SPATIAL DISTRIBUTION OF FAR EASTERN LEOPARD IN SOUTHWEST PRIMORSKI KRAI, AND RECOMMENDATIONS FOR THEIR CONSERVATION

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INTRODUCTION

The Far Eastern, or Amur leopard (*Panthera pardus orientalis*) is one of the most endangered subspecies of large cats in the world. Reduced to a fraction of its original range, one remnant population remains in southwest Primorski Krai of the Russian Far East (Pikunov and Korkishko 1992), and perhaps a few individuals in Jilin and Heilongjiang Provinces of northeast China (Shihe et al. 1998, Sun et al. 1999). There are likely wild Amur leopards in DPR Korea, but their status is unknown, and there have been recent but unconfirmed reports of leopards in South Korea. Recognized as a genetically discrete population (Miththapala et al. 1996, Uphyrkina et al, in review), this subspecies deserves protection as a northernmost, unique genetic contribution of the species and region, and as a top carnivore indicator of ecosystem health and integrity.

While anonymity can be a form of protection, for the Far Eastern leopard, it has been a curse. Forced to live in the shadows of the more glamorous, charismatic Amur tiger (*Panthera tigris altaica*), with whom it has overlapping ranges, the leopard has been largely ignored by conservationists, wildlife management specialists, and the local citizenry. While millions of dollars from the international conservation community has been invested in protection and study of the Amur tiger since the opening of Russia in 1992, until recently the leopard has been virtually ignored.

Despite its anonymity, the threat of extinction is much greater for the Far Eastern leopard than for the Amur tiger. While a 1996 survey of Amur tigers suggested that 330 to 370 adults survived in Russia (Matyushkin et al. 1996), a series of surveys on leopards has consistently pegged the number of remaining individuals to be between 25-44 (Pikunov and Korkishko 1992, Aramilev et al. 1998, Pikunov et al. 2000). While the range of tigers extends 600 miles north into Russian territory, the historic range of leopards, who are apparently less tolerant of snow and cold (Pikunov and Korkishko 1992), includes only the southern section of Primorski Krai. With much of its former habitat eliminated in China, the Far Eastern leopard's range has been compressed into one small fragment of habitat along the Chinese-Russian boundary. Habitat destruction, intensive logging, elimination of prey base, and direct hunting (both legal, and more recently, illegal) have all played a role in reducing this subspecies to a fragment of its former habitat. Now, with such a small, isolated population, the threat of inbreeding and loss of genetic variation has lead many Russian biologists to fear that the days of the Far Eastern leopard are numbered.

Concern for the survival of this subspecies has spurred some recent activities, including a series of 4 surveys between 1997 and 2000 (Pikunov et al. 1997, Aramilev et al. 1998, Pikunov et al. 2000, Aramilev and Fomenko 2000). While survey reports by Aramilev et al. (1998, 2000) suggest an increase in numbers, it is unclear whether this difference reflects a true change in numbers, or a difference in methodologies. There is debate as to whether reproduction rates are dropping (Pikunov et al. 2000).

At the same time, there is relatively little known about habitat requirements of this leopard, which makes development of concrete land management and conservation recommendations difficult. To increase leopard numbers, it will likely be necessary to both create/restore habitat and increase the quality of existing habitat. To do so will require a clear understanding of what constitutes good leopard habitat.

Presumably, the existing spatial distribution of leopards is dependent on a host of natural and anthropogenic features of the landscape that can be identified and categorized. We used data obtained during the last 4 surveys of leopards in Southwest Primorye Krai, Russia, and developed a geographic database that categorized topographic cells by landscape characteristics. In particular, we sought to assess the following issues:

1. How is the spatial distribution of leopards affected by human disturbance, human landuse patterns, and natural biotic and abiotic features of the landscape?
2. What is the relationship of deer farms, which are considered a key forage resource for leopards (Pikunov and Korkishko, 1992) to spatial distribution of leopards?
3. Is there spatial separation of Far Eastern leopards to Amur tigers; is there any indication that the two large felids compete for space or prey (Aramilev and Fomenko 2000)?
4. Are there distinct patterns of spatial distribution of females with kittens?
5. Can suitable habitat be clearly defined, and used in developing land management recommendations for Far Eastern leopards?

We attempt to define leopard habitat based on the results of this analysis, and propose how existing land management regimes might be adjusted to create new habitat and increase the quality of existing habitat.

STUDY AREA

Southwest Primorski Krai is a thin sliver of land (approximately 200 km long, and 60 km at its widest point) that is dominated by the eastern slopes of the East Manchurian Mountains (Figure 1). To the west, it is bounded by the Chinese province of Jilin, except in the northwest, which lies opposite Heilongjiang Province. To the south, it is bounded by the Tumen River and the Democratic People’s Republic of Korea, and to the east, by Peter the Great and Amur Bays, which outlet to the Sea of Japan (Figure 1). There are 4 raions or counties (Oktyabriski, Ussuriski, Nadeshdinski, and Khasanski) that comprise Southwest Primorye, but the majority of the land is comprised of Khasanski raion, which over its entirety, represents no more than 40 km of land in an east-west direction between Peter the Great Bay and the Chinese border (Figure 1).

The main road and railway that travel close to the coast are dotted with small settlements and agricultural collectives, and the large town of Slavyanka (with a population of 17,000)is the administrative center of Khasanski raion. The entire region is readily accessible to inhabitants of Vladivostok (over 700,000 people) and Ussurisk (40,000), who can reach almost any part of Southwest Primorye in 1 - 4 hours by vehicle (Figure 6).

There are 7 deer farms scattered across the region that raise sika deer for harvest of antlers in velvet, which are sold and used in Traditional Chinese medicines. These deer farms were originally part of larger collectives farms; some have been privatized, and some have fallen into disrepair.

The largest economic development scheme in the region is the UNDP-sponsored Tumen River Development Project, which is a concerted effort by 4 nations to develop this region into a economic free zone for trade and export. There are expansive plans (in various stages of completion) to improve the transportation network, reduce trade barriers, and increase export

Figure 1. Map of study area, showing relationship to China, DPR Korea, and major metropolitan areas of Russian Far East.

capacity of the ports in Southwest Primorye. The landlocked countries of China and Mongolia have perhaps the greatest interest in this project, as it would provide a northern outlet for import and export.

METHODS

Leopard surveys and survey routes.

Four surveys of leopards were conducted in Southwest Primorski Krai between 1997 and 2000, largely in a similar fashion (details of surveys have been reported elsewhere: Pikunov et al. 1997, Aramilev et al. 1998, Pikunov et al. 2000, Aramilev et al. 2000). A network of survey routes was established in those areas considered potential leopard habitat. Because leopards have been studied extensively in Southwest Primorye (Pikunov and Korkishko 1992, Augustine et al. 1996), much was already known about leopard habitat selection, resulting in a informal "stratification" process that eliminated those areas and habitat types where probability of leopards was very low (e.g. wetlands, grasslands, agricultural areas, settlements). Survey routes were positioned to provide the greatest probability of encountering tracks (i.e., areas were not randomly sampled), and two slightly different methods were employed: 1) simultaneous surveys, in which a large number of trained observers were sent out nearly simultaneously (within 2-3 days) to survey all survey routes (Aramilev et al. 1998, and Aramilev et al. 2000; and, 2) "sweep" surveys, in which a small team of highly trained specialists moved from basin to basin (in a north-south gradient) to cover the entire region where leopards may occur (requiring up to a month) (Pikunov et al. 1997, Pikunov et al. 2000). Both types of surveys result in similar data output: a set of survey routes with locations and size measurements of leopard tracks. In 2000, fresh ungulate tracks (less than or equal to 24-hours old) were recorded along all transects.

Results of the surveys are summarized in Figure 2a-d. A total of 270 leopard tracks and 131 tiger tracks were reported (though note that tigers were not reported in the 1997 survey).

Delineation of Spatial Sampling Units (cells) and Effect of Sampling Effort within Cells on Probability of Detecting Leopard Tracks

To assess the importance of various anthropogenic and natural parameters to spatial distribution of leopards in Southwest Primorski Krai, we divided the entire forested region of Southwest Primorye into topographically defined cells. Use of topography (aspect, slope, and elevation) as a means of defining cells was done with the assumption that these characteristics often define habitat (plant community) type, snow depth, availability of forage, and anthropogenic impacts, which should in turn should be important factors affecting spatial distribution of leopards and their prey. We delineated cell size at a level necessary to capture topographic features of the region, and at a level to reflect site specific characteristics that may relate to leopard use. Cells were defined for all regions that were considered potential leopard habitat – essentially all forested and shrub tracts of Southwest Primorye. Lakes, wetlands, human settlements, and large tracts of open grasslands with partial shrublands were not included (although smaller tracts were retained) (see below). This process resulted in delineating 1707 topographic cells that ranged in size from 0.58 to 10.91 km^2 (x = 3.21, Standard Deviation = 1.85) (Figure 4).

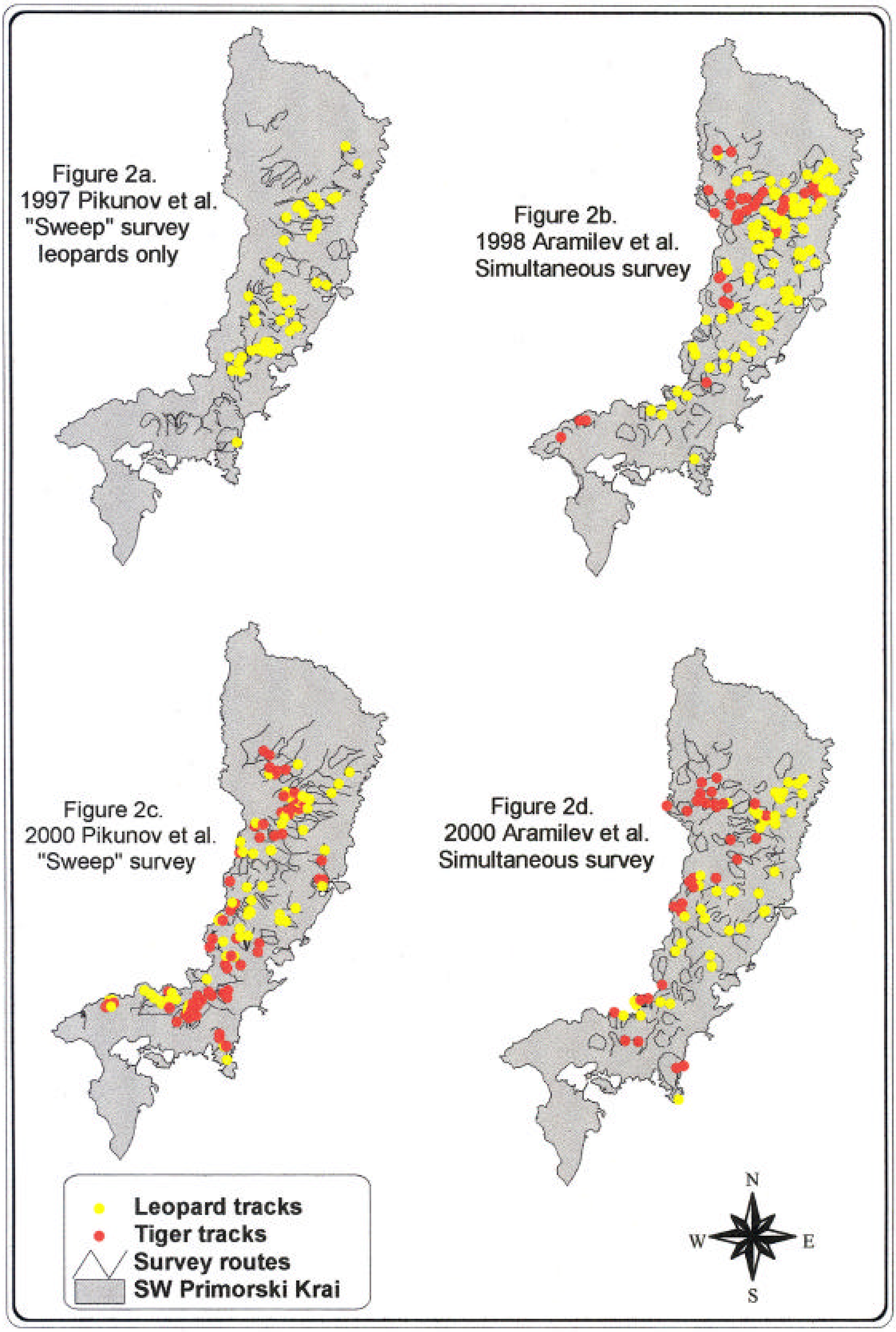


Figure 2a-d. Surveys of leopards conducted between 1997 and 2000: a. 1997 leopards only using a "sweep" survey (Pikunov et al. 1997); 1998 leopards and tigers using a simultaneous survey (Aramilev et al. 1998); 2000 leopards, tigers, and ungulates using a sweep survey (Pikunov et al. 2000); 2000 – leopards, tigers, and ungulates using a simultaneous survey (Aramilev 2000).

The 270 leopard tracks reported for the 4 surveys were distributed across 198 topographic cells (11.6% of cells), with a maximum of 6 tracks reported in one cell. Tiger tracks were distributed across 117 cells (6.8%), with a maximum of 3 tracks reported per cell.

Two characteristics of the survey methodology may bias analyses of the relationship of leopard spatial distribution and landscape characteristics. Because survey routes were designed to maximize the chance of determining leopard presence, their positioning was intentionally biased towards those regions where there were higher probabilities of finding leopards. This bias presented problems in using these data for habitat analyses because they are do not represent a random sample of potential sites where leopards may occur. In essence, cells where transects were situated had already been pre-selected in a preliminary "stratification" process in those areas with higher probabilities of having leopards. This selection process deleted regions of South Primorye where probabilities of leopards are low, e.g., settlements, lakes and wetlands and open grasslands. However, extensive regions of shrublands mixed with grasslands, of which there are considerable amounts in SW Primorye (see map on habitat types) were also not included in survey routes (except where they occurred in small patches), with the assumption that leopards do not use these areas. Although this assumption is supported by analyses of movements of 5 radio-collared leopards in and around Kedrovya Pad Zapovednik (Augustine et al, unpubl. data), our analyses are by necessity restricted to those portions of the region where survey routes were located, or where characteristics of cells are similar to those where survey routes were situated. We did not attempt to extrapolate to regions/landscape characteristics for which there were insufficient data.

A second variable potentially biasing our analysis is the fact that topographic cells were sampled at different intensities. Of the 1707 cells delineated, 75% were sampled over the course of the 4 surveys, but the total distance covered by survey routes within a given cell varied from 12 m to 29 km. The probability of reporting presence of leopards or tigers in any given cell is likely to vary considerably with the sampling intensity.

We derived an estimate of sampling intensity as the density of survey routes for all 4 surveys collectively in any given cell (km survey routes/km^2 of cell). We investigated how track density (tracks/km transect) changed with sampling intensity (km survey routes/km^2 of cell) (Figure 3a), and then related sampling intensity to the probability of detecting presence of leopards using two measurements: 1) percentage of cells with leopard tracks (Figure 3b), and; 2) tracks/cell (Figure 3c). The range of values for transect density were sorted and divided into 20 equal-sized intervals (n = 64 cells/interval) to derive an average value for each interval.

As expected, track density fluctuated widely with low sampling intensity, but became more stable and varied relatively little when sampling effort reached 0.4 km/km^2 (Figure 3a), suggesting that sampling intensity lower than 0.4 km/km^2 provides low resolution (high variance) in assessing the value of cells as leopard habitat. Although estimates of both tracks/cell and percentage of cells with leopard tracks increased with increasing sampling intensity (Figures 3b-c), those cells with sampling intensity greater than 0.4 km/km^2 seem to break into two classes: those cells with sampling intensity between 0.4 and 1.5 km/km2, and those with greater sampling intensity. Above 1.5 km/km^2, the percentage of cells with tracks exceeds 20% in all but one case, and tracks/cell exceeds 0.3 except in one case. Both these changes reflect the effects of a higher sampling intensity.

The dramatic increase in track frequency in the more highly sampled cells is not due to an actual higher track density (which would occur if more intensively sampled cells were indeed areas of higher leopard density) because track density remains stable despite greater sampling effort (Figure 3a). The higher values of tracks/cell and percentage of cells with tracks is simply a reflection of more intensive sampling, i.e., the more an area is searched, the greater the probability of detecting leopard presence.

Use of all cells in our analysis would lead to a bias in assuming leopards were not present in some cells, when in fact absence may be due to low sampling effort. To adjust for this bias, we classified the 1707 topographic cells into four categories: 1) unsampled (no transects bisected these cells), 2) cells poorly sampled (less than 0.4 km/km^2); 3) cells moderately sampled (0.5-1.5 km^2), and, 4) cells well sampled (greater than 1.5 km/km^2) (Table 1) (Figure 4). For overall analyses we included all cells where presence of leopards was established (from any sampling category) in any one of the four surveys (n=198 cells) (except for the comparison to tiger presence – see below) to compare to those cells that were well sampled (sampling category 4) where leopards were not reported (n=330) (Table 1), resulting in a subsample total of 528 cells used for analyses. Although use of only cells well sampled (sampling category 4) reduced sample size and was biased in that some regions were oversampled (e.g. middle portions of Borisovskoe Plateau) it seemed preferable to restrict statistical analyses to this category to reduce the probability of mistakenly categorizing cells as unused by leopards when in fact they may have been used. Preliminary exploratory analysis suggested that most univariate tests of the effect of cell parameters were similar using either category 4 only or both category 3 and 4 cells, suggesting that the results were robust.

In comparing the relationship of presence of tigers and leopards in topographic cells, we restricted comparisons only to category 4 cells (i.e., deleted cells where leopards were present but sampling intensity was lower than 1.5 km/km^2) because probability of detecting tigers would be lower with decreased sampling intensity, even if leopards were detected.

Table 1. Relationship of sampling effort (km of survey route/km^2) to presence of leopards in 1707 topographic cells defined for analysis of spatial distribution of leopards in Southwest Primorski Krai, based on 4 surveys conducted between 1997 and 2000.

Category for topographic cells	Sampling intensity (km/km^2)	N	Total cells (%)	# cells with leopard tracks	# leopard tracks (n)	Cells with tracks (%)	Track density (tracks/cell)
1	not sampled	428	25.07	3*	3*	-	-
2	< 0.49	320	18.75	15	15	4.69	0.047
3	0.49 - 1.5	512	29.99	63	76	12.30	0.148
4	> 1.5	447	26.19	117	176	26.17	0.394
Total		1707	100	198	270	11.60	0.158

*tracks in unsampled cells represent both reports of tracks off transects, and mapping errors along cell boundaries.

Figure 3a. Effect of increasing sampling effort (transect density) on estimates of leopard track density (tracks/km of transect) in topographic cells in Southwest Primorski Krai, based on 4 surveys conducted between 1997 and 2000.

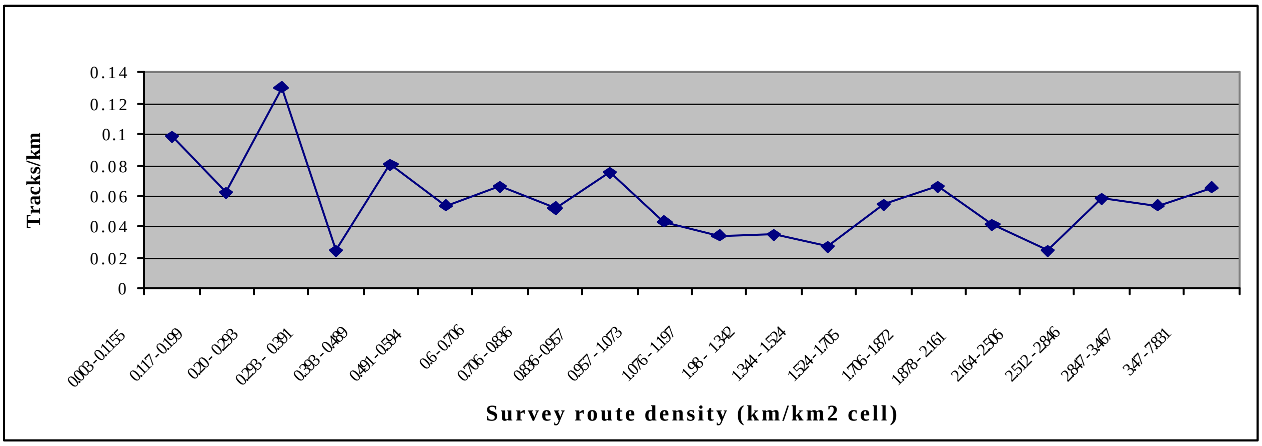


Figure 3b. Relation of sampling effort (km of survey route/km^2 of cell area) to percentage of cells with Far Eastern leopard tracks reported during 4 surveys in Southwest Primorski Krai, Russia, from 1997-2000.

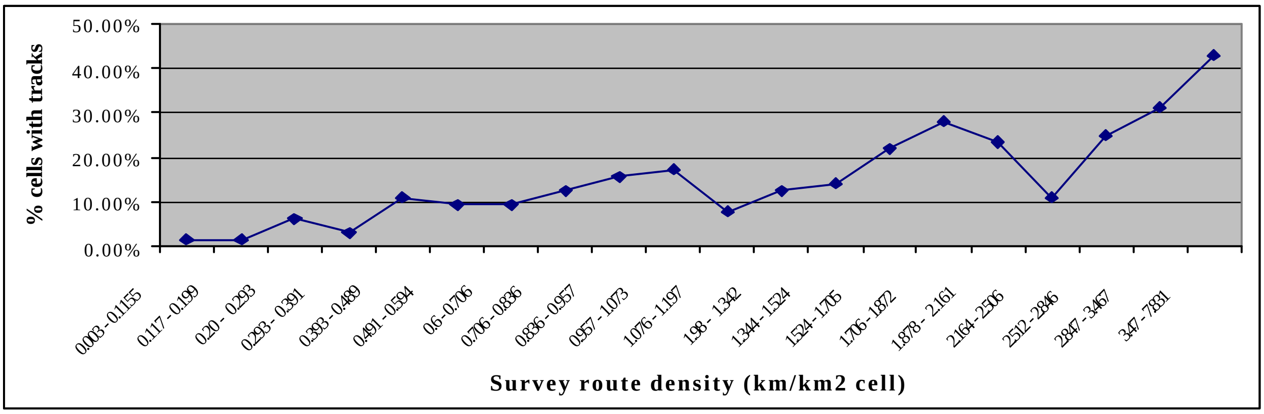
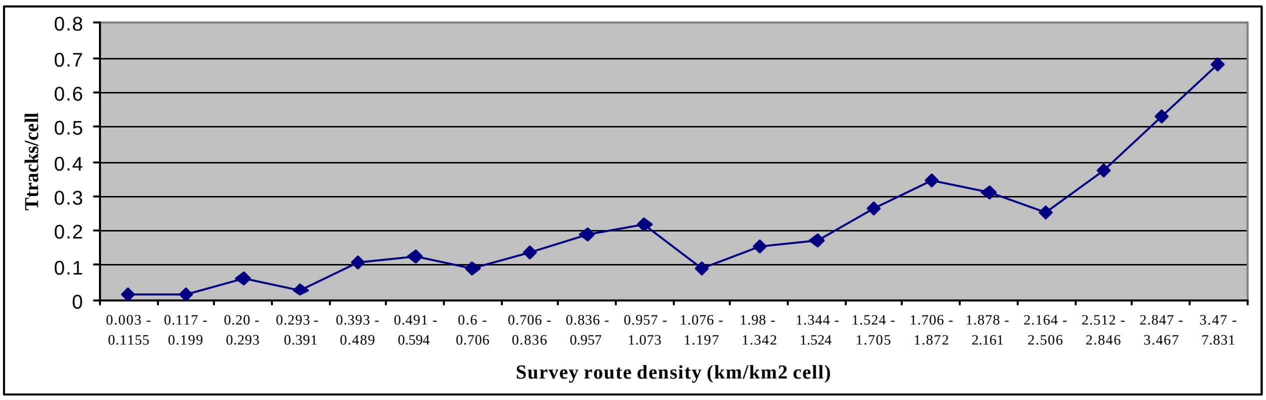


Figure 3c. Relation of sampling effort (km of transect/km^2 of cell area) to number of Far Eastern leopard tracks/topographic cell reported during 4 surveys in Southwest Primorski Krai, Russia, from 1997-2000.



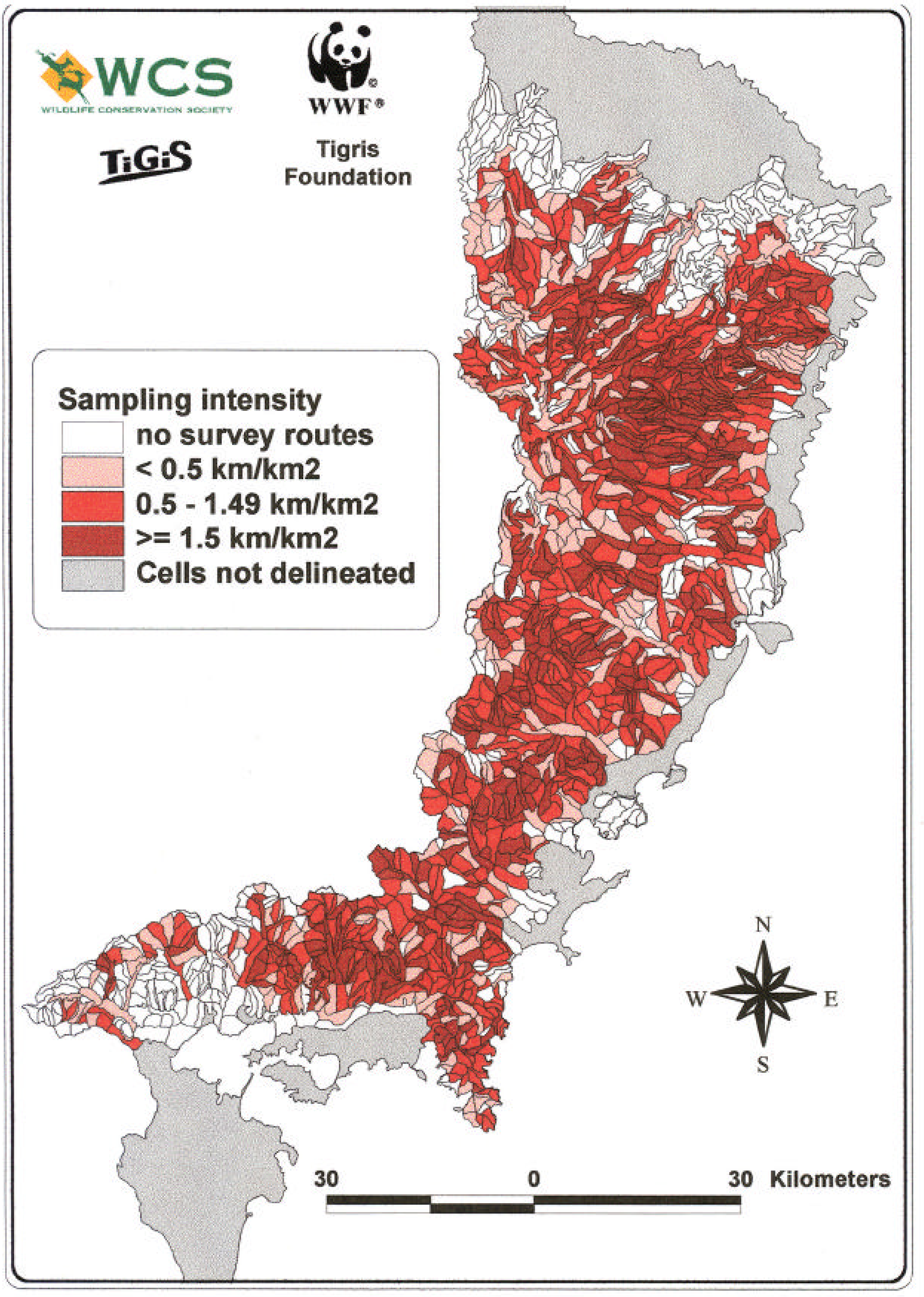


Figure 4. Distribution of topographic cells used as a basis for analysis of spatial distribution of leopards, and sampling intensity within those cells based on all four surveys of leopards conducted between 1997 and 2000.

Characteristics of Topographic Cells

We hypothesized that use of any given cell by leopards should be determined by the extent of human impacts, human landuse patterns, and natural characteristics of that cell (e.g., slope, elevation, plant community type, prey density, snow depth, etc.). Therefore, we defined each cell on the basis of whether leopard tracks were reported there (presence/absence) and characterized each cell on the basis of 16 anthropogenic and natural characteristics (Table 2) to assess which characteristics determine leopard presence. Although in other studies human impacts (e.g. traffic volume, recreational days in forests) have been directly measured, and can be modeled (e.g. Merrill et al. 1999), the type and extent of these impacts have not been directly measured in southwest Primorski Krai. Therefore, we developed conservative estimates of impacts based on our understanding of human uses of the region and commonly employed agricultural/husbandry practices.

In addition to these parameters for each cell, some characteristics of the landscape (e.g. deer farms and presence of tigers) required more detailed analysis to assess their relevance to leopard spatial distribution. Details of these methodologies are presented below as well as descriptions of cell characteristics for appropriate parameters.

Table 2. Parameters defined for each topographic cells to relative to presence/absence of Far Eastern leopards in Southwest Primorski Krai.

Parameter	Measurement units	Range of values
Human disturbance parameters		
1. Distance from settlement	km	1 m – 30 km
2. Settlement Impact Coefficient	? $(Area_{ik} * HCI_i * (Pop. Size/1000)/Area_{ik}$	0 - 45
3. Distance to closest road	km	0.3 m – 5.6 km
4 Road density	% of cell	0 – 20%
5.Primary travel corridors	% of cell	0 – 22%
Human landuse parameters		
6. Dominant land ownership	5 categories	
7. Dominant land use	9 categories	
8. Protected status	3 categories	
9. Proximity to border fence (KSP)	2 categories	
10. Proximity to deer farms	2 categories	
Natural parameters		
11. Slope	4 categories	
12. Aspect	9 categories	
13. Elevation	5 categories	
14. Habitat types	7 categories	
15 Tiger presence	2 categories	
16. Prey densities	$RelDen_k=(RD_{kboar}*1.0)+(RD_{ksika}*0.85)+(RD_{kroe}*0.4)$	0 - 182

Human Disturbance Parameters

Location of settlements was digitized from 1:100,000 maps of the region produced by State Geodesic and Cartography Service of the Russian Federation (created from 1976-1987) and then corrected using Landsat 7 satellite images. Population densities for each settlement were taken from "Publishing Office of PrimKraiStat Vladivostok 2000" which included data from 1999. The road and railway network for Southwest Primorye was digitized from 1:100,000 maps, then corrected using Landsat 7 imagery, and then categorized into 4 categories: 1) main roads; 2) secondary roads (gravel); 3) forest roads; 4) railroads. The following anthropogenic characteristics were defined for each cell from these data.

1. Distance from settlement. This factor was measured as the distance from the center of a settlement to the center of each cell, and then assigned to one of 4 categories (0-1 km, 1-5 km, 5-10 km, > 10 km);

2. Settlement impact coefficient (SIC). Most settlements are scattered along the coast in Southwest Primorski Krai (Figure 1), but use of the immediate surrounding regions for hayfields, gardens, gathering of wild plants as food and medicine, firewood collection, and hunting could all infringe and reduce habitat quality for leopards. We defined three circular impact zones that represent different types and intensities of use (based on typical village land-use practices of the region) and adjusted the impact with a Relative Impact Coefficient (RIC) based on the relative intensity of use, and settlement population size:

1) < 500 m, a region intensively used for gardening and livestock grazing, which was given an RIC = 1;

2) 500 m –5 km, where hayfields, livestock grazing, collection of non-timber forest products and firewood can be conducted by foot from the village center, where RIC = 0.1;

3) 5 km-10 km, where local hunting would be most intensive, but many activities would require use of a vehicle. This third zone was given a Relative Impact Coefficient of 0.01.

Impact in each of these zones were further adjusted by a multiple of the population size for each settlement, and the total Settlement Impact Coefficient (SIC) was summed (from all villages within 10 km) for each cell as:

$$SIC = ?\ (Area_{ik} * RIC_{i} * (\text{Village Population Size}/1000)/Area_{ik}),\ \text{where:}$$

i = 1,…I, represents each designated impact zone that lays within a cell;
k = 1,…K represents each topographic cell.

The resulting values for each topographic cell, which were logarithmic in character, were categorized as: zero impact (SIC = 0); low impact (0.00001 – 0.05); moderate impact (0.005 – 0.5), and heavy impact (0.5 – 45).

3. Distance to closest road. This factor was measured as the distance from the closest road to the center of the cell, which took on values from 0 to 20 km, and were classified into 6 categories: 1) < 50 m; 2) 50 – 199 m; 3) 200 – 499 m; 4) 500 – 999 m; 5) 1.0 – 1.9 km; 6) >= 2 km;

4. Road density. Road density was estimated for each cell by applying a buffer, or zone of impact, that varied with the type of road: primary roads were given a 40 m buffer; secondary gravel roads were given a 30 m buffer, and forest logging roads were given a 20 m buffer. The percent of the total area of each cell covered by the sum of the area of all roads and buffers was defined as road density, and categorized as: 1) 0%; 2) 0.001 – 1.49%; 3) 1.5 - 3.9%; 4) 4.0 - 6.9%; 5) 7.0 - 20%.

5. Proximity to primary travel corridors – Primary roads and railroads represent a human impact on a different order of magnitude than secondary and forest roads because human use and conversion of landscape is so much greater close to these travel corridors. Therefore, a special parameter was defined to delineate those cells that are part of these corridors. A 50-m zone was delineated around primary roads and all railways, and the impact of primary travel corridors was defined as a percent of the total area of each cell comprised of the total primary roads, railways, and their 50-m impact zones.

Human Landuse Parameters

6. Dominant Land Ownership. There are relatively few organizations (nearly all state-owned) that retain the right to own land in Russia, so categorization of land ownership is relatively easy. For Khasanski Raion, landowner data were digitized from 1:100,000 maps with data from 1998, while for Ussuriski and Nadeshdenski Raions data were digitized from 1:500,000 maps with data from 1995. Each cell was designated as one of 5 categories based on the dominate landowner. Where there was no dominant landowner (< 60% of a cell allocated to one agency), a 0 value was delineated.

1. Agricultural collectives, commercial transportation and energy collectives;
2. Townships, private lands, and reserved lands (undesignated use);
3. Specially protected territories (zapovedniks);
4. GosLesFund (State Forest Fund lands, administered by Russian Forest Service); and,
5. Other.

7. Dominant Land Use. Dominant landuse was mapped at the same resolution as land ownership, and each cell was designated as being used predominately for one of 9 categories:

1. Land under tillage, hayfields, and pastures;
2. Deer farms;
3. Forested lands;
4. Lakes, wetlands, marshes;
5. Zapovednik;
6. Shrublands; and,
7. Other.

8. Protected Status/hunting leases. Hunting leases and protected areas were mapped at 1:500,000 scale for the entire region of Southwest Primorski Krai, based on the most recent data from Primorski Krai Hunting Management Department, and Primorski Krai Department for Environmental Protection (2000). Each cell was designated as having one of three levels of protection: unprotected, zakaznik (Barsovy, Borisovskoe Plateau, and Paltovski), or zapovednik (Kedrovya Pad). Cells which included both protected and unprotected lands (representing 3% of cells analyzed) were allocated as protected.

9. Proximity to KSP. Extending along the border between China and Russia is a border protection barrier (often referred to as the "KSP"), which includes a 3-m high barbed fence, a 20-m zone of cleared vegetation, and a road that parallels the fence along its entire length (see Figures 4 and 5). This "KSP" varies from 2.5 to 12 km from the border with China. The KSP is patrolled by the Russian Border Guards, and the region between the KSP and China is technically not open to use. Thus these guarded lands could provide a secure region for leopards, acting much like a zapovednik. However, it is generally acknowledged that extensive hunting occurs within the KSP zone. Each cell was categorized as within the KSP boundary (between the fencing and China) or outside. Cells that were bisected by the KSP were excluded from analysis.

10. Proximity to deer farms. In Southwest Primorye there are 7 deer farms where sika deer are maintained in semi-domestic enclosures to harvest and sell antlers in velvet for the traditional Chinese medicine market. These deer farms are large, fenced enclosures where the density of sika deer, a natural prey species, exists at a level several orders of magnitude higher than in the surrounding forests. Leopards (and tigers) have relatively little trouble negotiating the fencing, and use deer farms extensively. It has been hypothesized that deer farms may even represent critical habitat for leopards, and that an inordinate number of females with young rely on deer farms as a sure source of prey (e.g. Pikunov et al. 2000, Aramilev and Fomenko 2000).

We designated all cells within 2 km of deer farms as “close to deer farms”, and cells greater than 2 km as “far from deer farms” to assess proximity to deer farms as a factor explaining presence and absence of leopards in topographic cells.

Natural Parameters

11. Slope. Slope and aspect were the key elements used in defining each cell. We used one of four categories to characterize slope: ridgetops, valley bottoms, slopes, and deltas. Deltas were excluded from analyses due to small sample sizes.

12. Aspect. Nine categories were defined: north, northeast, east, southeast, south, southwest, west, northwest, and flat.

13. Elevation. A digital elevation model (DEM) was constructed from 100 m contour intervals, peak elevations (point locations), and the river system (TOPOGRID in ARCINFO) using 1:100,000 maps of the region produced by State Geodesic and Cartography Service of the Russian Federation (created from 1976-1987). Average elevation for each cell was determined by the average of all grids within each cell.

14. Habitat types. Dominant vegetative categories were defined using a Landsat 7 image (resolution to 30m) from Sept. 20, 1999. Classification was accomplished using GRASS GIS and ArcView Image Analyst, using a combination of automatic and semiautomatic classification processes, followed by intensive ground-truthing in well-defined areas with known forest habitat types. The process resulted in 17 identifiable cover types, which for our purposes were collapsed into 8 categories:

1. Broadleaved-Korean pine-Black fir forests (deciduous trees dominant);
2. Korean pine-broadleaved-black fir forests (coniferous trees dominant);
3. Broad-leaved forests (dominated by oak);
4. Narrow-leaved forests (dominated by birch);
5. Riverine forests;
6. Grasslands/shrublands
7. Agricultural fields, villages (human-dominated landscapes);
8. Lakes, wetlands.

We deleted lakes and wetlands from the analysis, and we assigned a cell a dominant habitat type if at least 60% of that cell were comprised of one habitat type. Other cells were given a 0 value and not included in this analysis.

15. Tiger Presence. It has been hypothesized that tigers and leopards compete directly for space and resources, and that tigers have the capacity to exclude leopards from some regions (Aramilev and Fomenko 2000). We therefore assigned each cell a “tiger present value” if tracks of tigers were located in a cell from any survey. Tiger locations were not reported in the 1997 survey.

To further assess this relationship, we developed coverages of relative track density estimates based on a kernel estimator using the standard ARCVIEW density estimate (in SPATIAL ANALYSIS), for both leopards and tigers, and then overlaid track densities to determine if there existed overlap areas where densities of both leopard and tiger tracks were high.

Both of the above analyses for tiger-leopard overlap assess the differences in spatial distribution over all surveys combined. If spatial separation is more immediate (e.g. leopards vacate areas where tigers occur, but reoccupy in the absence of tigers) the above analyses may mask the temporal component of spatial segregation. If tigers and leopards are spatially separating on a more temporal basis, we predicted that: 1) for any given survey, tiger tracks would be more likely closer to other tiger tracks than leopard tracks (and leopard tracks closer than to other leopard tracks) than to the other species (i.e., the nearest neighbor to any given track is more likely to be of the same species than the other). Secondly, we predicted that the average distance between nearest neighbor tracks would be larger for leopard-tiger combinations than for tiger-tiger or leopard-leopard tracks. We report the nearest neighbor to each tiger and leopard track (resulting in 4 possible combinations: leopard-leopard, leopard-tiger, tiger-tiger, and tiger-leopard) and measured the distance between each track and its nearest neighboring for each survey separately (excluding the 1997 survey, for which no data on tigers exists). We then compared the ratio of these associations to expected ratios (based on the relative abundance of tiger and leopard tracks in each survey), assuming random distribution of tracks, and measured the distance between tracks to compare mean distances between three pairs of tracks (tiger-tiger, leopard-leopard, and tiger-leopard). An unbalanced ANOVA (SAS GLM 1999) was employed, using pair type (tiger-tiger, leopard-leopard, and tiger-leopard) and survey (1998, 2000 Aramilev, 2000 Pikunov) as variables.

16. Prey densities. Leopards prey on a wide variety of mammalian and avian fauna, but in winter their predominant diet is comprised of ungulates, the most common of which are sika deer, roe deer, and wild boar (Pikunov and Korkishko 1992). In the 2000 survey, fresh tracks (estimated as less than or equal to 24 hours old) of all ungulate species crossing survey routes were counted to provide an index of relative density (RelDen) of prey species (tracks/10 km transect). To estimate relative ungulate abundance for each cell, we combined the abundance index for each transect, and adjusted for relative length of transects within a cell:

$$RelDen_{jk} = ?\ \{Length_{ik}/?\ (Length_{ik})\} * Density_{ij},$$

where $Length_{ik}$ = length of ith survey route in the kth topographic cell;
$Density_{ij}$ = track density (tracks/10 km) of the jth ungulate species on the ith survey route;
i = 1…I, where I = number of survey routes in the kth topographic cell;
j = 1…J, where J = number of ungulate species reported in the cell; and,
k = 1…K, where K = number of topographic cells.

Using the three most common and important ungulate prey species, relative density of each species was combined into a single estimate of relative numbers of prey weighted, for each track, by the relative weight of each species. We used weights of adult females as a weighting factor (0.4 for roe deer, 0.85 for sika deer, and 1 for wild boar) because they are often the most dominant component of an ungulate population, and information on female weights exists (Bromley and Kucherenko 1983). Using this weighting factor, we were able to derive an estimate of relative density of ungulates for each cell:

$$RelDen_k = (RelDen_{kboar} * 1.0) + (RelDen_{ksika} * 0.85) + (RelDen_{kroe} * 0.4).$$

Analysis of Spatial Distribution of by Leopards

We used a combination of univariate and multivariate statistical tests to assess the importance of natural and human-related variables on distribution of leopards in Southwest Primorye. We first conducted likelihood ratio chi-square tests (SAS 1996) on all 16 variables to test their relation to presence of leopards. We then constructed a logistic model using stepwise logistic regression to define characteristics of cells used by leopards, incorporating

15 of the 16 parameters in the first iterations of the model (ungulate data was not complete for all surveys).

To define suitable habitat of leopards, we used those parameters selected by both the logistic regression model and univariate analyses to determine which components of each parameter were most closely associated with leopard presence. We estimated the strength of this association by comparing results to actual presence of leopards in topographic cells to identify minimally suitable, slightly preferred, moderately preferred, and highly preferred habitat.

Tracks of females with young (both leopards and tigers) were plotted separately to define areas of high importance for reproducing females.

We developed a map of present leopard distribution in Southwest Primorye by creating a buffer around each track of 1.8 km, which represents half the radius of an average home range for an adult female (40 km^2) (Augustine and Miquelle 1996). Assuming that, on average, each animal is represented by numerous tracks in our survey, creating a full home range buffer around each track would greatly exaggerate total area used by leopards.

A map of recommended management zones was based on cumulative results of this analysis, using the map of preferred habitat and existing leopard distributions as basis for determining priority areas for protection and special management regimes.

RESULTS

Univariate Statistical Analyses

Human disturbance parameters

Of the five human disturbance parameters measured (Tables 3-7), only distance to nearest road was significantly associated with presence of leopards in topographic cells (likelihood ratio chi square $G = 12.577$ df= 5, $P = 0.028$) (Table 5, Figure 5). This relationship, however, was not linear, i.e., leopard presence was not correlated with increasing distance from roads (Figure 5). Instead, leopards showed a preference for intermediate distances (0.5 – 2 km from roads) (Table 5). A large portion of the total chi square value is due to an avoidance of cells greater than 2 km from roads, which occur predominately in the upper reaches of the Borisovkoe Plateau (Figure 5), a region where leopards were not reported during the four surveys.

The absence of an association between leopard presence and human impacts is probably due to two factors. First, areas closest to human settlements and primary roads were rarely sampled, and therefore are largely already excluded from these analyses. Hence, a lack of significance simply reflects a lack of adequate sampling across all zones. But more importantly, these results indicate that, although roads do negatively impact leopards, proximity to other human disturbances did not play a major role in determining distribution of leopards (Figure 6). A comparison of settlement impact zones and the extensive road network in Southwest Primorski Krai to distribution of leopard tracks suggests that leopards can tolerate substantial anthropogenic impacts (Figure 6). Across Southwest Primorski Krai, human-dominated landscapes are predominant in the low elevation, coastal zones, and the extensive network of roads makes almost the entirety of the region accessible by vehicle (Figure 6). Although leopard tracks were virtually absent within 500 m of settlements, tracks were commonly reported within the next two buffer zones (500 m -5 km and 5-10 km). Leopards did not demonstrate an inverse correlation to human disturbance – in fact those regions furthest from settlements and roads were least used.

Table 3. Relationship of distance to closest settlement to presence of leopards in 528 topographic cells well sampled (> 1.5 km/km^2) in Southwest Primorski Krai, based on 4 surveys, 1997-2000.

	Leopards Absent (n = 330) (% cells)	Leopards Present (n = 198) (% cells)
Distance to closest settlement		
0 - 0.9 km	2.1	1.0
1 - 4.9 km	23.3	25.8
5 - 9.9 km	34.2	35.4
> 10 km	40.3	37.9
Total	100.0	100.0

G* = 1.496, P = 0.683

*G = Likelihood ratio chi square

Table 4. Relationship of immediate human population pressures (IMPP) from settlements to presence of leopards in 528 topographic cells well sampled (> 1.5 km/km2) in Southwest Primorski Krai, based on on 4 surveys, 1997-2000.

	Leopards Absent (n = 330) (% cells)	Leopards Present (n = 198) (% cells)
IMPP		
0	37.3	31.8
0.001 - 0.05	44.2	46.0
0.05 - 0.5	15.2	19.2
0.5 - 45	3.3	3.0
Total	100	100

G* = 2.368, P = 0.500

*G = Likelihood ratio chi square

Table 5. Relationship of distance to closest road to presence of leopards in 528 topographic cells well sampled (> 1.5 km/km^2) in Southwest Primorski Krai, based on 4 surveys, 1997-2000.

	Leopards Absent (n = 330) (% cells)	Leopards Present (n = 198) (% cells)
Distance to closest road		
< 50m	4.5	2.5
50 - 199 m	13.3	8.6
200 - 499 m	24.9	24.2
500 - 999 m	22.7	31.3
1-2 km	24.2	28.3
> 2 km	10.3	5.0
Total	100.0	100.0

G* = 12.577, P = 0.028

*G = Likelihood ratio chi square

Table 6. Relationship of road density (% of cell occupied by roads and their buffer zones) to presence of leopards in 528 topographic cells well sampled (> 1.5 km/km^2) in Southwest Primorski Krai, based on 4 surveys, 1997-2000.

	Leopards Absent (n = 330) (% cells)	Leopards Present (n = 198) (% cells)
Road density (% of cell)		
0	31.8	25.3
0.001-1.49	20.9	27.3
1.5-3.9	20.9	24.8
4.0-6.9	12.4	13.6
7.0-20	13.9	9.1
Total	100	100

G* = 7.41, P = 0.116

*G = Likelihood ratio chi square

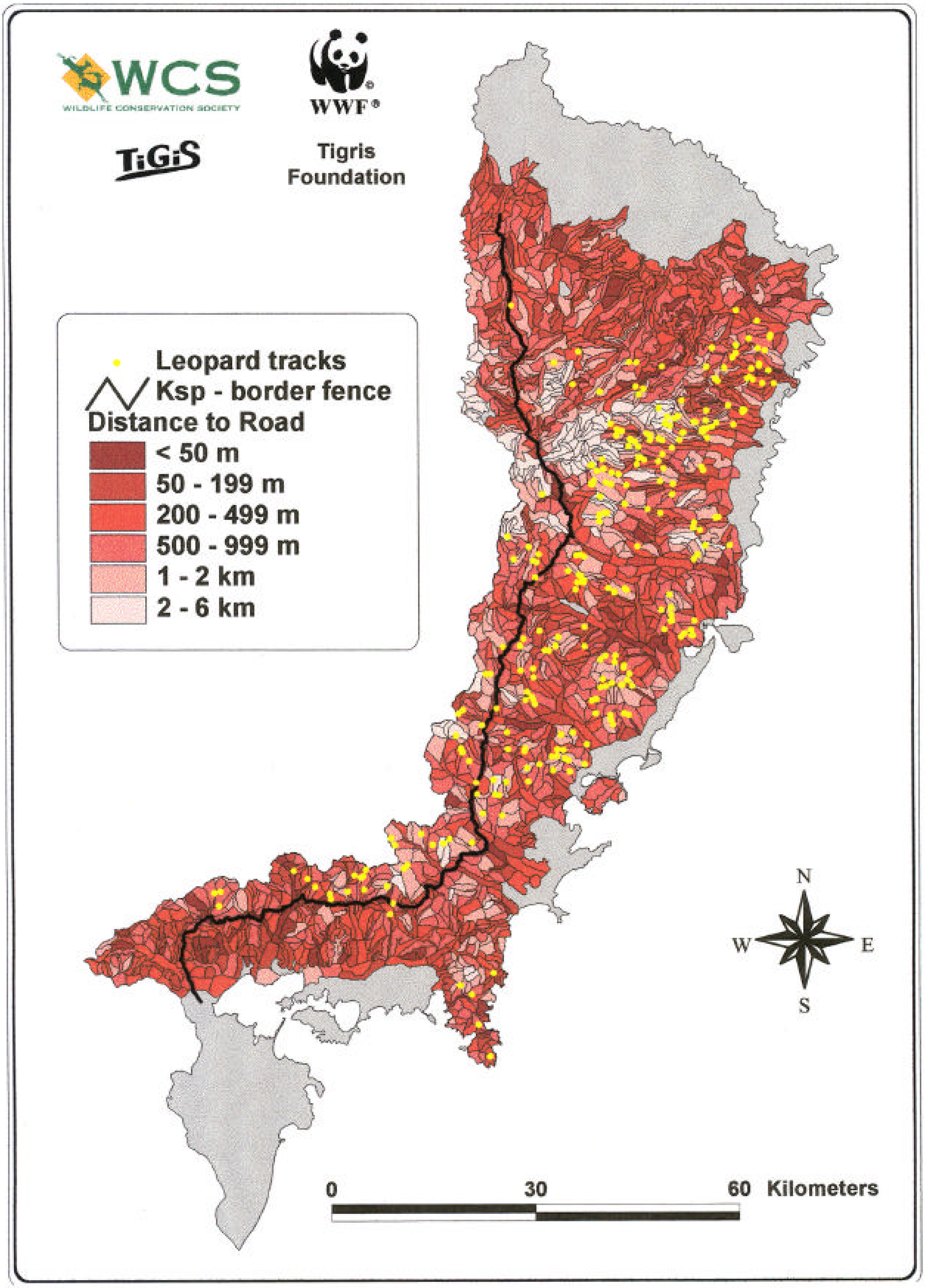


Figure 5. Distance from roads for all cells included in analysis of spatial distribution of leopards in Southwest Primorski Krai, and location of leopard tracks, based on 4 surveys conducted between 1997 and 2000.

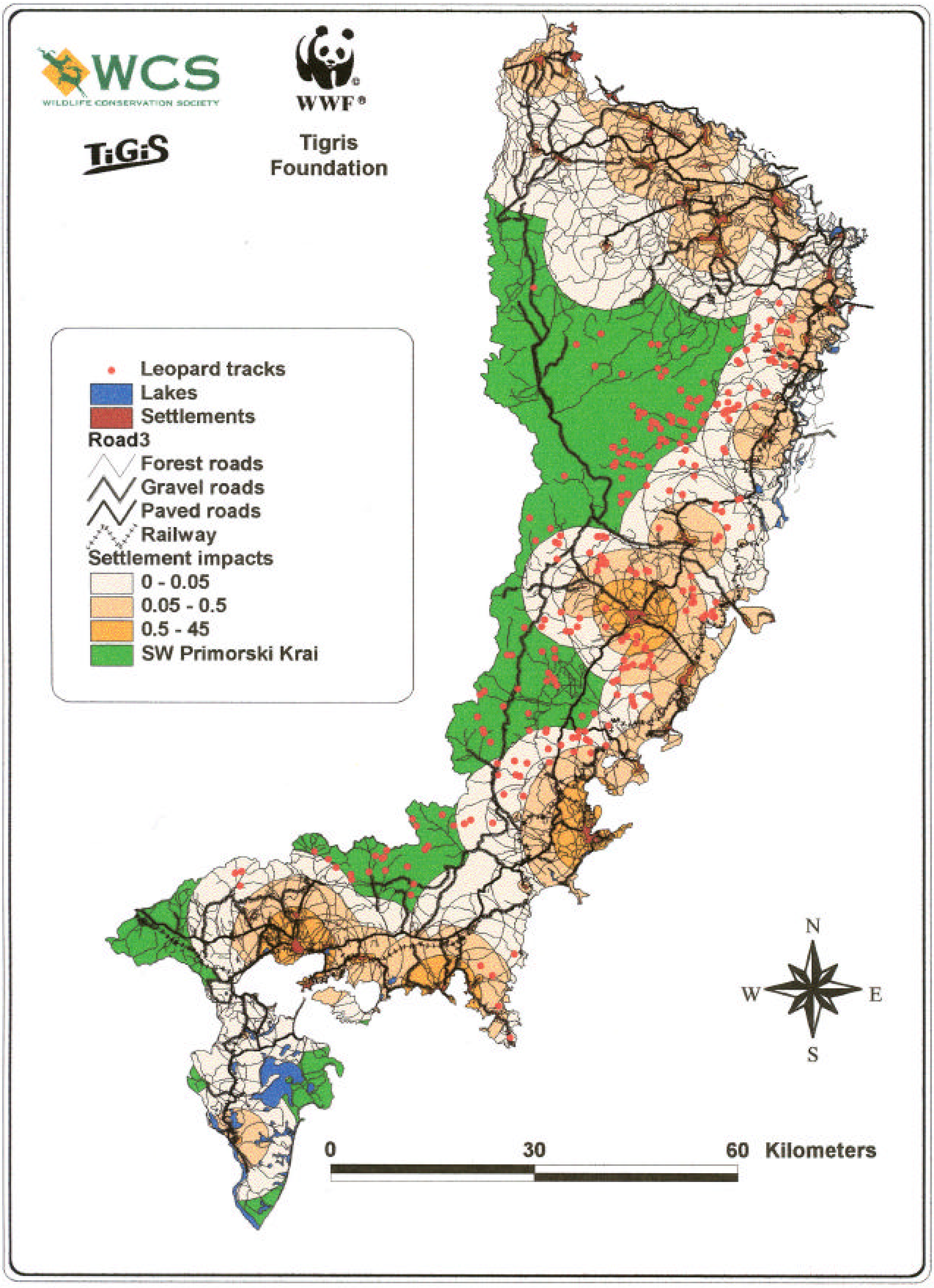


Figure 6. Human population pressures (reported in concentric buffers around settlements) and the road network in Southwest Primorski Krai, in comparison to location of leopard tracks reported in 4 surveys between 1997 and 2000.

Table 7. Relationship of primary travel corridors (main roads and railways) and their buffer zones) to presence of leopards in 528 topographic cells well sampled (> 1.5 km/km^2) in Southwest Primorski Krai, based on 4 surveys, 1997-2000.

	Leopards	
	Absent	Present
	(n = 330)	(n = 198)
	(% cells)	(% cells)
Road density (% of cell)		
0	92.4	87.9
0.006-2.9	4.2	6.1
3 - 22	3.3	6.1
Total	100	100
G* = 3.132, P = 0.209		

*G = Likelihood ratio chi square

Table 8. Relationship of land ownership to presence of leopards in 528 topographic cells well sampled (> 1.5 km/km^2) in Southwest Primorski Krai, based on 4 surveys, 1997-2000.

	Leopards	
	Absent	Present
	(n = 330)	(n = 198)
	(% cells)	(% cells)
Land Ownership		
Agricultural	23.0	25.4
Settlements	13.9	15.2
Zapovednik	2.4	6.1
State Forest Fund	60.6	53.3
Total	100	100
G* = 5.760, P = 0.124		

*G = Likelihood ratio chi square

Table 9. Relationship of dominant landuse to presence of leopards in 528 topographic cells well sampled (> 1.5 km/km^2) in Southwest Primorski Krai, based on 4 surveys, 1997-2000.

	Leopards	
	Absent	Present
	(n = 330)	(n = 198)
	(% cells)	(% cells)
Dominant land use		
Pastures, Agr. Fields	14.6	8.1
Deer Farms	3.9	9.6
Forested	65.5	66.0
Zapovednik	3.3	6.1
Shrublands	0.3	1.52
Other	12.41	8.63
Total	100	100
G* = 16.872, P = 0.010		

*G = Likelihood ratio chi square

Table 10. Relationship of protected status of lands and presence of leopards in in 528 topographic cells well sampled (> 1.5 km/km^2) in Southwest Primorski Krai, based on 4 surveys, 1997-2000.

	Leopards	
	Absent	Present
	(n = 330)	(n = 198)
	(% cells)	(% cells)
Protected status		
Unprotected	54.2	45.5
Zakaznik	41.8	47.0
Zapovednik	3.9	7.6
Total	100	100
G* = 5.621, P = 0.060		

*G = Likelihood ratio chi square

Table 11. Relationship of border patrol fence (KSP) to presence of leopards in 528 topographic cells well sampled (> 1.5 km/km^2) in Southwest Primorski Krai, based on 4 surveys, 1997-2000.

	Leopards	
	Absent (n = 330) (% cells)	Present (n = 198) (% cells)
Border patrol fence (KSP)		
Outside KSP	83.6	82.9
Inside KSP	16.4	17.1
Total	100.0	100.0
G* = 0.048, P = 0.827		

*G = Likelihood ratio chi square

Table 12. Relationship of deer farms to presence of leopards in 528 topographic cells well sampled (> 1.5 km/km^2) in Southwest Primorski Krai, based on 4 surveys, 1997-2000.

	Leopards	
	Absent (n = 330) (% cells)	Present (n = 198) (% cells)
Distance to closest deer farm		
> 2 km	91.2	81.8
<= 2 km	8.8	18.2
Total	100.0	100.0
G* = 9.783, P = 0.002		

*G = Likelihood ratio chi square

Table 13. Relationship of elevation to presence of leopards in 528 topographic cells well sampled (> 1.5 km/km^2) in Southwest Primorski Krai, based on 4 surveys, 1997-2000.

	Leopards	
	Absent (n = 330) (% cells)	Present (n = 198) (% cells)
Elevation (m)		
7 - 124	24.6	20.7
125 - 249	34.6	42.9
250 - 374	21.2	25.8
375 - 499	13.4	9.1
> 500	6.1	1.5
Total	100.0	100.0
G* = 13.272, P = 0.010		

*G = Likelihood ratio chi square

Table 14. Relationship of slope to presence of leopards in 528 topographic cells well sampled (> 1.5 km/km^2) in Southwest Primorski Krai, based on 4 surveys, 1997-2000.

	Leopards	
	Absent (n = 330) (% cells)	Present (n = 198) (% cells)
Slope		
Ridgetops	6.1	1.0
Valleys	13.9	8.1
Slopes	80.0	90.9
Total	100.0	100.0
G* = 14.873, P = 0.001		

*G = Likelihood ratio chi square

Table 15. Relationship of aspect to presence of leopards in 528 topographic cells well sampled (> 1.5 km/km^2) in Southwest Primorski Krai, based on 4 surveys, 1997-2000.

		Leopards	
		Absent (n = 330) (% cells)	Present (n = 198) (% cells)
Aspect			
	North	13.3	11.6
	Northeast	9.1	14.1
	East	11.5	13.6
	Southeast	14.6	12.1
	South	14.6	17.7
	Southwest	12.1	14.1
	West	7.88	8.59
	Northwest	10.91	7.07
	Flat	6.06	1.01
	Total	100	100
	G* = 16.621, P = 0.034		

*G = Likelihood ratio chi square

Table 16. Relationship of habitat type to presence of leopards in 528 topographic cells well sampled (> 1.5 km/km^2) in Southwest Primorski Krai, based on 4 surveys, 1997-2000.

		Leopards	
		Absent (n = 290) (% cells)	Present (n = 198) (% cells)
Habitat type**			
	Korean pine	26.2	31.6
	Oak	38.3	50.9
	Birch	21.7	14.1
	Riverine	2.1	1.7
	Grass/shrub	11.7	1.7
	Total	100.0	100.0
	G* = 13.272, P = 0.010		

*G = Likelihood ratio chi square

**Habitat types with small sample sizes (human impacted cells, wetlands) and all cells without a dominant habitat type (>60% of cell) were excluded from analysis.

Table 17. Relationship of tiger presence to presence of leopards in 528 topographic cells well sampled (> 1.5 km/km^2) in Southwest Primorski Krai, based on 4 surveys, 1997-2000.

		Leopards	
		Absent (n = 330) (% cells)	Present (n = 117)** (% cells)
Tigers			
	Absent	87.9	81.2
	Present	12.1	18.8
	Total	100.0	100.0
	G* = 3.059, P = 0.080		

*G = Likelihood ratio chi square

**Only cells well sampled (Sampling category 4) were included to avoid bias of low sampling intensity in cells where leopard tracks were found.

Table 18. Relationship of relative ungulate density** to presence of leopards in topographic cells well sampled in Southwest Southwest Primorski Krai, winter 2000

		Leopards*	
		Absent (n = 105) (% cells)	Present (n = 24) (% cells)
Relative Ungulate Density**			
	Low	34.3	25
	Moderate	37.1	20.8
	High	28.6	54.2
	Total	100.0	100.0
	G*** = 5.880, P = 0.053		

*Leopard presence/absence inferred from Pikunov et al. (2000) and Aramilev and Fomenko (2000).

**See text for definition of relative ungulate density.

***G = Likelihood ratio chi square.

Leopards appeared to use the middle portions of these extremes – neither those regions closest to human settlements and highest road densities, nor those regions furthest from these factors. However, roads do appear to be associated with fragmentation points in leopard distribution (Figures 15, 16), and their impact must be considered in management recommendations.

Human Landuse Parameters

Human landuse parameters played a more important role in defining spatial distribution of leopards than human disturbance factors (Tables 8-12).

Land ownership/land use. Although land ownership was not related to presence of leopards (Table 8), there was a strong relationship between the dominant land use by humans and leopard presence (Table 9, Figure 7). Agricultural lands and hayfields were avoided, deer farms and zapovednik lands were preferred, and forests were used approximately in relation to their availability (neutral selection).

Protected status/hunting leases. The protected status of lands appeared to partially explain distribution patterns of leopards. In general, leopard tracks were more likely to be found inside protected areas (both zapovednik and zakazniks) than expected (Figure 8), but this trend was not significant ($P = 0.060$, Table 10). Protected areas, which cover 40% of Southwest Primorski Krai, contained 55% of all recorded leopard tracks, but not all protected areas are used by leopards. Leopards were distributed throughout Barsovy Zakaznik, and are clearly concentrated in Kedrovya Pad Zapovednik, but leopards only occurred in the easternmost section of Borisovkoe Plateau Zakaznik (partly created for protection of leopards) (Figure 8), and are absent from Poltavski Zakaznik (which was never intended to protect leopards). Neither Khasanski Nature Park (created to protect wetlands) or the Far Eastern Maritime Zapovednik (which is an aquatic reserve) contain leopard habitat. An index of the relative value of lands (based on track density from all 4 surveys combined) suggests that leopard use of protected lands is in general higher than in adjacent hunting leases (Table 19). The one exception was in the lower Borisovkoe Plateau region, within lands leased by the Neshinskoe Naval Hunting Society (Table 19, Figure 8). The relative value of lands (for leopards, based on track density for all 4 surveys) leased to the Neshinskoe Naval Hunting Society is exceeded only by Kedrovya Pad Zapovednik (Table 19).

Border Patrol Fence (KSP). No relationship was found between the distribution of leopards and the border patrol fence (KSP) (Table 11). Leopards were just as likely to be found on both sides of the fence (e.g., see Figure 5). Although the fence may act as a barrier to other wildlife (including prey species), it does not appear to inhibit movement of leopards.

Deer farms. As has been noted repeatedly in the past, deer farms proved to be a strong attractant for leopards (Figure 9): leopard tracks were much more likely to be found within 2 km of deer farms than elsewhere (Table 12)

There are, however, dramatic differences in the frequency with which different deer farms are used by leopards (Table 20, Figure 9). Of the six deer farms in Southwest Primorye, only 3 were intensively used. There were no tracks recorded in any of the 4 surveys at Monakeno, while 47 leopard tracks (17% of all tracks reported, and 66% of tracks reported within 2 km of any deer farm) were recorded at Kedrovski Deer Farm. Based on survey data, it is clear that Kedrovski, Pechanya, and Bezverkovski Deer Farms are much

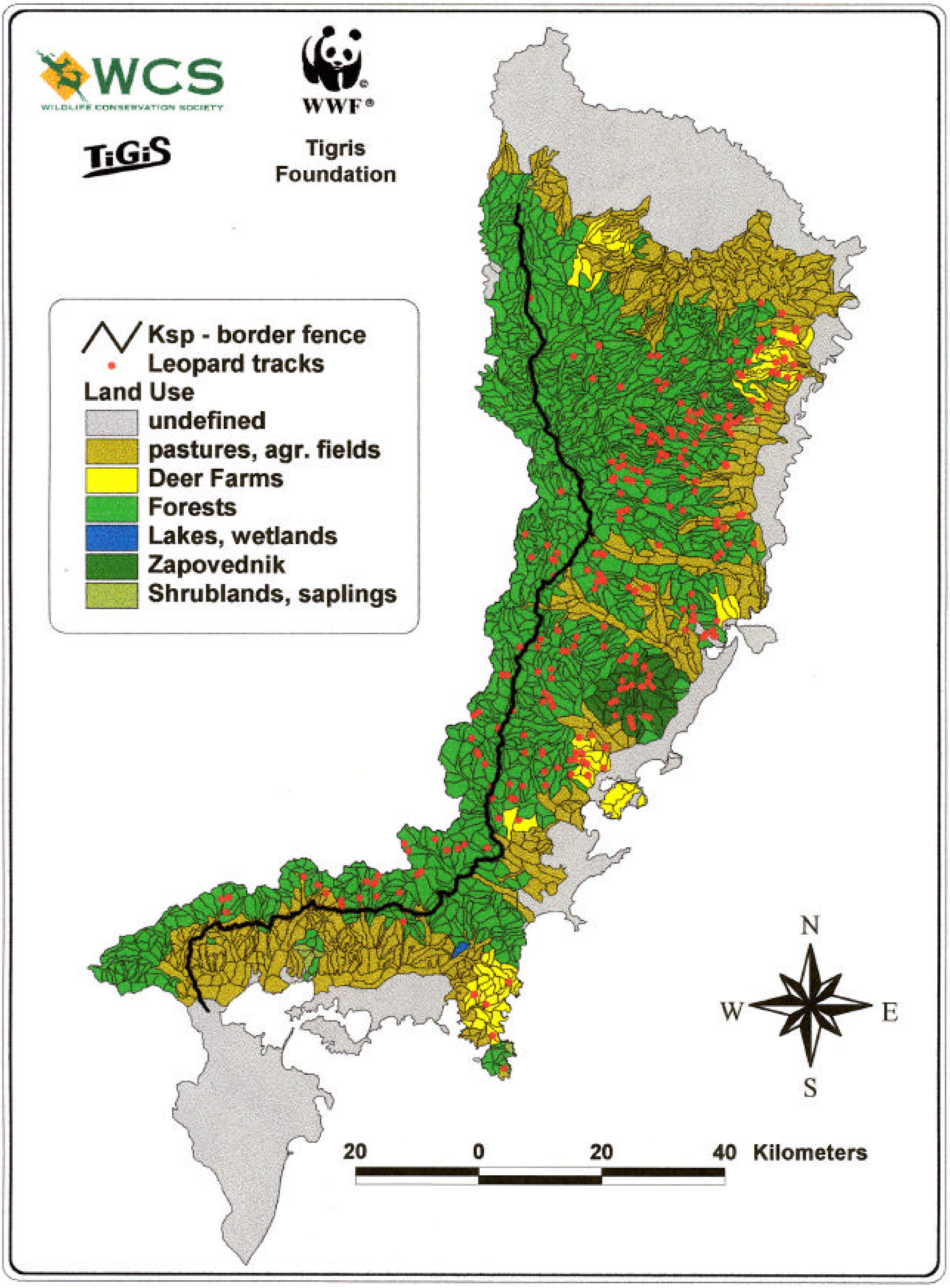


Figure 7. Human landuse patterns in relation to leopard tracks in Southwest Primorski Krai, based on 4 surveys of leopards between 1997 and 1998.

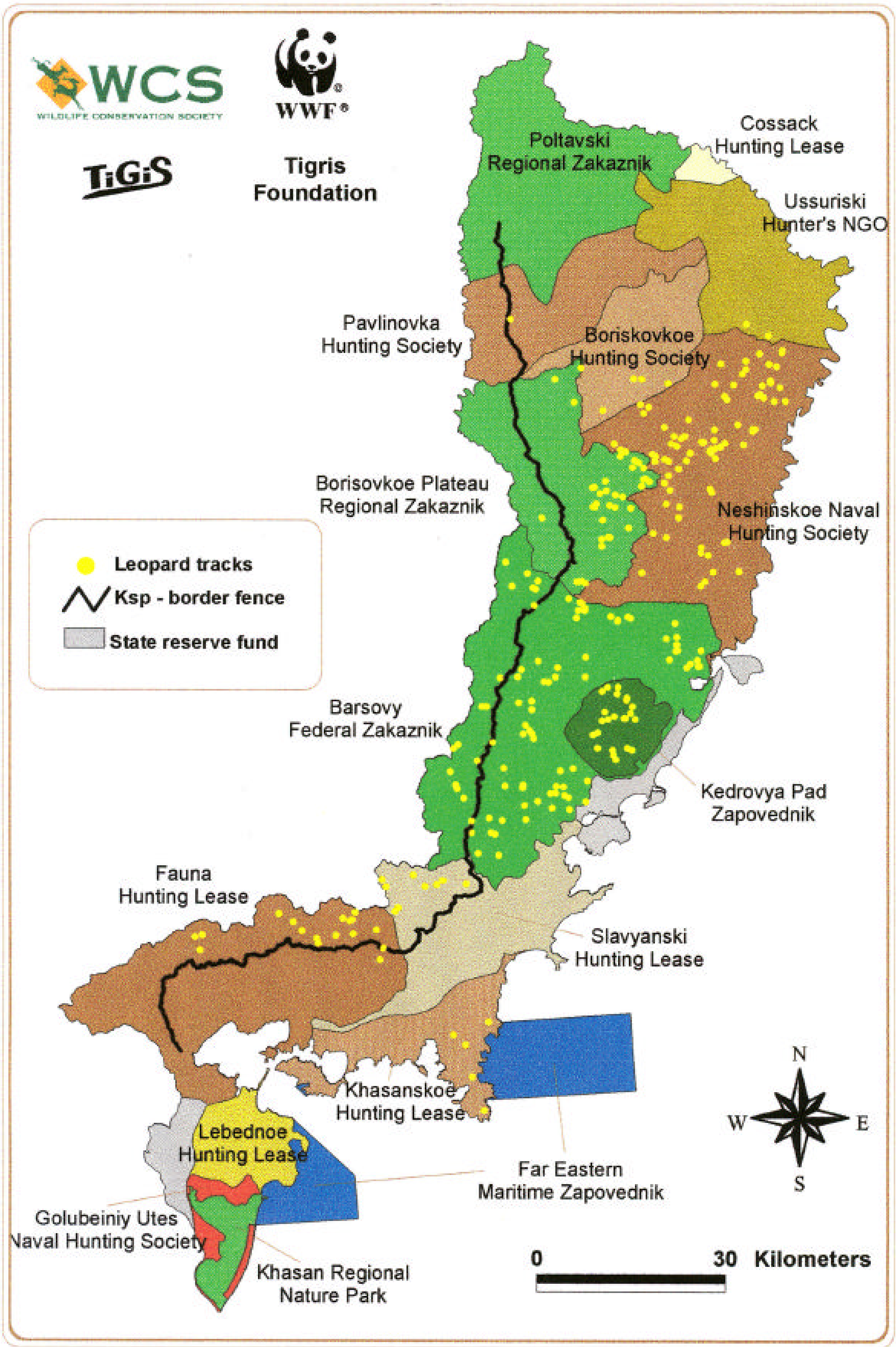


Figure 8. Protected areas and hunting leases in relation to distribution of leopards, based on 4 surveys conducted in Southwest Primorski Krai between 1997 and 2000.

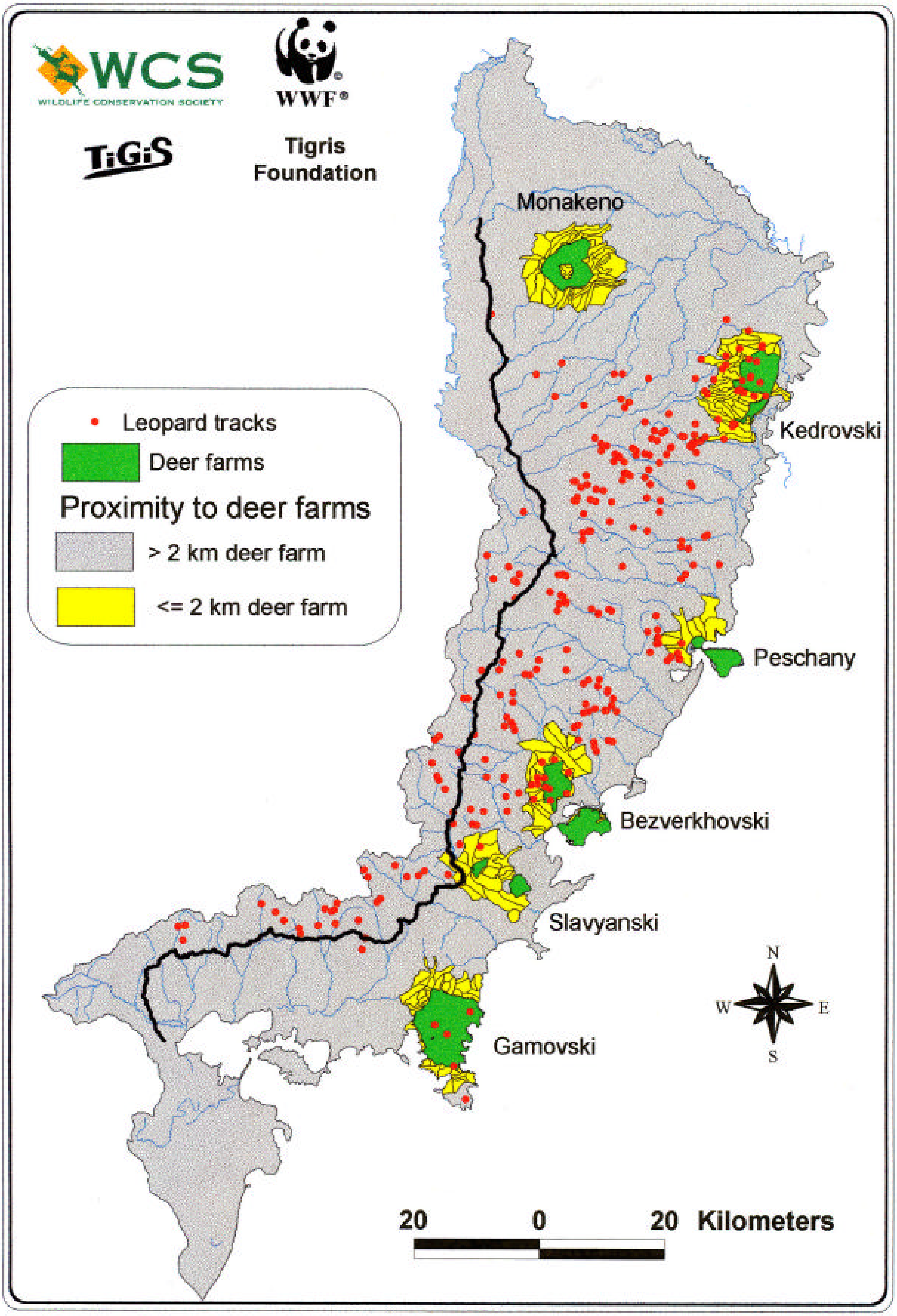


Figure 9. Relationship of deer farms and distribution of leopard tracks, based on 4 surveys conducted in Southwest Primorski Krai between 1997 and 2000.

Table 19. Area, number of leopard tracks, percentage of total tracks, relative value (based on overall track density), and amount of suitable habitat (% of of all suitable habitat) on protected territories and hunting leases in Southwest Primorski Krai, based on cumulative occurrence of leopard tracks from 4 surveys, 1997-2000.

Status	Area	Area (km^2)	Number of leopard tracks	Percent of total tracks (%)	Relative value of area (tracks/10 km^2)	Percent total suitable habitat***
Protected areas						
	Kedrovya Pad Zapovednik	180	23	8.5	1.278	5.4
	Barsovy Federal Zakaznik	1219	89	33.0	0.730	27.1
	Borisovkoe Regional Zakaznik	613	38	14.1	0.620	8.9
	Khasanki Regional Nature Park	98	0	0.0	0.000	0.0
	Poltavski Regional Zakaznik	753	0	0.0	0.000	4.7
	Far Eastern Maritime Zapovednik**	-	-	-	-	0.0
Hunting leases						
	Neshinskoe Naval Hunting Society	1025	81	30.0	0.790	19.0
	Fauna Hunting Lease	901	17	6.3	0.189	9.9
	Slavyanski Hunting Lease	530	9	3.3	0.170	9.5
	Khasankoe Hunting Lease	302	5	1.9	0.166	4.5
	Borisovkoe Hunting Society	362	5	1.9	0.138	5.7
	Ussuriski Hunter's NGO	506	2	0.7	0.040	0.2
	Pavlinovka Hunting Society	409	1	0.4	0.024	5.1
	Cossak Hunting Lease	39	0	0.0	0.000	0.0
	Golubeiniy Utes Hunting Society	166	0	0.0	0.000	0.0
	Lebednoe Hunting Lease	194	0	0.0	0.000	0.0
	Total**	6446	270	100	0.419	100

*Maritime zapovednik does not include land area.
**Total area of region was adjusted to accoount for overlapping jurisdictions of of Khasanksi Nature Park and Golubeiniy Hunting Society
***See Figure 16

more important than Monakeno, Slavyanski, and Gamovski Deer Farms. Slavyanski Deer Farm has fallen into disrepair, and no longer holds sika deer, explaining the absence of leopards. Both tigers and leopards use Gamovski Deer Farm, but poor barriers to travel between this peninsula and the main forested area closer to the KSP may explain the relatively low use of this farm. If deer farms are to be incorporated into a conservation strategy for leopards, it is clear that developing a working relationship with Kedrovski Deer Farm should be of highest priority, and increasing suitable habitat around other farms (such as Gamovski) could greatly increase the amount and quality of existing leopard habitat.

Natural Parameters

Elevation. Elevation was strongly associated with spatial distribution of leopards (Table 13, Figure 10). Leopards were more commonly located in the mid-range elevations,

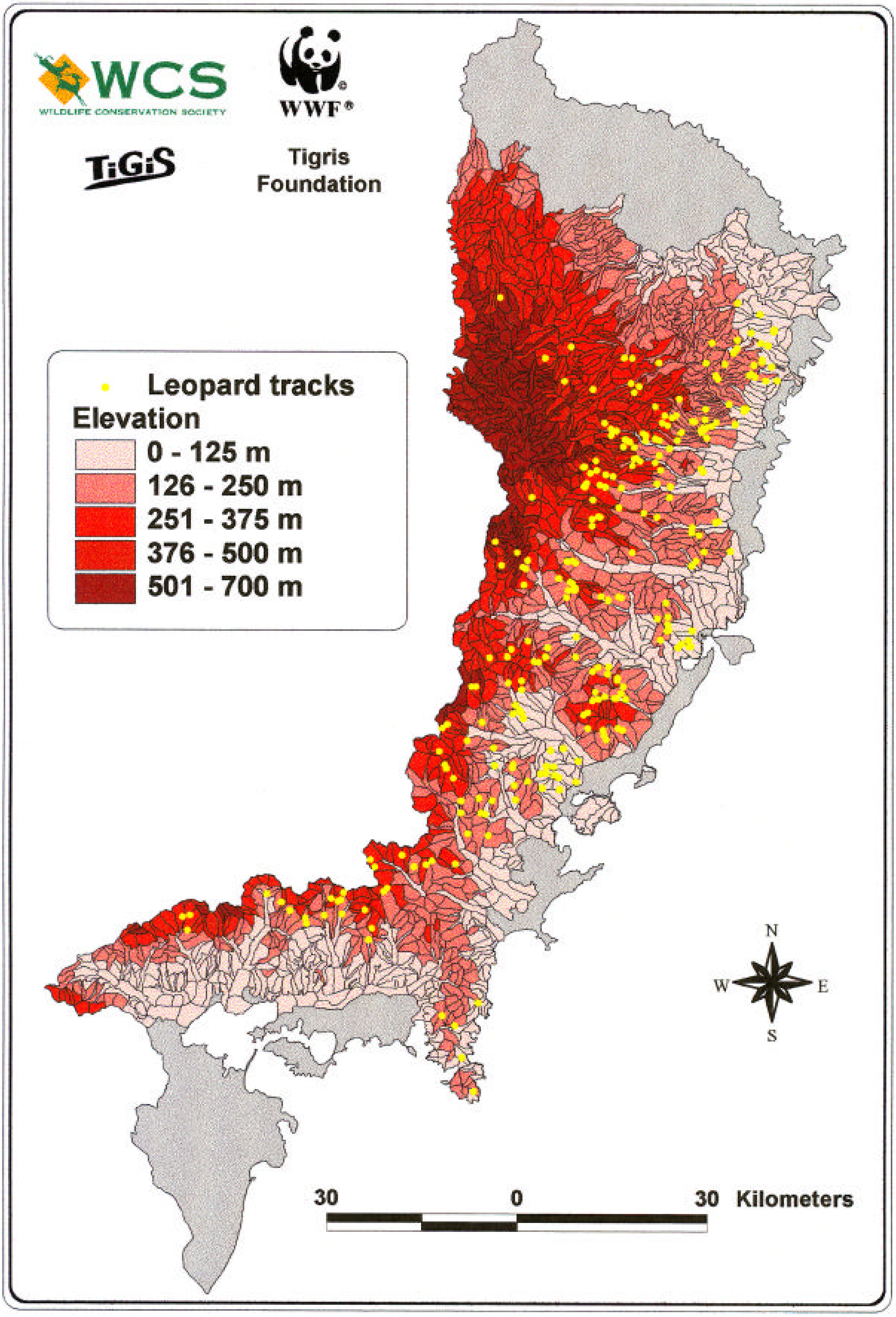


Figure 10. Relationship of elevation to spatial distribution of leopard tracks, based on 4 surveys conducted in Southwest Primorski Krai between 1997 and 2000.

Table 20. Number of topographic cells within 2 km of deer farms, number of Far Far Eastern leopard tracks reported near deer farms, and ratio of tracks/cell, based on 4 surveys in Southwest Primorski Krai, 1997-2000.

	# cells within 2 km	cells within 2 km sampled*	# leopard tracks in cells	Tracks/cell*
1. Monakeno	55	33	0	0.00
2. Kedrovski	46	42	47	1.12
3. Pechanya	9	6	4	0.67
4. Bezverkhovski	35	27	14	0.52
5. Slavyanski	20	14	1	0.07
6. Tomovski	68	63	5	0.08
Total	233	185	71	0.38

*reported only for those cells sampled (cell categories 1, 2 and 3).

particularly between 125 and 375 m. Leopards were rarely recorded at the lowest elevations near the coast (except at deer farms) and the apparent aversion to low elevation zones may be due to the severe human disturbance of those areas, and lack of suitable habitat. Leopards were also extremely rare at high elevations (above 500 m). Avoidance of high elevation habitats may partially explain the absence of leopard tracks in the upper reaches of Borisovkoe Plateau. However, inadequate sampling of both coastal areas and the upper reaches of Borisovkoe Plateau makes it difficult to tease out which factors are most important in determining avoidance of those areas by leopards. Nonetheless, it is clear that elevation can be used as a strong predictor of leopard distribution in Southwest Primorye.

Slope. Slope was very strongly associated with distribution patterns of leopards (Table 14). Leopards showed a strong preference for slopes and largely avoided valley bottoms and ridgetops. This association appears to be largely driven by an avoidance of ridgetops (cell chi squares for presence and absence of ridgetops represent 58% of total chi-square value), but avoidance of valleys was also a strong contributor to the total chi square value.

Aspect. Leopard distribution was significantly linked to aspect (Table 15), but the majority of the effect (over 50% of cell chi-squares) could be traced to leopard avoidance of flat areas (i.e., no aspect). Despite reports that leopards prefer southern exposures, this analysis did not demonstrate any such tendency. Both aspect and slope indicate the same tendency, i.e., that leopards prefer slopes to extensive, flat terrain, whether it be high (ridgetops) or low (valley) elevation.

Habitat type: Korean pine/broad-leaved deciduous/black fir forests and oak forests were clearly preferred by leopards (greater observed presence than expected) (Figure 11, Table 16). Birch forest were used in approximate proportion in which they occurred (neither selection for nor against) and shrublands were strongly selected against.

Tiger presence. Tiger presence was not quite significant (P = 0.08 in the univariate chi-square analysis) in explaining leopard absence in any given cell (Table 17). However, the analysis of spatial distribution of tigers and leopards using a kernel estimator for track density suggested that tigers and leopards largely segregated in their use of Southwest Primorski Krai

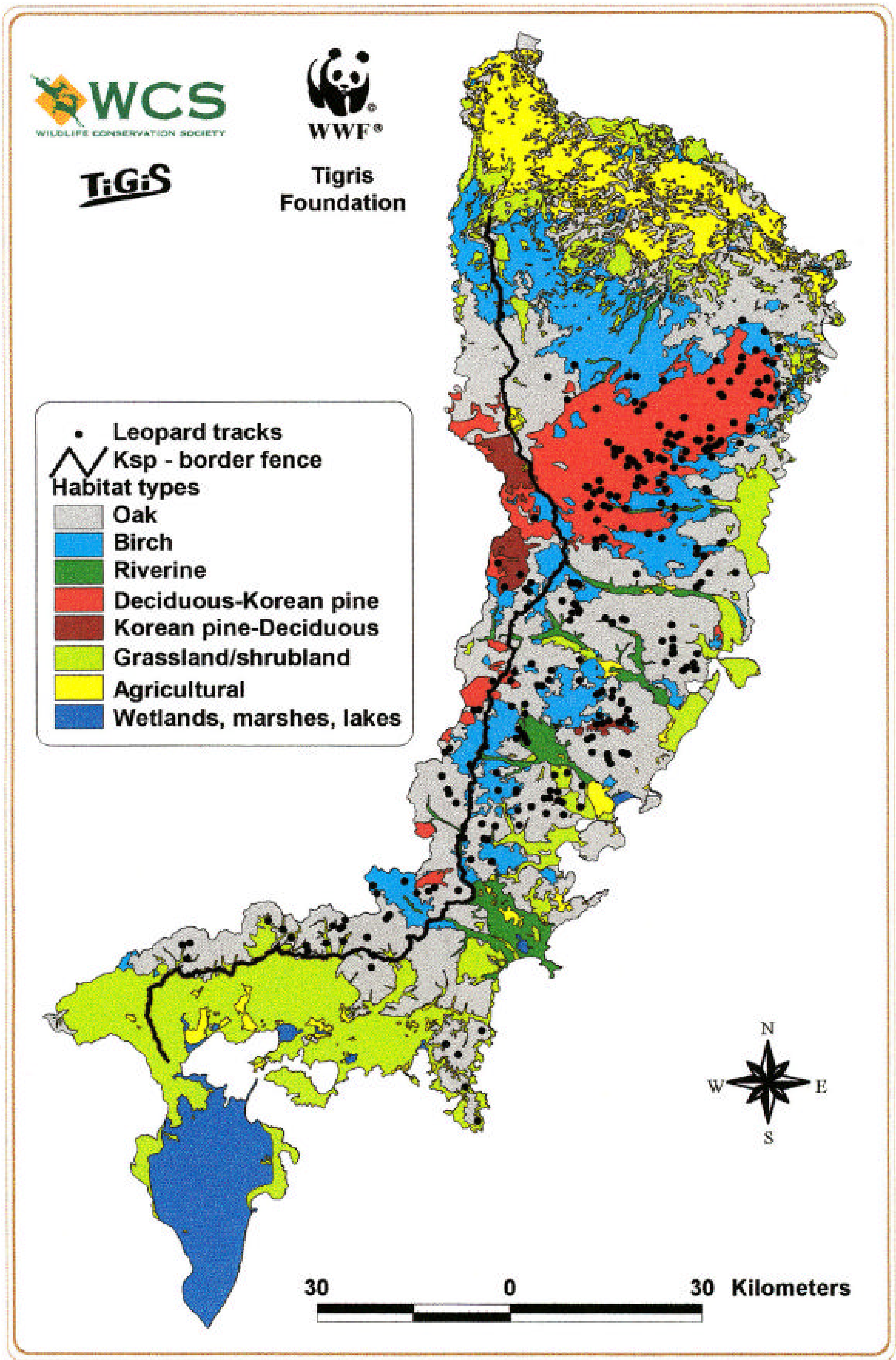


Figure 11. Relationship of habitat types to spatial distribution of leopard tracks, based on 4 surveys conducted in Southwest Primorski Krai between 1997 and 2000.

(Figures 12a-c), although there is one area in Borisovkoe Plateau region where densities of both leopard and tiger tracks is high, suggesting that overlap can occur.

However, because these analyses did not account for potential temporal segregation, we compared expected to observed ratios of nearest neighbors tracks for both species for each survey separately (Table 21). The two surveys by Aramilev (Aramilev et al. 1998, Aramilev and Fomenko 2000) suggested dramatic differences in observed versus expected associations of tiger and leopard tracks: tigers tracks were much more likely be associated with other tiger tracks than leopard tracks, and similarly leopard tracks were much more likely to be associated with other leopard tracks. However, the survey by Pikunov et al. (2000), while showing the same trend (Table 21), did not demonstrate a significant difference.

Table 21. Analysis of associations of leopard and tiger tracks (measured as an occurrence of tiger or leopard track as the nearest neighbor to any given track) compared to expected occurrences if track locations were randomly distributed, based on distribution of tracks from 3 winter surveys conducted from 1998 and 2000 in Southwest Primorski Krai.

			Nearest neighbor to tiger		Nearest neighbor to leopard		Log-likelihood	
Survey		N	tiger	leopard	leopard	tiger	G-statistic	Probability
1998	Observed	138	27	5	104	2		
Aramilev	Expected		7.42	24.58	81.42	24.58	94.70	P < 0.001
2000	Observed	71	20	10	34	7		
Aramilev	Expected		12.68	17.32	23.68	17.32	19.17	P < 0.001
2000	Observed	128	39	24	39	26		
Pikunov	Expected		31.01	31.99	33.01	31.99	6.32	0.05<P<0.1

Based on a two-way ANOVA, distances between tracks did vary by both type of nearest neighbor (tiger versus leopard) ($F = 5.00$, $df = 2$, $P = 0.007$) and survey ($F = 21.9$ $df = 2$, $P = 0.0001$), but this analysis was complicated by a significant interaction between these two variables ($F = 3.51$, $df = 4$, $P = 0.008$). Thus, distance between leopards and tigers varied among the surveys (Table 22), indicating that there was not a straight-forward relationship explaining spatial separation between tigers and leopards that extended across all three surveys. Distances between nearest neighbor tiger tracks were greater than distances between nearest neighbor leopard tracks or between nearest neighbor leopard and tiger tracks (Table 22), counter to our prediction that the greatest distance should be between leopards and tigers.

Although tiger tracks were more likely to be associated with other tiger tracks (Table 21), suggesting spatial separation, the results of both this association, and distance between tracks appears to be obscured by differences in survey methodology, as indicated by the importance of survey type in determining the level of significance in both analyses (Tables 21-22). Although the evidence strongly suggests spatial separation between tigers and leopards, several factors that indicate other potential explanations must be considered:

1. Survey type played a strong role in explaining the associations between tigers and leopards;

2. Since single animals are likely responsible for numerous tracks, it is likely that tracks of that animal will be closer to each other than to tracks of other animals. Thus, the expected distribution, irrespective of spatial separation of species, is a single-species clumped

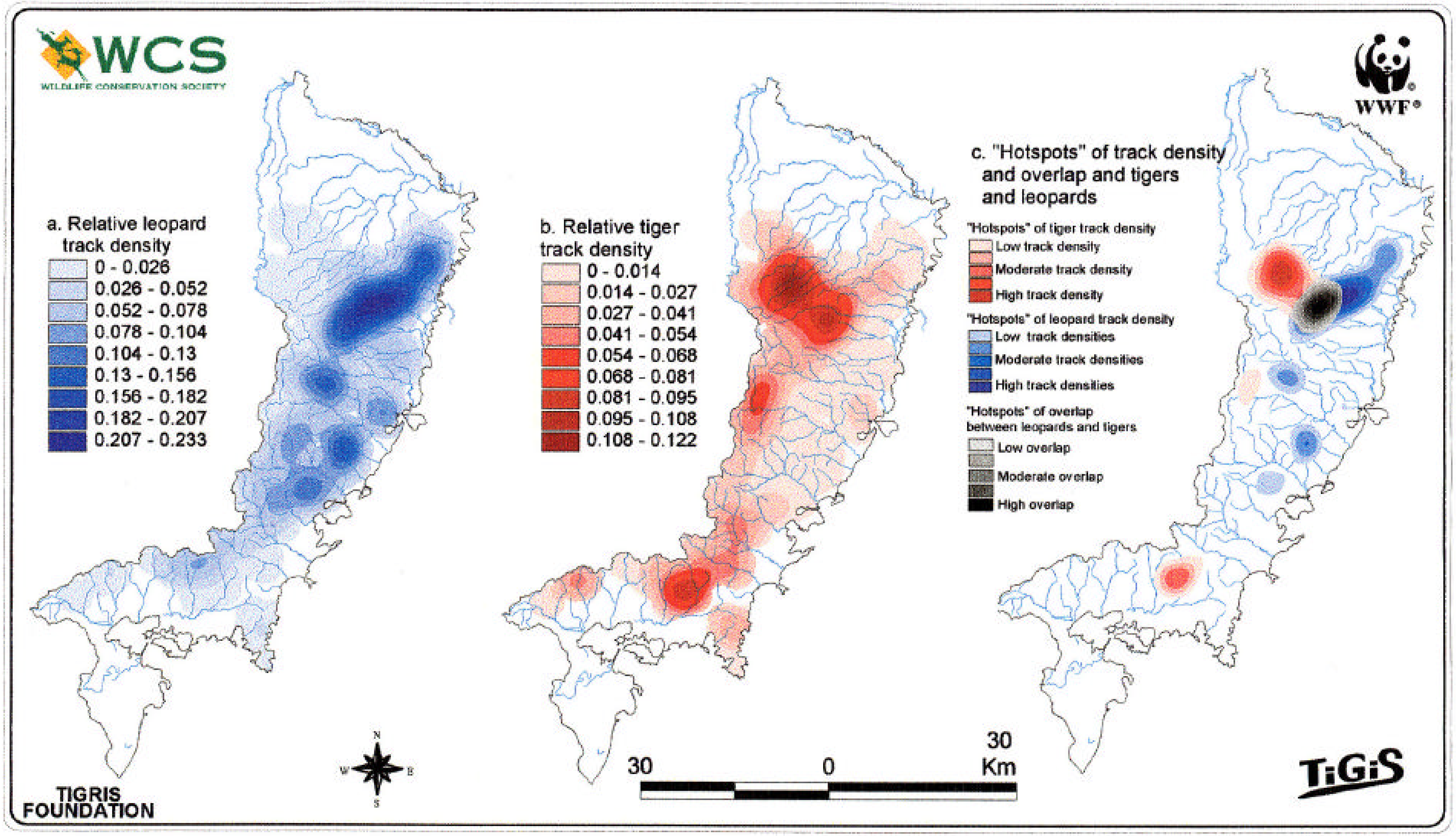


Figure 12a-c. Track density for: (a) leopards; and, (b) tigers, using a kernel estimator of track density; and, (c) areas of overlap in high density contours of both species pattern. It is very difficult to disentangle this natural clumped distribution from spatial separation of species

3. Finally, these data do not indicate whether spatial segregation, which seems real, is due to a difference in habitat requirements, or competitive exclusion. More detailed information may be necessary to determine the exact nature of the relationship.

Table 22. Sample size, mean, and standard errors of distances between nearest neighbor tracks for leopard-leopard, tiger-tiger, and leopard-tiger combinations for 3 surveys of leopards in Southwest Primorski Krai, 1998 - 2000.

	Leopard-leopard			Tiger-tiger			Leopard-tiger			Overall**		
Survey	n	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE
1998	104	1915	165	27	2803	429	7	3567	719	138	2173 [a]	159
2000 Aramilev	34	3175	365	20	5156	718	17	3528	611	71	3818 [b]	316
2000 Pikunov	39	2249	282	39	2070	162	50	1992	225	128	2094 [c]	132
Overall*	177	2231 [a]	139	86	3018 [b]	259	74	2494 [ab]	231	337	2489	112

* Means with different superscripts in this row are significantly different (P < 0.05), based on protected LSD using least square means.

** Means with different superscripts in this column are significantly different (P < 0.05), based on protected LSD using least square means.

Prey densities. Based on survey data from Pikunov et al. (2000), sika deer were by far the most abundant ungulate species, accounting for 70% of the weighted contribution to relative prey densities. Roe deer were considerably more abundant than wild boar, and red deer were exceedingly rare.

There was a marginally non-significant relationship between relative prey densities and presence of leopards in topographic cells (Table 18, Figure 13). Although prey densities are likely a critical factor determining distribution of leopards, this analysis failed to demonstrate a clear relationship, probably due to a number of confounding factors associated with the structure of the data. A more intensive analysis of prey distribution and numbers is likely needed to more fully elucidate this relationship.

Distribution of Females with Young

Female leopards with young showed a strong tendency to associate with deer farms (Figure 14). Six of seventeen tracks of female with young (35%) were located in cells within 2 km of deer farms ($?^2 = 8.59$, df = 1, P < 0.005), whereas only 2 of 9 (22%) tracks of tigresses with cubs were located near deer farms ($?^2 = 0.833$, df = 1, P > 0.25). An additional 4 leopard tracks (collectively with previous 6 representing nearly 60% of females with young) occurred within 10 km of deer farms. Although a large number of tracks also occurred at greater distances from deer farms, it is not clear whether these distant females with cubs also occasionally visit deer farms. Tigresses with young did not demonstrate the same association with deer farms as did leopards, although at least some tigresses do use deer farms. Surprisingly, not a single female with young was reported in Neshinskoe Hunting Lease (Figure 14), which has one of the highest densities of leopard tracks (Table 19).

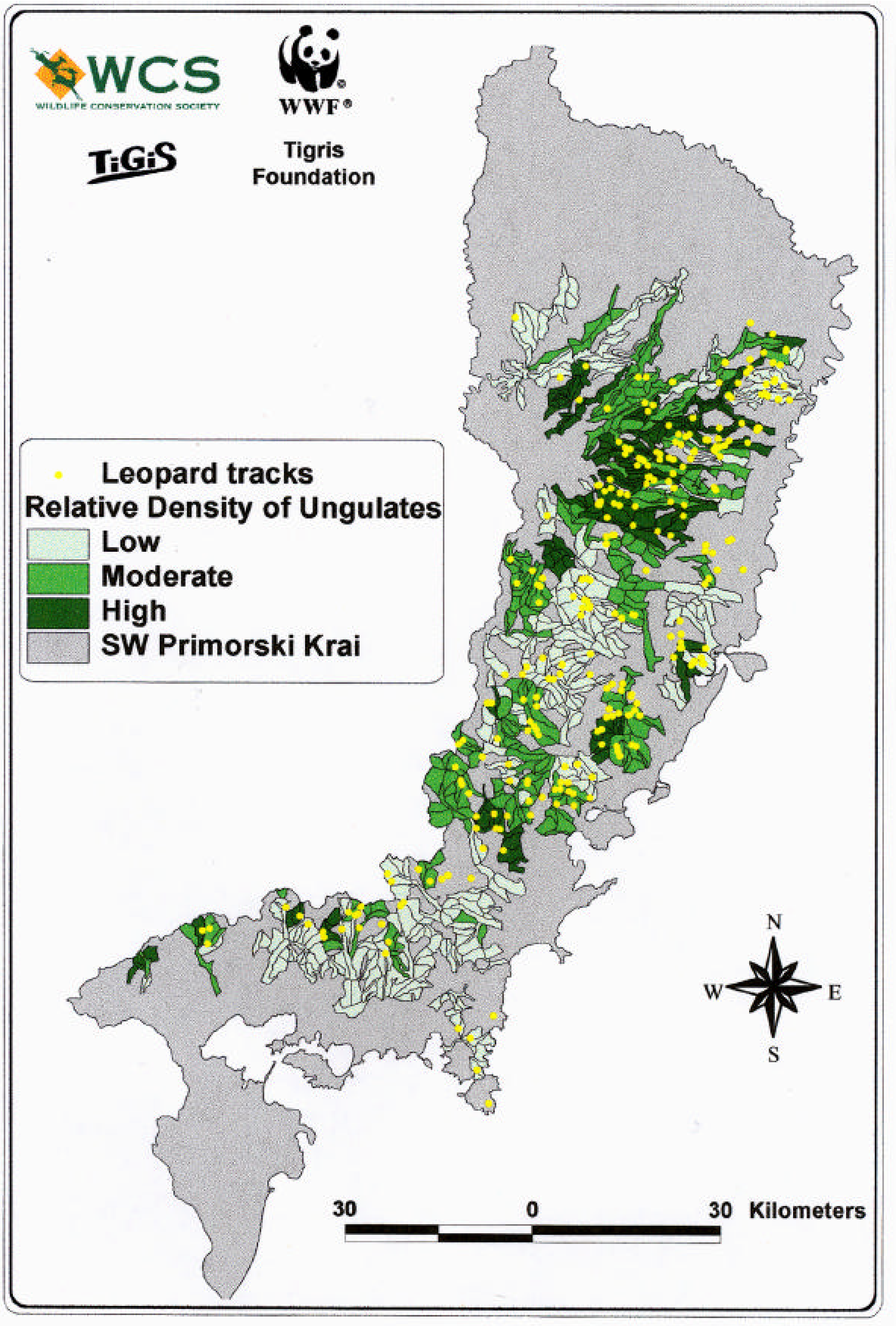


Figure 13. Relationship of prey density to distribution of leopard tracks, based on ungulate data from Pikunov et al. (2000) and leopard distribution from Pikunov et al. (2000) and Aramilev and Fomenko (2000).

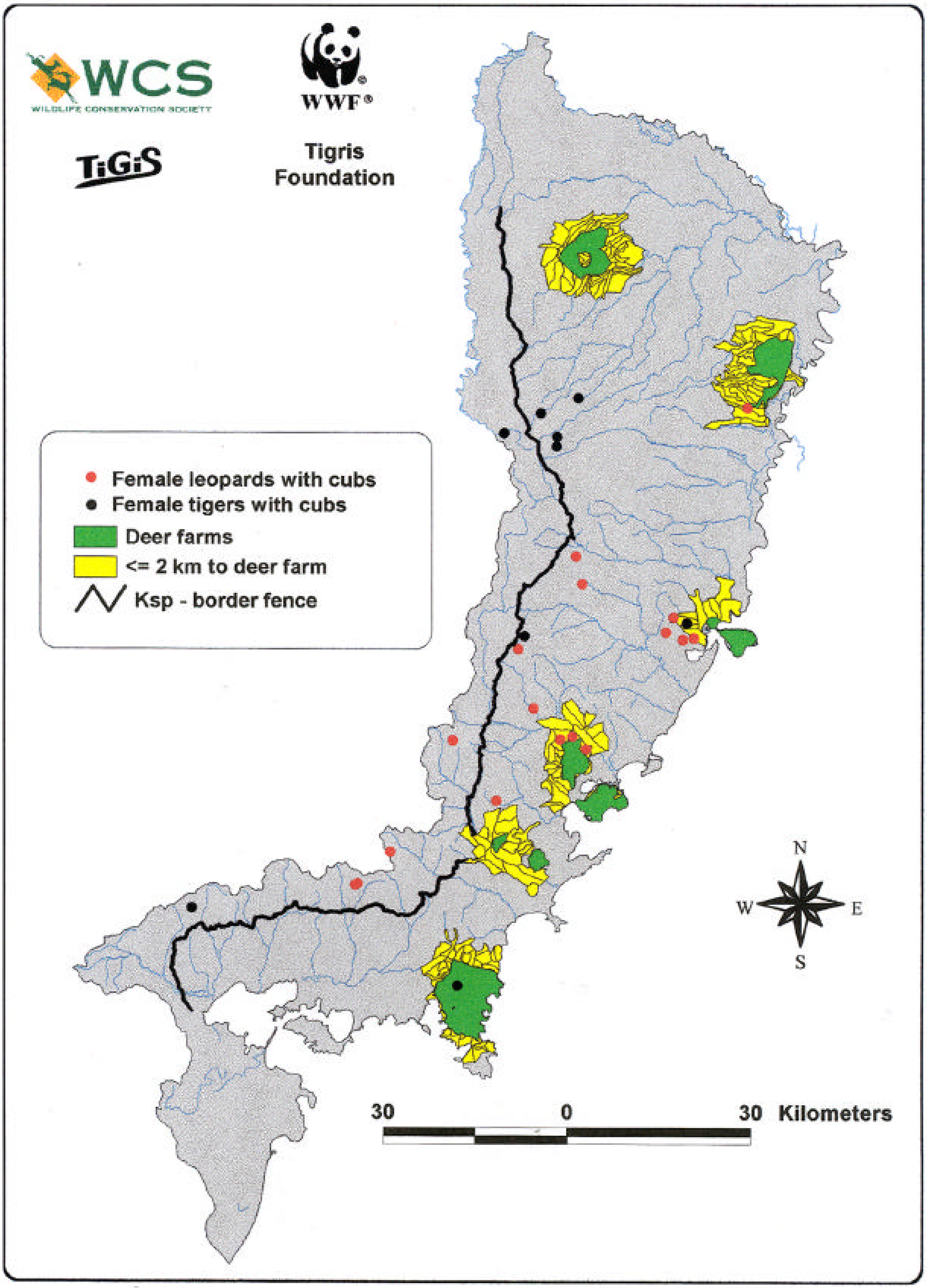


Figure 14. Distribution of leopard females with kittens and tigresses with cubs in Southwest Primorski Krai, based on 4 surveys conducted in Southwest Primorski Krai between 1997 and 2000.

Distribution of Leopards in Southwest Primorski Krai

We developed a map of leopard distribution in Southwest Primorski Krai by drawing a buffer zone with a 1.8-km radius around each leopard track, and then smoothing the distribution borders by hand (Figure 15). Total area of leopard distribution, based on this procedure, collectively represented 2233 km^2, and suggests that there exist many fragmentation points in this population. While these fragmentation points do not likely prevent movement between areas, they do indicate where poor habitat exists, and possibly where greater mortality risks occur. River valleys with major roads appear to disrupt distribution of leopards right to the Chinese border, and areas of use close to the coast (Gamovski and Peschany deer farms) also appear to be isolated habitat fragments. Identifying causes of fragmentation, and eliminating those causes, should be a primary objective of increasing habitat quality in Southwest Primorski Krai.

Preferred Habitat

We used a combination of the univariate analyses described above and a stepwise logistic regression model to identify key variables for defining suitable habitat for leopards. Based on the results of those analyses, we used components of 5 parameters to define habitat preferences of leopards in topographic cells in Southwest Primorye (Table 23), and constructed a hierarchical structure of preferred habitat with the following categories: minimally suitable habitat, neutral/slightly preferred habitat, moderately preferred habitat, highly preferred habitat, and "special" highly preferred habitat (deer farms) (Figure 16). Using the criteria as defined in Table 23, a total 3554 km^2 of suitable habitat were identified in Southwest Primorski Krai, spread across all raions, all protected areas (except Khasanski Nature Park), and most of the hunting leases (Table 24). Collectively, this selection

Table 23. Characteristics used to identify preferred habitats, based on analysis of 16 variables used to describe leopard spatial distribution, and actual track density (tracks/cell) in each category.

Landscape characteristic	Minimally suitable habitat	Neutral/ slightly preferred	Moderately preferred	Highly preferred	High (special)
Habitat type	All forest types, Grasslands/shrublands	Korean Pine-broadleaved, Oak, Riverine forests	Korean Pine-broadleaved, Oak	Korean Pine-broadleaved, Oak	-
Dominant landuse	GosLesFund, Shrublands	Zapovednik, GosLesFund	Zapovednik, GosLesFund	Zapovednik	Deer farms
Slope	Ridgetops, Valleys, Slopes	Slopes	Slopes	Slopes	-
Elevation	7-500 m	7-375 m	125-375 m	125-375 m	-
Proximity to Deer Farm	-	-	-	-	< 2 km
Leopard tracks/cell	0.138	0.203	0.256	0.382	0.292

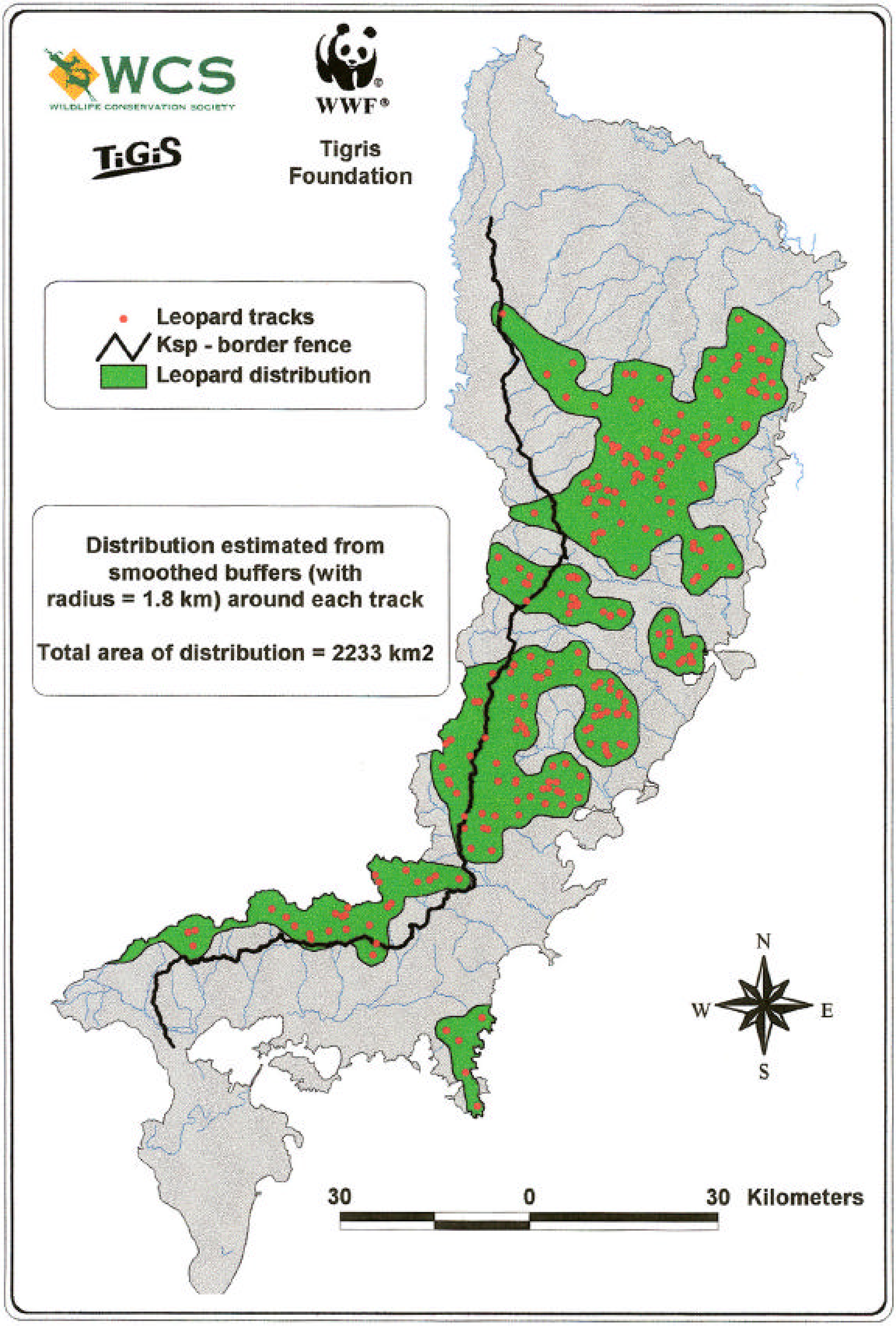


Figure 15. Present distribution of leopards in Southwest Primorski Krai, using a buffer radius of 1.8 km (1/2 radius of female leopard home range) surrounding each track located during 4 surveys between 1997 and 2000.

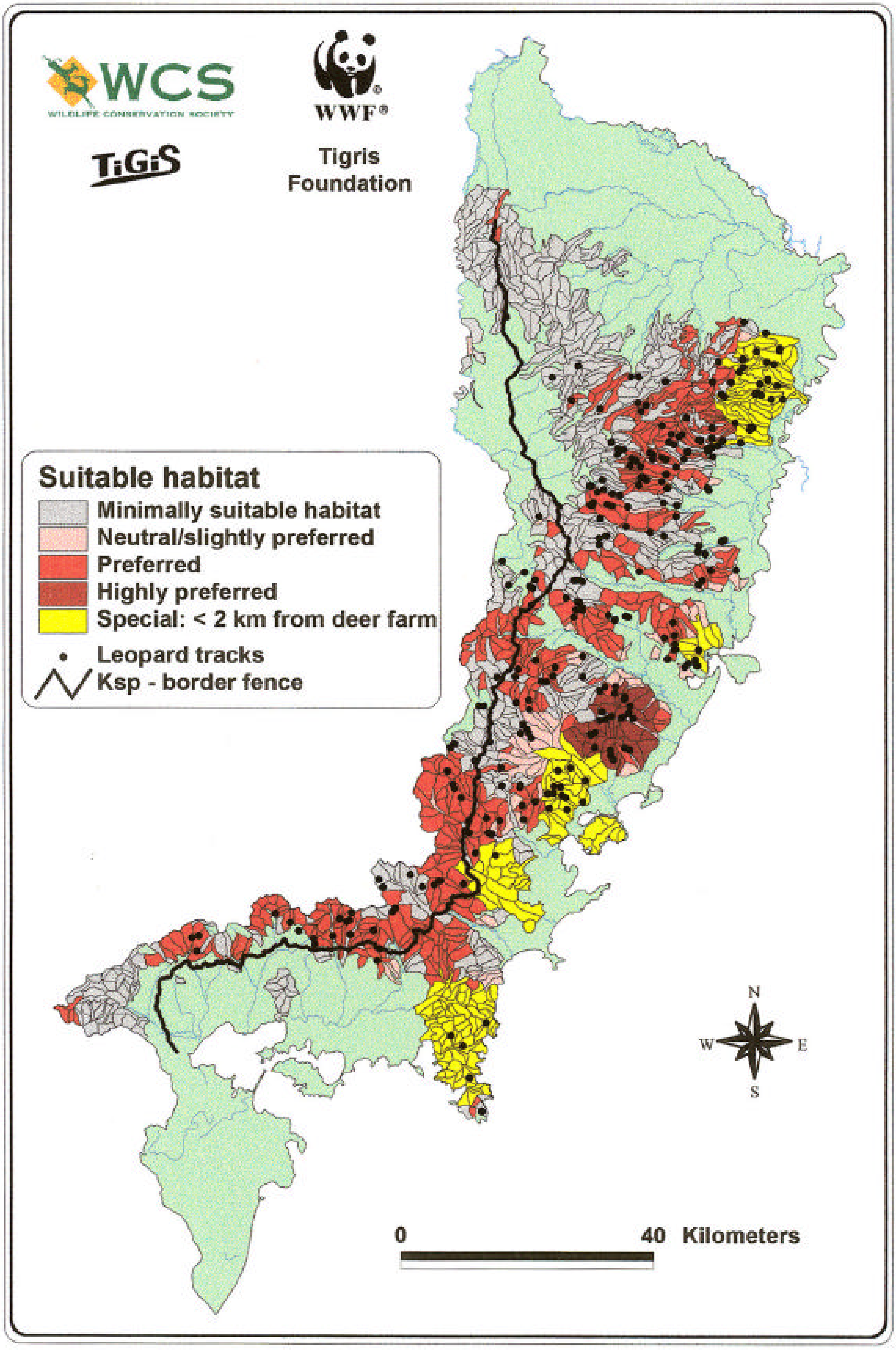


Figure 16. Suitable habitat, based on analysis of landscape characteristics of topographic cells and spatial distribution of leopards from four surveys in Southwest Primorski Krai, 1997-2000.

represents 68% of the topographic cells analyzed, but includes 92% of all tracks recorded, suggesting it is a fairly robust description of landscapes used by leopards. A comparison of track density in each preference category (from least to most preferred) (Table 23) suggests that our ranking of habitat characteristics mimics the actual frequency of occurrence of leopards within cells with such characteristics.

Using track density as a basis for ranking the importance of land units for leopards, Kedrovya Pad, Neshinskoe Hunting Lease, Barsovy Zakaznik, and Borisovkoe Plateau Zakaznik (in that order) are most important in Southwest Primorski Krai (Table 19). However, if total area of suitable habitat is used as the criteria for ranking the importance of land units, Barsovy Zakaznik and Neshinskoe Hunting Lease clearly provide the largest tracts of suitable habitat for leopard conservation in the region (Table 24). Borisovkoe Plateau Zakaznik, Fauna and Slavyanski Hunting leases represent a second "tier" of land units retaining important tracts of land. Again, based on total area of suitable habitat, a 3rd-tier of land units, each containing approximately 5% of the total area of suitable habitat, includes Kedrovya Pad and 4 hunting leases. However, there are clearly differences in quality of habitat within these areas. For instance, nearly all habitat within Kedrovya Pad was considered highly preferred, while most of the land in the (3rd tier) hunting leases was ranked minimally suitable (or represented areas where deer farms were located) (Table 24).

Table 24. Suitable habitat for Far Eastern leopards in Southwest Primorski Krai, based on analysis of landscape characteristics and distribution of leopards during 4 surveys conducted between 1997-2000.

	Total suitable habitat (km^2)	Percent of total suitable habitat (%)					
		Minimally suitable	Neutral/ Slightly Preferred	Preferred	Most Preferred	Special-deer farms	Percent total
Barsovy Zakaznik	963.4	7.2	3.4	12.3	0.0	4.2	27.1
Neshinskoe Hunting Lease	675.9	6.4	0.9	7.1	0.0	4.6	19.0
Fauna Hunting Lease	350.9	4.8	0.2	4.9	0.0	0.0	9.9
Slavyanski Hunting Lease	338.7	2.7	0.4	4.2	0.0	2.2	9.5
Borisovkoe Plateau Zakaznik	315.8	6.1	0.1	2.7	0.0	0.0	8.9
Borisovkoe Hunting Lease	204.3	4.9	0.0	0.8	0.0	0.0	5.7
Kedrovya Pad Zapovednik	190.6	0.5	0.6	0.5	3.4	0.4	5.4
Pavlinovka Hunting Lease	180.7	5.0	0.1	0.0	0.0	0.0	5.1
Poltavski Zakaznik	165.5	4.5	0.0	0.2	0.0	0.0	4.7
Khasankoe Hunting Lease	159.7	0.2	0.2	0.2	0.0	4.0	4.5
Ussuirski Hunting Lease	8.2	0.1	0.0	0.1	0.0	0.0	0.2
Total	3553.7	42.3	5.9	33.0	3.4	15.4	100.0

Management Recommendations

We suggest that habitat management to improve conditions for leopards in Southwest Primorski Krai should consist of two components: 1) increasing the quantity of total suitable habitat, and increasing the quality of habitat. Based on these analyses, we make the following land-use management recommendations on how to increase total area of leopard habitat, and increase quality of habitat.

Landuse management plan

1. We propose that a Leopard Management Zone should be adopted and incorporated into the land-use decision making process in Southwest Primorski Krai (Figure 17). The total area of this zone includes those portions of all land management units in which suitable leopard habitat occurs (Table 24), and includes most of the existing protected areas and hunting leases. Total area of this Leopard Management Zone is slightly less than 4800 km^2.

2. Within the Leopard Management Zone, land areas should be broken into three landuse types (Figure 17):

i. Zapovednik regime (1275 km^2). All lands inside the KSP border patrol fence would be included into a zapovednik regime (Figure 17). This region includes extensive tracts of high quality leopard habitat (Figure 16), and should act a key linkage with proposed protected areas on the Chinese side of the border. Presently hunting within the KSP border patrol region is having a serious negative impact on the leopard population. By strictly protecting the KSP zone, and by creating a strictly protected link between Kedrovya Pad and the KSP, there exists an extensive tract of land where reproduction of leopards can occur in relative security, something that is dramatically lacking in the present situation. Although it is known that reproduction occurs in Kedrovya Pad (Augustine et al. 1996), the zapovednik by itself is too small to provide a secure site for reproducing females. These analyses made it is clear that a zapovednik regime is highly favorable to leopards (Table 19), and increasing the total area of strictly protected area is a key step to securing a future for leopards in Southwest Primorski Krai.

ii. Zakaznik regime (1181 km^2). Those parts of Borisovkoe Plateau and Barsovy Zakaznik that are inside the KSP would be converted to a zapovednik regime (Figure 17). Additionally, a “zapovednik corridor” linking Kedrovya Pad to the KSP would split Barsovy Zakaznik into two sections. The remaining segments of these two zakazniks would retain their existing status. In total, the area of zakaznik regime would decrease in Southwest Primorski Krai. The southernmost section of Poltavski Zakaznik (that portion that is included in GosLesFund – 180 km^2) would also be included as part of the Leopard Management Zone).

We proposed that these two management zones should be merged into a single protected area, represented by two zones of use.

iii. Special Management regime (2061 km^2). In those hunting leases where suitable leopard habitat exists, lands would be designated as special management zones (Figure 17). These regions include

- a “buffer zone between the KSP border patrol fence and the coast in Fauna Hunting lease, which could be managed to improve conditions for leopards (see below);
- that portion of Khasankoe Hunting lease that includes the Gamovski Deer Farm and its surroundings;
- that portion of Slavyanski Hunting lease that acts as a corridor linking the Gamovski Peninsula to better habitat nearer the KSP (Figure 17);
- all of Neshinskoe Hunting Lease that includes forested habitat (i.e., nearly all lands west of the highway;

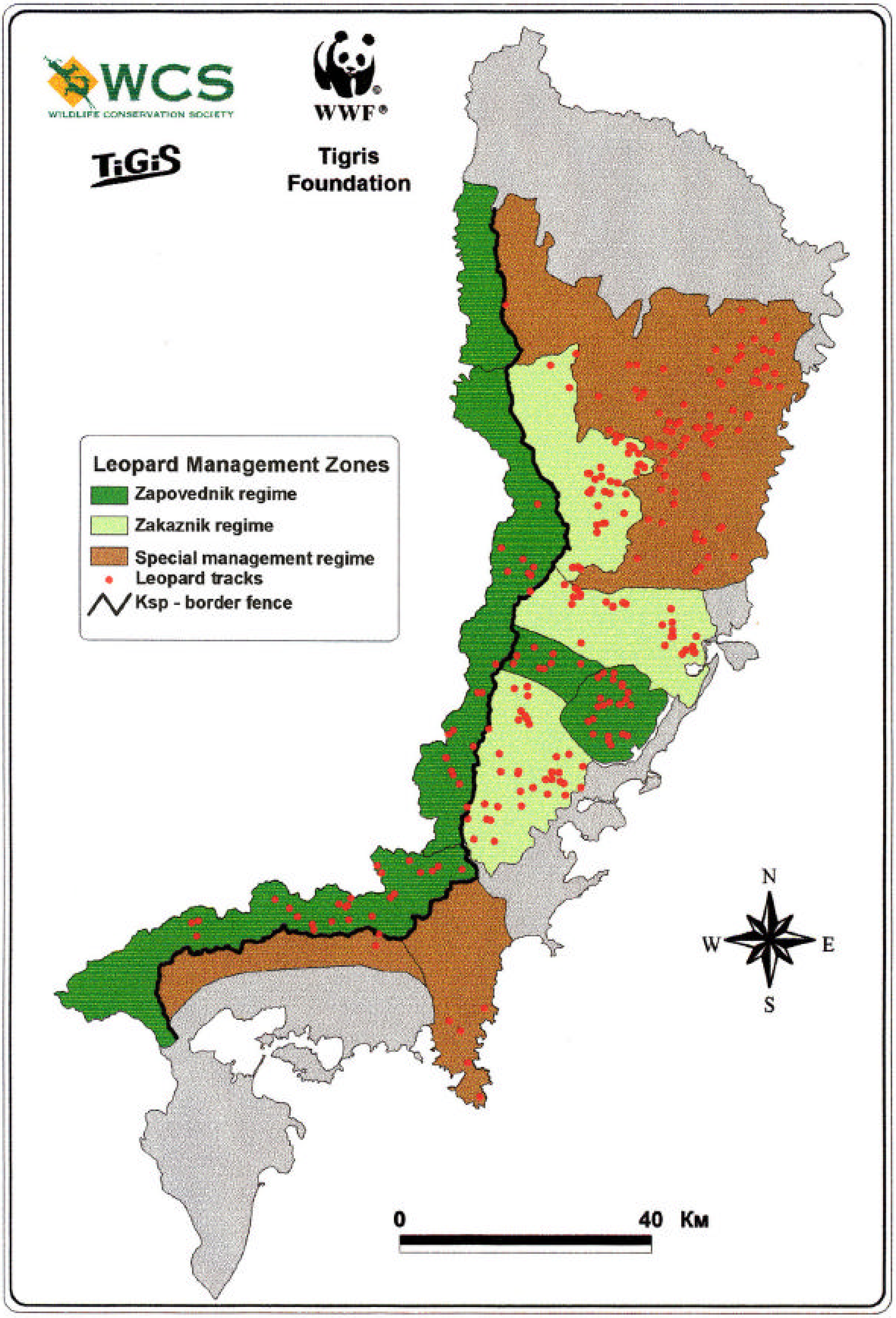


Figure 17. Proposed land management zones for Far Eastern leopards in Southwest Primorski Krai, including zapovednik, zakaznik, and special management regimes in hunting leases.

- southernmost sections of Ussuriski, Borisovkoe, and Pavlinovka Hunting Leases – i.e., those sections that fall within the land ownership regime of GosLesFund (Figure 18).

The specific management regime that should be imposed on this Special Management Zone will be the topic of debate at the Workshop for Conservation of the Far Eastern Leopard in the wild in May 2001. We recommend the following key points for incorporation into this special management regime:

- use of roads in these areas be strictly controlled;
- roads should be closed whenever possible (access is a major factor increasing mortality of prey species and leopards themselves);
- trapping with steel traps should be banned in this zone;
- hunting should be strictly controlled;
- in some regions of this special management zone hunting should be halted to allow recovery of prey and leopard populations.

Recovery of suitable habitat

To recovery degraded habitat, and increase the total area of suitable habitat, we recommend the following steps be taken:

1. Fire should be strictly controlled in all parts of the Leopard Management Zone, but particular importance should be placed on the Special Management Regime areas, which include severely degraded habitats. Recovery of grasslands and shrublands into forested areas could be a key means of increasing the amount of high quality habitat for leopards.

2. Request that American Foresters program, which is implemented in association with Pacific Institute of Geography and Primorye Forest Service, include in their tree planting program some of these degraded habitats in the Leopard Management Zone.

3. Special focus should be placed on three areas where recovery of habitat could provide a means increasing the amount of quality leopard habitat:

i. the buffer zone in Fauna Hunting Lease, as well as the KSP zone of the Fauna Hunting Lease, is severely degraded habitat, as a result of repeated fires. This region could become important leopard habitat if it is adequately protected;

ii. The corridor of shrublands between Gamovski Deer Farm and forests closer to the KSP (Figure 11) needs to be improved to become suitable habitat for leopards. Reduction of fire, and control of illegal hunting could provide a secure corridor linking the Gamovski Peninsula and good leopard habitat inland.

iii. Our analysis identified extensive tracts of land in the northern section of Southwest Primorski Krai (Ussuriski and Oktyabriski Raions) as suitable for leopards (Figure 16), but records of leopards there are exceedingly rare (Figure 15). This area represents a fragmented patchwork of habitat types (Figure 11) and intensive human use (Figure 7), but also holds promise as a site for expansion of suitable leopard habitat. Efforts should be focused on the Hunting leases in that region (particularly Pavlinovka, Borisovkoe, and Neshinskoe) to determine ways of improving habitat and protection for leopards.

Potential size of Far Eastern Leopard Population in Southwest Primorski Krai.

Although the actual size of the present population of leopards in Southwest Primorski Krai is debated (Pikunov et al. 2000, Aramilev 2000), a perhaps more important question is what is the potential maximum population that can be expected in the region, and whether the region, isolated as it presently is, provides any chance of long-term security for a viable population of leopards. We used two sets of criteria to estimate population size. In the first set, we used existing habitat, as defined by analyses presented here, to estimate leopard density across all suitable habitat. In a second criteria, we applied similar density estimates to the Leopard Management Zones defined above (Figure 17). Maximum leopard densities were assumed to be similar to those observed in Kedrovya Pad Zapovednik (Augustine et al. 1996), and are assumed would exist in highly preferred territory. Other estimates are based on existing literature references (Abramov and Pikunov 1974, Pikunov and Korkishko 1992).

We suggest that a conservation population goal should be maintenance of a population of at least 50 breeding adults in this region. Using our estimate of suitable habitat, and applying expected adult leopard densities that vary with habitat quality, it appears that no more than approximately 30 adult leopards can exist in Southwest Primorski Krai (Table 25). If all existing suitable habitat were high quality, that number might increase up to 50 individuals, but dramatic conservation actions would be necessary to achieve this population density across all Southwest Primorye. It is clear that under existing circumstances, without changes in existing management, the feasibility of a population increase to 50 adults is low.

Table 25. Potential size of Far Eastern leopard population using: 1) existing suitable habitat, based on analysis of landscape characteristics; and 2) all lands incorporated into a Leopard Management Zone, using density estimates that reflect known densities in existing habitats.

Habitat	Area	Assumed adult leopard density (adults/100 km^2)	Total population size
Scenario 1. Existing suitable habitat (from analyses presented here)			
Minimally Suitable	1493	0.5	7
Slightly preferred	210	0.7	1
Preferred	1173	1	12
Highly preferred	121	1.5	2
Special - Deer farms	547	1.5	8
Total			31
Scenario 2. All lands in Leopard Management Zone (Figure 17)			
KSP Zapovednik regime (high elevation)	200	0.0	0
KSP Zapovednik regime (other)	1075	1.5	16
Kedrovya Pad and corridor	270	1.5	4
Zakaznik regime	1181	1.5	18
Fauna Hunting lease	228	0.5	1
Slavyanka/Khasanskoe Hunting Leases	333	1.0	3
Northern Hunting Leases (Neshinskoe, Borisovkoe, Pavlinovka)	1500	1.0	15
Total			57

Implementation of our proposed Leopard Management Zoning process, and full use of all zones by leopards, could provide a means of obtaining the conservation goal of 50 adult breeding leopards (Table 25). To provide conditions for a viable population of leopards in Southwest Primorski Krai will require a commitment on the part of raion, regional, and federal administrations to insure that conditions exist that provide for leopard survival and reproduction, and at the same time provide do not seriously impact the capacity of local citizens to improve their conditions as well.

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