigers today in the Russian Far East. Unfortunately, this level of precision is available only for habitat south of the Amur River. As yet, detailed coverages of landcover types are not available for the northern reaches (north of the Amur River) of current day tiger distribution.

A total of 352,740 km² are thus defined as suitable habitat for tigers. Of the 5 habitat types included, Korean pine is the most common, representing 58% of the total area, with oak the other dominant component, representing nearly 30%. Birch forests cover 6.5% of the area while riverine forests (1.4%), larch (3.9%) and wetlands (0.7%) make relatively minor

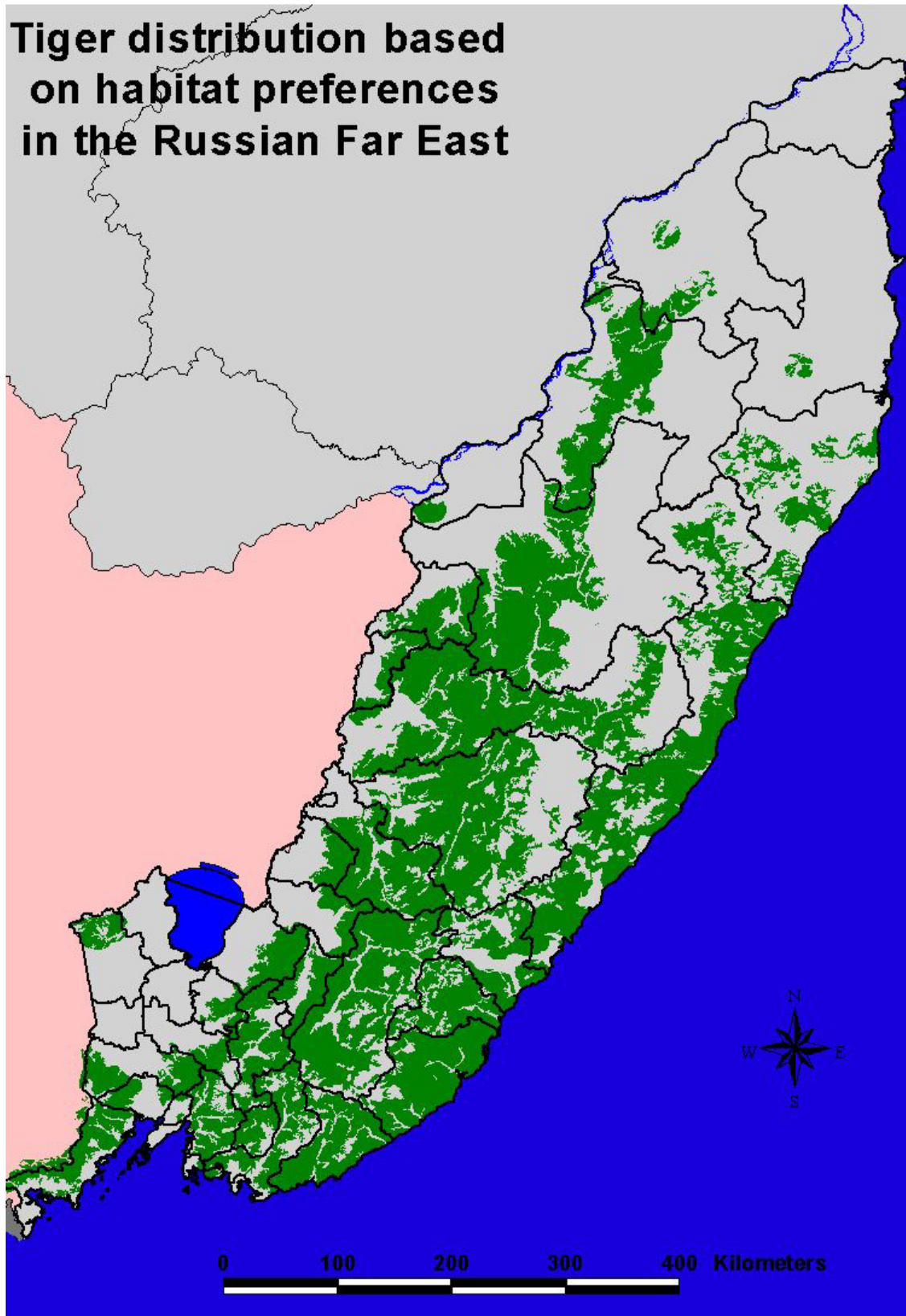


Map 12. Movements of an adult male tiger in Amur Oblast, winter 2003-2004, in relation to tiger distribution as reported from the 2004-2005 winter survey.

contributions. Although, riverine forests appear to make up a relatively minor component of tiger habitat, we believe that their importance is underrepresented by this map. Riverine forests are probably more common than is indicated in the mapping process, and its importance to tigers and their prey has been confirmed in other habitat analyses (Miquelle et al. 1999).

This map of tiger habitat (Map 13) is important as it represents clearly defined areas that are of priority for conservation. This map can be used in environmental impact assessments associated with logging operations or other development proposals, as it can provide a relatively quick and easy assessment of the value of lands to tiger conservation.

Two general conclusion derived from this analyses are: 1) Korean pine and oak forests are the two key habitat types for tigers and their prey, as they are widely dispersed across the region and are highly preferred by tigers. Protection and/or well defined management restrictions on all Korean pine and oak forests would go a long ways towards



Map 13. Suitable habitat of tigers in the Russian Far East, based on distribution of tiger tracks with a 12-km radius restricted by the 5 most preferred habitat types, as defined in Table 3.

securing a future for tigers in the Russian Far East. 2) Although riverine forests are not as common as Korean pine or oak forests, they are also critical habitat, and represent areas most commonly impacted by humans (road development, logging, and human activities are generally concentrated along river bottoms). Because riverine habitats are commonly used as travel corridors and for hunting by tigers, and because they represent key winter habitat for many species of prey, especially in deep snow winters, protection of riverine habitat is also critical to conservation of tigers. Map 13 provides a first attempt at explicitly defining where these habitats exist.

NUMBER OF AMUR TIGERS IN RUSSIA.

Estimating numbers of rare, elusive animals is an exceedingly difficult task. Any method applied to estimating tiger abundance will have advantages and disadvantages. As explained in the methods and elsewhere (Miquelle et al. in press), we rely on three approaches to derive estimates of tiger abundance. First, we use an expert assessment approach that applies two sets of criteria to the same dataset, thereby deriving a range of potential values for tiger abundance. Secondly, we use an estimate of track abundance to provide an indication of relative abundance of tigers, which can be used to compare areas, and results of this survey to previous surveys. Finally, we employ a computer-based algorithm that uses the same criteria applied in the expert assessment, but applies rigorous definitions for interpreting track data. The advantage of using an algorithm is that parameter variables input into the model can be easily varied to assess their influence in deriving estimates of tiger abundance. The advantage of the expert assessment is that it brings local knowledge, and years of experience in interpreting track abundance. Track densities provide a simple, direct measure of the original data, without the need of developing criteria to interpret the data. Comparing these three approaches provides a means of assessing the validity of all, and assessing confidence in the results.

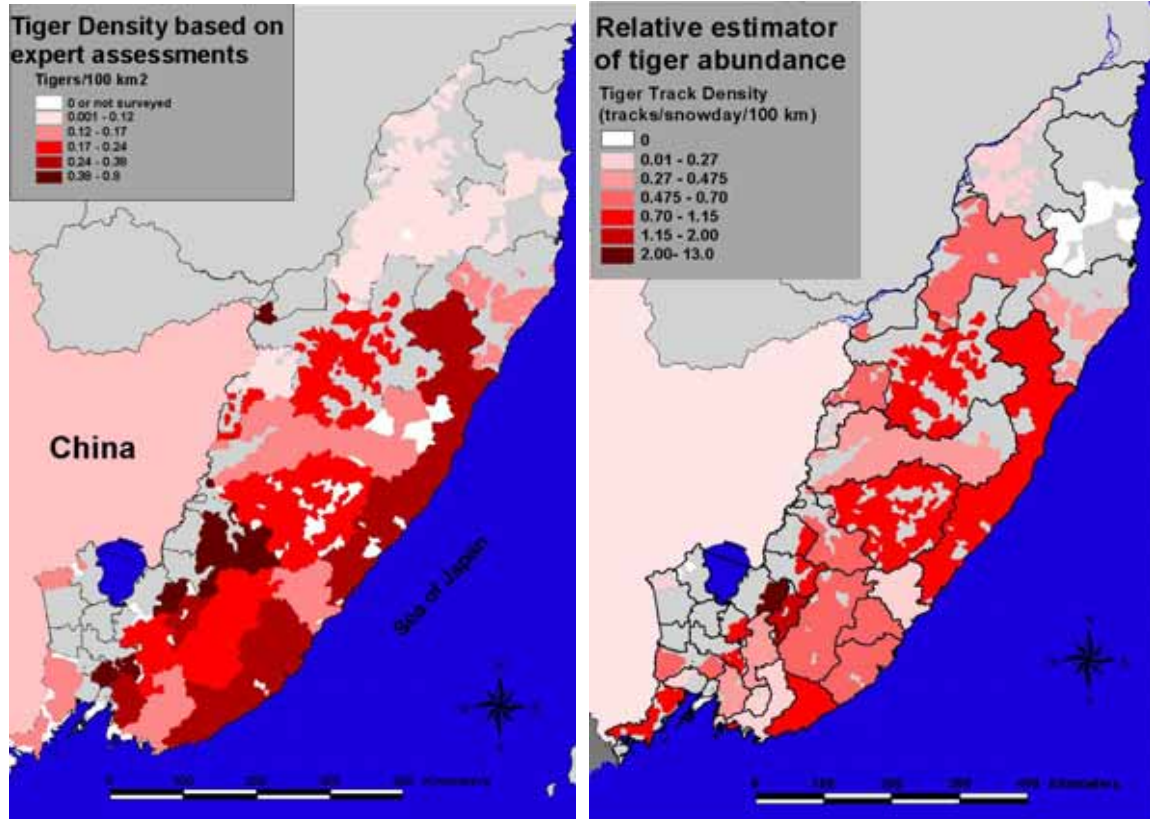
EXPERT ASSESSMENT OF TIGER NUMBERS

Expert assessments, which provide a range of values based on “conservative” and “relaxed” criteria, indicate that there are 52-57 adult/subadult tigers in Khabarovski Krai, and 279-336 adults/subadults in Primorski Krai, for a total of 331-393 adult/subadult tigers in the Russian Far East (Table 10). Additionally, it was estimated that there were 97-109 cubs in the region (19-21 in Khabarovsk, and 78-89 in Primorye) bringing the total number of tigers, including cubs, to 428-502. We emphasize that our primary focus, when reporting numbers of tigers in the Russian Far East should be on the total number of adults and subadults, as cub mortality is high and variable, and the key parameter in considering status of the tiger population is the number of breeding-age individuals in the population. Hence, we estimate tiger density, and compare numbers of tigers based on numbers of adults and subadults.

Density of tigers, by county (raion) based on expert estimates and the total area surveyed (i.e., the area of those survey units, summed for each raion, that were surveyed in either the all winter or simultaneous survey) demonstrated a number of general trends (Map 14a). The coastal areas of Primorye, aside from Dalnegorski Raion, tended to have relatively high tiger densities. Similarly, the inland side of the Sikhote-Alin Mountains, i.e., those counties closer to the Ussuri Basin, tended to have relatively high tiger densities. It is not clear, in many instances, whether tiger densities were indeed so extremely high in the small

Table 10. Numbers of tigers in the Russian Far East, based on expert assessments using "conservative" and "relaxed" criteria based on distribution, size, and age of tracks reported from the simultaneous and winter seasonal datasets from the Amur tiger 2004-2005 winter survey. The first value for each raion and sex-age class represents the conservative estimate, the second the relaxed estimate; where only one value exists application of the two criteria provides the same value. Tiger density estimated as the mean number of adult/subadult tigers (average of conservative and relaxed criteria) divided by the sum area of survey units for each county (raion).

Province (Krai)	County (Raion)	Number of tigers					Tiger Density			
		Adult males	Adult females	Sub- adults	Unknown sex adult/ subadult	Cubs	Total adults+ subadults	Total adults, subadults, & cubs	Total area surveyed (km ²)	Mean density of adult/ subadult tigers (individuals/ 100 km ²)
Khabarovsk										
	Bikinski	1	2	0	0	2	3	5	1366	0.220
	Vyazemski	2	2-3	0	0	2	4-5	6-7	3943	0.114
	Lazo	9-10	10-11	4	0	9-10	23-25	32-35	13,340	0.180
	Nanaiski	2	3	4-5	0	4	9-10	13-14	16,564	0.057
	Khabarovski	1	2	0	0	0	3	3	574	0.523
	Komsomolski	2	0	0	0	0	2	2	8,445	0.024
	Vaninski	0	1	0	0	0	1	1	8,062	0.012
	Sovgavanski	2-3	4	1	0	2	7-8	9-10	6,183	0.121
Primorye										
	Anuchenski	2-3	4-5	1	0	1	7-9	8-10	3,797	0.211
	Chernigovski	1	0-1	0-1	0	0	1-3	1-3	893	0.224
	Chuguevski	11-12	11-12	4	0	4	26-28	30-32	12,393	0.218
	Dalnegorsk	1-2	6	0	1-2	1-2	8-10	9-12	5,309	0.170
	Dalnerechenski	4-5	11-12	3	1	5	19-21	24-26	5,216	0.383
	Kirovski	2	2-3	0	0	3	4-5	7-8	1,396	0.322
	Krasnearnemski	8-10	20-22	4-7	5-6	15	38-44	53-59	17,111	0.240
	Lazovski	3-4	10-13	0	1-2	8	14-19	22-27	4,709	0.350
	Lesozavodski	1	3	0	0	2	4	6	824	0.485
	Metropolitan area of Vladivostok	0	0	0	0	0	0	0	221	0.000
	Mikhailovski	1	3	0	1	1	5	6	710	0.705
	Olginski & Kaveleroski	6-10	10-15	0	7	4-12	23-32	27-44	10,433	0.264
	Partizanski (city & raion)	1-2	5-6	0	0	4	6-8	10-12	5,568	0.126
	Pogranichniy & Khankaiski	1	1	0	0	0	2	2	1,512	0.132
	Pojarski	9-10	18-21	0	1-2	9	28-33	37-42	18,199	0.168
	Shkotovski	3-4	4-5	1	0	1	8-10	9-11	2,456	0.366
	Spassk	1	2-3	3-4	0	2	6-8	8-10	1,498	0.467
	SW Primorye (Khasanski, W. Ussurski, & Nedeshdinski)	3	4-5	0	1	2-4	8-9	10-13	5,237	0.162
	Terney	25-30	26-31	0	12-15	13	63-76	76-89	25,632	0.271
	Ussuriski (eastern)	2	2	0	0	2	4	6	936	0.428
	Yakolevski	2	2-3	1	0	1	5-6	6-7	2,127	0.259
Totals										
	Khabarovsk	19-21	24-26	9-10	0	19-20	52-57	71-77	58,476	0.093
	Primorye	87-106	144-172	17-22	31-36	78-89	279-336	357-425	126,176	0.244
	Total	106-127	168-198	26-32	31-36	97-109	331-393	428-502	184,652	0.196



Map 14a. Tiger density, by county (raion) across Primorski and southern Khabarovski Krai, based on expert estimates of tiger numbers (number of adults and subadults/100km²) from the 2004-2005 Amur tiger winter survey. 14b. Relative tiger density, by county (raion) across Primorski and southern Khabarovski Krai, based on tiger track densities, estimated as the number of tracks/survey unit, divided by total km of survey routes in that unit, divided by days since snow, x100.

inland raions, or if the high densities are an artifact of estimating tiger densities over relatively small areas (e.g., Spassk, Chernigovski raions had few tigers, who likely used other raions as well, but with so little available habitat, density estimates were inflated). The central raions, including the heart of the Sikhote-Alin Mountains, tended to have lower tiger densities than either the coastal or inland raions. Northern raions of Khabarovski Krai had, as expected, the lowest densities of tigers, but in some areas, such as Lazo and Vyazemski raions, densities were moderately high (Map 14).

Comparison of expert assessments between 1996 and 2005 tiger survey. The expert assessment from the 1996 survey indicated that there were 330-371 adults/subadults, and a total of 415-476 tigers in the Russian Far East (Table 11). A direct comparison of the results suggests that tiger numbers may have increased slightly over that time interval, by 13-26 animals. Therefore, it is important to assess whether this difference represents a true increase in tiger numbers, or whether some other factor may be influencing the results.

At first glance, many of the coordinators were the same for both surveys, and therefore it would appear unlikely that interpretation of track data would vary significantly between surveys.

Table 11. Number of tigers estimated in the Russian Far East, 1996 and 2005, based on expert assessments of tiger tracks.

	Cubs		Adults/Subadults		Total	
	1996	2005	1996	2005	1996	2005
Khabarovsk	16-18	19-20	48-53	52-57	64-71	71-77
Primorye	69-87	78-89	282-318	279-337	351-405	357-426
Total	85-105	97-109	330-371	331-394	415-476	428-502

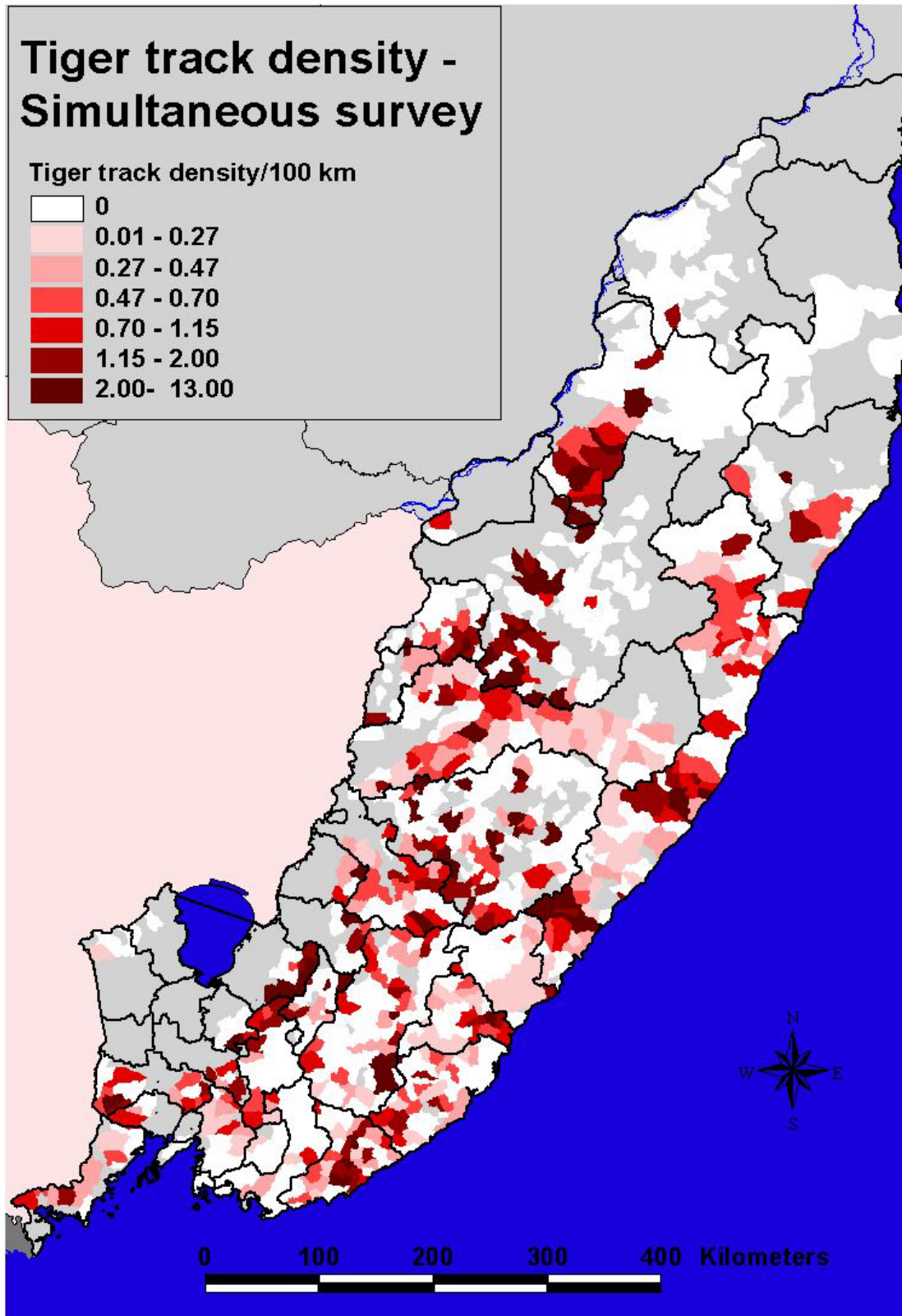
However, we argue that there are at least two reasons to suspect that differences between the survey results are methodological, and do not represent an increase in tiger numbers, and in fact, may represent a decrease in tiger numbers. Although many of the coordinators were the same as in the two surveys, in 2005 we requested coordinators to apply well defined criteria (Appendix I) for interpretation of tracks, which represents a major change from all previous surveys, in which no criteria were defined, or as in the case in 1996, where criteria were defined, but coordinators were not obligated to use them. As will be demonstrated below (in section on the algorithm), when criteria are rigorously applied, the number of animals estimated tends to increase.

Perhaps more important than the extent to which criteria were applied is the variation in survey effort between 1996 and 2005. Although 1996 was the most complete full-range survey ever to be conducted in Russia, the 2005 survey was substantially larger and more comprehensive. More survey units were defined (1026 versus 595), more routes were covered (1537 versus 594) and total number of kilometers covered during the simultaneous survey was 31% greater (26,031 versus 17,188). Consequently, it is not surprising that more tiger tracks were reported (5267 versus 3644). With more comprehensive coverage, it is to be expected that more tigers will be identified. Indeed, although the total number of tracks reported in 2005 was 1.44 times greater than in 1996, the number of tigers reported was only 1.03-1.05 times greater. In fact, given the great discrepancy in survey effort, and the very small difference in survey results, we may even consider whether tiger numbers have actually decreased since 1996, and that the “stability” in numbers is only due to a more comprehensive, complete survey effort in 2006. We will return to this issue in the summary of tiger numbers.

TRENDS AMONG AREAS AND ACROSS TIME BASED ON TRACK DENSITY

We used tiger track density along survey routes of the simultaneous survey, adjusted by the number of days since snow (reported as tracks/snowday/100 km), as an indicator of tiger abundance. For the 2005 survey, 1318 tiger tracks were reported on 1537 routes, while for the 1996 survey 825 tiger tracks were reported on 1068 routes. We used track density estimates averaged for each survey unit as a sampling unit, and therefore, sample sizes for the 1996 and 2005 surveys were 595 and 991, respectively.

Relative abundance of tigers based on track density in the 2004-2005 winter. There was great variation in track densities, even in adjacent survey units (Map 15). Relative abundance of tigers, based on track density estimates derived from the simultaneous survey, was higher in Primorski Krai (0.640 ± 0.097 tracks/snowday/100 km [$n=748$]) than in Khabarovsk



Map 15. Tiger track density, estimated from each survey unit as the total number of tracks reported on “simultaneous survey” routes within the survey unit/km traveled on survey routes/days since last snow x 100.

Table 12. Tiger track density for raions (counties) surveyed for tigers, estimated as the total number of tracks reported on "simultaneous survey routes" within a survey unit/days since snow/km routes*100. All survey routes were covered in February 2005.

Krai	Survey zone	Raion (county)	Tiger Track Density (tracks/snowday/100 km)		
			n	Mean	± 95% CI
Primorye	Southwest	Khasanski	13	0.7904	0.7965
		Nadesdinski	5	0.2282	0.4200
		Ussuriski (western half)	8	0.5627	0.4490
	West	Pogranichniy	4	0.0452	0.1437
		Khankaiski	2	0.0000	0.0000
	Southcentral	Spasski	12	2.5911	1.9884
		Yakolevski	19	1.7163	1.6816
		Chernigovski	13	0.9820	1.4262
		Mikhailovski	6	0.9441	0.7322
		Ussuriski (eastern half)	10	0.6704	0.4272
		Chuguevski	83	0.5399	0.3062
		Anuchinski	15	0.4397	0.3198
		Shkotovski	13	0.2875	0.2154
		Vladivostok (city limits)	1	0.0000	
		Southeast	Lazovski	48	0.7901
	Kaverlovski		34	0.6559	0.3365
	Olginski		50	0.4875	0.2043
	Partizanski		35	0.0866	0.0783
	Fokino		2	0.0000	0.0000
	Northeast	Terneiski	104	0.7144	0.2091
		Dalnegorski	40	0.1667	0.1142
	Northwest	Krasnearmenski	122	0.8134	0.3121
		Kirovski	10	0.7544	1.1946
Lesozavodski		5	0.7394	1.1041	
Dalnerechenski		31	0.4971	0.2056	
Pojarski		63	0.3916	0.1222	
Khabarovsk	Southwest	Vyasemski	35	0.5933	0.2784
		Bikinski	10	0.2461	0.3123
	Central	Lazo	79	0.9558	0.4003
		Khabarovski	2	0.5472	
	Northwest	Nanaiski	47	0.4790	0.2740
		Komsomolski	38	0.0307	0.0622
	Southeast	Sovgavanski	22	0.3973	0.4540
	Northeast	Vaninski	10	0.0000	0.0000
Total			991	0.6168	0.0825

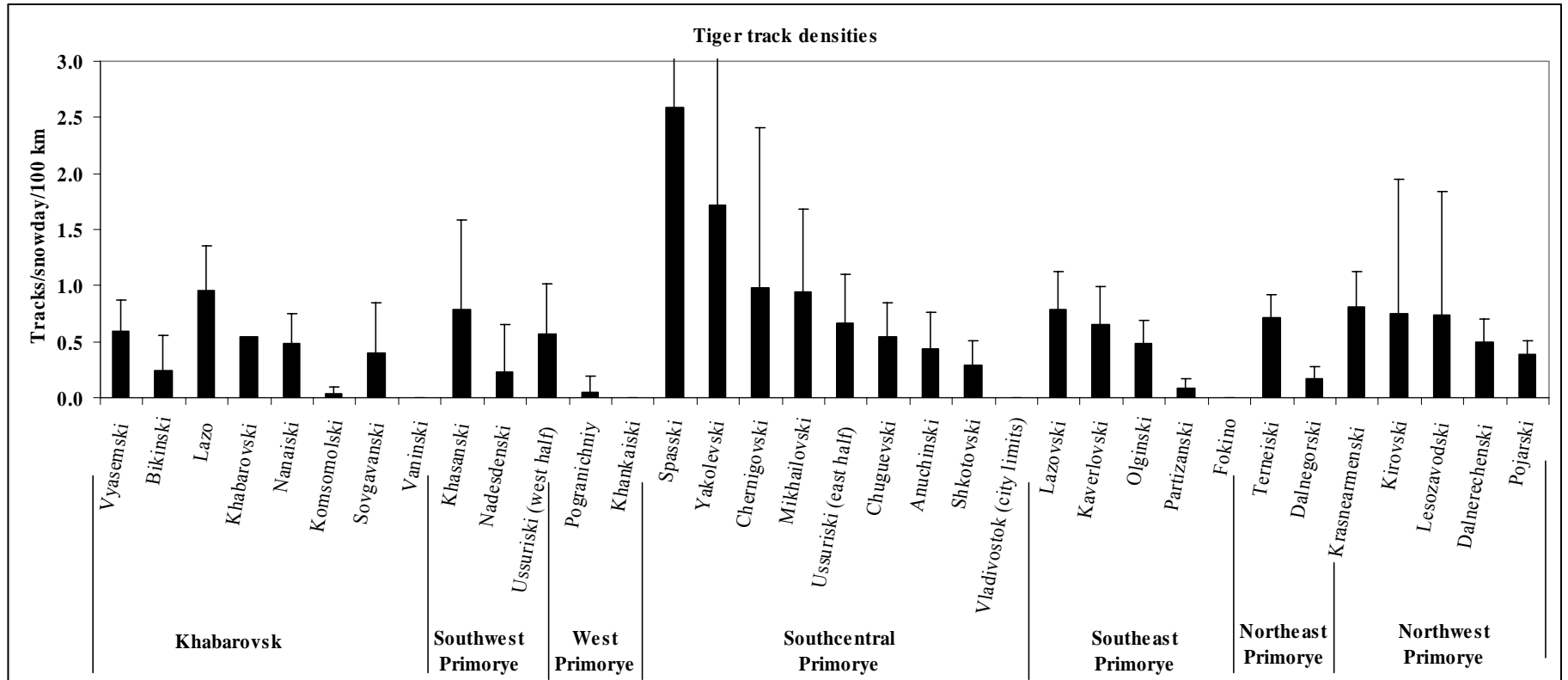


Figure 10. Tiger track densities in raions (counties) surveyed in the 2005 winter survey. Track densities estimated as the average track density across survey routes for each raion.

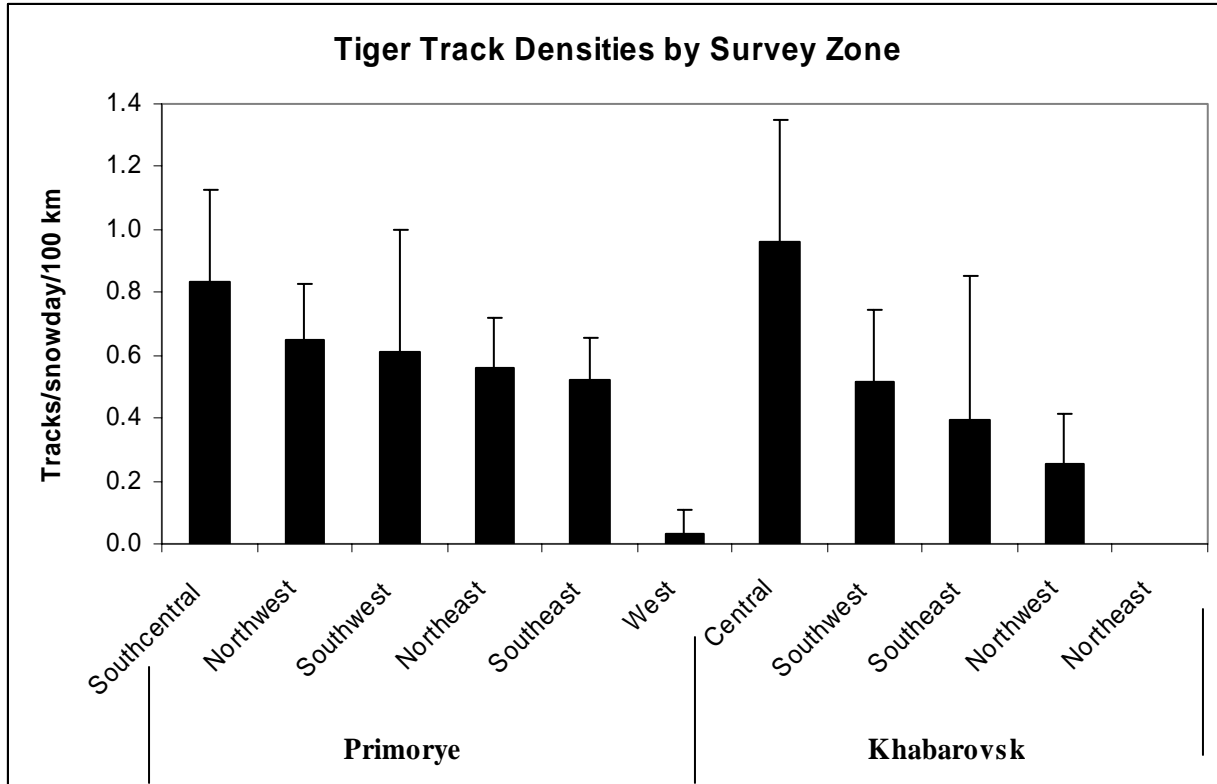


Figure 11. Tiger track densities averaged across survey zones, using an estimate of track density for each survey unit, derived from the total count of tiger counts reported on routes of the simultaneous survey, total distance of routes within each unit, and adjusted by the number of days since snow.

(0.544 ± 0.155 [$n=243$]), but not significantly different statistically ($F = 0.9689$, $df = 1, 989$, $p = 0.325$). The raion with the highest track density was actually in Khabarovsk Krai (Lazo track density = 0.955 ± 0.400) (Table 12). Although an ANOVA demonstrated statistical differences in track density across all raions ($F = 46.39$, $df = 32, 958$, $p < 0.0001$), there were in actuality few raions that differed significantly from others (Table 12, Figure 10). Raions in the furthest north regions surveyed in Khabarovsk (Komsolmoski, Vaninski) had, as expected, zero or very low track densities, and in general, track density varied less between raions of Khabarovsk than Primorye (Figure 10). In Primorye, track density estimates ranged from zero (for instance, in the city limits of Vladivostok, where no tigers were reported in this survey, but were present in the 1995 survey) to Spasski Raion, where track densities reached 2.59 ± 1.99 tracks/snowdays/100 km. Track densities tended to be higher in raions in Southcentral Primorye, but there was quite a bit of variation even within this one zone (Figure 10). Track densities were also high in raions within Southeast Primorye (except for Partizanski raion) and in Northwest Primorye (Figure 10). An ANOVA indicated significant differences among survey zones ($F = 39.50$, $df = 10, 980$, $p = 0.015$). However, as with the comparison of raions, there were few instances where track density varied dramatically among zones (Figure 11). Track densities were highest in central Khabarovsk and Southcentral Primorye. There were few differences amongst zones in Primorye except in West Primorye, where track densities were very low. Differences amongst zones in Khabarovsk were larger, with track densities lowest in the northernmost zones.

Comparison of tiger track densities in the 1996 and 2005 surveys. A comparison of track densities for the two most recent surveys, adjusted by time since snow, suggests that relative abundance of tigers in 2005 was significantly lower than in 1996 (Figure 12). These results are in contradiction to the expert assessments, which indicate that tiger numbers are stable, or have increased slightly. A comparison of track densities, by raion, suggests that there are some fairly dramatic differences between years in some raions (Figure 18a). The 2-way factorial ANOVA confirms significant differences between years ($F = 96.627$, $df = 1$, 1469 , $p < 0.00001$), between raions ($F = 7.842$, $df = 27$, 1469 , $p < 0.00001$) and also in the interaction term ($F = 8.599$, $df = 27$, 1469 , $p < 0.00001$), suggesting that track densities were not uniformly lower in all raions in 2005 compared to 1996. In 1996 track density varied among raions to a much greater extent than in 2005, suggesting that there were some areas where tiger densities were much higher than others, while in 2005 track densities were remarkably consistent across all raions, in both krais. There also appeared to have been some major changes in track densities in selected raions, specifically: Sovganski in Khabarovsk, Anuchinski, Mikhailovski, and Ussuriski Raions had much higher track densities than other raions in 1996;

These results are important, because if track density is a reliable indicator of relative tiger abundance, they indicate that tiger densities have dropped since the 1996 survey. Therefore, a critical assessment of these results is important. We propose that there may be at least 3 reasons other than a real decrease in tiger numbers for the variation observed between years:

1. Our estimate of track density, which incorporates time since last snow, may not be appropriate. The relationship between time since snow and track density has only been assessed in one region (Sikhote-Alin Zapovednik), and the results may not apply equally across all areas inhabited by tigers. There was a snowstorm just prior to the survey in 1996 across much of the region, whereas in 2005 snow had not fallen in many areas for an extended period prior to the survey. A large number of days since snowfall in 2005 could lead to a reduced track density value, since the estimate includes a correction factor for days since snow.

- 2) The variation between years could be driven not by changes in track densities across the entire range, but in specific locals.

- 3) In 2005 we increased the number of routes surveyed, and the location of survey routes, in an attempt to obtain a better estimate of ungulate densities. The location of these routes were not placed to maximize probability of encountering tiger tracks (as was the case with all routes in 1996), but to provide an accurate reflection of ungulate numbers in the survey unit. Such routes represented slightly less than half of all survey routes, and could be responsible for the decrease in tiger track densities.

- 4) The difference in values may indicate that track density does not correlate well, or at least not linearly, with actual tiger density. For instance, if daily movements vary under changing conditions (e.g. snow depths, varying prey densities), track densities will vary, resulting in a large amount of variation in track densities for any given tiger density.

To assess whether the track density parameter is flawed, we recalculated track density without the correction factor for time since snow (i.e. track density = # tracks reported per survey unit/total km surveyed per unit*100). Three important results emanated from this recalculation (Figure 12). First, as expected, the absolute value of the track density estimate without the snow correction was higher than the estimate when the snow correction factor was incorporated. Secondly, as might also be expected, the track density estimator without the snow correction factor has greater variance (reflected in larger confidence intervals with the snow correction

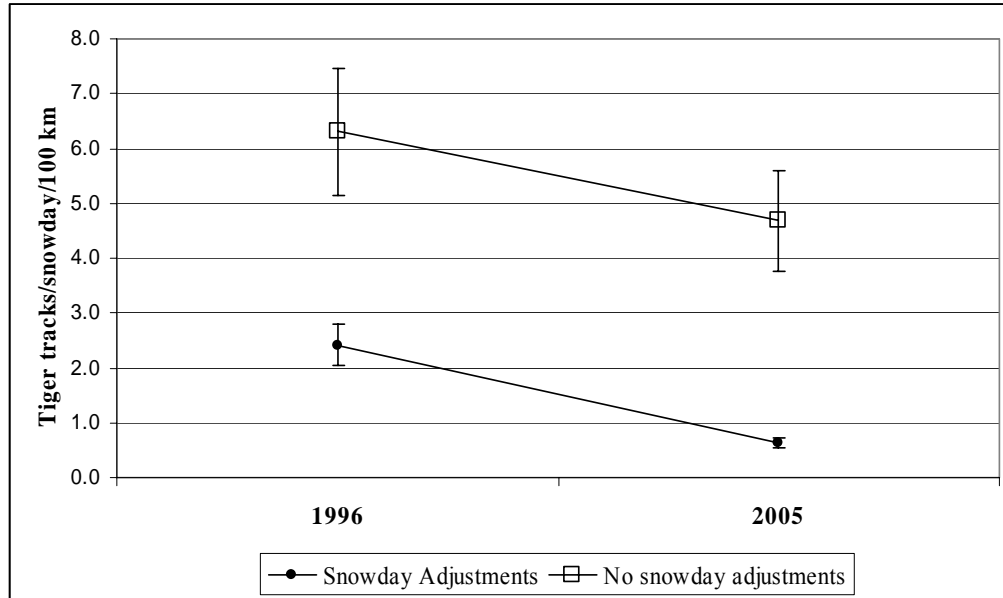


Figure 12. Tiger track densities, estimated both with and without adjustments for time since snow, for the 1996 and 2005 winter surveys.

factor removed) (Figure 12). Most importantly though, the difference between 1996 and 2005 track densities were virtually identical using either estimator, as reflected in a nearly identical slope between 1995 and 2005 with both estimators (Figure 12). This analysis therefore suggests that the track density estimator with adjustments since snow provides a more precise estimation, and that adjustments to this parameter do not change the findings that track densities were indeed lower in 2005 than in 1996.

Despite the fact that the overall relationship between surveys is not affected by how track density is estimated (Figure 12), a comparison of the two estimators by raion suggests that the snow adjustment factor may be partly responsible for the variation observed between surveys. Using the track density estimator adjusted for days since snow, there appear to be 6-7 raions in which tiger track densities were dramatically higher in 1996 than in 2005 (Figure 13a). When the snow adjustment factor is removed, track densities vary among raions more in both years, and while there is still a statistically difference between years ($F = 4.603$, $df = 1, 1469$, $p = 0.032$) and raions ($F = 2.888$, $df = 27, 1469$, $p = 0.00001$), the interaction value is not significant, and graphically, it is clear that the differences between years for each raion are no where near as dramatic (Figure 13b). These results suggest that the relationship between numbers of tracks observed on routes and days since snow may not be linear, and may require further investigation.

These results, however, do not negate the fact that no matter how track density is calculated, there is a real and significant difference between years.

Although we cannot assess directly how well the track density estimator reflects true tiger densities, track densities correlate fairly well with the other estimates used in this survey (see below, Figure 20, Table 15). An attempt to assess this relationship is underway using camera traps, but results will take several years to develop. Nonetheless, we believe that the variation in track density between years likely is a reflection of the difference in how survey routes were laid out between years. When routes are placed to cover the full spectrum of habitat types and aspects in a survey unit (see Methods), the probability of encountering tiger tracks will decrease,

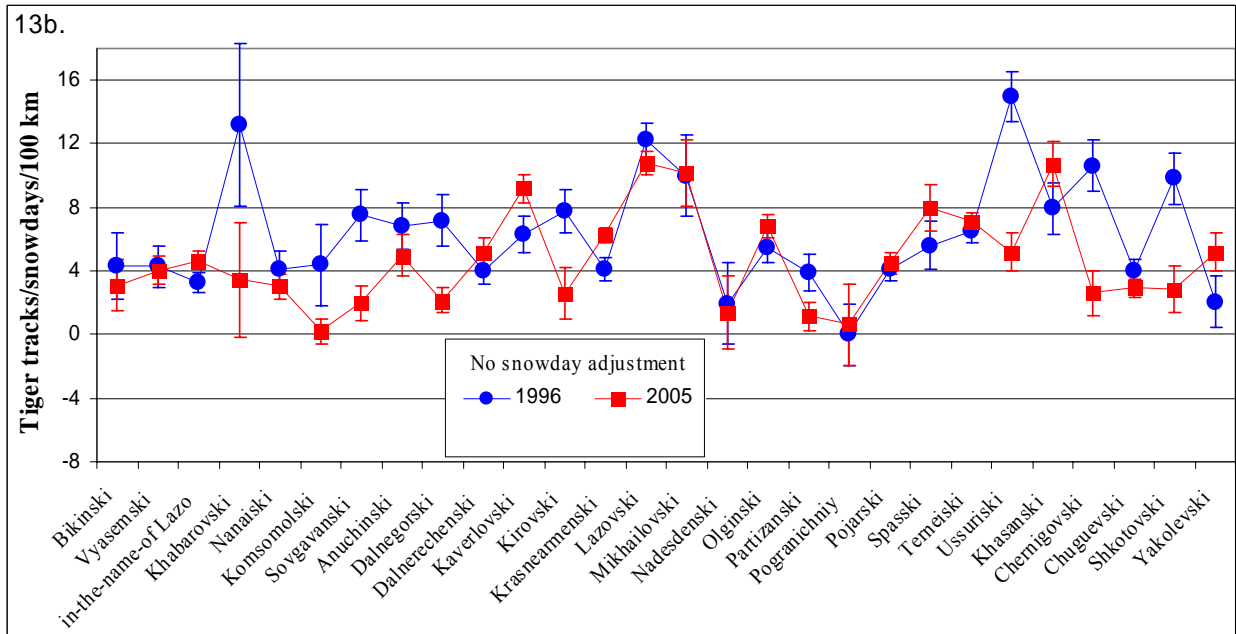
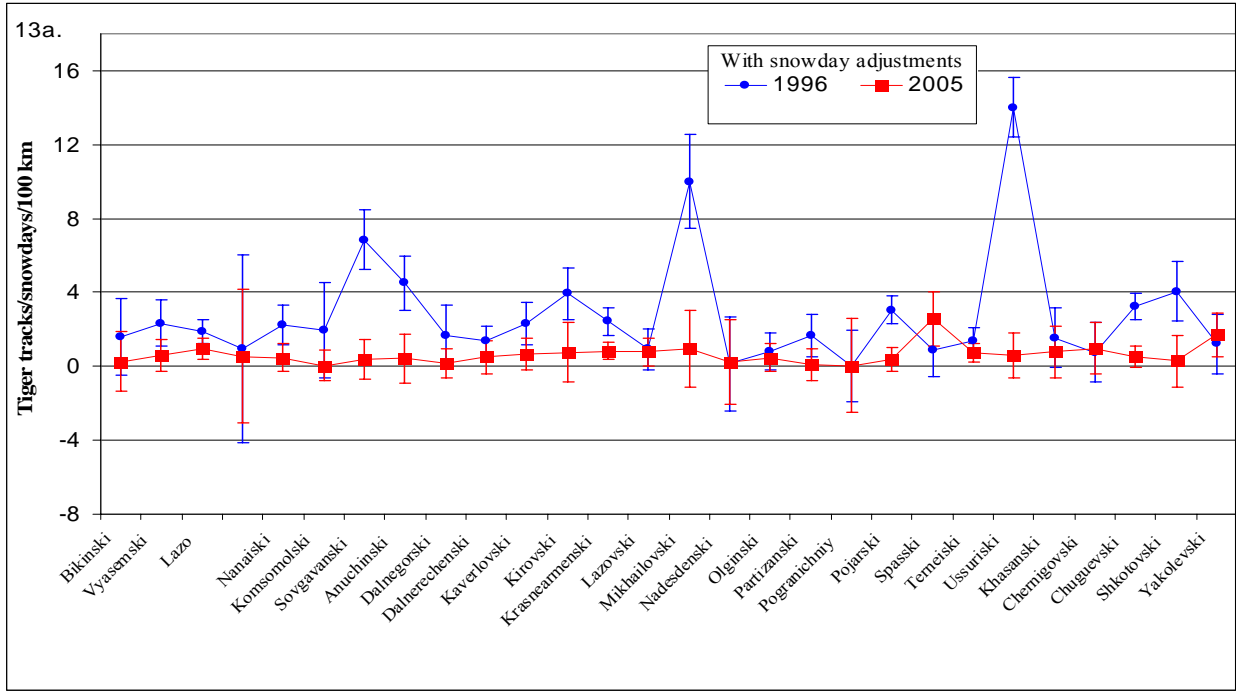


Figure 13a-b. Comparison of track density estimates, by raion, for the 1996 and 2005 surveys when a) time since snow is incorporated into the estimator; and b) time since snow is not incorporated into the estimator.

and we believe that this decrease is reflected in the 2005 survey. A full analysis of this issue is forthcoming, but not yet available. For the time being, we suggest that the difference in track density between 1996 and 2005 is likely a reflection of sampling design, and does not represent a real decrease in tiger numbers.

TIGER NUMBERS ESTIMATED BY ALGORITHM

To provide an independent assessment of tiger numbers, we used an algorithm that employed the same parameters as those used by experts (Appendix I), but because it was computer generated, was constant in interpretation of those parameters. The algorithm estimated 501 tigers using the “hard” criteria, and 581 total tigers using the “soft” criteria (Table 13). Number of tracks allocated to one tiger varied from 1 to a maximum of 45 for the hard criteria, and up to 36 tracks with the “soft” criteria. The majority of tigers were associated with 1 to 6 tracks, with the maximum number associated with 4 tracks (Figure 14).

Estimates of numbers based on the algorithm exceeded those of experts by 73-79 tigers (hard and soft criteria, respectively) (Table 13). Overall, coordinators estimated about 15% fewer tigers than did the algorithm, but ratios varied greatly, from nearly 50% of the algorithm in Southeast Khabarovsk, to 120% of the algorithm estimate in Northeast Primorye (Table 13). Two of the three instances in which expert assessments and the algorithm estimates matched

Table 13. Number of tigers in the Russian Far East, based on two sets of criteria ("hard" and "soft") derived by expert assessments and by a computer-generated algorithm, for data collected in the 2004-2005 winter survey.

Krai (Province) Zone	Number of tigers				Ratio expert/algorithm	
	Hard criteria		Soft criteria		Hard	Soft
	Expert Assessment	Algorithm	Expert Assessment	Algorithm		
Primorye						
Southwest	10	17	13	22	0.588	0.591
West	2	2	2	2	1.000	1.000
Southcentral	74	87	85	100	0.851	0.850
Southeast	59	89	83	104	0.663	0.798
Northeast	85	77	101	84	1.104	1.202
Northwest	127	127	141	154	1.000	0.916
Khabarovsk						
Southwest	11	20	12	21	0.550	0.571
Central	35	41	38	49	0.854	0.776
Northwest	15	25	16	28	0.600	0.571
Southeast	9	16	10	17	0.563	0.588
Northeast	1		1			
Total	428	501	502	581	0.854	0.864

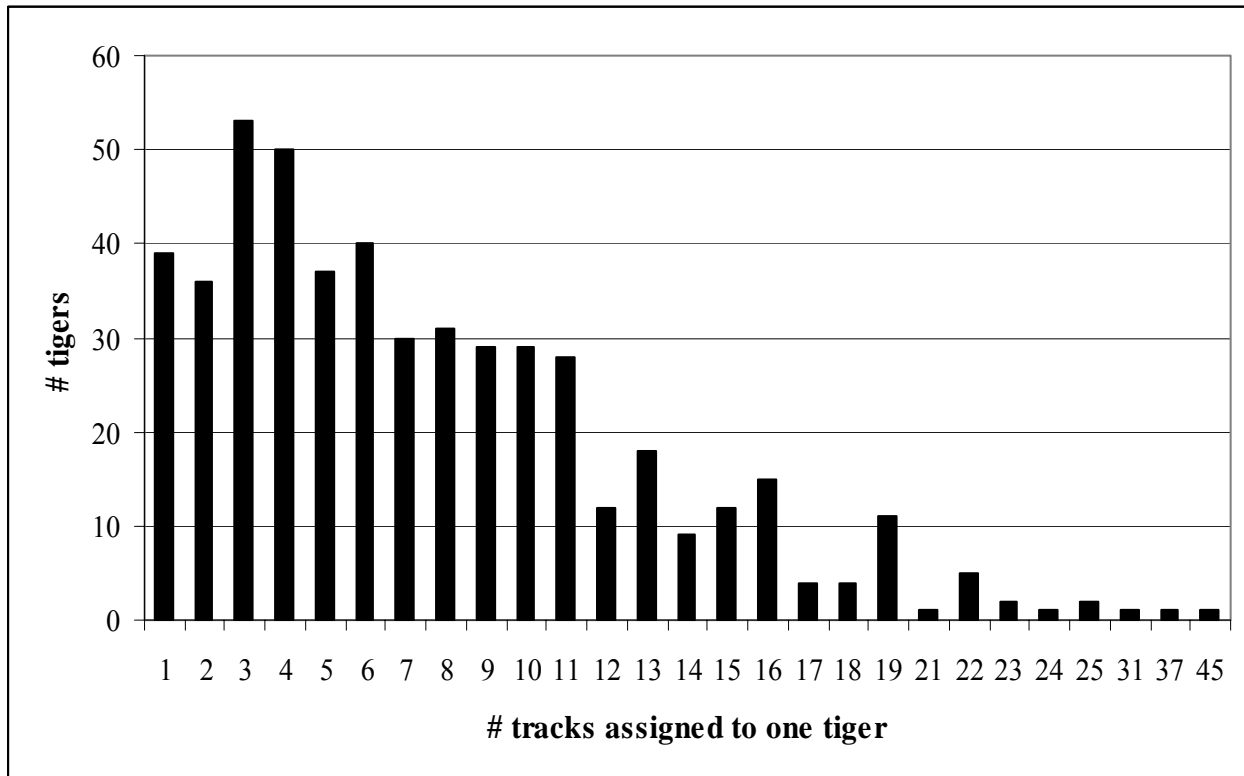


Figure 14. The number of tracks assigned to individual tigers by the minimum count algorithm derived with criteria as defined in Appendix I.

were in West Primorye (both “hard” and “soft” criteria matched), where few tracks limited potential options for interpretation. However, coordinator estimates of tigers in Northwest Primorye also perfectly matched estimates by the algorithm, where 127 tigers were estimated. Of 20 comparisons (“hard” and “soft” criteria for 10 survey zones not including Northeast Khabarovsk) between coordinators and the algorithm only twice did coordinators estimate more tigers than the algorithm: 75% of the time coordinators estimated fewer tigers than the algorithm.

There are likely two primary reasons why results varied between the expert assessments and the algorithm. First, one of the criteria used by experts is the presence of barriers in the landscape that restrict movement of tigers (large expanses of open fields, human settlements, or tall mountain ranges exceeding 700 m). Incorporation of this criterion into the algorithm proved problematic, and was not included in this version. Therefore, it is to be expected that expert assessments would be slightly lower than those derived from the algorithm. But the important implication is that experts did not rely strictly on defined criteria when estimating numbers of tigers, but also relied on their own “intuition” in interpreting track data. This does not negate the value of the expert assessment, and is indeed what distinguishes the expert assessments from the computer-generated estimates. In general, the results demonstrate that experts were more conservative in estimating tiger numbers than the algorithm.

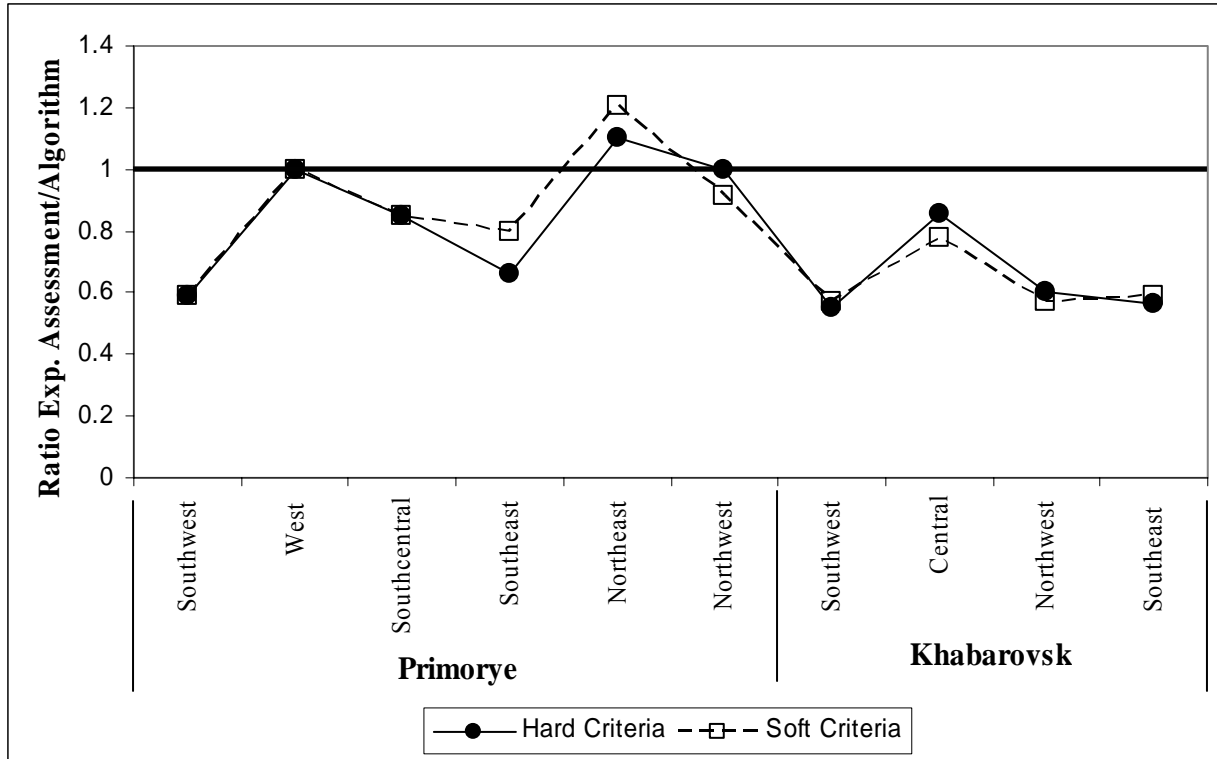


Figure 15. Ratio of number of tigers estimated by expert assessments/number of tigers estimated by an algorithm, using two sets of criteria (“hard” and “soft”) for tracks reported for the 2004-2005 Amur tiger winter survey. A ratio of 1 represents perfect matching of the two estimates.

Sensitivity Analysis of Parameters. Three key parameters used in both expert assessments and in the algorithm to estimate tiger numbers are: 1) variation in pad width measurements (meaning both variation in size of different tracks of the same animal, and variation in measurement by various fieldworkers); 2) diameter of home range, which has only been measured accurately in one small region of Amur tiger range, but which could vary significantly across their range; and 3) daily travel distance, which has been estimated in two areas (Yudakov and Nikolaev 1974, Miquelle et al. in press) but which may also vary over time and space, in relation to prey density and other factors. To assess how changes in these variables will affect estimations of tiger numbers in both the expert assessment and the algorithm, we conducted a “sensitivity” analysis by varying values of these three parameters within the algorithm. We attempted to select values that are reflective of the true potential variation of these variables (Table 12). For example, tiger surveys in Russia have generally assumed that error in pad width measurements between tracks of the same individual will be no more than 1 cm, yet recent observations suggest this error may be as great as 2 cm (Yudin 2007). The values used for each parameter in the sensitivity analysis were not necessarily centered on a mean “expected” value, so the actual results, in terms of numbers of tigers, are less important than assessing the impact of variation in specific values.

Using the full range of parameters described in Table 12, we found that estimates of tiger numbers ranged from a high of 958 to a low of 338 (Figure 16). We used a general linear model ANOVA to assess the relative importance of these three parameters in affecting the estimate of tiger numbers (used as the dependent variable). Daily travel distance had the greatest influence

Table 14. Values used in algorithm to mimic expert assessment of tigers numbers, and to conduct sensitivity analysis of the impact of variables on estimates of tiger numbers.

Parameters	Values used to mimic expert assessment of				
	tiger numbers	Range of variables for sensitivity analysis			
Variation in pad width measurement	1 cm	1	1.5	2	
Maximum diameter of home range - females	34.5 km	20	30	40	
Maximum diameter of home range - males	43.0 km	20	40	60	
Daily travel distance - males (pad width ≥ 10.4 cm)	12.3 km	5	10	15	20
Daily travel distance - females (pad width 9 - 10.4 cm)	9.9 km	2	4	8	12
Daily travel distance - pad width < 9 cm	7.5 km	2	4	8	12

on estimates of tiger numbers ($F = 247.6$, $df = 3$, $p < 0.00001$), followed by home range diameter ($F = 113.5$, $df = 2$, $p < 0.00001$). Error in pad size measurements contributed least to the overall model ($F = 50.1$, $df = 2$, $p < 0.00001$) but was nonetheless an extremely significant parameter as well. Figure 16 demonstrates that estimates of tiger numbers drops dramatically as daily travel distance increases, and that the variation among estimates (the “spread” between lines) increases as well.

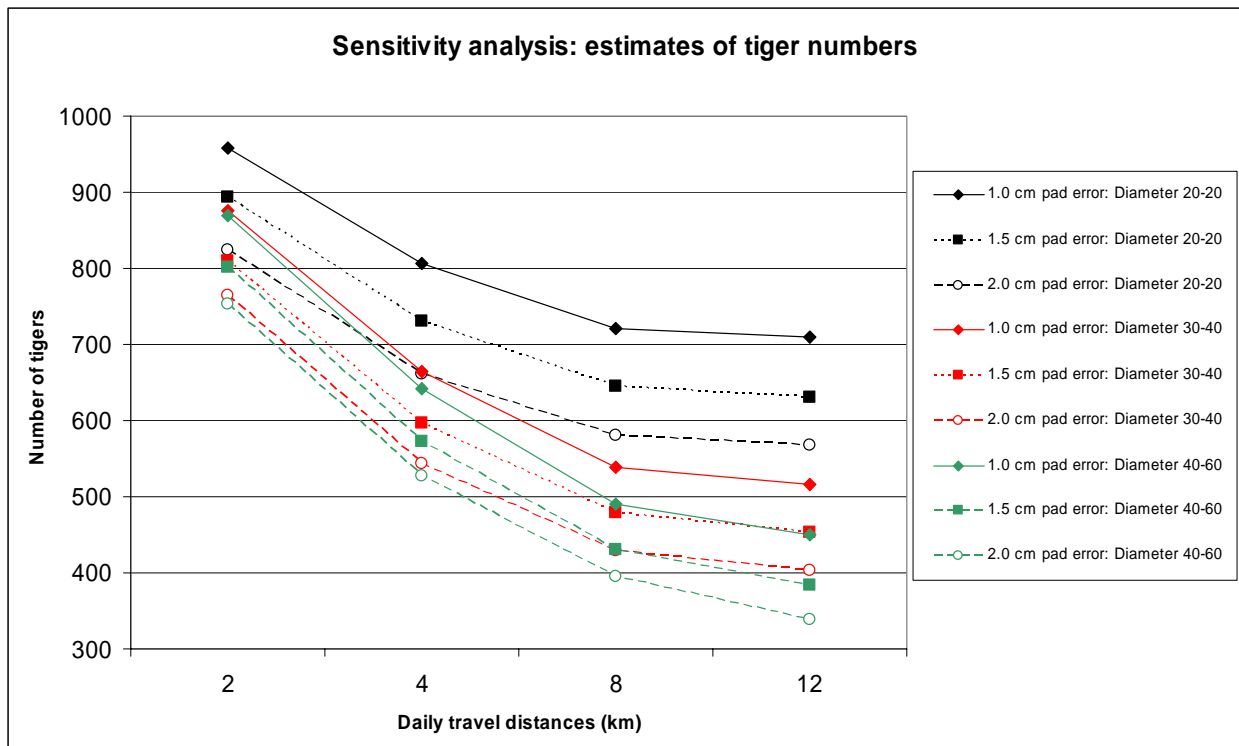
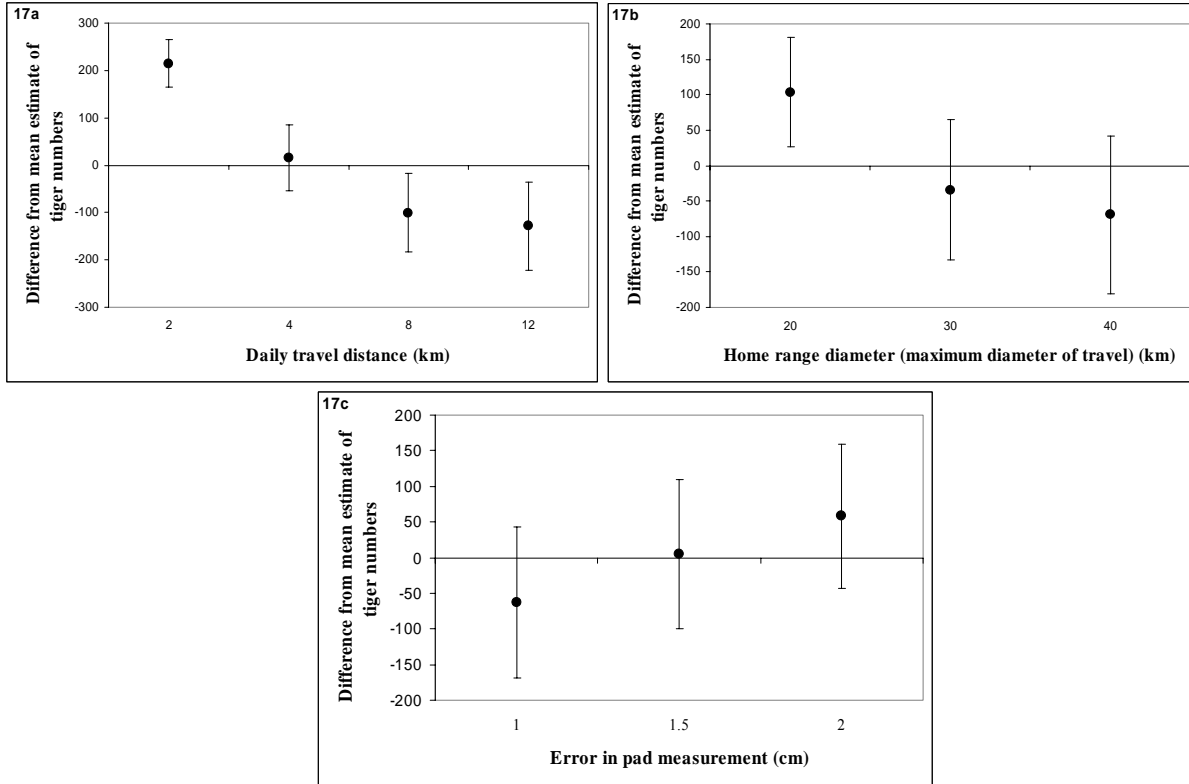


Figure 16. Sensitivity analysis of the effect of varying key parameters (pad width, daily travel distance, and maximum diameter of home range) in an algorithm to define tiger numbers. Three sets of 3 colored lines (black, red, green) represent estimates where home range diameter (“Diameter” in the key) is held constant (values for both females and males given) and pad width measurement errors varied between 1, 1.5, and 2 cm.



Figures 17a-c. Variation from the overall mean of tiger numbers estimated, using varying values for three key parameters (daily travel distance, home range diameter, and variation in pad width measurements) of an algorithm derived to estimate minimum number of tigers.

Separately graphing the extent to which values for each parameter varied from the overall mean of tiger numbers from all combinations of parameters also demonstrates that daily travel distance had the greatest impact in altering results (Figure 17a); tiger numbers varied from over 200 individuals above the average, to about 130 individuals below the overall average. Changes in both home range diameter and error associated with pad width measurements also dramatically changed estimates of tiger abundance (Figures 17b and 17c).

COMPARISON OF 3 ESTIMATES OF TIGER ABUNDANCE: EXPERT ASSESSMENTS, TIGER TRACK DENSITY ESTIMATOR, AND THE ALGORITHM.

Expert Assessment and Track Density. A strong correlation between the tiger track density estimator and tiger density based on expert assessment (Map 14a and b) would reinforce the assumption that both estimators are accurate reflections of actual tiger densities. Using the data on tiger density by raion (Table 10) and tiger track density by raion (Table 12) it appears that, although there is a significant correlation, there is a high degree of heteroscedascity in the original scale (Figure 18a), suggesting that a natural log transformation may be useful. In fact, the transformation does reduce the problem of heteroscedascity (Figure 18b), and a simple linear regression is highly significant ($p = 0.0045$), with a higher correlation coefficient than in the original scale ($r^2 = 0.38$ versus 0.18). Nonetheless, the correlation coefficient is not high,

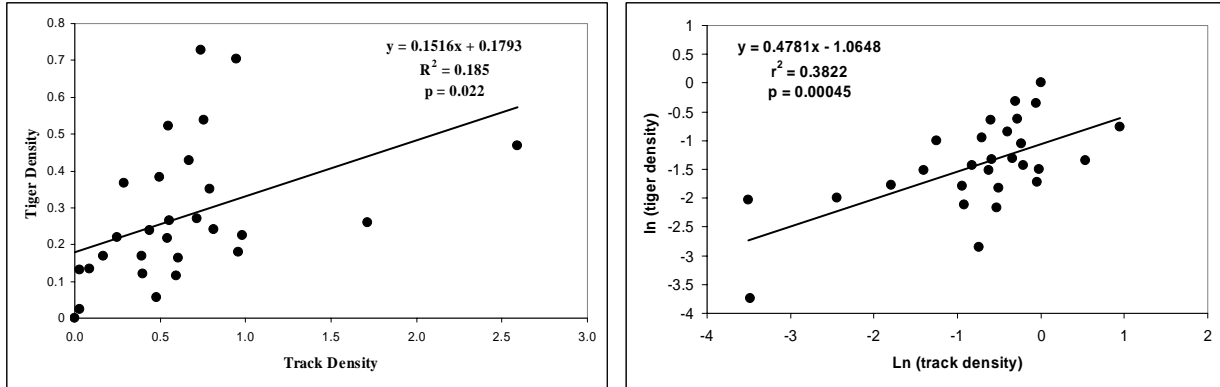


Figure 18a-b. a. The relationship between tiger density, as estimated by experts, and tiger track density, estimated as the density of tracks on survey routes adjusted by days since snow, averaged for both estimators by raion (county). b. The natural logarithm transformation of the tiger density and tiger track density has a better relationship than in the original scale.

suggesting that other parameters may be influencing this relationship. Overall, the strongly significant relationship provides some validation for both indicators of tiger abundance, but the variability inherent in this relationship (Figure 18b) also indicates that a more intensive investigation to determine the relationship of both estimators to actual tiger density is critical.

Expert Assessment and Algorithm. A much stronger relationship exists between estimates derived from the expert assessment and the algorithm (Figure 19). Using either the “hard” or “soft” criteria, the relationship between the algorithm results and expert assessments is very high ($r^2 > 0.95$). Thus, although the actual estimate of experts is generally lower than the algorithm (Figure 15, the two appear to “track” each other quite well, suggesting that although track data appear to be interpreted differently by each coordinator (Figure 15) overall the expert assessments are in line with the results derived from the algorithm. How well either of these estimates reflect true tiger density will depend on how well the criteria accurately reflect the relationship of tracks, as interpreted by the set of criteria, to actual tiger numbers. Nonetheless, because the criteria adjust tiger numbers based on the proximity and size of tiger tracks (i.e., dampening the effect of multiple tracks reported for a single individual), it is likely that both the expert assessments and the algorithm provide, at minimum, a better reflection of relative density of tigers than the estimator derived using track density.

TIGER NUMBERS: SUMMARY

Using the two sets of criteria for expert assessments and the algorithm, plus the estimate of track density, results in 5 different estimates of tiger numbers. All but the tiger track density estimate correlate with each other well (Figure 20), and even the correlations of track density to other estimators is moderately high (> 0.6) (Table 15). Such a high degree of concordance reinforces the belief that these values are all, at the very least, an accurate reflection of relative abundance of tigers, and can be used to assess trends. However, the results of the sensitivity analysis suggest that relatively small changes in the criteria used for estimating tiger numbers (either by expert assessments or the algorithm) can result in relatively dramatic differences in

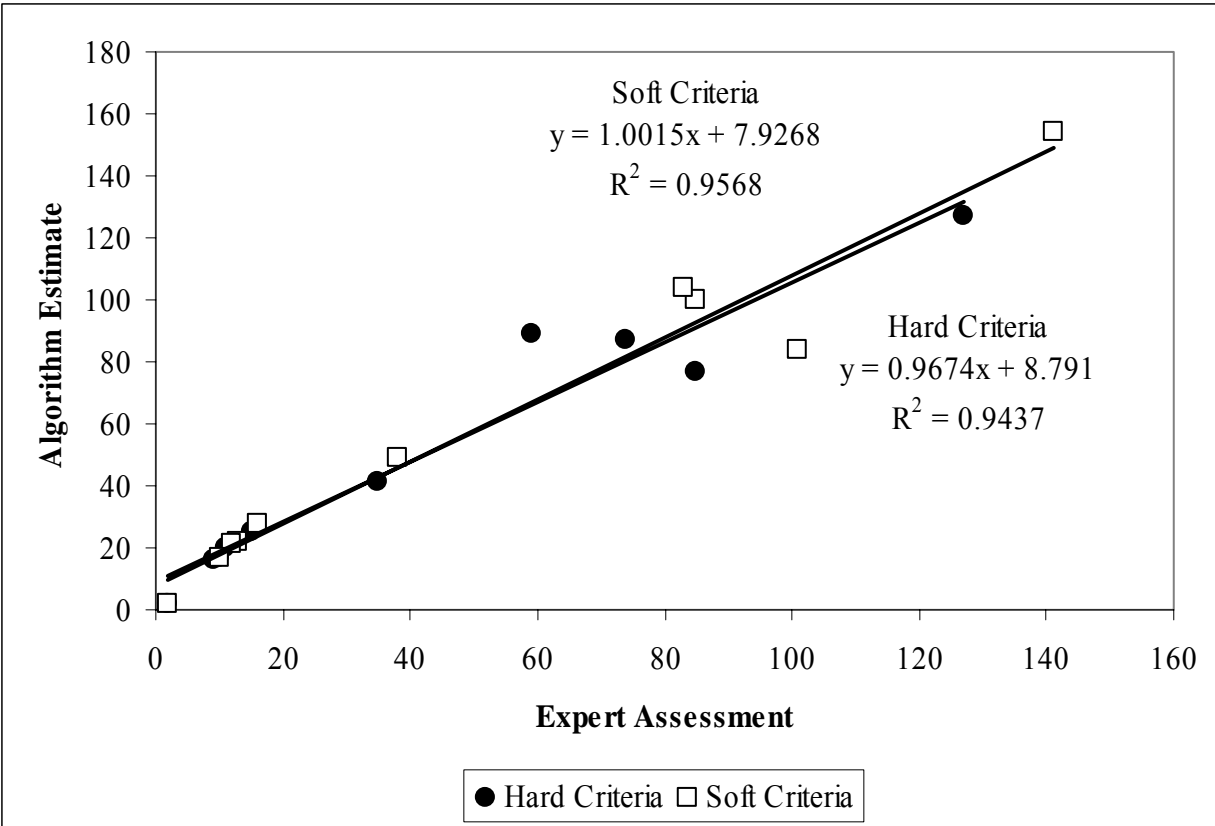


Figure 19. A strong linear relationship exists between the expert assessments and results of the algorithm to estimate tiger numbers, using both the “hard” and “soft” criteria for interpreting tracks of data collected from the 2005 winter survey.

estimates of tiger abundance. Perhaps the most important result deriving from development of the algorithm and associated sensitivity analyses is that results of both the algorithm and expert assessments appear to be extremely sensitive to variation in all parameters used to derive estimates of tiger numbers. Since the real variation of these parameters across tiger range is unknown, this in turn suggests that there is likely a large, unknown error associated with estimating tigers using either of these approaches, as the parameters used likely vary across the range of tigers, vary across years, and in how fieldworkers and coordinators make measurements. For instance, expert assessments were made assuming that error in pad with measurements of an individual tiger does not exceed 1 cm. However, if error in pad width measurements actually varies by 2 cm, as demonstrated by Yudin (2006), estimates of tiger numbers could be exaggerated by more than 100 individuals (Figure 17c). Similarly, variation in estimates of daily travel distance by 4 km can change estimates of tiger numbers by 200 individuals (Figure 17a). Therefore, caution should be used in interpreting results of these surveys, and it is best to be conservative in deriving estimates of tiger numbers, as overestimates appear to be much more likely than underestimates.

Another result derived from analyses of these estimates of tiger numbers is that the estimates derived from expert assessments, and even more so the algorithm, are largely influenced by survey effort. As the number of tracks reported increases, the number of individuals estimated also increases. Expert assessments appeared to be more conservative in

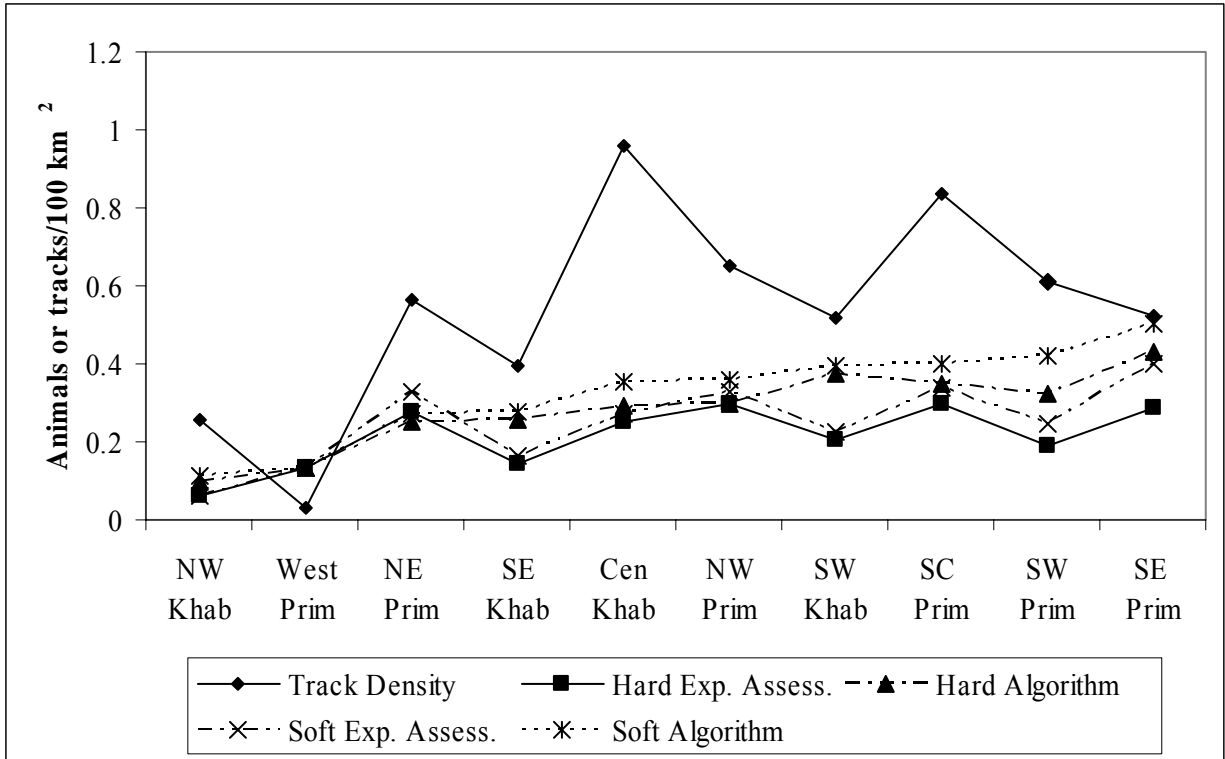


Figure 20. A comparison of expert assessments of tiger numbers (using “hard” and “soft” criteria), an algorithm estimate of tiger density (also using “hard” and “soft” criteria) and tiger track density, for each raion (county) surveyed in Khabarovsk and Primorski Krai for the 2004-2005 Amur tiger winter survey.

Table 15. Correlation matrix between estimates of tiger density derived from expert assessments and an algorithm to estimate tiger numbers, both using "hard" and "soft" criteria (Appendix I), and track density, based on tiger track data collected during the 2005 winter survey.

	Hard Expert	Hard Algorithm	Soft Expert	Soft Algorithm	Track Density
Hard Expert	1.000				
Hard Algorithm	0.745	1.000			
Soft Expert	0.967	0.804	1.000		
Soft Algorithm	0.751	0.982	0.821	1.000	
Track Density	0.732	0.628	0.669	0.676	1.000

this aspect, but it is clear that the fact that more tigers were reported in 2005 than any other survey is at least partly a reflection of the fact that the survey effort was substantially greater than in previous efforts. Hence, we should be cautious in interpreting results in comparison to previous surveys. The fact that tiger track densities have decreased significantly across tiger range, in comparison to 1996, is also likely a product of survey design and effort. Therefore, interpreting trends based on a comparison of simply numbers of tigers should be done with extreme caution.

Results of the algorithm suggest that most past surveys, which are based exclusively on expert assessments, are likely conservative in defining numbers of tigers. And even though the results of the 2005 expert assessments are conservative in comparison to the algorithm, because the criteria used were more rigorously defined than in past years, it is likely that the results of the expert assessments are larger than they would have been if clearly defined criteria were not applied.

We believe that in determining appropriate conservation actions for endangered species, it is wise to be conservative in assessing their status. The official estimate of tiger numbers in the Russian Far East is 428–502 (331-393 adults/subadults), and available indicators suggest that tiger numbers appear to have been stable over the past 10 years. There are indicators that tiger numbers have decreased, suggesting that the 1996 survey may have underestimated numbers of tigers. This fact should be considered in developing appropriate conservation plans.

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APPENDIX I.

STANDARIZED CRITERIA USED TO INTERPRET TIGER TRACK DATA TO DERIVE EXPERT ASSESSMENTS OF TIGER NUMBERS IN THE RUSSIAN FAR EAST

(first derived by E. N. Matyushkin et al., 1996 unpublished. Updated and revised by D.G. Miquelle et al., in press)

Introduction

These criteria are to be used by all coordinators to provide an expert assessment of number of tigers for the 2005 Amur Tiger Survey. Please note that to provide standardization in conducting expert assessments, all coordinators must use these criteria in defining the number of tigers in the area you are responsible for.

1. *Use of Simultaneous and "Seasonal winter" data.* First, conduct an analysis of track data from the simultaneous survey, using the criteria as defined below, and then include additional track data from the "seasonal winter" data set. Each track, from both the simultaneous survey and seasonal winter field diaries, should be assigned to a specific tiger, or labeled as "not included." The forms for reporting these tracks are attached.
2. *Tracks excluded from analysis.* Tracks reported as "not included" represent tracks which were not correctly reported by the fieldworker (e.g. pad width = 20 cm), or any tracks that for any reason were not used in determining the number of tigers on your area.
3. *Size of each track for analysis.* If a fieldworker reported a range of values for a track size (for instance 10,0-10,5 cm), then for analysis the average of the range should be used.
4. *What track size category to use for differentiating individuals.* In the 1996 tiger survey, coordinators agreed that Следы, которые отличаются по размеру больше чем на 1 см, считаются принадлежащими разным особям. Since then, information from Yudin (in press) and Salkina and Kerley (in prep.) suggest that with different substrates and different counters, differences up to 2 cm are possible. Salkina and Kerley propose that tracks whose size varies by < 1.5 cm should be considered made by the same animal. We will use two criteria, one to maintain consistency with previous surveys, and one to represent existing knowledge of errors in measuring track size:
 - a) For "relaxed set of criteria" tracks which are separated in size by less than or equal to 1 cm, are considered to be potentially from the same animal.
 - b) For "strict criteria," tracks which are separated in size by less than or equal to 1.5 cm, are considered to be potentially from the same animal.

Table 1. Track classes based on size of front pad of Amur tigers

Track class	Pad width (cm)	Sex-age class
1	8,5	Cubs less than 9 months
2	8,5-10,5	Adult females, subadult females (> 1 year), and males < 16 months
3	>10,5	Subadult and adult males

Note: Sex-age class #2 is most difficult to differentiate. However, the following points will help:

1. Cubs less than 12 months are normally in association with their mother, or there are at least tracks of the mother coming into and out of areas where cubs are. Additionally, cubs less than 12 months are usually with other members of the litter.

2. Cubs between 12 and 18 will often be without their mother, but are often in association with other members of the litter.

5. *Classification of tracks.* For separation of tracks in sex-age categories we will use the following gradation in track size (from Yudin 2005):

6. *Sex-age classes for analysis.* We recommend classifying tracks into the following groups based on size of tracks and association with other tigers:

i. Cubs. All tracks less than 8.5 cm.

ii. Female with cubs: at least one set of tracks 8.5-10.5, with an additional set (from 5 – 10.5 cm). In the situation where a single young male cub (> 15 months) is still traveling with mother, it will be difficult to delineate between a female with one male cub, and a female with an adult male consort. Repeated observations of such a pair for more than a week would determine such a pair to be a female with a single male cub. All other sets of tracks (2 or more animals) should be easily identified as a female with cubs. Tracks of cubs, with no trace of a mother, can occur, but are relatively rare (unless there is fresh snow or the mother has been killed). Females with cubs, however, often hunt and travel without their cubs, so a female with cubs can often be registered as a single individual as well.

iii. Adult and subadult males (>16 months) males: all tracks > 10.5 cm except those that are in constant association with one female (see above).

iv. Subadult and adult females: most subadult males will be in association with either their mother, or a sibling. Therefore, the majority of tracks of lone tigers with a pad size of 8.5-10.5 will be adult and subadult females.

v. Unknown category.

7. *Barriers that separate tracks as separate individuals.*

i. *Elevation.* Due to deep snow conditions, it is assumed that elevations greater than 700 m will be effective barriers to travel for tigers. Therefore, tracks of the same size but which are separated by such elevation gradients will be considered separate animals. If snow depth is particularly low in a year or particular region, then this geographic barrier will not exist.

ii. *open fields.* Open, unforested (and generally free of vegetation (e.g., plowed fields) greater than 3 km and 10 km long represent effective barriers to travel for tigers, irrespective of snow depth.

Table 2. Sex-age classes of Amur tigers based on size of front pad.

Sex-age class	Pad width (cm)	Criteria
i. Cubs	8,5	Track size
ii. Female with cubs	8,5-10,5	1.Any group with at least 1 track 8.5-10.5, and others less than 8.5; 2.Any group of more than 2 tigers; 3.If one track > 10.5, and group size = 2, but tracks consistently together over winter period
iii. Male	> 10.5	Track size
iv. Female	8.5 -10,5	Lone track consistently reported in one area
v. Unknown	> 8.4	Tracks for some reason are not consistent with above groups

iii. Settlements. We assume that tigers will not travel THROUGH settlements, but usually travel along their edge and around them. Therefore distance between two tracks, if there is a settlement between them, is the distance it takes to travel around the settlement.

8. *Age of tracks.* If tracks were identified by field workers to have been created on the same day, there is some likely distance a single tiger is likely to travel to create two or more sets of tracks. Therefore, “freshness” of tracks is an important variable useful in distinguishing individuals within a specific region. However, as tracks get older, the precision with which their age can be determined diminishes greatly. It is generally believed that tracks less than 24 hours old can be reliably identified. Tracks of 1-3 days can also be identified, but accuracy already diminishes at this age. Based on likely travel distances (see #4), tracks older than 4 days are of less significance because most tigers have the capacity to travel across their entire home range in that period, making distances greater than that walked in that amount of time unimportant. It was assumed, in the criteria worked out for the 1996 survey, that an error of 1 day is possible in calculating track age between 1 and 4 days.

9. *Average daily travel distance and likely maximum distance between tracks of a single individual.* Determining whether the distance separating tracks is sufficient to consider them made by separate individuals will usually be determined by the likely daily travel distance, and the diameter of home ranges of resident tigers. Yudakov and Nikolaev reported that adult male tigers travel, on average, 9.6 km (maximum = 41 km) per day when not at a kill, and adult female tigers travel on average, 7 km (maximum = 22 km) per day. This is the actual distance traveled. Linear distance between two sets of tracks, which is the variable that will be assessed in the track data, will be less than actual travel distance.

In Sikhote-Alin, locations of radio-collared tigers on sequential days were analyzed to provide an indication of the average, median, and quartile estimates of daily distances moved by radio collared tigers on sequential days. Separate summaries are provided for females, females with cubs, and males. These data demonstrate that when on kills, animals travel very short distances only. When not on kills, females with cubs travel slightly shorter distances than females without cubs, and males travel greatest distances (Table 5).

Table 3. Daily straight-line distance traveled by tigers, based on radio locations of individual tigers on

Sex	Cubs	# tigers	n	Means	SD	Straight-line distance between locations on two consecutive days (m)				
						20% quartile	25% quartile	Median	75% quartile	80% quartile
Females	cubs	9	731	3236	3321	526	744	2113	4717	5468
	no cubs	13	582	5015	3931	1669	1925	4053	7078	8324
Males		7	163	6699	4960	2061	2672	5573	9660	10786

Criteria developed for the 1996 survey employed 5 km and 7.5 km as the daily travel distance of females and males, respectively. Use of a mean would include only half of the daily travel distances for any sex-age class. To be more inclusive, we recommend using the 75% quartile, which would include, on average 75% of all daily travel distances for a sex-age class. Using the 75% quartile as a base, daily average travel distance would be 4.7 km for females with cubs, 7.1 km for females without cubs, and 9.6 km for males.

10. *Maximum likely distance between tracks of one individual.* As differences in ages of adjacent, similar-sized tracks increases, the possibility of those tracks being made by a single individual increases as the probable distance a tiger could move over larger periods of time increases. However, for resident tigers that typically confine their movements to well-defined home ranges, the likely distance between two tracks that could have been made by one individual reaches a threshold that is dependent on the size (diameter) of an animal's home range. For female tigers radio-collared in and near Sikhote-Alin Zapovednik the average home range size of 12 adult females was 440 km² (minimum convex polygon) and 1450 km² for 3 males (Goodrich et al. in prep). Assuming that home ranges can be represented in the abstract by a circle, the diameter of these home ranges would average approximately 24 km for females, and 43 km for males. Yudakov and Nikolaev (1986) reported maximum home range diameters of 35 and 27 km for two females and 45 km for a male. Our estimate from Sikhote-Alin is an abstraction, and is no doubt lower than the maximum diameter of any single home range, which is not in actuality circular. Based on these measurements, no matter how many days separate the age of neighboring tracks, if those tracks were created by animals with the same size track, but are greater than 25 km apart for females, or 43 km for males, there is a high probability that they were created by different animals. . However, when we measured the widest diameter of each home range, the potential maximum distance between two tracks of the same animal increases slightly (Table 4).

Table 4. Home range diameters of Amur tigers (Sikhote-Alin Zapovednik)

Sex-age class	Average home range diameter (km)	Maximum home range diameter (km)
Adult male	43	54
Adult female	24	29
Adult female with cubs	24	29

11. *Distinguishing individuals based on track age and distance between tracks.* To distinguish between individual tigers it is necessary to assess the distance between tracks in relation to their age. Tigers with track sizes in the same size category will be considered to be different if the distance between them is greater than the estimated travel distance for the period of time separating them, for tracks separating in time by 3 or less days. For tracks separated by at least 4 days, tigers can potentially travel across their entire home range, and therefore the maximum distance (diameter of home ranges) should be used.

12. *Conservative and Relaxed Criteria.* In assessing distances between tracks two sets of criteria were developed: “relaxed” and “strict”. Strict criteria, applied to a set of track data, should provide a more conservative estimate of tiger abundance, while “relaxed” data will provide a larger estimate of abundance. Development and application of these two sets of criteria are necessitated by the great heterogeneity of data, and the difficulty in objective assessment of the many factors influencing the census results. It is possible, for example, that a single set of criteria for both high and low density populations of tigers cannot be established. The “conservative” criteria may be considered a conservative means of determining the guaranteed minimum number of tigers. In both sets of criteria the average values of “male” and “female” track groups are used for animal of undetermined sex. In situations where tracks that fall into different size groups are being compared (i.e., 10.3 and 10.7 size tracks), criteria for the larger size class should be applied.

13. *Conservative (Minimum) Criteria.* In developing the “conservative” criteria the following conditions are used:

- i. if the dates of passage of two tracks coincide (i.e., zero difference in time tracks were laid down), tracks can be considered created by one animal if the distance between tracks is less than or equal to the 24-hour travel distance for that size class;
- ii. an additional 24-hour travel distance is added to account for tracks created on different days (e.g. if tracks were created two days apart, the distance criteria would be three 24-hour movements).
- iii. taking into consideration the high possibility of errors in determining the dates tracks were created, and often the inaccuracy of plotting location of tracks on maps, the 24-hour travel distance used in distinguishing individuals should be double the actual observed average travel distance of tigers.

Table 5. “Conservative” criteria for determining if two tracks (which are no more than 1.5 cm difference in size) were made by the same individual.

Size class (size of front pad, cm)	Difference in age of tracks (days)					
	0	1	2	3	4	≥5
8.5-10.5 (female with cubs)	5	10	15	20	24	24
8.5-10.5 (female without cubs)	7	14	21	24	24	24
>10,5	10	20	30	40	45	45

Table 6. “Relaxed” criteria for determining if two tracks (which are no more than 1 cm difference in size) were made by the same individual.

Size class (size of front pad, cm)	Difference in age of tracks (days)					
	0	1	2	3	4	≥5
8.5-10.5 (female with cubs)	2.5	7.5	12.5	17.5	23.5	24
8.5-10.5 (female without cubs)	3.5	10.5	17.5	24	24	24
>10,5	5	15	25	35	45	45

These criteria are shown in the table below for up to 3 successive travel days (including where there is no difference in dates tracks were made) where the smaller value corresponds to the limit above which tracks are considered possibly made by different individuals, and the upper value the limit above which tracks are considered definitely made by separate individual tigers. Values are calculated to the nearest 0.5 km.

13. *Relaxed Criteria.* In developing the “relaxed” criteria the following conditions are used:

i. If the dates of passage of two tracks coincide (i.e., zero difference in time tracks were laid down), half the estimated daily travel distance is used to determine whether tracks are considered representative of one individual tiger;

ii. For tracks that are separated by one day, the daily travel distance used will be equal to 1.5 travel days; for two-day differences will be 2.5, and for three-day differences will be 3.5 line distance;

iii. The quantities used to separate tracks based on 24-hour linear distances is not doubled.

14. *“Questionable” individuals.* Sets of tracks that are difficult to distinguish due to specific problems with the original material (i.e., contradictions or inaccuracies of documents) should be identified as tigers of doubtful identity, and included in this category in the summary tables.

15. *Coordination with adjacent territories.* Each coordinator is responsible to meet with coordinators from adjacent regions to review data and determine whether individual animals could be using both territories. In those cases where it is agreed that an animal crosses boundaries between coordinators, those two (or more) coordinators must agree among themselves who will report the animal (so there are not duplicate counts).