



Integrated assessments call for establishing a sustainable meta-population of Amur tigers in northeast Asia

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ABSTRACT

With most large carnivore populations and habitats suffering massive declines across the world, efforts to restore their populations in the wild are of high conservation priority. China attaches great importance to protecting Amur tigers and has made considerable progress towards this goal, but most efforts have been focused on the single Laoyeling landscape. Here we assess all four major forested landscapes (including Laoyeling, Zhangguangcailing, Wandashan and Lesser Khinghan Mountains) that may be suitable for tigers in northeast China. Between 2013 and 2018, in total 54 wild Amur tigers were recorded through camera trap surveys and 30 individuals were identified through genetic analyses. The finite rate of increase of the population in the Laoyeling landscape, the only landscape with a breeding population, fluctuated greatly, but averaged 1.51. Total habitat used by Amur tigers during this period amounted to 47,813 km². We estimated that based on density and home range sizes in nearby Russia, these landscapes could support 311 tigers, including 119 resident breeding females. However, prey density, especially of preferred prey, was extremely low, and likely a primary constraint to population recovery in landscapes other than Laoyeling, especially the Wandashan and Lesser Khinghan Mountains landscapes. To achieve the goal of a large meta-population of Amur tigers across northeast Asia, in addition to prey restoration, we recommend extensive landuse planning, reducing anthropogenic impacts, improving ecology connectivity, and extensive international cooperation, as well as a feasibility assessment for introducing orphaned cubs as a means of speeding recovery in landscapes without breeding females.

1. Introduction

Currently, most of the world's large carnivores are listed as threatened by the International Union for Conservation of Nature (IUCN) and

are still suffering population declines and habitat loss (Ripple et al., 2014). The tiger (*Panthera tigris*) is the most endangered of the large cats (Goodrich et al., 2015), with a total population which has declined from an estimated 100,000 individuals at the beginning of the 20th century to

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no more than 3500 tigers at the beginning of the 21st century (Seidensticker, 2010). Furthermore, about 93% of their historical habitat has been lost, with rapid land clearing continuing in the new century (Goodrich et al., 2015). In 2010, 13 tiger range countries agreed to double the world's wild tiger population by 2022, a commitment which has received worldwide attention (Global Tiger Recovery Program, 2010). Although countries like India claim progress towards recovery (Sharma, 2019), estimates are confounded by methodological issues (Harihar et al., 2017; Gopalaswamy et al., 2019) and are far from sufficient in achieving the goal of doubling tigers across the range. More ambitious conservation plans are needed.

Four subspecies of tigers occurred in China at the beginning of the 20th century, including Amur tigers (*Panthera tigris altaica*) with about 500 individuals (He et al., 1997; Meng et al., 1995). Although the Chinese government banned tiger hunting in the 1950s and listed this species as a protected species in 1977 (Meng et al., 1995), tiger populations continued to shrink. By 1976 there were an estimated 151 individuals remaining (He et al., 1997), and by 2000, the only remaining population was an estimated 12–16 individual Amur tigers found along the border with Russia (Ma and Zhang, 2009). Since then, the national Natural Forest Protection Project (NFPP) (Jiang et al., 2017) has led to the relocation of forest workers and the recovery of forests. Assessments of how tigers might recover in northeast China have also been developed, which have mostly focused on the Changbai Mountains of eastern Jilin and southeastern Heilongjiang Provinces (Luan et al., 2011;

Hebblewhite et al., 2012; Wang et al., 2016a).

The creation of Hunchun Amur Tiger National Nature Reserve, among others (Shevtsova et al., 2018), improved anti-poaching efforts, and compensation for human-tiger conflicts have further helped to ease the pressures facing tigers in northeast China (Jiang et al., 2017). Consequently, camera trap surveys from August 2012 to July 2014 detected 26 individual tigers in the Laoyeling (LYL) forest landscape in north of Changbai Mountains (Wang et al., 2016b) and the presence of breeding females was also confirmed in 2013 (Jiang and Qi, 2014; Jiang et al., 2017). With indications of recovery underway, the Chinese government created the Northeast Tiger Leopard National Park (NTLNP) in 2016 in the eastern LYL forests, abutting the border with Russia (Northeast Tiger Leopard National Park, 2016). At 14,600 km², this park includes most of the current Amur tiger habitat in LYL, including Hunchun Amur Tiger National Nature Reserve, and represents the largest protected area for tigers in the world.

Currently, the Chinese government and the public both focus their main attention devoted to Amur tiger conservation on the NTLNP or the extent of the Changbai Mountains (McLaughlin, 2016; Northeast Tiger Leopard National Park, 2016). Meanwhile, there are at least three other landscapes in northeast China which have conservation potential, yet have been only been partially assessed for their capacity to support tigers (Zhang et al., 2013; Li et al., 2016) (Fig. 1). A viable population of tigers is thought to require at least 83 breeding females (Chapron et al., 2008), which is more than twice the capacity of NTLNP based on the

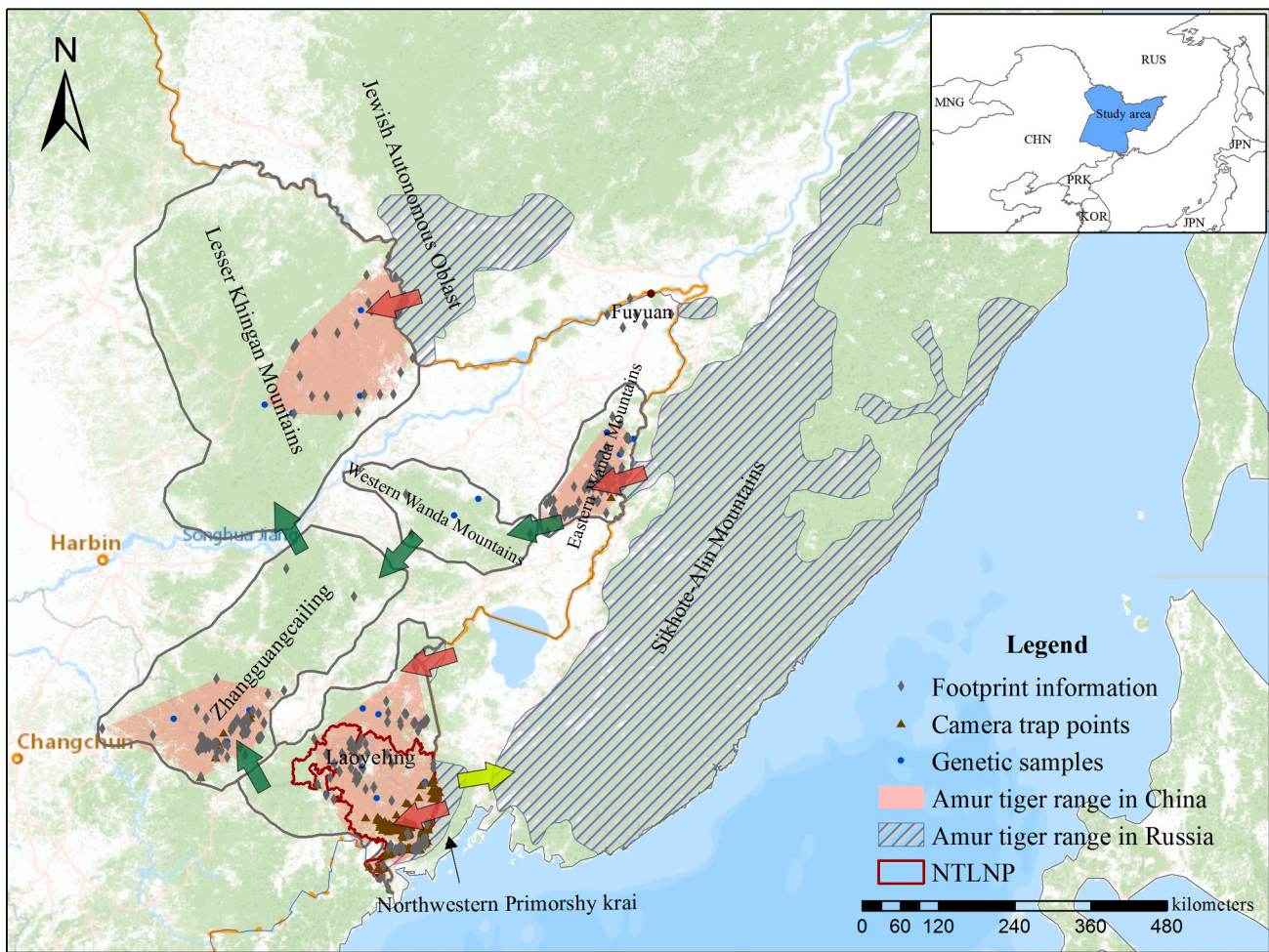


Fig. 1. Locations of tiger observations collected from January 2013 to December 2018 in China, and the potential and existing tiger landscapes in northeast China and Far East Russia. Arrows represent key ecological national and international corridors for Amur tigers in China (green), Russia (yellow), and between the two countries (red). NTLNP is the Northeast Tiger and Leopard National Park. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

average home range size of tigresses in Russia (Goodrich et al., 2010; Hernandez-Blanco et al., 2015). Therefore, it is crucial to assess the potential for connectivity and the recovery of tigers across multiple landscapes in order to achieve a meta-population of sufficient size and long-term viability. Presently in Russia, tigers occur along the boundaries of three of the four landscapes in China, representing a source for recovery (Fig. 1), and tigers have been reported in each of these four forested landscapes in China. However, the area of potential habitat, existing prey densities, and the possibility of connectivity between all four landscapes will ultimately be key determinants in the recovery process and feasibility across a much larger region, and hence, also aid the prioritization of conservation resources.

In this study, information of wild Amur tigers and their ungulate prey were continuously collected throughout all potential tiger landscapes across northeast China since January 2013 through a comprehensive survey method including camera traps, transects survey, snow-tracking and telephone hotline. On the basis of these data, we attempt to ascertain the status of tigers in China, to evaluate prey populations, potential tiger populations, and the needed linkages to Russian landscapes for the creation of a meta-population of tigers across northeast Asia. Following this comprehensive synthesis, we provide clear recommendations for the continued recovery and persistence of the Amur tiger in northeast Asia, especially in China.

2. Materials and methods

2.1. Study area

We collected data between 1 January 2013 and 31 December 2018 in 4 forested landscapes in northeast China: LYL, Zhangguangcailing (ZGCL), Wanda Mountains (WDM) and Lesser Khingan Mountains (LKM) (Fig. 1). The most common vegetation types in the study areas are deciduous forests of Mongolian oak (*Quercus mongolica*), Japanese white birch (*Betula platyphylla*), Manchurian ash (*Fraxinus mandshurica*), and poplar (*Populus davidiana*). Mixed coniferous-deciduous forests of Korean pine (*Pinus koraiensis*), Mongolian oak, and yellow birch (*B. dahurica*) occur only at higher elevations and latitudes. Ungulates include roe deer (*Capreolus pygargus*), wild boar (*Sus scrofa ussuricus*), sika deer (*Cervus nippon*), red deer (*Cervus elaphus*), musk deer (*Moschus moschiferus*), Moose (*Alces alces*), and goral (*Naemorhedus caudatus*). However, roe deer and wild boar are the two most common prey species in all landscapes according to our survey data.

Among these landscapes, the LYL landscape, which is the most important core habitat of wild tigers in China, is approximately 32,600 km² and is connected to the southwest Primorye tiger range in Russia (Jiang et al., 2014). The LYL landscape also contains the NTLNP, which shelters most of the wild Amur tigers in China and attracts wide attention throughout the world. ZGCL, 28,500 km² in size, is the only landscape in northeast China not connected to the Amur tiger range in Russia. Its higher elevation and inland position results in a colder climate, making Korean pine, larch (*Larix* spp.) and spruce (*Picea* spp.) forests more common. WDM, approximately 12,000 km², is connected to the central Sikhote-Alin Mountains of Russia where about 500 tigers survive (Jiang et al., 2014). A highway and intensive human development separate the WDM landscape into East and West segments, and likely impede or prevent the movement of tigers between these two areas. Sika deer were not recorded in WDM during this research. The northern-most potential tiger landscape in northeast China, LKM, is the largest one, and abuts tiger habitat in the Jewish Autonomous Oblasts of Russia (Fig. 1) where a tiger reintroduction program has been ongoing since 2013 (Miquelle et al., 2016). In the north of LKM, there are patches of permafrost and the proportion of coniferous forests (Korean pine, larch) is much greater than in the other landscapes. LKM is the only landscape in our research occupied by moose.

The local economy in all landscapes is mainly based on agriculture and forestry. Among them, as the only landscape far from the border,

ZGCL has a comparatively higher density of main roads (0.10 km/km²), railway tracks (0.05 km/km²), and human population (75 individuals/km²) than the other landscapes, as well as a highest GDP (\$45.54 USD/km²); the protected areas in ZGCL also account for the smallest proportion (8%) of the total landscape area (Appendix A). The landscape of LKM is least affected by human disturbance, and the proportion of land cover marked as protected areas is the largest (22%) (Appendix A). WDM has a very low railway track density (0.02 km/km²) and high proportionate land coverage of protected areas (21%). Except for the high density of main roads (0.10 km/km²), all other indicators in LYL are in the mid-range of values among the four landscapes (Appendix A).

Within each landscape, the local Forestry and Grassland Bureaus divide their jurisdiction into forestry "stations" that range in size from 100 to 300 km², with each station relatively independent in setting forest management priorities. We used forestry stations as sampling blocks both for camera trap surveys and ungulate transect surveys.

2.2. Amur tiger population size, dynamics, and distribution within landscapes

We used camera traps and genetic analyses to estimate population sizes of Amur tigers in each landscape. Camera traps were utilized for continuous surveying, maintained (including data collection, changing batteries and replacing faulty cameras) once every four months. While for some areas, due to the lack of camera equipment, we applied a rotational method. In order to avoid missing important information as much as possible, we decided that the rotation period of each monitoring area should not be less than six months, i.e. only after an area had been continuously monitored for at least six months, we move the camera traps to another area. A total of 1229 camera traps were placed in core areas across all four landscapes at a density of 1 pair of cameras per 10 km² (Appendix B, C).

Cameras were set in pairs to capture stripe patterns on both sides of tigers, and then applied two methods for individual identification. First, Extract Compare software was used for the systems-based identification of good quality images which captured the main body of tigers (Hiby et al., 2009). Extract Compare provides probability estimates of whether two photos represent the same individual, leaving the ultimate decision on individual identification to human interpretation. While for the other images, such as only part of the body, we used manual comparison to determine individual identity. Our identifications were verified by trained experts from the Land of Leopard National Park in Russia and the Wildlife Conservation Society team in China. Based on traits visible in photos (i.e., presence/absence of testes), we determined the sex of each individual when possible. On some occasions, only one camera was triggered and/or photographed a quality image for confident individual identification. Thus, only a left or right side body image was collected in these instances; we treated the larger total number of individuals identified from either side (i.e., left side or right side) as the final number of tiger individuals.

For genetic analyses, we collected scats and other genetic samples (like urine, hairs) whilst walking transect surveys to estimate ungulate abundance (see below), snow-tracking tigers, or visiting sites (such as kill sites) after reports from a telephone hotline. We stored all samples in a refrigerator at -80 °C for further analysis.

DNA was extracted by using the QIAamp Fast DNA Stool Mini Kit following the manufacturer's protocols. We used mitochondrial DNA Cytochrome b gene (Cytb) fragment (Sugimoto et al., 2006) for species identification. We then conducted 18 short tandem repeat and genotyped polymorphic microsatellite markers (FCA5 FCA32, FCA43, FCA44, FCA69, FCA77, FCA90, FCA94, FCA105, FCA161, FCA176, FCA211, FCA220, FCA290, FCA293, FCA304, FCA310, FCA391) across all samples to identify individuals (Zou et al., 2015). For sex identification, we utilized two pairs of primers (ZFX-PF/ZFX-PR, DBY7-PF/DBY7-PR) to amplify the ZFX gene of the X chromosome and the DBY gene of the Y chromosome, and each sample was amplified three times

to ensure accuracy of identification (Sugimoto et al., 2006). We Only used fecal samples in this part of analysis.

For population dynamics analysis, as most wild Amur tigers in China currently occur in the LYL landscape, we conducted an open population capture-recapture analysis to evaluate the yearly population size and other population parameters in the LYL landscape based on the camera trap data (Gardner et al., 2010; Wang et al., 2018). We used the openCR package in R for this analysis (Efford, 2020). Given that a non-spatial model was currently more robust than a spatial model, and a conditional likelihood form is more powerful in estimating population parameters of apparent survival rate and population growth rate (Efford, 2020), we built JSSA (Jolly-Seber-Schwarz-Arnason) models, which were non-spatial and conditional likelihood (Schwarz and Arnason, 1996; Efford, 2020), for estimating parameters. Since the camera traps in the northeast of NTLNP were designed with a rotational method, and the monitoring areas outside NTLNP were scattered non-uniformly, this analysis only focuses on the southeast area within NTLNP covered by camera traps which were designed with a continuous method (Fig. 1). We made such restrictions also because all Amur tigers recorded by camera traps in LYL mainly distribute in this southeastern part, including two individuals (CT-C10 and CT-C10, Appendix D) which were also recorded a few times in the northeast of NTLNP.

We used photographs, scat samples, and footprints to identify the distribution of tigers over the 6-year study period. We also included other evidence of tiger occurrences (e.g. tracks) collected through telephone hotline, snow-tracking or other methods during this research in this spatial analysis (Appendix B). Surveys in most areas were not duplicates (except areas surveyed by camera traps), and the occurrence locations were not enough for modeling the entire landscapes efficiently. Thus, for this analysis, within each landscape of continuous forest, we created a minimum convex polygon in ArcGIS for the locations of tiger occurrences less than 100 km from each other to represent the current areas used by Amur tigers in northeast China (Rodgers and Kie, 2007). Within each polygon, only forested land was included to estimate amount of occupied habitat. We also analyzed the distribution areas of female tigers with cubs based on camera traps data.

2.3. Ungulate prey densities and Amur tiger carrying capacities

Forestry Stations, as independent management units, were randomly selected within each landscape, and we designed parallel transects in each selected Forestry Station with an average spacing of approximately 3 km. We counted the number of fresh tracks (less than 24 h old) in snow for each ungulate species along 662 transects (averaging 5 km in length) in the four landscapes to estimate ungulate abundance (Stephens et al., 2006a, Appendix C). Transects were sampled in winter when there was sufficient snow cover to allow identification of tracks. Species were distinguished based on relative track size and distinctive patterns (Pikunov et al., 2004). In order to be consistent with long-standing methods in the Sino-Russia area, we then used the Formozov-Malyshev-Pereleshin (FMP) method to estimate ungulate densities in each landscape, relying on daily travel distances from the Russian Far East (Stephens et al., 2006a).

Subsequently, we estimated the number of tigers that the current prey densities could support using the relationship between tiger density and prey density developed by Karanth et al. (2004):

$$T = \frac{0.1}{56} U\delta$$

where T is tiger density, U is ungulate density, and δ is a random variable with a mean of 1. The value 0.1 is an estimated annual proportion of all available prey removed by tigers. As the research of Karanth et al. (2004) focused on the tigers in India, and the average annual kill rate of Amur tigers per year is very different, we used a value of 56 instead of the original 50 used by Karanth et al. (2004) for our evaluation (Miller

et al., 2013).

As tigers prefer large ungulate prey, the mismatch between prey species composition and differential selection of prey species by tigers would also greatly limit their recovery (Miquelle et al., 2010). To evaluate whether the species composition of ungulate prey in China is reasonable for tiger conservation, we also evaluated the viable tiger densities that each single prey species could support individually by modifying the annual percentage of all available prey removed by tigers to the annual percentage of each ungulate species removed by tigers; this formulation was based on the proportion of each ungulate species consumed by tigers in winter in northeast China (Gu et al., 2018; Yang et al., 2018). The modified equation is thus:

$$T = \sum_i \frac{0.1r_i}{56} U_i\delta_i$$

where r_i is the proportion of ungulate species i fed upon by tigers, which was estimated by averaging the research result of Gu et al. (2018) and Yang et al. (2018). Total tiger density capacity was then estimated by summing the tiger densities that each ungulate species could support individually. For both approaches, the total number of tigers that the current ungulate prey density could support in each landscape was obtained by multiplying the tiger density and landscape area. The population densities of each ungulate species in each landscapes were estimated based on the transect surveys data.

To estimate the potential capacity of each landscape to support tigers based on a current distribution area basis, we used the target average population density of 0.65 adults/100 km² in Sikhote-Alin of Russia estimated by Harihar et al. (2018). Because the number of resident females is a key indicator of population viability, we also estimated the maximum number of adult females that could survive in each landscape by dividing the size of a landscape by the average home range size of female tigers (400 km²; Goodrich et al., 2010; Hernandez-Blanco et al., 2015). Using this value also assumes that prey densities similar to those in Russia can be achieved to allow females to retain home ranges of this size and successfully raise cubs.

As it was suggested that comprehensive site-specific baseline population densities would be more helpful for the recovery targets than the maximum density attained within well-protected regions (Harihar et al., 2014), we also estimated the number of tigers each landscape could support based on a baseline population density of 0.22 adults/100 km² in Sikhote-Alin of Russia, estimated by Harihar et al. (2018). We assumed that the tiger habitat quality in these landscapes in China could be protected (and restored) to the average level in Sikhote-Alin of Russia.

3. Results

3.1. Amur tiger population size, dynamics, and distribution within landscapes

From 1 January 2013 to 31 December 2018, cameras traps operated a total of approximately 2,230,100 trap nights (including approximately 1,384,400 in LYL, 367,600 in ZGCL, 153,300 in WDS, and 324,800 in LKM), and collected a total of 1873 captures of tigers. Most photographs of tigers were in the LYL landscape with an annual average capture rate of 0.14 times per 100 trap nights, while in the other landscapes the capture rates were much lower (smaller than 0.01). At least 54 individuals (including 20 cubs) were identified, including at least 16 solitary females, 22 males and 17 animals of undetermined sex (Table 1, Appendix D). Considering capture rates of individuals (individuals captured per 10,000 trap nights) among different landscapes, the results were: 0.36 in the LYL landscape, 0.05 in ZGCL, 0.20 in WDM, and 0.06 in LKM. The sex ratio (female: male) averaged at 0.73, a much lower ratio than expected in stable populations (Miquelle et al., 2015), suggesting that a large proportion of the population in China is comprised of

Table 1

Yearly minimum Amur tiger numbers (cubs) identified in each landscape in northeast China based on camera trap data and DNA analysis outcomes. LYL, ZGCL, WDM, and LKM were the landscapes of Laoyeling, Zhangguangcailing, Wanda Mountains, and Lesser Khingan Mountains, respectively.

Year	Camera-traps					Genetic analysis				
	LYL	ZGCL	WDM	LKM	Total	LYL	ZGCL	WDM	LKM	Total
2013	7	0	0	0	7	3	0	1	0	4
2014	22 (6)	1	0	1	23	1	0	0	1	2
2015	13 (1)	2	1	0	15	4	2	0	0	6
2016	16 (5)	1	0	0	17	2	1	0	0	3
2017	22 (7)	1	1	0	24	11	0	2	0	13
2018	29 (11)	1	2	1	33	4	2	3	2	11
Total	50	2	3	2	55	19	4	4	3	30

dispersing males.

The vast majority of individual tigers identified (50 individuals, 89% of the total tigers recorded by camera trap) occurred in the LYL landscape; 2 males were identified in ZGCL, 2 males in LKM, and 3 males in WDM (Table 1), indicating that only LYL seems to hold the promise of supporting a ‘population’. The two males in ZGCL dispersed from LYL and WDM respectively, and were the only identified individuals which moved between landscapes during six-year study period, from 2013 to 2018. All tigers identified in LKM were record after a reintroduction program has reestablished a population in the Pri-Amur region (Miquelle et al., 2016). The records from Fuyuan, which were of a rehabilitated tiger that dispersed from Russia and quickly returned there, were not included in further analysis.

We obtained 167 fecal samples of Amur tigers and identified 30 individuals through DNA analysis. Nineteen of them were exclusively found in LYL, and 4, 4, and 3 (all males) were found in ZGCL, WDM and LKM respectively.

The open population capture-recapture models showed that the number of Amur tigers in LYL increased from 7 individuals in 2013 to 26 individuals in 2018. The average finite growth rate within LYL was 1.51, but this was driven largely by a huge jump in numbers between 2013 and 2014 (from 7 to 22 tigers). The finite growth rate within LYL excluding these first two years, averaged only 1.21 (Table 2). In addition, the apparent annual survival rate was averaged as 0.74.

Based on the spatial distribution of all tiger records obtained in this study, we estimated the total forest area at least temporarily occupied by tigers in northeast China to be 47,813 km²: 18,029 km² in LYL; 10,941 km² in ZGCL; 5580 km² in WDM, and; 13,263 km² in LKM (Fig. 1). The area occupied by females with cubs was restricted to LYL and was only 3511 km².

3.2. Ungulate prey densities and current prey-based Amur tiger carrying capacities

Results of snow tracking count surveys in WDM and LKM indicated that the diversity and density of ungulate prey were both very low (Table 3). Conversely, overall ungulate densities with 95% confidence intervals in LYL (2.81–4.03 individuals/km²) and ZGCL (2.15–3.57 individuals/km²) approached densities observed in protected areas in

Table 2

Parameters on Amur tiger population in LYL landscape estimated by openCR models, including Standard Error (SE). *p* is recapture probability, *φ* is apparent survival, *λ* is finite rate of increase, *n* is year-specific population size. LYL, ZGCL, WDM, and LKM were the landscapes of Laoyeling, Zhangguangcailing, Wanda Mountains, and Lesser Khingan Mountains, respectively.

Year	<i>p</i>	SE. <i>p</i>	<i>φ</i>	SE. <i>φ</i>	<i>λ</i>	SE. <i>λ</i>	<i>n</i>	SE. <i>n</i>
2013	–	–	1.00	NA	3.14	0.98	7.00	2.66
2014	1.00	NA	0.54	0.12	0.78	0.19	22.00	4.74
2015	0.76	0.15	0.72	0.14	1.00	0.25	17.17	4.79
2016	0.87	0.12	0.67	0.12	1.27	0.29	17.25	4.52
2017	1.00	0.00	0.77	0.09	1.36	NA	22.00	4.69
2018	1.00	NA	–	–	–	–	26.00	5.12

Table 3

Ungulate density (individuals/km²) under 95% confidence interval in four landscapes where Amur tigers occur in northeast China and an analogous site in Sikhote-Alin Biosphere Zapovednik (SABZ), Russia (Stephens et al., 2006b) based on snow track counts surveys during winter. LYL, ZGCL, WDM, and LKM were the landscapes of Laoyeling, Zhangguangcailing, Wanda Mountains, and Lesser Khingan Mountains, respectively.

Habitat landscape	Roe deer	Wild boar	Red deer	Sika deer	Total
LYL	2.60–3.34	0.18–0.44	0.02–0.08	0.01–0.17	2.81–4.03
ZGCL	1.84–2.58	0.16–0.24	0.15–0.75	0	2.15–3.57
WDM	1.01–1.61	0.03–0.15	0.02–0.04	0	1.06–1.80
LKM	1.09–1.33	0.07–0.11	0.03–0.02	0	1.19–1.46
SABZ, Russia	1.0–2.5	0.1–0.5	1.5–3.0	Occur focally	3.6–7.0

Russia (3.6–7.0 individuals/km²; Table 3, Stephens et al., 2006b). However, the majority of prey were small-bodied roe deer, while sika deer, red deer, and wild boar were either absent or occurred at low densities in these landscapes.

Based on these estimates of overall prey abundance we calculated that the LYL landscape could support 0.61 tigers/100 km². Given our above estimated 18,029 km² of suitable habitat in LYL, this estimate suggests the landscape could possibly support 110 tigers. However, when we calculated potential tiger density adjusted for the selection preference of different prey species, we calculated that this prey population could support only 0.13 individual tigers/100 km², i.e., about 23 tigers. The For the other three landscapes, assuming the same selection preferences for different prey species, existing prey densities could support 56 tigers in ZGCL, 14 tigers in WDM and 31 tigers in LKM. However, when adjusted by relative selection preference of prey species these estimates dropped to 10, 3, and 6, respectively (Fig. 2).

3.3. Area-based potential population of Amur tigers in northeast China landscapes

Assuming a conservation target density of 0.65 adults/100 km², the LYL landscape could support approximately 117 individuals, while the other three landscapes could support 71 individuals (ZGCL), 36 individuals (WDM), and 86 individuals (LKM) (Fig. 2), totaling a potential population of 310 tigers. Assuming a standard exclusive territory for breeding females of 400 km² (Goodrich et al., 2010; Hernandez-Blanco et al., 2015), we estimated that 45 resident female tigers could survive in LYL, 27 in ZGCL, 14 in WDM and 33 in LKM (Fig. 2), representing a meta-population of 119 breeding females.

While, once a baseline population density of 0.22 adults/100 km² in Sikhote-Alin in Russia was treated as the recovery targets, the supportable numbers of tigers in each landscape would be 40 (LYL), 24 (ZGCL), 12 (WDM) and 29 (LKM) (Fig. 2).

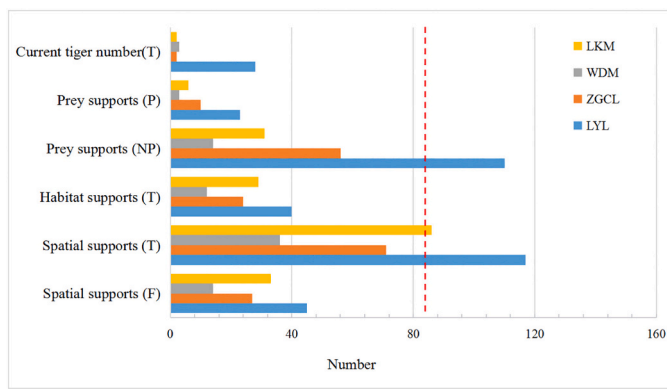


Fig. 2. The number and carrying capacity of tigers in each landscape. LYL, ZGCL, WDM, and LKM were the landscapes of Laoyeling, Zhangguangcailing, Wanda Mountains, and Lesser Khingan Mountains, respectively. Current tiger number (T) is the larger numbers identified by camera traps data or DNA analysis in each landscape; Prey supports (P) is estimated current carrying capacity of each landscape based on prey adjusted by use of each species; Prey supports (NP) is estimated current carrying capacity of each landscape based on number of prey species when all were used equally; Habitat supports (T) is the potential number tigers within each landscape based on the current average density in Sikhote-Alin of Russian estimated by Harihar et al. (2018); Spatial supports (T) is the potential number tigers within a landscape based on the target average density in Sikhote-Alin of Russian estimated by Harihar et al. (2018); Spatial supports (F) is potential number of resident breeding females within a landscape based on average home range size in Russia. The red dashed vertical line represents the number of female tigers needed to ensure viability of a tiger population according to Chapron et al. (2008). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

4. Discussion

Previous research involving a similar landscape-scale camera trap survey in LYL between August 2012 and July 2014, recorded 26 individual tigers, indicating the return of this species to China (Wang et al., 2016b). This study also provided a landscape-scale conservation plan to bring Amur tigers back to parts of their historical range in China. After that, increased protection at the national level, such as NTLNP, and international cooperation, have contributed to the overall recovery of the Amur tiger throughout China. Our results suggest that the tiger population in the LYL landscape has significantly increased, and some individuals have successfully resettled in the other three landscapes. Increases in tiger numbers have been associated with a suite of policy changes, including a decrease in human densities due to a human-relocation project, recovery of forests (banning of logging), and improved anti-poaching efforts (Jiang et al., 2017). At the same time, the increased tiger populations in adjacent Southwest Primorye, Russia also greatly contributed to the recovery of Amur tiger population in LYL through cross-border movement (Amur Tiger Center of Russia et al., 2015; Shevtsova et al., 2018). In fact, the successful re-establishment of tigers in the landscapes of WDM and LKM also greatly benefitted from the tiger population recovery in Sikhote-Alin and Jewish Autonomous Oblasts of Russia, respectively.

4.1. Challenges to establishing a meta-population of Amur tigers

We recognize that our extrapolations of potential numbers of females and total tigers within landscapes are both simplistic and almost certainly overestimates. Nonetheless, these “maximums” provide some guidance in understanding how much more needs to be done in China for the recovery of tigers. Currently, the predominance of males at all other landscapes besides LYL indicates that only LYL seems to hold the promise of supporting a ‘population’. But even in LYL, if current

conditions can support only 23 tigers, as our estimates based on relative prey availability suggest, the population cannot be considered viable (Chapron et al., 2008). Thus, creating a viable meta-population connecting all four landscapes in China and even the tiger habitat in Russia seems to be the only approach to realize the full recovery and sustainable survival of wild Amur tigers in China. And it’s also crucial for the entire Amur tiger subspecies. But based on our results and those of other studies, establishing a single, interconnected trans-boundary meta-population of Amur tigers faces great challenges.

Firstly, the lack of breeding females makes the population in China unsustainable. Our results show that, except LYL, the other landscapes are only occupied by a few male tigers, and no females were found. Without external replenishment, these individuals cannot therefore, persist for a long time. The good news, however is that both LKM and WDM are linked to breeding population habitats in Russia, thus still hold a great potential for recovery. In fact, breeding females have been recorded in WDM in 2011, before this research (Hu, 2011). However, even though the all four landscapes are very well protected, only 33 adult females could be supported by any particular landscape at most, and there is therefore, still no single landscape which could support a sustainable healthy population (Chapron et al., 2008). Even in LYL, where the largest number of tiger individuals were recorded, the tiger population is still under great pressure to survive. Most of them crowd near to the boundary areas, especially the breeding females, which only distribute in an area of 3511 km² abutting the Sino-Russia boundary.

Secondly, the scarcity of ungulate prey resources is an important limitation to the recovery of Amur tigers. Population densities of large predators are closely tied to the biomass or density of prey (Hayward et al., 2007; Karanth et al., 2004; Miquelle et al., 2010). As tigers prefer medium and large sized prey (Hayward et al., 2012; Miquelle et al., 2010) and their successful reproduction is likely dependent on adequate densities of these preferred species (Miller et al., 2014; Miquelle et al., 2018), our estimates of tiger carrying capacity based on total number of prey is considered overly simplistic and an overestimate. In contrast, the estimates of tiger carrying capacity adjusted for relative availability among different prey species are therefore, likely more realistic as a basis for estimating present carrying capacity. The result indicate that the current prey species composition and population size is unable to support the effective recovery (in ZGCL, WDM, LKM) or continued growth (in LYL) of Amur tigers. This study suggests that the recovery of medium to large deer (sika deer and red deer) and wild boar is essential if tigers are to recolonize some of these landscapes and reach viable numbers. Low densities of these preferred species in WDM and LKM are no doubt at least one of the factors preventing recovery and local colonization of tigers there. Even in LYL and ZGCL, although total ungulate density is comparable with Russian estimates, the low density of preferred prey species represents a barrier to continued recovery (Sugimoto et al., 2015; Yang et al., 2018).

Thirdly, anthropogenic activities and their influences within and between landscapes is a factor that must be considered to establish a meta-population of Amur tigers. This study has identified over 47,800 km² of potential habitat for tigers in northeast China, and a potential recovery population of 311 tigers. However, almost all habitats are affected in one way or another by human disturbance. Zhang et al. (2013) suggested that poaching of prey using cable snares and poison was the primary cause of low prey numbers in WDM. Forest cattle grazing in LYL is also considered a major hindrance to prey recovery (Wang et al., 2018). These may also be contributing factors in other landscapes as well, though more conclusive ecological evaluations and practical recommendations in this regard are urgently needed. Furthermore, both between and even within the four landscapes in China there exist a multitude of villages, farmlands, roads and other human disturbances that limit the movement of tigers, lowering the permeability of the landscape.

Finally, severe isolation and lack of connectivity between the four landscapes which significantly limits the movement of tigers across the

landscape should be the greatest problem to be solved in establishing a meta-population of Amur tigers in China. While we found evidence of tigers in all four landscapes studied, and their occurrence indicates connection with a source population either in Russia for LYL, LKM and WDM (Shevtsova et al., 2018) or within China for ZGCL (these data), the three landscapes (i.e., all except LYL) appeared to be inhabited solely by a low number of dispersing males, suggesting dispersal is relatively rare, and that conditions are not suitable for survival and reproduction of tigers. Even if local conditions are improved in each of these landscapes, movement of tigers between them and between countries will be vital to recovery (Wang et al., 2016b), to avoid inbreeding and genetic drift, as well as vulnerability to stochastic processes that make small populations prone to extinction (e.g., Seimon et al., 2013). To ensure connectivity across all potential landscapes across both China and Russia, thereby supporting a single meta-population of Amur tigers, national and international corridor construction will be required (Fig. 1).

4.2. To establish a meta-population of Amur tigers

On 6 June 2019, Chinese President Xi Jinping and Russian President Vladimir Putin signed the “Joint statement between the People’s Republic of China and the Russian Federation on developing a comprehensive strategic partnership of coordination for the new era.” This joint statement, together with [Global Tiger Recovery Program \(2010\)](#) and NTLNP construction ([Northeast Tiger Leopard National Park, 2016](#)), represents a new stage of international cooperation in tiger conservation, and a great opportunity to establish a meta-population of Amur tigers. Here, based on our results and the challenges highlighted above, some of the key issues that need to be addressed in the immediate future are:

1) Restoration of Amur tigers and ungulate prey population

All conservation measures (like anti-poaching activities, food supplementary for ungulate populations, and so on) already in place should be continued in all potential habitats to promote the recovery of Amur tiger populations and their prey, especially the border area of LYL landscape, which represents the only current breeding area in China. Only by recovering the ungulate prey population can an increase in the tiger source population be expected and the associated increase in the number of individuals spreading from source population to other landscapes be promoted. At the very least, our estimates of prey densities, in comparison to nearby Russia, particularly of large bodied ungulate prey, demonstrate a strong need to recover large ungulate prey such as wild boar, sika deer and red deer as a first step towards recovery of tigers.

2) Reduction of human impacts

Successful conservation will be dependent on dramatic reductions of human impacts in these landscapes. Urbanization, common in China and in other parts of the developing world (Sanderson et al., 2018), could play an important role in reducing human impacts, but planning for the socio-economic future of northeast China must take into account conservation of its biodiversity, including tigers. The NFPP, one of the world’s largest government-funded projects aiming to rehabilitate and restore natural forest resources, is an example of the scale of change that will be needed for the recovery of forest ecosystems in the region (Jiang et al., 2017). Land-use planning that prioritizes tigers, at least in specific designated zones, will be key to recovery within landscapes and in securing ecological corridors.

3) Creating and improving ecological connectivity

Three of the four landscapes in China (i.e., LYL, LKM, and WDM) connect with one of the breeding populations in Russia, and there is documentation of tigers cross-boundary immigration into these landscapes (Shevtsova et al., 2018). As with Amur leopards (Vitkalova et al., 2018), the existence of a source population in Russia is likely a critical component of the tiger recovery process in China. Furthermore, ZGCL is the only landscape which does not connect with Russia, and two tigers recorded in this landscape were moved from LYL and WDM before 2016, indicating the importance of diffusion in maintaining the tigers’ survival in this landscape. While after that, the expressway construction and other developmental activities between landscapes further limited their movement. It is greatly needed to rebuild or improve the connections between ZGCL and other landscapes to avoid local extinction.

Thus, creating and improving ecological connectivity among these four landscapes and the tiger habitat in Russia is crucial for establishing a meta-population to benefit the entire wild Amur tiger population, especially for the population in China. While, creating and improving ecological connectivity will require a detailed plan for each of these corridors, it is important to recognize that tigers will recover only if they are a priority management goal and are included in development planning both within these large landscapes and across the international boundary.

4) Preparation for female translocation or reintroduction

Experiences of restoring other species highlight the important role of translocation in meta-population management (Buk et al., 2018). A successful technique of reintroducing orphaned cubs has been responsible for the recovery of tigers in the Pri-Amur region of Russia, a place where tigers had been absent for approximately 50 years (Miquelle et al., 2018). A similar reintroduction program could assist in the recovery of tigers in some of the landscapes in northeast China. However, large carnivore reintroduction is often difficult and controversial. Failures that result in “problem animals” can easily lead to negative attitudes from local people, reversing any conservation gains. But reintroduction could represent an effective and efficient means of “jump-starting” tiger populations in landscapes where tigresses have not been reported and where immigration of tigers in general is rare. For the Amur tiger population in China, whose future is still not yet clear, reintroduction-related research and preparation will likely be advantageous and necessary.

5) Trans-boundary cooperation

The joint statement between China and Russia on 6 June 2019 included Amur tiger trans-boundary conservation and corridor construction as an important part of future cooperation ([Central People’s Government of The People’s Republic of China, 2019](#)). Creation of trans-boundary corridors, a trans-boundary biosphere reserve, and exchange of tiger cubs for reintroduction are all key components of a comprehensive Amur tiger conservation plan that will depend on international cooperation. As the conservation of the Amur tiger in China is largely dependent on the source population in Russia, conservation efforts to help connect isolated populations in both China and Russia, and closer cooperation between the two countries, will be critical to develop a single meta-population of tigers.

6) Strengthen population surveys and research

Meta-population establishment and management needs an adaptive approach based on scientific research and evidence to identify and solve key management issues (Buk et al., 2018). Accurate and real-time

information on population dynamics is an important precondition for effective conservation. While surveying elusive carnivores that occur in low-density populations have always been a great challenge, this research, representing the first continuous Amur tiger survey across the four landscapes in China, demonstrates the great practical and conservation value of such investment of effort. Just as how we have adopted multiple data collection methods here, a comprehensive survey combining techniques and data sources in these areas is clearly important for obtaining detailed information on tiger population status. But, emphasis should be placed on the development of more efficient investigation methods in order to maximize return on investment, whilst also ensuring programs receive adequate financing and resources. Current research priorities which should be strengthened in order to guide, evaluate and improve the establishment and management of the tiger meta-population include: research on large ungulate prey recovery, human activities management, ecological corridors design and creation, and individual translocation and reintroduction.

5. Conclusion

Our study paints a rough but panoramic picture of the wild Amur tiger population in China based on a comprehensive survey over a period of about six years. Evaluating these data, we have discussed the plight of Amur tiger conservation in China at landscape scales, and proposed priority recommendations for establishing a tiger meta-population connecting all four landscapes in China and with tiger habitat in Russia. It is clear that there is still a long way to go to build a viable future for tigers in northeast China and northeast Asia, yet the opportunities have never been better. While there are still great ecological, social and political challenges, the science and political will to resolve these problems has also never been greater. When national leaders have accorded specific attention to Amur tiger conservation, tiger population recovery in northeast China could be enabled by restoring prey populations, creating a permeable landscape of well-connected habitat and compatible human land use, strengthening reintroduction research and trans-boundary cooperation, and collecting scientific data to guide adaptive management. This could ensure long-term security for Amur

tigers, and result in the creation of a critically important tiger meta-population in one of the largest conservation landscapes in the world.

CRedit authorship contribution statement

Guangshun Jiang, Dale G. Miquelle, Minghai Zhang, Jianzhang Ma and Jiang Chang designed this research; Jinzhe Qi, Jiayin Gu, Yao Ning, Dusu Wen, Xin Liang, Shuyan Liu, Eryan Yang, Jianmin Lang, Fuyou Wang, Cheng Li, Zhuo Liang, Peiqi Liu, Yi Ren, and Shaochun Zhou all contributed to the data collection work; Data analysis was mainly carried out by Jinzhe Qi, Jiayin Gu, Yao Ning, and Eryan Yang; Jinzhe Qi wrote the first draft of the manuscript; Dale G. Miquelle, Marcel Holyoak and Nathan James Roberts reviewed and improved it. All authors read and approved the final manuscript.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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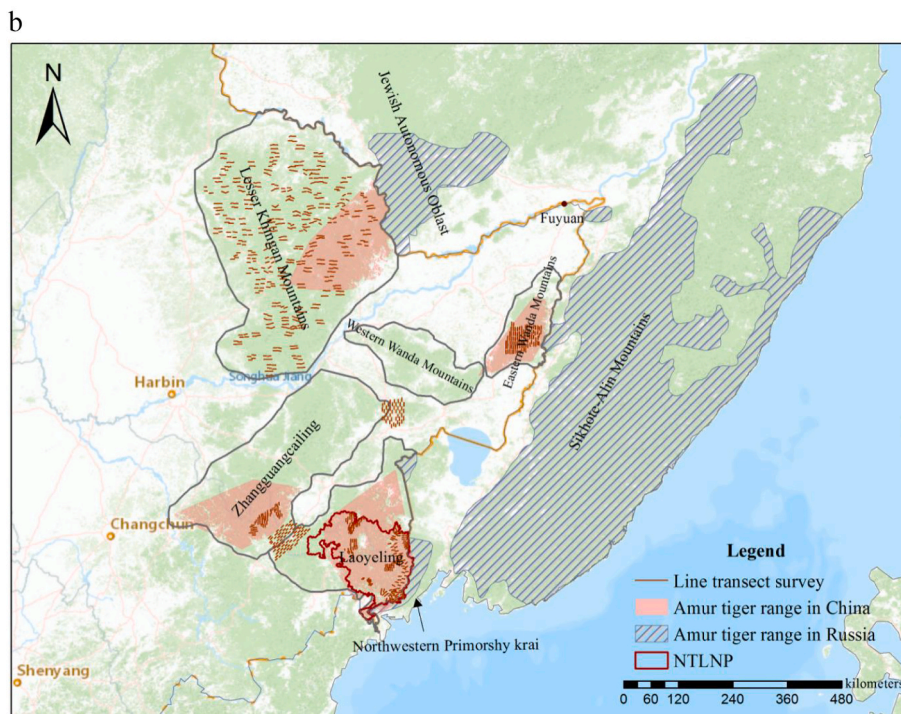
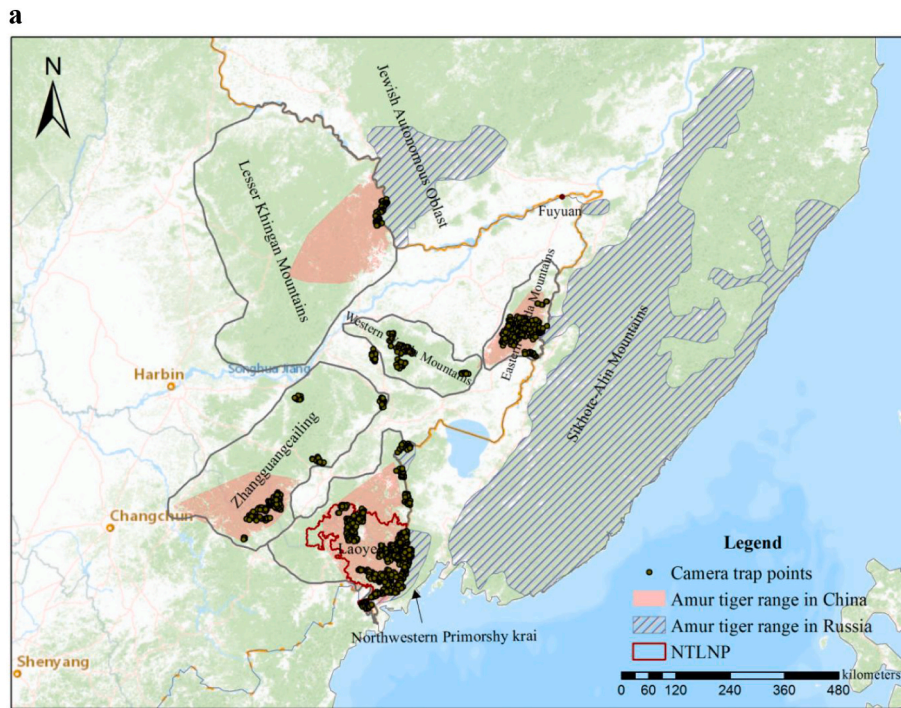
Appendix A. Human disturbance and socio-economic factors in the four landscapes. LYL, ZGCL, WDM, and LKM were the landscapes of Laoyeling, Zhanguangcailing, Wanda Mountains, and Lesser Khingan Mountains, respectively.

	LYL	ZGCL	LKM	WDM
Total area (km ²)	32600	28500	50000	12000
Main road density (km/km ²)	0.10	0.10	0.08	0.08
Railway density (km/km ²)	0.03	0.05	0.05	0.02
Human population density (individual/km ²)	56.72	74.99	39.39	64.93
GDP (\$/km ²)	40.09	45.54	14.98	32.68
Protected area/total area (rate)	0.15	0.08	0.22	0.21

Appendix B. Field survey effort in each of the four landscapes in northeast China from January 2013 to December 2018. Fecal samples were collected from transect line surveys and snow-tracking tigers. Other sources mainly derived from encounters of tracks and information from reliable witnesses. LYL, ZGCL, WDM, and LKM were the landscapes of Laoyeling, Zhanguangcailing, Wanda Mountains, and Lesser Khingan Mountains, respectively.

Landscapes	No. of transect lines	Total length of transect lines (km)	No. of camera traps	Camera trap days	No. of fecal samples	No. of other sources	Areas of the landscapes (km ²)
LYL	179	894.23	662	1 384 400	107	45	22702
ZGCL	164	793.86	214	367 600	12	23	25237
WDM	203	1035.21	244	153 300	18	54	18018
LKM	116	580	109	324 800	9	0	17404
Total	662	3303.30	1229	2230100	146	122	83361

Appendix C. The spatial distributions of camera traps (a) and transect lines (b) in each landscapes.



Appendix D. Information of Amur tigers recorded from 1 January 2013 to 31 December 2018. Note: Y, yes; -, absence; LR, left and right sides; R, right side only; L, left side only. LYL, ZGCL, WDM, and LKM were the landscapes of Laoyeling, Zhangguangcailing, Wanda Mountains, and Lesser Khingan Mountains, respectively.

Individual ID	Sex	Adult /cub	Flank	Recorded year						Landscape	Information source
				2013	2014	2015	2016	2017	2018		
CT-C01	Female	Adult	LR	Y	Y	Y	Y	Y	-	LYL	Camera traps
CT-C02	Male	Adult	LR	Y	Y	Y	-	-	-	LYL	Camera traps
CT-C03	Female	Adult	LR	Y	Y	Y	Y	Y	Y	LYL	Camera traps
CT-C04	Male	Adult	LR	Y	Y	Y	-	-	-	LYL	Camera traps
CT-C05	Female	Adult	LR	-	Y	-	-	-	-	LYL	Camera traps
CT-C06	Unknown	Adult	R	-	Y	-	-	-	-	LYL	Camera traps
CT-C07	Male	Adult	LR	Y	Y	-	-	-	-	LYL	Camera traps
CT-C08	Female	Adult	LR	Y	Y	-	-	-	-	LYL	Camera traps
CT-C09	Male	Adult	LR	-	Y	Y	-	-	-	LYL	Camera traps
CT-C10	Male	Adult	LR	-	Y	Y	Y	Y	Y	LYL, ZGCL	Camera traps
CT-C11	Male	Cub	LR	-	Y	Y	Y	-	-	LYL	Camera traps
CT-C12	Female	Cub	LR	-	Y	-	-	-	-	LYL	Camera traps
CT-C13	Male	Adult	LR	-	Y	-	-	-	-	LYL	Camera traps
CT-C14	Unknown	Adult	R	-	Y	-	-	-	-	LYL	Camera traps
CT-C15	Male	Adult	LR	-	Y	-	-	-	-	LYL	Camera traps
CT-C16	Female	Adult	LR	-	Y	Y	Y	Y	Y	LYL	Camera traps
CT-C17	Female	Adult	LR	-	Y	Y	Y	Y	Y	LYL	Camera traps
CT-C18	Female	Adult	LR	-	Y	-	Y	-	-	LYL	Camera traps
CT-C19	Unknown	Cub	R	-	Y	-	-	-	-	LYL	Camera traps
CT-C21	Unknown	Cub	L	-	Y	-	-	-	-	LYL	Camera traps
CT-C22	Male	Adult	LR	-	-	Y	-	-	-	ZGCL, WDM	Camera traps
CT-C23	Male	Adult	LR	-	-	Y	Y	Y	Y	LYL	Camera traps
CT-C24	Unknown	Cub	L	-	Y	-	-	-	-	LYL	Camera traps
CT-C25	Unknown	Adult	R	Y	-	-	-	-	-	LYL	Camera traps
CT-C26	Male	Adult	LR	-	-	Y	Y	Y	Y	LYL	Camera traps
CT-C27	Male	Adult	LR	-	-	Y	Y	Y	Y	LYL	Camera traps
CT-C28	Male	Adult	LR	-	-	Y	Y	Y	Y	LYL	Camera traps
CT-C29	Male	Adult	LR	-	-	-	Y	Y	Y	LYL	Camera traps
CT-C31	Female	Cub	LR	-	-	-	Y	Y	Y	LYL	Camera traps
CT-C32	Female	Cub	LR	-	-	-	-	Y	Y	LYL	Camera traps
CT-C33	Male	Cub	LR	-	-	-	Y	-	-	LYL	Camera traps
CT-C34	Male	Adult	LR	-	-	-	-	Y	Y	LYL	Camera traps
CT-C35	Female	Adult	LR	-	-	-	-	Y	Y	LYL	Camera traps
CT-C36	Unknown	Cub	R	-	-	-	Y	-	-	LYL	Camera traps
CT-C37	Unknown	Cub	R	-	-	-	Y	-	-	LYL	Camera traps
CT-C38	Female	Cub	LR	-	Y	-	-	Y	Y	LYL	Camera traps
CT-C39	Male	Adult	LR	-	-	-	-	Y	Y	LYL	Camera traps
CT-C40	Unknown	Adult	L	-	-	-	-	Y	-	LYL	Camera traps
CT-C41	Female	Adult	LR	-	-	-	-	Y	-	LYL	Camera traps
CT-C42	Female	Adult	LR	-	-	-	-	-	Y	LYL	Camera traps
CT-C43	Unknown	Adult	LR	-	-	-	-	-	Y	LYL	Camera traps
CT-C44	Unknown	Adult	L	-	-	-	-	-	Y	LYL	Camera traps
CT-C45	Male	Adult	LR	-	-	-	-	-	Y	LYL	Camera traps
CT-C46	Male	Adult	L	-	-	-	-	-	Y	LYL	Camera traps
CT-C47	Unknown	Cub	R	-	-	-	-	-	Y	LYL	Camera traps
CT-C48	Unknown	Cub	LR	-	-	-	-	Y	Y	LYL	Camera traps
CT-C49	Female	Adult	LR	-	-	-	-	-	Y	LYL	Camera traps
CT-C50	Female	Cub	LR	-	-	-	-	Y	Y	LYL	Camera traps
CT-C51	Unknown	Cub	LR	-	-	-	-	Y	Y	LYL	Camera traps
CT-C52	Unknown	Cub	LR	-	-	-	-	Y	-	LYL	Camera traps
CT-C53	Unknown	Cub	LR	-	-	-	-	-	Y	LYL	Camera traps
CT-C54	Unknown	Cub	LR	-	-	-	-	-	Y	LYL	Camera traps
CT-C55	Unknown	Cub	LR	-	-	-	-	-	Y	LYL	Camera traps
CT-C56	Unknown	Cub	LR	-	-	-	-	-	Y	LYL	Camera traps
CT-C57	Male	Adult	LR	-	Y	-	-	-	-	LKM	Camera traps
CT-C58	Male	Adult	LR	-	-	-	-	-	Y	LKM	Camera traps
CT-C59	Male	Adult	LR	-	-	-	-	Y	Y	WDM	Camera traps
CT-C60	Male	Adult	R	-	-	-	-	-	Y	WDM	Camera traps
CT-G01	Male	-	-	Y	-	-	-	-	-	LYL	Genetic analysis
CT-G02	Male	-	-	Y	-	-	-	-	-	LYL	Genetic analysis
CT-G03	Male	-	-	Y	-	-	-	-	-	LYL	Genetic analysis
CT-G04	Unknown	-	-	-	Y	-	-	-	-	LYL	Genetic analysis
CT-G05	Female	-	-	-	-	Y	-	Y	-	LYL	Genetic analysis
CT-G06	Male	-	-	-	-	Y	-	Y	-	LYL	Genetic analysis
CT-G07	Female	-	-	-	-	Y	-	Y	-	LYL	Genetic analysis
CT-G08	Male	-	-	-	-	Y	-	-	-	LYL	Genetic analysis
CT-G09	Female	-	-	-	-	-	Y	-	-	LYL	Genetic analysis
CT-G10	Male	-	-	-	-	-	Y	Y	-	LYL	Genetic analysis
CT-G11	Male	-	-	-	-	-	-	Y	Y	LYL	Genetic analysis
CT-G12	Unknown	-	-	-	-	-	-	Y	-	LYL	Genetic analysis

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Individual ID	Sex	Adult /cub	Flank	Recorded year						Landscape	Information source
				2013	2014	2015	2016	2017	2018		
CT-G13	Male	-	-	-	-	-	-	Y	-	LYL	Genetic analysis
CT-G14	Male	-	-	-	-	-	-	Y	-	LYL	Genetic analysis
CT-G15	Male	-	-	-	-	-	-	Y	-	LYL	Genetic analysis
CT-G16	Male	-	-	-	-	-	-	Y	-	LYL	Genetic analysis
CT-G17	Male	-	-	-	-	-	-	Y	Y	LYL	Genetic analysis
CT-G18	Male	-	-	-	-	-	-	-	Y	LYL	Genetic analysis
CT-G19	Male	-	-	-	-	-	-	-	Y	LYL	Genetic analysis
CT-G20	Male	-	-	-	-	-	-	-	Y	ZGCL	Genetic analysis
CT-G21	Male	-	-	-	-	Y	Y	-	-	ZGCL	Genetic analysis
CT-G22	Unknown	-	-	-	-	Y	-	-	-	ZGCL	Genetic analysis
CT-G23	Male	-	-	-	-	-	-	-	Y	ZGCL	Genetic analysis
CT-G24	Unknown	-	-	-	-	-	-	-	Y	WDM	Genetic analysis
CT-G25	Male	-	-	-	-	-	-	Y	Y	WDM	Genetic analysis
CT-G26	Male	-	-	-	-	-	-	Y	Y	WDM	Genetic analysis
CT-G27	Male	-	-	Y	-	-	-	-	-	WDM	Genetic analysis
CT-G28	Male	-	-	-	-	-	-	-	Y	LKM	Genetic analysis
CT-G29	Male	-	-	-	-	-	-	-	Y	LKM	Genetic analysis
CT-G30	Male	-	-	-	Y	-	-	-	-	LKM	Genetic analysis

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