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The Persian Leopard

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

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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).

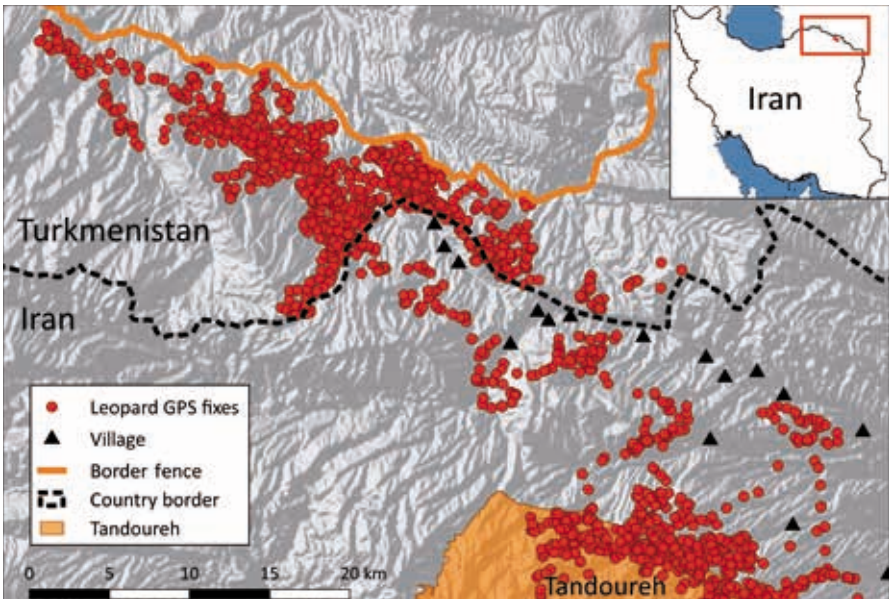

Fig. 2. GPS-tracked locations of a collared Persian leopard that dispersed from Tandoureh National Park in north-east Iran to Turkmenistan (Farhadinia et al. 2018). These locations show that although the leopard moved freely across the international border, the security fence lying further north within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

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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).

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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

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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 Cau-

casus 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.

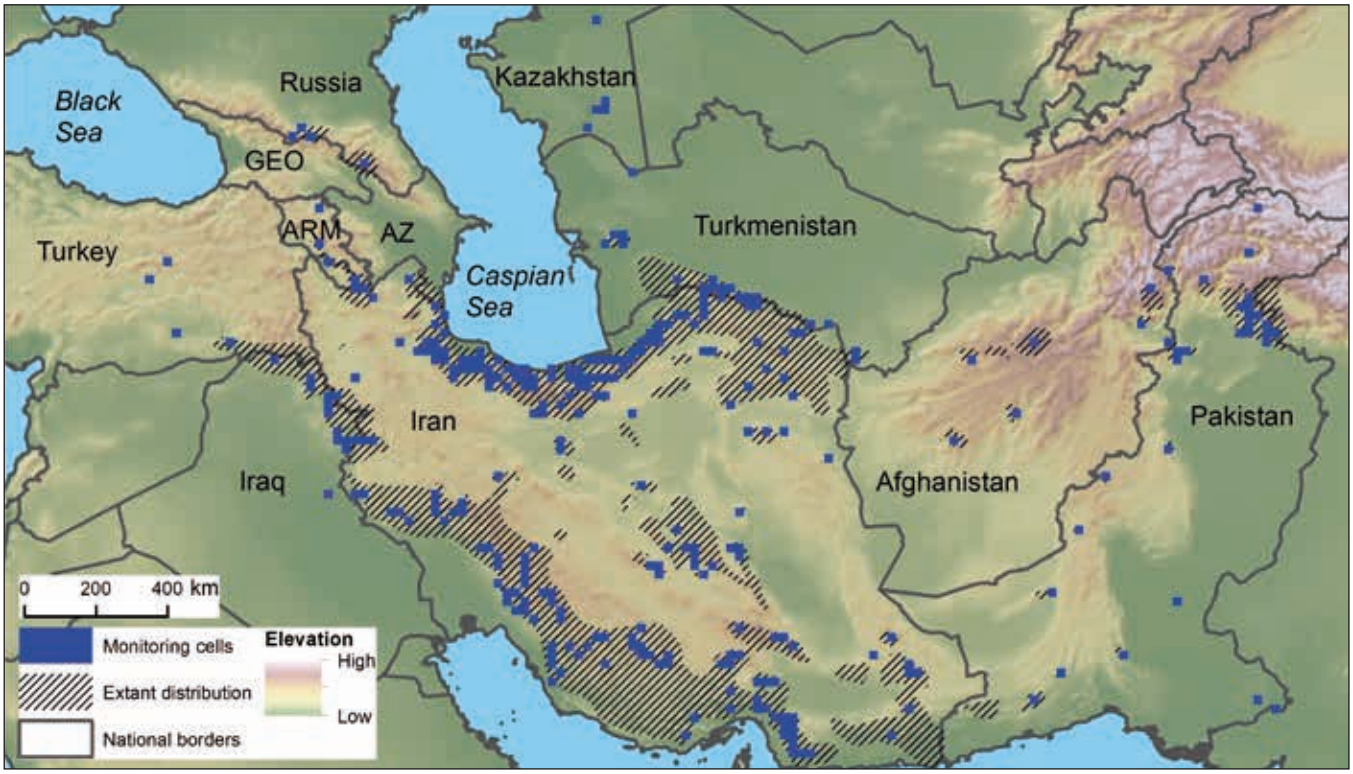

Fig. 1. The distribution of identified monitoring units (25x25 km) of the Persian leopard and its prey across eleven countries with confirmed presence of the species since 2010 overlayed on the distribution map of Persian leopard from Bleyhl et al. (2022).

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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