Biological Conservation xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Biological Conservation

journal homepage: www.elsevier.com/locate/bioc

# A science-based approach to guide Amur leopard recovery in China

Tianming Wang [a], Limin Feng [a,*], Haitao Yang [a], Boyu Han [a], Yiheng Zhao [a], Lin Juan [a], Xinyue Lü [a], Liang Zou [a], Tong Li [a], Wenhong Xiao [a], Pu Mou [a], James L.D. Smith [b], Jianping Ge [a]

[a] State Key Laboratory of Earth Surface Processes and Resource Ecology, Ministry of Education Key Laboratory for Biodiversity Science and Engineering & College of Life Sciences, Beijing Normal University, Beijing, 100875, China
[b] Department of Fisheries, Wildlife and Conservation Biology, University of Minnesota, St Paul, MN 55108, USA

ARTICLE INFO

*Article history:*
Received 16 November 2015
Received in revised form 7 March 2016
Accepted 15 March 2016
Available online xxxx

*Keywords:*
Amur leopard
Camera trapping
Human disturbance
Cattle grazing
Habitat use
Zero-inflated model

ABSTRACT

The future of the critically endangered Amur leopard (*Panthera pardus orientalis*) is at a crucial point, and effective conservation strategies implemented within its primary historical range in Northeast China may determine the fate of this species. However, when a conservation plan was first developed for the species, scarce information on the leopards' status existed. To illustrate regional conservation challenges, we focused on the Hunchun Nature Reserve and the surrounding area along the China-Russia border, a potential stronghold for Amur leopard conservation. We conducted large-scale data analysis with a field camera-trapping network to present the first population estimates for this species using a spatially explicit capture–recapture approach. We then used a zero-inflated regression model to analyze the relationship of leopards with major prey species and anthropogenic disturbances. Our results indicate that leopards are returning to China, but most of them are part of a "border population" or are transient; their numbers are far too few to establish a healthy population. The spatial counts of leopards were noticeably high in areas with high prey richness and areas far from settlements and roads. Areas with few prey species and high human and cattle use exhibited a greater probability of "excess absences" of leopards. Mitigating human disturbances by progressively minimizing cattle and human impacts on the forest should be pursued along with habitat expansion for large ungulates, whose presence is essential for leopard occupancy. This study provides crucial information to support Chinese government recovery efforts and for refining conservation practices in human-dominated landscapes to ensure the long-term survival of this species.


## 1. Introduction

The increasing pressures resulting from human activities, especially habitat loss, poaching and prey depletion, are likely causing large carnivore declines because of their relatively slow fertility rates, wide ranges and naturally low densities (Chapron et al., 2014; Pimm et al., 2014; Ripple et al., 2014). When population sizes are reduced below certain thresholds, demographic and ecological processes can lead to rapid local extinction, and the loss of a top carnivore often results in an oversimplified ecosystem with unpredictable cascade impacts. Like that of other large carnivores, the habitat of the leopard (*Panthera pardus*), especially throughout Asia, has been fragmented due to anthropogenic habitat modification and increasing human populations. Once large populations have been subdivided, they become smaller, less viable populations (Dutta et al., 2013; Miquelle et al., 2015). Sometimes and somewhere, the leopard has to share spaces with people in human-use habitats, employing different strategies to deal with different threats posted by humans (Athreya et al., 2013, 2015).

Attempts at recovering small, threatened populations of Asian carnivores often involve expanding their range into outside of protected areas in human-dominated landscapes (Carter et al., 2012). This is the case with the endangered Amur leopard (*P.p. orientalis*), which is one of the rarest big cat in the world. This subspecies of leopard once roamed the mixed Korean pine–broadleaved forests of Northeast China, the Sikhote-Alin Mountains of the Russian Far East and northern Korea (Pocock, 1930; Uphyrkina et al., 2002). Since the 1970s, its range has shrunk, and in the late 1990s, the Amur leopard disappeared from most of Northeast China (Feng et al., 2011; Jutzeler et al., 2010; Yang et al., 1998). The subspecies is now confined to approximately 4,000 $km^2$ in southwestern Primorsky Krai of Russia and to adjacent habitat in Jilin and Heilongjian Provinces in China (Hebblewhite et al., 2011; Pikunov et al., 2009; Wang et al., 2015b; Xiao et al., 2014). This trans-boundary population of no less than 80 individuals (http://leopard-land.ru/news/3399), which shares habitat with the Amur tiger (*Panthera tigris altaica*), is at a viability threshold due to the stresses of habitat isolation, inbreeding, environmental stochasticity, and infectious diseases (Sugimoto et al., 2014; Uphyrkina et al., 2002). Despite the immediacy of the threat, conservation efforts to save leopards in the region have been inadequate to reverse the trend toward extinction.

* Corresponding author at: No. 19, XinJieKouWai St., HaiDian District, Beijing 100875, China.
*E-mail address:* fenglimin@bnu.edu.cn (L. Feng).

http://dx.doi.org/10.1016/j.biocon.2016.03.014

To ensure the species' long-term persistence, the effective population size of the Amur leopard must increase, either via reintroduction in southern Sikhote-Alin and/or population expansion into the Changbaishan Mountain ecosystem of China (Hebblewhite et al., 2011; Miquelle et al., 2015; Wang et al., 2015b); the Changbaishan Mountain ecosystem would provide approximately 25,000 km$^2$ of potential habitat (Hebblewhite et al., 2012). The last refuge for Amur leopards in southwestern Primorsky Krai holds critical source populations for leopard resettlement in China. To achieve recovery, China and Russia are developing a bilateral conservation strategy for the Amur leopard (Jutzeler et al., 2010; Wang et al., 2015b). The Chinese government has proposed a multi-stage plan for expanding the Amur leopard's range into the Changbaishan Mountain landscape. Restoring this charismatic flagship species in northeast Asian forest ecosystems will catalyze broader conservation efforts in the region.

Currently, this landscape comprises a complex of intact healthy forests and forests with intensive grazing and timber harvests interspersed with rural villages, agricultural lands and medium and large urban centers. There is a lack of information about leopards in China, and in response, the Chinese government is establishing a science-driven approach to leopard recovery. Priority research initiatives include population estimations, monitoring the dispersal of leopards and identifying factors that threaten this subspecies so that human activities can be modified to foster leopard recovery.

As elsewhere, the availability and spatial distribution of both domestic and wild prey may play a crucial role in determining the future of large felids (Butler et al., 2013; Karanth et al., 2004; Steinmetz et al., 2013). Other factors include human disturbances (e.g., logging, human settlements, roads, and livestock grazing). Although leopard density is lower closer to human settlements in Africa and Thailand (Henschel et al., 2011; Ngoprasert et al., 2007), leopards also shift to edge habitat to avoid tigers in Nepal, Thailand and India (Carter et al., 2015; Harihar et al., 2011; Steinmetz et al., 2013). Recent results from India further showed that a relatively high density of leopard occurred in human-dominated agricultural landscapes and primarily subsisted on a diet of domestic dogs and livestock (Athreya et al., 2013). The spatial heterogeneity of prey density and competition with tigers determine leopard space use in relation to prey (Carter et al., 2015; Steinmetz et al., 2013). In Northeast China, information on the ecology, habitat use, distribution and abundance of the Amur leopard is needed to guide its recovery.

Camera traps are now widely used to assess wildlife ecology and conservation (Burton et al., 2015; O'Connell et al., 2010), particularly for the study of elusive and rare species such as tigers and leopards (Karanth and Nichols, 1998; Wang and Macdonald, 2009). Population size is a key requirement for informing local decision-making in species-based management and conservation initiatives (Stephens et al., 2015). To facilitate leopard restoration in China, reliable estimates of population size are essential to assessing the effectiveness of conservation interventions. The unique spot patterns on leopards can be used to accurately identify individuals, enabling more precise estimates of population size and dynamics. A recently developed spatially explicit model (Efford et al., 2009; Royle et al., 2009) provides a robust tool with which to directly calculate the densities of this patterned species using photographic capture–recapture data from camera trapping surveys (Athreya et al., 2013; Carter et al., 2015).

In this study, we conducted the first comprehensive assessment of Amur leopard status and habitat requirements and we evaluated the ecological correlates that predict leopard distribution and abundance. We hypothesized that leopards require a threshold density of wild prey and that domestic livestock compete for forage and degrade the habitat of the leopard's natural prey. We also aim to better understand the relationship between the spatial distribution of present-day Amur leopard abundance and spatial patterns of other human disturbance features, represented by human presence, roads and settlements. The results of our research will inform recommendations for integrating leopard recovery into a landscape scale plan that includes leopard and tiger restoration and meets the local and regional ecological service needs.

## 2. Materials and methods

### 2.1. Study area

This study was carried out in the northern portion of the Changbai Mountains in Jilin and Heilongjiang Provinces in China, bordering southwestern Primorsky Krai in Russia to the east and North Korea to the southwest (Fig. 1). This region is considered the highest priority Tiger and Leopard Conservation Area in China because it has a large network of habitat patches that are connected to the source populations of tiger and leopard in Russia (Hebblewhite et al., 2012). Three Natural Reserves (Hunchun, Wangqing and Laoyeling) are located in the study area; they form the core of a potential recovery landscape for these felids in China. These reserves are on a rugged, mountainous landscape with elevations ranging from 5 to 1477 m. The major vegetation types include Korean pine (*Pinus koraiensis*) forests, oak forests, coniferous forests, natural shrublands, and agricultural areas (Hebblewhite et al., 2012; Tian et al., 2011). The majority of forests have been logged, and many low-elevation forests have been converted into secondary deciduous forests over the past 5 decades (Li et al., 2009). The prey of leopards include Siberian roe deer (*Capreolus pygargus*), sika deer (*Cervus nippon*) and wild boar (*Sus scrofa*), along with small animals such as Asian badgers (*Meles leucurus*), Manchurian hares (*Lepus mandshuricus*) and raccoon dogs (*Nyctereutes procyonoides*) (Tian et al., 2011; Xiao et al., 2014). Other predators, including Amur tigers, Asiatic black bears (*Ursus thibetanus*), Eurasian lynx (*Lynx lynx*) and sables (*Martes zibellina*), coexist with the leopard in our study area. Over the past decade, the study area has been exposed to increasing levels of agricultural and industrial development, particularly mining and new road building, which has led to habitat fragmentation. Timber harvesting has occurred extensively for decades, and there has recently been a rapid expansion of ginseng farms. Other human activities include the collection of edible ferns, frog farming, cattle grazing and poaching.

### 2.2. Data collection and field methods

Beginning in 2007, we progressively established a long-term Tiger Leopard Observation Network (TLON) of camera traps along the border with Russia and in the Laoyeling, Hunchun and Wangqing reserves and surrounding areas (Wang et al., 2015a, 2015b) (Fig. 1). The TLON used 3.6 × 3.6 km grids to guide camera placement. The cameras were placed in grids, except those on farmland and in villages; the cameras were located along trails, roads and ridges, which are common travel for leopards, tigers and their prey. The cameras (currently, LTL6210M, Shenzhen, China) were fastened on trees approximately 40–80 cm above the ground and were programmed to take photographs 24 h/day with a 1-min interval between consecutive events. Approximately 70% of stations had two cameras and no single sided camera trap leopard photo was used unless it matched a photo from a double sided station. The cameras were operated continuously throughout the year. Each camera was visited monthly to download photos and check batteries. This study (from August 2013 to July 2014) used 356 camera trap stations covering 4858 km$^2$.

We analyzed leopards, tigers, their principal wild prey (sika deer, wild boar and roe deer), domestic livestock, and human presence (e.g., rural people using the forest and border patrols) as “entities” in the camera traps. Each leopard was identified by its unique spot pattern, and the sex could usually be determined due to visible testes. Leopard cubs (<1 year old) were removed from the density analyses because they exhibit high levels of mortality (Athreya et al., 2013). Our identifications of leopard individuals were independently verified by two trained experts in Russia and Thailand, both confirmed the identity of

Please cite this article as: Wang, T., et al., A science-based approach to guide Amur leopard recovery in China, Biological Conservation (2016), http://dx.doi.org/10.1016/j.biocon.2016.03.014