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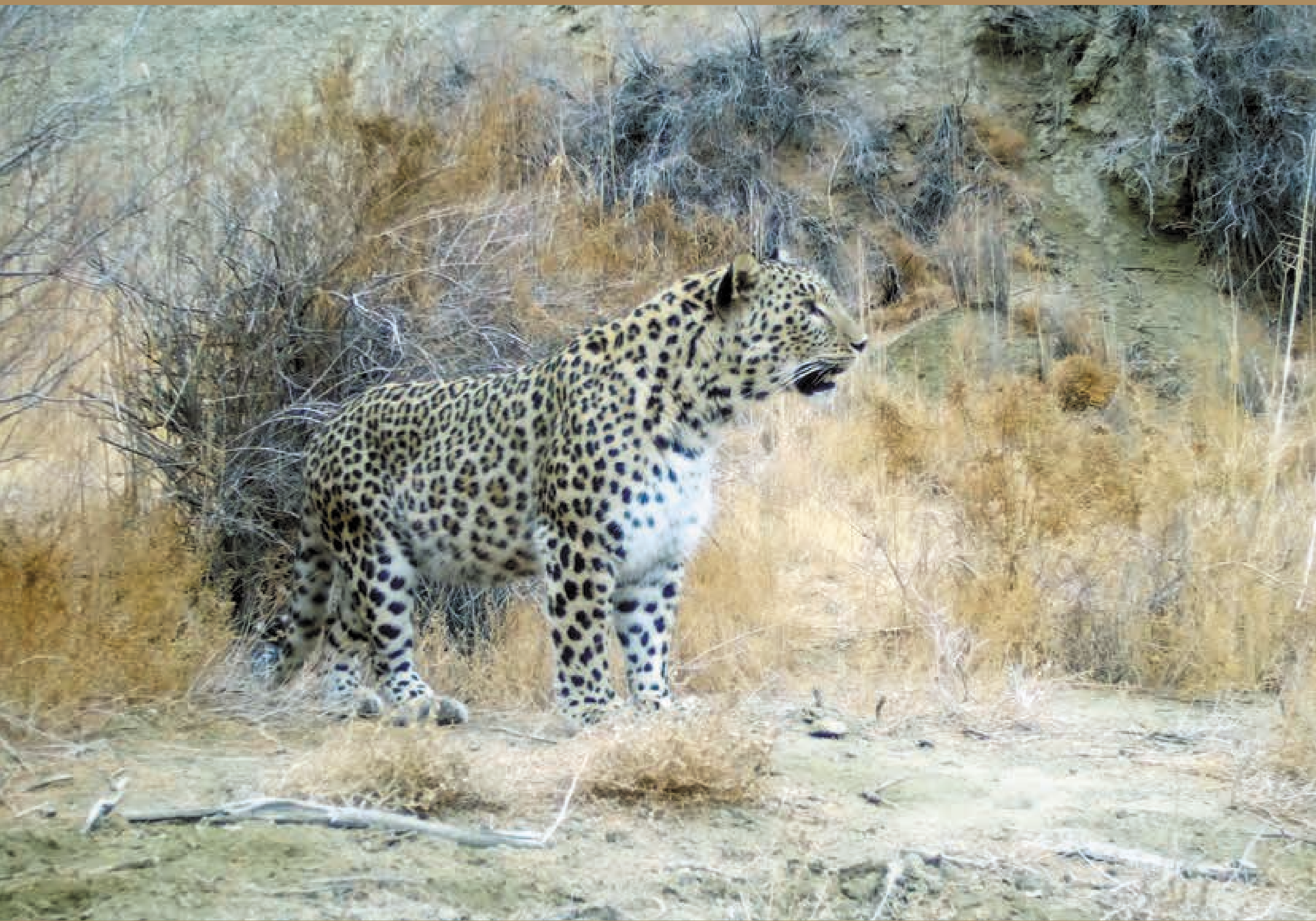
The Persian Leopard



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For joining the Friends of the Cat Group please contact Christine Breitenmoser at ch.breitenmoser@kora.ch

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Editors: Christine & Urs Breitenmoser
Co-chairs IUCN/SSC
Cat Specialist Group, KORA
Villettengässli 4, 3074 Muri,
Switzerland
Mobile ++41(79) 789 84 65 (C)
Mobile ++41(79) 410 14 39 (U)
<u.breitenmoser@kora.ch>
<ch.breitenmoser@kora.ch>

Cover Photo: Persian Leopard in Kazakhstan © USNR/CADI/ACBK, camera trap picture taken 1 January 2020, photo was provided by Tatjana Rosen

URS BREITENMOSER[1*], CHRISTINE BREITENMOSER-WÜRSTEN[1], ELINE BROUWER[1] AND TABEA LANZ[1]

Range-wide cooperation for the conservation of the Persian leopard – an introduction

The Persian leopard *Panthera pardus tulliana* (Kitchener et al. 2017) is a subspecies of leopard inhabiting Central and Southwest Asia (Bleyhl et al. 2022, Rosen & Mengüllüoğlu 2022). The Persian leopard is currently listed as Endangered (EN C2a(i)) on the IUCN Red List of Endangered Species (Khorozyan 2008). Its distribution range has been reduced substantially (Jacobson et al. 2016), and is fragmented into several isolated, mostly small populations, of which many are transboundary (Bleyhl et al. 2022, Farhadinia et al. 2022b). There is an urgent need for a concerted conservation approach across its entire range and hence international cooperation to address transboundary and range-wide conservation needs of the Persian leopard, its prey species and their habitats.

In 2002, a wildlife conservation programme with the Persian leopard as flagship was launched and is ongoing with remarkable successes (e.g. Khorozyan et al. 2022). Implementation of the long-term leopard conservation and monitoring programmes mainly by WWF teams of Armenia, Azerbaijan and Georgia in cooperation with national governments and NGOs for the restoration of the leopard's wild prey base in these countries has facilitated the Persian leopard recovery in the South Caucasus, specifically in the Zangezur triangle (Khorozyan et al. 2022). In the Caucasus Ecoregion, a Strategy for the Conservation of the Persian Leopard developed in 2007 and revised in 2017 (Breitenmoser-Würsten et al. 2007, Caucasus Leop- ard Working Group 2017) is guiding these efforts. This Strategy informed the development of the National Action Plans NAPs for the Persian Leopard in Armenia, Azerbaijan and Georgia in 2009 (Caucasus Leopard Working Group 2017) and 2019 (WWF Armenia 2019). However, the autochthonous populations outside the Caucasus region are continue to dwindle.

The Persian leopard is included in the Bern Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention) and in the Central Asian Mammals Initiative (CAMI) of the Convention on the Conservation of Migratory Species of Wild Animals (CMS; see UNEP/CMS/CAMI2/Outcomes), and these international conventions offer the platform for a coordinated range-wide conservation effort. At the 13th meeting of the Conference of Parties to CMS in 2020, CMS Parties adopted the Resolution and Programme of Work (PoW) (UNEP/CMS/Resolution 11.24 (Rev.COP13)) of the CAMI. Eleven specific points concerning the Persian leopard have been included in the CAMI PoW (Supporting Online Material SOM Table T1). One Activity of high priority is the development of a Range-wide Strategy for the Conservation of the Persian leopard, including also non-CAMI Range States i. e. Armenia, Azerbaijan, Georgia, Iraq and Turkey) and the subsequent update of national conservation action plans.

The IUCN SSC Cat Specialist Group was invited by the CMS Secretariat to facilitate the development of the range-wide Strategy (Rosen 2020). As the Covid-19 pandemic prevented

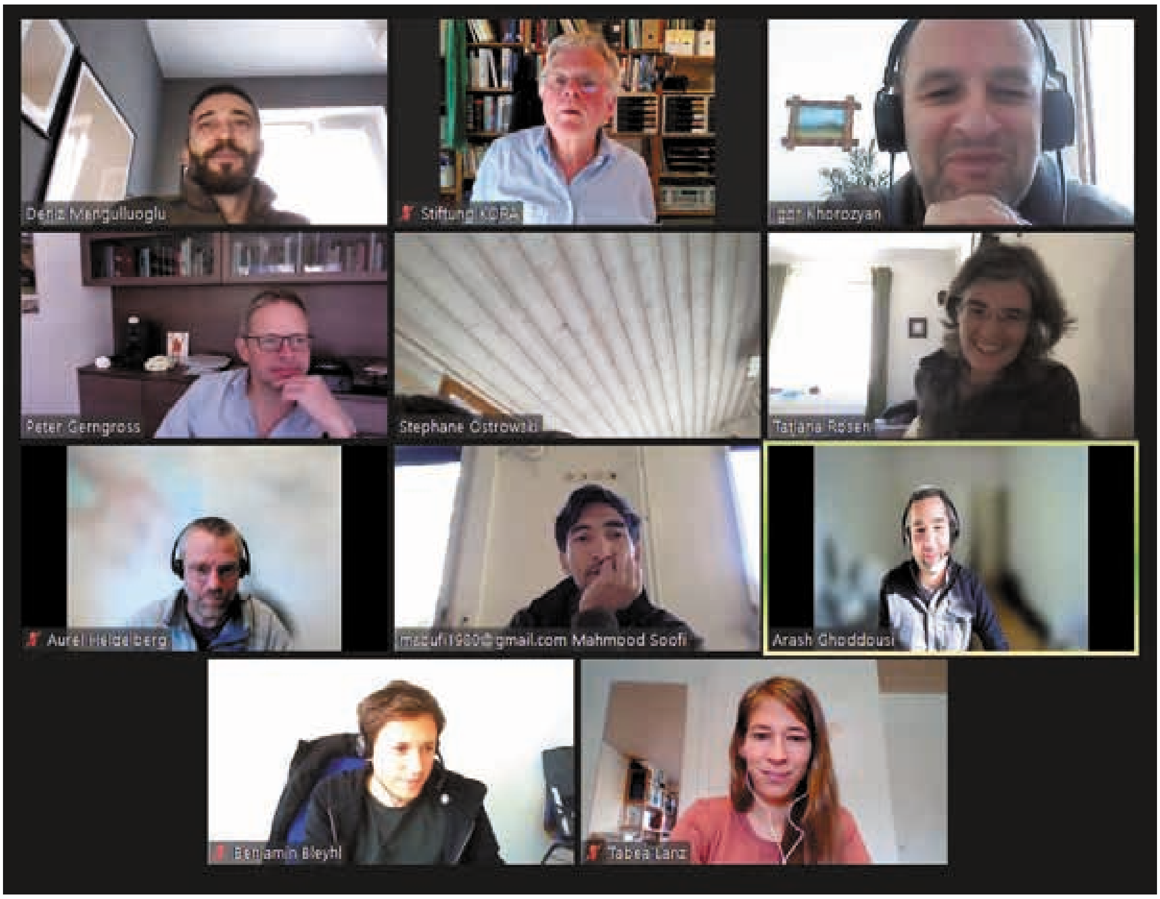

Fig. 1. Screenshot of some participants during one of the many online meetings that took place to discuss the progress of this Special Issue (Photo U. Breitenmoser).

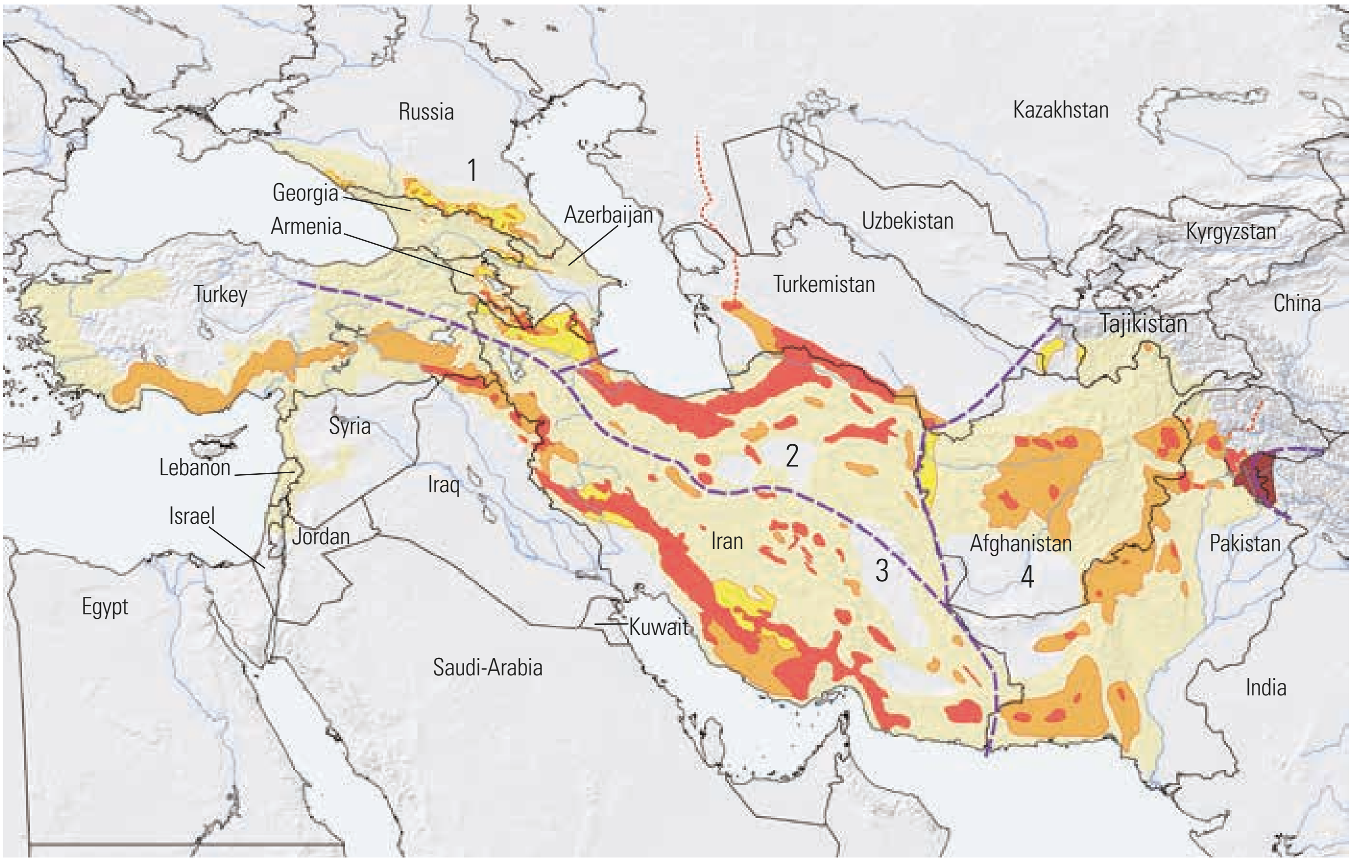

Fig. 2. Distribution of the Persian leopard in past and present times according to IUCN Red List distribution categories (red = extant; orange = possibly extant; yellow = possibly extinct; light yellow = extinct) and delineation of regions for the Persian leopard status review reports (1 = Caucasus, 2 = Alborz-Kopet Dagh, 3 = Zagros, 4 = Eastern Range (Pakistan, Afghanistan, historic distribution in Uzbekistan and Tajikistan)). The delineation of subspecies ranges follows the proposal of Kitchener et al. (2017), but there is evidence of intermixing of *P. p. tulliana* and *P. p. fusca* in northern Pakistan east of the Indus River. Map courtesy to Peter Gerngross, based on Bleyhl et al. (2022), Farhadinia et al. (2022a), Ghoddousi et al. (2022a), Khorozyan et al. (2022), and Ostrowski et al. (2022).

physical meetings, the Strategy was drafted by a group of experts on behalf of CMS and the Persian leopard Range States (see Strategy and related documents to be published on the CMS CAMI website) in several online workshops. Prior to the strategic planning workshops, the experts worked together to compile and review all information relevant for the conservation of the Persian leopard, its prey and their habitats (Fig. 1). The articles compiled in this Special Issue formed the knowledge base for drafting the Conservation Strategy, but they will also inform an updated IUCN Red List Assessment for the Persian leopard and can support the development of National Action Plans.

In a first step, the conservation status and the state of knowledge on Persian leopard was reviewed by experts from all Range States. The distribution range of the Persian leopard was divided into four regions/metapopulations, and status reports were produced for all region (Fig. 2; Chapters 4–7). Additionally, topical chapters addressing background information or specific approaches have been produced (Chapters 2, 3, 8–12). These status reports and topical chapters provide an overall view on the knowledge available on Persian leopard across its range and up-to-date information on its distribution and status.

The approach to Persian leopard conservation follows the IUCN recommendations for strategic planning for species conservation (IUCN SSC Species Conservation Planning Sub-Committee 2017). According to the IUCN SSC, strategic planning for species conservation should be participatory, transparent, and informed by the best available science. The first step in the Strategic Planning Cycle (Fig. 3) is "preparing the ground": defining the conservation unit, building partnerships, identifying stakeholders, securing political support and agreeing on the process and procedures. In a second step, all information available is compiled in a status review, which serves as an input document for the development of the Conservation Strategy. This Special Issue covers these first two steps in the planning cycle. The goal was to compile and critically review data and information relevant to Persian leopard conservation, identify gaps of knowledge, prioritise research questions and conservation needs.

Step 3 of the Strategic Planning Cycle – development of the range-wide Conservation Strategy – is done in a cooperation of the Persian leopard Range States and conservation experts under the auspice of CMS CAMI. Steps 4 (development or update of National Action Plans) and 5 (implementation of conservation measures) will then be mainly the responsibility of the national conservation organisations and national experts, however in transboundary and international cooperation wherever needed. However, the effectiveness of the Conservation Strategy and related NAPs need to be continuously evaluated against progress made in reality. This requires monitoring, reporting, and, as needed, revision of the Strategy or NAPs. Several Range Countries already have developed NAPs for the Persian leopard (e.g. Armenia, Azerbaijan and Georgia) and are invited to review and if needed revise their NAPs based on the new available information and the up-to-date

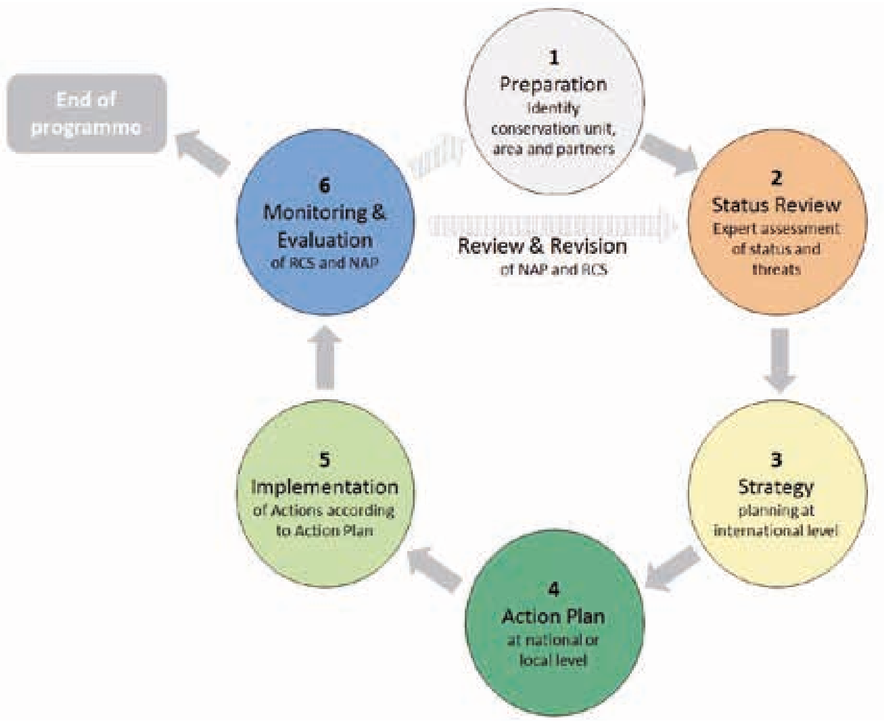

Fig. 3. Strategic Planning Cycle. The preparatory steps (Point 1 and 2) are important for sensible planning, which is the first step to successful conservation. The actual planning process (done in participatory workshops) is covered by Points 3 and 4. The ultimate goal of the whole procedure is the implementation of conservation actions (Point 5), but these will only be successful if properly planned and subsequently monitored and evaluated (Point 6). The purpose of the whole participatory process is not to have a plan but to implement effective conservation measures. The circle implies that conservation is an adaptive process (Breitenmoser et al. 2015).

range-wide Strategy. Countries with no NAP are encouraged to develop one. A step-by-step guidance for the development of a NAP in a participatory approach is provided by Breitenmoser et al. (2015). The regular CAMI Range States meetings will be used to review the implementation of the Persian Leopard Conservation Strategy and to decide about possible revision and adaptation of the Strategy.

The CMS CAMI POW, the Conservation Strategy and the information compiled in this Cat News Special Issue provide a comprehensive framework for the conservation not only of the Persian Leopard, but also of its habitat and prey species and enabling its coexistence with local communities.

References

Bleyhl B., Gerngross P., Askerov E., Farhadinia M., Ghoddousi A., Heidelberg A., … & Kuemmerle T. 2022. Mapping the distribution and habitat of Persian Leopard across its historical range. Cat News Special Issue 15, 9–18.

Breitenmoser U., Lanz T., Vogt K. & Breitenmoser-Würsten C. 2015. How to save the cat - Cat Conservation Compendium, a practical guideline for strategic and project planning in cat conservation. Cat News Special Issue 9, 36 pp.

Breitenmoser-Würsten C., Breitenmoser U., Mallon D. & Zazanashvili N. 2007. Strategy for the conservation of the Leopard in the Caucasus. Tbilisi, Georgia. 26 pp.

Caucasus Leopard Working Group 2017. Strategy for the Conservation of the Leopard in the Caucasus Ecoregion. Revised Version 2017. IUCN/SSC Cat Specialist Group, Muri b. Bern, Switzerland and WWF Caucasus Office, Tbilisi, Georgia. 29 pp.

Farhadinia M. S., Soofi M., Rosen T., Moghadas P., Hobeali K., Behnoud P., …& Linnell J. D. C. 2022a. Status of Persian leopard in the northern Iran and Central Asia. Cat News Special Issue 15, 29–35.

Farhadinia M., Khorozyan I., Orlinskiy I., Rosen T., Shahriari B., Raza H., …& Askerov E. 2022b. Priority areas for transboundary conservation of Persian leopards in west Asia and the Caucasus. Cat News Special Issue 15, 57–60

Ghoddousi A., Abolghasemi H., Arianejad M., Mozafari G. G., Joolaee L., Mousavi M., Nayeri D., Chahartaghi N. R., Raza H. & Sepahvand P. 2022. Distribution and status of the Persian leopard in its western range. Cat News Special Issue 15, 36–41.

IUCN SSC Species Conservation Planning Sub-Committee 2017. Guidelines for Species Conservation Planning. Version 1.0. Gland, Switzerland: IUCN. xiv + 114 pp.

Jacobson A. P., Gerngross P., Lemeris Jr J. R., Schoonover R. F., Anco C., Breitenmoser-Würsten C., ...& Dollar L. 2016. Leopard (*Panthera pardus*) status, distribution, and the research efforts across its range. PeerJ, 4, e1974.

Khorozyan I. 2008. *Panthera pardus ssp. saxicolor*. *In* IUCN 2009. IUCN Red List of Threatened Species. Version 2009.2.

Khorozyan I., Askerov E., Beruchashvili G., Kütükçü A. E., Lortkipanidze B., Malkhasyan A., …& Heidelberg A. 2022. Distribution and status of the Persian Leopard in the Caucasus Ecoregion. Cat News Special Issue 15, 19–28.

Kitchener A. C., Breitenmoser-Würsten C., Eizirik E., Gentry A., Werdelin L., Wilting A., ... & Tobe S. 2017. A revised taxonomy of the Felidae: The final report of the Cat Classification Task Force of the IUCN Cat Specialist Group. Cat News Special Issue 11, 80 pp.

Ostrowski S., Kabir M., Moheb Z., Gritsina M., Karimov K., Khan M. S. H. ...& Kholmatov I. 2022. Distribution and status of the Persian leopard in the eastern part of its range. Cat News Special Issue 15, 42–49.

Rosen T. 2020. Connecting the Spots: Expert Process to Develop Recommendations for a Range-wide Strategy for the Conservation of the Persian Leopard. CAMI Newsletter 04/2020, 10.

Rosen T. & Mengüllüoğlu D. 2022. Biology, Ecology and Taxonomy of the Persian Leopard. Cat News Special Issue 15, 6–8.

WWF Armenia 2019. Draft National Action Plan for Leopard (*Panthera pardus*) Conservation in Armenia 2020–2030.

Supporting Online Material SOM Tabe T1 is available at www.catsg.org.

[1] IUCN SSC Cat Specialist Group

*<u.breitenmoser@kora.ch>

TATJANA ROSEN[1] AND DENIZ MENGÜLLÜOĞLU[2*]

Biology, ecology and taxonomy of the Persian leopard

Among large felids, the Anatolian/Persian leopard *Panthera pardus tulliana* is the only extant felid that still occurs in Anatolia, Caucasus, Middle East and Central Asia. The Caspian tiger *P. tigris vigrata*, and the Asiatic lion *P. leo persica* have already gone extinct and the Asiatic cheetah *Acinonyx jubatus venaticus* is Critically Endangered. Persian leopard populations are significantly reduced in size however they continue to survive in fragmented populations.

Description, characteristics and morphology

Head and body length: 126–171 cm. Tail length: 94–106 cm. Shoulder height: 50–80 cm. Weight: 40–91 kg (male), 26–60 kg (female). Skull Length: 20.6 cm (male), 18.7 cm (female). Skull width: 15.6 cm (male), 12.8 cm (female). Dental formula: 30. Chromosome Number: 38.

The Persian leopard (Figs 1 & 2) is considered to be the largest of all the subspecies of leopards. It is a large spotted cat, with slender hindquarters and a long thick tail. The coat varies from light grey to pale yellow (Figs. 2 and 3). Hair cover of a single individual can vary across the seasons (Figs. 1 & 2). Spots and rosettes are few, black, with a brownish colouration. The ears are round. Females are smaller than adult males but can be often confused with sub-adult males. At birth, cubs are light brown, speckled with tiny dark brown and black spots (Castello et al. 2020).

Behaviour and reproduction

Persian leopards are more active during the night, but during cold season, they may be also active during the day (Fig. 1 and 2). They are very territorial and both male and female patrol their home ranges and scent-mark trees, shrubs, and rocks with urine mixed with anal gland secretions. Persian leopards use a variety of marking behaviours to communicate with each other, set territorial boundaries, and find mates. Urine spraying, scraping, claw marking and faeces are used as means of inter-individual communication (Ghoddousi et al. 2008).

In contrast to some other leopard populations (Balme et al. 2013), data suggest that Persian leopards might be seasonal breeders with a mating peak between January and March (Farhadinia et al. 2009). Both male and female leopards are solitary animals, however, during this period both sexes call (sawing) to attract mates and come together, which can last between 2–7 days. The gestation is typically 90–106 days and leopards are known to have 1–4 cubs, which are typically weaned after 70 to 100 days. Leopards reach sexual maturity at 24–28 months and are known to live 12 years in the wild. Young siblings, who leave their mother after two years, may often travel together for some time (Castello et al. 2020, Hunter 2020).

Fig. 1. A Persian leopard captured on camera (Photo Team Bars Turkmenistan).

Diet and prey preferences

Depending on the region, Persian leopards' diet may include urial sheep *Ovis vignei*, mouflon *O. gmelinii*, bezoar goat *Capra aegagrus*, East *C. cylindricornis* and West Caucasian tur *C. caucasiaca*, chamois *Rupicapra rupicapra*, wild boar *Sus scrofa*, red deer *Cervus elaphus*, fallow deer *D. dama*, roe deer *Capreolus capreolus*, goitered gazelle *Gazella subgutturosa* and porcupine *Hystrix indica*; they also feed on chukar *Alectoris chukar* and snowcock partridges *Tetraogallus* spp., hare *Lepus* spp. and pika *Ochotona rufescens* (Taghdisi et al. 2013, Farhadinia et al. 2014, Sharbafi et al. 2015, Ghoddousi et al. 2016, Farhadinia et al. 2018a). Opportunistically they will also prey on domestic livestock and dogs. Where available, caprid species are the most preferred prey due to their suitable size (Taghdisi et al. 2013, Farhadinia et al. 2014, Sharbafi et al. 2015, Ghoddousi et al. 2016, Farhadinia et al. 2018a) and leopard distribution is also influenced by the favourite prey species (Ebrahimi et al. 2020).

Taxonomy and population genetics

According to studies, the Western Asian population, from Afghanistan through Iran to Iraq and the Caucasus is distinctive phylogenetically (Miththapala et al. 1996, Uphyrkina et al. 2001), as supported by subsequent craniometric analysis (Meijaard 2004). One of the conclusions was that no significant geographical barriers are present leading to morphogenetic isolation of the subspecies in this region (Uphyrkina et al. 2001), with the exception of the population of the Arabian Peninsula (Uphyrkina et al. 2001, Khorozyan et al. 2006, Farhadinia et al. 2015, Farhadinia et al. 2020). Subsequent genetic studies have shown that there are three closely related haplotypes in Iran: one commonly found throughout Iran, south Caucasus and Turkmenistan and two localised haplotypes from southern Zagros and eastern Alborz, suggesting that the Persian leopard population in Iran as well as in neighbouring countries should be considered a single evolutionarily significant unit and thus can be protected as a large management unit through large-scale conservation planning (Farhadinia 2015). There is currently a genetic study in progress relying on microsatellite markers aimed at comparing population genetic diversity indices of leopards from Iran, Turkmenistan, Kazakhstan, Iraq and the Caucasus (T. Rosen, pers. comm.).

Distribution and habitat

The Persian leopard is found in Iran, Armenia, Azerbaijan, Georgia, Turkey, Iraq, Russia, Afghanistan, Pakistan, Turkmenistan, Kazakhstan (until 2021), and historically in Tajikistan. The presence in Uzbekistan has been anecdotally reported. The largest population is in Iran followed by Turkmenistan. In addi-tion to records from the south east and Lesser Caucasus region, there are recent leopard records from Taurus Mountains in southern Turkey (Karataş et al. 2021, D. Mengüllüoğlu pers. comm.).

The leopard inhabits a wide variety of habitats and ecosystems: from mountain areas up to 3,000 m in elevation, to grasslands and cold desert ecosystems, with a preference for cliff and rocky areas as well as juniper and pistachio woodlands that provide cover during hunting (Fig. 3). Occupied habitats are mainly prey driven. Persian leopards tend to avoid areas with deep and long snow cover, though (Castello et al. 2020).

Fig. 2. A Persian leopard caught on camera in Armenia on 18 February 2022 (Photo WWF Armenia).

Fig. 3. A Persian leopard captured on camera (Photo Team Bars Turkmenistan).

Spatial requirements

Persian leopards have spatial requirements generally influenced by density and the availability of prey (Farhadinia et al. 2018a). A study conducted in three protected leopard habitats in north-eastern Iran revealed high popula-tion densities varying between 3.1 ± 1.8 and 8.9 ± 3.6 individuals/100 km² (Farhadinia et al. 2019). Another study from North-eastern Iran reported a leopard population density of 2.6 individuals/100 km² (Hamidi et al. 2014). Persian leopard density in Bamou National Park in southern Iran was lower than these, and 1.9 individuals/100 km² (Ghoddousi et al. 2010). However, leopard population densities in the Caucasus and adjacent countries to Iran assumed to be much lower (i.e. Armenia: 0.5 individuals/100 km²; Khorozyan et al. 2008). The highest leopard density in the Caucasus region occurs in Nakhchivan, southern Caucasus where continuous breeding has been registered since 2014 (Askerov et al. 2020).

The study conducted in Tandoureh, Iran showed remarkable individual variation in leopard home range sizes, but also that leopards there occupied the largest mean home ranges (103.4 ± SE 51.8 km²) recorded to date for Asian landscapes with the exception of an adult male tracked in an arid montane habitat in central Iran (670 km²). The home ranges of predators correlated with body mass and habitat productivity: the large body masses of Persian leopards and the low primary productivity of the landscapes appeared to be the key determinants of their larger home range sizes (Farhadinia et al. 2018b).

Age, gender and reproductive status also impact ranging behaviour, with typically sub-adult males dispersing the furthest. Anthropogenic threats also influence ranging behaviour and spatial patterns for leopards (e.g. see Marker & Dickman 2005) although few data are available for Persian leopards.

Conflicts, threats and diseases

The key threats Persian leopards face are human-driven. Habitat fragmentation, loss of prey base and conflict with livestock have caused steep declines throughout the range. Leopards are killed in retaliation for harming livestock. They are also trapped and persecuted because of fear or the intention to illegally trade their skins and paws (Khorozyan 2008).

Linear infrastructure, especially border fences, severely hamper the movement of leopards as well, as does armed conflict. The presence of landmines along some of the borders in the region, might deter some poachers but kill or maim leopards (Avgan et al. 2016).

Diseases in Persian leopards are poorly studied. In 2018, a young and sick female Persian leopard was captured, treated and subsequently released, but the causes of the illness were never ascertained (M. Farhadinia, pers. comm.) and the cat tested negative for canine distemper, despite an outbreak in herders' dogs nearby. Two Persian leopards killed by vehicles in Golestan National Park tested positive for *Toxoplasma gondii* although whether Toxoplasmosis affects leopards is unknown. Drawing from research on snow leopards (Ostrowski & Gilbert 2016), it is known that tuberculosis, parvovirus, sarcoptic mange, canine distemper and most recently coronavirus have been identified as the culprit in several illnesses and deaths of captive snow leopards. Plague, anthrax and rabies are other diseases known to occur in Persian leopard range (i.e. large population of feral dogs exist in Iran, Nayeri et al. 2021) that could potentially be fatal for the cats.

References

Askerov E., Manvelyan K., Gurielidze Z., Mousavi M., Shmunk V., Trepet S.,Kütükçü A. E., Heidelberg A. & Zazanashvili N. 2020. Status of large carnivores in the Caucasus. In Ecoregional Conservation Plan for the Caucasus, 2020 Edition: Supplementary Reports. Zazanashvili N., Garforth M. & Bitsadze M. (Eds). WWF, KfW, Tbilisi. pp. 37–47.

Avgan B., Raza H., Barzani M. & Breitenmoser U. 2016. Do recent leopard *Panthera pardus* records from northern Iraq and south-eastern Turkey reveal an unknown population nucleus in the region? Zoology in the Middle East 62, 95–104.

Balme G. A., Batchelor A., De Woronin Britz N., Seymour G., Grover M., Hes L., Macdonald D. W. & Hunter L. T. B. 2013. Reproductive success of female leopards *Panthera pardus*: The importance of top-down processes. Mammal Review 43, 221–237.

Castelló J., Kitchener A. & Sliwa A. 2020. Felids and Hyenas of the World: Wildcats, Panthers, Lynx, Pumas, Ocelots, Caracals, and Relatives. University Presses. 280 p.

Ebrahimi A., Farashi A. & Rashki A. 2020. Habitat Overlap of Persian leopard, Wild Sheep and Wild Goat in Iran. Experimental animal Biology 8, 121–134.

Farhadinia M., Mahdavi A. & Hosseini-Zavarei F. 2009. Reproductive ecology of the Persian Leopard, *Panthera pardus saxicolor,* in Sarigol National Park, northeastern Iran: (Mammalia: Felidae). Zoology in the Middle East 48, 13–16.

Farhadinia M. S., Moqanaki E. M., & Hosseini-Zavarei F. 2014. Predator-prey relationships in a middle Asian Montane steppe: Persian leopard versus urial wild sheep in Northeastern Iran. European Journal of Wildlife Research 60, 341–349.

Farhadinia M. S., Farahmand H., Gavashelishvili A., Kaboli M., Karami M., Khalili B. & Montazamy S. 2015. Molecular and craniological analysis of leopard, *Panthera pardu*s (Carnivora: Felidae) in Iran: support for a monophyletic clade in Western Asia. Biological Journal of the Linnean Society 114, 721–736.

Farhadinia M. S., Johnson P. J., Hunter L. T. B. & Macdonald D. W. 2018a. Persian leopard predation patterns and kill rates in the Iran-Turkmenistan borderland. Journal of Mammalogy, 99, 713–723.

Farhadinia M. S., Johnson P. J., Macdonald D. W., & Hunter L. T. B. 2018b. Anchoring and adjusting amidst humans: Ranging behavior of Persian leopards along the Iran-Turkmenistan borderland. PLoS ONE 13(5): e0196602.

Farhadinia M. S., McClintock B. T., Johnson P. J., Behnoud P., Hobeali K., Moghadas P., Hunter L. T. B. & Macdonald D. W. 2019. A paradox of local abundance amidst regional rarity: the value of montane refugia for Persian leopard conservation. Scientific Reports 9(1): 14622.

Farhadinia M. S., Ashrafzadeh M. R., Senn H., Ashrafi S., Farahmand H., Ghazali M., Hunter L. T. B. & Macdonald D. W. 2020. Is there low maternal genetic variation in West Asian populations of leopard? Mammal Research 65, 701–708.

Gavashelishvili A. & Lukarevskiy V. 2008. Modelling the habitat requirements of leopard, *Panthera pardus*, in west and central Asia. Journal of Applied Ecology 45, 579–588.

Ghoddousi A., Soofi M., Hamidi A. K., Lumetsberger T., Egli L., Khorozyan I., Kiabi B. H. & Waltert M. 2016. Assessing the role of livestock in big cat prey choice using spatiotemporal availability patterns. PLoS ONE 11(4): e015343.

Ghoddousi A., Hamidi A. K., Ghadirian T., Ashayeri D., Hamzehpour M., Moshiri H., Zohrabi H. & Julayi L. 2008. Territorial marking by Persian leopard *(Panthera pardus saxicolor* Pocock, 1927) in Bamu National Park, Iran. Zoology in the Middle East 44, 101–103.

Ghoddousi A., Hamidi A. K., Ghadirian T., Ashayeri D. & Khorozyan I. 2010. The status of the Endangered Persian leopard *Panthera pardus saxicolor* in Bamu National Park, Iran. Oryx 44, 551–557.

Hamidi A. K., Ghoddousi A., Soufi M., Ghadirian T., Jowkar H. & Ashayeri S. 2014. Camera trap study of Persian leopard in Golestan National Park, Iran. Cat News 60, 12–14.

Hunter L. 2020. Field guide to carnivores of the world. Bloomsbury Publishing. 240 pp.

Karataş A., Bulut Ş. & Akbaba B. 2021. Camera trap records confirm the survival of the Leopard (*Panthera pardus* L., 1758) in eastern Turkey (Mammalia: Felidae). Zoology in the Middle East 67, 198–205.

Khorozyan I. 2008. *Panthera pardus ssp. saxicolor.* The IUCN Red List of Threatened Species 2008.

Khorozyan I. G., Baryshnikov G. G. & Abramov A. 2006. Taxonomic status of the leopard, *Panthera pardus* (Carnivora, Felidae) in the Caucasus and adjacent areas. Russian Journal of Theriology 5, 41–52.

Khorozyan I. G., Malkhasyan A. G., & Abramov A. V. 2008. Presence-absence surveys of prey and their use in predicting leopard (*Panthera pardus*) densities: a case study from Armenia. Integrative Zoology 3, 322–332.

Kitchener A. C., Breitenmoser-Würsten C., Eizirik E., Gentry A., Werdelin L., Wilting A., ...& Tobe S. 2017. A revised taxonomy of the Felidae: The final report of the Cat Classification Task Force of the IUCN Cat Specialist Group. Cat News Special Issue 11, 73–75.

Marker L. L. & Dickman A. J. 2005. Factors affecting leopard (P*anthera pardus*) spatial ecology, with particular reference to Namibian farmlands. South African Journal of Wildlife Research 35, 105–115.

Meijaard E. 2004. Biogeographic history of the Javan leopard (*Panthera pardus*) based on a craniometric analysis. Journal of Mammalogy 85, 302–310.

Miththapala S., Seidensticker J. & O'Brien S. J. 1996. Phylogeographic subspecies recognition in leopards (*Panthera pardus*): molecular genetic variation. Conservation Biology 10, 1115–1132.

Namroodi S., Gholami A. & Shariat-Bahadori E. 2016. Toxoplasmosis May Lead to Road Kills of Persian Leopards (*Panthera pardus saxicolor*) in Golestan National Park, Iran. Journal of Wildlife Diseases 52, 436–438.

Nayeri D., Mohammadi A., Qashqaei A., Vanak A., & Gompper M. 2021. Free-ranging dogs as a potential threat to Iranian mammals. Oryx 10, 1–7.

Ostrowski S. & Gilbert M. 2016. Diseases of Free-Ranging Snow Leopards and Primary Prey Species. Snow Leopards, 97–112.

Sharbafi E., Farhadinia M. S., Rezaie H. R. & Braczkowski A. R. 2016. Prey of the Persian Leopard (*Panthera pardus saxicolor)* in a mixed forest-steppe landscape in northeastern Iran (Mammalia: Felidae). Zoology in the Middle East 62, 1–8.

Stein A. B., Athreya V., Gerngross P., Balme G., Henschel P., Karanth U.,Miquelle D., Rostro-Garcia S., Kamler J. F., Laguardia A., Khorozyan I. & Ghoddousi A. 2020. *Panthera pardus* (amended version of 2019 assessment). The IUCN Red List of Threatened Species 2020: e.T15954A163991139.

Taghdisi M., Mohammadi A., Nourani E., Shokri S., Rezaei A. & Kaboli M. 2013. Diet and habitat use of the endangered Persian leopard (*Panthera pardus saxicolor)* in northeastern Iran. Turkish Journal of Zoology 37, 554–561.

Uphyrkina O., Johnson W. E., Quigley H., Miquelle D., Marker L., Bush M. & O'Brien S. J. 2001. Phylogenetics, genome diversity and origin of modern leopard, *Panthera pardus*. Molecular Ecology 10, 2617–2633.

[1] Caucasus Nature Fund, 8 Kortozia Street, 0177 Tbilisi, Georgia

[2] Leibniz Institute for Zoo and Wildlife Research, Berlin, Germany

*<denizmengulluoglu@gmail.com>

BENJAMIN BLEYHL[1*], PETER GERNGROSS[2], ELSHAD ASKEROV[3], MOHAMMAD S. FARHADINIA[4], ARASH GHODDOUSI[1], AUREL HEIDELBERG[5], IGOR KHOROZYAN[6], KAREN MANVELYAN[7], DENIZ MENGÜLLÜOĞLU[8], STÉPHANE OSTROWSKI[9], TATJANA ROSEN[10], VIATCHESLAV V. ROZHNOV[11], MAHMOOD SOOFI[12,13], ANNA YACHMENNIKOVA[11] AND TOBIAS KUEMMERLE[1,14]

Mapping the distribution and habitat of Persian leopard across its historical range

Persian leopards *Panthera pardus tulliana*, once widespread across Western and Central Asia, currently only occupy a fraction of their historical range. Identifying areas for restoring, connecting, and expanding extant populations is therefore important to safeguard this subspecies. Here, we used a large dataset of Persian leopard occurrences from 11 countries to map Persian leopard habitat across its historical range. We identified widespread potentially suitable habitat (about 1,290,000 km²), particularly in mountain regions. We highlight five clusters of habitat patches that could potentially host leopard metapopulations: the Caucasus (Armenia, Azerbaijan, Georgia, Iran, Russia, Turkey), the Alborz-Kopetdag Mountains (Iran, Turkmenistan), the Taurus Mountains (Turkey), the Zagros Mountains (Iran, Iraq, Turkey), and the Hindu Kush-Western Himalayas (Afghanistan, Pakistan). Further, we identified 174 core habitat patches with more than 250 km² of highly suitable habitat. Most of the core habitat patch area is found in Iran (204,005 km²; 38%), Turkey (100,651 km²; 19%), and Pakistan (51,868 km²; 10%), highlighting the importance of these countries for Persian leopard conservation. We then assessed the proportion of core patch area that is currently protected (9%) and updated the historical and current distribution maps, using all information gathered in this Special Issue. This revealed that 151 of all 174 potential habitat patches we found were historically occupied (i.e., overlapped with our historical distribution; 87%) and 53 patches are likely currently occupied (i.e., overlapped with our extant distribution; 30%). Finally, we mapped potential corridors among core habitat patches and identified three priority regions for population recovery, with clusters of unoccupied patches that have a high connectivity to currently occupied patches: the southern Caucasus, the southern Zagros Mountains, and the Hindu Kush-Spin Ghar. In sum, our analyses suggest a major potential for larger, viable Persian leopard metapopulations within their historical range, given conservation measures are implemented to halt and reverse ongoing population declines and local extinctions.

Many large carnivores today occupy only fractions of their historical ranges, persisting in small, fragmented populations (Ripple et al. 2014). The Persian leopard *Panthera pardus tulliana* is no exception. Once widespread across Anatolia, the Caucasus, and Western and Central Asia, only a few isolated populations remain today (Jacobson et al. 2016, Breitenmoser et al. 2017). Like other large carnivores, Persian leopards are mainly threatened by habitat destruction and fragmentation, illegal killings that often result from human-carnivore conflict, and prey depletion (Ghoddousi et al. 2017, 2020, Soofi et al. 2019, 2022). They require large areas of habitat and often roam beyond protected area boundaries and national borders (Ghoddousi et al. 2020, Farhadinia et al. 2021). Leopards often come into conflict with people, mainly over livestock depredation, and may get killed as a precaution or in retaliation (Ghoddousi et al. 2020, Soofi et al. 2022). Identifying suitable and safe areas to inform conservation where it might be possible to increase current population sizes, establish new populations, and work towards reducing human pressure is therefore urgently needed to safeguard leopards.

There are several regions that might still hold patches of suitable habitat within the historical Persian leopard range (e.g. in the Caucasus and Iran; Ahmadi et al. 2020, Bleyhl et al. 2021). Most of these habitat patches are however too small to host viable leopard populations (Zimmermann et al. 2007, Farhadinia et al. 2014). Therefore, regions should be identified that contain several large enough and safe habitat patches that are connected through functional corridors. In such regions, conservation efforts could seek to establish leopard metapopulations, consisting of several connected subpopulations that occur within the habitat patches (Bleyhl et al. 2021).

Achieving viable metapopulations is challenging. Often, there is a lack of information on which potential habitat patches are occupied and which would be the most promising sites to foster range expansions. Identifying candidate sites for leopard metapopulations has been done at country and regional levels (e.g., for the Caucasus; Farhadinia et al. 2015, Rozhnov et al. 2020a, Bleyhl et al. 2021), but needs to be scaled up to a range-wide level to develop a coordinated conservation strategy to safeguard Persian leopards in the future (Breitenmoser et al. 2007, Zimmermann et al. 2007, Gavashelishvili & Lukarevskiy 2008). Such information would help guiding (pro-)active conservation measures to mitigate human-leopard conflict and is further a requirement to distribute limited conservation funds most effectively. Knowledge on the current leopard distribution, patch sizes, and whether and how habitat patches are protected is thereby essential for robust conservation decisions. Additionally, it is often unclear whether functioning corridors exist between patches and where they are located. Without such corridors, population growth inside core patches can lead to a constant loss of individuals and high rates of conflict in sink areas (Khorozyan & Abramov 2007, Maharramova et al. 2018, Ghoddousi et al. 2020).

A range-wide assessment of habitat distribution is a key requirement to develop a coordinated strategy for the conservation of Persian leopards. Conservation planning is needed to safeguard existing populations, promote connectivity among them, and identify the most promising areas for natural range expansions and reintroductions. All this needs maps of the distribution of leopards and potentially suitable habitat, yet an up-to-date range-wide assessment of this kind is missing. Here, we used a large dataset of leopard occurrences from 11 range countries to map the historical, present, and potential Persian leopard distribution across the full range. Based on that, we identified core habitat patches and corridors among these patches and highlight candidate regions to establish leopard metapopulations and priority regions for population recovery. More specifically, we asked the following research questions:

1) What is the distribution of potential Persian leopard habitat?
2) How do Persian leopard habitat patches relate to the historical and current leopard distribution and how well are they connected?
3) Which regions are particularly promising for conservation interventions aimed at establishing viable Persian leopard meta-populations?
4) Which regions are particularly promising for leopard range expansion and population recovery?

Methods

Mapping potential Persian leopard habitat

As our study region, we used a broad area across Western and Central Asia comprising the Persian leopard range (Fig. 1; Jacobson et al. 2016). To make sure we map suitable habitat across the full range, we included contact zones and partly areas from neighbouring subspecies (i.e., Indian leopard *P. p. fusca* and Arabian leopard *P. p. nimr*, Jacobson et al. 2016). We considered all available leopard presence locations from the regional status reports (this Special Issue; in total 2,301 locations). From this, we only used records from 2010–2021 that had an exact location and were classified as C1 (hard fact, verified records such as photographs, camera-trap pictures, and results of genetic or biochemical analyses) or C2 (expert-confirmed records) according to the Status and Conservation of the Alpine Lynx Population (SCALP) criteria (Molinari-Jobin et al. 2012). Further, we excluded locations associated with leopard mortality and livestock kills (n = 66), because they might be in areas that are not safe, and filtered the remaining data to only retain one location per 1x1 km² cell. This resulted in a final dataset of 850 locations from 11 range countries: Afghanistan (n = 3), Armenia (n = 43), Azerbaijan (n = 24), Georgia (n = 1), Iran (n = 667), Iraq (n = 20), Kazakhstan (n = 10), Pakistan (n = 48), Russia (n = 3), Turkey (n = 2), and Turkmenistan (n = 29). To characterise habitat suitability, we used species distribution models. Species distribution models identify suitable habitat based on presence locations of species, absence, pseudo-absence, or background records, and a set of predictor variables (Franklin 2009). We used ten predictor variables related to landscape structure, landscape composition, climate conditions, and human disturbance (see SOM Table T1 in the Supporting Online Material for an overview). Regarding landscape structure, we used elevation data from the Shuttle Radar Topography Mission (SRTM; NASA JPL 2013) at 30-m resolution and calculated the terrain ruggedness index (TRI) at 1 km cell level as the square root of the sum of the squared differences between the centre pixel and its eight neighbours (Riley et al. 1999). Additionally, we calculated the mean proportion of tree and shrub cover as well as the proportion of grassland and water bodies from the Copernicus Global Land Service Land Cover Map for 2015 in each 1 km cell (Buchhorn et al. 2020). Regarding climate, we used the mean proportion of permanent snow as a predictor (Buchhorn et al. 2020) and assigned a habitat suitability of 0 to our final model predictions for all cells with a mean elevation >4,000 m, because in areas with permanent snow at high elevations, harsh winter conditions limit the range of Persian leopards and most of their prey (Lukarevsky et al. 2007a, Farhadinia et al. 2020). While data on snowfall intensity or snow depth would better characterise habitat constraints, such data is not consistently available across our study area. Regarding human disturbance, we calculated the mean distance to human settlements per 1-km cell, based on Euclidean distances to settlement centre points on a 100 m grid, as well as road density from Open Street Map data (categories for settlements: allotments, city, farm, hamlet, isolated dwelling, town, village; categories for roads: motorway, trunk, primary, secondary, tertiary; www.openstreetmap.org; downloaded on 10 September 2021). Additionally, we used the Copernicus Land Service Land Cover Map to

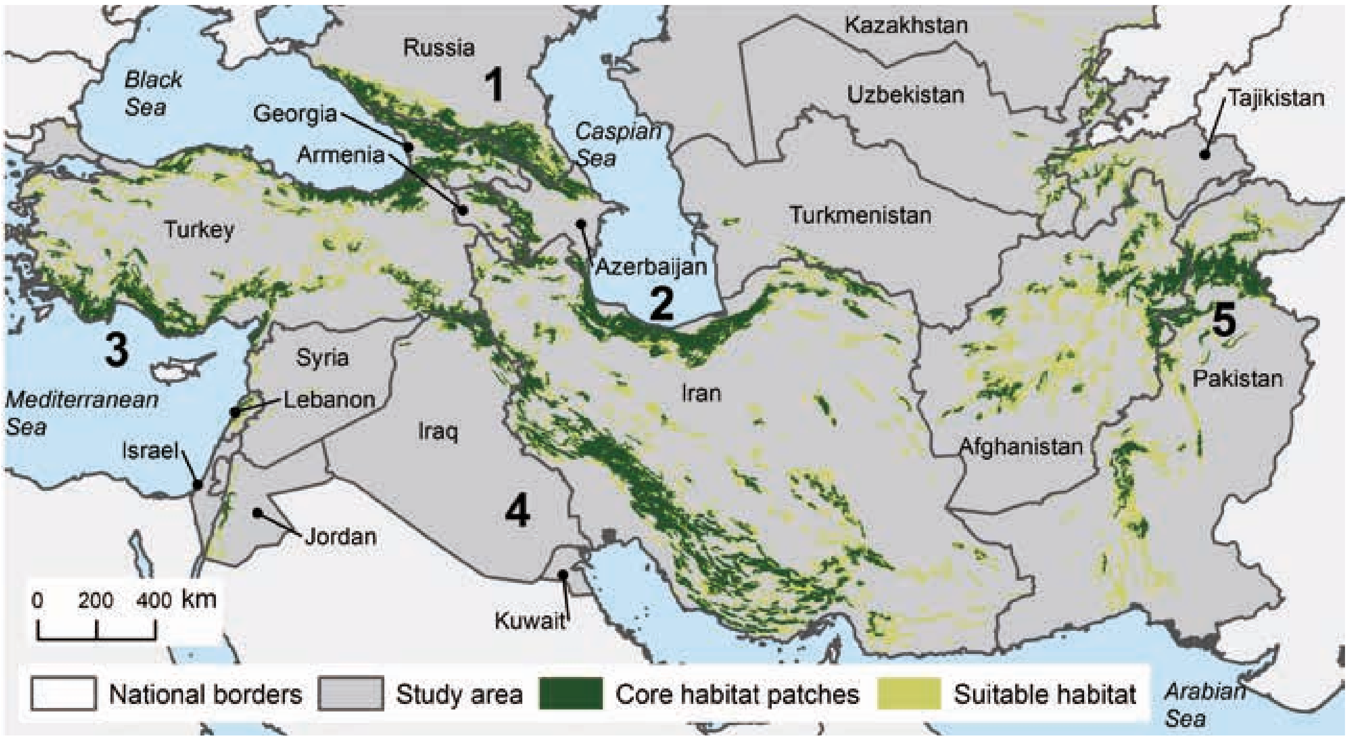

Fig. 1. Study area (dark grey), predicted suitable habitat (light green) and core habitat patches (dark green) for Persian leopards across their range. Numbers indicate the five candidate regions to host viable leopard metapopulations: (1) the Caucasus, (2) the Alborz-Kopetdag Mountains, (3) the Taurus Mountains, (4) the Zagros Mountains, and (5) the Hindu Kush-Western Himalayas.

Table 1. Core patch area, number of core patches per range country, and the respective proportion of these patches that is under protection*, sorted by decreasing core patch area. We here list only countries with core habitat area. The proportion of each country to our study area refers to the area delineated in Fig. 1 in dark grey.

Country	Proportion of total study area (%)	Core habitat area (km^2)	Number of core patches**	Area under protection (%)	Area under strict protection (%) (IUCN cat. I and II)
Iran	24	204,005	78	9.09	0.95
Turkey	12	100,651	31	9.41	0.01
Pakistan	13	51,868	16	4.79	0.02
Afghanistan	10	43,120	26	2.39	1.99
Russia	5	35,403	3	35.97	11.11
Georgia	1	33,704	4	12.16	10.44
Azerbaijan	1	17,501	4	24.18	12.89
Iraq	7	12,958	4	8.39	0.00
Tajikistan	2	8,964	9	11.22	4.46
Uzbekistan	7	6,661	7	26.68	23.30
Armenia	1	6,332	3	25.17	15.05
Turkmenistan	7	2,869	4	20.69	18.9
Jordan***	1	1,532	1	18.09	11.02
Lebanon	1	1,350	1	4.86	0.71
Kazakhstan	7	890	2	58.84	57.76
Syria	3	81	0	0.00	0.00

* The proportion under protection is based mostly on the global WDPA dataset (IUCN & UNEP-WCMC 2021; except for the Caucasus Ecoregion and Turkey), and therefore, we might underestimate protected area coverage for some countries (You et al. 2018).

** Patches crossing international borders were counted for each country if at least 250 km^2 were located in the respective country (i.e., some patches are counted multiple times in this column, once for each country with at least 250 km^2 of that patch).

*** Part of the Arabian leopard range (*P. p. nimr*) but might comprise a contact zone to Persian leopards.

calculate the proportion of cropland at the 1 km scale (Buchhorn et al. 2020), which can be a strong determinant of human-leopard conflict (Ghoddousi et al. 2020). Finally, we used a human population density map (Center for International Earth Science Information Network - CIESIN - Columbia University 2018). We resampled all our predictors to a 1-km resolution and projected them to an Albers equal-area projection. Correlation among our predictor variables was low ($r < |0.65|$).

To map potential leopard habitat, we used three species distribution modelling algorithms: boosted regression trees (BRT), a generalised linear model (GLM), and Maximum Entropy modelling (Maxent). We used these three algorithms to have a gradient from a statistical regression-based approach (GLM) to more complex ensemble (BRT) and machine-learning (Maxent) approaches and avoid having to choose one best algorithm (Hao et al. 2020). We ran all models in the R programming language (R Core Team 2021) using the *dismo* package (Hijmans et al. 2017). As pseudo-absence and background data, we randomly sampled the same number of presence points for our BRT and GLM models (i.e., n = 850) and 10,000 points for Maxent. We split our presence and pseudo-absence/background data into training (80%) and test (20%) sets to validate our models. For each model, we calculated the continuous Boyce index (CBI; Hirzel et al. 2006) and the area under the Receiver Operating Characteristics curve (AUC; Fielding & Bell 1997). The continuous Boyce index measures correlation between the predicted habitat suitability and the predicted to expected ratio of the frequency of validation points with a moving window of differing widths (negative values indicate an inverse model, values around zero a random model, and one a perfect model; Boyce et al. 2002, Hirzel et al. 2006). The AUC value contrasts sensitivity and specificity across all possible thresholds, with values ranging from 0 to 1 (1 indicating a perfect model; Jiménez-Valverde 2012). Finally, we predicted potential habitat for each algorithm and calculated an average prediction across all three algorithms, weighted by the respective AUC values, as our final potential habitat map (i.e., using the weighted arithmetic mean, where predictions from the model with the highest AUC contribute most to the average prediction). This map had habitat suitability values ranging from 0 (unsuitable) to 1 (highly suitable).

Identifying and assessing Persian leopard core habitat patches

To identify suitable core habitat patches, we converted our continuous habitat maps into binary maps using the training sensitivity plus specificity threshold (Liu et al. 2013). We then identified core habitat patches as contiguous cells with a habitat suitability above the 25th percentile of values at our presence locations (Pitman et al. 2017, Bleyhl et al. 2021) and a cumulative area of at least 250 km^2 (i.e., the minimum area for breeding populations in Iran; Farhadinia et al. 2018). While smaller minimum areas have been reported in very suitable habitat (Farhadinia et al. 2019), we chose 250 km^2 across the whole range for a conservative estimate. Based on the distribution of these core patches, we highlighted areas with clusters of core habitat by visual interpretation of our maps as regions that can potentially host a viable leopard metapopulation.

In a next step, we assessed the core habitat patches based on a range of different criteria. First, we assessed which patches were historically occupied and which patches are potentially currently occupied. To do so, we updated the historical (i.e., before the start of the Industrial Revolution) and current leopard

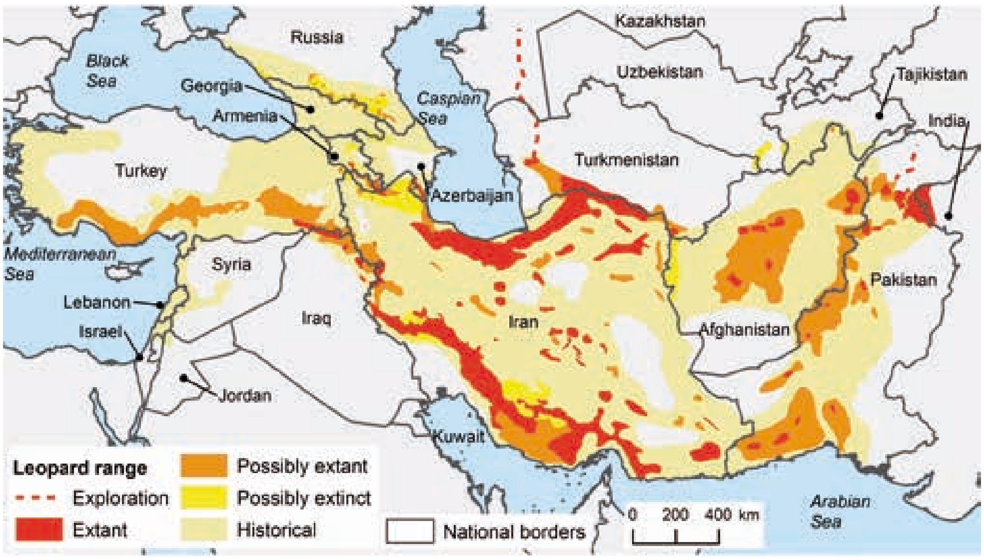

Fig. 2. Persian leopard range and historical distribution. Exploration lines are based on recent (post-2010) C1 records of leopards outside of the historical range in Turkmenistan, Kazakhstan, and Pakistan.

distributions from Jacobson et al. (2016) using the new leopard presence locations available through this Special Issue, and the results of our habitat model. The IUCN Red List Assessment for *Panthera pardus* (Stein et al. 2020) served as a basis for this procedure. For mapping the present distribution, we followed the IUCN mapping standards (IUCN Red List of Threatened Species 2021) to identify "Extant" and "Possibly Extant" areas. "Extant" areas are regions where leopards are confirmed by recent hard fact records (i.e., C1 records) or are very likely to occur within remaining suitable habitat. "Possibly extant" areas are regions where leopards may possibly occur, but recent (i.e., post 2010) hard fact records are not available. Possible occurrence is based on expert opinion or hard fact records prior to 2010 within areas of remaining suitable habitat. "Possibly extinct" areas are regions where the leopard used to occur, but no recent records are confirmed and, according to expert opinion, they are unlikely to be present due to habitat loss or other threats. "Extinct" areas are regions previously known or highly likely to support leopards, but it has been confirmed that the species no longer occurs, because exhaustive searches have failed to produce recent records and the intensity of threats could plausibly have extirpated the species. Additionally, we show advances of transient individuals (post-2010 C1 records) beyond the historic range into Kazakhstan, Turkmenistan, and Pakistan with "exploration" lines. To delineate the current distribution, we used C1 and C2 records from 2010 onwards and adjacent areas of potential leopard habitat (i.e., results of our habitat model prediction). Finally, we used existing local range maps and absence data from various local surveys to refine the distribution boundaries (i.e., from the regional status reports: Farhadinia et al. 2022a, Ghoddousi et al. 2022a, Khorozyan et al. 2022, Ostrowski et al. 2022).

Second, we calculated the area of each patch and the proportion of each patch that was officially protected using the World Database on Protected Areas (WDPA) and regional databases for the Caucasus Ecoregion and Turkey (IUCN, wwfcaucasus.net & UNEP-WCMC 2021). We acknowledge that WDPA data availability differs substantially across countries, and therefore, we might underestimate protected area coverage in some areas (You et al. 2018).

Third, we measured the connectivity of each unoccupied habitat patch (i.e., not overlapping with our extant distribution) to its closest neighbouring occupied patch (i.e., overlapping with our extant distribution). We measured connectivity as the length of least-cost corridors between patches based on our inverted habitat suitability map as a cost layer (with low length = high connectivity). For that, we used the Linkage Mapper Toolkit to calculate cumulative costs among core habitat patches and to identify least-cost paths (i.e., single-cell paths with the lowest cumulative cost from one patch to another; McRae & Kavanagh 2011). In case of disjunct constellations of patches (i.e., discrete clusters of patches that are only connected with corridors among themselves), we added corridors to their closest neighbouring patches until all constellations were connected (McRae & Kavanagh 2011). Based on this, we highlighted areas with clusters of unoccupied patches with high connectivity to current populations as promising regions for population recovery.

Fourth, to assess general connectivity among habitat patches, we also mapped least-cost corridors between all patches (McRae & Kavanagh 2011). We calculated least-cost paths between closest neighbouring patches in the Linkage Mapper Toolkit and defined corridors as those areas around the least-cost paths with a cumulative resistance below 200-km cost-weighted distance (McRae & Kavanagh 2011). Finally, to assess the permeability of the wider landscape towards leopard movement, we used Circuitscape in the programming language Julia and mapped current flow between 40 nodes randomly placed in a buffer around our study area (buffer width: 25% of the study area extent = 560 km in north-south and 1,250 km in east-west direction; Koen et al. 2010, Hall et al. 2021). Circuitscape models permeability between nodes as electric flows of current density (McRae et al. 2013). We also tested placing 50 nodes and found no substantial differences in the results. Placing the nodes randomly around our study area is a way to acknowledge that animals often have no predefined direction during dispersal and to attain a more general estimate of landscape permeability, compared to our corridor mapping (Koen et al. 2010, Pitman et al. 2017).

Results

Potential Persian leopard habitat

The three different species distribution modelling algorithms we used to map potential habitat across the Persian leopard range (i.e., BRT, GLM, and Maxent) performed similarly well, as evidenced by their high AUC and CBI values (all AUC > 0.88, all CBI > 0.92). Habitat suitability predictions did not differ substantially across algorithms (Pearson correlation coefficient r>0.7). Across all algorithms, ruggedness (TRI) was the most important predictor variable, followed by the proportion of tree cover and road density, as shown by high relative importance and percent contribution. In general, habitat suitability was highest at intermediate levels of ruggedness and increased with increasing tree and shrub cover and decreasing road density and cropland proportion (see SOM Table T1 for variable response types). Using an ensemble prediction across the three algorithms, we identified widespread areas of suitable habitat, most of which were located in the mountainous areas across our study region (in total 1,289,591 km²; Fig. 1).

Persian leopard core habitat patches and distribution

Based on our ensemble habitat map, we identified 174 core habitat patches with highly suitable habitat (i.e., areas with habitat suitability higher than at the 25th percentile of our presence locations) and a contiguous area of at least 250 km² (Fig. 1). Together, these patches covered about 528,000 km² (mean patch size = 3,035 km², median = 602 km², SD = 10.360 km²). The largest cumulative area of core patches was found in Iran (204,005 km²; 38%), followed by Turkey (100,651 km²; 19%) and Pakistan (51,868 km²; 10%; Table 1). In total, only 11% of the core patch area is currently under protection (3% under IUCN categories I and II), with substantial variation among range countries (Table 1). Among the five countries with the most habitat predicted, Russia had the highest proportion protected (36%) and Afghanistan the lowest (2%; Table 1). We then identified five regions with clusters of core habitat patches as candidate regions for hosting viable leopard metapopulations: (1) the Caucasus (Armenia, Azerbaijan, Georgia, Iran, Russia, Turkey), (2) the Alborz-Kopetdag Mountains (Iran, Turkmenistan), (3) the Taurus Mountains (Turkey), (4) the Zagros Mountains (Iran, Iraq, Turkey), and (5) the Hindu Kush-Western Himalayas (Afghanistan, Pakistan; Fig. 1).

We then compared our core habitat patches to an updated version of the historical and current leopard distribution developed in this study (Fig. 2). In total, our updated historical Persian leopard range covered an area of 3,314,667 km². In the west, it ranged from north-western Anatolia along the coast of the Aegean Sea to the southern coast of Anatolia and along the Mediterranean Sea and the Taurus Mountains to eastern Anatolia, Iran, Iraq, and to north-western Syria. From there, the distribution extended along the mountain ranges parallel to the Mediterranean coast of Syria and Lebanon to northern Israel, border-ing the Arabian leopard range (Jacobson et al. 2016). From there, the historical distribution extended north of the Tigris River across the northern and eastern parts of Iraq, but in contrast to Jacobson et al. (2016), we found no evidence of a former permanent leopard occurrence in the historical region of Mesopotamia within the Tigris-Euphrates River system. In the south, the range was limited by the coasts of the Persian Gulf, the Gulf of Oman, and the Arabian Sea. Leopards occurred throughout most of Iran (except for central and eastern desert regions, such as the Dasht-e-Kavir and Dasht-e-Lut; Fig. 2) and across large parts of Afghanistan. In the east, the range extended to the Indus River in Pakistan, bordering that of the Indian leopard (Jacobson et al. 2016). In the northern border region of Pakistan and India, east of the Indus, there is a contact zone where both subspecies, *P. p. tulliana* and *P. p. fusca*, have been genetically identified (Asad et al. 2019). The northern limit of the range included south-ern Turkmenistan and the southern parts of Uzbekistan and Tajikistan, and then the whole Greater and Lesser Caucasus. We found only 27% of the historical distribution to be still occupied (i.e., "extant" or "possibly extant" in our map). Most of our core patches were located within the historical range (151 patches/93% of the total patch area). Exceptions were the core patches in northern Turkey and in Kazakhstan, north-western Tajikistan, Uzbekistan, and Jordan (Fig. 3).

Overlaying our updated extant leopard distribution with the core habitat patches, we found that of all 174 core patches, 53 were currently likely occupied (i.e., overlapped with our extant distribution). Additionally, we ranked all potentially unoccupied core

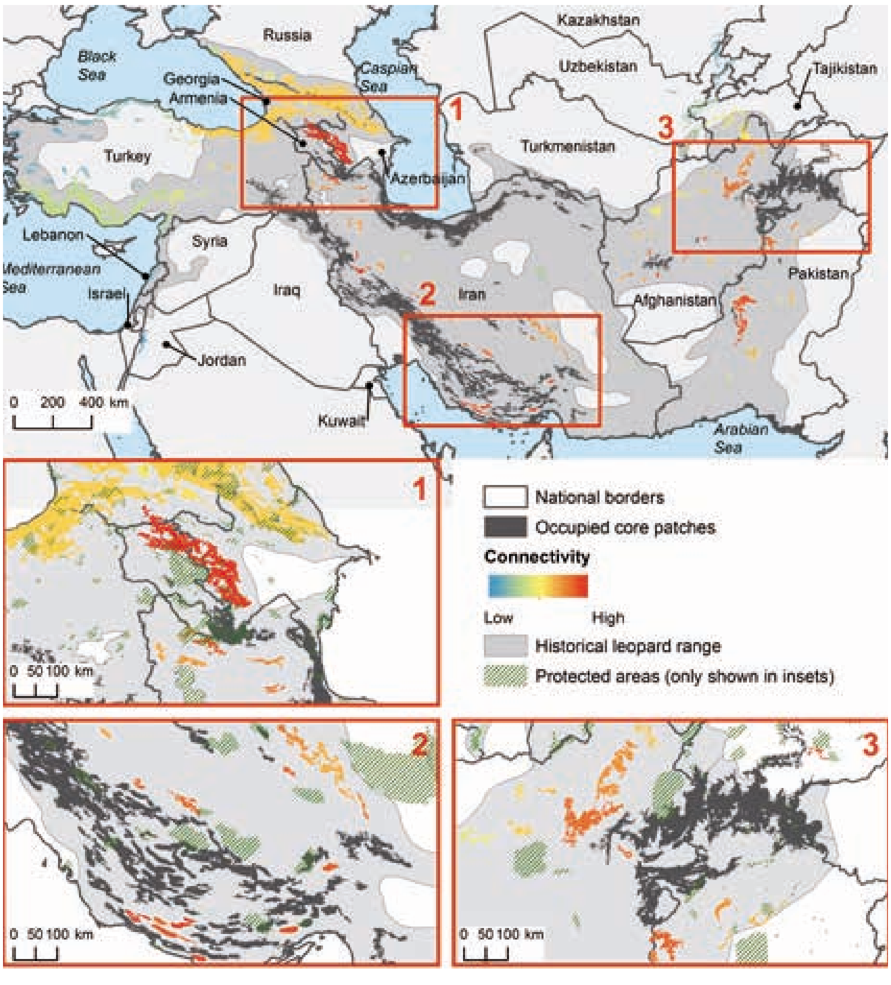

Fig. 3. Connectivity of each unoccupied patch (i.e., patches not overlapping with our extant distribution; coloured patches in the map) to its closest occupied patch (i.e., patches that overlap with our extant distribution; dark grey patches in the map). The three inset maps show the most promising regions for population recovery (clusters of unoccupied patches with high connectivity to current populations): (1) the southern Caucasus, (2) the southern Zagros Mountains, and (3) the Hindu Kush-Spin Ghar.

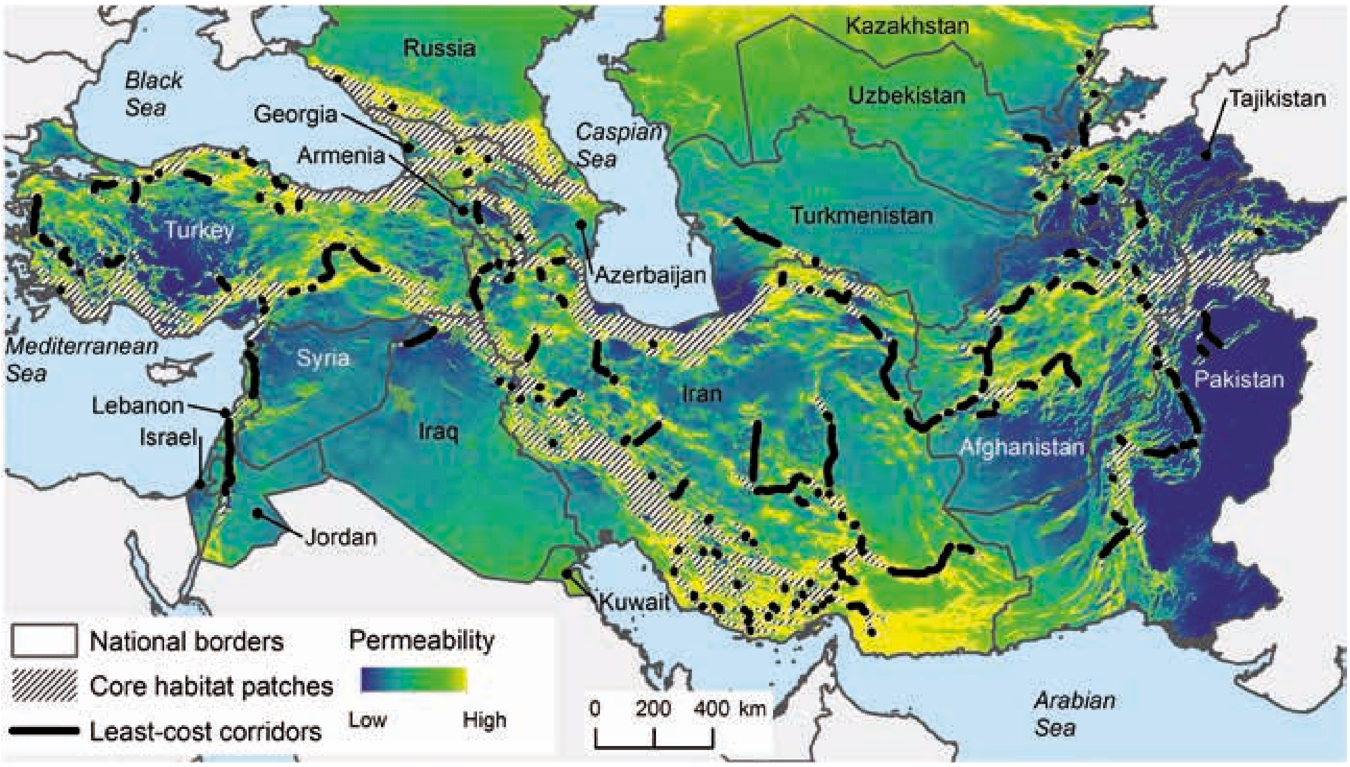

Fig. 4. Location of the least-cost corridors from each core habitat patch to its closest neighbouring patch and to the closest neighbouring disjunct group of patches and the general permeability of the landscape towards leopard movement.

habitat patches according to their connectivity to the closest occupied habitat patch. Thereby, we identified three regions as most promising areas for population recovery: (1) the southern Caucasus, (2) the southern Zagros Mountains, and (3) the Hindu Kush-Spin Ghar (Fig. 3).

Finally, we assessed the general landscape connectivity of our study area and the connectivity among core habitat patches. To do so, we first identified corridors among core habitat patches (Fig. 4). These corridors were on average 31 km long (range: 1–235 km, median: 12 km, SD: 43 km). From all 173 corridors, 7 corridors crossed international borders and 24 corridors passed through protected areas. In total, the corridors covered an area of 120,785 km², of which 6% is currently protected. The majority of the total corridor area (69%) was located in potential leopard habitat. The average cost of movement for leopards along the least-cost path between core habitat patches was 43 (range: 27–87, median: 43, SD: 9; lowest/highest possible cost: 1/100). The general permeability of the landscape towards leopard movement was moderate according to our analyses (mean current flow = 0.42; Fig. 4). Permeability was lowest in central Turkey and the eastern parts of the study area (i.e., southern Afghanistan, eastern Pakistan, and Tajikistan).

Discussion

Persian leopards today only occur in a fraction of their historical range (Jacobson et al. 2016). Restoring their populations and managing towards viable metapopulations requires the identification of clusters of suitable habitat patches and corridors among them. Here, we used a large dataset of presence records from 11 range countries to map potential Persian leopard habitat across its range. We identified widespread habitat, much of which is currently unlikely to be occupied (~70%). Our results suggest a large potential for restoring current populations and fostering recolonisations of formerly occupied habitat, and we highlight areas where conservation efforts could most effectively foster the establishment of viable metapopulations and population expansions.

Overall, our habitat model predictions were in line with regional studies that mapped suitable habitat across parts of our study area (Zimmermann et al. 2007, Gavashelishvili & Lukarevskiy 2008, Farhadinia et al. 2015, Ahmadi et al. 2020, Rozhnov et al. 2020b, Bleyhl et al. 2021). Mostly, suitable habitat was distributed across mountainous areas. This is likely due to the fact that leopards rely on either topographic heterogeneity or woody vegetation to ambush prey and find enough refuges, and because mountain areas are often less intensively used by humans (Lukarevsky et al. 2007b, Farhadinia et al. 2020). Based on our habitat map, we identified 174 core habitat patches with at least 250 km² of highly suitable habitat. Most suitable core habitat was found in Iran, underlining the importance of the country for the survival of the Persian leopard as a whole (Jacobson et al. 2016). Particularly the Talysh-Alborz-Kopetdag Mountains and the Zagros Mountains stood out as regions with relatively large contiguous habitat, found also in other regional studies (e.g., Ahmadi et al. 2020). Nevertheless, our presence locations were biased towards records from Iran (78% of our presence locations used for the models were from Iran) and we cannot rule out that we underestimated habitat suitability in other areas (e.g., in Afghanistan and Turkmenistan). With more data becoming available, our habitat model should be updated to make sure to highlight all areas potentially suitable for Persian leopards across their range. Additionally, we did not take prey availability into account, because of a lack of consistent data across the whole study area. Prey availability is a key factor for large carnivore survival, and therefore should be integrated in any follow-up regional studies wherever possible, for example by using atlas data (Wolf & Ripple 2016, Khosravi et al. 2021). Finally, with continuous monitoring data becoming available, methods that account for imperfect detection and survey effort such as occupancy models can substantially improve predictions of which areas are likely to be occupied (Guillera-Arroita 2017, Ghoddousi et al. 2022b).

We identified five main clusters with large contiguous patches of suitable habitat: the Caucasus, the Alborz-Kopetdag Mountains, the Taurus Mountains, the Zagros Mountains, and the Hindu Kush-Western Himalayas. In the Caucasus, there is currently only a small number of leopard individuals present, mostly in the south towards Iran (Askerov et al. 2015, 2019). Yet, the Persian leopard population might naturally expand towards north, as shown by records from the Karabakh Upland, northern Armenia, and Georgia, likely a result of extensive conservation efforts in the last two decades (Askerov et al. 2015, Breitenmoser et al. 2017). Additionally, there are sporadic sightings of leopards in the Greater Caucasus (Yarovenko & Zazanashvili 2016), and the ongoing reintroduction programme in Russia could complement a possible range expansion (Rozhnov et al. 2020a, 2022). Nevertheless, the establishment of a viable metapopulation in the Caucasus likely depends on substantial conservation actions, particularly to mitigate human-leopard conflict, reduce leopard persecution, increase prey availability, and establish connectivity towards Iran and among core habitat patches, including to the Greater Caucasus (Moqanaki et al. 2013, Farhadinia et al. 2015, Babrgir et al. 2017, Maharramova et al. 2018, Rozhnov et al. 2020a, Bleyhl et al. 2021). The second cluster of core habitat patches we found is in the Alborz-Kopetdag Mountains in northern Iran and Turkmenistan. This area is a stronghold for leopards, given the high densities of leopards within the national parks (Hamidi et al. 2014, Farhadinia et al. 2019). However, recent surveys indicate that increased poaching in response to livestock depredation might have severely decimated local populations, particularly in the Alborz region (Kaczensky et al. 2019, Soofi et al. 2019, 2022, Farhadinia et al. 2022a). Nevertheless, the availability of prey, high landscape connectivity and the existence of a protected area network make this cluster likely the most important region for the survival of the Persian leopard, possibly hosting the largest population within the entire range (Kiabi et al. 2002, Hamidi et al. 2014, Ghoddousi et al. 2016, Farhadinia et al. 2019). Further west, the Taurus Mountains in south-western Turkey were highlighted as a cluster of suitable habitat patches. Information on the status of leopards in this area are very limited. At the time of writing, no breeding leopards were reported from the Taurus Mountains (Karataş et al. 2021). Additionally, the Taurus Mountains are relatively isolated from larger current source populations (Fig. 1), suggesting that active translocations could be needed to establish a viable metapopulation there. A fourth cluster of larger patches with suitable habitat was located along the Zagros Mountains, underlining the general suitability of that area for leopards (Kaboodvandpour et al. 2021). Several protected areas in Iran's Zagros Mountains (e.g., Bamu National Park, Dena National Park) are known to host small but stable leopard populations (Ghoddousi et al. 2010, 2022a). Additionally, recent records from the border region between Iran, Iraq, and Turkey indicate that this region might still host a small leopard population but conservation measures need to be ramped up to establish a larger viable metapopulation (Avgan et al. 2016, Karataş 2021). Finally, a large contiguous region with core habitat patches was found in the Hindu Kush and western Himalayas. This region had larger patches towards eastern Afghanistan and northern Pakistan and is relatively isolated from the remaining Persian leopard populations (Hosseini et al. 2019), yet connecting to the east with the Indian leopard in the northern Indus area of Pakistan (Asad et al. 2019). Additionally, in this area, leopards suffer from a loss of habitat and wild prey, leading to an increase in human-leopard conflict over livestock depredation, while armed conflicts often hinder the enforcement of conservation regulations (Shehzad et al. 2015, Kabir et al. 2017, Ostrowski et al. 2022).

Almost 70% of our core habitat was identified as currently not occupied in our analyses (or, given that parts of our study area are not frequently surveyed, not known to be occupied). Additionally, Persian leopards likely lost 73% of their historical range according to our updated distribution maps (in line with Jacobson et al. (2016), who estimated 72–84% range loss). This suggests that Persian leopards are under considerable pressure across their range, which likely prevents a natural recolonisation of these historically occupied patches and the establishment of metapopulations. One of the main reasons for suitable but unoccupied habitat is persecution, particularly in retaliation or fear of leopards killing livestock (Bleyhl et al. 2021, Soofi et al. 2022). Such killings can have devastating effects on small leopard populations and are often hindering population recoveries (Ghoddousi et al. 2020, Soofi et al. 2022). In addition to direct persecution, insufficient prey in otherwise suitable habitat can prevent the colonization of habitat patches, which in turn is often a result of poaching on prey (Ghoddousi et al. 2017). Indeed, only 11% of the core habitat patch area is currently protected, which might make conservation measures to reduce anthropogenic pressure on leopards and their prey challenging. Yet, given the large home range sizes and territories of Persian leopards (Farhadinia et al. 2018), a key aspect of their conservation is likely to foster coexistence with people and restore prey species particularly also outside protected areas (Ghoddousi et al. 2020). Additionally, we likely missed protected area coverage in some areas, relying mostly on the global standardised WDPA data (You et al. 2018). Finally, limited connectivity to current populations can prevent dispersal to unoccupied habitat patches. Because the underlying constraints for re-occupation of suitable habitat likely differ across areas, local studies are needed to identify the most effective conservation measures at place to facilitate range expansion.

Based on the connectivity of unoccupied to currently occupied core habitat patches, we identified three priority regions for population recovery in the near future: the southern Caucasus, the southern Zagros mountains, and the Hindu Kush-Spin Ghar (Fig. 3). While the southern Caucasus is currently likely experiencing a recovery of its leopard population (Askerov et al. 2019, Khorozyan et al. 2022), the situation is unclear for the southern Zagros Mountains and the Hindu Kush-Spin Ghar. In the southern Zagros, natural fragmentation, the low elevation of the mountains, and the low prey availability create more vulnerable conditions for the Persian leopard. Nevertheless, sporadic leopard sightings show the potential of the area for recovery, once conservation interventions are in place (Ghoddousi et al. 2022). In the Hindu Kush-Spin Ghar area, insecurity and resulting limited scientific investigations are current constraints for a better picture of the status of the Persian leopard populations and the potential for recovery. Despite severe habitat fragmentation due to fast increasing human populations, the potential for recovery in this area exists but would require, perhaps here more than elsewhere, genuine enforcement of existing regulations, engagement with communities, and a continued political commitment at all levels (Ostrowski et al. 2022).

Our connectivity analysis further revealed the best areas for corridors among core leopard patches (Fig. 4). The distribution of these corridors was in general in line with other regional connectivity studies (Farhadinia et al. 2015, Bleyhl et al. 2017, Hosseini et al. 2019). Most corridors were relatively short, meaning that most core patches were located in close distance (Euclidean as well as cost-distance) to other core patches. Persian leopards can disperse across large distances (> 80 km), often undetected, which indicates their potential to recolonise suitable habitat, given that persecution is prevented and prey species are available (Farhadinia et al. 2018, Maharramova et al. 2018, Askerov et al. 2019). Yet, several corridors crossed international borders (e.g., between Iran and Iraq, and Iran and Afghanistan), highlighting the importance of transboundary conservation for wide-ranging species, where border walls or fences might be impenetrable barriers (Linnell et al. 2016, Farhadinia et al. 2021, 2022b).

Using a large training dataset, we highlighted that potential habitat for Persian leopards is still widespread across the subspecies' former range. Much of this habitat is currently unoccupied, indicating high pressure on current leopard populations that prevents a substantial range expansion. Our modelling results indicate areas where populations could most easily recover, but conservation measures are needed, particularly to mitigate human-leopard conflict, restore prey populations, and foster connectivity (Farhadinia et al. 2015, Ghoddousi et al. 2020, Bleyhl et al. 2021). Protected areas can play an important role to implement such measures (currently, only 11% of all core habitat and 6% of all corridor areas are protected), but need to be accompanied by measures targeted at multiple-use landscapes, particularly in terms of conflict mitigation, prey recovery, and connectivity restoration (Babrgir et al. 2017, Ghoddousi et al. 2020). Effects of climate change can pose an additional threat on possible population recoveries, particularly because a large part of the range is vulnerable to drought, which could make vast areas climatically unsuitable and further intensify depredation on livestock due to prey decline (Khorozyan et al. 2015, Ashrafzadeh et al. 2019). Effects of climate change can additionally lead to substantial structural changes in habitat suitability and the corridors we mapped here, and therefore local assessments are needed to complement our range-wide assessment with fine-scale climate change predictions. More broadly, our study highlights the potential for viable Persian leopard metapopulations across their historical range, but only if conservation measures were implemented and coordinated among range countries. Transboundary efforts such as the Bern Convention, the Ecoregional Conservation Plan for the Caucasus (Zazanashvili et al. 2020), and the Central Asian Mammals Initiative CAMI under the Convention on the Conservation of Migratory Species of Wild Animals CMS are important steps towards coordinating range countries in their conservation efforts (Farhadinia et al., 2022b) and ultimately managing towards the recovery of Persian leopards across their historical range.

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References

Ahmadi M., Farhadinia M. S., Cushman S. A., Hemami M. R., Nezami Balouchi B., Jowkar H. & Macdonald D. W. 2020. Species and space: a combined gap analysis to guide management planning of conservation areas. Landscape Ecology 35, 1505–1517.

Asad M., Martoni F., Ross J. G., Waseem M., Abbas F. & Paterson A. M. 2019. Assessing subspecies status of leopards (*Panthera pardus*) of northern Pakistan using mitochondrial DNA. PeerJ 7, e7243.

Ashrafzadeh M. R., Naghipour A. A., Haidarian M. & Khorozyan I. 2019. Modeling the response of an endangered flagship predator to climate change in Iran. Mammal Research 64, 39–51.

Askerov E., Talibov T., Manvelyan K., Zazanashvili N., Malkhasyan A., Fatullayev P. & Heidelberg A. 2015. South-Eastern Lesser Caucasus: the most important landscape for conserving the Leopard (*Panthera pardus*) in the Caucasus region (Mammalia: Felidae). Zoology in the Middle East 61, 95–101.

Askerov E., Talibov T., Manvelyan K., Zazanashvili N., Fatullayev P. & Malkhasyan A. 2019. Leopard (*Panthera pardus)* reoccupying its historic range in the South Caucasus: a first evidence (Mammalia: Felidae). Zoology in the Middle East 65, 88–90.

Avgan B., Raza H., Barzani M. & Breitenmoser U. 2016. Do recent leopard *Panthera pardus* records from northern Iraq and south-eastern Turkey reveal an unknown population nucleus in the region? Zoology in the Middle East 62, 95–104.

Babrgir S., Farhadinia M. S. & Moqanaki E. M. 2017. Socio-economic consequences of cattle predation by the endangered Persian leopard *Panthera pardus saxicolor* in a Caucasian conflict hotspot, northern Iran. Oryx 51, 124–130.

Bleyhl B., Baumann M., Griffiths P., Heidelberg A., Manvelyan K., Radeloff V. C., Zazanashvili N. & Kuemmerle T. 2017. Assessing landscape connectivity for large mammals in the Caucasus using Landsat 8 seasonal image composites. Remote Sensing of Environment 193, 193–203.

Bleyhl B., Ghoddousi A., Askerov E., Bocedi G., Breitenmoser U., Manvelyan K. … & Kuemmerle T. 2021. Reducing persecution is more effective for restoring large carnivores than restoring their prey. Ecological Applications 31, e2338.

Boyce M. S., Vernier P. R., Nielsen S. E. & Schmiegelow F. K. A. 2002. Evaluating resource selection functions. Ecological Modelling 157, 281–300.

Breitenmoser U., Breitenmoser-Würsten C., Mörschel F., Zazanashvili N. & Sylvén M. 2007. General conditions for the conservation of the leopard in the Caucasus. Cat News Special Issue 2, 34–39.

Breitenmoser U., Askerov E., Soofi M., Breitenmoser-Würsten C., Heidelberg A., Manvelyan K. & Zazanashvili N. 2017. Transboundary leopard conservation in the Lesser Caucasus and the Alborz Range. Cat News 65, 24–25.

Buchhorn M., Smets B., Bertels L., Roo B. D., Lesiv M., Tsendbazar N. E., Herold M. & Fritz S. 2020. Copernicus Global Land Service: Land Cover 100m: collection 3: epoch 2015: Globe. Zenodo https://doi.org/10.5281/zenodo.3939038

Center for International Earth Science Information Network - CIESIN - Columbia University. 2018. Gridded Population of the World, Version 4 (GPWv4): Population Density, Revision 11.

Farhadinia M. S., Moqanaki E. M. & Hosseini-Zavarei F. 2014. Predator–prey relationships in a middle Asian Montane steppe: Persian leopard versus urial wild sheep in Northeastern Iran. European Journal of Wildlife Research 60, 341–349.

Farhadinia M. S., Ahmadi M., Sharbafi E., Khosravi S., Alinezhad H. & Macdonald D. W. 2015. Leveraging trans-boundary conservation partnerships: Persistence of Persian leopard (*Panthera pardus saxicolor*) in the Iranian Caucasus. Biological Conservation 191, 770–778.

Farhadinia M. S., Johnson P. J., Macdonald D. W. & Hunter L. T. B. 2018. Anchoring and adjusting amidst humans: Ranging behavior of Persian leopards along the Iran-Turkmenistan borderland. PLoS ONE 13, e0196602.

Farhadinia M. S., McClintock B. T., Johnson P. J., Behnoud P., Hobeali K., Moghadas P., Hunter L. T. B. & Macdonald D. W. 2019. A paradox of local abundance amidst regional rarity: the value of montane refugia for Persian leopard conservation. Scientific Reports 9, 14622.

Farhadinia M. S., Heit D. R., Montgomery R. A., Johnson P. J., Hobeali K., Hunter L. T. B. & Macdonald D. W. 2020. Vertical relief facilitates spatial segregation of a high density large carnivore population. Oikos 129, 346–355.

Farhadinia M. S., Rostro-García S., Feng L., Kamler J. F., Spalton A., Shevtsova E., Khorozyan I., Al-Duais M., Ge J. & Macdonald D. W. 2021. Big cats in borderlands: challenges and implications for transboundary conservation of Asian leopards. Oryx 55, 452–460.

Farhadinia M. S., Soofi M., Rosen T., Moghadas P., Hobeali K., Behnoud P., … & Linnell J. D. C. 2022a. Status of Persian leopard in the northern Iran and Central Asia. Cat News Special Issue 15, 29–35.

Farhadinia M., Khorozyan I., Orlinskiy I., Rosen T., Shahriari B., Raza H., … & Askerov E. 2022b. Priority areas for transboundary conservation of Persian leopards in west Asia and the Caucasus. Cat News Special Issue 15, 57–60.

Fielding A. H. & Bell J. F. 1997. A review of methods for the assessment of prediction errors in conservation presence/absence models. Environmental Conservation 24, 38–49.

Franklin J. 2009. Mapping species distributions: spatial inference and prediction, Ecology, biodiversity and conservation. Cambridge University Press, Cambridge, United Kingdom & New York, U.S.A.

Gavashelishvili A. & Lukarevskiy V. 2008. Modelling the habitat requirements of leopard *Panthera pardus* in west and central Asia. Journal of Applied Ecology 45, 579–588.

Ghoddousi A., Hamidi A. K., Ghadirian T., Ashayeri D. & Khorozyan I. 2010. The status of the Endangered Persian leopard *Panthera pardus saxicolor* in Bamu National Park, Iran. Oryx 44, 551–557.

Ghoddousi A., Soofi M., Hamidi A. K., Lumetsberger T., Egli L., Khorozyan I., Kiabi B.H. & Waltert M. 2016. Assessing the role of livestock in big cat prey choice using spatiotemporal availability patterns. PLoS ONE 11, e0153439.

Ghoddousi A., Soofi M., Hamidi A. K., Lumetsberger T., Egli L., Ashayeri S., Khorozyan I., Kiabi B. H. & Waltert M. 2017. When pork is not on the menu: Assessing trophic competition between large carnivores and poachers. Biological Conservation 209, 223–229.

Ghoddousi A., Bleyhl B., Sichau C., Ashayeri D., Moghadas P., Sepahvand P., Hamidi A. K., Soofi M. & Kuemmerle T. 2020. Mapping connectivity and conflict risk to identify safe corridors for the Persian leopard. Landscape Ecology 35, 1809–1825.

Ghoddousi A., Abolghasemi H., Arianejad M., Mozafari G. G., Joolaee L., Mousavi M., Nayeri D., Chahartaghi N. R., Raza H. & Sepahvand P. 2022a.Distribution and status of the Persian leopard in its western range. Cat News Special Issue 15, 36–41.

Ghoddousi A., Bleyhl B., Askerov A., Heidelberg A., Kabir M., Lortkipanidze B., … & Kuemmerle T. 2022b. A range-wide monitoring framework for the Persian leopard and its prey. Cat News Special Issue 15, 61–66.

Guillera-Arroita G. 2017. Modelling of species distributions, range dynamics and communities under imperfect detection: advances, challenges and opportunities. Ecography 40, 281–295.

Hall K. R., Anantharaman R., Landau V. A., Clark M., Dickson B. G., Jones A., Platt J., Edelman A. & Shah V. B. 2021. Circuitscape in Julia: Empowering Dynamic Approaches to Connectivity Assessment. Land 10, 301.

Hamidi A. K., Ghoddousi A., Soufi M., Ghadirian T., Jowkar H. & Ashayeri S. 2014. Camera trap study of Persian leopard in Golestan National Park, Iran. Cat News 60, 12–14.

Hao T., Elith J., Lahoz-Monfort J. J. & Guillera-Arroita G. 2020. Testing whether ensemble modelling is advantageous for maximising predictive performance of species distribution models. Ecography 43, 549–558.

Hijmans R. J., Phillips S., Leathwick J. & Elith J. 2017. dismo: Species distribution modeling. R Package Version 1, 1–1.

Hirzel A. H., Lay G., Helfer V., Randin C. & Guisan A. 2006. Evaluating the ability of habitat suitability models to predict species presences. Ecological Modelling 199, 142–152.

Hosseini M., Farashi A., Khani A. & Farhadinia M. S. 2019. Landscape connectivity for mammalian megafauna along the Iran-Turkmenistan-Afghanistan borderland. Journal for Nature Conservation 52, 125735.

IUCN Red List of Threatened Species. 2021. Mapping Standards and Data Quality for the IUCN Red List Spatial Data Version 1.19 (May 2021). Prepared by the IUCN SSC Red List Technical Working Group.

IUCN & UNEP-WCMC. 2021. The World Database on Protected Areas (WDPA). WCMC, Cambridge, UK.

Jacobson A. P., Gerngross P., Lemeris Jr. J. R., Schoonover R. F., Anco C., Breitenmoser-Würsten C., … & Dollar L. 2016. Leopard (*Panthera pardus*) status, distribution, and the research efforts across its range. PeerJ 4, e1974.

Jiménez-Valverde A. 2012. Insights into the area under the receiver operating characteristic curve (AUC) as a discrimination measure in species distribution modelling. Global Ecology and Biogeography 21, 498–507.

Kabir M., Hameed S., Ali H., Bosso L., Din J. U., Bischof R., Redpath S. & Nawaz M. A. 2017. Habitat suitability and movement corridors of grey wolf (*Canis lupus*) in Northern Pakistan. PLoS ONE 12, e0187027.

Kaboodvandpour S., Almasieh K. & Zamani N. 2021. Habitat suitability and connectivity implications for the conservation of the Persian leopard along the Iran–Iraq border. Ecology and Evolution 11, 13464–13474.

Kaczensky P., Rustamov E., Karryeva S., Iankov P., Hudaykuliev N., Saparmyradov J., … & Linnell J. 2019. Rapid assessments of wildlife in Turkmenistan 2018. NINA report 1696. Norwegian Institute for Nature Research, Trondheim, Norway. 118 pp.

Karataş A., Bulut Ş. & Akbaba B. 2021. Camera trap records confirm the survival of the leopard (*Panthera pardus L.*, 1758) in eastern Turkey (Mammalia: Felidae). Zoology in the Middle East 67, 198–205.

Khorozyan I. G. & Abramov A. V. 2007. The leopard, *Panthera pardus*, (Carnivora: Felidae) and its resilience to human pressure in the Caucasus. Zoology in the Middle East 41, 11–24.

Khorozyan I., Soofi M., Ghoddousi A., Hamidi A. K. & Waltert M. 2015. The relationship between climate, diseases of domestic animals and human-carnivore conflicts. Basic and Applied Ecology 16, 703–713.

Khorozyan I., Askerov E., Beruchashvili G., Kütükçü A. E., Lortkipandize B., Malkhasyan A., … & Heidelberg A. 2022. Distribution and status of the Persian leopard in the Caucasus Ecoregion. Cat News Special Issue 15, 19–28.

Khosravi R., Hemami M. R., Malakoutikhah S., Ashrafzadeh M. R. & Cushman S. A. 2021. Prey availability modulates predicted range contraction of two large felids in response to changing climate. Biological Conservation 255, 109018.

Kiabi B.H., Dareshouri B. F., Ghaemi R. A. & Jahanshahi M. 2002. Population status of the Persian Leopard (*Panthera pardus saxicolor* Pocock, 1927) in Iran. Zoology in the Middle East 26, 41–47.

Koen E. L., Garroway C. J., Wilson P. J. & Bowman J. 2010. The effect of map boundary on estimates of landscape resistance to animal movement. PLoS ONE 5, e11785.

Linnell J. D. C., Trouwborst A., Boitani L., Kaczensky P., Huber D., Reljic S., … & Breitenmoser U. 2016. Border Security Fencing and Wildlife: The End of the Transboundary Paradigm in Eurasia? Plos Biology 14, e1002483.

Liu C., White M. & Newell G. 2013. Selecting thresholds for the prediction of species occurrence with presence-only data. Journal of Biogeography 40, 778–789.

Lukarevsky V., Akkiev M., Askerov E., Agili A., Can E., Gurielidze Z., Kudaktin A., Malkhasyan A. & Yarovenko Y. A. 2007a. Status of the leopard in the Caucasus. Cat News Special Issue 2, 15–21.

Lukarevsky V., Malkhasyan A. & Askerov E. 2007b. Biology and ecology of the leopard in the Caucasus. Cat News Special Issue 2, 9–14.

Maharramova E., Moqanaki E. M., Askerov E., Faezi S., Alinezhad H., Mousavi M., Kuemmerle T., Heidelberg A. & Zazanashvili N. 2018. Transboundary leopard movement between Azerbaijan and Iran in the Southern Caucasus. Cat News 67, 8–10.

McRae B. H. & Kavanagh D. M. 2011. Linkage Mapper User Guide. The Nature Conservancy, Seattle, WA.

McRae B. H., Shah V. B. & Mohapatra T. K. 2013. Circuitscape 4 User Guide. The Nature Conservancy.

Molinari-Jobin A., Wölfl S., Marboutin E., Molinari P., Wölfl M., Kos I., … & Breitenmoser U. 2012. Monitoring the Lynx in the Alps. Hystrix Italian Journal of Mammalogy 23, 49–53.

Moqanaki E. M., Breitenmoser U., Kiabi B.H., Masoud M. & Bensch S. 2013. Persian leopards in the Iranian Caucasus: a sinking "source" population? Cat News 59, 22–25.

NASA JPL. 2013. NASA Shuttle Radar Topography Mission Global 1 Arc Second.

Ostrowski S., Kabir M., Moheb Z., Gritsina M., Karimov K., Khan M. S. H., … & Kholmatov I. 2022. Distribution and status of the Persian leopard in the eastern part of its range. Cat News Special Issue 15, 42–49.

Pitman R. T., Fattebert J., Williams S. T., Williams K. S., Hill R. A., Hunter L. T. B., … & Balme G. A. 2017. Cats, connectivity and conservation: incorporating data sets and integrating scales for wildlife management. Journal of Applied Ecology 54, 1687–1698.

R Core Team. 2021. R: A language and environment for statistical computing. R foundation for Statistical Computing, Vienna, Austria.

Riley S. J., DeGloria S. D. & Elliot R. 1999. A terrain ruggedness index that quantifies topographic heterogeneity. Intermountain Journal of Sciences 5, 23–27.

Ripple W. J., Estes J. A., Beschta R. L., Wilmers C. C., Ritchie E. G., Hebblewhite M., … & Wirsing A. J. 2014. Status and ecological effects of the world's largest carnivores. Science 343, 1241484.

Rozhnov V. V., Yachmennikova A. A., Dronova N. A., Pkhitikov A. B., Magomedov M. R. D., Chestin I. E., … & Alibekov A. B. 2020a. The restoration of Persian leopard in the Caucasus (scientific approach). KMK Scientific Press Ltd., Moscow, Russia.

Rozhnov V. V., Pshegusov R. H., Hernandez-Blanco J. A., Chistopolova M. D., Pkhitikov A. B., Trepet S. A., Dronova N. A., Naidenko S. V. & Yachmennikova A. A. 2020b. MaxEnt Modeling for Predicting Suitable Habitats in the North Caucasus (Russian Part) for Persian Leopard (*P. p. ciscaucasica*) Based on GPS Data from Collared and Released Animals. Izvestiya, Atmospheric and Oceanic Physics 56, 1090–1106.

Rozhnov V. V., Yachmennikova A. A., Dronova N. A., Naidenko S. V., Hernandez-Blanco J. A., Chistopolova M. D., Pkhitikov A. B., Tembotova F. A., Trepet S. A. & Chestin I. E. 2022. Experience of the leopard recovering through reintroduction in the Russian Caucasus. Cat News Special Issue 15, 67–71.

Shehzad W., Nawaz M. A., Pompanon F., Coissac E., Riaz T., Shah S. A. & Taberlet P. 2015. Forest without prey: livestock sustain a leopard *Panthera pardus* population in Pakistan. Oryx 49, 248–253.

Soofi M., Ghoddousi A., Zeppenfeld T., Shokri S., Soufi M., Egli L., … & Khorozyan I. 2019. Assessing the relationship between illegal hunting of ungulates, wild prey occurrence and livestock depredation rate by large carnivores. Journal of Applied Ecology 56, 365–374.

Soofi M., Qashqaei A. T., Mousavi M., Hadipour E., Filla M., Kiabi B. H., … & Waltert M. 2022. Quantifying the relationship between prey density, livestock and illegal killing of leopards. Journal of Applied Ecology 59, 1536–1547.

Stein A. B., Athreya V., Gerngross P., Balme G., Henschel P., Karanth U., … & Ghoddousi A. 2020. *Panthera pardus*. The IUCN Red List of Threatened Species 2016: e.T15954A163991139. Gland Switzerland IUCN.

Wolf C. & Ripple W. J. 2016. Prey depletion as a threat to the world's large carnivores. Royal Society Open Science 3, 160252.

Yarovenko Y. & Zazanashvili N. 2016. Recent hard evidence for the occurrence of the Leopard, *Panthera pardus* (Mammalia: Felidae), in the Eastern Greater Caucasus. Zoology in the Middle East 62, 88–90.

You Z., Hu J., Wei Q., Li C., Deng X. & Jiang Z. 2018. Pitfall of big databases. PNAS 115, E9026–E9028.

Zazanashvili N., Sanadiradze G., Garforth M., Bitsadze T., Manvelyan K., Askerov E., … & Tavsel, S. D. 2020. Ecoregional Conservation Plan for the Caucasus: 2020 Edition. WWF, KfW, Tbilisi, Georgia.

Zimmermann F., Lukarevsky V. S., Beruchashvili G., Breitenmoser-Würsten C. & Breitenmoser U. 2007. Mapping the vision - potential living space for the leopard in the Caucasus. Cat News Special Issue 2, 28–33.

Supporting Online Material Table T1 is available at www.catsg.org.

[1] Geography Department, Humboldt-University Berlin, Unter den Linden 6, 10099 Berlin, Germany
* <benjamin.bleyhl@geo.hu-berlin.de>

[2] Silvestris e.U., Peter Jordan Strasse 161A/5, 1180 Vienna, Austria

[3] WWF-Azerbaijan, 6th Boyuk Gala dongesi 11, Sabayıl rayon, Baku, Az 1001, Azerbaijan

[4] Oxford Martin School and Department of Zoology, University of Oxford, 34 Broad Street, Oxford OX1 3BD, United Kingdom

[5] WWF Germany, Reinhardtstr. 18, 10117 Berlin, Germany

[6] Consultant, Göttingen, Germany

[7] WWF-Armenia, 11/1 Proshyan Str., Yerevan 0019, Armenia

[8] Leibniz Institute for Zoo and Wildlife Research, Alfred-Kowalke-Str. 17, 10315 Berlin, Germany

[9] Wildlife Conservation Society, 2300 Southern Boulevard, NY 10460 Bronx, USA

[10] Caucasus Nature Fund, 8 Givi Kortozia Street, 0177 Tbilisi, Georgia

[11] A.N. Severtsov Institute of Ecology and Evolution, Russian Academy of Sciences, Moscow, 119071 Russia

[12] CSIRO Land and Water, PMB 44 Winnellie, Darwin, 0822 NT, Australia

[13] Department of Conservation Biology, University of Göttingen, Bürgerstr. 50, 37073 Göttingen, Germany

[14] Integrative Research Institute on Transformations of Human-Environment Systems (IRI THESys), Humboldt-University Berlin, Unter den Linden 6, 10099 Berlin, Germany

IGOR KHOROZYAN[1*], ELSHAD ASKEROV[2], GIORGI BERUCHASHVILI[3], AHMET EMRE KÜTÜKÇÜ[4], BEJAN LORTKIPANIDZE[5], ALEXANDER MALKHASYAN[6], EHSAN MOQANAKI[7], MARZIEH MOUSAVI[8], ALIM PKHITIKOV[9], SERGEY TREPET[9,10], PAVEL WEINBERG[11], YURY YAROVENKO[12] AND AUREL HEIDELBERG[13]

Distribution and status of the Persian leopard in the Caucasus Ecoregion

The Persian leopard *Panthera pardus tulliana* has been Critically Endangered in the Caucasus Ecoregion. Therefore, its regional status assessment is a timely and essential measure to present the current situation and describe its changes due to existing conservation efforts. This report is aimed to address these issues by incorporating all available leopard records in the Caucasus Ecoregion from 2000–2021. The range of this big cat is confined to the mountain ridges of the Lesser Caucasus, Greater Caucasus, Talysh Mountains and their branches, and is heavily fragmented due to human activities. A continuous monitoring through camera-trapping shows that the minimum numbers of adult leopards are 3–9 in Armenia and 6–17 in Azerbaijan. There are very few individuals recorded in the Turkish and Russian parts of the Caucasus and only one confirmed individual is known from Georgia. Iran has been the main country for leopard survival in the Caucasus containing the largest population in the region, but of unknown size. Long-term and large-scale conservation activities coordinated by WWF and its partners led to the recovery and breeding of a small population in the Zangezur triangle, including the extreme south of Armenia, south-east of Azerbaijan's Nakhchyvan Autonomous Republic, and the adjoining part of north-western Iran. Some juveniles originated from this triangle disperse to other areas and potentially are able to re-establish new populations but such events are so far rare and documented only for males. Lack of breeding females and insufficient connectivity between the key areas of the range are the main problems for today's population of the leopard in the Caucasus.

The Persian leopard *Panthera pardus tulliana* = *P. p. saxicolor* = *P. p. ciscaucasica* is a very rare and globally threatened predator living in Southwest and Central Asia (Fig. 1). It also lives in the Caucasus Ecoregion, which is located between the Black and Caspian Seas and encompasses all territories of Armenia, Azerbaijan and Georgia and parts of Russia, Turkey and Iran (Zazanashvili et al. 2020a, b). Its status in the IUCN Red List of Threatened Species™ has not yet been updated, but the last assessment designated it as "Endangered" (EN C2a(i); Khorozyan 2008). At present, "Endangered" is the most appropriate category for the Persian leopard globally, but for the Caucasus it should be upgraded to "Critically Endangered", presumably as CR C2a(i); D (Khorozyan 2010), due to very small population size and high exposure to imminent threats such as habitat fragmentation and poaching (Bleyhl et al. 2017, 2021).

In the Caucasus, this big cat lives in arid grasslands, sparse and dense forests, subalpine and alpine meadows (Fig. 1). An essential requirement to leopard existence in this region is the presence of precipitous rocky areas which hold the main prey (especially bezoar goat *Capra aegagrus*), provide shelters and cover for hunting, and remain least accessible for people and livestock. As leopards are not well adapted to moving and hunting in deep snow, in winter they stay mostly on the southern slopes and at lower elevations (Khorozyan et al. 2010). They lead a very cryptic, mostly nocturnal, life and try to avoid interactions with humans.

Being a well-known flagship species, leopard attracts attention and resources to the conservation of biodiversity and habitats. Since the early 2000s, substantial efforts were mobilised to improve the status of leopard, its prey and habitats, and local livelihoods, within the framework of conservation projects coordinated by World Wide Fund for Nature (WWF) and its partners. In this report, we summarise the leopard status and its trends in the Caucasus Ecoregion from 2000 to 2021.

Methods

We collected all records of leopard occurrence in six countries of the Caucasus Ecoregion from the years 2000–2021. They were categorised as C1 ("hard facts", verified and unchallenged records such as photographs, camera-trap pictures and results of genetic or biochemical analyses), C2 (confirmed observations) and C3 (unconfirmed observations) following the Status and Conservation of the Alpine Lynx Population (SCALP) protocol (Molinari-Jobin et al. 2012). One of us (G. Be-

Fig. 1. A Persian leopard (left) and juniper sparse forest as its habitat (right) in Armenia (Photos WWF Armenia/A. Malkhasyan).

Table 1. Distribution of C1, C2 and C3 records in the countries of the Caucasus Eco-region.

Country/area	C1	C2	C3	Total
Armenia	116	177	13	306
Azerbaijan	46	10	0	56
Georgia	2	3	9	14
Iranian Caucasus	57	16	67	140
Russian Caucasus	5	16	13	34
Turkish Caucasus	3	0	1	4
Total	**229**	**222**	**103**	**554**

ruchashvili) mapped them and current leopard range in ArcGIS 10.2 (ESRI Co., USA). Distribution of C1–C3 records in each country of the Caucasus Ecoregion is provided in Table 1.

The range was divided into the categories "Extant", "Possibly Extant", "Possibly Extinct", and "Extinct" according to international standards (Red List Technical Working Group 2018). The "Extant" areas included only repeatedly obtained C1 records. The "Possibly Extant" areas encompassed C2, C3 and single C1 records. "Possibly Extinct" was specified for the areas which had no records, but contain suitable habitats and can potentially provide leopard records once the search effort is increased. This category is particularly important to identify, describe and survey corridors linking the areas of "Extant" and "Possibly Extant" categories. The boundaries of the areas of all three categories were delineated during consultations to indicate potential barriers or unsuitable habitats such as settlements, infrastructure, large rivers and glaciers. We strived to be conservative in range mapping and took all efforts to avoid the exaggeration of range areas, but also understood that leopards move widely and may cross their boundaries.

Current distribution

Distribution of the Persian leopard in the Caucasus is fragmented. Geographically, the core areas retaining the most reliable leopard records of C1 and C2 categories are located in the following areas and conservation landscapes (Zazanashvili et al. 2020b, Fig. 2):

1. Lesser Caucasus Ridge: the Zangezur triangle encompassing southern Armenia, Nakhchyvan Autonomous Republic of Azerbaijan (thereafter - Nakhchyvan), and West Azerbaijan and East Azerbaijan provinces of north-western Iran. Conservation landscapes: Eastern Lesser Caucasus, Arasbaran.
2. Alborz Ridge: Gilan Province of north-western Iran extending to the Talysh Mountains in Azerbaijan along the Caspian coastline. Conservation landscapes: Hyrcan.
3. Greater Caucasus Ridge: isolated patches in the republics of North Ossetia-Alania, Kabardino-Balkaria and Dagestan of the Russian Caucasus, and Tusheti in Georgia. Conservation landscapes: Central Greater Caucasus, Eastern Greater Caucasus.

Conservation landscape is "a geographically defined large area, typically larger than 5,000 km², identified as priority for conserving biodiversity and maintaining ecological processes and environmental services" (Zazanashvili et al. 2020b). All other parts of the leopard range in the Caucasus represent a network of actual and potential corridors linking these three core areas. This range structure makes the leopard extremely vulnerable to regional extinction if human activities, especially habitat fragmentation and direct poaching, continue (Bleyhl et al. 2021). The corridors are generally long and narrow, meaning that they are penetrable to anthropogenic pressures exerted from the outside. As leopards tend to avoid deserts, semi-deserts, permanent snow and human-dominated landscapes, viable corridors are limited to mountain ridgetops and canyons having dense vegetation and rugged terrain (Bleyhl et al. 2017).

Armenia

In Armenia, the range is extended from the Geghama Ridge (Khosrov Forest Reserve) in the south-western part of the country via the Vayk, Zangezur, Bargushat and Meghri ridges to the Araks River in the extreme south, over which the range merges with north-western Iran, including Kantal National Park, Dizmar Protected Area and Kiamaky Wildlife Refuge (Fig. 2). The first C1 records were collected in 2000–2004 from a leopard killing event and the biochemical analysis of faecal samples, until the first camera-trap pictures were produced in 2005 and 2007 (Khorozyan & Malkhasyan 2005, Khorozyan & Abramov 2007, Khorozyan et al. 2007, 2010).

Beginning from 2005, WWF-Armenia has been implementing large-scale monitoring of leopards and their prey within the WWF regional leopard conservation programme, mainly through camera-trapping and also, since recent times, faecal DNA analysis (Askerov et al. 2015, 2019). Apart from WWF, in 2002–2007 leopard camera-trapping was carried out in the Meghri Ridge and Khosrov Forest Reserve by an independent team of I. Khorozyan and A. Malkhasyan. Moreover, since 2013 until present camera-trapping has been done in the privately owned Caucasus Wildlife Refuge near Khosrov Forest Reserve by the Foundation for the Preservation of Wildlife and Cultural Assets FPWC.

In 2005–2013, leopards were camera-trapped only on the Meghri Ridge in Arevik National Park, until the first capture was obtained also in the Caucasus Wildlife Refuge in May–June 2013 (R. Khachatryan, pers. comm.). In 2018–2019, apart from Arevik, several new individuals appeared in Khosrov Forest Reserve, Arpa Protected Landscape and surroundings (Vayk Ridge), and the Caucasus Wildlife Refuge (Figs. 3 and 4). The male leopard from Khosrov Forest Reserve immigrated from its natal place in the south-eastern corner of Nakhchyvan, which is 170 km aerial distance away (Askerov et al. 2019). In January 2020, a very surprising case of a leopard capture took place in the area of Yenokavan, Tavush Province in north-eastern Armenia where leopard records were extremely rare even in historical times. This individual was identified as the one camera-trapped earlier in the Caucasus Wildlife Refuge (V. Ananyan, pers. comm.). In April 2021, a new male appeared in Arpa Protected Landscape (V. Ananyan, pers. comm.). All individuals from the Caucasus Wildlife Refuge have most likely arrived here from Nakhchyvan, and the individual captured there in 2013 was camera-trapped later in Nakhchyvan and Iran (R. Khachatryan, pers. comm.). On 16 November 2021, a female with two big cubs was video-recorded by a car driver at night in Zangezur Sanctuary, which is the first record of breeding leopards in the country (https://newsarmenia.am/news/armenia/leopardikha-s-detenyshami-zasvetilas-na-kameru-v-armenii-video/). The C2 and C3 records of sightings, tracks, scats, scrapes, and a few leopard killings and livestock kills are documented in all these areas. Apart from this, two interesting C3 records of a sighting and a killing were reported from the area of Arzakan in Kotayk Province of central Armenia, thus suggesting that local mountains and canyons can serve as a vital corridor connecting Khosrov Forest Reserve and Yenokavan and, generally, the southern and northern parts of Armenia. Yet, Kotayk Province is a risky potential corridor due to the presence of the Yerevan-Tbilisi highway and a number of popular ski and spa resorts such as Arzakan, Hankavan, Aghveran, and Tsaghkadzor.

Azerbaijan

In Azerbaijan, most leopard records are concentrated in Ordubad district on the Zangezur Ridge in the south-eastern part of Nakhchyvan very close to the borders with Armenia and Iran, and in Astara and Lankoran districts in the southern part of the Talysh Mountains (Fig. 2). Since 2005, WWF-Azerbaijan conducts large-scale leopard and prey monitoring by camera-trapping and faecal DNA analysis within the WWF regional leopard conservation programme. The most reliable and numerous evidence (C1) comes from intensive camera-trapping (Avgan et al. 2012, Askerov et al. 2015, 2019, Spassov et al. 2019), but several confirmed cases of leopard killings by people in the Talysh Mountains are also documented. The C2 records are originated from the same districts as C1, as well as from the neighbouring Jalilabad and Julfa districts and from Ilisu Reserve, and include a sighting, tracks, a livestock kill and a prey kill.

There is only one leopard record from northern Azerbaijan, namely tracks on the Akhar-Bakhar Ridge in Ilisu Reserve very close to the border with Georgia. This record is old (2005) and most likely belongs to the same male which was regularly camera-trapped in adjacent Vashlovani Protected Areas in south-eastern Georgia in 2004–2008 (see below). Subsequent camera-trapping in 2008–2011 failed to record leopards in Ilisu Reserve (Muradov 2011).

Ordubad district (Zangezur Ridge) and Hirkan National Park (Talysh Mountains) in Azerbaijan and Zangezur Sanctuary in Armenia are the only areas in the Caucasus, except for north-western Iran, where the presence of females and their breeding is confirmed (Breitenmoser et al. 2017, Askerov et al. 2019, see "Armenia" above). In Ordubad, one pair with three cubs was camera-trapped in 2016 and another pair with one cub in 2018, two cubs in 2020 and three cubs in 2021. In November 2021, a female with two cubs, possibly the same as from Ordubad, was recorded in Zangezur Sanctuary (Table 2). This was achieved due to the hunting ban declared in Nakhchyvan in 2001, low human density, and the functioning of Zangezur National Park and Ordubad Sanctuary whose landscapes are connected with those of Zangezur Biosphere Complex (including Zangezur Sanctuary) in Armenia on the opposite side of the Zangezur Ridge (Askerov et al. 2015). The dispersal of a sub-adult male born in this area to Khosrov Forest Reserve in south-western Armenia is documented (Askerov et al. 2019) and another male successfully dispersed further to Yenokavan in northern Armenia.

In Hirkan National Park, a female with two cubs was camera-trapped in 2014–2015. Here, leopard breeding resulted from strengthened conservation and the proximity of this area to Gilan Province of Iran. Yet, transboundary movements between the Talysh Mountains and Gilan can be risky and end up with leopard poaching (Maharramova et al. 2018). Also, leopards in the Talysh Mountains are more affected by retaliatory killing in response to attacks on cattle (Askerov 2002, Spassov et al. 2019, Askerov et al. 2020).

Most recently, in autumn 2021 a short video of a leopard was made on a mobile phone in the Kelbajar district. This is a very interesting record showing that the Karabakh Upland can be a vital corridor linking southern Armenia and Nakhchyvan with the Russian Caucasus, northern Azerbaijan and eastern Georgia.

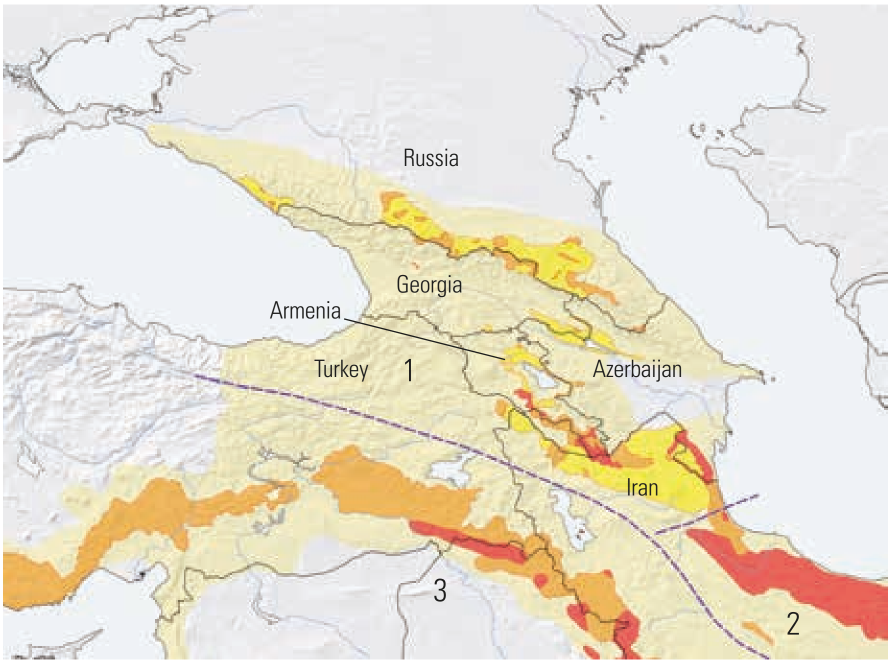

Fig. 2. Distribution of leopard *Panthera pardus* in the Caucasus (1) in 2000–2021. Red = extant, orange = possibly extant, dark yellow = possibly extinct, light yellow = extinct, violet lines = regional division. 1 = Caucasus Ecoregion, 2 = Alborz-Kopetdag, and 3 = Zagros range. Map courtesy to Peter Gerngross, based on Khorozyan et al. (2022).

Georgia

Since 2000, a leopard was documented in Georgia in 2003 when NACRES, a non-governmental organization, found a leopard track in Vashlovani Protected Areas in the extreme south-east of the country, close to the border with Azerbaijan (Lortkipanidze et al. 2004). As numerous camera-traps showed, a male leopard had been living in Vashlovani in 2004–2008, but after its track recorded in 2009 no further information has become available (Askerov et al. 2020). Vashlovani is the closest stepping stone between the Lesser and the Greater Caucasus (Fig. 2). All the other records from Georgia were indirect, such as tracks and observations in Svaneti, Khevsureti and Tusheti regions on the Greater Caucasus Ridge.

However, most recently on 25 August 2021 a leopard was camera-trapped in Tusheti Protected Areas on the northern slopes of the Greater Caucasus, close to the border with Russia (https://www.caucasus-naturefund.org/the-persian-leopard-is-back-in-georgia/). It is yet unclear, but important to know, whether this individual is resident or a migrant from the Russian Caucasus, northern Armenia or the Karabakh Upland.

Iranian Caucasus

Iran is the stronghold for the leopard in the Caucasus and generally in Southwest and Central Asia, hence it is not surprising that species records from this country are most numerous. Within the Caucasus part of Iran, most leopard records come from the humid Hyrcanian forest of Gilan Province, which extends to the small tract of this forest in the Talysh Mountains of Azerbaijan. There are also several records in the arid and rocky areas of Zanjan and Ardabil provinces to the south-west of the Hyrcanian forest. However, this region needs much stronger enforcement of conservation as the anthropogenic transformation of landscapes is ubiquitous there (Moqanaki et al. 2013, Farhadinia et al. 2015). Human-leopard conflicts over livestock depredation are quite frequent in Gilan, which may cause persecution and retaliatory killing of leopards (Babrgir et al. 2017, Soofi et al. 2019). Fewer records are available from the provinces of West Azerbaijan and East Azerbaijan adjacent to Armenia and Nakhchyvan. The record sites can be grouped into three areas, from the west to the east: Marakan Protected Area, Kiamaky Wildlife Refuge with Kantal National Park and Dizmar Protected Area, and Arasbaran National Park and Protected Area. It is notable that Kantal National Park, which strides close to the Araks River in front of Armenia, is marked mostly by C1 records such as camera-trap pictures and photographs, and also by C2 records including scats and sightings. Dizmar has one C1 and one C2 records. Marakan and Arasbaran hold mostly C3 records and only one C2, but no C1. The presence of hard facts from Kantal, but not Marakan, Kiamaky and Arasbaran, was also described by Moqanaki et al. (2013) and Askerov et al. (2020). Undisturbed prey-rich suitable habitats and the absence of livestock grazing and poaching are the main causes of the existence of leopards in Kantal, whereas in Marakan, Kiamaky and Arasbaran suitable habitats are limited and the densities of humans and livestock are higher (Moqanaki et al. 2013). Scientifically most reliable methods should be used to get confident information about such rare and elusive animals as leopards. In this sense, intensive camera-trapping efforts should be undertaken to elucidate the status of leopards in Marakan, Kiamaky and Arasbaran.

It is of particular importance to find and describe leopard records in the corridor, which in the Iranian Caucasus connects the Zangezur triangle with the Talysh Mountains and Gilan Province (Fig. 2). This corridor is stretched across the Garadagh Ridge in East Azerbaijan and Ardabil provinces, but recent records from this area are located mostly in its south and concentrated in the east towards Gilan, whereas vast areas located towards the mentioned triangle have no records. The northern parts of Ardabil Province connecting the triangle with the Talysh Mountains are almost deprived of leopard records, with only one C1 record of a male killed in 2007 (Maharramova et al. 2018). A disrupted structure of the Zangezur triangle-Talysh Mountains and the Zangezur triangle-Gilan corridors is also suggested by landscape modeling (Farhadinia et al. 2015, Bleyhl et al. 2017). Absence of leopards and the lack of their prey in Lisar Protected Area (Moqanaki et al. 2013, Soofi et al. 2018, 2019) just to the south of Hirkan National Park in Azerbaijan undermines the connectivity of the Talysh Mountains and Gilan Province, in addition to the poaching of leopards moving between these two areas (Askerov 2002, Maharramova et al. 2018).

Russian Caucasus

Recent C1 records of leopard presence in the Russian Caucasus began to appear much later than elsewhere in the Caucasus (Fig. 2). This may indicate that at least some individuals could be non-resident and immigrate here from the unknown areas of the South Caucasus. The probability of this is quite high considering that all documented leopards were large, i.e. most likely they were males capable of taking long-distance dispersal forays. These C1 records are mostly photographic: three in the North Ossetian experimental hunt-ing area (2013), Gizeldon (2015) and Zamarag (2017) hydropower plants of the Republic of North Ossetia-Alania and one in 2015 near Tlyaratinsky Federal Sanctuary of the Republic of Dagestan (Yarovenko & Zazanashvili 2016, Weinberg et al. 2018). Most recently, on 17 November 2021 a male leopard was camera-trapped on the boundary of Prielbrusye National Park in the Kabardino-Balkarian Republic (https://www.youtube.com/watch?v=xUh-ZbrRHAc). There is no evidence that these individuals belong to the reintroduced stock (see below).

The C2 records are more common, including direct sightings, tracks and hearsay in almost all mountainous parts of the North Caucasus, from the Krasnodar Region in the west to Dagestan in the east. There are several C2 and C3 records describing leopard sightings and livestock kills in the mountainous areas of southern and south-western Dagestan (Yarovenko 2017), up to the year 2020. In 2016, a shepherd observed a female with two cubs. In Kabardino-Balkaria, the C2 and C3 records include a sighting in 2016 and a number of sightings, tracks and a goat kill in 2003–2004 on the right bank of the Chegem River (Akkiev & Mokaev 2006), apart from hearsay in later years. There are also a few C2 and C3 records of leopard sightings and tracks in the western (Krasnodar Region, Karachay-Cherkess Republic and Caucasian Biosphere Reserve) and eastern (Republic of Ingushetia) parts of the Russian Caucasus (Kudaktin & Trepet 2008, Khokhlov & Khubiev 2016, Kudaktin 2016), but hard facts of leopard presence from these areas are missing.

In 2008, the Russian government approved a programme on leopard breeding in captivity in Sochi National Park and the reintroduction of trained second-generation individuals in the North Caucasus (Rozhnov & Lukarevsky 2008). The founder stock consisted of two wild males brought from Turkmenistan in 2009, two wild females from Iran in 2010, one male and one female from Lisbon Zoo in 2012, and a male from Parc des Félins in 2015. In total, they produced 15 cubs (Voronin & Kharchenko 2016). Following a series of studies to moni-

Fig. 3. A Persian leopard caught on camera in Armenia on 14 April 2022 (Photo WWF Armenia).

tor and select the best candidates for release (Rozhnov et al. 2007, 2011, Yachmennikova & Rozhnov 2011, Ertuev & Semenov 2016, Voronin & Kharchenko 2016), two females and four males were originally released into the wild. One female and three males were released in Caucasian Biosphere Reserve in the western North Caucasus in 2016 and 2018. The other male and female were released in 2018 in the central part of the North Caucasus, in Alania National Park of North Ossetia-Alania (Rozhnov et al. 2020). All these six individuals were tracked by GPS collars and monitored according to specially developed and published guidelines (Rozhnov et al. 2018, 2020). In 2020, one male and one female were released in Turmon Regional Sanctuary of North Ossetia-Alania (https://rg.ru/2020/09/02/reg-ufo/na-kavkaze-vypustili-na-voliu-chetyreh-peredneaziatskih-leopardov.html) and another male and female were released in Caucasian Biosphere Reserve (https://wwf.ru/resources/news/bioraznoobrazie/na-kavkaze-sostoyalsya-vypusk-dvukh-peredneaziatskikh-leopardov-v-dikuyu-prirodu/). Later in 2021, a female, presumably the one released in Alania National Park, was spotted in Kabardino-Balkaria and her collar with exhausted batteries was found not far from there (https://wwf.ru/resources/news/kavkaz/nayden-osheynik-samki-leoparda-volny/).

So, in total 10 individuals were released: six in Caucasian Biosphere Reserve and four in North Ossetia-Alania. Three of them died from unknown reasons (https://www.rgo.ru/ru/article/na-kavkaze-pogibla-samka-peredneaziatskogo-leoparda-laba), poaching and starvation (https://www.kuban.kp.ru/daily/26939/3990050/), of which two were females making these losses particularly poignant.

It is important to note that locations of reintroduced leopards are not shown in Fig. 2, otherwise the western and central North Caucasus would be overloaded with C1 records of their GPS locations and create a misleading impression that most of C1 records in the region are concentrated here. Thus, Fig. 2 contains records of only leopards born in the wild.

Turkish Caucasus

In Turkey, the only reliable mapped information on leopard presence is originated from the south-east of the country, to the south and west of Lake Van. A number of recent leopard killings (2001–2013) and camera-trap pictures (2018–2019) from there are known and published (Avgan et al. 2016, Toyran 2018, Karataş et al. 2021). As this area geographically belongs to the Zagros sub-region, it is not considered further in this report. Three C1 records of a skin photograph and photo/video material from mobile phones and thermal cameras were reported from Erzincan and Tunceli provinces in 2008–2019 to the south of the Turkish Caucasus. However, these records are not credible as thermal images from this area depicted other animals, even wild *Felis silvestris* and domestic *F. catus* cats, and were published as "leopard" records (Sari et al. 2020). Misidentification of different species as leopards has occurred in the past and such false positives have been readily published to claim that leopards are more common in Turkey than they are thought to be (Baskaya & Bilgili 2004, Sari et al. 2020), but fortunately such cases of misidentified leopards are unmasked (Spassov et al. 2016). Similarly, tracks claimed to belong to leopards have been confused with those of shepherd dogs and other animals (Spassov et al. 2016).

However, most recently it has become known that several C1 records of two males were taken by camera-traps and border surveillance cameras on the Agri dag (Mt. Ararat) in Iğdir Province and in Yusufeli district of Artvin Province. This information is not available to the public for security reasons. Therefore, these records are not presented in Fig. 2. Overall, it can be concluded that the current range of leopard in the Turkish Caucasus covers only the very east of Turkey close to the borders with Armenia and Georgia, but generally this part of the range can be ranked as uncertain presence.

Fig. 4. A Persian leopard caught on camera in Armenia on 31 July 2021 (Photo WWF Armenia).

Population size and trends

Leopards can be reliably recognised from their spot patterns, which are unique for each individual and also differ between the same animal's left and right flanks (Miththapala et al. 1989). Due to this, it is possible to estimate the minimum population size of leopards in southern Armenia and Azerbaijan (Nakhchyvan, Talysh Mountains) from the numbers of individuals captured by camera-traps over large areas. These estimates represent the minimum population size because there is always a possibility that some individuals may be present, but have so far gone undetected.

According to the results of camera-trapping in the South Caucasus, the numbers of camera-trap sites, leopard photographs and videos, and individual animals have increased over time since the early 2000s (Table 2). Poaching appears to decrease but remains an issue in the Talysh Mountains, mostly as a retaliatory or preventive measure to reduce cattle losses to leopard attacks (Askerov 2002, Spassov et al. 2019, Askerov et al. 2020). However, an increase in the numbers of photographs/videos and individuals should be treated with caution because these numbers are higher in longer periods due to active movements of leopards between Armenia and Nakhchyvan. For example, in Armenia there were eight leopards identified during five years between September 2014 and June 2019, but only four in one year from June 2020 to June 2021 (Table 2). As the Armenian population is dominated by males which actively move, it is unstable and fluctuating over time. These movements include not only transboundary forays between

Table 2. Sampling efforts and an output of leopard camera-trapping in Armenia, Azerbaijan and Georgia. Data from independent non-WWF camera-trapping in Nakhchyvan, Azerbaijan (B. Avgan) are not available.

Period/year	No. camera-trap sites	No. leopard photos/ videos	No. captures of females with cubs	No. identified individuals	No. known killings	Source
Armenia						
Sep 2002-May 2005	4	1/0	0	1	0	I. Khorozyan; WWF-Armenia data
Jan 2005-Dec 2013	32	1/0	0	1	1	WWF-Armenia data
Aug 2006-May 2007	22	1/0	0	1	2	I. Khorozyan; WWF-Armenia data
Mar 2013-Jul 2021	10	> 70/30	0	5	0	R. Khachatryan, FPWC
Dec 2013-Aug 2014	24	17/3[1]	0	3	0	Askerov et al. 2015; WWF-Armenia data
Sep 2014-Jun 2019	72	53/23	0	8	0	Zazanashvili et al. 2020a
Jun 2019-Jun 2020	88	88/29	0	5	0	WWF-Armenia data
Jun-Dec 2020	69	163/53	0	4	0	WWF-Armenia data
Jan-Jun 2021	85	37/14	0[2]	4	0	WWF-Armenia data
Azerbaijan						
Nakhchyvan, Jan 2013-Oct 2014	7	164/18	0	3	0	Askerov et al. 2015
Nakhchyvan, Nov 2014-Jun 2021	80	471/178	33[3]	11	0	Zazanashvili et al. 2020a; K. Ahmadova, WWF-Azerbaijan
Talysh, May 2013-Jul 2014	5	39/8	0	3	4[4]	Askerov et al. 2015
Talysh, May 2015-Jun 2021	21	34/12	1	6	2[5]	Zazanashvili et al. 2020a; K. Ahmadova, WWF-Azerbaijan
Georgia						
Vashlovani PAs, Dec 2003-Dec 2009	6	23/0	0	1	0	NACRES data
Tusheti, Jul 2009-Nov 2009	11	0/0	0	0	0	WWF/NACRES data
Tusheti, Jul 2010-Oct 2010	16	0/0	0	0	0	WWF/NACRES data
Vashlovani-Chachuna, Feb 2011-Jun 2011	25	0/0	0	0	0	NACRES data
Khevsureti, Jun 2012-Sep 2012	25	0/0	0	0	0	WWF/NACRES data
Khevsureti, Jul 2013-Oct 2013	28	0/0	0	0	0	WWF/NACRES data
Chachuna, Feb 2014-Apr 2014	7	0/0	0	0	0	NACRES data
Poladauri, Oct 2018-Apr 2019	9	0/0	0	0	0	NACRES data
Tusheti, Jul 2021-in progress	24	2/0	0	0	1	WWF/NACRES data

[1] Videos were produced in an additional site within the project conducted by the Foundation for the Preservation of Wildlife and Cultural Assets (FPWC).
[2] Later on 16 November 2021 a female with cubs (possibly, the same as [3] going next) was video-recorded in Zangezur Sanctuary of Armenia.
[3] Later on 24 September 2021 a female with cubs was camera-trapped in Zangezur National Park of Nakhchyvan.
[4] This number of leopards was killed in the Talysh Mountains from 2002 to 2014.
[5] One leopard was killed in Iran (Maharramova et al. 2018).

Armenia and Azerbaijan, but also movements within the countries to the areas where camera-traps are not present and animals may have been missed. Consequently, transboundary movements can produce double counts of the same individuals captured in Khosrov Forest Reserve, Caucasus Wildlife Refuge and Nakhchyvan. High numbers of photographs and videos do not indicate an increase in population size as camera-traps can be placed to repeatedly capture the same individuals moving over the same trails.

As Table 2 shows, current leopard population size is a minimum of 3–9 individuals in Armenia and a minimum of 6–17 individuals in Azerbaijan. However, the actual population in Azerbaijan should be lower because populations of large mammals, including predators, are estimated in numbers of adults and not of all individuals.

Although some camera-trapping efforts were undertaken in the Iranian Caucasus, e.g., in Kantal National Park, no population estimates are available from this part of the range.

The most reliable methods of population size estimation in leopards are the capture-recapture analysis of camera-trap pictures and the genetic analysis of faecal material or hairs (Sugimoto et al. 2014, Rostro-García et al. 2018). Capture-recapture analysis has been proposed by the regional wildlife monitoring framework for the future use in the Caucasus (Ghoddousi et al. 2019). As these methods have not yet been used, or at least not published, only minimum numbers from Table 2 and the numbers of reintroduced leopards in the Russian Caucasus should be considered as reliable, until the population size is estimated more precisely by capture-recapture and/or genotyping.

Some information about leopard densities in the Caucasus is also available in the literature. The density of 0.34 individuals/100 km² in the Meghri Ridge of southern Armenia (Khorozyan et al. 2008) and the density of 3 individuals/100 km² in Hirkan National Park of south-eastern Azerbaijan (Askerov et al. 2021) have been recorded.

It is impossible to evaluate trends in leopard numbers before and after 2000, because current C1 records come mostly from camera-trapping and older C1 records originated mainly from leopard killings, which are incomparable in principle. It is even harder to estimate or even guess trends in the areas which have only C2 and, let alone, C3 records. Dynamics of leopard records appear to be strongly biased by survey efforts in particular areas rather than related to leopard numbers. This trend was evident in historical times and continues to be plausible now.

However, one trend can be clearly ascertained since the mid-2000s when camera-trapping began to be widely used in the Caucasus: from the year 2010 onward, the population is recovering in the southern part of the Lesser Caucasus within the Zangezur triangle (Askerov et al. 2015, Breitenmoser et al. 2017, Askerov et al. 2019, Zazanashvili et al. 2020a). Breeding females are present on the Nakhchyvan and Armenian sides of the Zangezur Ridge and two long dispersals of sub-adult males to Khosrov Forest Reserve in south-western Armenia and to Yenokavan in northern Armenia are proven (Askerov et al. 2019, see above). The appearance of leopards in North Ossetia-Alania and Dagestan of the Russian Caucasus in 2013–2017 also can imply immigrations, although the existence of a small local population cannot be ruled out. A camera-trap video of a leopard in Kabardino-Balkaria in 2021 (see above) supports the idea of possible existence of an independent "nucleus" in the Russian Caucasus as this individual was not recorded previously in Armenia and Azerbaijan (A. Yachmennikova, pers. comm.).

Population structure

No scientific research of the sex and age structure of the leopard population was ever conducted in the Caucasus. However, the analysis of camera-trap images and video materials shows that most of captured individuals are males whereas females are known only from the Zangezur triangle, Talysh Mountains, and a few places in Gilan Province and nearby.

Space use by females indicates the areas of best suitability in terms of sufficient prey resources and shelters and a minimum level of disturbance (Snider et al. 2021). Subadult females tend to move much shorter distances than males and show a strong fidelity to their natal sites. In turn, male movements are more exploratory in nature and directed towards the search of mates. Hence, male leopards can potentially be found anywhere and their presence is less related to habitat suitability (Breitenmoser et al. 2017). In contrast, the areas of presence of females and/or their breeding cases (proven by females with cubs) represent the core habitats.

This can be best illustrated with the example of the leopard recovery in the Zangezur triangle. Here, females live on the Nakhchyvan side of the Zangezur Ridge (two breeding females are known – see above, and a female found dead in May 2021) and only recently in 2021 a breeding female, possibly one of those two, was recorded on the Armenian side. Dispersing males moving, inter alia, to Armenia fail to find mates in spite of intensive territorial marking. This is a case for a resident male from Khosrov Forest Reserve (Fig. 4), which stays alone since he arrived in 2018 (Askerov et al. 2019) and also for the males from the Meghri Ridge and Yenokavan (V. Ananyan, pers. comm.).

All wild-living leopards in the Russian Caucasus, Georgia and eastern Turkey are males and the only two females are the ones released within the reintroduction programme. Lack of females and breeding is also a problem for the Iranian Caucasus where only three C1 records of females are indicated in the dataset: Deylaman-e-Dorfak No-Hunting Area in Gilan Province (Breitenmoser et al. 2017, Farhadinia et al. 2018), Kantal National Park, and south-eastern East Azerbaijan Province near the border with Gilan (Fig. 2). Many more records of females with or without cubs belong to C2 and C3 records (M. Sofi, pers. comm.).

Ecology, prey and threats

Ecology, prey, distribution patterns and threats related to the Persian leopard in the Caucasus are very similar to those in other parts of its range, which are described in other chapters. However, several aspects are known to be specific to this region.

Ecology

One of the main natural factors limiting the leopard distribution in the Caucasus is snow (Khorozyan & Abramov 2007, Gavashelishvili & Lukarevskiy 2008, Khorozyan et al. 2010). As leopard is tropical by origin, it has a high paw pressure and cannot move and hunt in deep snow (Pikunov & Korkishko 1992). For this reason, it prefers southern slopes at low and middle elevations, and stays on northern slopes only during the snow-free seasons (Khorozyan et al. 2010). This makes leopards suffer from the deficiency of suitable habitats and become vulnerable to clashes with people, who in the Caucasus are present mostly in lowlands, mountain valleys and canyons. From a phylogeographic point of view, the Caucasus represents a dead end where the leopard presence was limited by the Greater Caucasus Ridge, with only slight penetration towards the plains of Russia (Vereschagin 1959).

Prey

Three mid-sized ungulates are the unique prey species for the leopard in the Caucasus: western tur *C. caucasica*, eastern tur *C. cylindricornis* and chamois *Rupicapra rupicapra* (Mallon et al. 2007). Both turs are the endemics of the Greater Caucasus Ridge and chamois occurs in Europe where leopards are absent. The wild boar *Sus scrofa* is the second most important prey for leopards after the bezoar goat in the region (Ghoddousi et al. 2017), but in the Christian countries like Armenia and Georgia where swine breeding is common, wild boars have been heavily affected by transmission of African swine fever (Sarkisyan et al. 2019). The key protected areas located in forests of Armenia, namely Shikahogh Reserve and Dilijan and Arevik National Parks, experience a sharp long-term decline of wild boar numbers. This possibly poses a serious threat to leopard survival in Armenia. In contrast, wild boars are very abundant in Azerbaijan's Talysh Mountains (Askerov et al. 2021) and Iran (Ghoddousi et al. 2017) where swine are not bred for religious reasons.

Threats

In Armenia, Azerbaijan, Georgia and Russia, hunting (often with official bounties) was the main threat to leopard before the 1960s and 1970s when it was granted official protection. During that time, leopards and other large predators had been wiped out as vermin for livestock breeding and for fur trade (Heptner

& Sludsky 1972, Aghajanyan 1986). Since the 1970s, poaching still continued to be a major threat, especially after the collapse of the Soviet Union until the mid-2000s, but trade ceased and leopards used to be killed for own trophies or as a threat to livestock. From the mid-2000s onwards, leopards appear to be threatened predominantly by fragmentation of habitat patches intensified by the socio-economic development and politically challenging conditions.

Leopard conservation efforts in a nutshell

The main reason for the leopard recovery in the South Caucasus, first of all in the Zangezur triangle, is the implementation of the long-term leopard conservation and monitoring programme by the national WWF teams of Armenia, Azerbaijan and Georgia in cooperation with the national governments. These efforts include, among others, the monitoring of leopards and their prey by camera-trapping and field tracking, assistance in establishing new protected areas or effective management of existing ones, establishment of wildlife corridors, awareness-raising events and engaging local people in Persian leopard conservation. The Persian leopard programme in the Caucasus was launched in 2002 and keeps on running until now due to main funding from WWF Germany and WWF Switzerland. Generous co-funding, which allowed to expand and develop project activities, came or continues to come from the Critical Ecosystem Partnership Fund (CEPF, https://www.cepf.net), Ministry of Foreign Affairs of Norway (https://www.regjeringen.no/en), Eco-Corridors Fund for the Caucasus (https://www.ecfcaucasus.org) and the Caucasus Nature Fund (https://www.caucasus-nature-fund.org), to name a few. More information about leopard conservation activities in Armenia is available online (https://leopard.am). Another reason of leopard recovery is the restoration of its prey base, first of all bezoar goats, in Nakhchyvan Autonomous Republic due to the hunting ban lasting from 2001. In Iran, conservation of leopards and other wildlife species has been implemented by the Iranian Department of Environment. Leopard reintroduction in the Russian Caucasus began only recently (Rozhnov et al. 2022) and it takes time to assess its effectiveness.

Conclusion

Continuous conservation efforts, including the long-term projects on population conservation, monitoring and reintroduction, and the maintenance of hunting ban in a key area, allow the leopard population to recover in the Caucasus. Population recovery in the Zangezur triangle is encouraging, but also shows a very shaky ground for the long-term sustainability of the leopard population in the Caucasus. The regional leopard population is still small, fragmented and demographically unstable. The main concern is the lack of females and the failure of males to find mates. All possible efforts should be directed towards the creation and maintenance of transboundary and in-country connectivity of leopard habitats, and the continuation of support to protected areas, anti-poaching activities, and awareness-raising.

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References

Aghajanyan F. S. 1986. Analiz dinamiki chislennosti khischnykh mlekopitayuschikh Armianskoi SSR [An analysis of population dynamics of the carnivores of Armenian SSR]. Zoologicheskii sbornik Akademii Nauk Armianskoi SSR 20, 150-161. (in Russian)

Akkiev M. I. & Mokaev A. B. 2006. Leopard (Felidae, Carnivora) v Kabardino-Balkarskoi Respublike (tsentralnyi Kavkaz) (istoriya i sovremennost) [Leopard (Felidae, Carnivora) in the Kabardino-Balkarian Republic (Central Caucasus) (history and modern times)]. In Problemy Ekologii Gornykh Territoriy [Ecological Problems of Mountainous Areas]. Tembotova F. A. (Ed). KMK Publishers, Moscow, Russia, pp. 9–13. (in Russian)

Askerov E. K. 2002. Novye dannye o leoparde (*Panthera pardus* L.) v Azerbaijane i mery po ego okhrane [New data on leopard (*Panthera pardus* L.) in Azerbaijan and its conservation measures]. Bilgi 3, 69–72. (in Russian)

Askerov E., Manvelyan K., Gurielidze Z., Mousavi M., Shmunk V., Trepet S., Kütükçü A. E., Heidelberg A. & Zazanashvili N. 2020. Status of large carnivores in the Caucasus. In Ecoregional Conservation Plan for the Caucasus, 2020 Edition: Supplementary Reports. Zazanashvili N., Garforth M. and Bitsadze M. (Eds). WWF and KFW, Tbilisi, Georgia, pp. 35–45.

Askerov E., Talibov T., Manvelyan K., Zazanashvili N., Fatullayev P. & Malkhasyan A. 2019. Leopard (*Panthera pardus*) reoccupying its historic range in the South Caucasus: a first evidence (Mammalia: Felidae). Zoology in the Middle East 65, 88–90.

Askerov E., Talibov T., Manvelyan K., Zazanashvili N., Malkhasyan A., Fatullayev P. & Heidelberg A. 2015. South-eastern Lesser Caucasus: the most important landscape for conserving the leopard (*Panthera pardus*) in the Caucasus region (Mammalia: Felidae). Zoology in the Middle East 61, 95–101.

Askerov E., Trepet S. A., Eskina T. G., Bibina K. V., Narkevich A. I., Pkhitikov A. B., Zazanashvili N. & Akhmedova K. 2021. Otsenka plotnosti populiatsiy vidov zhertv i konkurentov leoparda (*Panthera pardus*) v Girkanskom natsionalnom parke (Azerbaijan) [Estimation of population densities of leopard (*Panthera pardus*) prey and competitor species in Hirkan National Park (Azerbaijan)]. Zoologicheskii zhurnal 100, 947–955. (in Russian)

Avgan B., Raza H., Barzani M. & Breitenmoser U. 2016. Do recent leopard *Panthera pardus* records from northern Iraq and south-eastern Turkey reveal an unknown population nucleus in the region? Zoology in the Middle East 62, 95–104.

Avgan B., Talibov T. H., Ismayilov A., Fatullayev P., Askerov E. & Breitenmoser U. 2012. First hard evidence of leopard in Nakhchivan. Cat News 57, 33.

Babrgir S., Farhadinia M. S. & Moqanaki E. M. 2017. Socio-economic consequences of cattle predation by the endangered Persian leopard *Panthera pardus saxicolor* in a Caucasian conflict hotspot, northern Iran. Oryx 51, 124–130.

Baskaya S. & Bilgili E. 2004. Does the leopard *Panthera pardus* still exist in the eastern Karadeniz mountains of Turkey? Oryx 38, 228–232.

Bleyhl B., Baumann M., Griffiths P., Heidelberg A., Manvelyan K., Radeloff V. C., Zazanashvili N. & Kuemmerle T. 2017. Assessing landscape connectivity for large mammals in the Caucasus using Landsat 8 seasonal image composites. Remote Sensing of Environment 193, 193–203.

Bleyhl B., Ghoddousi A., Askerov E., Bocedi G., Breitenmoser U., Manvelyan K., Palmer S. C. F., Soofi M., Weinberg P., Zazanashvili N., Shmunk V., Zurell D. & Kuemmerle T. 2021. Reducing persecution is more effective for restoring large carnivores than restoring their prey. Ecological Applications 31, e02338.

Breitenmoser U., Askerov E., Soofi M., Breitenmoser-Würsten C., Heidelberg A., Manvelyan K. & Zazanashvili N. 2017. Transboundary leopard conservation in the Lesser Caucasus and the Alborz Range. Cat News 65, 24–25.

Ertuev M. M. & Semenov U. A. 2016. Behavioral features of the Persian leopard (*Panthera pardus saxicolor*) during different stages of the estrous cycle. Nature Conservation Research 1, 59–69.

Farhadinia M. S., Ahmadi M., Sharbafi E., Khosravi S., Alinezhad H. & Macdonald D. W. 2015. Leveraging trans-boundary conservation partnerships: persistence of Persian leopard (*Panthera pardus saxicolor*) in the Iranian Caucasus. Biological Conservation 191, 770–778.

Farhadinia M. S., Alinezhad H., Hadipour E., Memarian I., Ostrowski S., Hobeali K., Dadashi-Jourdehi A., Johnson P. J., Macdonald D. W. & Hunter L. T. B. 2018. Intraspecific killing among leopards (*Panthera pardus*) in Iran (Mammalia: Felidae). Zoology in the Middle East 64, 189–194.

Gavashelishvili A. & Lukarevskiy V. 2008. Modelling the habitat requirements of leopard *Panthera pardus* in west and central Asia. Journal of Applied Ecology 45, 579–588.

Ghoddousi A., Bleyhl B., Pötzschner F., Rakowski J., Kuemmerle T., Weinberg P., ...& Heidelberg A. 2019. Towards adoption of systematic wildlife monitoring framework in the Southern Caucasus. WWF, Tbilisi and Humboldt University, Belin. 16 pp.

Ghoddousi A., Soofi M., Hamidi A. K., Lumetsberger T., Egli L., Ashayeri S., Khorozyan I., Kiabi B. H. & Waltert M. 2017. When pork is not on the menu: assessing trophic competition between large carnivores and poachers. Biological Conservation 209, 223–229.

Heptner V. G. & Sludsky A. A. 1972. Mlekopitayuschie Sovetskogo Soyuza, t. 2. Khischnye (Gieny i Koshki) [The Mammals of the Soviet Union, vol. 2. Carnivores (Hyenas and Cats)]. Vysshaya shkola, Moscow. 550 p. (in Russian)

Karataş A., Bulut Ş. & Akbaba B. 2021. Camera trap records confirm the survival of the leopard (*Panthera pardus* L., 1758) in eastern Turkey (Mammalia: Felidae). Zoology in the Middle East 67, 198–205.

Khokhlov A. N. & Khubiev A. B. 2016. O sovremennom rasprostranenii i chislennosti peredneaziatskogo leoparda v Karachaevo-Cherkessii [On current distribution and population size of the Persian leopard in Karachay-Cherkassia]. In Prirodnye Resursy i Ekologicheskoe Obrazovanie na Severnom Kavkaze i Sosednikh Territoriyakh [Natural Resources and Ecological Education in the North Caucasus and Neighboring Areas]. Khokhlov A. N. and Pushkin S. V. (Eds). North Caucasus Federal University, Stavropol, Russia, pp. 3–8. (in Russian)

Khorozyan I. 2008. *Panthera pardus ssp. saxicolor.* In: IUCN 2009. IUCN Red List of Threatened Species. Version 2009.2.

Khorozyan I. 2010. Leopard – *Panthera pardus* (Linnaeus, 1758). In The Red Book of Animals of the Republic of Armenia. Invertebrates and Vertebrates. 2nd ed. Aghasyan A. and Kalashyan M. (Eds). Ministry of Nature Protection, Yerevan, Armenia, p. 344. (in Armenian and English)

Khorozyan I. G. & Abramov A. V. 2007. The leopard, *Panthera pardus* (Carnivora: Felidae), and its resilience to human pressure in the Caucasus. Zoology in the Middle East 41, 11–24.

Khorozyan I. G., Cazon A., Malkhasyan A. G. & Abramov A. V. 2007. Using thin-layer chromatography of fecal bile acids to study the leopard (*Panthera pardus ciscaucasica*) population. Biology Bulletin 34, 361–366.

Khorozyan I. & Malkhasyan A. 2005. Persian leopard photographed in Armenia. Cat News 43, 13.

Khorozyan I. G., Malkhasyan A. G. & Abramov A. V. 2008. Presence-absence surveys of prey and their use in predicting leopard (*Panthera pardus*) densities: a case study from Armenia. Integrative Zoology 3, 322–332.

Khorozyan I. G., Malkhasyan A. G., Asmaryan S. G. & Abramov A. V. 2010. Using geographical mapping and occupancy modeling to study the distribution of the critically endangered leopard (*Panthera pardus*) population in Armenia. In Spatial Complexity, Informatics, and Wildlife Conservation. Cushman S. and Huettmann F. (Eds). Springer Publishers, Tokyo, Japan, pp. 331–347.

Kudaktin A. N. 2016. Vozvraschenie leoparda v gory Kavkaza [Return of the leopard to the Caucasus mountains]. Mordovsky zapovednik 11, 24–26. (in Russian)

Kudaktin A. N. & Trepet S. A. 2008. Perspektivy vozrozhdeniya populiatsii barsa (leoparda) na Kavkaze [Perspectives of leopard recovery in the Caucasus]. In Materialy Vserossiiskoy Nauchno-Prakticheskoy Konferentsii "Sostoyanie Sredy Obitaniya i Fauna Okhotnichyikh Zhivotnykh Rossii" [Proceedings of the All-Russian Scientific and Practical Conference "Habitat Conditions and the Fauna of Game Species of Russia"], 28–29 Feb. 2008, Moscow. Per Se, Moscow, Russia, pp. 123–129. (in Russian)

Lortkipanidze B., Darchiashvili G. & Kopaliani N. 2004. Leopard in Georgia (new evidence). Proceedings of the Institute of Zoology 22, 325–328. (in Georgian, with summary in English and Russian)

Maharramova E., Moqanaki E. M., Askerov E., Faezi S., Alinezhad H., Mousavi M., Kuemmerle T., Heidelberg A. & Zazanashvili N. 2018. Transboundary leopard movement between Azerbaijan and Iran in the Southern Caucasus. Cat News 67, 8–10.

Mallon D., Weinberg P. & Kopaliani N. 2007. Status of the prey species of the leopard in the Caucasus. Cat News Special Issue 2, 23–27.

Miththapala S., Seidensticker J., Phillips L. G., Fernando S. B. U. & Smallwood J. A. 1989. Identification of individual leopards (*Panthera pardus kotiya*) using spot pattern variation. Journal of Zoology 218, 527–536.

Molinari-Jobin A., Wölfl S., Marboutin E., Molinari P., Wölfl M., Kos I., Fasel M., Koren I., Fuxjäger C., Breitenmoser C., Huber T., Blažič M. & Breitenmoser U. 2012. Monitoring the lynx in the Alps. Hystrix 23, 49–53.

Moqanaki E. M., Breitenmoser U., Kiabi B. H., Masoud M. & Bensch S. 2013. Persian leopards in the Iranian Caucasus: a sinking "source" population? Cat News 59, 22–25.

Muradov A. S. 2011. Teriofauna Akhar-Bakhara Azerbaijana soglasno metodu fotolovushek [The mammalian fauna of Akhar-Bakhar, Azerbaijan as studied by camera-trapping]. In Materialy Nauchnoi Konferentsii "Distantsionnye Metody Issledovaniya v Zoologii" [Proceedings of the Scientific Conference "Remote Methods of Zoological Research"], 28–29 Nov. 2011, Moscow. KMK Publishers, Moscow, Russia, p. 57. (in Russian)

Pikunov D. G. & Korkishko V. G. 1992. Leopard Dalnego Vostoka [The Leopard of the Far East]. Nauka, Moscow. 189 p. (in Russian)

Red List Technical Working Group. 2018. Mapping Standards and Data Quality for the IUCN Red List Categories and Criteria. Version 1.16.

Rostro-García S., Kamler J. F., Crouthers R., Sopheak K., Prum S., In V., Pin C., Caragiulo A. & Macdonald D. W. 2018. An adaptable but threatened big cat: density, diet and prey selection of the Indochinese leopard (*Panthera pardus delacouri*) in eastern Cambodia. Royal Society Open Science 5, 171187.

Rozhnov V. V. & Lukarevsky V. S. 2008. Program for Reintroduction of Central Asian Leopard in the Caucasus Region. KMK Publishers, Moscow. 65 p. (in Russian and English)

Rozhnov V. V., Lukarevsky V. S. & Sorokin P. A. 2007. Reintroduktsia leoparda (*Panthera pardus L.*, 1758) na Kavkaze: molekuliarno-geneticheskiy aspect [Reintroduction of the leopard (*Panthera pardus L.*, 1758) in the Caucasus: a molecular-genetic aspect]. In Materialy Mezhdunarodnoi Konferentsii "Mlekopitayuschie Gornykh Territoriy" [Proceedings of the International Conference "Mammals of Mountainous Areas"], 13–18 Aug. 2007, Moscow. KMK Publishers, Moscow, Russia, pp. 275–278. (in Russian)

Rozhnov V. V., Lukarevskiy V. S. & Sorokin P. A. 2011. Application of molecular genetic characteristics for reintroduction of the leopard (*Panthera pardus* L., 1758) in the Caucasus. Doklady Biological Sciences 437, 97–102.

Rozhnov V. V., Yachmennikova A. A., Naidenko S. V., Hernandez-Blanco J. A., Chistopolova M. D., Sorokin P. A., ...& Magomedov M. R. D. 2018. Monitoring Peredneaziatskogo Leoparda i Drugikh Krupnykh Koshek [Monitoring of the Persian Leopard and Other Big Cats]. KMK Pub-lishers, Moscow, Russia, 121 p. (in Russian)

Rozhnov V. V., Pshegusov R. H., Hernandez-Blanco J. A., Chistopolova M. D., Pkhitikov A. B., Trepet S. A., Dronova N. A., Naidenko S. V. & Yachmennikova A. A. 2020. MaxEnt modeling for predicting suitable habitats in the North Caucasus (Russian part) for Persian leopard (*P. p. ciscaucasica*) based on GPS data from collar-ed and released animals. Izvestiya, Atmospheric and Oceanic Physics 56, 1090–1106.

Rozhnov V. V., Yachmenikova A. A., Dronova N. A., Naidenko S. V., Hernandez-Blanco J. A., Chistopolova M. D., Pkhitikov A. B., Tembotova F. A. & Chestin I. 2022. Experience of the leopard recovering through reintroduction in the Russian Caucasus. Special Issue Cat News 15, 67–71.

Sari A., Gündoğdu E., Başkaya Ş. & Arpacik A. 2020. Habitat preference by the Anatolian leopard (*Panthera pardus tulliana* Valenciennes, 1856) in north-eastern Anatolia, Turkey. Belgian Journal of Zoology 150, 153–168.

Sarkisyan K. V., Markosyan T. A., Akopyan V. L. & Elbakyan A. L. 2019. Istoriya razvitiya epizootii afrikanskoi chumy svinei v Respublike Armenia [The history of development of the African swine fever epizootic in the Republic of Armenia]. Veterinarnaya patologia 3, 11–16. (in Russian)

Snider M. H., Athreya V. R., Balme G. A., Bidner L. R., Farhadinia M. S., Fattebert J., ...& Kays R. 2021. Home range variation in leopards living across the human density gradient. Journal of Mammalogy 102, 1138–1148.

Soofi M., Ghoddousi A., Zeppenfeld T., Shokri S., Soufi M., Jafari A., ...& Waltert M. 2018. Livestock grazing in protected areas and its effects on large mammals in the Hyrcanian forest, Iran. Biological Conservation 217, 377–382.

Soofi M., Ghoddousi A., Zeppenfeld T., Shokri S., Soufi M., Egli L., ...& Khorozyan I. 2019. Assessing the relationship between illegal hunting of ungulates, wild prey occurrence and livestock depredation rate by large carnivores. Journal of Applied Ecology 56, 365–374.

Spassov N., Ignatov A. and Acosta-Pankov I. 2016. On the status of the leopard in Turkey, again. Cat News 64, 18–21.

Spassov N., Askerov E., Akosta-Pankov I. & Ignatov A. 2019. New data on the occurrence of *Panthera pardus* in the Talysh Mountains, Azerbaijan (Carnivora: Felidae). Lynx 50, 113–118.

Sugimoto T., Aramilev V. V., Kerley L. L., Nagata J., Miquelle D. G. & McCullogh D. R. 2014. Noninvasive genetic analyses for estimating population size and genetic diversity of the remaining Far Eastern leopard *(Panthera pardus orientalis*) population. Conservation Genetics 15, 521–532.

Toyran K. 2018. Noteworthy record of *Panthera pardus* in Turkey (Carnivora: Felidae). Fresenius Environmental Bulletin 27, 7348–7353.

Vereschagin N. K. 1959. Mlekopitayuschie Kavkaza [The Mammals of the Caucasus]. USSR Academy of Sciences Press, Moscow and Leningrad. 703 p. (in Russian)

Voronin N. E. & Kharchenko N. N. 2016. K voprosu o reintroduktsii leoparda na Zapadnom Kavkaze [On the issue of leopard reintroduction in the Western Caucasus]. Lesotekhnicheskii zhurnal 4, 37–48. (in Russian)

Weinberg P. I., Komarov Yu. E. & Dzutsev Z. V. 2018. Monitoring vstrech peredneaziatskogo leoparda v gorakh Respubliki Severnaya Osetia-Alania vo vtoroi polovine XX i nachale XXI vv. [Monitoring of encounters with Persian leopards in the mountains of the Republic of North-Ossetia-Alania in the second half of the 20th century and the beginning of the 21st century]. In Materialy Yubileinoi XX Mezhdunarodnoi Nauchnoi Konferentsii "Biologicheskoe Raznoobrazie Kavkaza i Yuga Rossii" [Proceedings of the Jubilee 20th International Scientific Conference "Biological Diversity of the Caucasus and Southern Russia"], 6–8 Nov. 2018, Makhachkala. Institute of Applied Ecology, Makhachkala, Russia, pp. 379–381. (in Russian)

Yachmennikova A. A. & Rozhnov V. V. 2011. Vliyanie sotsialnogo obogascheniya sredy na ispolzovanie territorii voliera peredneaziatskimi leopardami (*Panthera pardus ciscaucasica*) [Effect of social enrichment on enclosure space use by Persian leopards (*Panthera pardus ciscaucasica*)]. In Materialy Nauchnoi Konferentsii "Tekhnologii Sokhraneniya Redkikh Vidov Zhivotnykh" [Proceedings of the Scientific Conference "Technologies of Rare Species Conservation in Animals"], 21–23 Nov. 2011, Moscow. KMK Publishers, Moscow, Russia, p. 64. (in Russian)

Yarovenko Y. A. 2017. Primernaya otsenka chislennosti i territorialnogo raspredeleniya peredneaziatskogo leoparda (*Panthera pardus*) v Dagestane [A preliminary assessment of population size and distribution of the Persian leopard (*Panthera pardus*) in Dagestan]. Trudy gosudarstvennogo prirodnogo zapovednika "Dagestansky" 13, 123–129. (in Russian)

Yarovenko Y. A. & Zazanashvili N. 2016. Recent hard evidence for the occurrence of the leopard, *Panthera pardus* (Mammalia: Felidae), in the eastern Greater Caucasus. Zoology in the Middle East 62, 88–90.

Zazanashvili N., Manvelyan K., Askerov E. & Heidelberg A. 2020a. Leopard in the South Caucasus. Conservation Summary since 2000. WWF, Tbilisi, Georgia, 20 p.

Zazanashvili N., Sanadiradze G., Garforth M., Bitsadze M., Manvelyan K., Askerov E., Mousavi M., Krever V., Shmunk V., Kalem S. & Devranoğlu S. 2020b. Ecoregional Conservation Plan for the Caucasus, 2020 Edition. WWF and KFW, Tbilisi, Georgia, 58 p.

[1] Consultant, Goettingen, Germany
* <igorkhorozyan@gmail.com>
[2] WWF-Azerbaijan, Baku, Azerbaijan
[3] WWF-Caucasus Programme Office, Tbilisi, Georgia
[4] WWF-Turkey, Istanbul, Turkey
[5] Centre for Biodiversity Conservation and Research-NACRES, Tbilisi, Georgia
[6] WWF-Armenia, Yerevan, Armenia
[7] Norwegian University of Life Sciences, Ås, Norway
[8] Department of Environment, Tehran, Iran
[9] A. K. Tembotov Institute of Ecology of Mountain Territories, Nalchik, Kabardino-Balkarian Republic, Russia
[10] Kh.G. Shaposhnikov Caucasian State Nature Biosphere Reserve, Sochi, Krasnodar Krai, Russia
[11] North Ossetian State Nature Reserve, Alagir, North Ossetia-Alania, Russia
[12] Precaspian Institute of Biological Resources, Dagestan Federal Research Centre of the Russian Academy of Sciences, Makhachkala, Republic of Dagestan, Russia
[13] WWF-Germany, Berlin, Germany

MOHAMMAD S. FARHADINIA[1*], MAHMOOD SOOFI[2,3], TATJANA ROSEN[4], PEYMAN MOGHADAS[5], KAVEH HOBEALI[5], POUYAN BEHNOUD[5], ARAZMURAT AMANOV[6], TIL DIETERICH[7], HOJAMURAD HOJAMURADOV[8], NURMUHAMMET HUDAIKULIEV[9], SHIRIN KARRYEVA[10], PETRA KACZENSKY[11], SHANYAZ MENGLIEV[12], AKTAN MUHASHOV[13], ZHASKAIRAT NURMUHAMBETOV[4]. MARK PESTOV[15], AKNABAT POTAEVA[16], VLADIMIR TERENTYEV[17], FARID SALMANPOUR[18], HAMED TIZROUYAN[18], HOSSEIN ALINEZHAD[19], BEHROUZ JAFARI[20], MOUSA OMMATMOHAMMADI[21], KUROS RABIE[22], ATAMYRAT VEYISOV[23] AND JOHN D. C LINNELL[24]

Status of Persian leopards in northern Iran and Central Asia

The Persian leopard *Panthera pardus tulliana* is an endangered large felid living in mountainous landscapes of the Caucasus, Southwest Asia and parts of Central Asia. In this paper, we review available literature to update our information on the status, population, ecology, threats, and management recommendations in regard to this big cat in the region. Most of the Alborz and Kopetdag Ecoregions harbour the largest population of Persian leopard with some protected areas having the highest densities of these carnivores. A total of 348 to 440 leopards are guessed to exist in the region, making it one of the largest continuous leopard hotspots across Asia. Almost 80% of the population exists in Iran, followed by Turkmenistan which holds the second largest Persian leopard population, while the leopard population in Kazakhstan mainly depends on transboundary transient individuals from Turkmenistan. Habitat types vary from Irano-Turanian landscapes to highland scrublands and Hyrcanian temperate forests, with urial *Ovis vignei,* bezoar goat *Capra aegagrus* and wild pig *Sus scrofa* being the main prey of leopard. Resident males occupy a mean home range of 103.4 ± SE 51.8 km² which is larger than the ones observed in other studies of male Asian leopards. Persian leopards occur continuously across the Alborz and Kopetdag mountains ranges, and face multiple anthropogenic threats such as: (i) inadequate livestock grazing or husbandry practices; (ii) illegal killing of leopards; (iii) and wild prey depletion. Livestock grazing is commonplace in the range countries, particularly inside protected areas. Conflict mitigation measures in Iran, and generally in the range countries, should be implemented at least in the areas with high leopard mortality provoked by livestock losses. Also, given the occasion-al occurrence of problem individuals responsible for a disproportionate impact on human interests, particularly in northeastern Iran, we suggest to apply selective management which would target on specific individuals and become effective for conflict mitigation.

The Persian leopard is an endangered large felid living in mountainous landscapes of the Caucasus, Southwest Asia and parts of Central Asia (Jacobson et al. 2016). In northern Iran including Alborz and Kopetdag mountain ranges, and Central Asia, this subspecies faces different situations. While high densities of leopards exist in parts of Iran (Farhadinia et al. 2019, Hamidi et al. 2014), the leopard exist at low densities in Turkmenistan (Kaczensky et al. 2019) and the leopard population in Kazakhstan is dependent on transboundary movements (Kaczensky et al. 2019). In this paper, we review available literature to provide a background on the Persian leopard status, population, and ecology in the region. We then provide a detailed profile of key threats and conservation recommendations that potentially may secure the leopard viability in northern Iran and Central Asia.

Table 1. Number of Persian leopard records collected between 2000 and 2021 in northern Iran (Alborz and Kopetdag mountain ranges) and Central Asian countries (Turkmenistan and Kazakhstan). C1 = confirmed and C2 = probable.

Region/Country	C1	C2
northern Iran (Alborz and Kopetdag mountain ranges)	278	263
Turkmenistan	38	0
Kazakhstan	10	0
Total	**326**	**263**

Methods

To describe the occurrence and population status of the Persian leopard in northern Iran (Alborz and Kopetdag mountain ranges) and Central Asian countries (Turkmenistan and Kazakhstan), we relied on multiple data sources such as opportunistic camera-trapping records and direct sightings collected between 2000 and 2021. Records in the database were attributed to two categories of reliability, namely "confirmed" (C1) and "probable" (C2) observations. Confirmation of presence (C1) was based on available photos or movies, or leopard carcasses or other remains of the species that were verified by reliable experts whereas observations by trained persons (e.g., field biologists, skilled rangers, experienced hunters, and taxidermists) were assigned to C2. This resulted in a final dataset of 589 locations from 3 range countries (Table 1). We guesstimated country-specific leopard population sizes using ranger-based (unpublished data of the Iranian Department of Environment 2021) and expert opinion (Turkmenistan and Kazakhstan) data across the study area. We also measured the proportions of different mortality types (human-induced threats and natural mortality) of leopards from 2000 to 2021 in northern Iran (unpublished data of the Iranian Department of Environment 2021). Finally, we propose several management actions to boost the existing leopard conservation efforts.

Distribution

Persian leopards occur in 602,000 km² of mountainous landscapes of Southwest and Central Asia, as well as the Caucasus, which cover 16% of their historic range in this region (Jacobson et al. 2016; Fig. 1). Over 75% of the extant range of Persian leopards lies within Iran (Jacobson et al. 2016). Nonetheless, recent habitat modelling showed that the continuous suitable habitat for Persian leopards in Iran is extended over 316,984 km² (Ahmadi et al. 2020), suggesting that the extant distribution area of Persian leopards can be smaller across its range than expected (Ashrafzadeh et al. 2020). Importantly, a high percentage of suitable habitats is still locat-ed outside the existing network of protected areas; for example, only 24% of suitable leopard habitats are managed as protected areas on the Iranian side of the Ko-

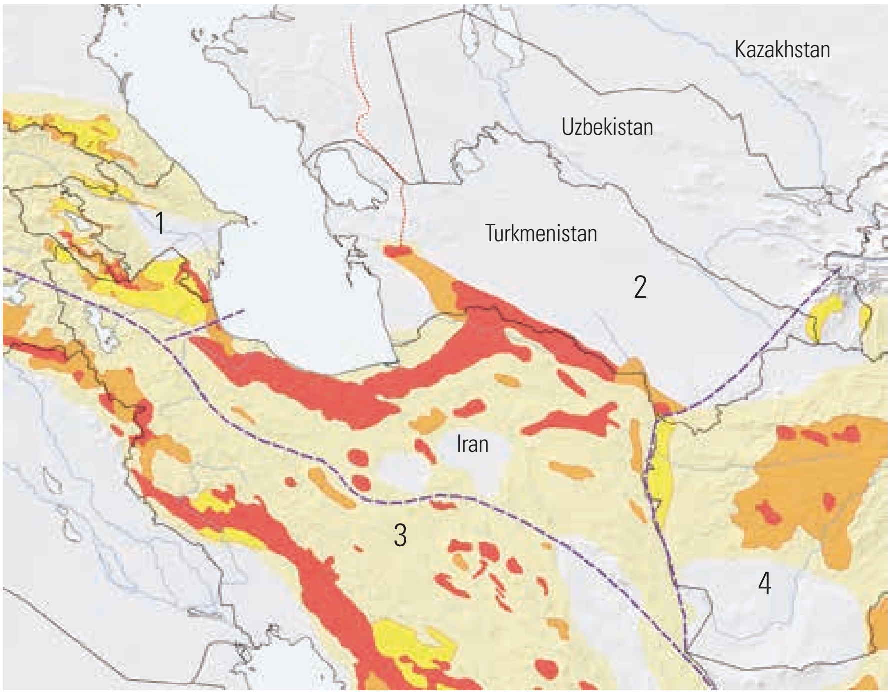

Fig. 1. Distribution of leopard in northern Iran and Central Asia (2). Red = extant, orange = possibly extant, dark yellow = possibly extinct, light yellow = extinct, violet lines = regional division. 1 = Caucasus Ecoregion, 2 = Alborz-Kopetdag, 3 = Zagros, 4 = eastern range. Map courtesy to Peter Gerngross, based on Farhadinia et al. (2022).

petdag Ecoregion (Hosseini et al. 2019). Just recently in 2022, a female leopard with her two cubs was sighted and filmed in the Ghazanghayeh No Hunting Area in north-eastern Iran, next to the Iran-Turkmenistan border (V. Kheirabadi & M. Soofi pers. comms.).

The second largest range for Persian leopard is found in Turkmenistan (Lukarevsky 2001), mostly in the borderline areas along the Kopetdag and Sunt Hasardag mountain ranges between Turkmenistan and Iran (Farhadinia et al. 2021). Leopards have also been recorded in Badhyz State Nature Reserve on the border with Iran and Afghanistan (Kaczensky et al. 2019). A small breeding population was recently (2020) confirmed by camera-traps in the Uly Balkan range north of the Kopetdag and by local herders' sightings reported from the Kichi Balkan lying between the Uly Balkan and the Kopetdag. Furthermore, leopards have been reported along the Garabogazgol depression on the Turkmen side using the Ustyurt Plateau as a corridor. In 1989, leopard tracks were spotted in the Kulansai Gorge at Garabogaz-gol (Lukarevsky 2001). In 2020, a leopard was sighted near the settlement of Arsary Baba on the edge of the Garabogaz-gol basin (ca. 120 km north-east of the Uly Balkan range). Since the Ustyurt Plateau stretches far into Kazakhstan and Uzbekistan, it is most likely that leopards had been historically dispersing into Kazakhstan, and until recently continue to do so. For example, in the autumn of 2018 a young male Persian leopard was recorded by camera-traps in Ustyurt Nature Reserve UNR of Kazakhstan for the first time (Pestov et al. 2019). The distance from UNR in Kazakhstan to Arsary Baba in Turkmenistan as the nearest confirmed leopard range is about 170 km. After multiple detections (Fig. 2) during different seasons, this leopard was found dead about 370 km north-east of UNR (Mangistau region, Kazakhstan). Prior to 2018, the leopard presence in Mangystau was recorded in 2007 and 2015 when leopards were trapped and killed by shepherds. A dead leopard was also recorded in 2000 on the banks of the Talas River near the town Toguskem, in the Mujunkum desert in eastern Kazakhstan. In addition, during interviews with members of local communities in the region we obtained anecdotal reports and images of several leopard encounters in Mangystau region in Kazakhstan over the past fifty years.

Population abundance and density

The Persian leopard population size in Iran is guesstimated to be about 550–850 individuals (Kiabi et al. 2002), making it the main stronghold for leopard populations in the region. The Alborz and Kopetdag Ecoregions harbour the largest population of Persian leopard with some protected areas having the highest densities of these carnivores. Based on the guesstimates provided in Table 2, a total of 348 to 440 leopards are believed to exist in the region, making it one of the largest continuous leopard hotspots across Asia (Jacobson et al. 2016). Almost 80% of the region's leopards (288 to 355 individuals) exist in Iran (Table 2).

The density of leopards in northeastern Iran was reported to vary between 2.63 and 8.86 individuals/100 km² (Farhadinia et al. 2019, Hamidi et al. 2014). With 30 and 20 adult individuals detected during camera trapping surveys in Tandoureh and Golestan National Parks, respectively, these two reserves hold the largest populations of Persian leopards in west and central Asia (Table 3). Along Alborz range, opportunistic camera trapping efforts as well as DNA fingerprinting have detected small populations of leopards along Alborz mountains,northern Iran (Table 3)

In the early 2000s, it was guesstimated that approximately 80–100 Persian leopard may still be found in Turkmenistan, with the highest densities recorded in the Kopetdag range along the southern boundary of the country (Lukarevsky 2001, Red Book of Turkmenistan 2011). Opportunistic camera-trapping and observations over the past decade did not provide sufficient information to make reliable estimates of Persian leopard numbers, but these together with the information from adjacent Iran suggest that the Kopetdag and its extension into the Sunt Hasardag in the north and Badhyz in the southeast remains the most important stronghold of the leopard in Turkmenistan. Recent records also highlight the importance of the Uly and Kichi Balkan ranges for the expansion of the leopard distribution further north to the Ustyurt Plateau (T. Rosen, pers. obs.).

The Persian leopard had never been considered an extant species in Kazakhstan, despite the existence of sightings and reports since the 1970s. The first recent occurrence of Persian leopard in Kazakhstan was documented by camera-traps in 2018, but then this individual died in 2021. The occurrence of leopard in UNR and the earlier sightings on the Ustyurt Plateau in Turkmenistan suggest a good chance for recolonization from Turkmenistan if its population increases. To facilitate dispersals of sub-adult leopards from Turkmenistan to Kazakhstan and Uzbekistan, a careful analysis of the risks associated with barriers to movements, such as the international border fences (Pestov et al.

Fig. 2. Different habitat types of leopard in northern Iran and central Asia: Top from left: the highlands of the Hyrcanian relic temperate forests and rugged mountains in Kiasar National Park, northern Iran (Photo H. Tizrouyan & K. Ateni); Ustyurt plateau, Kazakhstan (Photo USNR/ACBK/CADI); middle from left: the Hyrcanian relic temperate forests in Kiasar National Park, northern Iran (Photo H. Tizrouyan & M. Abbaszadeh) and the steppic mountains of Tandoureh National Park, Iran-Turkmenistan border (Photo Future4Leopards Foundation), bottom from left: Kopetdag mountains in Turkmenistan (Photo Team Bars Turkmenistan) and Turan Biosphere Reserve, southern Alborz (Photo Iranian Cheetah Society/DoE/Stichting SPOTS).

2019) should be done. Also, protection efforts need to be strengthened to increase the prey base and to safeguard leopards within and beyond protected areas.

Habitat and ecology

Persian leopards occur in a variety of habitat types (Fig. 2), from Irano-Turanian arid landscapes to highland scrublands and the Hyrcanian temperate forests of Iran. Leopard habitat distribution often overlaps with the ranges of main wild prey species such as urial *Ovis vignei* and bezoar goat *Capra aegagrus* (Hosseini et al. 2019). Also, leopards in Iran can range across a wide continuum of altitudes, from the sea level in lowlands of Mazandaran Province up to nearly 4,000 m on the Alborz peaks. Vegetation of the areas where leopards were recorded in UNR (Kazakhstan), Badhyz and Uly Balkan (Turkmenistan) is typical for cold desert ecosystems and includes the sub-shrubs (*Anabasis eriopoda*, *A. brachiata* and *Nanophyton erinaceum*); abrasive plants *Atraphaxis replicata*, dwarf shrubs *Convolvulus fruticosus*, drift plants *Limonium suffruticosum*, pockholt plant species *Zygophyllum ovigerum*, tamarisk plants *Tamarix* spp., wormwood *Artemisia* spp. shrubs, and pistachio *Pistacia vera* woodlands. Vegetation of the Kopetdag range is dominated by junipers *Juniperus* spp., woodlands, bulbous bluegrass *Poa bulbosa*, and desert sedge *Cyperaceae*.

The studies of the Persian leopard diet in northern Iran are based on the analyses of faecal samples (Farhadinia et al. 2014, Ghoddousi et al. 2016, Sharbafi et al. 2016, Taghdisi et al. 2013) and the kills of radio-collared leopards (Farhadinia et al. 2018). All show a consistent dominance of wild ungulates in the diet, estimated to constitute 80–95% of the consumed biomass. The key

Table 2. Baseline information on the guesstimated population size of Persian leopards in Alborz and Kopetdag Ecoregions based on expert opinions.

Country and province	Population guesstimate	Reference
Iran, Razavi Khorasan	100	Iranian Department of Environment, unpublished report 2020
Iran, North Khorasan	35-45	Iranian Department of Environment, unpublished report 2020
Iran, South Khorasan	3-5	Iranian Department of Environment, unpublished report 2019
Iran, Semnan	40-60	Iranian Department of Environment, unpublished report 2020
Iran, Mazandaran	80-100	Iranian Department of Environment, unpublished report 2019
Iran, Alborz	20-25	Iranian Department of Environment, unpublished report 2020
Iran, Tehran	10-20	Iranian Department of Environment, unpublished report 2019
Turkmenistan	60-80	Team Bars Turkmenistan, 2021
Kazakhstan	0-5	Red Book of Endangered Species, Kazakhstan 2021
Total	**348-440**	

wild prey species for leopards across the Kopetdag Ecoregion (Iran, Turkmenistan and the adjacent areas of the Ustyurt Plateau in Kazakhstan) are urial, bezoar goat, wild pig *Sus scrofa* and goitered gazelle *Gazella subgutturosa* (Kaczensky et al. 2019), while red deer *Cervus elaphus* and roe deer *Capreolus capreolus* make only a contribution to the leopard diet in temperate forests of the Alborz range (Ghoddousi et al. 2016, Sharbafi et al. 2016). Despite this diversity of prey resources, livestock depredation by leopards is common across the region, targeting mainly cattle in forest areas of the Alborz range (Babrgir et al. 2017, Ghoddousi et al. 2016) and smaller stock such as sheep and goats in steppe landscapes (Farhadinia et al. 2018). Dogs have also been widely taken by leopards across the region, with some individuals specialising in killing and consuming dogs (Farhadinia et al. 2018).

As Persian leopard is a wide-ranging predator, resident males occupy a mean home range of 103.4 ± SE 51.8 km² which is larger than the ones observed in other studies of male Asian leopards (Farhadinia et al. 2018). Larger home range size is leopards is negatively correlated with landscape productivity (Snider et al. 2021). A satellite telemetry-based study also revealed that a young male leopard, possibly a dispersing individual, moved 82 km from Iran to Turkmenistan (Farhadinia et al. 2018). Compared to other sympatric carnivores in the Alborz and Kopetdag, leopards respond differently from wolves Canis lupus to land use patterns, with higher occupancy of human-free areas such as national parks, whereas wolves tend to occur more in communal lands (Mohammadi et al. 2021). Given the high occurrence of brown bears Ursus arctos and Persian leopards along the Alborz range, future studies are encouraged to investigate possible intra-guild interactions between these two species.

Threats

Persian leopard populations face multiple anthropogenic threats that continue to contribute to population declines and range contraction across the range countries (Lukarevsky 2001, Soofi et al. 2019). These threats mainly include, but are not limited to: (i) inadequate livestock grazing or husbandry practices, (ii) illegal killing of leopards, (iii) and wild prey depletion. Below we describe these threats separately for each country.

Iran

Livestock grazing practices are commonplace in Iran, even inside protected areas (Khorozyan et al. 2020, Soofi et al. 2018). A recent study by Soofi et al. (2018) in the Hyrcanian forests of northern Iran identified that the occurrence of Persian leopard and its wild prey was very fragmented and negatively affected by livestock presence across different seasons. The second threat that impacts the persistence of leopards is wild prey poaching. Leopards need large tracts of quality prey-rich habitats to survive, so when prey abundance is low they inevitably have to move widely, clash with people, and occasionally die from poaching and collisions on roads and railways (Naderi et al. 2018). As a common consequence of prey scarcity, leopards have to hunt livestock and often being killed in retribution or to prevent further attacks on livestock (Babrgir et al. 2017, Farhadinia et al. 2018, Soofi et al. 2019, Khorozyan et al. 2020). Losses from livestock depredation by leopards are particularly large and financially detrimental for small-scale households and near protected areas (Khorozyan et al. 2020). In response to this damage, pastoralists tend to kill leopards illegally by trapping, poisoning or shooting (Khorozyan et al. 2020).

Over the past 21 years (2000–2021; unpublished data of the Iranian Department of Environment), 158 individual leopards were reported to be killed along the Alborz range in northeastern Iran (n = 74 for illegal killing, 34 for unknown, 27 for vehicle collisions, and 23 for natural causes). A recent study reports that 54% of the leopard mortalities were related to livestock depredation across Iran (Soofi et al. 2022). This result suggests a dire need for the development and application of practical and effective conflict mitigation measures along with anti-poaching and prey recovery initiatives. Support to livestock protection should address the ecology of leopards (Farhadinia et al. 2018, Khorozyan et al. 2020), as well as livestock grazing patterns and landscape structure (Ghoddousi et al. 2016, Soofi et al. 2019).

Turkmenistan and Kazakhstan

In Turkmenistan and Kazakhstan leopards were reported to be trapped and killed. The possible reasons for leopard killings are preventive protection of livestock from predator attacks and retaliatory persecution in response to actual attacks and livestock losses. Furthermore, there is evidence of high poaching pressure on the leopard's wild prey, namely urial sheep, goitered gazelle and bezoar goat, which results in decreasing wild prey densities and may increase leopard depredation on livestock.

While border security zones provide some degree of protection to leopards and other wildlife, poaching of wild prey remains a significant threat especially in Badhyz, Uly Balkan, and the Ustyurt Plateau in Turkmenistan, where some of the authors found the first-hand evidence of poaching of goitered gazelles and bezoar goats (Kaczensky et al. 2019). Another significant threat is the presence of border fences, especially those on the borders between Iran, Turkmenistan, Afghanistan, Kazakhstan, and Uzbekistan (Farhadinia et al. 2021), which can severely limit movements of leopards and its wild prey. The border fences between Kazakhstan and Turkmenistan, Iran and Turkmenistan as we all as Turkmenistan and Uzbekistan consist of two parallel rows of multi-strand barbed wire fences that make crossing impossible for ungulates and extremely challenging for leopards. For example, a collared leopard dispersing from Iran could not pass the border fence along the Turkmenistan border (Farhadinia et al. 2021). The border between Turkmenistan and Iran is one row of equally impassable multi-strand barbed wire fence.

Conservation and management

Conflict mitigation measures in Iran and other range countries should be implemented at least in the areas with high leopard mortality provoked by livestock losses, for example, in parts of Mazanzadarn Province in northern Iran. These measures can be implemented within community-based approaches and include (1) training and support of local herders to livestock protection techniques (e.g. protective collars for cattle, predator-proof corrals); (2) compensation payment schemes; and (3) provision, handling, training and care of livestock guarding dogs. Livestock guarding dogs have been commonly used by herders to protect their livestock from predators, but they also can provoke predator attacks, threaten other people, livestock and wildlife, and transmit diseases (Khorozyan et al. 2017). Thus, it is important to educate and raise the awareness of pastoralists in order to help them guide their livestock husbandry practices properly and in environmentally and socially friendly ways. For example, training of guarding dogs can reduce negative impacts on wildlife (Leib et al. 2021) so that they are trained only to effectively deter predators, such as leopards (Khorozyan et al. 2017, 2020). Pastoralists hold official permits with specified sizes of their pastures and grazing periods (2–3 months), but often overuse pasture lands and penetrate deep into the core zones located beyond their land allotments and, when patrolling is insufficient, often inside protected areas (Soofi et al. 2018). Such large-scale and extended grazing activities make livestock vulnerable to depredation by carnivores. Thus, the above-mentioned conflict mitigation measures are essential to promote coexistence between herders and leopards in shared landscapes. Given the occasional occurrence of problem individuals, which can be responsible for a disproportionately high impact on livestock, we also suggest to apply selective management which would target specific livestock-killing individuals and ensure the effectiveness of conflict mitigation (Swan et al. 2017). For example, translocation of live-captured individuals to low-density and remote areas should be considered the only alternative to shooting problem leopards (Farhadinia et al. 2015). Vehicle collisions also contributes to leopards mortality in Iran, but these collisions were mainly common in the Golestan National Park in northeastern Alborz, where the Asiatic road crosses the park connecting Tehran to Mashhad (Soofi et al. 2022). Hence, it is of high priority for building wildlife overpass bridges in the park to reduce the risk of collisions. In addition, speed limit enforcement signs can also be implemented along the road to effectively reduce not only vehicle collisions with leopards but also other wildlife species which are frequently being killed on the road (Naderi et al. 2018).

In Turkmenistan, all protected areas require greater funding support. In the case of Badhyz and Kopetdag state nature reserves, since these reserves largely fall in the border security zone, rangers and scientific staff should be given access to the exclusion zone for monitoring of leopards and other wildlife. The proposed establishment of Uly Balkan Reserve is an important step for leopard conservation, which should be followed up by designation of a wildlife corridor stretching from Uly Balkan to protected areas on the Ustyurt Plateau in Turkmenistan and in adjacent areas of Kazakhstan and Uzbekistan.

In Kazakhstan, in the wake of the rediscovery of the Persian leopard, a scientific justification led to the inclusion of the Persian leopard in the Red Data Book of Kazakhstan and the preparation of the National Action Plan. While leopard was included in the Red Data Book in 2021, integration of the Action Plan into Kazakhstan's legislation is still pending and debatable given the death of the only known individual. UNR is largely under-funded, and its personnel's motivation is low. In addition, most of the camera-traps placed to monitor leopards were stolen, making wildlife moni-

Table 3. Population densities of Persian leopards in Iran within the Alborz and Kopetdag Ecoregions estimated from camera-trapping. Abbreviations: NA – not available, non-SECR - spatially non-explicit, i.e., conventional, capture-recapture method, SECR - spatially explicit capture-recapture method.

Area	Province	Year	# adult animals	Density (ind./100 km²)	Method	Reference
Tandoureh National Park	Razavi Khorasan	2016	30	5.57	Photographic secr	Farhadinia et al. (2019)
Sarigol National Park	North Khorasan	2015	10	8.86	Photographic secr	Farhadinia et al. (2019)
Salouk National Park	North Khorasan	2015	11	3.10	Photographic secr	Farhadinia et al. (2019)
Golestan National Park	Golestan Province	2011	20	2.63	Photographic non-secr	Hamidi et al. (2014)
North Alborz PA	Mazandaran Province	2018	7	NA	Opportunistic camera trapping	Salmanpour & Tizrouyan, Unpublished report (2021)
Kiasar National Park	Mazandaran Province	2018	10	NA	Opportunistic camera trapping	Salmanpour & Tizrouyan, Aradni and Ateni, Unpublished report (2021)
Parvar PA	Semnan Province	2013-2015	7	NA	DNA fingerprinting	Ardani et al. (2019)

Fig. 3. Persian leopard on a bezoar goat kill in Central Alborz Protected Area, northern Iran (camera trap set up by A. Rahbarizadeh).

tor-ing even more challenging. Large resources are required to support and motivate park rangers and other staff members, which could translate into better protection on the ground. Establishment of the proposed South Ustyurt State Nature Reserve in Kazakhstan, which covers the key habitats for urials and goitered gazelles, may provide a refuge for leopards in the future. In the broader scale, the establishment of protected areas on the Ustyurt Plateau will also require coordinated actions between the conservation authorities of Turkmenistan, Kazakhstan, and Uzbekistan to allow for wildlife movements across borders (Linnell et al. 2016, Pestov et al. 2019). Such transboundary cooperation is also essential for Turkmenistan, Iran, and Afghanistan.

We conclude that Persian leopards occur continuously across the Alborz (Fig. 3) and Kopetdag mountains ranges (Fig. 4). These landscapes contain the areas with the highest densities, especially inside Iranian protected areas. However, leopards have been reported to be killed across the region by shooting, poisoning and trapping, mostly in relation to livestock depredation, which adds to natural mortality. Considering that human developments in the shared landscape are inevitable, it is of paramount importance to promote coexistence between people and leopards to ensure the survival of the leopard population. We suggest the following activities to improve and promote leopard conservation in the region: (a) to educate and train pastoralists within community-based initiatives to livestock protection techniques in order to help them apply good livestock grazing practices; (b) to focus on managing problem leopards; (c) to monitor leopards and their prey effectively; (d) establishment of new protected areas and (e) capacity building and awareness-raising in local communities and staffs of protected areas in conflict managemnt and conservation initiatives.

References

Ahmadi M., Farhadinia M. S., Cushman S. A., Hemami M. R., Nezami Balouchi B., Jowkar H. & Macdonald D. W. 2020. Species and space: a combined gap analysis to guide management planning of conservation areas. Landscape Ecology 35, 1505–1517.

Ardani P., Rezaei H., Dibadj P., Asharioun A., Babaki S. & Kaboli M. 2019. Noninvasive molecular genetic method for individual identification of Persian leopard (*Panthera pardus saxicolor*) in Parvar Protected Area, Semnan, Iran. Wildlife Research and Conservation.

Babrgir S., Farhadinia M. S. & Moqanaki E. M. 2017. Socio-economic consequences of cattle predation by the endangered Persian leopard *Panthera pardus saxicolor* in a Caucasian conflict hotspot, northern Iran. Oryx 51, 124–130.

Farhadinia M. S., Memarian I., Hobeali K., Shahrdari A., Ekrami B., Kaandorp J. & Macdonald D. W. 2017. GPS collars reveal transboundary movements by Persian leopards in Iran. Cat News 65, 28–30.

Farhadinia M. S., Moqanaki E. M. & Hosseini-Zavarei F. 2014. Predator–prey relationships in a middle Asian Montane steppe: Persian leopard versus urial wild sheep in Northeastern Iran. European journal of wildlife research 60, 341–349.

Farhadinia M. S., Johnson P. J., Hunter L. T. B. & Macdonald D. W. 2018. Persian leopard predation patterns and kill rates in the Iran–Turkmenistan borderland. Journal of Mammalogy 99, 713–723.

Farhadinia M. S., Johnson P. J., Macdonald D. W. & Hunter L. T. B. 2018. Anchoring and adjusting amidst humans: Ranging behavior of Persian leopards along the Iran-Turkmenistan borderland. PLoS One 13(5): e0196602.

Farhadinia M. S., McClintock B. T., Johnson P. J., Behnoud P., Hobeali K., Moghadas P., Hunter L. T. B. & Macdonald D. W. 2019. A paradox of local abundance amidst regional rarity: the value of montane refugia for Persian leopard conservation. Scientific Reports 9, 1–12.

Farhadinia M. S., Rostro-García S., Feng L., Kamler J. F., Spalton A., Shevtsova E., Khorozyan I., Al-Duais M., Ge J. & Macdonald D. W. 2021. Big cats in borderlands: challenges and implications for transboundary conservation of Asian leopards. Oryx 55, 452–460.

Ghoddousi A., Soofi M., Hamidi A. K., Lumetsberger T., Egli L., Khorozyan I., Kiabi B. H. & Waltert M. (2016). Assessing the role of livestock in big cat prey choice using spatiotemporal availability patterns. PloS One, 11(4), e0153439.

Hamidi A. K., Ghoddousi A., Soufi M., Ghadirian T., Jowkar H. & Ashayeri S. 2014. Camera trap study of Persian leopard in Golestan National Park, Iran. Cat News 60, 12–14.

Hosseini M., Farashi A., Khani A. & Farhadinia M. S. 2019. Landscape connectivity for mammalian megafauna along the Iran-Turkmenistan-Afghanistan borderland. Journal for Nature Conservation 52.

Jacobson A. P., Gerngross P., Lemeris Jr J. R., Schoonover R. F., Anco C., Breitenmoser-Würsten C., Durant S. M., Farhadinia M. S., Henschel P. & Kamler J. F. 2016. Leopard (*Panthera pardus*) status, distribution, and the research efforts across its range. PeerJ, 4, e1974.

Kaczensky P., Rustamov E., Karryeva S., Iankov P., Hudaykuliev N., Saparmyradov J., Veyisov, A., Shestopal A., Mengliev S. & Hojamyradov H. 2019. Rapid assessments of wildlife in Turkmenistan 2018.

Khorozyan I., Soofi M., Soufi M., Hamidi A. K., Ghoddousi A., & Waltert M. 2017. Effects of shepherds and dogs on livestock depredation by leopards *(Panthera pardus*) in north-eastern Iran. PeerJ, 5, e3049.

Khorozyan I., Ghoddousi S., Soufi M., Soofi M. & Waltert M. 2020. Studded leather collars are very effective in protecting cattle from leopard (*Panthera pardus*) attacks. Ecological Solutions and Evidence 1(1), e12013.

Linnell J. D. C., Trouwborst A., Boitani L., Kaczensky P., Huber D., Reljic S., ...& Breitenmoser U. 2016. Border Security Fencing and Wildlife:

The End of the Transboundary Paradigm in Eurasia? PLoS Biology 14(6): e1002483

Lukarevsky V. S. 2001. The Leopard, Striped Hyena, and Wolf in Turkmenistan. Moskva: Signar.

Mohammadi A., Lunnon C., Moll R. J., Tan C. K. W., Hobeali K., Behnoud P., Moghadas P., Macdonald D. W. & Farhadinia M. S. 2021. Contrasting responses of large carnivores to land use management across an Asian montane landscape in Iran. Biodiversity and Conservation 30, 4023–4037.

Naderi M., Farashi A., Erdi M. A. 2018. Persian leopard's (*Panthera pardus saxicolor*) unnatural mortality factors analysis in Iran. PLoS ONE 13(4): e0195387.

Pestov M. V, Nurmukhambetov Z. E., Munkhashov A. T., Terentyev V. A. & Rosen T. 2019. First camera trap record of Persian leopard in Ustyurt State Nature Reserve, Kazakhstan. Cat News 69, 14–16.

Sharbafi E., Farhadinia M. S., Rezaie H. R., & Braczkowski A. R. 2016. Prey of the Persian leopard (*Panthera pardus saxicolor*) in a mixed forest-steppe landscape in northeastern Iran (Mammalia: Felidae). Zoology in the Middle East 62, 1–8.

Soofi M., Ghoddousi A., Zeppenfeld T., Shokri S., Soufi M., Jafari A., ...& Waltert M. 2018. Livestock grazing in protected areas and its effects on large mammals in the Hyrcanian forest, Iran. Biological Conservation 217, 377–382.

Soofi M, Ghoddousi A., Zeppenfeld T., Shokri Sh., Soufi M., Egli L., ...& Khorozyan I. 2019. Assessing the relationship between illegal hunting of ungulates, wild prey occurrence and livestock depredation rate by large carnivores. Journal of Applied Ecology 56, 365–374.

Soofi M., Qashqaei, A. T., Mousavi M., Hadipour E., Filla, M., Kiabi, B. H., ...& Waltert M. 2022. Quantifying the relationship between prey density, livestock and illegal killing of leopards. Journal of Applied Ecology 59, 1536–1547

Swan G. J., Redpath S. M., Bearhop S. & McDonald R. A. 2017. Ecology of problem individuals and the efficacy of selective wildlife management. Trends in Ecology & Evolution 32, 518–530.

[1] Oxford Martin School and Department of Zoology, University of Oxford, UK
*<mohammad.farhadinia@zoo.ox.ac.uk>

[2] Department of Conservation Biology, University of Goettingen, Bürgerstr. 50, 37073, Goettingen, Germany

[3] CSIRO Land and Water, PMB 44, Winnellie, Darwin, 0822, Northern Territory, Australia

[4] Center for Large Landscape Conservation, Turkmenistan

[5] Future4Leopards Foundation, Tehran, Iran

[6] Kaplankyr State Nature Reserve, Turkmenistan, amanowarazmurat@gmail.com[7] Norwegian University of Life Sciences, Ås, Norway

[7] NABU, Germany

[8] Society of Nature Protection of Turkmenistan

[9] Badhyz State Nature Reserve, Turkmenistan

[10] CADI, Turkmenistan

[11] Inland Norway University of Applied Sciences, Norway

[12] Koytendag State Nature Reserve, Turkmenistan

[13] Ustyurt State Nature Reserve, Kazakhstan

[14] Ustyurt State Nature Reserve, Kazakhstan

[15] Eco-center "Dront", Russian Federation

[16] Kopetdag State Nature Reserve, Turkmenistan

[17] ACBK, Kazakhstan

[18] Department of Biodiversity and Ecosystem Management, Research Institute of Environmental Sciences, Shahid Beheshti University, Tehran, Iran

[19] Gilan Provincial Office of the Department of the Environment, Rasht, Iran

[20] North Khorasan Provincial Office of the Department of the Environment, Bojnurd, Iran

[21] Khorasan Razavi Provincial Office of Department of the Environment, Mashhad, Iran

[22] Mazandaran Provincial Office of the Department of the Environment, Sari, Iran

[23] Center for Large Landscape Conservation, Turkmenistan

[24] NINA, Norway

Fig. 4. Persian leopard on a wild pig kill in Tandoureh National Park, Kopetdag mountains, Iran-Turkmenistan border (Photo H. Eslahi).

ARASH GHODDOUSI[1*], HAMED ABOLGHASEMI[2], MORTEZA ARIANEJAD[3], GHOLAMREZA GHADERI MOZAFARI[4], LEILA JOOLAEE[5], MARZIEH M0USAVI[6], DANIAL NAYERI[7], NILOUFAR RAEESI CHAHARTAGHI[8], HANA RAZA[9], AND POORIYA SEPAHVAND[8]

Distribution and status of the Persian leopard in its western range

Persian leopard in its western range is distributed in Iran, Iraq and Turkey. The habitat in this region is mainly characterised by the Zagros Mts. as well as isolated mountain ranges in central and south-eastern Iran. The species has been studied intensively only in a handful of protected areas and the remaining information comes from sporadic and opportunistic sightings. Importantly, the status of the species is widely unknown in southern Turkey, northern Iraq and parts of western, south-eastern and central Iran. We collected all available contemporary (> year 2000) leopard occurrences as well as information on the species ecology and threats in this range to assess its status. After filtering for repeated or unreliable data, we identified 438 occurrences classified based on their reliability levels C1 (verified observations, n = 243), C2 (confirmed, n = 107) and C3 (unconfirmed, n = 88). Mapping the potential distribution of the species based on this information and expert knowledge resulted in around 153,400 km² of habitat in Iran and Iraq, mainly along the Zagros Mts. The presence of the leopard is highly probable in another ca. 70,500 km², which requires further investigations. The density in the few protected areas with intensive camera trapping survey was estimated between 1.0-1.9 leopard/100 km². According to our assessment, the main threats to the species are retaliatory or precautionary killing by livestock pastoralists, prey depletion and road accidents. Moreover, given the increasing fragmentation of leopard habitat, identification and protection of (transboundary) corridors are conservation priorities.

The Persian leopard (*Panthera pardus saxicolor* [= *P. p. tulliana*]; cf. Kitchener et al. 2017) distributed in Central and Southwest Asia is an endangered subspecies in need of immediate conservation attention (Stein et al. 2020). To assess its status, this vast area was divided into different subregions based on biogeographic characteristics (e.g., mountain ranges as the main leopard habitat) as well as socio-political elements (e.g., regional collaborations). Here we report on the western range, defined as eastern and southern Turkey, the entire range in Iraq, and western, central and southern Iran. This range is among the largest and most important areas for the survival of this subspecies (Sanei et al. 2016) and is mainly characterised by the oak woodlands and semi-arid steppes of the Zagros Mts., spreading from southern Turkey and northern Iraq to western and southern Iran. Additional important habitats of the species are isolated arid mountain ranges in central and south-eastern Iran with possible connections to subpopulations in Pakistan.

This region has a long history of human habitation and agriculture, which widely overlaps with leopard habitat, and occasionally causes conflict between humans and the leopards over space and resource use (Naderi et al. 2018; Parchizadeh and Belant 2021). The region has also experienced several socio-economic and political shocks in recent decades, including the Iran-Iraq war (1980–88) and sporadic armed conflicts in border areas, which may have affected the species survival and the availability of conservation support (Avgan et al. 2016). Given this situation, a better understanding of the status of the species in this range is needed for better identification of knowledge gaps and conservation priorities. To our knowledge, this report is one of the first regional efforts to shed light on the status and distribution of the Persian leopard in its western range. By compiling information on different aspects of leopard ecology and threats to its survival, we hope to create a foundation for future conservation efforts.

Table 1. The C1 (verified), C2 (confirmed) and C3 (unconfirmed) occurrence points, according to the SCALP criteria, of the Persian leopard in its western range.

Country	C1	C2	C3
Iran	215	105	55
Iraq	29	2	33
Turkey	0	0	0
Total	**242**	**107**	**88**

Methods

We strived to obtain all available published and unpublished reports, peer-reviewed publications and grey literature as well as our own sightings (e.g., camera trapping surveys) on the Persian leopard from this region to compile a dataset on occurrences from the year 2000 onwards. This year has been chosen by the IUCN SSC Cat Specialist Group to assign the 'contemporary/current' status of the species. We classified the occurrences into three levels of reliability, namely: C1 (i.e., verified and unchallenged observations such as georeferenced and dated photos or dead animals), C2 (i.e., confirmed observations such as verified observations of livestock kills or leopard signs by experts) and C3 (i.e., unconfirmed observations by non-experts or those that cannot be verified) adopting the Status and Conservation of the Alpine Lynx Population SCALP criteria (Molinari-Jobin et al. 2012). We delineated Persian leopard distribution based on these occurrence points and the expertise within our team. We classified the distribution into four levels, namely: 'Extant' (i.e., where the species is very likely to occur characterised mainly by C1 and C2 data and available habitat), 'Possibly Extant' (i.e., where the species may occur characterised mainly by C3 data and expert opinion or areas where the species may occur based on habitat characteristics but there is a lack of information or the area has not been surveyed), 'Possibly Extinct' (i.e., areas where the species is likely to be extinct), and 'Extinct' (areas where the species is thought to be extirpated). Furthermore, we cross-checked the resulted distribution with the IUCN range map of the species (Stein et al. 2020) and the Mammals Atlas of Iran maps (Karami et al. 2016), and modified our delineations where necessary. We extracted other information on leopard abundance, density, diet, and threats based on available literature as well as the expert knowledge and field observations by our team.

Distribution and abundance

Overall, we gathered 561 occurrences from across this range. After filtering for repeated or unreliable datapoints or those without accurate geographical information, we identified presence points in three reliability levels (C1 = 243, C2 = 107, C3 = 88; Table 1, Fig. 1). Around 14% (n = 62) of the datapoints were from Iraq and the remaining (n = 376) were from Iran. We were not able to receive any datapoints from Turkey. Delineation of the leopard distribution in this range resulted in around 153,362 km² of 'extant' habitat and in ca. 70,525 km² the species is 'possibly extant'. We were not able to reach any regional estimates for the Persian leopard abundance. However, in a number of sites in Iran the density of the species has been estimated using camera traps (see below). Similarly, reaching an overall trend in the species population was impossible given the scarcity of data. However, the intensity of human-wildlife conflict and associated leopard mortalities (see below) is concerning and may lead to decreasing population of this species.

Iran

The country holds >75% of the distribution of *P. p. saxicolor* (Jacobson et al. 2016). The area of occupancy (AOO) and the extent of occurrence (EOO) of the species in entire Iran based on 485 data points were estimated at around 6,050 and 1,573,343 km², respectively (Yusefi et al. 2019). For the western range, we assessed the status of Persian leopard in the provinces of Bushehr, Chahar-Mahal & Bakhtiari, Fars, Hamedan, Hormozgan, Ilam, Isfahan, Kerman, Kermanshah, Khuzestan, Kohgiluyeh & Boyer-Ahmad, Kurdistan, Lorestan, Markazi, Qom, Sistan & Baluchistan, and Yazd. Apart from Hamedan and Qom, we obtained information on the distribution of the leopard in all the remaining provinces. However, in a number of these provinces (e.g., Bushehr, Markazi) leopard records were extremely rare (Abdoli et al. 2008). Moreover, in a number of provinces in central (e.g., Mehriz County in Yazd Province; T. Ghadirian, unpublished report 2016) and western (e.g., Kermanshah Province, M.R. Ashrafzadeh, unpublished report 2019) parts of the country, the landscape is naturally highly fragmented (i.e., sporadic mountains surrounded by non-habitat deserts) and limited information on the presence of Persian leopard exists (Kaboodvandpour et al. 2021). We are aware of only one national-level population assessment for Iran. A previous guesstimate puts leopard abundance for the entire country at between 550–850 individuals (density = 0.06–0.1 leopard/100 km²), roughly corresponding to 200–320 leopards in our study area (Kiabi et al. 2002). However, validation of some of the site-specific guesstimates using robust population estimation methods showed marked discrepancies. For example, Kiabi et al. (2002) guesstimated 15–20 individuals in Bamu National Park but camera trapping surveys revealed the presence of between 5–11 individuals in this area (Ghoddousi et al. 2010, Pars Wildlife Guardians Foundation, unpublished report 2016). Conversely, 5–10 individuals were guesstimated in Dena Protected Area (Kiabi et al. 2002) but 18 individuals were identified through a multi-year camera trapping survey in this area (A. Shafaeipour, unpublished report 2020).

Within the western range, the species has been comparatively more studied in Bamu and Bakhtegan national parks (Fars Province), Bafq Protected Area (Yazd), Dena Protected Area (Kohgiluyeh & Boyer-Ahmad), and unprotected areas in eastern Hormozgan Province. The leopard density in most of these studies was proven to be low and abundance was rarely above ten adult individuals (apart from Dena Protected Area and eastern Hormozgan; see below). In Bamu National Park, 1,012 trap-nights of camera trapping led to the identification of six individuals (two males and four females) and using the capture-recapture methodology the density was estimated at 1.87 leopard/100 km² in 2008 (Ghoddousi et al. 2010). Follow-up camera trapping efforts in this area resulted in the identification of five individuals in 2019 and seven individuals in 2021 (Pars Wildlife Guardians Foundation, unpublished report 2021). Similarly, 6,724 trap-nights of camera trapping effort in Bafq Protected Area resulted in the identification of eight (in 2012) and five (in 2016) individuals, and using spatial capture-recapture methodology the density was estimated at 1.6 leopard/100 km² for 2012 and 1.0 leopard/100 km² in 2016 (Farhadinia et al. 2021). In Bakhtegan National Park, camera trapping led to the identification of six adult individuals (Pars Wildlife Guardians Foundation, unpublished report 2019). A camera trapping study with 5,311 trap-nights targeted at carnivores of the Mehriz County, Yazd Province (encompassing one protected area and two private conservancies) identified only a single male leopard (T. Ghadirian, unpublished report 2016). A camera trapping survey over three years period resulted in the identification of 18 leopards in the Dena Protected Area (A. Shafaeipour, unpublished report 2020). Camera trapping survey in eastern Hormozgan Province resulted in the identification of four individuals in the Zendan Mt. and 18 individuals in the Hashtbandi area between 2015–2019 (M. Arianejad, unpublished data 2016). However, at least three individuals of the latter subpopulation are known to be killed due to human-leopard conflict. A more

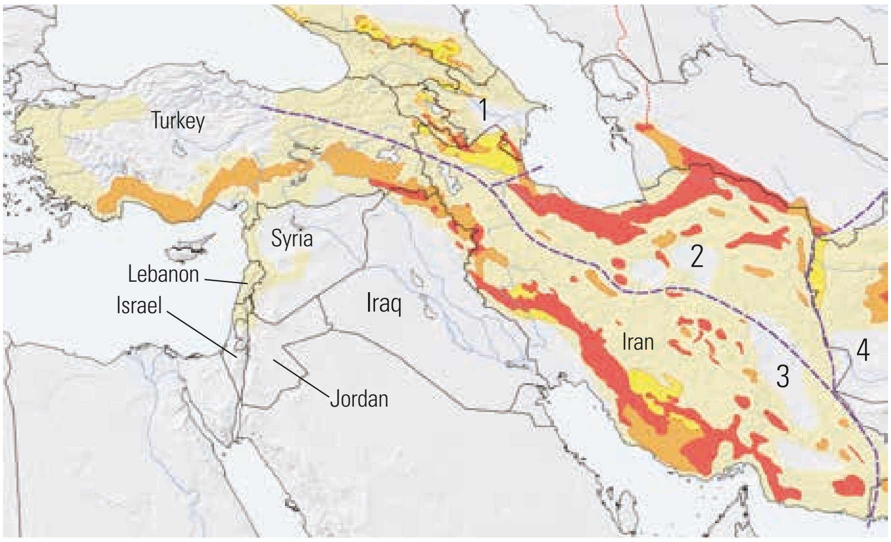

Fig. 1. Distribution of Persian leopard in its western range (3). Red = extant, orange = possibly extant, dark yellow = possibly extinct, light yellow = extinct, violet lines = regional division. 1 = Caucasus Ecoregion, 2 = Alborz-Kopetdag, 3 = Zagros range, and 4 = eastern range. Map courtesy to Peter Gerngross, based on Ghoddousi et al. (2022).

recent assessment using a systematic camera trapping design and over a shorter period in the Hashtbandi area in 2020 resulted in the identification of only 11 individuals (M. Arianejad, unpublished data 2020). Unfortunately, due to the lack of long-term monitoring data in protected areas, the trend in the population of the species in this range is largely unknown. While a few studies (Farhadinia et al. 2021, Ghoddousi et al. 2010, Pars Wildlife Guardians Foundation, unpublished report 2016) may suggest a rather stable population trend inside protected areas, lethal control in response to livestock depredation severely affects the survival of the species outside protected areas (M. Arianejad, unpublished data 2020).

Iraq

The knowledge on the distribution of the leopard in Iraq is still incomplete (Avgan et al. 2016). However, a few studies (Börmann 2019, Raza et al. 2012) have resulted in a better understanding of the species distribution. The species persists almost entirely in the Kurdistan region and specifically in Qara Dagh, Khoshk, and Bamo Mts (Ahmed and Majeed 2020). Additionally, there are sporadic reports from Diyala, Sulaymaniyah, Erbil and Halabja provinces (see Avgan et al. 2016 for a review). There has been no research in the leopard's northernmost range in Iraq. However, there have been occasional unconfirmed reports of leopard sightings from various sites in the Duhok Governorate until December 2021 when a male leopard was captured after a local from Zirize village of Zakho set a gin trap for an unknown carnivore that was attacking his livestock. The leopard was captured alive but it had lost one of its hind legs, and it is now being kept at the Duhok Zoo until the process of sending it outside of the country to a facility for the Persian leopard breeding programme is completed. Since 2011, the camera trapping survey by Nature Iraq has led to the identification of seven individuals and other camera trapping efforts by local people have resulted in the identification of four additional leopards, which will be the basis for a population estimation study (H. Raza, unpublished data 2021). Based on these records and a questionnaire survey, recent research by Börmann (2019) using occupancy modelling showed ca. 1,152 km² of suitable leopard habitat in Qara Dagh and Darbandikhan regions, and a smaller habitat (ca. 256 km²) in the Halabja region. Reports of leopard breeding in Iraq are scarce (Avgan et al. 2016), however, one female was killed and its stuffed skin was later discover-ed (Avgan et al. 2018). Addition-ally, unconfirmed observations of females with cubs exist, indicating the need for further investigation.

Fig. 2. Dena Protected Area, Iran (top) and Qara Dagh proposed protected area, Iraq (below) are among the main habitats of the Persian leopard in the Zagros Mountains (Photos A. Ghoddousi (top), H. Raza (bottom)).

Turkey

Leopard reports up to the 1970s were common in Turkey (Karataş et al. 2021). However, in recent years these reports are rather scarce and limited to a few confirmed cases. Importantly, in this assessment, we did not consider western Anatolia (e.g., Taurus Mts.) where the *P. p. tulliana* subspecies was reported and its presence in recent years is highly unknown (Karataş et al. 2021, Spassov et al. 2016). The presence of leopard has been confirmed from Sirnak (2010) and Diyarbakir (2013) provinces in south-eastern Turkey (Avgan et al. 2016). A recent camera-trapping effort of around 32,000 trap-nights from 2018–2019 also revealed the existence of possibly one individual in Mount Cudi in Sirnak Province (Karataş et al. 2021). The last confirmed records from the Caucasus region dates back to the 1970s and recent reports from nearby Eastern Karadeniz Mts. seem questionable due to misidentifications and poor quality of images (Sarı et al. 2020, Spassov et al. 2016). The situation is also highly unknown in south-central parts of Turkey and no recent records exist for the leopard in this region (Karataş et al. 2021).

Habitat and ecology

Leopard is known to be a flexible species in their choice of habitat (Stein et al. 2020). In this region, their habitat spreads across most mountain ranges and forests, avoiding vast plains and deserts (Karami et al. 2016). The majority of the Persian leopard habitat in the western range is located in the Zagros Mts., which is predominantly covered by sparse oak (*Quercus* spp.) forest (Fig. 2). This ecoregion is called 'Zagros Mountain Forest Steppe' and is part of the Irano-Anatolian biodiversity hotspot. The leopard habitat stretches further to the east and contains a number of arid mountain ranges in central and south-eastern Iran. In Iran, the species is present in most rugged mountainous regions where sufficient wild prey exists (predominantly in protected areas; Khosravi et al. 2021). However, not the entire expanse of protected areas could be used by leopards. For example, in Bamu National Park the species occupied only around 56% of the protected area (Ghoddousi et al. 2010). The species can also be found in a wide elevational range. In eastern Hormozgan Province, for example, the Persian leopard habitat is the rugged mountains from 600–2,000 m (M. Arianejad, unpublished data 2021). In Iraq, the species has been recorded from 42 m in Diyala to 2,028 m in Permargoon Mountain (H. Raza unpublished data 2021). In the Bafq Protected Area, a GPS-collared leopard roamed at around 2,000 m elevation (Cheraghi et al. 2019). The Persian leopards are wide-ranging species and therefore, require vast tracts of suitable habitat to have a viable population.

The Persian leopard home range in the Bafq Protected Area was estimated at 408 km² from a telemetry study of a male individual (Cheraghi et al. 2019). The farthest aerial dis-tance between two captures of a male leopard in Mehriz County, Yazd Province was 42 km (T. Ghadirian, unpublished report 2016). Three adult males in Bafq Protected Area were detected in multiple camera traps over 50 km apart (M.S. Farhadinia, unpublished data 2021). A male leopard was identified moving between Bamu and Bakhtegan national park, corresponding to ca. 112 km aerial distance (Pars Wildlife Guardians Founda-tion, unpublished data 2021; Fig. 3). In Bamu National Park, the longest aerial distance between two detections of a single male was around 12 km (Ghoddousi et al. 2010). Leopards are known to use scrapes on the ridgetop trails (ca. 39 cm long) and scratches on trees (ca. 90 cm long) to mark their vast territories (Ghoddousi et al. 2008). When protected and having a sufficient prey base, leopards could live up to around 15 years as observed in Bamu National Park (Ghoddousi et al. 2010, Pars Wildlife Guardians Foundation, unpublished report 2016). Similarly, a male leopard first detected in 2003 as an adult in Bafq Protected Area was still present in the area until 2012–2013, corresponding to an approximate age of 13 years.

Fig. 3. 'Cyrus', the dominant male leopard of the Bamu National Park, Iran camera trapped continuously between 2007 and 2018 (Photo Pars Wildlife Guardians Foundation).

Similar to other parts of its range, *P. p. tulliana* predominantly preys upon wild ungulates such as bezoar goat *Capra aegagrus*, goitered gazelle *Gazella subgutturosa*, mouflon *Ovis gmelini*, roe deer *Capreolus capreolus*, wild boar *Sus scrofa* and urial *Ovis vignei* in this region (Ghoddousi et al. 2016). Smaller prey such as Indian crested porcupine *Hystrix indica* is also recorded as leopard prey (Ghoddousi et al. 2016, Sanei et al. 2016). Bezoar goat is known to be a particularly important prey species (Ebrahimi et al. 2017, Sanei et al. 2016) and it seems to be highly preferred by leopards (Ghoddousi et al. 2017). Livestock (most importantly sheep, goat and cattle but also camel and dog) also constitute a considerable share of the Persian leopard diet (Ghoddousi et al. 2016). Despite the presence of diet studies from other parts of the range, to our knowledge, this issue has not been assessed specifically in the western range. However, unpublished and sporadic reports on leopard predation and diet exist. In Kermanshah Province, a survey among 80 farmers revealed that around 20% experienced depredation of livestock by leopard, corresponding to 76 sheep and goat and four cattle between 2015–2019 (M. R. Ashrafzadeh, unpub. report 2019). In eastern Hormozgan Province, the species mainly survives on livestock and feral animals (e.g., donkeys; M. Arianejad, unpub. data 2021). As a special case, a female leopard and her cubs have been repeatedly recorded entering a Persian fallow deer (*Dama mesopotamica*) enclosure in Arjan & Parishan Protected Area and successfully hunting the species (Fars provincial office of Department of Environment, unpublished report 2021).

A number of other large carnivores share habitat with Persian leopard in its western range, including Asiatic black bear *Ursus thibetanus*, Asiatic cheetah *Acinonyx jubatus venaticus*, brown bear *U. arctos*, caracal *Caracal caracal*, Eurasian lynx *Lynx lynx*, golden jackal *Canis aureus*, grey wolf *C. lupus*, and striped hyaena *Hyaena hyaena*. Apart from a few studies (Cheraghi et al. 2019, Khosravi et al. 2021) on differences in the movement and distribution patterns between Persian leopard and Asiatic cheetah, the trophic and spatial niche competition among these large carnivores is largely unknown and require further research.

Threats

In its western range, the Persian leopard is threatened by a range of different human pressures. Most importantly, precautionary or retaliatory killing by livestock pastoralists poses a major threat to the species (Avgan et al. 2016, Kiabi et al. 2002; Fig. 4). Additionally, prey depletion and road accidents are important threats (Ghoddousi et al. 2017). Although no studies assessed Persian leopard mortality specifically in its western range, a number of studies from entire Iran exist. Around 70% of leopard mortalities recorded in Iran were due to poaching according to Sanei et al. (2016). Parchizadeh & Adibi (2019) also identified around 76% of unnatural mortalities of the leopard to be due to poaching, and the remaining due to road accidents. Naderi et al. (2018) identified 60% of unnatural leopard mortalities due to poaching and 26% due to road accidents. Much of these poaching cases are known to be a response to the actual or perceived risk of livestock depredation by pastoralists using poison, snare or direct shooting (Bleyhl et al. 2021, Memarian et al. 2018). Additionally, rare leopard attacks on humans have been reported across Iran, which could lead to the removal of leopards (Parchizadeh & Belant 2021). Moreover, habitat fragmentation due to human developments in lower elevations is observable in much of this range that threatens the connectivity of Persian leopard subpopulations. This issue is particularly important in central Iran where leopard appears to be locally extinct or occur in extremely low numbers in the naturally fragmented mountain ranges of this region despite the presence of prey species (e.g., protected areas in Isfahan, Markazi and Yazd provinces; T. Ghadirian, unpublished report 2016). Climate change also appears to be a challenge for leopards since the habitat of the species in Iran is predicted to shrink in the next decades (Ebrahimi et al. 2017). Despite the occasional confiscation of leopard body parts or cubs from poachers and in illegal markets in Iran, there is little known on the severity and trend in the illegal trade of this species.

Fig. 4. Lethal control as a precautionary or retaliatory response to livestock depredation is a major threat to the Persian leopard in its western range (Photo M. Arianejad).

Conservation and management

The species has been classified nationally as ‘Endangered’ C2a(i) in Iran based on a preliminary assessment of its conservation status (Yusefi et al. 2019) and is a ‘protected species’ by the Iranian Department of Environment. It is also protected in Turkey since 2003 and since 2010 in Iraq (Avgan et al. 2016). In Iraq, poaching of the leopard has a penalty of one million Iraqi Dinar (~US$686, 2021) and in Iran, this penalty is 1200 million Rial (~US$4300, 2021). Apart from the law enforcement by the Iranian Department of Environment in protected areas, a number of non-governmental organizations (NGOs) conduct research and conservation activities focused on the Persian leopard (e.g., Pars Wildlife Guardians Foundation, Hormuz Wildlife Guardian Foundation). Namely, these NGOs assessed the population of the Persian leopard in Bamu and Bakhtegan national parks, Dena Protected Area, and the landscapes of eastern Hormozgan Province. Moreover, efforts to mitigate human-leopard conflict are underway in a number of these sites, such as vaccination of livestock and distribution of foxlights to install on corral fences (Hormuz Wildlife Guardians Foundation, unpublished report 2021). As another example, conservation activities targeted at the education of local people has been conducted with positive outcomes to reduce human-leopard conflict in Bamu National Park (Tavakkoli Mehr et al. 2011). In Iraq, the Nature Iraq NGO is currently working with the Kurdish government agencies to establish the Qara Dagh Nature Reserve as a protected area dedicated to the protection of the Persian leopard.

Conclusions

The western extent of the Persian leopard is one of the most important areas for the survival of this subspecies. The Zagros Mts. is a large and connected habitat, which act as an important source population for other subpopulations. Therefore, the conservation of the Persian leopard as an emblematic flagship species in this mountain range should be a conservation priority. To achieve this, promoting transboundary conservation efforts, especially to secure movement corridors of the species is of high importance (Bleyhl et al. 2022, Kaboodvandpoor et al. 2021). Moreover, mitigation of the human-leopard conflict in this range would reduce leopard mortality and secure the goodwill of local people to safeguard this endangered species. Importantly, continued support of protected areas and expanding their network (where justified based on available evidence), would allow for the persistence of this species and its prey species. According to our report, the status of the Persian leopard is yet widely unknown in a large proportion of its western range. Therefore, supporting field surveys in Turkey, northern Iraq and south-eastern Iran is necessary despite complications due to security issues and the presence of land mines (Avgan et al. 2016)

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References

Abdoli A., Ghadirian T., Hamidi A. K., Mostafavi H., Moshiri H., Pour’salem S., Ghoddousi A. 2008. First evidence of Persian leopard from Khaeez area, Southern Iran. Cat News 48, 17.

Ahmed S. H. & Majeed S. I. 2020. Monitoring of the wild mammal fauna in Bamo mountain in northern Iraq (Kurdistan) for the first time using camera trap method and raising awareness for ist conservation. Bulletin of the Iraq Natural History Museum 16, 161–172.

Avgan B., Raza H., Barzani M. & Breitenmoser U. 2016. Do recent leopard *Panthera pardus* records from northern Iraq and south-eastern Turkey reveal an unknown population nucleus in the region? Zoology in the Middle East 62, 95–104.

Avgan B., Raza H., Barzani M. & Breitenmoser U. 2018. Correction to: Do recent leopard *Panthera pardus* records from northern Iraq and south-eastern Turkey reveal an unknown population nucleus in the region? Zoology in the Middle East 64, 94–94.

Bleyhl B., Ghoddousi A., Askerov E., Bocedi G., Breitenmoser U., Manvelyan K., ...& Kuemmerle T. 2021. Reducing persecution is more effective for restoring large carnivores than restoring their prey. Ecological Applications 31, e02338.

Börmann A. 2019. Occupancy modeling for mapping the distribution of the Persian leopard and its prey in the northern Zagros Mountains, In Geography Department. Humboldt-University Berlin, Berlin, Germany.44 pp.

Cheraghi F., Delavar M. R., Amiraslani F., Alavipanah K., Gurarie E., Jowkar H., Hunter L., Ostrowski S. & Fagan W. F., 2019. Inter-dependent movements of Asiatic Cheetahs *Acinonyx jubatus venaticus* and a Persian Leopard *Panthera pardus saxicolor* in a desert environment in Iran (Mammalia: Felidae). Zoology in the Middle East 65, 283–292.

Ebrahimi A., Farashi A. & Rashki A. 2017. Habitat suitability of Persian leopard (*Panthera pardus saxicolor*) in Iran in future. Environmental Earth Sciences 76, 697.

Farhadinia M. S., Behnoud P., Hobeali K., Mousavi S. J., Hosseini-Zavarei F., Gholikhani N. Akbari H., Braczkowski A., Eslami M., Moghades P. & Macdonald D. W. 2021. Estimating the density of a small population of leopards (*Panthera pardus*) in central Iran using multi-session photographic-sampling data. Mammalian Biology 101, 363–371.

Ghoddousi A., Hamidi A. K., Ghadirian T., Ashayeri D., Hamzehpour M., Moshiri H., Zohrabi H. & Julayi L. 2008. Territorial marking by the Persian Leopard *(Panthera pardus saxicolor* Pocock, 1927) in Bamu National Park, Iran. Zoology in the Middle East 44, 101–103.

Ghoddousi A., Hamidi A. K., Ghadirian T., Ashayeri D. & Khorozyan I. 2010. The status of the Endangered Persian leopard *Panthera pardus saxicolor* in Bamu National Park, Iran. Oryx 44, 551–557.

Ghoddousi A., Soofi M., Hamidi A. K., Lumetsberger T., Egli L., Khorozyan I., Kiabi B. H., Waltert M. 2016. Assessing the role of livestock in big cat prey choice using spatiotemporal availability patterns. PLoS ONE 11, e0153439.

Ghoddousi A., Soofi M. Hamidi A. K., Lumetsberger T., Egli L., Ashayeri S., Khorozyan I. Kiabi H. B. & Waltert M. 2017. When pork is not on the menu: Assessing trophic competition between large carnivores and poachers. Biological Conservation 209, 223–229.

Jacobson A. P., Gerngross P., Lemeris Jr J. R., Schoonover R. F., Anco C., Breitenmoser-Würsten C. Durant S. M., ...& Dollar L. 2016. Leopard (*Panthera pardus*) status, distribution, and the research efforts across its range. PeerJ 4, e1974.

Kaboodvandpour S., Almasieh K. & Zamani N. 2021. Habitat suitability and connectivity implications for the conservation of the Persian leopard along the Iran–Iraq border. Ecology and Evolution 11, 13464–13474.

Karami M., Ghadirian T. & Faizolahi K. 2016. The Atlas of Mammals of Iran. Jahad Daneshgahi, Kharazmi, Karaj, Iran.

Karataş A., Bulut Ş. & Akbaba B. 2021. Camera trap records confirm the survival of the Leopard (*Panthera pardus L*., 1758) in eastern Turkey (Mammalia: Felidae). Zoology in the Middle East 67, 198–205.

Khosravi R., Hemami M. R., Malakoutikhah S., Ashrafzadeh M. R. & Cushman S. A. 2021. Prey availability modulates predicted range contraction of two large felids in response to changing climate. Biological Conservation 255, 109018.

Kiabi B. H., Dareshouri B. F., Ghaemi R. A. & Jahanshahi M. 2002. Population status of the Persian Leopard (*Panthera pardus saxicolor* Pocock, 1927) in Iran. Zoology in the Middle East 26, 41–47.

Kitchener A. C., Breitenmoser-Würsten C., Eizirik E., Gentry A., Werdelin L., Wilting A., … &Tobe S. S. 2017. A revised taxonomy of the Felidae: The final report of the Cat Classification Task Force of the IUCN Cat Specialist Group. 80 pp.

Memarian I., Ostrowski S., Kordestani H., Khakpour F. & Pouyanshad N. 2018. The illegal use of snares and gin traps threatens endangered leopard in Iran. Cat News 67, 10–14.

Molinari-Jobin A., Wölfl S., Marboutin E., Molinari P., Wölfl M., Kos I., …& Breitenmoser U. 2012. Monitoring the Lynx in the Alps. Hystrix, the Italian Journal of Mammalogy 23, 49–53.

Naderi M., Farashi A. & Erdi M. A. 2018. Persian leopard's (*Panthera pardus saxicolor*) unnatural mortality factors analysis in Iran. PLoS ONE 13, e0195387.

Parchizadeh J. & Adibi M. A. 2019. Distribution and human-caused mortality of Persian leopards *Panthera pardus saxicolor* in Iran, based on unpublished data and Farsi gray literature. Ecology and Evolution 9, 11972–11978.

Parchizadeh J. & Belant J. L. 2021. Human-caused mortality of large carnivores in Iran during 1980–2021. Global Ecology and Conservation 27, e01618.

Raza H., Ahmad S. A., Hassan N. A., Ararat K., Qadir M. & Ali L., 2012. First photographic record of the Persian leopard in Kurdistan, northern Iraq. Cat News 56, 34–35.

Sanei A., Mousavi M., H. Kiabi B., Masoud M. R., Gord Mardi E., Mohamadi H., Shakiba M., Baran Zeh, A., Teimouri M. & Raeesi T. 2016. Status assessment of the Persian leopard in Iran. Cat News Special Issue 10, 43–50.

Sarı A., Gündoğdu E., Başkaya Ş. & Arpacık A. 2020. Habitat preference by the Anatolian leopard (*Panthera pardus tulliana* Valenciennes, 1856) in north-eastern Anatolia, Turkey. Belgian Journal of Zoology 150, 153–168.

Spassov N., Ignatov A. & Acosta-Pankov I. 2016. On the status of the leopard in Turkey, again. Cat News 64, 18–21.

Stein A. B., Athreya V., Gerngross P., Balme G., Henschel P., Karanth U., ...& Ghoddousi A. 2020. *Panthera pardus* (amended version of 2019 assessment), In The IUCN Red List of Threatened Species 2020: e.T15954A163991139. https://dx.doi.org/10.2305/IUCN.UK.2020-1.RLTS.T15954A163991139.en

Tavakkoli Mehr S., Talebi Y., Sedaghati Khayat A., Hamidi A. K., Moshiri H. & Ghoddousi A. 2011. School kid saved a female leopard and her cub. Cat News 55, 35.

Yusefi G. H., Faizolahi K., Darvish J., Safi K. & Brito J. C. 2019. The species diversity, distribu-tion, and conservation status of the terrestrial mammals of Iran. Journal of Mammalogy 100, 55–71.

[1] Geography Department, Humboldt-University Berlin, Berlin, Germany
*<arash.ghoddousi@hu-berlin.de>

[2] Rafsanjan Nature Custodian, Rafsanjan, Iran

[3] Hormuz Wildlife Guardians Foundation, Minab, Iran

[4] Pars Wildlife Guardians Foundation, Shiraz, Iran

[5] Fars provincial office of Iranian Department of Environment, Shiraz, Iran

[6] Iranian Department of Environment, Tehran, Iran

[7] Department of Wildlife, California State Polytechnic University Humboldt, Arcata, United States

[8] Kooch Foundation for Biodiversity Conservation, Tehran, Iran

[9] Nature Iraq, Sulaimani, Kurdistan Region, Iraq

STEPHANE OSTROWSKI[1*], MUHAMMAD KABIR[2], ZALMAI MOHEB[3] MARIYA GRITSINA[4], KHALIL KARIMOV[5], MUHAMMAD SAMAR HUSSAIN KHAN[6], SHARIF UD DIN BALOCH[7], NOOR MOHAMMAD[8], MUHAMMAD AWAIS KHAN[9], JALLALUDDIN NASERI[10], MUHIBULLAH FAZLI[10], RUSTAM MURZAKHANOV[11], NATALYA MARMAZINSKAYA[12], ABDUSALOM NORMATOV[13], ABDUKODIR MASKAEV[14], MIRZO N. MIRZOEV[15], AND ISMOIL KHOLMATOV[16]

Distribution and status of the Persian leopard in the eastern part of its range

The present report uses published and grey literature and expert observations to review the distribution and conservation status of the leopard *Panthera pardus* in Afghanistan, Pakistan, Tajikistan and Uzbekistan. The study confirmed the presence of the species in the central and eastern parts of Afghanistan, in lower Himalayan range and south western borders of Pakistan, and did not identify confirmed contemporary records (>2000) from Tajikistan and Uzbekistan where nowadays the species is believed to be extinct (Tajikistan) or quasi-extinct (Uzbekistan). The present study provides novel information on the species distribution in Pakistan outside the Himalayan range, and confirms its wider distribution in Afghanistan. The leopard population size in the assessed region remains unknown. Poaching has been identified as the one outstanding, most critical threat that significantly affects leopards on a large scale and across all the assessment area. In north Pakistan and east Afghanistan this threat very likely results from the rapid loss of its preferred forest habitat and primary natural prey-base. Infrastructural development such as fences along the international Pakistan-Afghanistan border presumably contribute at further fragmenting the leopard habitat and isolate the species in more or less disjunct sub-populations vulnerable to depleted genetic variation and chronic stress. While across the region science and awareness are increasingly supported by proactive and alerting conservationists, the implementation of active and effective conservation measures remains vastly underdeveloped and is complicated by regional political instabilities, such as in Afghanistan, where the recent change in governing leadership might require new approaches to support wildlife conservation.

In the present report, the eastern part of the Persian leopard distribution range is the Asian region extending from Afghanistan in the west to Pakistan in the east and including also Tajikistan and Uzbekistan. Recent information on the distribution, ecology and conservation status of the leopard in the region is scarce outside Pakistan. This is due in part to the region remoteness and limited national investments in wildlife studies, but also in Afghanistan to a lack of detection efforts because of decades of political unrest or armed conflicts (e.g., Smallwood et al. 2011, Gaynor et al. 2016). It has been presumed that the leopard distribution range in the assessment area, as in most of Asia, is fragmented and that populations are declining (Jacobson et al. 2016). At the 13th Conference of Parties to the Convention of Migratory Species CMS in February 2020 the Range States have agreed to include the Persian leopard under the Central Asian Mammals Initiative CAMI, which coordinates conservation activities, cross-border cooperation and efforts to address major threats to a selection of focal species and landscapes in Central Asia. In the present chapter, a broad representation of leopard specialists have evaluated the recent information on the geographic distribution and habitat, prey and threats of Persian leopard in the eastern part of its distribution range and have created a foundation for the future development of an action plan piloted by the CMS and the International Union for the Conservation of Nature IUCN.

Methods

We used multiple data sources to consolidate information on the leopard in Afghanistan, Pakistan, Tajikistan and Uzbekistan. The assessment used a standardised questionnaire developed by the IUCN SSC Cat Specialist Group CSG and completed by co-authors based on original data published in peer-reviewed, grey literature and unpublished information collected from reliable sources and often released with photographs on social media networks. To characterise leopard habitats, feeding habits, threats and national conservation statuses we reviewed about 40 contemporary and old publications in English and Russian. The present assessment which is to guide a conservation action plan focuses only at "contemporary" records (>2000). Leopard records were categorised according to their robustness based on Status and Conservation of the Alpine Lynx Population (SCALP) criteria: C1 ("Hard facts", verified and unchallenged observations), C2 ("confirmed observations", e.g. verified reports by experts/trained staff"), or C3 ("unconfirmed observations"), adapted from Molinary-Jobin et al. (2012). To produce the regional distribution map, we overlayed the C1, C2 and C3 georeferenced records with polygon shapes according to the IUCN Red List distribution categories: Extant (the species is known to occur), Possibly Extant (the species may possibly occur or likely occurs but the the area could not be surveyed, such as in Afghanistan where, for security reasons, vast areas have not been surveyed since 2000), Possibly Extinct (the species is likely to be extinct in the area), and Extinct (the species is thought to be extirpated in the area). In Pakistan Extant and Possibly Extant polygons were drawn based on presence evidence, published peer-reviewed information and habitat suitability. In Afghanistan where most verified records (C1) could not be more precisely georeferenced than the district level (i.e., first territorial sub-categorization within the administrative province), the district polygons were overlaid by a distributional gap analysis geographic model produced by the Wildlife Conservation Society WCS in 2009 that delineated higher and lower priority areas of interest as suitable habitat for the leopard (Kanderian et al. 2009, Fig. 1). Final Extant polygons corresponded to suitable habitat areas within the districts with C1 and C2 records. Possibly Extant polygons were drawn manually based on the possibility of leopard presence in these areas. Areas along Iranian and Turkmen international borders were considered as Possibly Extinct for resident leopard population. In Uzbekistan areas encompassing C3 records were categorised as Possibly Extinct.

Taxonomical remarks

The revised taxonomy of the Felidae carried out by the Cat Classification Task Force of the CSG proposed to include *ciscaucasia* and *saxicolor* subspecies under *Panthera pardus tulliana* (Valenciennes, 1856) as the prior sy-

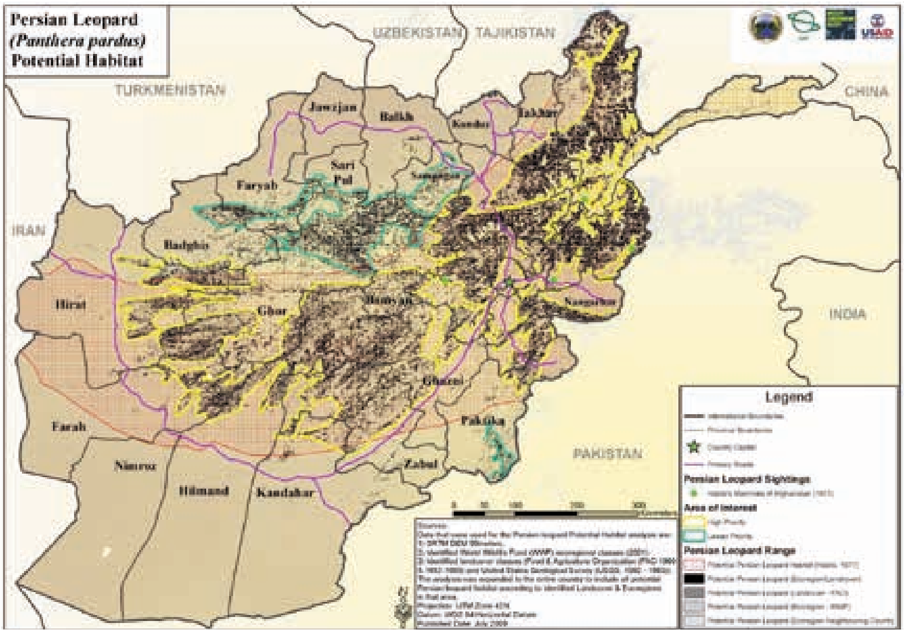

Fig. 1. Persian leopard potential habitat across Afghanistan, with areas of interest (high in yellow and lesser in green) displayed based on a preliminary gap analysis modelling carried out by Kanderian et al. (2009).

nonym, with a distribution extending from Turkey in the west to Pakistan to the east (Kitchener et al. 2017). This subspecies (known as the Persian leopard) is distinct from *Panthera pardus fusca* (Meyer, 1794) distributed across the Indian subcontinent, Burma and western China. While the present study confirms the presence of the leopard *Panthera pardus* in Afghanistan and Pakistan, there remain uncertainties on the taxonomy of leopards in Pakistan, a contact zone for the subspecies *P. p. tulliana* and *P. p. fusca* (Jacobson et al. 2016). Based on a very limited number of samples (n=2), the genetic information retrieved from leopards in Balochistan (Baluchistan), southwest Pakistan, suggests that this subpopulation is closely related to *P. p. tulliana* (Uphrykina et al. 2001, Jacobson et al. 2016, Asad et al. 2019a). However, in the north Indus area the hypothesis that the Indus River separates both species (Khorozyan et al. 2006, Jacobson et al. 2016) has recently been weakened by a study that showed the presence of both subspecies east of the Indus where only *P. p. fusca* was assumed to be present (Asad et al. 2019a, Fig. 2). The geographical extent of this overlap will have to wait for further genetic investigations to achieve clarity, but it is possible that *P. p. tulliana* and *P. p. fusca* haplotypes extend more to the east and west, respectively, than anticipated. Northern Pakistan appears therefore as an area of potential high gene flow between these two subspecies (or two subpopulations) assuming no mating restrictions exist (Asad et al. 2019a). However, the still imperfect understanding of subspecies and subpopulation situations in Pakistan should not shadow the fact that leopards, regardless of their genetic profiles are all Critically Endangered in Pakistan (Sheikh & Molur 2004) and remain in great need of conservation. In the course of this regional assessment, we have therefore incorporated all recent leopard records from Pakistan regardless of their possible affiliation to two different subspecies.

Distribution and habitat

We gathered a total of 182 locality records in the current assessment out of which 132 and 50 were points and polygon data, respectively. We could confirm 156 as C1, 6 as C2 and 20 as C3. Pakistan is undoubtedly the stronghold of the species in the region with 159 location points. Uzbekistan provided 13 C3 location records, Afghanistan 10 C1, C2, and C3 location points, and Tajikistan nil (Table 1). In Pakistan data retrieval varied according to the geography and time. Eighty seven percent of C1 and C2 locations with known dates in Pakistan referred to the period 2019–2021, suggesting a collection bias towards most recent records, probably as a result of more readily accessible information to assessors and perhaps also increased detection/reporting. It is also interesting to note that the majority (82.4%) of location data were collected from the north Indus/Himalayan region encompassing Azad Jammu and Kashmir (87), Khyber Pakhtunkhwa (35), Islamabad Capital Territory (8) and Gilgit Baltistan (1). In contrast only 17.6% of location data came from the rest of the country in Balochistan (20), Sindh (6), and Punjab (2). Without doubt these geographical differences highlight a far greater detection and reporting effort in the Himalayan landscape of north Pakistan than in the rest of the country and possibly also a higher leopard abundance in this area. Because of the known scarcity of data from the south of the country, assessors have made great efforts at retrieving information from this area. As a result, the dataset for the south of Pakistan, presumably referring to *P. p. tulliana* only (see taxonomical note), is probably the most exhaustive in recent years, whereas admittedly data collection from the north has been less exhaustive than anticipated. Yet, because of the relatively good geographical coverage of location reports in the north, it is unlikely that missed information would have changed the proposed final distribution map significantly. In contrast, far fewer location data were collected from Afghanistan and all but one (i.e., Moheb and Bradfield 2014) resulted from a passive, hence presumably more random-ised, information collection process essent-ially vectored by social media (6/7 of reported C1 records). The geographical distribution of leopards in this country is therefore far less detailed and extensive than in Pakistan but presumably less biased towards a specific area, assuming a similar access to social media communication across the country. No confirmed data locations were retrieved from Tajikistan and Uzbekistan.

Afghanistan

The distribution of the leopard in Afghanistan is imprecisely known. Habibi (2003) citing mostly Hassinger (1973) and adding information he collected prior to the Soviet invasion in 1979, reported that the species occurred in all of the major dry mountain ranges in Afghanistan, including the Hindu Kush, Koh-e

Baba, Koh-e Paghman and Safed Koh ranges of the central highlands, the Wakhan District in Badakhshan Province and also in the lowland riparian forests of Darqad area in Takhar Province. Using collated habitat descriptions, important location data from field surveys or community questionnaires, two forms of land classification system, and a number of environmental refining factors, WCS conducted in 2009 a distributional gap analysis modelling for the government of Afghanistan that allowed to delineate higher and lower priority areas of interest as suitable habitat for the leopard (Kanderian et al. 2009, see also methods). Unfortunately, the chronic insecurity that prevailed for the following 13 years in many parts of the country hindered the extend and comprehensiveness of zoological investigations that could be safely undertaken to ground-truth the proposed distribution model. However, the contemporary verified and confirmed records (C1 and C2) have so far not contradicted the gap analysis model, and support that the central part of the Hindu Kush Mountain range and its offshoots to the east, are two main strongholds of the species in Afghanistan (Fig. 2). It includes monsoonal western Himalayan forests in the province of Nuristan (Karlstetter 2008), dry steppe and rocky mountainous outcrops in Bamyan Plateau protected area, Bamyan Province (Moheb & Bradfield 2014), Farah (2016), Daykundi (2018), Ghor and Laghman (2021), and dry open woodlands in broken hilly areas of Nangarhar (2020) provinces. Although photographic evidence and DNA barcoding failed to confirm the presence of the Persian leopard and snow leopard *Panthera uncia* in Nuristan (Stevens et al. 2011), the leopard species was among those reported as most often sighted by local residents (73%; Karlstetter 2008), and the photograph of a specimen recently killed near Sar-e Pul Village, Wama District, was released on social media in late February 2022 (Z. Moheb, pers. comm.). In contrast, because few residents (<15%) reported the presence of the leopard, and there is possibility of confusion with the snow leopard, its presence in the dry mountains of Darwaz District in north-east Afghanistan remains questionable (Moheb & Mostafawi 2013). Based on the confirmed presence of leopard in immediately adjacent locations of Pakistan, the assessment has delineated 'Possibly Extant' areas along the international border with Pakistan between latitudes N 30°56' and N 33°49' and in the northwestern part of the country in Herat Province, the area along the international borders with Iran and Turkmenistan does not seem to present any longer suitable habitat (Kanderian et al. 2009, Fig.1), and resident leopards have been considered Extinct in this area. The vast Possibly Extant area in the central Hindu Kush encompasses several Extant polygons and overlaps to a great extent suitable habitat area proposed by Kanderian et al. (2009). Finally, in Wakhan District, where high altitude dry and cold habitat prevails, the WCS has deployed camera traps in a variety of habitats and altitudes between 2011 and 2020, but to no avail for Persian leopard despite more than 7,000 wildlife capture events, including numerous snow leopard captures (S. Ostrowski pers. comm.), supporting that the Persian leopard is currently absent from this area. Records gathered during the last decade, confirm that in Afghanistan the leopard is present in a range of forested to open mountain habitats, including in areas of the central Hindu Kush Mountain range where its occurrence had never been confirmed in the past. However, because of the great variance in detection efforts according to geographical areas and security conditions, our understanding of the species distribution in Afghanistan remains very patchy, as reflected in the proposed distribution map (Fig. 2).

Pakistan

Pakistan provided the largest number of verified records of leopard in the assessed area, but the species current distribution still remains partially understood owing to varying detection efforts. Based on the global trend affecting leopard populations in Asia, the leopard population in Pakistan is likely to be fragmented and possibly with depleted genetic variation (Asad et al. 2019a). In this country, leopards were once widely distributed across the country in a variety of habitats and regions in Azad Jammu and Kashmir AJK, Balochistan, Khyber Pakhtunkhwa KP (before known as North-West Frontier), Punjab, Sindh (Roberts 1997). Nowadays the species seems to be more sparsely distributed across the country. Recently AJK and KP provinces, where *P. p. tulliana* and *P. p. fusca* intermingle in distribution (Asad et al. 2019a), have reported the highest number of contemporary records in particular from the Himalayas, Hindu Raj mountains and Hindu Kush mountains. The species occurs in the lower arid hilly areas to the Himalayan monsoonal forest areas at high altitude, and in the fragmented hilly parts all over Swat, Waziristan, Galliat, Kohistan, Abbottabad and Kaghan valley (Kabir et al. 2013). The species is also found in forested hilly areas of Abbottabad, Mansehra, Shangla, Battagram, Haripur, Kohat, Kurram, Orakzai Swat, Kohistan, and Upper Dir. In 2017 WWF-Pakistan photo-captured a leopard in a typical snow leopard habitat in Chitral Gol National Park, KP. In AJK leopards are found in all hilly and forested areas in districts of Kotli, Mirpur, Bhimber, Muzaffarabad, Neelum, Hattian Bala, Haveli, Bagh, Sudhanoti and Poonch. The species has also been reported by a joint study of the Snow Leopard Foundation (SLF) and Islamabad Wildlife Management Board in Margalla Hills National Park in Islamabad Capital Territory, in the foothills of the Himalayan range. In 2021 during a camera trapping study of northern red muntjac *Muntiacus vaginalis* in the area, leopards were photographed at eight out of 19 different camera trap locations (Muhammad Kabir/Wildlife Ecology Lab/ UOH, pers. comm.). Noticeably, in AJK leopards are frequently encountered in areas relatively distant from their natural habitats, particularly in agriculture lands where they rest during day to enter rural semi-urbanised areas at night, and prey on livestock and dogs (M. Kabir pers. comm.).

In Gilgit Baltistan (northernmost part of Pakistan) there are unverified reports of leopard presence near Chilas in Diamer District. In 2018, a camera trapping study conducted by SLF confirmed the presence of a leopard in Passu Valley at an elevation of 3,000–3,300 m. Both common and snow

Table 1. Number of contemporary (>2000), C1 ("verified"), C2 ("confirmed") and C3 ("unconfirmed") occurrence records of the leopard (*Panthera pardus*) compiled in this study.

	Point locations			Polygon locations		
Country	**C1**	**C2**	**C3**	**C1**	**C2**	**C3**
Afghanistan	1	0	1	6	1	1
Pakistan	127	3	0	22	2	5
Tajikistan	0	0	0	0	0	0
Uzbekistan	0	0	0	0	0	13
Total	**128**	**3**	**1**	**28**	**3**	**19**

leopard were photo-captured at this station. The presence of the common leopard in the snow leopard habitat in Chitral Gol National Park in 2017 and Passu Valley in 2018 suggests a possible expansion of the former species to higher, cooler elevations. In Punjab, leopards are still found in Murree hills, Kotli Sattian, Kahuta area of district Rawalpindi and possible Kala Chita hills. Its survival in the salt range in Punjab is not clear, though it is claimed to still be present in small numbers. Leopards are less recorded from elsewhere in Pakistan although this could result from lower detection efforts. We have gathered patchily distributed contemporary records of leopards from broken and dry hilly mountainous areas of Balochistan (Fig. 2) and Sind, and forested hills in Punjab. The leopard is found in the Kirthar Mountain Range of Sind and the Toba Kakar, the Makran and the Suleiman ranges of Balochistan. A recently photographed specimen in Hazarganji-Chiltan National Park by Balochistan Wildlife Department, in the Sulaiman mountain range suggests that the species uses a desertic habitat with localised dry and scattered woodlands in this remote area. Leopards in Pakistan seem to adjust fairly efficiently to a wide range of habitats from lowland tropical humid forests to deserts and dry steppes, scrub, to mid and high elevation forests up to the tree limits (Shehzad et al. 2015). The protected areas in Pakistan with authenticated records of leopard include Margalla Hills, Ayubia, Murree-Kotli Sattian-Kahuta, Ayubia, Machiara, Pir Lasorsa, Tolipir, Mahasheer, Ghamot, Musk deer, Deva vatal, Hazarganji-Chiltan and Chitral Gol national parks.

Tajikistan

Verified (C1), Confirmed (C2) and unconfirmed (C3) contemporary data (>2000) on the species were not recorded in Tajikistan, and the species, as a functional ecological entity, is probably extinct in this country. Recent records in Babatag, a mid-mountain range consisting primarily of loess hills and rugged dry ravines in Uzbekistan, bordering Tajikistan to the southwest, are unconfirmed. On the Tajik side the extreme scarcity of water for most of the year combined to the lack of claims of livestock loss to leopard predation despite large flocks pasturing the area over winters, and the declining number of large wild prey species (i.e., urial *Ovis vignei*, wild boar *Sus scrofa* and possibly goitered gazelle *Gazella subgutturosa*) advocate for the species no longer residing in this area.

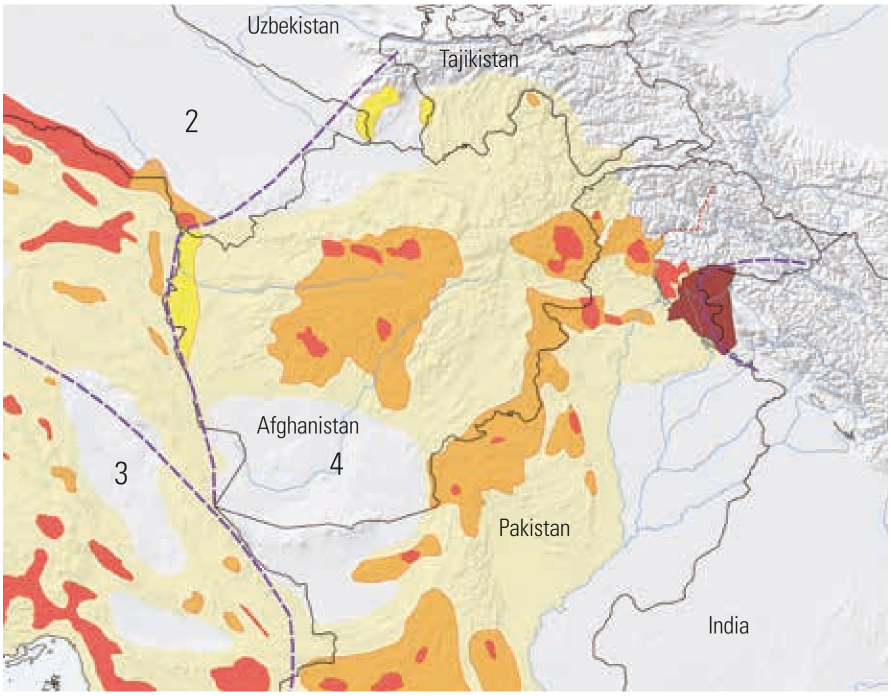

Fig. 2. Geographic distribution of the leopard (*Panthera pardus*) in Afghanistan, Pakistan, Tajikistan and Uzbekistan (4) mapped according to contemporary (>2000) occurrence records collated in this study. Red = extant, orange = possibly extant, dark yellow = possibly extinct, light yellow = extinct, black shaded red area = overlapping Extant area of *P. p. fusca* and *P. p. tulliana*, violet lines = regional division. 2 = Alborz-Kopetdag, 3 = Zagros range, and 4 = eastern range. Map courtesy to Peter Gerngross, based on Ostrowski et al. (2022).

Uzbekistan

Assessors did not recover verified and confirmed (C1, C2) contemporary data (>2000) on the species in Uzbekistan. All contemporary records were unconfirmed (C3) and originated from three mid-mountains ranges; Babatag, and the complex composed of Kugitang and Boysun, in the far southeastern part of Uzbekistan bordering Afghanistan, Tajikistan, and Turkmenistan (Marmazinskaya 2016, Marmazinskaya and Abdunazarov 2019). The reliability of the record from Boysun is questionable due to possible confusion with the snow leopard. The habitat is composed of deep ravines and rocks with bare vegetation and open woodlands. All these records refer to direct sightings by local people including shepherds and foresters but lack supportive documentation. If any Persian leopards still survive in south-east Uzbekistan, there are to be very few, and in absence of immigration of new specimens the functionality and survival of this population would be in immediate jeopardy.

Prey

Leopards are extremely opportunistic, killing virtually everything easy to capture and available in number in their environment (Hunter 2011). Almost nothing is known about the leopard's diet in Afghanistan but the species occurs in areas where one or more of the following four species of mountain ungulates occur; Himalayan ibex *Capra sibirica*, wild goat *Capra aegagrus*, urial *Ovis vignei*, and markhor *Capra falconeri*, as well as a variety of small prey species including carnivores and rodents, lagomorphs, birds and reptiles. Recent events of capture and killing of leopards in Afghanistan resulted from them allegedly preying on domestic sheep and goats. Because the eastern part of its Afghan distribution range is ecologically similar to its range in northern Pakistan, particularly in KP, the leopard diet can probably be inferred from extensive studies carried out in Pakistan (Dar et al. 2009, Kabir et al. 2013, Shehzad et al. 2015, Ahmad et al. 2016, Hussain et al. 2019, Khan et al. 2018, Khan et al. 2020, Akrim et al. 2021). All these authors point out that in Pakistan domestic animal species, including cattle, buffalo, sheep, goat, horse, donkey and dog are usually significant part of leopard's diet. Among medium- and small-sized wildlife preyed upon by leopards the most frequently reported in northern Pakistan are Himalayan ibex, wild boar, rhesus monkey *Macaca mulatta*, Himalayan gray langur *Semnopithecus*

Fig. 3. An adult Persian leopard with an amputated left front limb at Kabul Zoo, April 2021. The animal was snared with a gin trap by villagers in Laghman Province, Afghanistan, who alleged that the animal had killed their sheep and goats in March 2021 (Photo WCS/Ali Madad Rajabi).

schistaceus, Himalayan goral *Naemorhedus goral*, northern red muntjac, Kashmir musk deer *Moschus cupreus,* as well as a variety of small carnivores, lagomorphs, rodents and birds. In contrast very little recent information is available on the diet of leopards in Balochistan and Sind. Roberts (1977) reported that wild goat, markhor, urial and porcupine *Hystrix indica*, were amongst favorite wild prey species in these parts of Pakistan and also underlined that leopard in the south and southwest is notorious for killing a variety of livestock as large in size as adult dromedaries.

Threats

The assessment did identify poaching as the one outstanding, most critical threat that significantly affects leopards on a large scale and across all the assessment area. Primary reasons for leopard killing vary, are often multiple and operate in anticipated or opportunistic associations. They include retaliation over livestock predation, intentional killing to sell the skin or body parts, self-defense and probably more frequently than usually reported killing out of fear or pride in the course of an opportunistic encounter. In Afghanistan and Pakistan killing as retaliation to livestock loss seems preponderant, and possibly also in the past in Tajikistan and Uzbekistan as a result of opportunistic encounters with hunters, armed shepherds or border military. In Afghanistan the three most recent (2021 and 2022) confirmed records of leopard presence were linked to a poaching case in Ghor, a foot-snare capture in Laghman (Fig. 3), and a poaching case in Nuristan, in all cases these intentional retaliatory actions resulted from the leopard killing sheep and/or goats (Z. Moheb, pers. comm.). In Pakistan destruction of leopards in retaliation of livestock or human predation seems widespread (Dar et al. 2009, Kabir et al. 2013, Akrim et al. 2021; Fig. 4). Lodhi (2007) compiled data from the Wildlife Department of Pakistan since 2000 on human-leopard conflict in and around Ayubia National Park and reported nine human deaths by leopards, 30 leopard killings, and 82 instances of livestock predation. Kabir et al. (2013) reported 301 livestock killed between June 2007 and August 2008 by leopards in and around Machiara National Park and in another study in the same area Dar et al. (2009) found that leopards were responsible for the majority (90.6%) of the 363 livestock killed, mainly goats (57.3%) and sheep (27.8%). In Galliat region including Ayubia National Park, livestock represented the staple of the leopard diet, with a frequency always greater than 80%, goat was not only the most frequently used food item, but it also constituted the large majority of the consumed volume (Khan et al. 2020). Respondents to a questionnaire survey in this area lost 209 domestic animals to leopard attacks, primarily goats (78.5%), followed by dogs (11%; Akrim et al. 2021). Results of these studies and dietary analyses based on fecal investigations support that leopards forage consistently and significantly on domestic animals in several areas of the Himalayan range (Chattha et al. 2015, Shehzad et al. 2015, Akrim et al. 2018). Inevitably such high level of livestock preda-tion generates a great deal of resentment and hostility within affected rural communities although people often recognise the species as protected under national law (Dar et al. 2009). Between 2000 and 2010, Kabir & Waseem (2010) reported six retaliatory killings in Pir Lasora National Park, and Kabir et al. (2013) mentioned four such instances in Machiara National Park between June 2007 and August 2008. In Kashmir four leopards were killed in retaliation by the local community at Ghaziabad, Narakot, Surang and Rangla in 2009–2010 (Bibi et al. 2013), 17 leopards killed between 2000 and 2016 in Pir Lasora National Park (Kabir et al. 2017), on average 2.5 leopards/year in the Abbottabad District alone (Khan et al. 2020), and at least 6 leopards/year at the national level (105 individuals from 1998 to 2015; see Khan et al. 2018). Retaliation to attacks on humans and destruction to collect and sell the high value skin or other body parts are also described by Irshad et al. (2018) and Asad et al. (2019b) in Pakistan, and several surveys carried out in Afghanistan have confirmed that leopard skins are still offered for sell in this country (Mishra & Fitzherbert 2004, Johnson & Wingard 2010), although in fewer numbers than in the past (Shoemaker 1993).

Natural prey depletion is also a main threat to leopards in the studied area presumably at the origin of leopards shifting their diet towards more vulnerable and 'easy' domestic prey. In Asia the historic range of the leopard has decreased by 80% (Jacobson et al. 2016). As for mountain-dwelling ungulates, the populations of Himalayan goral, the Kashmir musk deer and the northern red muntjac have declined or disappeared locally, which has narrowed the prey spectrum for large carnivores in general and more specifically leopards targeting mid-sized prey species (Anwar et al. 2011, Shehzad et al. 2015, Khan et al. 2018). In Uzbekistan overhunting of markhor and urial, two key prey species for leopards, might have been the main driver to the species possible extinction. A main seminal threat to leopards in the Himalayan/Indus range in north Pakistan and in the eastern offshoots for the Hindu Kush in Afghanistan is degradation and loss of forest habitat, which in turn have resulted in wild prey loss and increased conflicts with humans (FAO 2007, Karlstetter 2008, Ripple et al. 2014). Isolation resulting from fragmentation of habitats further threatens leopards in the east part of the eastern range by presumably reducing genetic diversity and increasing deleterious edge effects (O'Brien & Johnson 2005, Balme et al. 2010). Locally, linear infrastructure contributes remarkably to this ongoing fragmentation process, such as along the Afghanistan-Pakistan border, where Pakistan has been erecting a fence since 2017 that renders movements of leopards and prey very difficult. Even so leopards are excellent climbers the new border fence could be a significant barrier to them and prey. It is made of two sets of 4-meter-high chain-link fences topped with razor wire separated by 2-meter space that has been filled with concertina wire coil. Recently Pakistan army has claimed that it completed 90% of fence along Afghan border (Yousaf 2021), though it is not clear which segments of the 2,611 km of the international border with Afghanistan are concerned by this 'closure' operation. Fences along larger areas are widely considered as ecological barriers (Xu et al. 2021) and the fences along the Afghan-Pakistan border could not be an exception.

Finally, the ongoing aridification of the Persian leopard landscape, both due to increasing human footprint and climate change is a significant threat to a species dependent in part of its range on moist ecosystems and in the most arid parts of its distribution on sources of drinking water that become inaccessible because of droughts and human use.

Future research and conservation

Although the Persian leopard is officially protected in the four countries of its eastern range its protection remains scarcely implemented. Significant research attentions have been devoted to the leopard in the north-Indus region of Pakistan (Fig. 5) and, as a result, current status is better understood in this part of the country. Similar efforts in the future should be devoted to other areas of Pakistan and particularly Balochistan and Sind provinces. Continuing research and monitoring of surveyed areas in the north is high priority and should in the future inform through modeling efforts leopard's suitable habitat, distribution and occupancy, and perhaps also abundance trends. While in Pakistan the impetus in science and monitoring is largely positive, and served by a competitive and pro-active community of scientists, the concrete actions at conserving leopards and reducing human-leopard conflicts remain comparatively less developed. There is great need at developing a national conservation action plan for the species and piloting on the ground practical and socially acceptable measures to reduce conflict levels and favor a safer cohabitation with leopards. Such an approach that aims at changing the behaviour of a majority of people will require protracted investments supported by a consistent political will from the government and genuine implementation of existing policies. The situation of the leopard in Afghanistan remains poorly known and fragmentary. In August 2021, Afghanistan witnessed a historical change in its national governance. The situation, that has unfolded at unexpected speed, resulted on 15 August in the fall of the elected government to the benefit of a new regime led by the Taliban. This situation has acted as a brake, hopefully transitorily, on the fledging efforts of the country at protecting wildlife. The new administration will have to enact effectively existing environmental policies, and address in the challenging context of chronic food insecurity and degraded economy, threats on biodiversity and the environment from people using unsustainably natural resources for food or incomes. Ideally a blanket hunting ban, as enacted in the early 2000's, and control over weapons should be called for as beneficial to security and wildlife. Concomitantly the greater engagement of academics and the development of participatory and citizen science approaches to monitor leopard presence and collect, store information on human-leopard conflicts could be explored to the best extent possible. In this country the future adoption of human-leopard conflict resolution practices will likely benefit to some extent from international aid and support.

In Uzbekistan where the leopard is on the brink of extinction, it is urgent to organise a specific and comprehensive field survey, using modern methodology, to clarify the situation of any remaining leopard individual in the country, and whether transboundary movements to Tajikistan and Turkmenistan exist.

Conclusions

The number of leopard records was the highest in Pakistan presumably because detection efforts have been more consistent in space and time. This is mostly because there is increased awareness of the species, most of the country is accessible to a highly capacitated active scientific community, and possibly also because leopards remain relatively abundant close to large urban areas (e.g., Islamabad Capital Territory). In Pakistan the assessment confirmed broadly what has recently been published on the leopard distribution in the north of the country (e.g., Jacob-

Fig. 4. An adult common leopard killed by people in Sudhnoti District, Azad Jammu and Kashmir, Pakistan (left), and another leopard which was roaming free in Samani area, Bhimber District, Azad Jammu and Kashmir, Pakistan, and was killed, for no clear reasons, by a mob from surrounding villages (right; Photo A. Mughal, 2021).

Fig. 5. Camera-trapped leopards in forested areas in Margalla Hills National Park, Islamabad Capital Territory, Pakistan (left) (Photo Islamabad Wildlife Management Board), and in Hindu Raj Mountain range, Khyber Pakhtunkwa, Pakistan (right) (Photo Wildlife Ecology Laboratory, University of Haripur), 2021.

son et al. 2016), and added a rather unique set of contemporary records for the south part of the country, especially in Balochistan. In Afghanistan, although many areas seemingly suitable to leopards have remained unexplored because of poor security condition, recent records mostly vectored through social media have provided unique new locations of leopard presence. The lack of confirmed records from Tajikistan and Uzbekistan despite efforts at documenting any evidence of presence, combined to the occurrence of large numbers of livestock with no reports of possible leopard predation (in Tajikistan) signal a local extinction or quasi-extinction situation of the species. This assessment supports that killing by herders or other armed people is the one outstanding and critical cause of mortality for leopards in the eastern part of its range. Retaliation resulting from livestock destruction seems to be the main driver for leopard killing in the region. Exploitation of the species for its fur and other body parts could also be a significant threat in the region although the nature of this exploitation (organised vs. opportunistic), scale, and trends are poorly understood. The distribution map we proposed for the leopard in the region supports that leopards occur in habitat patches, and the extent to which anthropogenic activities impact the persistence and connectivity of these patches is not known but likely significant, such as in the case of the border fence currently erected by Pakistan along its international border with Afghanistan. Based on this regional evaluation, we suggest that the leopard should be classified as conservation priority species in Pakis-tan and Afghanistan where the situation should be actively monitored including through citizen and participatory science initiatives, and human-wildlife conflict innovative actions implemented. A specific comprehensive field survey in Uzbekistan is urgently needed to appreciate the situation of any remaining resident population in the country

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References

Ahmad S., Hameed S., Ali H., Khan T. U., Mehmood T. & Nawaz M. A. 2016. Carnivores' diversity and conflicts with humans in Musk Deer National Park, Azad Jammu and Kashmir, Pakistan. European Journal of Wildlife Research 62, 565–576.

Akrim F., Mahmood T., Nadeem M. S., Andleeb S. & Qasim S. 2018. spatial distribution and dietary niche breadth of the leopard *Panthera pardus* (Carnivora: Felidae) in the northeastern Himalayan region of Pakistan. Turkish Journal of Zoology 42, 585–595.

Akrim F., Mahmood T., Belant J. L., Nadeem M. S., Qasim S. & Asadi M. A. 2021. Livestock depredations by leopards in Pir Lasura National Park, Pakistan: characteristics, control and costs. Wildlife Biology, https://doi.org/10.2981/wlb.00782

Anwar M. B., Jackson R., Nadeem M. S., Janečka J. E., Hussain S., Beg M. A., Muhammad G. & Qayyum M. 2011. Food habits of the snow leopard *Panthera uncia* (Schreber, 1775) in Baltistan, Northern Pakistan. European Journal of Wildlife Research 57, 1077–1083.

Asad M., Martoni F., Ross J. G., Waseem M., Abbas F. & Paterson A. M. 2019a. Assessing subspecies status of leopards (*Panthera pardus*) of northern Pakistan using mitochondrial DNA. PeerJ 7,e7243.

Asad M., Waseem M., Ross J. G. & Paterson A. M. 2019b. The uncommon leopard: presence, distribution and abundance in Gallies and Murree Forest division, Northern Pakistan. Nature Conservation 37, 53–60.

Balme G. A., Slotow R. & Hunter L. T. B. 2010. Edge effects and the impact of non-protected areas in carnivore conservation: leopards in the Phinda-Mkhuze Complex, South Africa. Animal Conservation 13, 315–323.

Bibi S. S., Minhas R. A., Awan M. S., Ali U. & Dar N. I. 2013. Study of ethni-carnivore relationship in Dhirkot, Azad Jammu and Kashmir (Pakistan). The Journal of Animal and Plant Sciences 23, 854–859.

Chattha S. A., Hussain S. M., Javid A., Abbas M. N., Mahmood S., Barq, M. G. & Hussain M. 2015. Seasonal diet composition of leopard (*Panthera pardus*) in Machiara National Park, Azad Jammu and Kashmir, Pakistan. Pakistan Journal of Zoology 47, 201–207.

Dar N. I., Minhas R. A., Zaman Q. & Linkie M. 2009. Predicting the patterns, perceptions and causes of human-carnivore conflict in and around Machiara National Park, Pakistan. Biological Conservation 142, 2076–2082.

FAO 2007. State of the world's forests. http://www.fao.org/3/a-a0773e.pdf

Gaynor K. M. Fiorella K. J., Gregory G. H., Kurz D. J., Setto K. L., Withey L. S. & Brashares J. S. 2016. War and wildlife linking armed conflict to conservation. Frontiers in Ecology and the Environment 14, 533–542.

Habibi K. 2003. Mammals of Afghanistan: their distribution and status. Zoo Outreach Organization, Coimbatore, India. 168 pp.

Hassinger J. 1973. A survey of the mammals of Afghanistan resulting from the l965 Street Expedition. Fieldiana Zoology 60, 153–154.

Hunter L. 2011. Carnivores of the world. Princeton University Press.

Hussain A., Mahmood T., Akrim F., Andleeb S., Fatima H., Hamid A. & Waseem M. 2019. Depleting wild prey compels common leopard (*Panthera pardus*) to sustain on livestock. Animal Biology 69, 213–230.

Irshad N., Yousaf I., Mahmood T. & Awan M. S. 2018. Occurrence of common leopard (*Panthera pardus*) in Abbaspur area, district Poonch, Azad Jammu and Kashmir. Pakistan Journal of Zoology 50, 1581–1584.

Jacobson A. P., Gerngross P., Lemeris Jr. J. R., Schoonover R. F., Anco C., Breitenmoser-Würsten C. …& Dollar L. 2016. Leopard (*Panthera pardus*) status, distribution, and the research efforts across its range. PeerJ 4, e1974

Johnson M. F. & Wingard J. R. 2010. Wild fauna trade in Afghanistan. Wildlife Conservation Society Unpublished Report. Kabul, Afghanistan.

Kabir M. & Waseem M. 2010. Human-leopard conflict assessment in Pir Lasora national Park, Kotli, Azad Jammu and Kashmir, Pakistan. WWF-Pakistan Unpublished Report, Lahore, Pakistan.

Kabir M., Ghoddousi A. Awan M. S. & Awan M. N. 2013. Assessment of Human-Leopard Conflict in Machiara National Park, Azad Jammu & Kashmir, Pakistan. European Journal of Wildlife Research 60, 291–296.

Kabir M., Waseem M., Ahmad S., Goursi U. H. & Awan M. N. 2017. Livestock depredation by leopard, an alarming intimidation for its conservation in Pir Lasoora National Park Nakial, Azad Jammu and Kashmir. International Journal of Conservation Science 8, 295–302.

Kanderian N., Johnson M., Shank C., Rahmani H. & Sanger R. 2009. The fauna approach to identifying Afghanistan's biodiversity priority zones. Programme of Work for Protected Areas (PoWPA), Technical Report, NEPA/WCS, 76 pp.

Karlstetter M. 2008. Wildlife surveys and wildlife conservation in Nuristan, Afghanistan. WCS unpublished report, 62 pp.

Khan U., Lovaru S., Shah S. A. & Ferretti F. 2018. Predator, prey and humans in a mountainous area: loss of biological diversity leads to trouble. Biodiversity and Conservation 27, 2795–2813.

Khan U., Ferretti F., Ali Shah S. & Lovari S. 2020. A large carnivore among people and livestock: The common leopard. Problematic Wildlife II. Springer.

Khorozyan I., Baryshnikov G. F. & Abramov A. V. 2006. Taxonomic status of the leopard, *Panthera pardus* (Carnivora, Felidae) in the Caucasus and adjacent areas. Russian Journal of Theriology 5, 41–52.

Kitchener A. C., Breitenmoser-Würsten C., Eizirik E., Gentry A., Werdelin L., Wilting A. …& Tobe S. 2017. A revised taxonomy of the Felidae: The final report of the Cat Classification Task Force of the IUCN Cat Specialist Group. Cat News Special Issue 11, 80 pp.

Lodhi A. 2007. Conservation of leopards in Ayubia national Park, Pakistan. MSc thesis. The University of Montana, Missoula, USA.

Marmazinskaya N. V. 2016. Striped hyena, Persian Leopard and Asiatic cheetah in Uzbekistan and neighboring countries, conservation opportunities. In the proceedings "Modern problems of conservation of rare, endangered and poorly studied animals in Uzbekistan". Tashkent. 113–118. (In Russian)

Marmazinskaya N. V. & Abdunazarov B. B. 2019. Persian Leopard. In Red Data Book of the Republic of Uzbekistan. Volume II. Animals. 330–331. (In Russian)

Mishra C. & Fitzherbert A. 2004. War and wildlife: a post-conflict assessment of Afghanistan's Wakhan Corridor. Oryx 38, 102–105.

Moheb Z. & Bradfield D. 2014. Status of the common leopard in Afghanistan. Cat News 61, 15–16.

Moheb Z. & Mostafawi S. N. 2013. Biodiversity reconnaissance survey in Maymai District, Darwaz Region, Badakhshan Province, Afghanistan. WCS unpublished report. Kabul, Afghanistan.

Molinari-Jobin A., Kéry M. Marboutin E., Molinari P., Koren I., Fuxjäger C. …& Breitenmoser U. 2012. Monitoring in the presence of species misidentification: the case of the Eurasian lynx in the Alps. Animal Conservation 15, 266–273.

O'Brien S. J. & Johnson W. E. 2005. Big cat genomics. Annual Review of Genomics and Human Genetics 6, 407–429.

Ripple W. J., Estes J. A., Beschta R. L., Wilmers C. C., Ritchie E., Hebblewithie M. …& Wirsing A. 2014. Status and ecological effects of the world's largest carnivores. Science 343(6167).

Roberts T. J. 1997. The mammals of pakistan (revised ed.) Oxford University Press. Karachi, Pakistan, 525 pp.

Shehzad W., Nawaz M. A., Pompanon F., Coissac E., Riaz T., Shah S. A. & Taberlet P. 2015. Forest without prey: livestock sustain a leopard *Panthera pardus* population in Pakistan. Oryx 49, 248–253.

Sheikh K. M. & Molur S. 2004. Status and red list of Pakistan's mammals based on the Pakistan mammal conservation assessment & management plan. IUCN, Karachi City. 312 pp.

Shoemaker A. 1993. The status of the leopard, *Panthera pardus*, in nature. A country-by-country analysis. Riverbanks Zoological Park, Columbia, South Carolina, USA.

Smallwood P., Shank C., Dehgan A. & Zahler P. 2011. Wildlife conservation… in Afghanistan? Conservation projects multitask in conflict zones, blending development and conservation goals. BioScience 61, 506–511.

Stevens K., Dehgan A., Karlstetter M., Rawan F., Tawhid M. I., Ostrowski S., Ali J. M. & Ali R. 2011. Large mammals surviving conflict in the eastern forests of Afghanistan. Oryx 45, 265–271.

Uphyrkina O., Johnson W. E., Quigley H., Miquelle D., Marke L., Bush M. & O'Brien S. J. 2001. Phylogenetics, genome diversity and origin of modern leopard, *Panthera pardus*. Molecular Ecology 10, 2617–2633.

Yousaf M. 2021. Pakistan army completes 90% of fence along Afghan border. AP News. https://apnews.com/article/pakistan-bd-8165697772792b69d65c8509633cd9 (Accessed 13.01.2022)

Xu W., Dejid N., Herrmann V., Sawyer H. & Middleton A. D. 2021. Barrier Behaviour Analysis (BaBA) reveals extensive effects of fencing on wide-ranging ungulates. Journal of Applied Ecology 58, 690–698.

[1] Wildlife Conservation Society, Bronx, NY, USA
*<sostrowski@wcs.org>

[2] Quaid-i-Azam Universtiy, Islamabad, Pakistan

[3] Wildlife Conservation Society, Kabul, Afghanistan

[4] Institute of Zoology, Tashkent, Uzbekistan

[5] Dushanbe, Tajikistan

[6] Ministry of Climate Change, Islamabad, Pakistan

[7] Conservator of Wildlife Balochistan, Quetta, Pakistan

[8] Forest and Wildlife Department Balochistan, Quetta, Pakistan

[9] Wildlife Department Khyber, Pakhtunkhwa, Peshawar, Pakistan

[10] National Environmental Protection Agency, Kabul, Afghanistan

[11] Succow Foundation, Greifswald, Germany

[12] Zarafshan National Park, Samarkand, Uzbekistan

[13] Research and Development Institute of Forestry, Tashkent, Uzbekistan

[14] Committee of the Environmental Protection under the Government of the Republic of Tajikistan, Dushanbe, Tajikistan

[15] Association of Nature Conservation Organizations of Tajikistan, Ishkashim, Tajikistan

[16] Institute of Zoology, National Academy of Sciences, Dushanbe, Tajikistan

MAHMOOD SOOFI[1,2*], IGOR KHOROZYAN[3] AND BENJAMIN GHASEMI[4]

Coexistence between leopards and local people – challenges and solutions

Human-predator conflict can significantly affect rural livelihoods and the survival of many predator species worldwide. The Persian leopard *Panthera pardus tulliana* is not an exception, and its distribution range has markedly shrunk to a few Middle Eastern and Central Asian countries. Economic growth and various human activities such as livestock husbandry practices are increasingly overlapping with leopard habitats, making human-leopard conflicts inevitable. Such conflicts are particularly common in areas with reduced wild prey availability, which force leopards to prey on domestic animals. As a result, leopards have often been killed in retaliation or as a preventive measure to reduce livestock losses. To ensure the long-term population persistence of leopards, it is crucial to mitigate conflicts by promoting human-leopard coexistence in shared landscapes. In this paper, we describe potential approaches and related case studies where efforts have been made to foster positive interactions between humans and leopards in their range countries. We synthesized published evidence and suggest practical interventions, including: (i) protective collars for livestock, (ii) predator-proof corrals, (iii) deterrents, (iv) financial incentives and compensation programmes, and (v) livestock guarding dogs and herding. We underline that the success of these interventions will require systematic monitoring and evaluation plans allowing the objective assessment of outcomes to facilitate informed and effective management decisions.

Human-wildlife conflicts continue to challenge conservation efforts (Khorozyan et al. 2020) and need to be managed to reduce negative impacts on biodiversity, local livelihoods and human well-being (Redpath et al. 2013). A typical example of human-wildlife conflict is when a species, or a group of species, damages local economic assets such as crops or livestock (Fig. 1), causing anger and fear among affected people, and leading to retaliatory or preventive removal of the animals. Socio-psychological effects of and responses to the conflict may vary greatly among different social groups (local people, NGOs, government, international organisations) because they usually hold different values, and the situation can escalate through rumours, social media, and social networks.

The Persian leopard (*Panthera pardus tulliana*) is a flagship big cat whose distribution has contracted dramatically and is now restricted only to several Middle Eastern and Central Asian countries (Jacobson et al. 2016). A number of key threats continue to contribute to population declines and range contraction, particularly in the Iranian stronghold (Kiabi et al. 2002), as well as in other range countries. These threats include, but are not limited to, wild prey depletion (Ghoddousi et al. 2019, Soofi et al. 2019) and illegal killing of leopards (Parchizadeh & Belant 2021a, Soofi et al. 2022). Persian leopards have been persecuted for multiple reasons, such as social conflicts and financial costs induced by livestock depredation (Khorozyan et al. 2015), in retaliation to and for preventing attacks on humans (Parchizadeh & Belant 2021b), or to make money by trading skins. The amounts of livestock depredation and, correspondingly, the intensity of human-leopard conflict have been worsened by inadequate livestock grazing and handling practices (Ghoddousi et al. 2016, Babrgir et al. 2017, Soofi et al. 2018, 2022).

The availability of wild and domestic prey on which leopards depend for their survival is one of the main factors of this conflict. For example, when wild prey becomes scarce, leopards may switch to domestic species (Fig. 1; Khorozyan et al. 2015, Braczkowski et al. 2018). However, leopard predation on livestock may also exist when wild prey abundance is high because wild prey availability may support larger predator populations and thus increase encounters of predators with livestock (Soofi et al. 2022). Either way, livestock becomes vulnerable to predation by leopards, which ultimately triggers a conflict.

Human-predator interactions can go far beyond the competition for space, food, and human safety (Treves & Karanth 2003) and represent a multifaceted process incorporating different social, psychological, and legal issues (Brouwer 2021, Carter et al. 2021). Clearly, the Persian leopard's charismatic status is insufficient to avert it from the risk of extinction. Laws, regulations, and high financial penalties for violators fail to halt leopard killings across the region since they are rarely enforced (Soofi et al. 2022), and their effectiveness is questionable. Therefore, it is vital to ensure the long-term persistence of the leopard population (Bleyhl et al. 2021) by promoting coexistence with humans in shared landscapes. This is a daunting task as the wide-ranging behaviour of leopards (Farhadinia et al. 2018) coupled with rural development and urbanization lead to an increased risk of encounters between people, grazing livestock and leopards (Soofi et al. 2018, 2022). Reducing all kinds of illegal leopard killings (shooting, poisoning, trapping and vehicle collisions) related to livestock losses

Fig. 1. A female leopard feeding on a cattle carcass in Mazandaran Province, northern Iran (Photo K. Rabie, Mazandaran provincial office of the Department of Environment).

(Babrgir et al. 2017, Soofi et al. 2019) and attacks on humans (Parchizadeh & Belant 2021b, Soofi et al. 2022) is essential to recover the leopard population (Bleyhl et al. 2021). Coexistence between humans and leopards should become a long-term strategy, especially in and around protected areas where leopard densities are usually higher, and land sharing between people and leopards becomes most problematic (Lukarevsky 2003, Soofi et al. 2019, 2022). Conservation programmes for leopard population recoveries should be geared toward preventing the escalation of human-leopard conflicts and developing and applying practical coexistence mechanisms.

Procedures for developing human-leopard coexistence practices are generally lacking across the range of this big cat. Threats and opportunities related to human-leopard coexistence should be clearly identified concerning the financial costs of conservation measures, social acceptance (perceptions, traditions and beliefs), and education and outreach (awareness-raising, capacity building and alternative livelihoods; Carter et al. 2021). Implementa-tion of conflict mitigation and other measures required to promote coexistence should not only be based on the global experience, but also be meticulously considered in terms of their applicability and associated risks in the Middle East and Central Asia.

In this paper, we describe a number of practices and their potential impacts on fostering positive interactions between humans and leopards in shared landscapes of the region. We focus on ways to minimise leopard-caused damage to livestock, which is the main cause of human-leopard conflicts in some parts of the region, including Iran (Memarian et al. 2018, Soofi et al. 2019, 2022), the Talysh Mts. in Azerbaijan (Khorozyan et al. 2022) and northern Afghanistan (Karlstetter 2008). Our aims were to:

1. Introduce practical and socially acceptable measures facilitating human-leopard coexistence;
2. Describe roadmaps that can be embedded within the regional conservation strategy and national action plans related to the resolution of human-leopard conflicts and the establishment of coexistence practices;
3. Suggest insights for a regionally standardised and nationally adapted monitoring programme for collecting, maintaining, reporting, analyzing, and disseminating information on human-leopard conflict resolution practices;
4. Summarise the information on the extent of illegal killings occuring in the region and their impact on the Persian leopard population.

Human-leopard conflict in the range countries

Livestock losses to leopards are likely the main cause of human-leopard conflicts in some parts of the Middle East and Central Asia (Khorozyan et al. 2022, Soofi et al. 2022). Hence, here we synthesize the existing evidence from the literature, case studies of conflicts and their practical solutions in the region. Illegal killings cause a strong adverse effect on smaller leopard populations existing in neighbouring countries, which depend on immigrant leopards from Iran.

For instance, in 2013, a leopard was camera-trapped in Hirkan National Park located in the Talysh Mts. of south-eastern Azerbaijan, but after a year, the same individual was poached by a hunter in Gilan Province of Iran (Maharramova et al. 2018). Such incidents suggest a vital role of protected areas that are adjacent to the borders (e.g., Hirkan National Park in Azerbaijan, Lisar Protected Area and Dorfak no-hunting area in Iran). These areas can bridge the source population in Iran and the recipient populations in the Talysh and other areas of the South Caucasus (Moqanaki et al. 2013, Breitenmoser et al. 2017, Shokri et al. 2020). Consequently, continuing illegal killing of leopards in the source population may hamper the dispersal of individuals from Iran (Breitenmoser et al. 2017, Bleyhl et al. 2021). This highlights the need for international cooperation in the areas such as the Caucasus Ecoregion where transboundary conservation is crucial to leopard conservation (Breitenmoser et al. 2017), including cooperation in mitigating human-leopard conflicts. Illegal killing in retaliation to livestock depredation also occurs in northern Afghanistan, where the Persian leopard is the second most frequently livestock-killing predator (52%), provoking local people to often hunt leopards and sell the skins on the black market (Karlstetter 2008). Karlstetter (2008) further reported that leopard attacks on humans were relatively rare, but occurred as a result of precautionary or retaliatory killings.

Drivers of conflict

Socio-ecological factors

In response to losses to leopards, some livestock owners might seek to kill problem predators to retaliate and prevent future depredations (Soofi et al. 2022). A decision "to kill or not to kill" and its follow-up actions depend on the tolerance levels of individual herders (Treves & Bruskotter 2014) and a number of other factors. For example, predators have often been killed in response to livestock predation when solutions such as compensation payments or other interventions are not in place and livestock is the main, or the only, source of income. Farmers receiving compensation payments for livestock losses tend to tolerate predators more than those who do not (Karlsson & Johansson 2010).

Social media

As an iconic large predator, the leopard always attracts attention from the public and the media. Social media have become an important platform for driving public perceptions and opinions. People rapidly share wildlife-related news such as livestock depredation and human injuries/deaths caused by predators on online social networks (Nanni et al. 2020). The social media audience participates in active discussions over human-predator conflict issues and thus influences each other's opinions and perceptions. However, pub-lic perceptions are not uniform, and they can be shaped differently in various professional and social groups such as rural communities, herder and hunter associations, non-governmental organizations, urban people, scientists, and authorities. Eventually, the outcomes of such interactions can directly or indirectly influence the process and direction of decision-making by individuals and organisations involved in the conflict (Redpath et al. 2013). Constant engagement of scientists in the media is required to increase public support for conflict mitigation measures. This would promote dissiminating accurate information and halting the flow of misinformation before it becomes widespread (Nanni et al. 2020).

Protective collars for livestock

Leopards often kill their prey by biting the animal's throat, which blocks the pharynx and causes suffocation (Kitchener et al. 2010). Therefore, it is reasonable to protect the animal's neck with a physical barrier, which could reduce the chance of death (McManus et al. 2015). In parts of Iran, cattle often graze within dense vegetation without shepherds or dogs, which provides a favourable condition for the ambush predators like leopards to hunt (Farhadinia et al. 2018). A studded leather collar (Fig. 2) was developed to protect freely grazing cattle in Iran. Such collars can

Fig. 2. Studded leather collars fitted on the necks of cattle in Mazandaran Province, northern Iran to protect from leopard bites (Photos S. Ghoddousi & I. Khorozyan).

be readily made by local people (Khorozyan et al. 2020). The collar resembles a regular belt and can be fitted to different neck sizes. Its effectiveness still needs to be tested on sheep and goats as well as in non-forest landscapes. McManus et al. (2015) successfully applied all-metal mesh collars to sheep in South Africa. However, in Iran they did not work on cattle, sheep and goats because they irritated the neck skin, disturbed animals, and changed their feeding and offspring caring behaviour (Khorozyan et al. 2020).

Predator-proof corrals

Samelius et al. (2019) set up protective night-time electric fences (18×18 m in size, 2 m high, aluminum nets supported by metal poles and electric wires set on the top) around corrals and found that predation of sheep and goats by snow leopards *Panthera uncia* decreased to nil, resulting in better attitudes towards predators among the livestock owners. Their findings suggested that fenced night corrals can be an effective tool to create and maintain coexistence between people and predators. That study was carried out in Mongolian mountainous habitats similar to those of leopards in the Middle East and Central Asia. Testing this approach on the Persian leopard may provide an important knowledge transfer to this region (Fig. 3). Alternatively, predator-proof corrals can be constructed without fences. In this case, the reinforced sheds are made of stones or concrete with a solid roof and have no openings through which leopards could sneak into the corral. Such sheds are very common in the region's villages, but they are often weak, poorly maintained, and easily accessible to predators. Simple maintenance of sheds, such as fixing strong, well-fit doors and covering openings with metal mesh, can be a cheap and effective way to minimise livestock losses (Khorozyan & Waltert 2019). At the same time, corrals hinder the mobility of herders and their livestock as in many areas of the Middle East and Central Asia transhumant practices are used with seasonal long-distance movements in search of green pastures. For this reason, it is logistically and economically most practical for the pastoralist communities to set up temporary and mobile fenced corrals, primarily within the conflict hotspot areas (Samelius et al. 2019).

Predator deterrents

The effectiveness of predator deterring tools, such as shock collars and devices producing frightening lights and sounds, varies across different predator species and has not yet been sufficiently tested on wild cats (Table 1; Miller et al. 2016). Deterrents are highly sensitive to environmental conditions, vulnerable to malfunctioning, and difficult to use in the field. Another problem that hampers the application of these techniques is that their effectiveness usually diminishes within three months or less (Breitenmoser et al. 2005). Inefficacy of deterrents results from fast habituation of predators to harmless novelties, especially in human-dominated landscapes where predators are adapted to lights and sounds (Khorozyan & Waltert 2019). Also, the effectiveness of deterrents may depend greatly on the individual characteristics of predators and more studies are needed on this aspect. Despite these limitations, predator deterrents can be effectively used during short periods of high predation risks, such as calving/lambing seasons or when livestock is grazed close to predator habitats (Miller et al. 2016, Khorozyan & Waltert 2019). Adopting short-term livestock protection techniques and the alternating usage of different interventions can be the most practical and harmless solution for herders.

Financial incentives and compensation programmes

A local livelihood-enhancing programme of selling handcrafted products in the Altai Mountains of Mongolia was shown to offset livestock losses by snow leopards (Mishra et al. 2003). Thus, alternative livelihoods (e.g., ecotourism and associated businesses) can be applied to increase tolerance towards predators, protect them from illegal killing, and improve local livelihoods (Mishra et al. 2003). Financial incentives have been widely practiced in many regions of the world to promote coexistence between people and large predators. In Sweden, for example, a conservation performance payment system was designed to pay to the Sami communities upon confirmed reproduction of predators such as Eurasian lynx *Lynx lynx* to compensate for the projected predation of grown-up offsprings of semi-domestic reindeer (Zabel & Holm-Müller 2008). In another example, the payment scheme was based on mere occurrence records of brown bears *Ursus arctos* regardless of density and reproductive events (Rauset et al. 2016). A similar approach could be applied to Persian leopards. More specifically, performance payments (also known as 'pay for presence') could be paid through state-funded programmes, community-led funds, private insurers and other sources for observations of leopard offspring in breeding areas or generally for observations of leopards, especially females, in the areas where this species is rare or locally extinct. These payments should not be based on the number of killed livestock but should instead reduce potential threats to leopards in the future. This approach seems promising but is potentially prone to misuse or abuse as people would most likely increase false reporting in anticipation of payments. Also, this could create conflicts between targeted persons or communities because they have intrinsically different chances of seeing leopards or their offspring. However, it can be a promising tool for protected areas as a state-managed system of bonus payments to rangers in order to motivate them to better monitor leopards, their prey, and habitats.

Financial incentives, especially compensation programmes, are prone to problems such as poor management, high transaction costs, lack of trust and transparency, and significant time lags in payments (Madhusudan 2003, Jacobs & Main 2015, Babrgir et al. 2017). Compensations are usually based on confirmed evidence, e.g. livestock carcasses, which is difficult to find especially in challenging terrain (mountains, forest). That is why compensation programmes tend to pay much less than expected and usually do not cover indirect costs such as reduced productivity of stressed animals, which are hard to prove but incur much cost (Widman et al. 2019). Moreover, Babrgir et al. (2017) reported that despite existing compensation schemes in Iran, herders claimed they were unaware of them. Therefore, awareness-raising among local people about the goals and procedures of compensation schemes and conservation interventions is essential for success. However, even if local people are aware of compensation payments, their support is not guaranteed as they may be reluctant to pay premiums because livestock losses are rare and unpredictable.

Performance and compensation payments can reduce the illegal killing of predators when combined with other techniques applied in the same area, such as payments to local people for participation in wildlife monitoring, livestock protection, or research (Hazzah et al. 2014). To build public trust, it is vital to make such payments compliant with local culture, involve a broad spectrum of local communities, and secure the long-term availability of funds (Zabel & Holm-Muller 2008, Hazzah et al. 2014).

An interesting example of a compensation programme in Turkmenistan can be replicated elsewhere in the Middle East and Central Asia. A community-based compensation payment scheme was developed by World Wide Fund for Nature (WWF) in the Sari-Su River basin of Turkmenistan (Lukarevsky 2003). Since 1999, the local community purchased and managed a sheep flock to become an economically sustainable compensation stock for replacing sheep killed by leopards in the area. This approach can work effectively to compensate for sheep losses, improve local attitudes toward leopards, and reduce retaliatory killing of leopards if well managed and coordinated. Like other financial incentives and compensation payments, this compensatory stock programme may fail because of false reports of livestock mortality (e.g., deaths from diseases, lack of care, or other predators assigned to leopards) and misuse of this intervention (Sh. Karryeva, pers. comm.), urging for proper monitoring of the whole process to secure its efficacy.

Livestock guarding dogs

Livestock guarding dogs have been used in the region for millennia and are still being globally used to reduce livestock predation (Abade et al. 2014, Landry et al. 2020, Leib et al. 2021). Several global reviews suggest that guarding dogs are among the most effective interventions in reducing predation rates by predators (Miller et al. 2016, van Eeden et al. 2017, Khorozyan & Waltert 2019). Khorozyan et al. (2017) further reported that the presence of guarding dogs reduced surplus killings (two and more killed per attack) of sheep and goats in north-eastern Iran but did not reduce the total numbers killed by leopards. The most recent study in the same area also confirmed that guarding dogs could reduce sheep and goat losses per leopard attack (down to 1.4 individual/attack; Soofi et al. under review) but not eliminate losses. This means that guarding dogs should not only be present but essentially be properly trained (Rigg et al. 2017, Leib et al. 2021) to deter leopards effectively. However, dog training and handling (vaccination, feeding, shelter) are expensive and time-consuming.

Also, the effectiveness of guarding dogs in deterring predators relies on their personality (Landry et al. 2020). For instance, disobedient dogs may stray around without being present near the grazing herd, and generally, such individuals should not be used in stock guarding (Leib et al. 2021). Such disobedience can be an individual trait and a result of improper care forcing dogs to search for food away from livestock. A usual practice of feeding dogs with human leftovers cannot raise a good guarding dog. Many guarding dogs are trained only to bark and inform the herder about the predator's presence but this behaviour may provoke leopards to attack livestock and even a shepherd or his dog (Khorozyan et al. 2017). In this case, dogs are counter-effective and cause more harm.

Fig. 3. A fenced corral commonly used to protect sheep and goats in Iran, which is generally ineffective (Photo M. Soofi).

Table 1. Different types of interventions proposed to promote coexistence between humans and Persian leopards.

Intervention	Effectiveness	Advantages	Disadvantages	Country and references
Protective collars for livestock	Cattle: very effective; sheep and goats require further testing	Inexpensive, easy to use, flexible, locally producible, and durable	Not reported, but need more testing	Iran - Khorozyan et al. 2020
Predator-proof corrals	Variable	Only strong corrals are effective. Protective against various predators. Inexpensive if only minor maintenance works (e.g. closure of openings on roof and walls) are required	Costs of time, effort, and budget required for construction and maintenance. Inappropriate for seasonally moving (transhumant) societies	Not tested in the region, but see Khorozyan & Waltert (2019) and Samelius et al. (2019) for details
Deterrents	Effective but only for a short period	Effective against various predators during short periods of high depredation risk (e.g., lambing or calving seasons)	Fast habituation of predators, especially in human-modified landscapes, difficult to set up and use, sensitive to environmental conditions, and vulnerable to malfunctioning	Not tested in the region, but see Miller et al. (2016) and Khorozyan & Waltert (2019) for details
Financial incentives and compensation programmes	Variable	Can increase local people's trust in conservation	Need for secured funding and good management, risks of bureaucracy, misuse and abuse, high costs, false reports of kills, no motivation to change behaviour and attitudes	Iran - Babrgir et al. 2017; Turkmenistan - Lukarevsky 2003
Livestock guarding dogs and shepherds	Variable	Effective if dogs are properly trained and kept, and if shepherds are skilled	Costs of time, effort and budget, lack of motivation among local men to become shepherds	Georgia - Rigg et al. 2017; Iran - Khorozyan et al. 2017, Soofi et al. under review

Another problem with untrained dogs is that they may harass and kill wildlife, sometimes even predators (Ekernas et al. 2017, Drouilly et al. 2020, Landry et al. 2020). Dogs can also transmit lethal diseases, including canine distemper, which is an imminent danger for tigers *P. tigris* and leopards in the Russian Far East (Seimon et al. 2013) and to lions *P. leo* in East Africa and India (Davidson-Phillips et al. 2019, Mourya et al. 2019). This threat can be mitigated by dog vaccination (Woodroffe et al. 2007). This work should be done in close cooperation with herders who can manage their dogs, which are generally aggressive to unfamiliar people, and incorporate regular monitoring of the process (Soofi et al. under review).

Shepherds

Training of local shepherds will increase their skills in various aspects. Shepherds need to know how to effectively use interventions (such as protective collars) and also to train and care for their dogs. Also, shepherds should have necessary skills to minimise predator attacks on their livestock, e.g., grazing away from dense vegetation and rocks, staying present and vigilant near livestock, keeping livestock in compact groups and not letting them disperse widely. Moreover, considering how sharply the numbers of shepherds are decreasing in the modern urbanised world, shepherds should be financially and emotionally motivated to do their job. A growing number of shepherd schools and training courses in the EU (Mettler 2021) can serve as a good model for shepherd training within the Persian leopard range. Eventually, trained shepherds will not only successfully protect their livestock but also become an integral and committed part of wildlife conservation.

Potentially effective interventions to reduce livestock losses to leopards

Developing and applying practical and socially acceptable interventions is vital to reducing conflicts and promoting coexistence between people and leopards. Multiple approaches have been described in the literature (van Eeden et al. 2017, Khorozyan & Waltert 2019), but priority should be given to the long-lasting interventions which reduce the ability of predators to become habituated (Khorozyan & Waltert 2019). The appropriateness of interventions depends on the sufficiency of wild prey for leopards in a given area. If livestock is successfully protected by interventions, but wild prey is limited or absent, then leopards will die from hunger or move away to other areas. In this case, it is most effective to pay compensations for killed livestock or translocate individual problem leopards to other places (Breitenmoser et al. 2005). In contrast, when prey densities are moderate to high, such as in the Hyrcanian forest of Iran, livestock protection by shepherds, dogs, or protective predator-proof corrals is appropriate and safe as leopards will switch to preying on wild species, especially abundant wild boars *Sus scrofa* (Ghoddousi et al. 2019). Ineffective interventions are costly, time-consuming, and demotivating, and may even lead to increased livestock losses compared to business-as-usual practices without interventions.

Our synthesis of the published information suggests a number of livestock protection interventions (Table 1) as the most appropriate and potentially effective ones in the Middle East and Central Asia.

Insights into future developments

We underline that the interventions suggested above for the Persian leopard will succeed only if they rely on effective systematic monitoring plans. The monitoring here refers to how data related to human-leopard conflicts and associated livestock protection interventions are being systematically collected over time. In the absence of monitoring, it is not possible to evaluate the effectiveness of interventions (e.g., the incidence of livestock kills, locality, date, time of predation) and adjust them to improve their performance. Interventions should be able not only to reduce livestock losses but also to change people's intentions to kill leopards in retribution. We suggest strengthening the linkage between the effectiveness of interventions and the conservation outcomes, such as leopard densities, which is a weak point and a missing link in many conservation efforts. Monitoring of conflict situations should be implemented in close cooperation with local communities and with their participation. Encouraging local communities' participation in monitoring and evaluation of conservation interventions would help increase transparency and mutual trust. Information on conflict situations and their solutions obtained through participatory monitoring could then be disseminated through online platforms for general discussions and scientific research on intervention effectiveness. This would ensure the bottom-up flow of information and the involvement of multiple stakeholders in conflict mitigation.

To avoid propagation of disinformation related to human-leopard conflicts, scientists should be actively engaged in the media, especially on the Internet and TV, to provide accurate and understandable explanations, give timely updates, and shape public attitudes based on existing evidence (Nanni et al. 2020, Schell et al. 2021). People living in urban areas tend to be much more supportive of predator conservation (Schell et al. 2021) compared to rural populations, especially those affected by living close to predators (Montgomery et al. 2018). As a result, the views of different stakeholders may collide with each other and ultimately increase the perceived risks of predators regardless of the actual risk (Montgomery et al. 2018). Strategic planning of human-leopard coexistence should essentially incorporate several components including: (a) collaboration with diverse stakeholders such as local communities, NGOs, universities, and conservation authorities; (b) application of effective livestock protection measures such as protective collars, predator-proof collars, deterrents, financial incentives, compensation payments, livestock guarding dogs and shepherds; and (c) science-based monitoring of human-leopard conflicts (determinants, socio-economic and psychological effects, conflict hotspots) and their solutions (effectiveness of livestock protection measures).

References

Abade L., Macdonald D. W. & Dickman A. J. 2014. Assessing the relative importance of landscape and husbandry factors in determining large carnivore depredation risk in Tanzania's Ruaha landscape. Biological Conservation 180, 241–248.

Babrgir S., Farhadinia, M. S. & Moqanaki E. M. 2017. Socio-economic consequences of cattle predation by the endangered Persian leopard *Panthera pardus saxicolor* in a Caucasian conflict hotspot, northern Iraq. Oryx 51, 124–130.

Bleyhl B., Ghoddousi A., Askerov E., Bocedi G., Breitenmoser U., Manvelyan K., Palmer S. C. F., Soofi M., Weinberg P., Zazanashvili N., Shmunk V., Zurell D. & Kuemmerle T. 2021. Reducing persecution is more effective for restoring large carnivores than restoring their prey. Ecological Applications 31, e02338.

Braczkowski A. R., O'Bryan Ch. J., Stringer M. J., Watson J. E. M., Possingham H. P. & Beyer H. L. 2018. Leopards provide public health benefits in Mumbai, India. Frontiers in Ecology and the Environment 16, 176–182.

Breitenmoser U., Angst C., Landry J. M., Breitenmoser-Würsten C., Linnell J. D. C. & Weber J. M. 2005. Non-lethal techniques for reducing depredation. In People and wildlife: Conflict or coexistence? Woodroffe R., Thirgood S. & Rabinowitz A. (Eds.) Cambridge University Press, Cambridge, UK, pp. 49–71.

Breitenmoser U., Askerov E., Soofi M., Breitenmoser-würsten C., Heidelberg A., Manvelyan K. & Zazanashvili N. 2017. Transboundary leopard conservation in the Lesser Caucasus and the Alborz Range. Cat News 65, 24–25.

Brouwer E. 2021. Human-Pantherinae conflicts in South and Southeast Asia and their implications for conservation. Master thesis. University of Utrecht, Netherlands.

Carter N. H., Nelson P. & Easter T. 2021. A call for a national collaborative predator coexistence Programme. People and Nature 3, 788–794.

Davidson-Phillips S., Davidson-Phillips P., Canning G., Schroder B., Swart J. & Berger A. 2019. Canine distemper virus management in lions (*Panthera leo*) on Welgevonden Game Reserve. African Journal of Wildlife Research 49, 155–166.

Drouilly M., Kelly C., Cristescu B., Teichman K. J. & O'Riain M. J. 2020. Investigating the hidden costs of livestock guarding dogs: a case study in Namaqualand, South Africa. Journal of Vertebrate Biology 69, 20033.

Ekernas L. S., Sarmento W. M., Davie H. S., Reading R. P., Murdoch J., Wingard G. J., Amgalanbaatar S. & Berger J. 2017. Desert pastoralists' negative and positive effects on rare wildlife in the Gobi. Conservation Biology 31, 269–277.

Farhadinia M. S., Johnson P. J., Macdonald D. W. & Hunter L. T. B. 2018. Anchoring and adjusting amidst humans: Ranging behavior of Persian leopards along the Iran-Turkmenistan borderland. PLoS One 13, e0196602.

Ghoddousi A., Soofi M., Hamidi A. Kh., Lumetsberger T., Egli L., Khorozyan I., Kiabi B. H. & Waltert M. 2016. Assessing the role of livestock in big cat prey choice using spatiotemporal availability patterns. PLoS One 11, e0153439.

Ghoddousi A., Soofi M., Hamidi A. K., Ashayeri S., Egli L., Ghoddousi S., Speicher J., Khorozyan I., Kiabi, B. H. & Waltert M. 2019. The decline of ungulate populations in Iranian protected areas calls for urgent action against poaching. Oryx 53, 151–158.

Hazzah L., Dolrenry S., Naughton L., Edwards C. T. T., Mwebi O., Kearney F. & Frank L. 2014. Efficacy of two lion conservation programs in Maasailand, Kenya. Conservation Biology 28, 851–860.

Jacobs C. E. & Main M. B. 2015. A conservation-based approach to compensation for livestock depredation: The Florida panther case study. PLoS One 10, e0139203.

Jacobson A. P., Gerngross P., Lemeris J. R. Jr., Schoonover R. F., Anco C., Breitenmoser-Würsten C., ...& Dollar L. 2016. Leopard (*Panthera pardus)* status, distribution, and the research efforts across its range. PeerJ 4, e1974.

Karlsson J. & Johansson O. 2010. Predictability of repeated carnivore attacks on livestock favours reactive use of mitigation measures. Journal of Applied Ecology 47, 166–171.

Karlstetter M. 2008. Wildlife surveys and wildlife conservation in Nuristan, Afghanistan. Wildlife Conservation Society & United States Agency for International Development. 62 pp.

Khorozyan I., Askerov E., Beruchashvili G., Kütükçu A. E., Lortkipanidze B., Malkhasyan A., ...& Heidelberg A. 2022. Distribution and status of the Persian leopard in the Caucasus Ecoregion. Cat News Special Issue 15, 19–28.

Khorozyan I. & Waltert M. 2019. How long do anti-predator interventions remain effective? Patterns, thresholds and uncertainty. Royal Society Open Science 6, 190826.

Khorozyan I., Ghoddousi A., Soofi M. & Waltert, M. 2015. Big cats kill more livestock when wild prey reaches a minimum threshold. Biological Conservation 192, 268–275.

Khorozyan I., Soofi M., Soufi M., Hamidi A. Kh., Ghoddousi A. & Waltert M. 2017. Effects of shepherds and dogs on livestock depredation by leopards (*Panthera pardus)* in north-eastern Iran. PeerJ 5, e3049.

Khorozyan I., Ghoddousi S., Soufi M., Soofi M. & Waltert M. 2020. Studded leather collars are very effective in protecting cattle from leopard (*Panthera pardus*) attacks. Ecological Solutions and Evidence 1, e12013.

Kiabi B. H., Dareshouri B. F., Ghaemi R. A. & Jahanshahi M. 2002. Population status of the Persian leopard (*Panthera pardus saxicolor* Pocock, 1927) in Iran. Zoology in the Middle East 26, 41–47.

Kitchener A. C., Van Valkenburgh B. & Yamaguchi N. 2010. Felid form and function. In Biology and conservation of wild felids. Macdonald D. W. & Loveridge A. J. (Eds.) Oxford University Press, Oxford, UK, pp. 83–106.

Landry J. M., Borelli J. L. & Drouilly M. 2020. Interactions between livestock guarding dogs and wolves in the southern French Alps. Journal of Vertebrate Biology 69, 20078.

Leib Z., Tumurbaatar B., Elfström B. & Bull J. 2021. Impact of livestock guardian dogs on livestock predation in rural Mongolia. Conservation Science and Practice 3, e509.

Lukarevsky V. 2003. Saving the Central Asian leopard in Turkmenistan. Carnivore Damage Prevention News 6, 13–15.

Madhusudan M. D. 2003. Living amidst large wildlife: livestock and crop depredation by large mammals in the interior villages of Bhadra Tiger Reserve, South India. Environmental Management 31, 466–475.

Maharramova E., Moqanaki E. M., Askerov E., Faezi S., Alinezhad H., Mousavi M., Kuemmerle T., Heidelberg A. & Zazanashvili N. 2018. Transboundary leopard movement between Azerbaijan and Iran in the Southern Caucasus. Cat News 67, 8–10.

McManus J. S., Dickman A. J., Gaynor D., Smuts B. H. & Macdonald D. W. 2015. Dead or alive? Comparing costs and benefits of lethal and non-lethal human-wildlife conflict mitigation on livestock farms. Oryx 49, 687–695.

Mettler D. 2021. The shepherd's challenge: learning by being. Carnivore Damage Prevention News 22, 32–35.

Memarian I., Ostrowski S., Kordestani H., Khakpour H. & Pouyanshad N. 2018. The illegal use of snares and gin traps threatens endangered leopards in Iran. Cat News 67, 10–14.

Miller J. R. B., Stoner K. J., Meyer T. K., Middleton R. D. & Scmitz O. J. 2016. Effectiveness of contemporary techniques for reducing livestock depredations by large carnivores. Wildlife Society Bulletin 40, 806–815.

Mishra C., Allen P., McCarthy T., Madhusudan M. D., Bayarjargal A. & Prins H. H. T. 2003. The role of incentive programs in conserving the snow leopard. Conservation Biology 17, 1512–1520.

Montgomery R. A., Elliott K. C., Hayward M. W., Gray S. M., Millspaugh J. J., Riley S. J., ...& Macdonald D. W. 2018. Examining evident interdisciplinarity among prides of lion researchers. Frontiers in Ecology and Evolution 6, 49.

Moqanaki E., Breitenmoser U., Kiabi B. H., Masoud M. & Bensch S. 2013. Persian leopards in the Iranian Caucasus: a sinking 'source' population? Cat News 59, 22–25.

Mourya D. T., Yadav P. D., Mohandas S., Kadiwar R. F., Vala M. K., Saxena A. K., ...& Bhargava B. 2019. Canine distemper virus in Asiatic lions of Gujarat State, India. Emerging Infectious Diseases 25, 2128–2130.

Nanni V., Caprio E., Bombieri G., Schiaparelli S., Chiorri C., Mammola S., Pedrini P. & Penteriani V. 2020. Social media and large carnivores: sharing biased news on attacks on humans. Frontiers in Ecology and Evolution 8, 71.

Parchizadeh J. & Belant J. L. 2021a. Human-caused mortality of large carnivores in Iran during 1980–2021. Global Ecology and Conservation 27, e01618.

Parchizadeh J. & Belant J. L. 2021b. Brown bear and Persian leopard attacks on humans in Iran. PLoS OneE 16, e0255042.

Rauset G. R., Andre H., Swenson J. E., Samelius G., Segerstro P., Zedrosser A. & Persson J. 2016. National parks in northern Sweden as refuges for illegal killing of large carnivores. Conservation Letters 9, 334–341.

Redpath S. M., Young J., Evely A., Adams W. M., Sutherland W. J., Whitehouse A., Amar A., Lambert R. A., Linnell J. D. C., Watt A. & Gutiérrez R. J. 2013. Understanding and managing conservation conflicts. Trends in Ecology and Evolution 28, 100–109.

Rigg R., Goldthorpe G., Popiashvili, T. & Sillero-Zubiri C. 2017. Livestock guarding dogs in Georgia: a tradition in need of saving? Carnivore Damage Prevention News 15, 19–27.

Samelius G., Suryawanshi K., Frank J., Agvaantseren B., Baasandamba E., Mijiddorj T., Johnsson O., Tumursukh L. & Mishra C. 2019. Keeping predators out: testing fences to reduce livestock depredation at nighttime corrals. Oryx 55, 46–472.

Schell C. J., Stanton L. A., Young J. K., Angeloni L. M., Lambert J. E., Breck S. W. & Murray M. H. 2021. The evolutionary consequences of human–wildlife conflict in cities. Evolutionary Applications 14, 178–197.

Seimon T. A., Miquelle D. G., Chang T. Y., Newton A. L., Korotkova I., Ivanchuk G., Lyubchenko E., Tupikov A., Slabe E. & McAloose D. 2013. Canine distemper virus: an emerging disease in wild enrdangered Amur tigers (*Panthera tigris altaica*). mBio 4, e00410-13.

Shokri S., Jafari A., Rabei K., Hadipour E., Zeppenfeld T., Soufi M., ...& Soofi M. 2020. Conserving populations at the edge of their geographic range: the endangered Caspian red deer (*Cervus elaphus maral*) across protected areas of Iran. Biodiversity and Conservation 30, 85–105.

Soofi M., Ghoddousi A., Zeppenfeld T., Shokri S., Soufi M., Jafari A., ...& Waltert M. 2018. Livestock grazing in protected areas and its effects on large mammals in the Hyrcanian forest, Iran. Biological Conservation 217, 377–382.

Soofi M., Ghoddousi A., Zeppenfeld T., Shokri S., Soufi M., Egli L., ...& Khorozyan I. 2019. Assessing the relationship between illegal hunting of ungulates, wild prey occurrence and livestock depredation rate by large carnivores. Journal of Applied Ecology 56, 365–374.

Soofi M., Qashqaei A. T., Mousavi M., Hadipour E., Filla, M., Kiabi B. H., ...& Waltert M. 2022. Quantifying the relationship between prey density, livestock and illegal killing of leopards. Journal of Applied Ecology 59, 1536–1547.

Treves A. & Bruskotter J. T. 2014. Tolerance for predatory wildlife. Science 344, 476–477.

Treves A. & Karanth K. U. 2003. Human-carnivore conflict and perspectives on carnivore management Worldwide. Conservation Biology 17, 1491–1499.

van Eeden L. M., Crowther M. S., Dickman C. R., Macdonald D. W., Ripple W. J., Ritchie E. G. & Newsome T. M. 2017. Managing conflict between large carnivores and livestock. Conservation Biology 32, 26–34.

Widman M., Steen M. & Elofsson K. 2019. Indirect costs of sheep depredation by large carnivores in Sweden. Wildlife Society Bulletin 43, 53–61.

Woodroffe R., Frank L. G., Lindsey P. A., le Ranah S. M. K. & Romanach S. 2007. Livestock husbandry as a tool for carnivore conservation in Africa's community rangelands: a case–control study. Biodiversity Conservation 16, 1245–1260.

Zabel A. & Holm-Muller K. 2008. Conservation Performance Payments for Carnivore Conservation in Sweden. Conservation Biology 22, 247–251.

[1] Department of Conservation Biology, University of Goettingen, Bürgerstr. 50, 37073, Goettingen, Germany
*<mahmood.soofi@biologie.uni-goettingen.de>

[2] CSIRO Land and Water, Darwin, NT, Australia

[3] Consultant, Goettingen, Germany

[4] Colorado State University, Fort Collins, CO, United States

MOHAMMAD FARHADINIA[1*], IGOR KHOROZYAN[2], POLINA ORLINSKIY[3], TATJANA ROSEN[4], BAHAREH SHAHRIARI[5], HANA RAZA[6], BENJAMIN BLEYHL[7], SHIRIN KARRYEVA[8], MARK PESTOV[9], MUHAMMAD KABIR[10], ZALMAI MOHEB[11], VLADIMIR TERENTIEV[9] AND ELSHAD ASKEROV[12]

Priority areas for transboundary conservation of Persian leopards in West Asia and the Caucasus

Large carnivores have extensive spatial requirements, with ranges that often span geopolitical borders. Consequently, management of transboundary populations is subject to several political jurisdictions, often with heterogeneity in conservation challenges. In West Asia and the Caucasus, the endangered Persian leopard *Panthera pardus tulliana* occurs with transboundary populations spanning 13 countries with 26% of the extant ranges in borderlands. Overall, in 10 of 13 countries the majority of the remaining leopard range is in borderlands, and thus in most countries conservation of this subspecies is dependent on transboundary collaboration. We nominated a total of 10 key transboundary areas that are of high importance for the survival of Persian leopards, of which only one has an ongoing transboundary initiative. We highlighted the conservation challenge and potential opportunities for transboundary conservation of Persian leopards in the region.

Large carnivores have extensive spatial requirements that may extend beyond geopolitical borders. Consequently, these wide-ranging animals can fall under several political jurisdictions, resulting in a diversity of conservation challenges and efforts (Pestov et al. 2019, Farhadinia et al. 2021). Neighbouring states may have different levels of technical expertise, knowledge, capacity and financial resources (Karlstetter & Mallon 2014). These challenges can add to the already precarious circumstances of many large carnivores, which often occur at low densities and are prone to demographic and environmental stochasticity.

In Asia, the leopard *Panthera pardus* subspecies currently occur in <16% of their historical range (Jacobson et al. 2016, Stein et al. 2016). Persistence of many small populations of leopards is dependent on source–sink dynamics across international borders (Khorozyan et al. 2014, Farhadinia et al. 2015, Maharramova et al. 2018, Askerov et al. 2019). However, transboundary conservation was not considered in the latest IUCN assessment of leopards (Stein et al. 2016).

Here, we highlighted the importance of implementing transnational strategies for the conservation of leopards that range across West Asia and the Caucasus. We focused on the conservation status and challenges of transboundary populations of Persian leopard, and identified initiatives with which conservation practitioners can facilitate effective transboundary cooperation for the conservation of leopards, and perhaps other large mammals, such as prey species. We defined borderland as a buffer zone of 80 km from the borderline on both sides of the border and we considered a habitat patch as transboundary if it overlapped with borderlands. We chose this size because it is the maximum dispersal distance for leopards in Asia, recorded by telemetry in north-east Iran (Farhadinia et al. 2018).

Transboundary ranges and conservation initiatives

In continental Asia, in 18 of 23 countries where threatened leopard subspecies occur, the majority of the current leopard range is found within 80 km of international borders (Farhadinia et al. 2021). The Persian leopard occurs across the rugged terrain of 13 countries (Fig. 1), with a total population of 800–1,000 individuals (Khorozyan 2008), spread across an area of 933,597 km² covering parts of the Middle East, Central Asia and the Caucasus (Jacobson et al. 2016). A total of 3,415 km of borderline runs through the Persian leopard range, causing 26% (247,035 km²) of this subspecies' range to be within the borderland area (Farhadinia et al. 2021).

Currently, >75% of the subspecies' extant range is located within Iran (Jacobson et

Fig. 1. The current range of the Persian leopard *Panthera pardus tulliana* and the locations of 10 key transboundary areas for Persian leopards: 1) the entire Iran-Afghanistan border, 2) Badhyz, 3) Aral Paygambar, 4) Kopetdag, 5) south-western Ustyurt, 6) Babatag, 7) Zagros, 8) Lesser Caucasus, 9) Greater Caucasus and 10) Hindu Kush range. ARM = Armenia, AZ = Azerbaijan, and GEO = Georgia.

al. 2016). In 10 of 13 countries in West Asia and the Caucasus where the Persian leopard exists, its range is located exclusively in the borderlands (Farhadinia et al. 2021), in small populations of generally <10 individuals (Askerov et al. 2015, Avgan et al. 2016). These countries appear to hold the sink populations that are on the brink of extinction (Askerov et al. 2015, Avgan et al. 2016, Stein et al. 2016, Maharramova et al. 2018). However, animals from these populations are able to recolonise other suitable habitats, if appropriate conservation measures are put in place (Askerov et al. 2019).

The Persian leopard populations in the Caucasian countries of Armenia, Azerbaijan, Georgia, and the Russian North Caucasus, are most dependent on borderlands as the majority of the animals occur within these areas. Importantly, there is an ongoing transboundary conservation initiative which is actively working with the range states to facilitate leopard conservation across borders in the Caucasus (Askerov et al. 2015).

In addition, the Persian leopard has recently become part of another transboundary initiative. The Central Asian Mammals Initiative CAMI under the aegis of the Convention on the Conservation of Migratory Species of Wild Animals CMS included the Persian leopard as one of the 14 species it covers in Central Asia and beyond. The CMS focuses on the conservation of migratory wildlife that cross international borders, under which the leopard has been listed since 2018. The priority activities in the CAMI Programme of Work 2020–2026 that was adopted by the CMS Parties in 2020, include eleven activities to enhance the conservation of the Persian leopard, including the creation of a range-wide conservation strategy for the subspecies.

The CMS study "Mapping transboundary hotspots for the Central Asian Mammals Initiative", originally presented at the second range state meeting of the CMS/CAMI, nominated six key transboundary areas for Persian leopards, including the entire Iran-Afghanistan border, Badhyz, Aral Paygambar, Kopetdag, south-western Ustyurt, and Babatag. Turkmenistan has a key role in securing the transboundary areas for Persian leopards in four of the six nominated areas (CMS 2019). We also recommend four additional areas that are of significance for the conservation of transboundary populations and movements of Persian leopards: Zagros (Iran, Iraq and Turkey), Lesser Caucasus (Iran, Armenia, Azerbaijan, Georgia), Greater Caucasus (Georgia, Azerbaijan and Russia) and parts of the Hindu Kush range (Pakistan and Afghanistan). Despite the significance of transboundary conservation of the Persian leopard and the identified areas of importance, there is currently only one transboundary conservation initiative across the range of the species, namely in the Lesser Caucasus (Askerov et al. 2019).

Threats to Persian leopards in borderlands

Previous studies have highlighted poaching of leopards and their prey, and habitat loss as the main reasons for the decline of leopards across most of their range, including West Asia and the Caucasus (Farhadinia et al. 2015, Jacobson et al. 2016, Pestov et al. 2019, Bleyhl et al. 2021). We identified three main challenges for the conservation of transboundary populations of Asian leopards, which are fully applicable to Persian leopards: (1) different levels of legal protection and management across national jurisdictions, (2) military activities and armed conflict, and (3) border security fences that block the movement of leopards and their prey.

There are varied levels of legal protection and management for leopards across national jurisdictions across most range states, with substantial monetary fines and/or imprisonment for illegal killing (Table 1). However, the year when legal protection came into force differs substantially between the adjacent states with differences of up to several decades concerning several large borderland populations, such as those shared between Iran, Iraq and

Table 1. Populations and legal status of the Persian leopard (*Panthera pardus tulliana*) in West Asia (updated from Farhadinia et al. 2021).

Countries	Year national protection granted	Fine for illegal killing (USD)	Population size	% country range in borderlands	Reference for population size
Afghanistan	2008	None	200–300	17.5	Khorozyan (2008)
Armenia	1972	210,000 outside protected areas, five times higher in protected areas	<10	100	Askerov et al. (2015)
Azerbaijan	1976	1,950 (outside protected area) to 5,820 (inside protected area)	<10	100	Askerov et al. (2015)
Georgia	1982	19,000	<3	100	Askerov et al. (2015)
Iran	1965	6,100	550–850	28.2	Kiabi et al. (2002)
Iraq	2010	8,350	<10	100	Avgan et al. (2016)
Kazakhstan	2021	9,690	<3	100	
Pakistan	1974	See below for details*	Not known	74.8	
Russia	1956	2–9 years in prison plus a fine up to 45,700	<10	100	Khorozyan (2008)
Tajikistan	2008	424–25,000	Not known	100	
Turkey	2003	13,600	<10	100	Avgan et al. (2016)
Turkmenistan	1970s	600 (outside protected area) to 1,700 (inside protected area)	100–105	91.1	O. Pereladova, pers. comm. (2020)
Uzbekistan	1983	7,300 (for Uzbek citizens), 40,000 (for foreign citizens)	Not known	100	

* In Pakistan, the common leopard is a protected animal. There are different fines for killing a leopard in Pakistan based on different provinces. For example, in Khyber Pakhtunkhwa, the penalty is Rs. 145000 ($852.19) fine plus value of property. In contrast, in Azad Jammu & Kashmir, it is Rs. 10,000 ($58.77) fine or six-month imprisonment or both; plus, value of property or two months imprisonment in lieu thereof and maximum is Rs. 30,000 ($176.32) fine or six months imprisonment or both; plus, value of property or six months imprisonment in lieu thereof.

Turkey (Table 1). Neighbouring countries may have different agendas, technical capacities, and resources available for leopard conservation, potentially hindering the recovery of transboundary populations.

Military activities and armed conflicts occur within a large proportion of the Persian leopard range. Political unrest compromises law enforcement and effective conservation. Potential effects of military activities and armed conflicts on leopards and their prey are currently not known. It has been documented that old mines occasionally kill leopards and other wildlife (Raza et al. 2012, Avgan et al. 2016).

Finally, border fences and associated roads are concerns for transboundary movement of leopards in west and central Asia (Moheb 2007, Farhadinia et al. 2018). Border fences and walls may impede movements of leopards and their prey along the Iran–Turkmenistan, Afghanistan–Turkmenistan, Afghanistan-Pakistan, Turkmenistan-Kazakhstan, Iran-Armenia and Iran-Azerbaijan borders, and parts of the Turkish borders (Fig. 2).

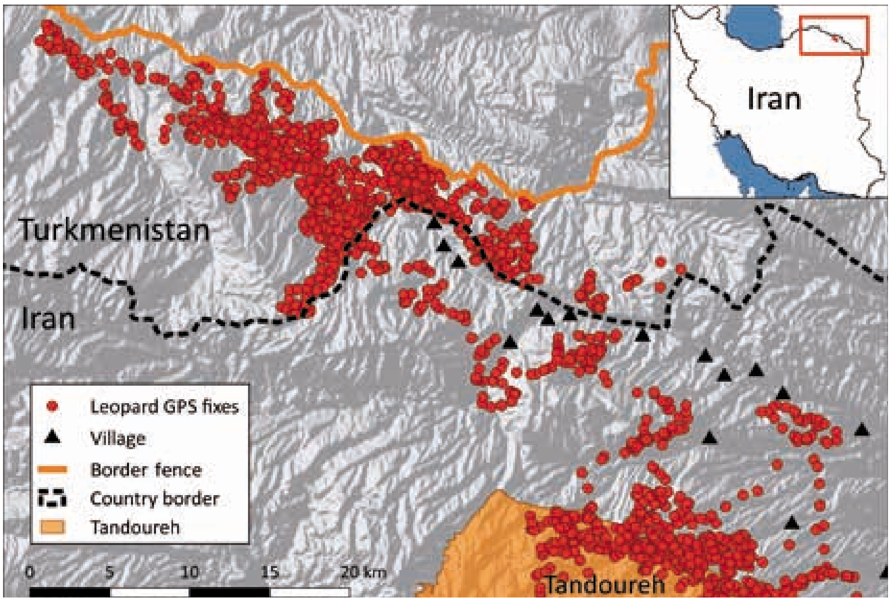

Fig. 2. GPS-tracked locations of a collared Persian leopard that dispersed from Tandoureh National Park in north-east Iran to Turkmenistan (Farhadinia et al. 2018). These locations show that although the leopard moved freely across the international border, the security fence lying further north within Turkmenistan was a barrier for the leopard's movements.

Conservation opportunities for Persian leopards in borderlands

Cooperation on conserving transboundary landscapes is widely recommended as a means to encourage intergovernmental partnerships. The concept of an international Peace Park as a way of linking biodiversity conservation with promoting peace has been proposed for the area between Arevik National Park in Armenia and Dizmar Protected Area in Iran, and Hawraman-Darbandikhan-Qara Dagh areas in Iraq and Shaho Kohsalan and Buzin Marakhil Protected Areas in Iran, where leopards occur. Conservation initiatives by the international conventions and conservation organisations that promote joint conservation and research efforts between conflicting neighbouring countries can potentially be effective in motivating the countries to work together and conserve wildlife along the borderlines.

However, this approach is not always applicable, especially when countries are facing security challenges that reduce opportunities for transboundary cooperation. Therefore, each of the neighbouring countries can unilaterally enforce the conservation of their transboundary populations and shift their conservation investments towards the borderland (Farhadinia et al. 2021). An example is leopard conservation in Armenia and Azerbaijan's Nakhchyvan Autonomous Republic which, despite a political dispute, has succeeded in maintaining protected areas for leopards and supporting population recovery on both sides of the border (Askerov et al. 2019).

For a wide-ranging carnivore such as the leopard, the same individuals may be counted in more than one country, thus biasing abundance estimates (Maharramova et al. 2018, Askerov et al. 2019). This emphasises the need for the establishment of joint monitoring and information sharing programmes. Transboundary information exchange can improve the accuracy and precision of population estimates, which can lead to a better understanding of the status of leopard populations. Importantly, effects of border fences on leopard movements and demography need to be better understood. Joint population monitoring (Askerov et al. 2019) and satellite telemetry (Farhadinia et al. 2018) can help elucidate the locations of corridors and source-sink dynamics across international borders.

There are areas within the historical range of Persian leopards where this subspecies might still occur in borderlands, even though there is currently no data to support this. To improve the knowledge of the subspecies' distribution in these areas, surveys may be undertaken, particularly where leopard presence is confirmed at least on one side of an international border. These areas include the borders between Turkey and Iran, Turkey and Iraq, Kopetdag Mountains along the Iran-Turkmenistan border, Babatag Mountains along the Tajikistan-Uzbekistan border, Koytendag/Kugitang shared between Turkmenistan and Uzbekistan, and Afghanistan (Fig. 3; CMS 2019). In particular, anecdotal reports of leopard presence come from the Kugitang and Babatag (and adjacent Baysuntau and southern Hissar Range) mountains of Uzbekistan (CMS 2019). Also, the borderland between Afghanistan and Iran or Pakistan (other than Badakhshan) may be surveyed for the presence of leopards, as the subspecies has been occasionally reported there.

In addition to the CMS, there are other conventions that have a direct effect on the conservation of large carnivores and their habitats in the Persian leopard range such as the Bern Convention on the Conservation of European Wildlife and Natural Habitats and the Convention on International Trade in Endangered Species of Wild Fauna and Flora CITES. The Bern Convention facilitated the development of the strategy for the conservation of the leopard in the Caucasus Ecoregion. Finally, the Economic Cooperation Organization ECO as an intergovernmental organisation of which most of the regional countries within the ranges of the Persian leopard are members can provide a framework for the establishment of transboundary cooperation for leopard conservation through the ECO's Division on Social Welfare and Environment.

References

Askerov E., Talibov T., Manvelyan K., Zazanashvili N., Malkhasyan A., Fatullayev P. & Heidelberg A. 2015. South-eastern Lesser Caucasus: the most important landscape for conserving the leopard

Fig. 3. Photographic evidence of Persian leopards in borderlands: (a) an individual with an amputated leg along the Armenia–Azerbaijan–Iran border in the Caucasus (Photo WWF), (b) an individual in north-east Iran, with Turkmenistan's mountains in the background (Photo Future4Leopards Foundation), (c) an individual in Ustyurt State Reserve, Kazakhstan (Photo USR/CADI/ACBK), and (d) an individual in Kopet Dag State Nature Reserve along the Iran-Turkmenistan border (Photo Team Bars Turkmenistan).

(*Panthera pardus*) in the Caucasus region (Mammalia: Felidae). Zoology in the Middle East 61, 95–101.

Askerov E., Talibov T., Manvelyan K., Zazanashvili N., Fatullayev P. & Malkhasyan A. 2019. Leopard (*Panthera pardus*) reoccupying its historic range in the South Caucasus: a first evidence (Mammalia: Felidae). Zoology in the Middle East 65, 88–90.

Avgan B., Raza H., Barzani M. & Breitenmoser U. 2016. Do recent leopard *Panthera pardus* records from northern Iraq and south-eastern Turkey reveal an unknown population nucleus in the region? Zoology in the Middle East 62, 95–104.

Bleyhl B., Ghoddousi A., Askerov E., Bocedi G., Breitenmoser U., Manvelyan K. ...& Kuemmerle T. 2021. Reducing persecution is more effective for restoring large carnivores than restoring their prey. Ecological Applications, 31, e02338.

CMS. 2019. Mapping transboundary hotspots for the Central Asian Mammals Initiative, Second range state meeting of the CMS Central Asian Mammals Initiative (CAMI), Ulaanbaatar, Mongolia, UNEP/CMS/CAMI2/Inf.3.

Farhadinia M. S., Ahmadi M., Sharbafi E., Khosravi S., Alinezhad H. & Macdonald D. W. 2015. Leveraging trans-boundary conservation partnerships: persistence of Persian leopard (*Panthera pardus saxicolor*) in the Iranian Caucasus. Biological Conservation 191, 770–778.

Farhadinia M. S., Johnson P. J., Macdonald D. W. & Hunter L. T. B. 2018. Anchoring and adjusting amidst humans: ranging behavior of Persian leopards along the Iran-Turkmenistan borderland. PLoS One, 13, e0196602.

Farhadinia M. S., Rostro-García S., Feng L., Kamler J. F., Spalton A., Shevtsova E., Khorozyan I., Al-Duais M., Ge J. & Macdonald D. W. 2021. Big cats in borderlands: challenges and implications for transboundary conservation of Asian leopards. Oryx 55, 452–460.

Jacobson A. P., Gerngross P., Lemeris J. R., Schoonover R. F., Anco C., Breitenmoser-Würsten C., ...& Dollar L. 2016. Leopard (*Panthera pardus*) status, distribution, and the research efforts across its range. PeerJ 4, e1974.

Karlstetter M. & Mallon D. 2014. Assessment of gaps and needs in migratory mammal conservation in Central Asia. In A Report for the Convention on the Conservation of Migratory Species of Wild Animals (CMS) and the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ). United Nations Environment Programme/Convention on Migratory Species Secretariat, Bonn, Germany.

Khorozyan I. 2008. *Panthera pardus* ssp. *saxicolor*. In The IUCN Red List of Threatened Species. Version 2015.1. iucnredlist.org [accessed 11 June 2017].

Kiabi B., Dareshouri B., Ghaemi R. & Jahanshahi M. 2002. Population status of the Persian Leopard (*Panthera pardus saxicolor* Pocock, 1927) in Iran. Zoology in the Middle East 26, 41–47.

Maharramova E., Moqanaki E. M., Askerov E., Faezi S., Alinezhad H., Mousavi M., Kuemmerle T., Heidelberg A. & Zazanashvili N. 2018. Transboundary leopard movement between Azerbaijan and Iran in the Southern Caucasus. Cat News 67, 8–10.

Moheb Z. 2007. Mammal survey in Herat. WCS Unpublished report.

Pestov M. V., Nurmukhambetov Z. E., Munkhashov A. T., Terentyev V. A. & Rosen T. 2019. First camera trap record of Persian leopard in Ustyurt State Nature Reserve, Kazakhstan. Cat News 69, 14–16.

Raza H. A., Ahmad S. A., Hassan N. A., Ararat K., Qadir M. & Ali L., 2012. First photographic record of the Persian leopard in Kurdistan, northern Iraq. Cat News 56, 34–35.

Stein A. B., Athreya V., Gerngross P., Balme G., Henschel P., Karanth U., ...& Ghoddousi A. 2016. *Panthera pardus* (errata version published in 2016). In The IUCN Red List of Threatened Species. 2016: iucnredlist.org [accessed 31 July 2019].

Trouwborst A., Blackmore A., Boitani L., Bowman M., Caddell R., Chapron G., ...& Linnell J. D. 2017. International wildlife law: understanding and enhancing its role in conservation. BioScience 67, 784–790.

[1] Oxford Martin School and Department of Zoology, University of Oxford, Oxford, UK
*<mohammad.farhadinia@zoo.ox.ac.uk>
[2] Consultant, Göttingen, Germany
[3] Convention on the Conservation of Migratory Species of Wild Animals, Bonn, Germany
[4] Caucasus Nature Fund, Tbilisi, Georgia
[5] Iranian Department of Environment, Tehran, Iran
[6] Nature Iraq, Sulaimani-Kurdistan Region, Iraq
[7] Geography Department, Humboldt Universität zu Berlin, Berlin, Germany
[8] SBSTTA/CBD Focal Point, Turkmenistan
[9] Organization for Conservation of Amphibians and Reptiles of the Eco-center "Dront", Nizhny Novgorod, Russia
[10] Wildlife Ecology Lab, Department of Forestry & Wildlife Management, University of Haripur, Pakistan
[11] Wildlife Conservation Society, Kabul, Afghanistan
[12] Ilia State University, Tbilisi, Georgia and Institute of Zoology of Azerbaijan NAS, Baku, Azerbaijan

ARASH GHODDOUSI[1*], BENJAMIN BLEYHL[1], ELSHAD ASKEROV[2], AUREL HEIDELBERG[3], MUHAMMAD KABIR[4], BEJAN LORTKIPANIDZE[5], KAREN MANVELYAN[6], DENIZ MENGÜLLÜOĞLU[7], ZALMAI MOHEB[8], MARZIEH MOUSAVI[9], ALIM PKHITIKOV[10], HANA RAZA[11], TATJANA ROSEN[12], VIATCHESLAV V. ROZHNOV[13], PAUL WEINBERG[14], ANNA YACHMENNIKOVA[13], TOBIAS KUEMMERLE[1,15]

A range-wide monitoring framework for the Persian leopard and its prey

The long-term survival of the Persian leopard *Panthera pardus tulliana* requires concerted regional conservation efforts. Understanding occurrence patterns and population trends of the leopard and its prey are key prerequisite for planning conservation interventions and ensuring their effectiveness. However, systematic monitoring for these purposes is scarce across the Persian leopard range, despite progress towards more systematic monitoring in some parts (e.g., the Caucasus Ecoregion). Using the example of the monitoring system in the Caucasus, we propose a framework for range-wide monitoring of Persian leopard and its prey. We suggest focusing on 297 units of 25x25 km, spread across eleven range countries. Adopting a coordinated monitoring strategy and ensuring information exchange will assist range countries to better achieve their conservation targets, including the objectives of the regional conservation initiatives such as the Convention on the Conservation of Migratory Species of Wild Animals CMS Central Asian Mammals Initiative CAMI and its Range-Wide Strategy for the Conservation of the Persian Leopard. More broadly, a systematic monitoring framework will be crucial for the identification of knowledge gaps and priority areas to ramp up conservation actions for safeguarding megafauna in this region.

Persian leopard, a subspecies of leopard distributed across Central and Western Asia, and the Caucasus, has experienced a range decline of ca. 70–85% since the 19th century and is now extinct in five of its former range countries (Bleyhl et al. 2022, Jacobson et al. 2016). Reversing this trend calls for concerted conservation actions across the entire Persian leopard range, which in turn requires robust information on the status and distribution of the leopard and its prey. However, this information is largely lacking for most of the species' range. Importantly, the Persian leopard has one of the largest areas of unknown distribution among leopard subspecies (Jacobson et al. 2016), underlining important knowledge gaps. Moreover, the low population density and fragmented habitat across the region makes the Persian leopard susceptible to local extinctions (Bleyhl et al. 2021). To better understand the distribution and abundance of the Persian leopard and to ensure its long-term survival, there is an urgent need for a systematic monitoring of the leopard and its prey species. Such information would allow for the identification of core areas where leopard populations still occur, as well as prioritisation of conservation actions such as human-leopard conflict mitigation or prey restoration. More broadly, monitoring is a key step in a wider conservation planning strategy (Ghoddousi et al. 2019a).

One of the main challenges for monitoring the Persian leopard is its vast potential suitable habitat across its range (ca. 1,290,000 km² in eleven countries; Table 1; Bleyhl et al. 2022). Much of the Persian leopard habitat is in remote and rugged landscapes, which makes implementing common monitoring methods, such as camera trapping and ground surveys, slow, costly and complicated. Moreover, ca. 13% of the core habitat patches cross international borders (Bleyhl et al. 2022), including areas that suffer from years of armed conflicts and instability. Finally, at least 89% of the Persian leopard core habitat patches are unprotected (Bleyhl et al. 2022), making the implementation of conservation and monitoring activities complicated. Despite these challenges, there have been sporadic national and international efforts to improve monitoring of the Per-sian leopard in recent years (Ghoddousi et al. 2019a, Zazanashvili et al. 2012, 2020), which have resulted in better information on the status, distribution and threats to the species (Farhadinia et al. 2022, Ghoddousi et al. 2022, Khorozyan et al. 2022, Ostrowski et al. 2022). However, given the persisting critical conservation status of the Persian leopard in much of its range, and given vast areas with considerable uncertainty about its survival, there is a need to step up systematic monitoring and to promote information exchange across the region.

We first provide an overview of ongoing monitoring efforts focused on the distribution and abundance of the Persian leopard and its prey within the range countries. Then, we use the example of a recently developed monitoring strategy for the southern Caucasus (Ghoddousi et al. 2019a) to highlight how a range-wide systematic monitoring framework could look like in order to understand the outcomes of conservation measures and to inform future conservation actions.

Current monitoring efforts

The Persian leopard is a nocturnal and elusive species and is considered rare in most of its range. These characteristics, together with the challenges in surveying its rugged habitat limit the availability of data on the species, and apart from a number of well-known protected areas, basic information on its occurrence was largely lacking until recently. The use of camera traps has improved the level of knowledge on Persian leopard occurrence and distribution across the region. However, most of these efforts have been short-term and opportunistic or restricted to small areas, typically without coordination with other regions. To our knowledge, in only a handful of sites in some of the range countries the distribution and abundance of the Persian leopard have been consistently monitored by state agencies or NGOs over longer time periods (Table 1). For example, in the Russian Caucasus, a detailed monitoring framework focused on the Persian leopard reintroduction programme, has been developed and implemented (Rozhnov et al. 2020, Rozhnov et al. 2019).

Monitoring framework in the southern Caucasus

Throughout the 20th century, there has not been systematic monitoring of leopard abundance or distribution for research or conservation purposes in the Caucasus, which arguably contributed to the decline of the species and its currently perilous status in the region (Zazanashvili et al. 2007). In the 21st century, the situation improved, both regarding research effort and conservation planning and action. For example, WWF started a leopard

Table 1. Examples of the monitoring of the distribution and abundance of Persian leopard and prey across range states.

Country	Monitoring efforts		Example sites
	Persian leopard	***Prey species***	
Afghanistan	Camera trapping and interview surveys in potential habitats, data collection on leopard mortality[1]	Aerial and total count surveys of Asiatic ibex and urial, and interview surveys in potential habitats[1]	Bamyan Plateau, Band-e-Amir National Park, Darwaz region
Armenia	Camera trapping across selected monitoring units[2]	Occasional bezoar goat and mouflon block counts[2]	Khosrov Forest State Reserve, Arevik National Park, Zangezur Sanctuary, Ijevan Sanctuary, Arpa Protected Landscape Community Conserved Area
Azerbaijan	Camera trapping across selected monitoring units[2]	Occasional bezoar goat, mouflon, roe deer and wild boar block counts[2]	Zangezur National Park, Hirkan National Park, Goy Gol National Park
Georgia	Selected camera trapping in potential habitats[2,3]	(Double-observer) point counts for bezoar goat, eastern and western turs as well as pellet count for red deer in potential habitats[3,4]	Tusheti National Park, Pshav-Khevsureti National Park, Lagodekhi National Park, Borjomi National Park, Kazbegi National Park, Vashlovani Protected Area, Chachuna Managed Reserve
Iraq	Camera trapping in known and potential habitats[5]	Camera trapping in known and potential habitats[5]	Proposed Qara Dagh Protected Area
Iran	Centralized data collection on leopard mortality and sightings[6,7]; camera trapping and GPS-tracking in known and potential habitats[8,9,10]	Annual census of bezoar goat, mouflon and urial in all protected areas and a few unprotected sites[6]; prey population estimates (e.g., line transect, double-observer point count) in a number of protected areas[8,9,10]	Bamu National Park, Tandureh National Park, Golestan National Park, Dena National Park, Kamki Wildlife Refuge, Bafq Protected Area, Kalmand Protected Area, Bashagard and Minab
Kazakhstan	Camera trapping in known and potential habitats[11]	Point count in known and potential habitats	Ustyurt State Reserve, Manashi Reserve, proposed South Ustyurt Strict Nature Reserve
Pakistan	Camera trapping in known and potential habitats[11,12,13,14] and data collection on leopard mortality[11]	Population surveys and camera trapping to monitor prey abundance[12]	Pir Lasoora National Park, Machiara National Park, Margalla Hills National Park, Ayubia National Park, Murree-Kotli Sattian-Kahuta National Park, Kalam and Bahrain Valley, Swat, Dir, Haripur, Kaghan and Parachinar
Russia	GPS-tracking of reintroduced leopards, camera trapping and field surveys (e.g., checking kill-sites) in protected areas; hotline telephone number and system of social media data collection[15,16]	Annual census of roe deer, red deer, wild boar, eastern and western turs, bezoar goat and chamois in all protected areas using winter track counts in lowland forests and visual detection in mountain areas[15,16]	Caucasus Biosphere Nature Reserve, North-Ossetian Nature Reserve, Federal Managed Reserve Tseiskii, Federal National Park Alania, Kabardino-Balkarian Nature Reserve, Federal National Park Prielbrusie, Regional Managed Reserve Turmonskii, Daghestan Nature Reserve, Federal Managed Reserve Tlyaratinskii
Turkey	Camera trapping in known and potential habitats[17]	Annual census of bezoar goat and chamois in protected areas[17]	Taurus Mountains, southeastern Turkey, Lesser Caucasus
Turkmenistan	Camera trapping in known and potential habitats[18]	Point count in known and potential habitats[18]	Badhyz Strict Nature Reserve, Kopetdag Strict Nature Reserve, Sunt Hasardag Strict Nature Reserve, Uly and Kichi Balkan ranges, Qarabogazgol

[1]Wildlife Conservation Society, Afghanistan Program; [2]WWF-Caucasus Programme Office; [3]NACRES; [4]Caucasus Nature Fund; [5]Nature Iraq; [6]Iranian Department of Environment; [7]Fars provincial office of Department of Environment; [8]Pars Wildlife Guardians Foundation; [9]Hormuz Wildlife Guardians Foundation; [10]Future4Leopards Foundation; [11]CADI/ACBK/CLLC; [11]Wildlife Ecology Lab of University of Haripur; [12]Wildlife Ecology and Conservation Lab of University of Kotli, Azad Jammu & Kashmir; 13Islamabad Wildlife Management Board; [14]WWF-Pakistan; [15]A.N. Severtov Institute of Ecology and Evolution of the Russian Academy of Sciences; [16]A.K. Tembotov Institute of Ecology of Mountain Territories, Russian Academy of Sciences, Nalchik, Russia, [17]General Directorate of Nature Conservation and National Parks; [18]Team Bars Turkmenistan/CLLC

Table 2. Summary of the systematic monitoring framework implementation in the southern Caucasus. Numbers in brackets represent the number of units targeted at prey monitoring

Country	No. of units		Monitoring efforts				Partners involved
	Monitoring	*Survey*	*Leopard*	*Frequency*	*Prey*	*Frequency*	
Armenia	21 (9)	19 (4)	Camera traps	Entire year[1]	Transects, point counts	Occasionally[2]	WWF-Armenia
Azerbaijan	7 (6)	16 (2)	Camera traps	Entire year[1]	Transects, point counts	Occasionally[3]	WWF-Azerbaijan
Georgia	6 (6)	7 (1)	Camera traps	Entire year	Double-observer point count, pellet group count	Every three years[4]	NACRES, WWF-Caucasus Programme Office, Caucasus Nature Fund

[1] Apart from the herb collection season (April-June) due to a higher chance of camera trap theft.
[2] In spring (end of May-beginning of June) and the rut season (December)
[3] Post-parturition (June-July) and the rut season (November-December)
[4] Post-parturition (June) and the rut season (November-December), spring (March-April) for pellet counts

conservation programme in the southern Caucasus in 2001, including some monitoring of leopard and prey distribution (Zazanashvili et al. 2020). The regional strategy for leopard conservation and national action plans in Armenia and Azerbaijan further emphasised the importance of ramping up monitoring activities in the southern Caucasus (Zazanashvili et al. 2020). Since 2018, the WWF-Caucasus Programme Office with support of the Conservation Biogeography group at Humboldt-University Berlin has adapted their formerly opportunistic approach to a more systematic monitoring effort to generate baseline information on the abundance and distribution of the Persian leopard and its prey. These efforts have started in Armenia and Azerbaijan, and are now expanding to Georgia led by NACRES – Centre for Biodiversity Conservation & Research. The aims of this joint initiative are (1) to increase the spatial coverage of monitoring efforts to assess abundance and distribution of leopard and its prey; (2) to store camera trap data (meta- and monitoring data) systematically in one database to optimise data accessibility for subsequent analyses, not only for leopard and its prey but also other species of conservation concern, and (3) to facilitate the exchange of findings between the countries. Here, we describe the main elements of this framework:

1. Systematic grid – establishing basic units for monitoring: For efficient monitoring of the abundance and distribution of leopard and its prey at the landscape level, the use of regular, systematic sampling units is important. Considering the movement patterns of the Persian leopard (Ghoddousi et al. 2010), a baseline grid of 5x5 km as the basic management unit was chosen. This cell size reflects the mean maximum distance moved by Persian leopards (Ghoddousi et al. 2010). However, we acknowledge that leopard home ranges and long-distance dispersals may be larger. For future comparative analyses and work at different spatial scales, sampling units with 1x1 km^2 and 25x25 km sizes were also created. These are hierarchically nested so that up- and downscaling is easily possible.

2. Monitoring and survey units – deciding on the type of monitoring: Two types of cells in which data collection efforts take place are distinguished in this framework. The term 'monitoring unit' is used for describing long-term, repeated, and proactive assessments of abundance and distribution of leopard and its prey in core leopard areas (where leopard presence has been confirmed in the last 10 years). The term 'survey unit' is used to describe short-term, targeted assessments, such as leopard presence/absence or corridor assessments in areas suspected to be potentially used by the Persian leopard. A clear definition of monitoring and survey units allows for better allocation of monitoring resources and an adaptive system of tracking future potential range expansions.

3. Leopard monitoring: Camera traps have been the most common and reliable source of data gathering on abundance and distribution of big cats. In both Armenia and Azerbaijan, the implementation of camera trapping campaigns has resulted in a better understanding of the occurrence and movement patterns of the Persian leopard (Askerov et al. 2019). However, these efforts have been implemented only in a few core areas, leaving large areas with uncertain or no information. As part of this monitoring framework, expansion of the use of camera traps to new units (e.g., initially survey units, potentially later upgraded to monitoring units) in the vicinity of monitoring units has been encouraged (Table 2). Furthermore, the use of camera trap data management tools to speed up compilation, management, and analysis from the expanding camera trapping work was promoted. Camelot (Hendry & Mann 2018) as an open-source and easy-to-use software was chosen. Relevant training to the WWF staff in handling the current and old camera trapping data with Camelot has been a part of this step, which has been initiated by the Humboldt-University Berlin team in several workshops.

4. Prey monitoring: A viable population of large carnivores require a healthy population of preferred prey species (Ghoddousi et al. 2017), hence monitoring prey abundance and distribution is necessary. Using the systematic monitoring approach outlined above, data from camera traps also include information on prey but additional field surveys are often necessary for prey species in monitoring units. Ungulate species are the most important prey species for the Persian leopard (Ghoddousi et al. 2017). In open mountainous landscapes, block count surveys for bezoar goat *Capra aegagrus* and mouflon *Ovis gmelini* have been implemented (Table 2). Moreover, regular monitoring of the presence of these species is done via so-called 'Leopard Caretakers', local individuals who use the phone applications 'EarthBeat' or 'Wildwatch', and provide their observation notes to WWF. Moreover, in Georgia, eastern tur *C. cylindricornis*, red deer *Cervus elaphus* and bezoar goat are monitored since 2010 in selected protected areas (all potential leopard habitat) according to the 10-year Plan for the Monitoring of Short List Indicators agreed with the Ministry of Environment Protection and Agriculture of Georgia (Shavgulidze 2021). Surveys have been carried out by NACRES with support from Caucasus Nature Fund and Humboldt-University Berlin, and the collected data could be integrated into the WWF monitoring database.

5. Reporting: Data collected from monitoring and survey units are transferred to the WWF country offices regularly for data curation, management and analysis. Results of efforts conducted in these units in each country are shared with other WWF offices in the Caucasus at regular intervals (Table 2). Annual meetings to further discuss the findings, challenges and cooperation opportunities are organised.

A range-wide monitoring framework

Based on the experiences from developing and implementing the abovementioned monitoring framework in the southern Caucasus, we propose concrete steps for a range-wide monitoring framework. As a starting point, we overlaid a grid network of 25x25 km^2 on the eleven countries with recent leopard records (Table 1; Bleyhl et al. 2022). We then used 736 Persian leopard occurrences (Farhadina et al. 2022, Ghoddousi et al. 2022, Khorozyan et al. 2022, Ostrowski et al. 2022) to identify monitoring units as cells with at least one confirmed record since 2010 (i.e., the year after which occurrences were considered as 'recent' in this Special Issue). We used one confirmed record per cell to identify potential monitoring units in all range countries. We used a larger cell size than in the example in the southern Caucasus as we intended to pinpoint the main leopard habitats within countries, as well as considering that logistical support for detailed surveys (e.g., at 5x5 km^2 level) might not be available in all countries. Nested within these cells, 5x5 km^2 cells are ecologically justified units for detailed abundance and distribution surveys. We only used verified records (C1; Molinari-Jobin et al. 2012) and excluded secondary observations without hard facts to remain conservative in the identification of monitoring units. We identified 297 monitoring units (the coordinates of which can be made available upon request) across the Persian leopard range (Fig. 1), which are the areas of high priority for monitoring the distribution and abundance of leopard and prey. The highest number of monitoring units were identified in Iran (n = 206; 69% of all units), Pakistan (n = 24; 8%), Iraq (n = 9; 3%) and Turkmenistan (n = 9; 3%), highlighting the importance of technical and financial support for monitoring in these countries. Although Iran holds the largest share of Persian leopard habitat (Bleyhl et al. 2022), the higher number of monitoring units in this country may reflect the efforts in consolidation of cases of leopard sighting and mortality in a centralised database (Parchizadeh and Adibi 2019). Moreover, 30 monitoring units (10% of all units) crossed international borders, which calls for coordinated transboundary monitoring efforts. Across the Persian leopard range, there are some regions with new sightings (e.g., in Kabardino-Balkaria, Dagestan and the Caucasus Biosphere Nature Reserve all in Russia) or repeated unconfirmed records (e.g., north-eastern Turkey), which makes them candidate sites for inclusion as monitoring units once verified records become available.

As a next step, organisations responsible for wildlife monitoring in each country should identify potential leopard habitat (e.g., using Bleyhl et al. 2022) in each monitoring unit to determine the exact areas for data collection. We recommend a special focus on camera traps as a common, effective and non-invasive method. Examples of camera-trapping protocols for monitoring Persian leopard (Ghoddousi et al. 2019a) and other Asian felids using rugged terrains such as snow leopard *P. uncia* (Sharma et al. 2019) exist, which could help practitioners to ensure a robust design and data collection. As an alternative to camera trapping, questionnaire surveys and/or citizen science approaches with local people could be conducted within monitoring and survey units as a cost- and time-efficient method to collect information on occurrences of leopard and its prey as well as their population trends across vast areas. These data can be analysed in an occupancy modelling framework to draw inferences on leopard and prey distribution beyond the surveyed area, as exemplified for northern Iran (Ghoddousi et al. 2020). Additionally, ques-tionnaire survey can help to identify units for future monitoring efforts with camera traps or other field surveys.

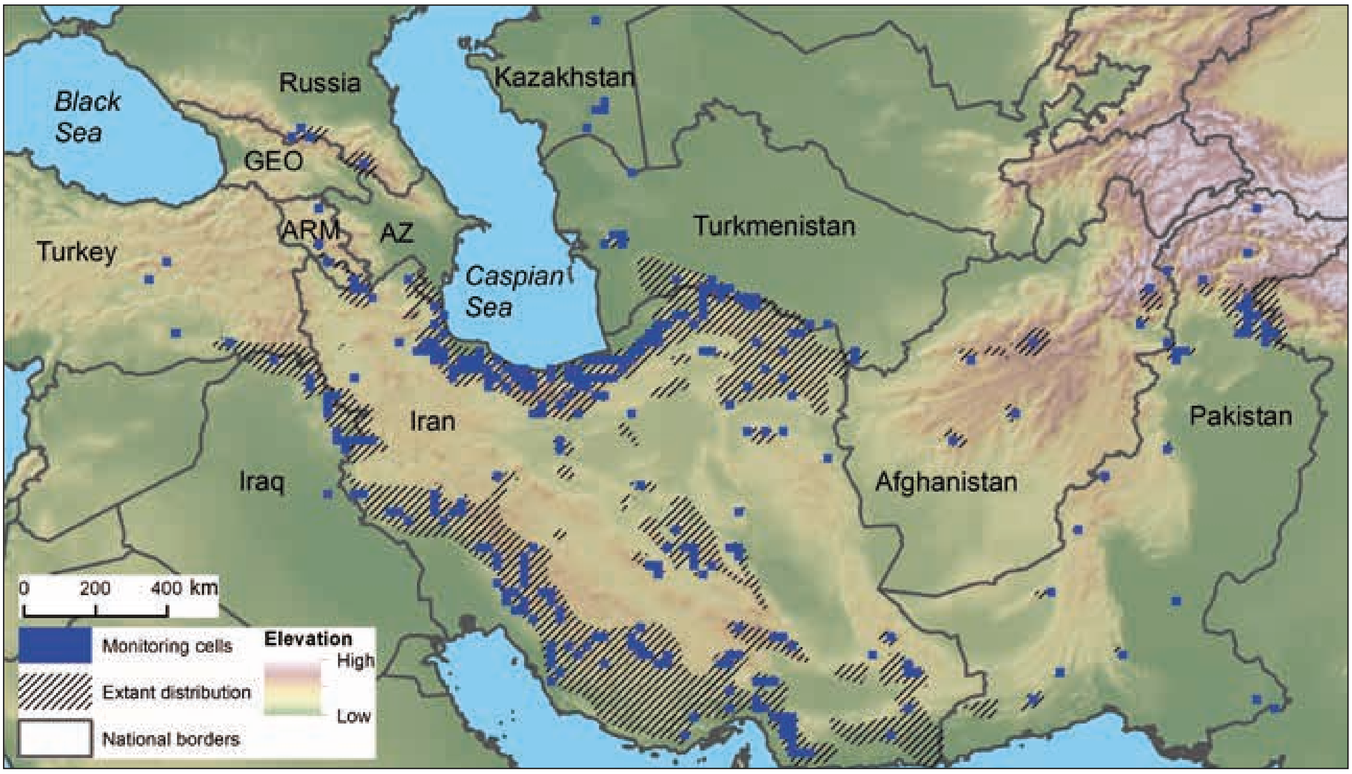

Fig. 1. The distribution of identified monitoring units (25x25 km) of the Persian leopard and its prey across eleven countries with confirmed presence of the species since 2010 overlayed on the distribution map of Persian leopard from Bleyhl et al. (2022).

The occurrence and population of leopard and prey should be monitored regularly in the monitoring units (e.g., a few times per year) and occasionally in the survey units (e.g., once a year) to update their status. Data from continued monitoring of leopard in these units should be compiled and stored in central repository systems. Additionally, any records of leopard sightings (e.g., by rangers or local people), as well as cases of leopard mortality (e.g., retaliatory killing by pastoralists, roadkill) should be added to the same database according to their verifiability levels (Molinari-Jobin et al. 2012). Examples of such databases at national agencies (e.g., Iranian Department of Environment) and regional institutions (e.g., Fars provincial office of Department of Environment) exist. Such data allows for the assessments of a minimum leopard population from individual identification, and estimations of density and distribution, all of which could shed light on the status of the Persian leopard and areas of high priority for threat mitigation.

One of the most important determinants of Persian leopard survival is the occurrence of healthy populations of its primary prey (Ghoddousi et al. 2017), which mainly include Asiatic ibex *C. sibirica*, bezoar goat, chamois *Rupicapra rupicapra*, eastern tur, grey goral *Naemorhedus goral*, markhor *C. falconeri*, musk deer *Moschus cupreus*, mouflon, red deer, urial *O. vignei*, western tur *C. caucasica*, and wild boar *Sus scrofa* (Farhadina et al. 2022, Ghoddousi et al. 2022, Khorozyan et al. 2022, Ostrowski et al. 2022). However, many of these species experience severe human pressures including poaching and habitat modifications (Bleyhl et al. 2019, Ghoddousi et al. 2019b, Kuemmerle et al. 2020, Soofi et al. 2018). Organisations should conduct regular assessments (e.g., twice a year) of prey abundance using available methods such as block counts within the outlined monitoring units. The use of other, more statistically robust, methods such as double-observer point count (Suryawanshi et al. 2012) in open landscapes, and random encounter models using camera traps (Rowcliffe et al. 2008) in forested landscapes should be considered once sufficient technical and financial support is provided. Importantly, prey monitoring methods should be further tested, evaluated and standardised within the Persian leopard habitat to allow cross-site comparisons. Furthermore, the use of digital applications and platforms (e.g., SMART, Earthranger) could facilitate the consolidation and reporting of the field data (e.g., by protected area rangers or local people). Similar to the leopard data, prey abundances should be stored in centralised databases and trends in their populations should be closely monitored. Finally, data on social-ecological indicators such as threats to wildlife and human-wildlife conflict incidents could be gathered to provide a clearer picture on the status of Persian leopard and its prey across the range.

Moving forward

Implementing a range-wide systematic monitoring framework in the vast landscapes of Central and Western Asia and the Caucasus is a challenging task given the imbalances in capacities and logistical support. Political instability, international sanctions and violent conflict in parts of the Persian leopard distribution on the one hand, and the low-income status of several range countries on the other, further complicate a continued monitoring across the 297 units identified here. However, the survival of the Persian leopard and its prey species is yet highly dependent on transboundary conservation planning and action, such as the expansion of protected areas, identification and safeguarding of important corridors, mitigation of human-wildlife conflict, or restoration of prey base – all of which should be science-based and planned and agreed upon within participatory and holistic approaches. Doing so depends on closely monitoring the population trajectories of these species and the prevalence of different threats. Our suggested framework is modified to address the basic information needed for this purpose.

Upon successful implementation of this framework, tracking changes in leopard abundance as well as distribution could be accomplished over time to foster conservation responses. By identifying the responsible actors for collecting and compiling monitoring data at the national level, further infrastructure and training support could be provided to ramp up monitoring activities. In this regard, strengthening the monitoring efforts in Iran, which contains the vast majority of proposed monitoring units should be considered a high priority in regional conservation plans. Furthermore, a high number of monitoring units crossed international borders, highlighting the need for knowledge and experience exchange within the region. Importantly, comparing the distribution of monitoring units with the potential leopard habitat (Bleyhl et al. 2022) highlights large areas of knowledge gaps on leopard occurrence, mostly in countries without ongoing monitoring efforts. This calls for broadening the focus of conservation support beyond the known regions of leopard persistence. To this end, identification of priority areas for monitoring within each country should be considered as the next step to better allocate limited funding and build on the lessons learned from pilot sites.

Finally, in addition to contributing to national-level conservation targets, the monitoring activities will allow range states to fulfil their international commitments, for example to the Convention on the Conservation of Migratory Species of Wild Animals CMS and to the Central Asian Mammals Initiative CAMI where Persian leopard is listed (Programme of Work 2021-2026 Species-Specific Measures 19.6, 19.7 and 19.8). Similarly, the Range-Wide Strategy for the Conservation of the Persian Leopard (PeLeWG 2022) urges range countries to "…implement reliable monitoring system for Persian leopard and key wild prey species within and outside protected areas to guide conservation measures" (Objective 3). Adopting the monitoring framework will allow an evidence-based approach to the conservation of the Persian leopard in the region and will facilitate transboundary knowledge exchange, both of which are desperately needed for the persistence of this threatened species.

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References

Askerov E., Talibov T., Manvelyan K., Zazanashvili N., Fatullayev P. & Malkhasyan A. 2019. Leopard (*Panthera pardus*) reoccupying its historic range in the South Caucasus: a first evidence (Mammalia: Felidae). Zoology in the Middle East 65, 88–90.

Bleyhl B., Arakelyan M., Askerov E., Bluhm H., Gavashelishvili A., Ghasabian M. …& Kuemmerle T. 2019. Assessing niche overlap between domestic and threatened wild sheep to identify conservation priority areas. Diversity and Distributions 25, 129–141.

Bleyhl B., Ghoddousi A., Askerov E., Bocedi G., Breitenmoser U., Karen M. …& Kuemmerle T. 2021. Reducing persecution is more effective for restoring large carnivores than restoring their prey. Ecological Applications 31:e02338.

Bleyhl B., Gerngross P., Askerov E., Farhadinia M., Ghoddousi A. Heidelberg A. …& Kuemmerle T. 2022. Mapping the distribution and habitat of Persian leopard across its historical range. Cat News Special Issue 15, 9–18.

Farhadinia M. S., Soofi M., Rosen T., Moghadas P., Hobeali K., Behnoud P., …& Linnell J. D. C. 2022. Status of Persian leopard in the northern Iran and Central Asia. Cat News Special Issue 15, 29–35.

Ghoddousi A., Kh. Hamidi A., Ghadirian T., Ashayeri D. & Khorozyan I. 2010. The status of the Endangered Persian leopard *Panthera pardus saxicolor* in Bamu National Park, Iran. Oryx 44, 551–557.

Ghoddousi A., Soofi M., Kh. Hamidi A., Lumetsberger T., Egli L., Ashayeri S., Khorozyan I., H. Kiabi B. & Waltert M. 2017. When pork is not on the menu: Assessing trophic competition between large carnivores and poachers. Biological Conservation 209, 223–229.

Ghoddousi A., Bleyhl B., Pötzschner F., Rakowski J., Kuemmerle T., Weinberg P. ...& Heidelberg A. 2019a. Towards adoption of systematic wildlife monitoring framework in the southern Caucasus. WWF-Germany.

Ghoddousi A., Soofi M., Kh. Hamidi A., Ashayeri S., Egli L., Ghoddousi S., Speicher J., Khorozyan I., Kiabi B. H. & Waltert M. 2019b. The decline of ungulate populations in Iranian protected areas calls for urgent action against poaching. Oryx 53, 151–158.

Ghoddousi A., Bleyhl B., Sichau C., Ashayeri D., Moghadas P., Sepahvand P., Kh Hamidi A., Soofi M. & Kuemmerle T. 2020. Mapping connectivity and conflict risk to identify safe corridors for the Persian leopard. Landscape Ecology 35, 1809–1825.

Ghoddousi A., Abolghasemi H., Arianejad M., Mozafari G. G., Joolaee L., Mousavi M., Nayeri D., Chahartaghi N. R., Raza H. & Sepahvand P. 2022. Distribution of the Persian leopard in its western range. Cat News Special Issue 15, 36–41.

Hendry H. & Mann C. 2018. Camelot—intuitive software for camera-trap data management. Oryx 52, 15–15.

Jacobson A. P., Gerngross P., Lemeris J. R. Jr., Schoonover R. F., Anco C., Breitenmoser-Würsten Ch. …& Dollar L. 2016. Leopard (*Panthera pardus*) status, distribution, and the research efforts across its range. PeerJ 4:e1974.

Khorozyan I., Askerov E., Beruchashvili G., Kütükçü A. E., Lortkipandize B., Malkhasyan A., …& Heidelberg A. 2022. Distribution and status of the Persian leopard in the Caucasus Ecoregion. Cat News Special Issue 15, 19–28.

Kuemmerle T., Bluhm H., Ghoddousi A., Arakelyan M., Askerov E. Bleyhl B. …& Zazanashvili N. 2020. Identify priority areas for restoring mountain ungulates in the Caucasus. Conservation Science and Practice 2:e276.

Molinari-Jobin A., Wölfl S., Marboutin E., Molinari P., Wölfl M., Kos I. …& Breitenmoser U. 2012. Monitoring the Lynx in the Alps. Hystrix, the Italian Journal of Mammalogy 23, 49–53.

Ostrowski S., Kabir M., Moheb Z., Gritsina M., Karimov K., Khan M. S. H., …& Kholmatov I. 2022. Distribution and status of the Persian leopard in the eastern part of its range. Cat News Special Issue 15, 42–49.

Parchizadeh J. & Adibi M. A. 2019. Distribution and human-caused mortality of Persian leopards *Panthera pardus saxicolor* in Iran, based on unpublished data and Farsi gray literature. Ecology and Evolution 9, 11972–11978.

PeLeWG. 2022. Range-wide strategy for the conservation of the Persian leopard *Panthera pardus tulliana*. Convention on the Conservation of Migratory Species of Wild Animals (CMS).

Rowcliffe J. M., Field J., Turvey S. T. & Carbone C. 2008. Estimating animal density using camera traps without the need for individual recognition. Journal of Applied Ecology 45, 1228–1236.

Rozhnov V. V., Hernandez-Blanco J. A., Chistopolova M. D., Naidenko S., Sergey T., Pkhitikov A. B. …& Yachmennikova A. A. 2019. Study and monitoring of big cats in Russia. Moscow.

Rozhnov V. V., Yachmennikova A. A., Dronova N., Pkhitikov A. B., Magomedov M., Igor C. …& Arthur A. 2020. The restoration of persian leopard in the Caucasus (scientific approach). Moscow.

Sharma K,. Borchers D., Mackenzie D., Durbach I., Sutherland C.,Nichols J., ... & Mishra C. 2019. Guidelines for estimating snow leopard abundance and distribution using a combination of spatial capture-recapture and occupancy models. Global Snow Leopard and Ecosystem Protection Program.

Shavgulidze I. 2021. 10-Year Plan for Monitoring of Short List Indicators. Tbilisi, Georgia: Caucasus Nature Fund.

Soofi M., Ghoddousi A., Zeppenfeld T., Shokri S., Soufi, M. Jafari A. …& Walter M. 2018. Livestock grazing in protected areas and its effects on large mammals in the Hyrcanian forest, Iran. Biological Conservation 217, 377–382.

Suryawanshi K. R., Bhatnagar Y. V. & Mishra C. 2012. Standardizing the double-observer survey method for estimating mountain ungulate prey of the endangered snow leopard. Oecologia 169, 581–590.

Zazanashvili N., Garforth M., Jungius H. & Gamkrelidze T. 2012. Ecoregion Conservation Plan for the Caucasus. WWF, KfW, BMZ.

Zazanashvili N., Mörschel F., Askerov E., Manvelyan K., Krever V., Farvar M. T. & Kalem S. 2007. Conservation of the leopard in the Caucasus. Cat News Special Issue 2, 4–8.

Zazanashvili N., Sanadiradze G., Garforth M., Bitsadze M., Karen M., Askerov E. …& Tavsel S. D. 2020. Ecoregional Conservation Plan for the Caucasus: 2020 Edition. Tbilisi: WWF/KfW.

[1] Geography Department, Humboldt-University Berlin, Berlin, Germany
* <arash.ghoddousi@hu-berlin.de>
[2] WWF-Azerbaijan, Baku, Azerbaijan
[3] WWF-Germany, Berlin, Germany
[4] Wildlife Ecology Lab, University of Haripur, Haripur, Pakistan
[5] NACRES – Centre for Biodiversity Conservation and Research, Tbilisi, Georgia
[6] WWF-Armenia, Yerevan, Armenia
[7] Leibniz Institute for Zoo and Wildlife Research (IZW), Berlin, Germany
[8] Wildlife Conservation Society, Kabul, Afghanistan
[9] Iranian Department of Environment, Tehran, Iran
[10] A. K. Tembotov Institute of Ecology of Mountain Territories, Russian Academy of Sciences, Nalchik, Russia
[11] Nature Iraq, Sulaimani, Kurdistan Region, Iraq
[12] Caucasus Nature Fund, Tbilisi, Georgia
[13] A.N. Severtsov Institute of Ecology and Evolution, Russian Academy of Sciences, Moscow, Russia [1]
[14] North Ossetian State Nature Reserve, Alagir, Russia
[15] Integrative Research Institute for Transformations in Human-Environment Systems (IRI THESys), Humboldt-University Berlin, Berlin, Germany

VIATCHESLAV V. ROZHNOV[1*], ANNA. A. YACHMENNIKOVA[1**], NATALIA A. DRONOVA[2], SERGEI V. NAIDENKO[1], JOSE A. HERNANDEZ-BLANCO[1], MARIA D. CHISTOPOLOVA[1], ALIM B. PKHITIKOV[3], FATIMAT A. TEMBOTOVA[3], SERGEY A. TREPET[4] AND IGOR E. CHESTIN[2]

Experience of the leopard recovering through reintroduction in the Russian Caucasus

A reintroduction project has started in Russia in 2007 with the goal to create a Persian leopard population nucleus in the northern part of its historical range, where the species disappeared due to direct and indirect human influence in mid-20th century. A small resident group should give opportunity of breeding also for leopards migrating naturally from the south. The reintroduction will give the opportunity to re-integrate leopard genes accumulated in zoos into the wild population. The project includes stages of breeding leopard pairs originated from zoos in a special center; training youngling to make them able to survive in the wild, checking their readiness, releasing those who are ready, post-release monitoring with GPS-VHF collars and field surveys of kill-sites and other important places. Modelling the habitat in its present stage is done when new release sites are planned. Nowadays, two release sites work, the North-West Caucasian and Central Caucasian (Ossetian). Successful survival of released animals during a full year cycle was confirmed, but breeding was not observed so far.

Why reintroduction instead of natural recolonisation?

Historically, the Russian Caucasus was the western edge of the leopard range (Dinnik 1914, Geptner & Sludsky 1972), a region with unique natural complexes and a very rich biodiversity. Most ecological food chains or food webs still exist undisturbed in natural structures. The Russian Caucasus includes large areas of preserved habitats with the potential for leopard migration and resettlement (Rozhnov et al. 2018, Rozhnov et al. 2019, Rozhnov et al. 2020a, Rozhnov et al. 2020b). The Russian part of Caucasus is the region with the highest potential for leopard recovery in the whole range of *P. p. tulliana* because it is the least affected by external influences. The region has a system of natural complexes, which can be preserved for a long and retained their "biological identity". However, the Caucasus ecosystems are vulnerable as they depend on relict faunistic and botanical complexes often classified as rare and endangered (Rozhnov et al. 2020a). The gaps between territories nowadays inhabited by Persian leopards in the north part of its extant range are huge and natural corridors for reaching the northern Caucasus are fragmented (Breitenmoser et al. 2017). The western part of the Lesser Caucasus from Turkey to South Georgia has virtually no leopards (1–2 animals detected). There is a certain probability of spreading from small natural population in Iran and Turkmenistan towards the west but much less to the north into the good habitats of the Greater Caucasus. The chance that leopards reach the Russian Caucasus through natural migration from Iran is presently very low (Mousavi & Moqanaki 2017), and single individuals would be lost in the vast areas of the Greater Caucasus. On the other hand, with a successful leopard reintroduction in the north part of the range, offspring could migrate to the south and supplement the small wild population nuclei (Rozhnov & Lukarevskiy 2008).

Why release ex situ-born individuals and not do wild-to-wild translocations?

Restoring leopard in the Russian Caucasus is only possible through reintroduction (Rozhnov & Lukarevskiy 2008). The wild population in the border of Turkmenistan and Iran contains not more than 300–500 individuals (Kiabi et al. 2002) and is too weak to remove animals for translocation. The risks for the wild population would be bigger than the possible gain (IUCN/SSC 2013). Furthermore, released animals could die before breeding, an important aspect when releasing animals at the age of dispersal and resettlement (e.g. 2 years old; Rozhnov et al. 2020b). Natural dispersal of young leopards is an important period of the animal's life cycle, because this way they find and establish their own home ranges, but at the same time, this age bears also the highest risk of death. The plan is to release at least 50 individuals into the Russian Caucasus to establish a breeding core of a population (Rozhnov et al. 2020b).

Methods developed for rearing leopards in the SBC

Breeding and training approach (without EEP details)

The breeding and training of leopards for release into nature has been implemented since

Fig. 1. Structure of Sochi Breeding Center (SBC). a) Training enclosures (0.6–0.95 ha) for young leopards to be prepared for the wild; b) Breeding enclosures (~0.3 ha) for breeding individuals received from zoos (Photo SBC, WWF-Russia, Russian Federal Project of Persian leopard reintroduction, Ministry of Environment and Natural resources of Russian Federation).

Fig. 2. Releasing of the female named Volna in the territory of Central Caucasus (Republic of North Ossetia-Alania) in the strictly protected National Park "Alania" in 2018 (Photo Regional Project of recovering Caucasian Leopard in North Ossetia under the IEE RAS & RusHydro management, Russian Federal Project of Persian leopard reintroduction).

2013 in a specially built and equipped Leopard Breeding Center in the Sochi National Park (SBC; Fig. 1). The Center's infrastructure currently allows regular breeding and providing young leopards for training and releasing. The aim is to establish reproductive groups (using cubs from different litters) in the Russian Caucasus in three regions selected. The SBC has the following characteristics, it: (1) is well-guarded; (2) has large (0.5–0.9 ha) isolated enclosures with vegetation and relief as found in the Caucasus; (3) has open-air enclosures where young leopards develop and feed without contact to humans, and can train their hunting skills; (4) has facilities and conditions for veterinary examinations and timely assistance to animals; (5) has a video monitoring system that allows to observe leopards remotely in all enclosures at any time. The main goal of the SBC is breeding leopard pairs provided by EAZA EEP zoos, rearing and training of young Persian leopards for their subsequent release into the designated places of their natural range (Rozhnov et al. 2020b).

Only pure-bred Persian leopards with confirmed genetic status must be used. The selection of these leopards from the zoos of Russia and Europe is carried out by EAZA experts, based on the EEP Studbook. After some kittens were born, grew up and were trained in the SBC, they are released into nature, where they spread through the habitats in a natural way. Other offspring, which are not related to the previously released animals should thereafter be selected for the further releasing on the same release sites. It is important to observe the genetic diversity of the population increasing and to reduce the potential inbreeding probability as it could appear as a result of leopards' reproduction with each other in the wild.

Behaviour is one of the most essential adaptations allowing animals to survive in a diverse environment. A correct behavioural response in any unique situation is key for the survival of an individual and, indeed, the entire species. Behaviour formation in leopards occurs during postnatal ontogenesis in accordance with the development of all morphological structures. The maturation of an animal's body and brain structures are tightly coordinated with the development of behavioural processes. This phenomenon happens during the so-called sensitive periods, which are age- and species-specific and occur in an exact, determined order one after another. Studying the ontogeny of leopards' behaviour creates a scientific basis for the correct methods for their rehabilitation and raising them for future reintroduction into the wild. The main focus of environmental enrichment during raising of young leopards in the SBC is to introduce active stimuli (releasers) in time at those places (enclosures) where kittens grow and young leopards are being kept. These active stimuli (releasers) help to initiate and normalise the formation of certain types of behaviour. During each period, kittens and young animals are especially sensitive to very specific releasers. Details for each behaviour type are described below: (1) social competence; (2) the ability to obtain food (hunting); (3) motor skills development; (4) environmental adaptability; and (5) human avoidance skills (Rozhnov et al. 2020b). Selecting animals for being released implies a proper decision-making system. Only healthy and socially competent leopards can be released, which have individually passed a standardised examination (testing hunting skills, avoidance of humans, avoidance of living objects associated with humans, e.g. domestic animals). The decision on releasing is made on the basis of a specially developed system of inciting tests based on a detailed and standardised testing plan (detailed in Protocol No. 6; Rozhnov et al. 2020b).

Release concept (spatially, timing) and experiences

During the project implementation, siblings of different sexes are released at different release sites to prevent inbreeding. Thus, from two pairs bred in the SBC, males from Pair 1 and females from Pair 2 were released in the Caucasus Nature Reserve (North-Western Caucasus), and contrary, females from Pair 1 and males from Pair 2 in the Central Caucasus (regions of North Ossetia and Kabardino-Balkaria). That way, brothers and sisters have a low probability to meet each other for breeding. The optimal age for releasing was established as 2 years (Rozhnov et al. 2020b). If animals stay longer in the SBC, they get used to people (staff of the SBC). 1.5–2 years is also the age for young leopards for dispers-ing in nature (Balme et al. 2013, Fattebert et al. 2015, Rozhnov et al. 2015, Vitkalova & Shevtsova 2016), hence the natural behaviour of searching and establishing their own home ranges. This is, however, also the weak side of the reintroduction project, because this age includes a higher risk of losing animals from the reintroduction site through dispersal. Young leopards should be released in early summer, when wild ungulates have calves, daily temperatures are relatively high, and hiding conditions are perfect to perform first hunts in the natural environment. Furthermore, potential competitors or kleptoparasites like bears prefer grass diet. Before release, all animals passed veterinary check-control, were dehelminted and vaccinated.

Post-release monitoring is a crucial part of the Project (Rozhnov et al. 2018, Rozhnov et al. 2019). All animals released were equipped with GPS/satellite collars (Lotek, Canada), which incorporate a VHF transmitter. The main features of the collars and parameters for the remote monitoring were set as follows:

- 12–24 locations per day. This frequency of locating the animal provides precise information about its movement, allowing searching for successful hunting places;
- 1–2 data transfers to the server per day. This level is the minimum requirement that enables a prompt reaction in case of conflict situations;
- The availability of an accelerometer to register motion, in order to detect collar ejection, death of an animal, etc. Data on leopard activity enables the determination of behaviour, the intensity of movement and to analyse how it changes in time in connection with other parameters, such as distance travelled per day;
- The availability of a VHF transmitter is required for the work of the field team, enabling rapid response in case of conflict situations, as it avoids meeting the animal. It furthermore allows to search for the collar once it has been discarded, or to find the animal if it needs to be re-caught;
- The drop-off mechanism is necessary to release the animal from a collar that has stopped working. When the collar is found, it is possible to download accumulated accelerometer data, which are not transmitted via satellite (Rozhnov et al. 2019, Rozhnov et al. 2020b).

Kill sites assumed on the basis of clusters of coordinates are checked in the field by a group of zoologists to confirm the type of prey killed. All leopard scats are collected for analysis of the leopard's diet, as small preys might not be detected by kill sites checking. Furthermore, a system of photo traps is established in the range of the release site to observe leopard movements after the collar's battery runs low. Photos also help to assess a leopard's body condition changes in time, and to eventually detect other individuals that may come into the territory.

First experience and follow up

The first stage of the Programme for the Restoration of the Persian Leopard in the Caucasus (2008 edition) included a set of tasks that were successfully implemented: the choice of site and the construction of the SBC; selection of leopards and their acclimatisation in the SBC; breeding of leopards; training of offspring for being released; approbation of leopard training methods; preparing of the site for the first release of subadult leopards; assessment of an additional territory of the Caucasian Nature Reserve suitability for the first leopards' releasing; preparation of the release and follow-up monitoring of the animals; and finally releasing the first animals. In July 2016, the first three leopards (two males and one female) were assessed suitable for living in the wild according to a preliminary protocol. They were successfully released in the Caucasus Natural Reserve.

In July 2018, during the second phase of the Programme, three leopards were trained for living wild at the SBC, and reintroductions in the Caucasus continued: One male was released in the Caucasus Nature Reserve, and another male and a female in the Alania National Park in the Republic of North Ossetia (Fig. 2).

Up to spring 2022, three males survived in Western Caucasus, and two females and one male in the Central Caucasus (Table 1). The main causes of mortality of the released individuals were natural hazards, e.g. deep snow and avalanches, and starvation due to weakness caused by the blood parasite Cytauxzoon felis. In November 2021, an unknown wild male leopard (Fig. 3) was detected by a photo trap in the territory of Kabardino-Balkaria, where one of the females released in 2018 established her home range. Two more wild individuals were detected in February 2022 and March 2022 at the territories of Chechnya and Dagestan, respectively.

Based on these first encouraging experiences, the necessity for planning further actions became obvious (e.g. Rozhnov et al., 2020b). The follow-up involves continuous monitoring of released animals (Fig. 4), developing of an standardised, steadily updated database, compiling information of all leopards in the Programme, investigating the selected terrain with special field expeditions, ground-proving the map (spatially explicit plan) and using it to identify other places suitable for reintroduction, and planning other release sites beyond the Caucasus Nature Reserve. At the SBC, further leopards for breeding need to be selected to generate more offspring for releases. A breeding plan was developed considering all experiences so far, and breeding and training in accor-

Table 1. Summary information on leopards bred in the Sochi Breeding Centre and released to the Russian Caucasus. Overall mortality of released animals was 40% (20% during 1st year after release).

Number of leopards	Total	Males	Females	Western Caucasus	Central Caucasus
Born in the Center	25	12	13	-	-
Trained for releasing*	20	10	10	-	-
Assessed for readiness for living free	13	7	6	5 males 2 females	2 males 4 females
Released to the wild	10	6	4	4 males 2 females	2 males 2 females
Survived in the wild for 1 year	8	5	3	4 males 1 female	1 male 2 females
Died in 1st year after release	2	1	1	1 female	1 male
Died in 2nd year after release	2	1	1	1 male 1 female	0
Still alive in the wild in February 2022	6	4	2	3 males	1 male 2 females
Having bred in the wild	0	0	0	0	0

* In 5 leopards in training in the SBC in February 2022.

Fig. 3. Wild leopard detected in the Central Caucasus (Kabardino-Balkarskian Republic, strictly protected National Park "Prielbrusie") in November 2021. This male was repeatedly pictured in December 2021, and in January, February and March 2022 (Photo IEMT RAS, WWF-Russia & National Park "Prielbrusie", Russian Federal Project of Persian leopard reintroduction, phototrap was established by Alim Pkhitikov, leader of Field Monitoring Group).

dance with the plan continues. The system for assessing the animals to confirm their readiness for living in the wild was updated. Complementary work includes the monitoring of the dynamics of leopard habitats and the reconstruction of the historic distribution of the subspecies based on literature.

Discussion

To reach the final goal, we also need to understand details such as the pathogenic situation in the leopard's range, and the project must increase the number of animals reintroduced. Obviously, the speed of the releases is now too slow to create a reproducing population nucleus. As work on tigers has shown, even five animals released at the same time into an area with a low-abundance presence of wild individuals can lead to recover a group of 20 individuals within 10 years (Rozhnov et al. 2021). But in absence of wild individuals, as it is the case for the leopard reintroduction project, it is advisable to release at least 10 individuals during each release phase. The present holding capacity of the SBC is three breeding pairs, and the targeted capacity not more than four pairs. This will not be enough to generate the number of young leopards needed to increase the efficiency of the programme. Comparable reintroduction programmes maintained at least two breeding centers, allowing to (1) increase in the number of simultaneously produced/released individuals, and (2) avoid the breakdown of the project in an emergency situation such as an epizootic.

Conclusion

The leopard reintroduction project in the Russian Caucasus has been implemented since 2007. As its strong side can be named: (1) the SBC infrastructure is generally well organised and allows efficient breeding and raising leopards; (2) the system of testing animals for their readiness for being released showed its effectiveness; (3) the post-release monitoring is robust and worked well even under the difficult conditions in the Greater Caucasus. Weak sides are still (1) some aspects of breeding and training of animals in SBC and (2) the small number of animals produced and released in a given year.

The Caucasus Leopard Reintroduction Project is a pioneer project in large felid conservation. There are not many reintroduction projects for cat species in total, and very few involved breeding and raising animals in captivity (Breitenmoser et al. 2002, Vargas et al. 2008, Breitenmoser et al. 2019). For large felids such as leopards, the project in the Russian Caucasus is the only of its kind – a complex and comprehensive project uniting a lot of people and organisations under one roof. Both, mistakes and successes learned from that project are providing important experiences for future projects.

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References

Balme G. A., Batchelor A., Woronin-Britz N., Seymour G., Grover M., Hes L., Macdonald D. W. & Hunter L. T. B. 2013. Reproductive success of female leopards *Panthera pardus*: the importance of top-down processes. Mammal Review 43, 221–237.

Breitenmoser U., Breitenmoser-Würsten C., Carbyn L. & Funk S. M. 2002. Assessment of carnivore reintroductions. *In* Glittelman J., Funk S.M., Macdonald D. & Wayne R.K. (Eds). Carnivore Conservation. Cambridge University Press, Cambridge, pp. 241–281.

Breitenmoser U., Askerov E., Soofi M., Breitenmoser-Würsten C., Heidelberg A., Manvelyan K., Zazanashvili N. 2017. Transboundary leopard conservation in the Lesser Caucasus and the Alborz Range. Cats News 65, 24–25.

Breitenmoser U., Lanz T. & Breitenmoser-Würsten C. 2019. Conservation of the wildcat (*Felis silvestris*) in Scotland: Review of the conservation status and assessment of conservation activities. IUCN SSC Cat SG, February 2019, 68 pp.

Dinnik N. Y. 1914. Zveri Kavkaza [Mammals of the Caucasus]. Vol. 2. Zap. Kavkaz. otd. i Russkogo geogr. obshch. Tiflis. No 27. P. 247.536. (In Russian).

Fattebert J., Balme G., Dickerson T., Slotow R. & Hunter L. 2015. Density-dependent natal dispersal patterns in a leopard population recovering from over-harvest. PLoS ONE 10(4): e0122355.

Geptner V. G. & Sludskiy A. A. 1972. Mlekopitayushchiye Sovetskogo Soyuza. T. 2. Ch. 2.

Fig. 4. Female leopard released in Caucasian Nature Reserve in 2020 (Photo S. Trepet and A. Pkhitikov).

Khishchnyye (giyeny i koshki). [Mammals of the Soviet Union. Part 2. Predatory (hyenas and cats)]. M.: Vysshaya shkola. 552 pp. (In Russian).

IUCN/SSC. 2013. Guidelines for Reintroductions and Other Conservation Translocations. Version 1.0. Gland, Switzerland: IUCN Species Survival Commission, viiii + 57 pp.

Kiabi B. H., Dareshouri B. F., Ghaemi R. A., Jahanshahi M. 2002. Population status of the Per-sian leopard (*Panthera pardus saxicolor* Pocock 1927) in Iran. Zoology in the Middle East 26, 41–47.

Mousavi M. & Moqanaki E. 2017. Leopard conservation in the Iranian Caucasus: 2017 Progress Report, Workshops on Revision of the Strategy for the Leopard Conservation in the Caucasus and Coordinating the Monitoring of Leopard and Prey Species in the Ecoregion 25–27 April 2017, Tbilisi, Georgia.

Rozhnov V. V. & Lukarevskyi V. S. 2008. Program for reintroduction of Central Asian leopard in the Caucasus region. Moscow: KMK. p. 65.

Rozhnov V. V., Chistopolova M. D., Lukarevskii V. S., Hernandez-Blanco J. A., Naidenko S. V. & Sorokin P. A. 2015. Home range structure and space use of a female Amur leopard (*Panthera pardus orientalis,* Carnivora, Felidae), Biology Bulletin 42, 821–830.

Rozhnov V. V., Yachmennikova A. A., Naidenko S. V., Hernandez-Blanco J. A., Chistopolova M. D., Sorokin P. A., ...& Magomedov M. R. D. 2018. Monitoring of the Persian leopard and other large cats. M.: Association of scientific publications KMK, 2018. 121 p. ISBN-978-5907099-14-2.

Rozhnov V. V., Yachmennikova A. A., Hernandez-Blanco J. A., Naidenko S. V., Chistopolova M. D., Sorokin P. A., ...& Magomedov M. R. D. 2019. Issledovanie i monitoring krupnykh koshek v Rossii (Study and Monitoring of Big Cats in Russia), Moscow: KMK.

Rozhnov V. V., Pshegusov R. H., Hernandez-Blanco J. A., Chistopolova M. D., Pkhitikov A. B., Trepet S. A., Dronova N. A., Naidenko S. V. & Yachmennikova A. A. 2020a. MaxEnt modeling for predicting suitable habitats in the North Caucasus (Russian part) for Persian leopard (*P. p. ciscaucasica*) based on GPS data from collared and released animals. Izvestiya, Atmospheric and Oceanic Physics, 2020, Vol. 56, No. 9, pp. 1090–1106. © Pleiades Publishing, Ltd., Issledovanie Zemli iz Kosmosa, 2020, No. 2, 35–55.

Rozhnov V. V., Yachmennikova A. A., Dronova N. A., Pkhitikov A. B., Magomedov M. R. D., Chestin I. E., ...& Alibekov A. B. 2020b. The restoration of Persian leopard in the Caucasus (scientific approach). Moscow. KMK Scientific Press Ltd., 219 pp.

Rozhnov V. V., Naidenko S. V., Hernandez-Blanco J. A., Chistopolova M. D., Sorokin P. A., Yachmennikova A. A., Blidchenko E. Y., Kalinin A. Y. & Kastrikin V. A. 2021. Restoration of the Amur Tiger (*Panthera tigris altaica*) Population in the Northwest of Its Distribution Area, ISSN 1062-3590, Biology Bulletin, 2021, Vol. 48, No. 8, pp. 1401–1423. © Pleiades Publishing, Inc., 2021. Russian Text © The Author(s), 2021, published in Zoologicheskii Zhurnal, 2021, Vol. 100, No. 1: 79–103.

Vargas A., Sanchez I., Martinez F., Rivas A., Godoy J. A., Roldan E., Simon M. A., Serra R., Perez Maj., Ensenat C., Delibes M., Aymerich M., Sliwa A. & Breitenmoser U. 2008. The Iberian lynx *Lynx pardinus* Conservation Breeding Program. International Zoo Yearbook 42, 190–198.

Vitkalova A. V. & Shevtsova E. I. 2016. A complex approach to study the Amur Leopard using camera traps in Protected areas in the southwest of Primorsky krai (Russian Far East), Nature Conservation Research. Zapovednaya Nauka 1, 53–58.

[1] A. N. Severtsov Institute of Ecology and Evolution, Russian Academy of Sciences, Moscow, 119071 Russia
**<felis.melanes@yandex.ru>
*<rozhnov-v-2015@yandex.ru>

[2] WWF Russia, Moscow,109240 Russia

[3] A. K. Tembotov Institute of Ecology of Mountain Territories, Russian Academy of Sciences, Nalchik, 360051 Russia

[4] Shaposhnikov Caucasian State Nature Biosphere Reserve, 354340 Russia

JOSÉ DIAS FERREIRA[1] AND ALEXANDER SLIWA[2*]

Ex situ conservation of the Persian leopard - the EAZA leopard EEP

The Persian Leopard Breeding Programme together with the Felid TAG of the EAZA is responsible for securing a self-sustaining captive population with the highest possible genetic diversity of this threatened leopard subspecies. The *ex situ* population is serving as a source for breeding leopards in the Sochi Breeding Center in the Russian Caucasus, but also aims to introduce further new founders into the captive population. Multiple tasks are carried out, including capacity building, assessing and improving the holding conditions and husbandry in institutions as well as facilitating the preservation of genes of underrepresented bloodlines through reproductive research and assistant reproductive techniques.

Introduction and organisational aspects

Formed in 1992, the EAZA's (European Association of Zoos and Aquaria) goal is to facilitate cooperation within the scientifically led European zoo and aquarium community with regard to conserving their captive (*ex situ*) animal populations, and more generally to advance education, research, and *in situ* conservation (EAZA 2016). Member zoos are bound by guidelines for collaboration in breeding programmes. The EAZA Taxon Advisory Groups (TAGs) decide, which species are recommended for management under EAZA Ex-situ Programmes (EEP), what the roles of each EEP for the respective taxon is, i.e. as an insurance population, source for animals for reintroduction, or educational. Within an EEP, several member zoos are breeding the species and working together under the supervision of the EEP coordinator. Regarding the Persian Leopard EEP, both the coordinator and the Felid TAG chair serve as partners for GOs and NGOs for *in situ* projects.

The primary goal of the Persian Leopard (PL) EEP, established in 1990, is to keep the captive population of this subspecies self-sustaining, genetically and behaviourally healthy, to serve as an insurance or source population for reintroductions or reinforcements, should the wild population decline further. Outside the EAZA region, only few PLs are kept in North America, Japan and in several range countries, which by themselves cannot form a self-sustaining breeding population.

History of the EEP

After the establishment of the PL EEP in 1990, there was a quick increase from 70 to 80 leopards within 3 years (Fig. 1). The population then remained largely stable at 80 individuals for 15 years. In this phase, the interest of the zoos to hold PL dwindled, which was linked to an increase in population number of the Amur leopard (*P. p. orientalis*) in EAZA zoos, as a preparation for a reintroduction programme in the Russian Far East (Christie & Arzhanova 2010). Meanwhile the PL EEP population was slowly aging (Fig. 2) and increasingly, PLs found their way to non-EAZA zoos. Some older male leopards were impossible to pair with females, resulting even in females being killed or injured. These males needed to be kept alone, leading to space problems in the EEP zoos.

Leopard is a complicated felid to breed, starting from the pairing of partners, which, when not done carefully for all individuals regarding age, temperament and enclosure conditions, can lead to severe aggression (Raffel 2006). A female usually produces two kittens (mean litter size = 1.9; Ferreira et al. 2017). Offspring typically stay with their parents until 15–18 months of age, but even longer if no new offspring are born (Stein & Hayssens 2013, Ferreira et al. 2017). The kittens undergo a relatively long period of socialisation and learning from their mother e.g. by observing her hunting behaviour (Stein & Hayssens 2013). Females hence produce a litter on average every second year, starting at 3–4 years of age. They remain fertile up to the age of 12–17 years; males can reproduce until the age of 20 years. Compared with i.e. Iberian lynx, which can produce a litter of 3 kittens every year (Vargas et al 2008), the leopard has a low productive rate. Nevertheless, the population continued to slowly increase from 100 in 2005 (Raffel 2006) to 103 in 2021 (Fig. 1).

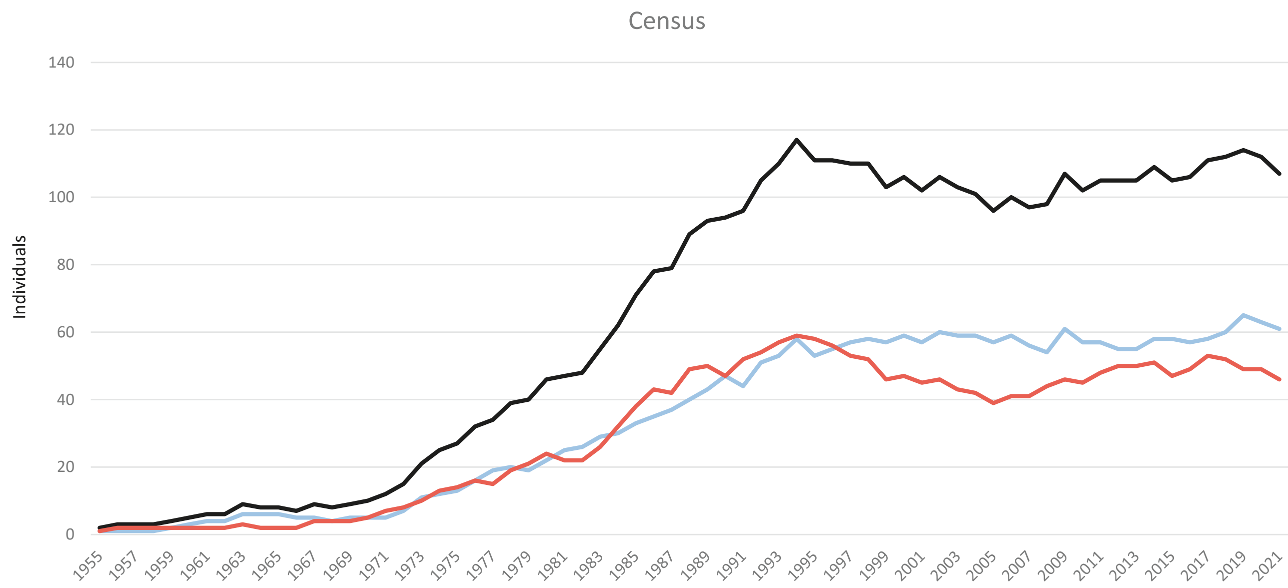

Fig. 1. Development of the Persian leopard population in European Zoos 1955–2021. The EEP was established in 1990.

The EEP as a source for reintroduction in the Caucasus

The Ministry of Natural Resources (MNRE) of the Russian Federation planned the reintroduction of leopards in the north-western Caucasus by breeding wild-caught leopards in the specifically built Sochi Breeding Center (SBC) (Rozhnov & Lukarevsky 2008). As sourcing suitable Persian leopards from the wild turned out to be impossible (Rozhnov et al. 2022), the MNRE asked assistance from IUCN and EAZA. After a visit to the SBC in October 2011, EAZA agreed that the PL EEP would provide leopards and technical support. A MoU was signed between the three institutions in 2012, and the Felid TAG and the IUCN SSC Cat Specialist Group were mandated to implement the MoU on behalf of EAZA and IUCN, respectively. Four members of these organisations formed the Caucasus Leopard Reintroduction Advisory Group – CLRAG (Fig. 3; Breitenmoser et al. 2015). The CLRAG is communicating with the MNRE, but also directly with the SBC on aspects of pairing of leopards (breeding recommendations), husbandry, medical interventions if EEP leopards are concerned, and on the assessment and permits for release offspring of EEP leopards. In order to integrate the SBC into the conservation breeding programme, the MNRE (as the owner of the SBC) joined the EEP as a non-EAZA member.

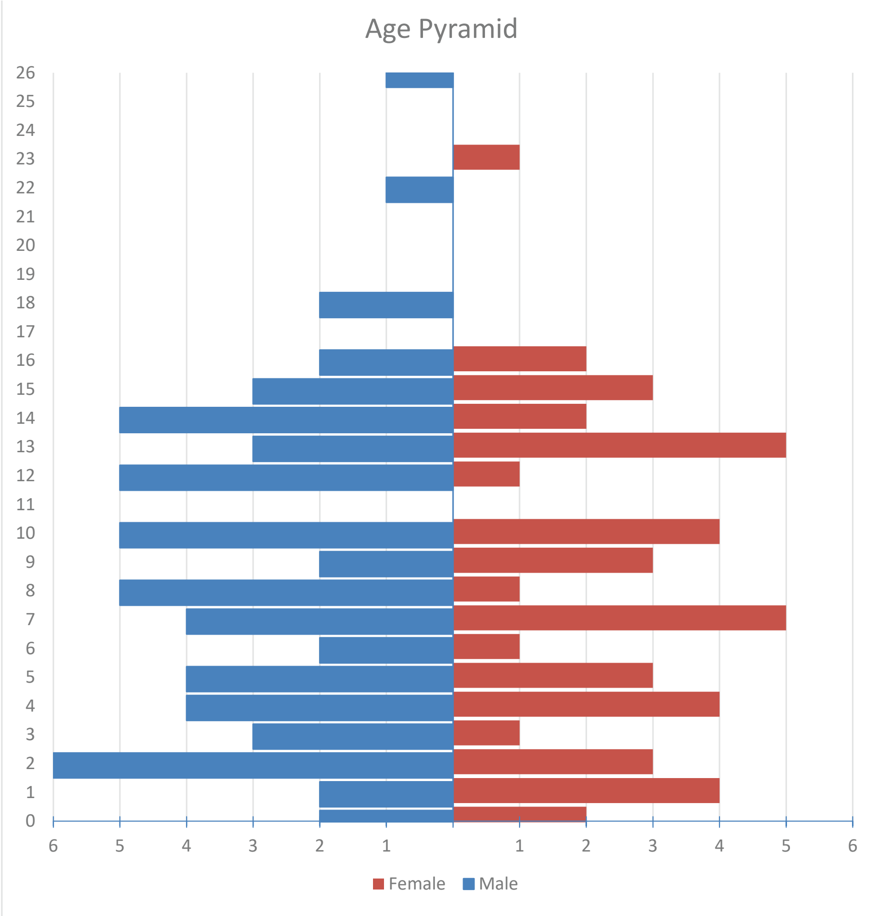

Fig. 2. Persian Leopard EEP Age Pyramid at 31.12.2021. Males are on the left side, females on the right.

Specific adaptation to the new role as source for reintroduction

Since 2012, specific measures have been implemented to enable the EEP specifically to serve as a source population for *in situ* releases. In 2017, a Long-Term Management Plan was developed (EAZA 2017). A target population of the PL EEP was set at 200 leopards, with the continuous role to serve as an insurance population, however with the additional task to provide leopards for the *in situ* programme. Measures implemented included:

- After raising awareness within and beyond the EAZA community, twelve new EAZA approved institutions joined the EEP.

Numerous transfers between approved participants (zoos) allowed creating twenty new PL breed-ing pairs. A specific effort was made to in-clude zoos in range countries (Turkey and Georgia, with further candidates in Armenia, Iraq and Afghanistan), which can also serve local educational purpose.

Fig. 3. CLRAG at SBC in 2015. From left to right: Alexander Sliwa, José Dias Ferreira, Marianne Hartmann, and Urs Breitenmoser, with Natalia Dronova (PL Species Officer WWF Russia; Photo A. Sliwa).

Fig. 4. Semen collection procedure on PL Rica, Tehran, Iran 2017. From left to right: Iman Memarian (Tehran Zoo), Imke Lüders (Geolifes) and Rui Bernardino (Lisbon Zoo; Photo P. Tabrizizade).

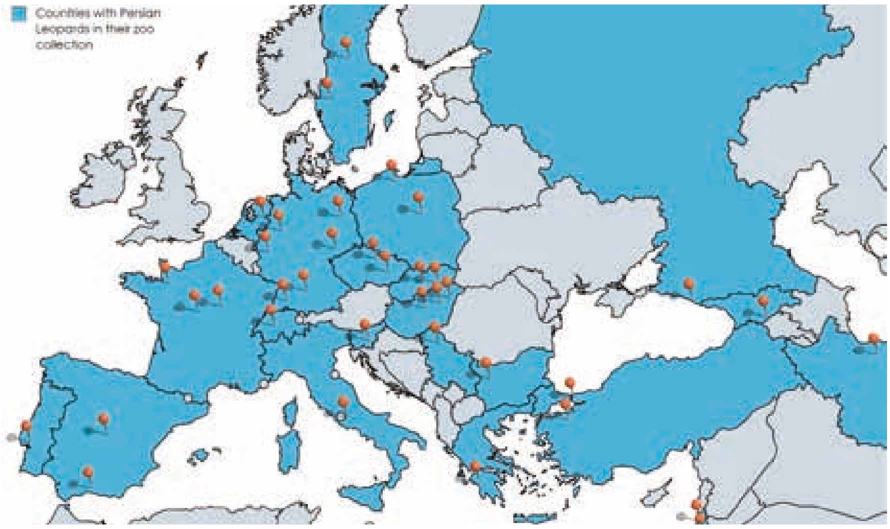

Fig. 5. Location of zoos (needles) participating in the Persian Leopard EEP in 2021.

- EAZA zoos sponsored and staffed actions to improve the genetic composition of the EEP. The first successful artificial insemination with PL took place at Nordhorn Zoo, Germany; three semen collection procedures (Fig. 4) from PL founders (France, Iran, Russia) were performed (Ferreira & Sliwa 2017); Tehran Zoo with their potential PL founders for the EEP was approved as a non-EAZA EEP participant. Currently, there are ongoing efforts to source new founder PLs from Afghanistan and Iraq.
- Communication to the PL holders was stepped up to better manage a growing PL population and to keep everyone informed about the *in situ* activities involving EEP leopards.
- Different new designs of enclosures for keeping and breeding leopards were developed. Greater emphasis was given to enclosure furnishing and enrichment schemes for PLs. Advice particularly towards to new holders was provided before leopards were transferred. In some cases, technical visits were made to address site-specific problems.
- All these developments of the PL EEP were repeatedly presented at international conferences to inform wider circles of both *in situ* and *ex situ* specialists.

The current EEP population stands at 106 (61.45) PL (Fig 1) in 40 holdings (31/12/2021; Fig. 5), having developed since 2012 from 85 (44.41) PL in 39 zoos. Renewed interest from holders was clearly stimulated through the perspective to provide leopards to support the reintroduction in the Caucasus. In the past 5 years, a total of 10 PLs were released in the Russian Caucasus (Caucasus Biosphere Reserve and Alanya National Park; Rozhnov et al. 2022); these leopards are no longer considered part of the EEP population.

The scientifically-led EAZA EEP zoos provide these services voluntarily and without specific funding for current (and future) felid reintroduction programmes: trained staff time to care for the animals, provide food and specific housing, organisation of transfers of sensitive and, in the case of leopards, potentially dangerous species between institutions, also including the specific breeding centres. International transfers are highly time consuming, and the professional capacity differs between institutions (zoos). It also includes negotiations regarding veterinary requirements, crate specifications, and permits, all in different languages which need translation. The mode and speed of transport, as well as international CITES and IATA regulations for import and export particularly for threatened and highly sensitive species is important and complex. For all of this, clear and timely communication (generally in English) is key to avoid misunderstandings and possible harm to the animals.

Training and advice to SBC staff and exchange of leopards

In 2013, five staff members of the Sochi Leopard Breeding Centre (SBC) participated in a 10 days training at Lisbon Zoo, Portugal, and Nordens Ark, Sweden, specifically tailored to the needs of the SBC regarding husbandry and veterinary care of leopards. In 2013 and 2014, repeated visits of the CLRAG to the SBC took place, in order to discuss improvements of enclosure structures, environmental enrichment, socialisation of cubs and the training for living in the wild.

After trials to breed Persian leopards from the wild population first failed, a proven breeding pair of PL (Fig. 6), was sent from Lisbon Zoo to the SBC in October 2012, which stimulated breeding there. In 2013, the first litter in Sochi was born from the Lisbon pair. In 2014, the Lisbon breeding female gave birth to 3 leopards sired by one of the wild-caught Turkmenistan males. These 3 offspring, born from a mating not recommended by the PL EEP, were subsequently transferred to European holders because they were closely related to the two genetic lines kept at SBC and were considered unsuitable for being reintroduced. In 2015, a sub-adult male was sent from the EAZA member Parc-des-Felins (Nesles, France) to the SBC to be trained and released. However, this leopard is still being kept isolated in the SBC. The Lisbon pair kept at SBC bred and raised three additional litters in 2016, 2018 and 2020. A second proven breeding pair was sent from the Nordens Ark Foundation (Sweden) to the SBC in late 2020 to introduce new genes to the programme and widen the gene pool of the founder population. In July 2021, the female gave birth to a litter of two kittens.

In 2017, following a semen quality check-up, a Persian leopard "Gaspar" was transferred from the EEP population (Lisbon Zoo) to the newly approved EEP participant, Tehran Zoo, to breed with a rescued wild female kept there. Unfortunately, this pair has not reproduced so far.

Discussion

Zoos have limited display and holding space for large cats, including Persian leopards, thus their interest in a programme is often proportional to their potential for involvement and to breed the cats. Most zoos are not specific centres for breeding-for-release and also need to consider economic aspects. Offspring of large cats are attractive to visitors, so breeding on display is highly liked by zoo managers, how-ever only with the opportunity to outplace these offspring due to limited holding capacity. Leopard cubs in displays are however not suited for being released to the wild because, because they are accustomed to people and may not avoid areas with human activity, which could eventually create human-leopard conflicts and jeopardise their survival. However, leopards which are not considered for release by an *in situ* programme and are also not needed for upholding the breeding population are obstructing holding space. Furthermore, the PL EEP also competes with the Amur leopard, the Chinese leopard (*Panthera p. japonensis*), and snow leopards (*Panthera uncia*) EEP for holding space within EAZA institutions.

The goal of the EEP is to conserve a high percentage of the wild gene pool. This requires integrating new founders from the wild into the EEP for safeguarding these genes. Altogether, monitoring the genetic constellation of the three populations is needed: (1) the wild, (2) the EEP, and (3) the founder population in the reintroduction project.

The PL EEP faced considerable challenges related to the commitment to help the reintroduction of the PL in the Caucasus. Over a nine-year period, the leopards from the EEP produced a total of 13 leopards at the SBC. A crucial challenge is the placing of SBC leopards, which are unsuitable for being released (for either genetic, behavioural or physical reasons) within the EEP holding community, as the SBC itself is lacking capacity in holding space for such animals.

The communication between EAZA/CLRAG and the SBC has not always been easy, not only because of language barriers, but also due to differing ideas about breeding, training, and release (e.g. age of such leopards). As there is no experience with the release of captive-born leopards (see also Rozhnov et al. 2022), all decisions need to be based on assumptions.

Over the next years, the EEP will have to provide more proven leopard breeding pairs to the SBC, to replace genetically over-represented and old leopards and to increase the output; essentially the turnover needs to be accelerated, although there is no holding space for surplus leopards at SBC. To achieve this, the EEP population must be very carefully managed, in order to provide sufficient suited breeders, but avoid surplus animals in the programme. This will require a close collaboration between the all partners and a agreement on the reintroduction scheme (Rozhnov et al. 2022). A zoo-based EEP has not the same possibilities as e.g. the six specific breeding centres created for the Iberian lynx reintroduction programme (Vargas et al. 2008). As breeding leopards requires much more space, time, and funding than breeding Iberian lynx, the capacity of specific centres such as the SBC will remain limited, and will continue to depend on breeding pairs provided by the EEP. There is an ongoing discussion on whether only animals bred and trained in the SBC, should be released or whether zoos may also provide animals suited to go directly into a training and re-wilding programme. Such an approach could considerably increase the output. Therefore, the EEP is currently considering the breeding in specific facilities with the aim to be able to provide a sufficient number of mentally and physically fit leopards either for further breeding or eventually for training for release. Either way, the reintroduction programme will need additional holding and training enclosures in order to prepare more individuals simultaneously (see also Rozhnov et al. 2022).

Fig. 6. Persian leopards 'Andrea' and 'Zadig' at SBC on 25 January 2013 (Photo Ministry of the Natural Resources and Environment (MNRE) of the Russian Federation).

References

Breitenmoser U., Sliwa A., Ferreira J. D. & Hartmann M. 2015. Intermediate report and assessment of the conservation breeding in the Sochi Leopard Breeding Centre (SLBC) and the preparation of leopards for the release in the Caucasian Biosphere Reserve. Unpubl. report on behalf of MNRE, EAZA, IUCN, WWF Russia, and SBC, 10 pp.

Christie S. & Arzhanova T. 2010. Far Eastern leopard conservation breeding programs for reintroduction. Appendix 8 in: A program for reintroduction of the Far Eastern leopard into southern Sikote Alin, Primorsky Krai, Russian Far East – Draft, pp. 97.

EAZA. 2016. EAZA Membership and Accreditation Manual - Version 4, European Association of Zoos and Aquaria, Amsterdam, The Netherlands.

EAZA. 2017. Long-term management plan for the Persian Leopard (*Panthera pardus tulliana*), European Association of Zoos and Aquaria, Amsterdam, The Netherlands.

Ferreira J. D. & Sliwa A. 2017. Persian leopard semen collection at Tehran Zoo. Cat News 65, 26.

Ferreira J. D., Nolasco S., Schad K, & Fienieg E. 2017. Long-term management plan for the Persian leopard (*Panthera pardus tulliana*) European Endangered Species Programme (EEP). Lisbon Zoo, Lisbon, Portugal.

Hartmann M., Ferreira J. D., Sliwa A. & Breitenmoser U. 2016. From the zoo to the wild. Zooaquaria 95, 14–15.

Rozhnov V. V. & Lukarevsky V. S. 2008. Program for reintroduction of central Asian leopard in the Caucasus region. Scientific Press Ltd. 65 pp.

Rozhnov V. V, Yachmennikova A. A, Dronova N. A, Naidenko S. V, Hernandez-Blanco J. A, Chistopolova M. D, Pkhitikov A. B, Tembotova F. A. & Chestin I. E. 2022. Experience of the leopard recovering through reintroduction in the Russian Caucasus. Cat News Special Issue 15, 67–71.

Raffel M. 2006. EEP Report 2006 and Regional Studbook Persian Leopard (*Panthera pardus saxicolor*). Allwetter Zoo Münster, pp.28.

Stein A. B. & Hayssens V. 2013. *Panthera pardus* (Carnivora: Felidae). Mammalian Species, No. 900, Vol. 45, 30–48.

Vargas A., Sanchez I., Martinez F., Rivas A., Godoy, J. A., Roldan E., ...& Breitenmoser U. 2008. The Iberian lynx Lynx pardinus conservation breeding program. Int. Zoo Yb 42, 190–198.

[1] EEP Coordinator Persian Leopard, Lisbon Zoo, 1549-004 Lisbon, Portugal
<jdferreira@zoo.pt >

[2] EAZA Felid TAG chair, Cologne Zoo, 50735 Köln, Germany
*<sliwa@koelnerzoo.de>

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