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Supporting wildlife movement amid the rise of border infrastructure

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Abstract

Transboundary areas of conservation importance affected by border infrastructure and militarization urgently need connectivity conservation solutions. Where human conflicts are ongoing and peace initiatives may be unviable, smaller-scale approaches can still be implemented. We propose a multi-faceted approach to support animal movement and minimize impacts of multiple border barriers on medium to large-sized mammals in Białowieża Forest, a UNESCO World Heritage Site shared by Belarus and Poland. These “wildlife border passages” require maximizing or modifying existing infrastructure or restoring known pathways as follows: 1) opening gates designed to facilitate wildlife movement between Poland and Belarus, also to release animals trapped between barriers; 2) creation of passages at barrier bottom to permit movement of medium-sized species including those highly threatened by border infrastructure such as Eurasian lynx; and 3) unfencing of riverine areas, which often serve as movement corridors for large mammals like moose. Joint monitoring of wildlife border passages to evaluate and improve their effectiveness will strengthen bilateral collaboration. Adopting less invasive security technologies, for example virtual fencing, can help realize such approaches at lower cost to the natural world.

Preserving ecosystems in a fenced world

Fences are among the most pervasive and prevalent human-made structures, exceeding the road network at least tenfold (Jakes et al. 2018). Border fences, often erected in transboundary landscapes of conservation importance (Liu et al. 2020), are particularly impassable (Zhuo et al. 2024; Lei & Wang 2025; Sennett & Chambers 2025). Such barriers are often built without environmental impact assessments, exempted from various laws in the name of national security (Nowak et al. 2024), and have an intensive construction phase followed by a prolonged phase of modification (Trouwborst et al. 2016). They are usually long, fortified with sharp elements, floodlights, alarm systems, associated with linear infrastructure such as roads, and continuous military, patrol, and maintenance activities (*ibid.*). Restricted access is usually imposed, impeding scientific data collection and monitoring, while mitigation may be challenging without compromising a border fence’s intended purpose of keeping out people.

Such fences are being constructed even in the few (11%) terrestrial transboundary areas where nature protection exists on both sides of a border (Zhang et al. 2025). They thus hinder cross-border conservation of wildlife, including peripheral taxa whose continued occurrence in one country depends on ecological connectivity with another (Thornton et al. 2017). Restricting animal movement cuts off gene flow and population viability, nutrient flow, seed dispersal, can exacerbate human-wildlife conflicts, and can be deadly if animals become entangled (Pokorný et al., 2017) or entrapped (Harrity et al. 2024). Animals may learn to avoid fenced areas, forfeiting resources or access to habitat (Jones et al. 2019; Xu et al. 2021), and hindering future connectivity restoration potential. Blocking animal movement has important consequences for

ecosystem functioning in the long-term and may reduce ecosystem resilience to global changes (Malhi et al. 2016).

There is urgent need to mitigate the ecological effects of border barriers in transboundary regions, and reconnect habitats and wildlife populations even in militarized natural areas. Among possible solutions are peace parks, e.g., a Greater Himalayan Peace Reserve was recently proposed as a diplomatic tool to safeguard one of the most biodiverse regions in the world (Pandit 2025). Peace parks have a nearly 100-year history. In 1924, the Kraków Protocol between Poland and then Czechoslovakia led to parks like Pieniny International Landscape Park. Around the same time, Rotary Club members in Canada and the United States initiated the creation of the world's first official peace park, Waterton-Glacier International Peace Park (1932), honoring ecological continuity on the formerly unsevered lands of the Blackfoot Confederacy (*Niitsitapi*) and strengthening US-Canada relations (Quinn 2012). Peace parks have since been proposed in areas of long-standing military conflict such as Siachen Glacier at the India-Pakistan border on the basis that a peace park would reduce costs—human, economic, and environmental (Biringer & Cariappa 2012). A related approach recently proposed is “ecological peace corridors” (Cazzolla-Gatti 2025), intended to “provide safe passages for migratory species and support the natural movement patterns of wildlife” in conflict zones.

Under scenarios of ongoing human conflicts and/or when peace parks or corridors are not possible, a smaller-scale approach is that of “wildlife border passages”. For instance, the Kazakhstan Border Service of the National Security Committee agreed to pilot 32 passages for ungulates in the border fences along Kazakhstan's state border with Uzbekistan and Turkmenistan. The passages, monitored with camera traps, provided evidence that a number of species are using them, including urial sheep (*Ovis vignei*), goitered gazelle (*Gazella subgutturosa*), kulan (*Equus hemionus*) and caracal (*Caracal caracal*) (Pestov et al. 2020). To strengthen conservation efforts in this critical transboundary hotspot, in 2024, Kazakhstan, Turkmenistan and Uzbekistan, within the frame of the Convention on the Conservation of Migratory Species of Wild Animals Central Asian Mammals Initiative, signed a Memorandum of Cooperation for Wildlife Conservation on the Ustyurt Plateau (“the Ustyurt Memorandum”) and agreed to a 2025-2030 Roadmap to the Ustyurt Memorandum, reinforcing the commitment of all three countries to protecting migratory wildlife, their habitat, and connectivity, and signaling to the international community that the Ustyurt Plateau is one of their conservation priorities.

Another example comes from the US-Mexico border, where, in 164 km of border wall, 13 small openings (sized 21.5 x 27.8 cm) at the base of the bollard barrier accommodate species such as coyotes (*Canis latrans*), bobcats (*Lynx rufus*), and javelinas (*Pecari tajacu*) (Harrity et al. 2024). In addition, on a seasonal basis, larger floodgates are opened during heavy rain and through these, black bear (*Ursus americanus*) and deer can pass. Researchers have encouraged the US

Department of Homeland Security to add more and larger openings, and keep floodgates open for longer periods to maintain connectivity and ensure wildlife movement and access to resources under changing conditions. Along this nearly 3145-km border, peace parks have also been proposed, at least earlier this century (Sifford and Chester 2007).

Białowieża Forest as a case study

An example of nature protection on both sides of an international border is Białowieża Forest, in the Polish-Belarusian borderland, recognized as a transboundary UNESCO World Heritage Site (WHS) in 1992, and extended in 2014 (currently covering 1,418.85 km², Fig. 1). Białowieża Forest is exemplary in its naturalness and preservation of ecological processes, often described as Europe's last primeval lowland forest (Jaroszewicz et al. 2019), historically characterized by not less than 70% canopy cover (Latałowa et al. 2016), and long-term field studies (Broughton et al. 2025). Białowieża Forest is inhabited by megafauna such as European bison (*Bison bonasus*), moose (*Alces alces*), red deer (*Cervus elaphus*) and grey wolf (*Canis lupus*), which may already be adversely affected by international border fencing (Nowak et al. 2024).

After World War II, Białowieża Forest, which was entirely located in Poland, became transboundary when the new borders of Europe were drawn and the forest was divided between Poland and Belarus (then part of the Soviet Union). Prior to 1981, animals moved freely across some parts of the Polish-Belarusian border (upper half of Białowieża Forest, between Narewka and Narew Rivers, Fig. 1); then, in 1981, the symbolic 1 meter-high fence of the *sistema* (soviet-era complex of border security infrastructure) was increased to 2.5 m in response to Poland's Solidarity movement and geopolitical transformation, thereby restricting ungulate movements, though not movements of large carnivores such as wolves, Eurasian lynx (*Lynx lynx*) and even dispersing brown bears (*Ursus arctos*) (Jędrzejewska & Jędrzejewski 1998; Diserens et al. 2020), which could cross it by digging under or climbing over. At the time of Białowieża Forest's UNESCO listing, framed during a period of cooperation between Poland and Belarus in Białowieża Forest that spanned the first part of the 21st century (Artemenko 2010), the *sistema* on the Belarusian side was recommended for removal. However, in 2021, geopolitical tensions and hostility escalated in the region, affecting the two neighbors and now harming the integrity of the forest and weakening environmental stewardship efforts (UNESCO 2024).

In 2022, Poland, Lithuania and Latvia constructed barriers along their borders with Belarus in response to increasing irregular cross-border movement of people from mainly Western Asian and African countries via Belarus (Ancite-Jepifánova 2024). The 186 km of fencing in Poland includes 53 km through Białowieża Forest, one of the main grounds of what some refer to as a humanitarian crisis (e.g., Helsinki Foundation for Human Rights 2022) and others call hybrid war (e.g., Dyner 2022). Poland's 5.5m-high border fence with steel bars, a concrete foundation, and topped with razor wire (Fig. 2) together with Belarus's *sistema*, consisting of a 2.5 m-high fence with barbed wire, dirt roads and ploughed strip, has resulted in a multi-fence/barrier

system, blocking not only cross-border movements of large mammals but also trapping animals in between the new fence and the old *sistema*. This critical and exceptional situation requires immediate attention and swift action.

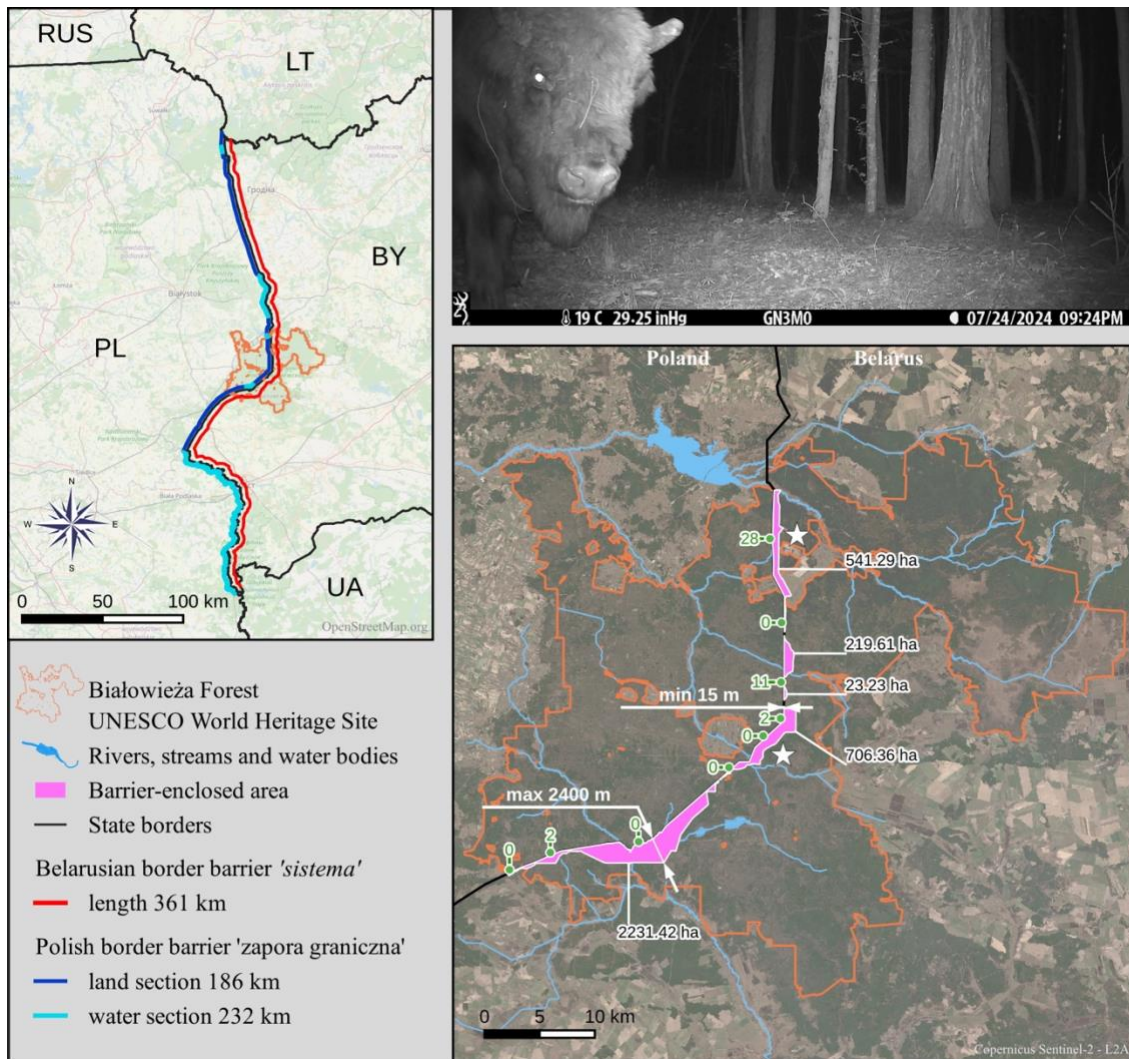


Fig. 1: Barriers on the Poland-Belarus border (upper left) and the habitat pockets created by the barriers in Białowieża Forest (lower right). The entire barrier-enclosed area from the tri-border of Ukraine (UA), Belarus (BY) and Poland (PL), to the border with Lithuania (LT), has an area of 155 km² (upper left); therefore, a quarter of such fenced habitat lies within Białowieża Forest where the narrowest (15 m) and widest (2.5 km) intervals between the barriers are found (lower right). Pockets of habitat in between the barriers in Białowieża Forest range in size from 23 ha to 2231 ha. On the basis of limited data, the northern part of Białowieża Forest appears to be most promising for restoring bison transboundary movement in that the most bison were detected in the northernmost site in 2023-2024 in 7,466 camera trap days along the border (Nowak et al. 2025). Further, in two sample areas (indicated with a white star on the map, in the north and center),

uniformed personnel stationed along the border reported seeing bison approaching the Polish barrier from the Belarusian side. By comparison, the only lynx near the border was camera-trapped near wetlands where no main barrier was built on the Polish side but where razor wire fences are used instead.

Multi-faceted approach to support wildlife movement

The fenced-off strip of land between fences in Poland and Belarus is of varying width, from 10 meters (where the two countries' fences come together) to more than 2 kilometers wide with wildlife such as European bison getting fenced in between according to reports from military personnel as well as a UNESCO 2024 mission report (UNESCO 2024). These patches of fenced off habitat range in size from 0.2 to more than 20 km² and form a chain of relatively ecologically isolated fragments which together constitute 37 km² just within Białowieża Forest. If using the following criteria: link or connector is fewer than 20 m wide and less than 100 m long, then there are five such fenced patches in Białowieża Forest, sized 23-2231 ha (Fig. 1). In the largest of these, there is a gap in Poland's main barrier because of wetlands, where instead there are rows of razor wire fencing. Even this largest habitat pocket (~22 km²) is smaller than the home ranges of large ungulates such as red deer and European bison while only the largest pocket could accommodate moose (Schmidt et al. 2024 and references therein). These ungulates not only have expansive home ranges but also depend on a variety of habitats which explains their seasonal movements. This habitat diversity is not likely to be adequately met in the fenced off areas leading to deterioration of both the borderland habitats and physical condition of animals.

According to Polish government authorities, nine of the 24 gates in Poland's barrier intended to facilitate wildlife movement are found in the section of the barrier that runs through Białowieża Forest; however, they have never been opened (Fig. 2). Opening more than one gate will be necessary to release animals from each of the disconnected patches and opening all gates may improve the likelihood of releasing trapped animals but may still not resolve the problem entirely. Unfencing further segments may be required, and a combination of approaches is ultimately needed to improve animal movement across the forest.

Considering available information on border barriers in Białowieża Forest, we propose to enhance connectivity by enabling wildlife movement in several ways (Fig. 3):

- 1) Make use of existing gates (Fig. 2) and coordinate their temporal opening in the Polish barrier and concomitant sections (technical doors) in the Belarusian *sistema* fence (Belarusian side) to encourage release of trapped animals and movement between the two sides of the forest;
- 2) Create wildlife passages (~22 cm x 28 cm), modeled on those in the US-Mexico border (Harrity et al. 2024), targeting species whose populations are predicted to be particularly impacted by the border fences such as lynx, while also accommodating movement of

common species such as European badger (*Meles meles*) and roe deer (*Capreolus capreolus*);

- 3) Unfence (permanently or at least seasonally) selected fragments of riverine areas as they are known to function as natural corridors for wildlife (e.g., Sánchez-Montoya et al. 2023); during initial planning phases of the border barrier, rivers were to remain unfenced. If unfencing is not possible (for security reasons), installing floodgates (as in the US-Mexico border wall) or a double door/gate system similar to corrals used to pen and guide farm animal movement may be an option;
- 4) Create additional openings in key locations, which might include open, non-forested areas, selected based on the best available knowledge, monitoring and modelling exercises. Identification and placement of additional passages may require collation of available data from Polish and Belarusian researchers and managers on animal movement routes within Białowieża Forest. These passageways may be strategic points to optimize movement for large mammals, particularly bison and moose.

First, animals in the fenced area between barriers of Poland and Belarus should be liberated with possible use of drones or involvement of trained personnel from both sides to get information on the species trapped (where and how many) and to encourage animals to leave the entrapped area. Preventing re-occupation by wildlife of the fenced-in area may require additional modification of existing infrastructure, e.g., gates that are one-way or unidirectional allowing animals to exit a space but preventing them from returning.

Secondly, wildlife movement across the entire WHS should be improved. One drawback is that animals are already learning about barriers and may take time to learn about openings. For that, it is important to act soon and for border passages to be considered and constructed together with any further fortification. Ultimately, if movement of wildlife is to span the entire Białowieża Forest and beyond, this will require sustained cooperation and sufficient political will.

Third, intensive, systematic and joint monitoring of wildlife passages and evaluation of their effectiveness will be required for each of the above. This would help restore cooperation between different stakeholders (scientists, border guard, managers) and bilateral transboundary cooperation. Restoring wildlife movement is consistent with recommendations in UNESCO's recent report (2024) that, "it would be important to restart the transboundary cooperation process at the technical and scientific level...including the development of urgent mitigation measures to address the impact of the border barrier" (UNESCO 2024). If the two neighboring countries cannot discuss solutions directly, then a third party such as UNESCO or IUCN can mediate dialogue, as explicitly suggested in the UNESCO report. Another possible intermediary might be the Peace Parks Foundation.

There is an imperative to develop “prototypes” of wildlife border passages, and evaluate their effectiveness, as was done decades ago for animal road crossing structures. This “experiment” will be of high relevance in the current global situation of growing border infrastructure and militarization.



Fig. 2: Fenced Narewka River (left), one of seven transboundary rivers in Białowieża Forest, and one of the 24 gates (right) installed in Poland’s 186-km barrier to enable wildlife movement (of those, 9 such gates are in Białowieża Forest, which is bisected by the border for 53.4 km).

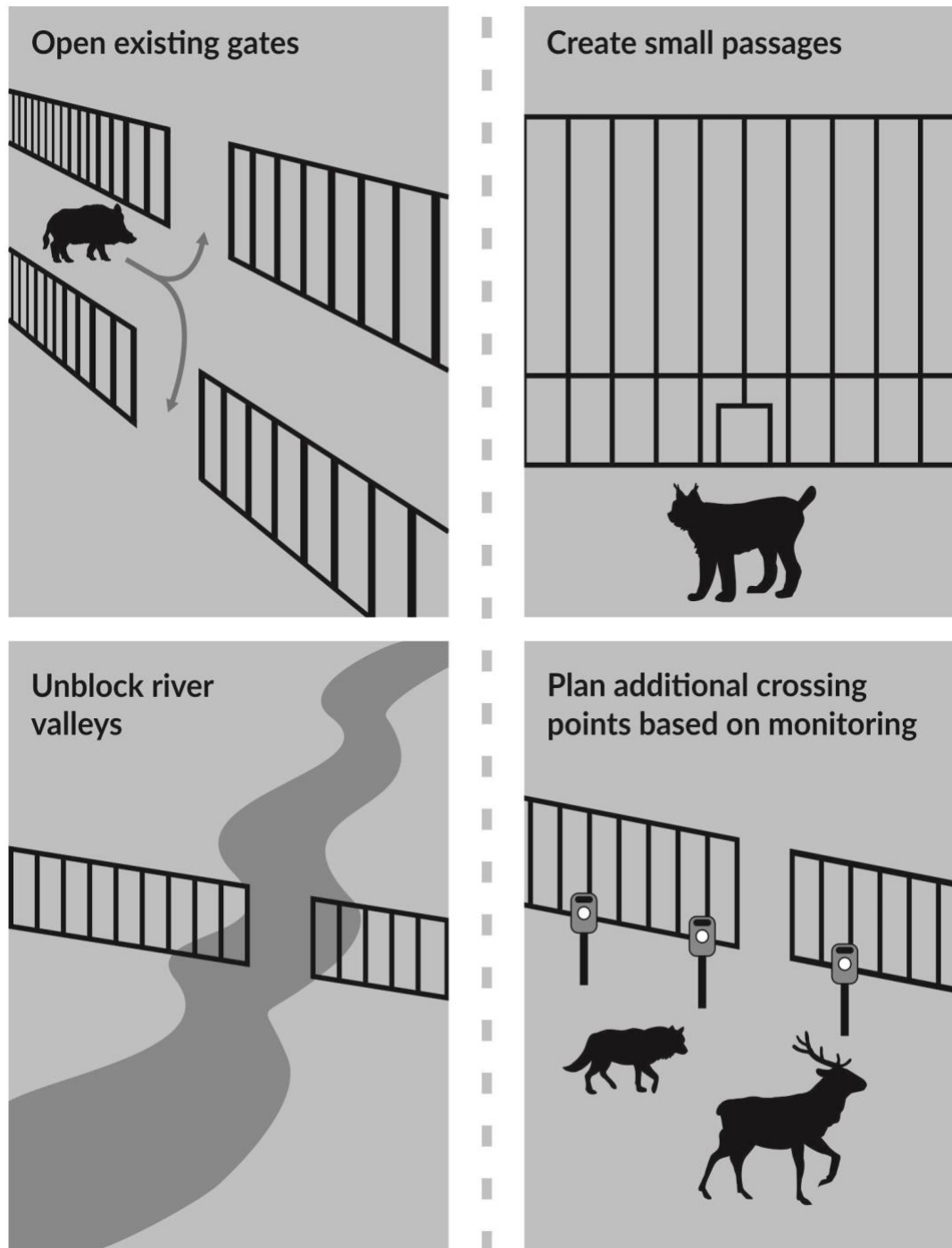


Fig. 3: Proposed multi-faceted approach to support wildlife movement currently constrained by border barriers. Upper left illustrates the opening of gates/doors/other segments of barriers to release animals trapped in between both countries' barriers and encourage transboundary movement. Lower left illustrates unfencing of rivers/streams to enable movement along water courses, known to be used as corridors by wildlife, and especially important under the documented climate warming and ongoing droughts in Białowieża Forest. Upper right shows creation of passages that can accommodate lynx and

other small to medium animals (modeled on passages in the US-MX border barrier through which similar species such as bobcats pass); these openings do not compromise the barrier's security purpose. Lower right represents monitoring during which wildlife is observed and their behavior and response to the barrier analyzed (Xu et al. 2021), to evaluate the effectiveness of the proposed approaches as well as improve and optimize additional ways to restore wildlife movement through, for example, virtual fencing which, together with video monitoring, may be in line with the goals of border authorities.

Lynx and moose as priority species

Lynx and moose are two priority species for restoring connectivity between Poland and Belarus. There are very few lynx on the Polish side of the border and their genetic diversity is the lowest in the species range (Lucena-Perez et al. 2020). The border fence further isolates this population by preventing movement of lynx and exchange of genes with eastern populations. Moreover, according to telemetry data, the same individuals occupied territories located on both sides of the Polish-Belarusian border; therefore, the fence splits this population and its habitat in Białowieża Forest into two parts. Such a division significantly changes the spatial organization of the population and reduces by half the size of suitable and available areas for the lynx living on both sides of the forest, which may have a serious negative impact on the survival of this isolated Polish population of the species in the long-term (Schmidt et al. 2024 and references therein).

Moose living on the Polish side of Białowieża Forest are part of a larger and genetically-distinct population of the species inhabiting north-eastern Poland and western Belarus. The south-western border of the continuous moose population runs through Poland, and the density of the species in Poland is one of the lowest in the European range of the species (Jensen et al. 2020). Until now, there has been extensive gene exchange among populations of the species living on the European mainland. The new, impermeable barrier stops the exchange of moose individuals and their genes and isolates the Polish population from the rest of the Eastern European population, the only external source population for moose in Poland (Niedziałkowska et al. 2016).

Foreseen challenges and conditions

Among anticipated (non-security related) challenges are tradeoffs between connectivity and genetics, disease, and asymmetric management practices. While the bison in the two countries have common origin, those on the Belarusian side have Caucasian bison genes while those on the Polish side are lowland “purebred” line (Tokarska et al. 2011). Recently expressed scientific opinion acknowledges that there may be more benefits than costs of hybridization given high levels of inbreeding in both lines and improbability of keeping them separate indefinitely (Schmidt et al. 2024); however, as the bison trapped in between the Polish border and Belarusian *sistema* are likely of lowland lineage given that bison are not known to cross the *sistema* (Kowalczyk et al. 2012), these bison could be released to the Polish side. A further challenge is

contrasting bison and wolf management approaches, and agreement by Belarus would be needed to not trophy hunt cross-border wildlife if their movement across the border is ultimately restored. A further impending potential threat to restoring transboundary connectivity is withdrawal by Poland, Baltic countries and Finland from conventions prohibiting anti-personnel mines and cluster munitions; the use of indiscriminate weapons would pose serious risk to civilians, wildlife, and the environment as well as to mitigation, monitoring and restoration efforts.

Several conditions we foresee as necessary for restoring transboundary wildlife movement include a binding agreement to not exploit wildlife passages for reasons that may impact national security. This formal bilateral agreement may also be beneficial to delineate wildlife border passage placement, joint patrolling and close monitoring of passages, harmonized management of large mammals, and other joint management (diseases, invasive species, fires). The agreement necessitates willingness to modify existing infrastructure, use of science to assess risks and harmonize management, as well as precaution in the planning of additional fortification to avoid further habitat degradation, blockage of animal movement, and deviation from recent UNESCO recommendations (UNESCO 2024) by, e.g., opting against additional roads and road upgrades (features of Poland's "East Shield" plan).

Addressing shared urgency amid political discord

We acknowledge that relations between Belarus and neighboring EU states are at a low point, that there exist tensions around human rights, migration, border security, and Belarus's alignment with Russia which limit diplomatic flexibility with EU countries especially since Russia's 2022 invasion of Ukraine. Yet, ecologically, the Belarus-EU borderlands harbor globally important habitats and species, many of which are within the Natura 2000 network, whose ecological integrity has been seriously affected by the transnational border fencing. It is urgent to test, improve and implement wildlife border passages. Maintaining animal movement and connectivity is particularly crucial under climate change, and can act as a driver of cooperation in transboundary landscapes. This is also an opportune moment because of Poland's nation-wide connectivity planning (aligned with EU requirements) which could inform additional wildlife crossing points across the Poland-Belarus border.

Re-establishing wildlife movement can be a stepping stone to eventual resumption of collaboration in a WHS where cooperation has precedence (Artemenko 2010). We think that, by taking this step, Poland and Belarus would uphold their commitments to transboundary conservation (as signatories of the Convention on Migratory Species), the EU Water Framework Directive, and recent UNESCO recommendations (UNESCO 2024), as well as provide a model for ecological cooperation amid political discord.

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