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Predicting potential habitat and population size for reintroduction of the Far Eastern leopards in the Russian Far East

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ABSTRACT

The Far Eastern Leopard (*Panthera pardus orientalis*; Schlegel, 1857) is perhaps the world's most endangered large felid subspecies occurring in a single population of ⩽30 adults, and faces immediate risk of extinction unless additional populations can be established within its historical range in the Russian Far East. We used locations of leopard tracks (and their ungulate prey) collected from snow track surveys from 1997 to 2007 to develop resource selection functions (RSF) to identify potential habitat for reintroduction. We compared models that include prey versus those based on landscape covariates, and also included covariates related to human-induced mortality. To estimate potential population size, we used a habitat-based population estimate based on the ratio of population size and RSF value of occupied range. Far Eastern leopards selected for areas with high ungulate density, lower-elevation Korean pine forests on southwest facing slopes, and in areas far from human activity. Using this RSF model, we identified a total of 10,648 km^2 in eight patches >500 km^2 of potential Far Eastern leopard habitat that could harbor a potential population of 105.3 (57.9–147.2) adults. In combination with the existing population, successful reintroductions could result in a total of 139.2 (76.5–194.6) adult leopards, a 3–4-fold increase in population size. Our habitat models assist the reintroduction planning process by identifying factors that predict presence and potential suitable habitat. Identifying the highest quality, most connected patches, in combination with appropriate selection and training of released animals, is recommended for successfully reintroducing Far Eastern leopards, and potentially other endangered carnivores into the wild.

1. Introduction

Restoration of large carnivores is recognized as an important strategy for biodiversity conservation (Ray et al., 2005), as an indicator of landscape-scale conservation success (Linnell et al., 2000; Carroll et al., 2001), and because of their important trophic role (Berger et al., 2001; Hebblewhite et al., 2005). As a result, policies towards large carnivores in many areas of the world have shifted away from active persecution (Musiani and Paquet, 2004). This paradigm shift has enabled carnivores to recolonize parts of their historic ranges, e.g., wolves (*Canis lupus*) in the European Alps (Breitenmoser, 1998; Marucco and McIntire, 2010), and the northwestern USA (Pletscher et al., 1997). However, for many endangered carnivores, favorable policies alone have not been enough, and active reintroductions have been required (Breitenmoser et al., 2001). Reintroductions have established successful populations where significant dispersal barriers or human persecution still exist, such as Lynx (*Lynx canadensis)* to Colorado (Devineau et al., 2010) and the Swiss Alps (*L. lynx*)(Breitenmoser, 1998), and lions (*Panthera leo*) and other carnivores in Africa (Hayward et al., 2007a; Hunter et al., 2007). Given declining trends for many carnivores, more reintroductions will likely be required in the 21st century (Weber and Rabinowitz, 1996; Dalerum et al., 2009).

The Far Eastern, or Amur leopard (*Panthera pardus orientalis*; Schlegel 1857) is probably the most endangered large felid subspecies in the world, and has been listed as critically endangered on the IUCN red list since 1996 (Jackson and Nowell, 2008). Originally distributed broadly in the southern-most portions of the Russian Far East, Northeast China and much of the Korean peninsula (Pocock, 1930; Nowell and Jackson, 1996), fewer than 10 leopards likely exist in China today (Yang et al., 1998), and the main population occurs in southwestern Primorski Krai (Province) in the Russian Far East (Fig. 1). In 1970 there were no more than 46 individuals in three isolated populations in southern Primorski Krai (Fig. 1) (Abramov and Pikunov, 1974). By 1985, leopards had disappeared from the two northern sites (Pikunov and Korkishko, 1985),

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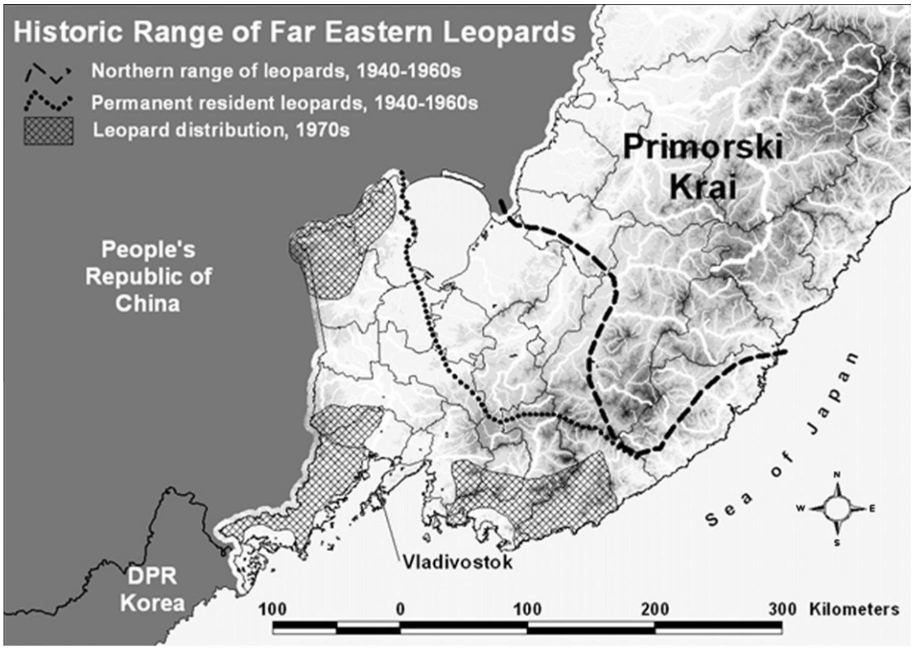

Fig. 1. Historic range of Far Eastern leopards in the southern Russian Far East (based on Heptner and Sludski, 1972, and Abramov and Pikunov, 1974). Currently leopards remain only in the southernmost hatched area in Southwest Primorski Krai (province).

and since then, a small population of 25–35 leopards has persisted in Southwest Primorski Krai (Fig. 1, Pikunov et al., 2009). This isolated population of leopards is faced with imminent extinction from continued poaching, illegal harvest of prey, habitat fragmentation, and inbreeding depression (Miththapala et al., 1996; Uphyrkina et al., 2002). It is critical that numbers of leopards increase to reduce extinction risk. However, given that natural expansion of this population seems unlikely because of high levels of agricultural and infrastructure development surrounding the population in Russia and China, reintroduction of individuals to form additional populations appears to be the best option for increasing numbers in the wild.

Quantitative assessments of reintroduction programs for mammals and birds (Griffith et al., 1989) indicate that one of the primary determinants of success is habitat quality of the release area. Various modeling approaches have been employed to identify potential habitat and colonization patterns of carnivores (Schadt et al., 2002a, b; Cianfrani et al., 2010). For many endangered carnivores, vegetation-based landscape covariates used in many habitat models are insufficient for two reasons. First, human-caused mortality – a parameter not easily tied to landscape covariates – is a primary influence on population persistence for many large carnivore populations (Chapron et al., 2008; Goodrich et al., 2008). Second, in the absence of high human-caused mortality, carnivore densities are correlated with preferred prey density (Karanth et al., 2004; Hayward et al., 2007a,b; Miquelle et al., 2010a). Therefore, to accurately identify potential habitat for reintroductions, it will be necessary to include anthropogenic influences as well as measures of prey abundance (Marucco and McIntire, 2010).

Our goal was to identify and prioritize potential habitat for reintroduction of Far Eastern leopards to their historical range in Russia, as requested by Russian authorities as part of the recovery planning process. We used extensive winter track surveys in the current range of leopards to develop a resource selection function (RSF, Boyce and McDonald, 1999) that defined the relative probability of leopard occurrence as a function of key resources. We compared models that included estimates of the probability of prey occurrence versus those based on landscape covariates, and also included anthropogenic covariates that relate to human-caused mortality of carnivores in the Russian Far East (Goodrich et al., 2008; Kerley et al., 2002). Next, we extrapolated this RSF to the historic range of Far Eastern leopards to identify best potential reintroduction sites. Using a habitat-based ratio estimator (Boyce and Waller, 2003) and estimates of the current population size, we then predicted leopard population sizes for potential habitat patches. Finally, we used the RSF models to assess connectivity of these patches with a least-cost path analysis (Chetkiewicz and Boyce, 2009). Habitat patch size, potential population size, and connectivity of patches were used as criteria for identifying priority areas for initiating a reintroduction program.

2. Study area

RSF models were first derived for the current range of leopards in Southwest Primorski Krai (current range), and then applied across their historic range in Southern Primorski Krai (historic range, Fig. 1). Their current range encompasses ~7000 km^2 along the eastern slopes of the East Manchurian Mountains on the border with China. Human activity is concentrated in low elevation agricultural river valleys, along main roads and railways, and near the main cities of Vladivostok (>700,000 people) and Ussurisk (40,000). Coastal areas are dominated by Mongolian oak (*Quercus mongolia*) and birch (*B. costata*, *B. lanata*) forests. Inland areas contain Korean pine (*Pinus koraiensis*), black fir (*Abies holophylla*), and a mixture of deciduous trees such as birch (*Betula* spp.), basswood (*Tilia amurensis*), maples (*Acer* spp.) and others. At higher elevations, conifers such as spruce (*Picea* spp.) fir (*Abies* spp.) and larch (*Larix* spp.) predominate. Two protected areas – Borisovkoe Plateau