

Title page

Supporting wildlife movement amid the rise of border infrastructure

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Abstract

1. 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.
2. We propose a multi-faceted approach to support animal movement and minimize impacts of multiple border barriers on medium to large-sized mammals. We focus on Białowieża Forest, a UNESCO World Heritage Site shared by Poland and Belarus and assessed as having a “critical” conservation outlook in 2025.
3. The “wildlife border passages” we describe would require maximizing or modifying existing infrastructure or restoring known pathways as follows: i) opening gates designed to facilitate wildlife movement between Poland and Belarus (both signatories of the Convention on the Conservation of Migratory Species of Wild Animals), also to release animals trapped in between barriers; ii) creation of “A4” sized passages at barrier bottom to permit the movement of medium-sized species including those highly threatened by border infrastructure such as Eurasian lynx; and ii) unfencing of riverine areas, which often serve as movement corridors for large mammals like moose.
4. Joint monitoring of wildlife border passages to evaluate and improve their effectiveness has the potential to renew and strengthen bilateral collaboration. Adopting less invasive security technologies, for example virtual fencing, would help minimize costs to the natural world.

KEYWORDS fences, barriers, border walls, transboundary conservation, mitigation, mammals, environmental peace-building, wildlife border passages, ecological connectivity

1 PRESERVING MOVEMENT IN A FENCED WORLD

Fences are among the most pervasive and prevalent of human-made structures, exceeding the road network by 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.

40 Such fences are being constructed even in the few (11%) terrestrial transboundary areas where
41 nature protection exists on both sides of a border (Zhang et al., 2025). They thus hinder cross-
42 border conservation of wildlife, including peripheral taxa whose continued occurrence in one
43 country depends on ecological connectivity with another (Thornton et al., 2017). Restricting
44 animal movement cuts off gene flow and population viability, nutrient flow, seed dispersal, can
45 exacerbate human-wildlife conflicts, and can be deadly if animals become entangled (Pokorny et
46 al., 2017) or entrapped (Harrity et al., 2024). Animals may learn to avoid fenced areas, forfeiting
47 resources or access to habitat (Jones et al., 2019; Xu et al., 2021), and hindering future
48 connectivity restoration potential. Blocking animal movement has important consequences for
49 ecosystem functioning in the long-term and may reduce ecosystem resilience to global changes
50 (Malhi et al., 2016).

51
52 There is urgent need to mitigate the ecological effects of border barriers in transboundary
53 regions, and reconnect habitats and wildlife populations even in militarized natural areas. Among
54 possible solutions are peace parks, e.g., a Greater Himalayan Peace Reserve was recently
55 proposed as a diplomatic tool to safeguard one of the most biodiverse regions in the world
56 (Pandit, 2025). Peace parks have a nearly 100-year history. In 1924, the Kraków Protocol
57 between Poland and then Czechoslovakia led to parks like Pieniny International Landscape Park.
58 Around the same time, Rotary Club members in Canada and the United States initiated the
59 creation of the world’s first official peace park, Waterton-Glacier International Peace Park
60 (1932), honoring ecological continuity on the formerly unsevered lands of the Blackfoot
61 Confederacy (*Niitsitapi*) and strengthening US-Canada relations (Quinn, 2012). Peace parks have
62 since been proposed in areas of long-standing military conflict such as Siachen Glacier at the
63 India-Pakistan border on the basis that a peace park would reduce costs—human, economic, and
64 environmental (Biringler & Cariappa, 2012). A related approach recently proposed is “ecological
65 peace corridors” (Cazzolla-Gatti, 2025), intended to “provide safe passages for migratory species
66 and support the natural movement patterns of wildlife” in conflict zones.

67
68 Under scenarios of ongoing human conflicts and/or when peace parks or corridors are not
69 possible, a smaller-scale approach is that of “wildlife border passages”. For instance, the
70 Kazakhstan Border Service of the National Security Committee agreed to pilot 32 passages for
71 ungulates in the border fences along Kazakhstan’s state border with Uzbekistan and
72 Turkmenistan. The passages, monitored with camera traps, provided evidence that a number of
73 species are using them, including urial sheep (*Ovis vignei*), goitered gazelle (*Gazella*
74 *subgutturosa*), kulan (*Equus hemionus*) and caracal (*Caracal caracal*) (Pestov et al., 2020). To
75 strengthen conservation efforts in this critical transboundary hotspot, in 2024, Kazakhstan,
76 Turkmenistan and Uzbekistan, within the frame of the Convention on the Conservation of
77 Migratory Species of Wild Animals Central Asian Mammals Initiative, signed a Memorandum
78 of Cooperation for Wildlife Conservation on the Ustyurt Plateau (“the Ustyurt Memorandum”)
79 and agreed to a 2025-2030 Roadmap to the Ustyurt Memorandum, reinforcing the commitment

80 of all three countries to protecting migratory wildlife, their habitat, and connectivity, and
81 signaling to the international community that the Ustyurt Plateau is one of their conservation
82 priorities.

83
84 Another example comes from the US-Mexico border, where, in 164 km of border wall, 13 small
85 openings (sized 21.5 x 27.8 cm) at the base of the bollard barrier accommodate species such as
86 coyotes (*Canis latrans*), bobcats (*Lynx rufus*), and javelinas (*Pecari tajacu*) (Harrity et al., 2024).
87 In addition, on a seasonal basis, larger floodgates are opened during heavy rain and through
88 these, black bear (*Ursus americanus*) and deer can pass. Researchers have encouraged the US
89 Department of Homeland Security to add more and larger openings, and keep floodgates open
90 for longer periods to maintain connectivity and ensure wildlife movement and access to
91 resources under changing conditions. Along this nearly 3145-km border, peace parks have also
92 been proposed, at least earlier this century (Sifford and Chester, 2007).

93 94 **2 BIAŁOWIEŻA FOREST AS A CASE STUDY**

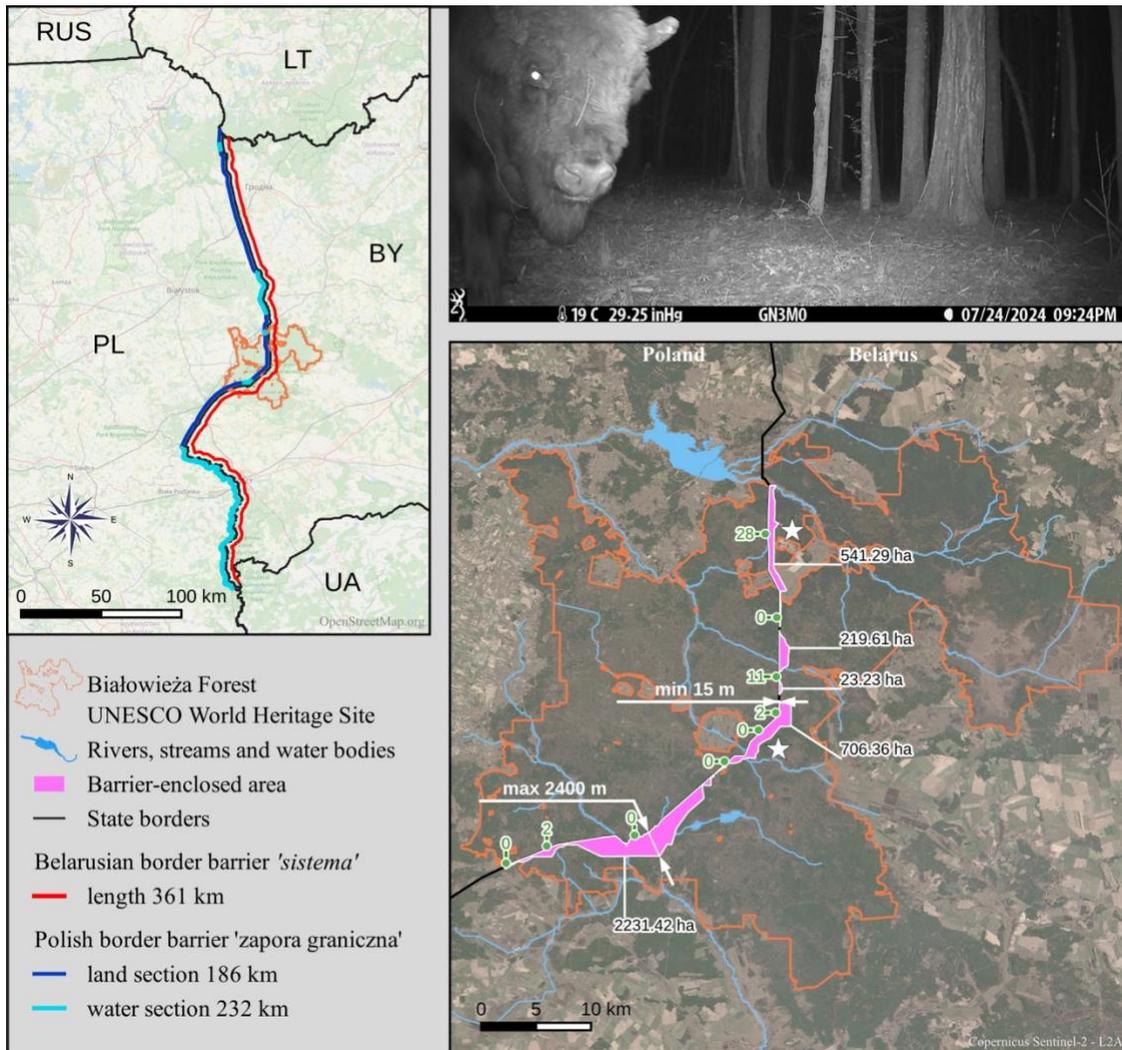
95 An example of nature protection on both sides of an international border is Białowieża Forest, in
96 the Polish-Belarusian borderland, recognized as a transboundary UNESCO World Heritage Site
97 (WHS) in 1992, and extended in 2014 (currently covering 1,418.85 km², Fig. 1). Białowieża
98 Forest is exemplary in its naturalness and preservation of ecological processes, often described as
99 Europe's last primeval lowland forest (Jaroszewicz et al., 2019), historically characterized by not
100 less than 70% canopy cover (Latałowa et al., 2016), and long-term field studies (Broughton et al.
101 2025). Białowieża Forest is inhabited by megafauna such as European bison (*Bison bonasus*),
102 moose (*Alces alces*), red deer (*Cervus elaphus*) and grey wolf (*Canis lupus*), which may already
103 be adversely affected by international border fencing (Nowak et al., 2024). In 2025, the status of
104 Białowieża Forest was assessed as “critical” largely on account of border infrastructure and
105 cessation of transboundary cooperation between Poland and Belarus (IUCN, 2025).

106
107 After World War II, Białowieża Forest, which was entirely located in Poland, became
108 transboundary when the new borders of Europe were drawn and the forest was divided between
109 Poland and Belarus (then part of the Soviet Union). Prior to 1981, animals moved freely across
110 some parts of the Polish-Belarusian border (upper half of Białowieża Forest, between Narewka
111 and Narew Rivers, Fig. 1); then, in 1981, the symbolic 1 meter-high fence of the *sistema* (soviet-
112 era complex of border security infrastructure) was increased to 2.5 m in response to Poland's
113 Solidarity movement and geopolitical transformation, thereby restricting ungulate movements,
114 though not movements of large carnivores such as wolves, Eurasian lynx (*Lynx lynx*) and even
115 dispersing brown bears (*Ursus arctos*) (Jędrzejewska & Jędrzejewski, 1998; Diserens et al.,
116 2020), which could cross it by digging under or climbing over. At the time of Białowieża
117 Forest's UNESCO listing, framed during a period of cooperation between Poland and Belarus in
118 Białowieża Forest that spanned the first part of the 21st century (Artemenko, 2010), the *sistema*
119 on the Belarusian side was recommended for removal. However, in 2021, geopolitical tensions

120 and hostility escalated in the region, affecting the two neighbors and now harming the integrity
121 of the forest and weakening environmental stewardship efforts (UNESCO, 2024).

122
123 In 2022, Poland, Lithuania and Latvia constructed barriers along their borders with Belarus in
124 response to increasing irregular cross-border movement of people from mainly Western Asian
125 and African countries via Belarus (Ancite-Jepifánova, 2024). The 186 km of fencing in Poland
126 includes 53 km through Białowieża Forest, one of the main grounds of what some refer to as a
127 humanitarian crisis (e.g., Helsinki Foundation for Human Rights, 2022) and others call hybrid
128 war (e.g., Dwyer, 2022). Poland's 5.5m-high border fence with steel bars, a concrete foundation,
129 and topped with razor wire (Fig. 2) together with Belarus's *sistema*, consisting of a 2.5 m-high
130 fence with barbed wire, dirt roads and ploughed strip, has resulted in a multi-fence/barrier
131 system, blocking not only cross-border movements of large mammals but also trapping animals
132 in between the new fence and the old *Sistema* (Fig. 3). This critical and exceptional situation
133 requires immediate attention and swift action.

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135

136 **FIGURE 1: Barriers on the Poland-Belarus border (upper left) and the habitat pockets**
137 **created by the barriers in Białowieża Forest (lower right). The entire barrier-enclosed area**
138 **from the tri-border of Ukraine (UA), Belarus (BY) and Poland (PL), to the border with**
139 **Lithuania (LT), has an area of 155 km² (upper left); therefore, a quarter of such fenced**
140 **habitat lies within Białowieża Forest where the narrowest (15 m) and widest (2.5 km)**
141 **intervals between the barriers are found (lower right). Pockets of habitat in between the**
142 **barriers in Białowieża Forest range in size from 23 ha to 2231 ha. On the basis of limited**
143 **data, the northern part of Białowieża Forest appears to be most promising for restoring**
144 **bison transboundary movement in that the most bison were detected in the northernmost**
145 **site in 2023-2024 in 7,466 camera trap days along the border (Nowak et al., 2025). Further,**
146 **in two sample areas (indicated with a white star on the map, in the north and center),**
147 **uniformed personnel stationed along the border reported seeing bison approaching the**
148 **Polish barrier from the Belarusian side. By comparison, the only lynx near the border was**
149 **camera-trapped near wetlands where no main barrier was built on the Polish side but**
150 **where razor wire fences are used instead.**

151

152 *Multi-faceted approach to support wildlife movement*

153 The fenced-off strip of land between fences in Poland and Belarus is of varying width, from 10
154 meters (where the two countries' fences come together) to more than 2 kilometers wide with
155 wildlife such as European bison getting fenced in between according to reports from military
156 personnel, a UNESCO 2024 mission report (UNESCO, 2024), and our own observations (Fig.
157 3). These patches of fenced off habitat range in size from 0.2 to more than 20 km² and form a
158 chain of relatively ecologically isolated fragments which together constitute 37 km² just within
159 Białowieża Forest. If using the following criteria: link or connector is fewer than 20 m wide and
160 less than 100 m long, then there are five such fenced patches in Białowieża Forest, sized 23-2231
161 ha (Fig. 1). In the largest of these, there is a gap in Poland's main barrier because of wetlands,
162 where instead there are rows of razor wire fencing. Even this largest habitat pocket (~22 km²) is
163 smaller than the home ranges of large ungulates such as red deer and European bison while only
164 the largest pocket could accommodate moose (Schmidt et al., 2024 and references therein).

165 These ungulates not only have expansive home ranges but also depend on a variety of habitats
166 which explains their seasonal movements. This habitat diversity is not likely to be adequately
167 met in the fenced off areas leading to deterioration of both the borderland habitats and physical
168 condition of animals.

169

170 According to Polish government authorities, nine of the 24 gates in Poland's barrier intended to
171 facilitate wildlife movement are found in the section of the barrier that runs through Białowieża
172 Forest; however, they have never been opened (Fig. 2). Opening more than one gate will be
173 necessary to release animals from each of the disconnected patches and opening all gates may
174 improve the likelihood of releasing trapped animals but may still not resolve the problem

175 entirely. Unfencing further segments may be required, and a combination of approaches is
176 ultimately needed to improve animal movement across the forest.

177

178 Considering available information on border barriers in Białowieża Forest, we propose to
179 enhance connectivity by enabling wildlife movement in several ways (Fig. 4):

180

181 1) Make use of existing gates (Fig. 2) and coordinate their temporal opening in the Polish
182 barrier and concomitant sections (technical doors) in the Belarusian *sistema* fence
183 (Belarusian side) to encourage release of trapped animals and movement between the two
184 sides of the forest;

185 2) Create wildlife passages (~22 cm x 28 cm), modeled on those in the US-Mexico border
186 wall (Harrity et al., 2024), targeting species whose populations are predicted to be
187 particularly impacted by the border fences such as lynx, while also accommodating
188 movement of common species such as European badger (*Meles meles*) and roe deer
189 (*Capreolus capreolus*);

190 3) Unfence (permanently or at least seasonally) selected fragments of riverine areas as they
191 are known to function as natural corridors for wildlife (e.g., Sánchez-Montoya et al.,
192 2023); during initial planning phases of Poland's border barrier, rivers were to remain
193 unfenced. If unfencing is not possible (for security reasons), installing floodgates (as in
194 the US-Mexico border wall) or a double door/gate system similar to corrals used to pen
195 and guide farm animal movement may be an option;

196 4) Create additional openings in key locations, which might include open, non-forested
197 areas, selected based on the best available knowledge, monitoring and modelling
198 exercises. Identification and placement of additional passages may require collation of
199 available data from Polish and Belarusian researchers and managers on animal movement
200 routes within Białowieża Forest. These passageways may be strategic points to optimize
201 movement for large mammals, particularly bison and moose.

202

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

209

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

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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.

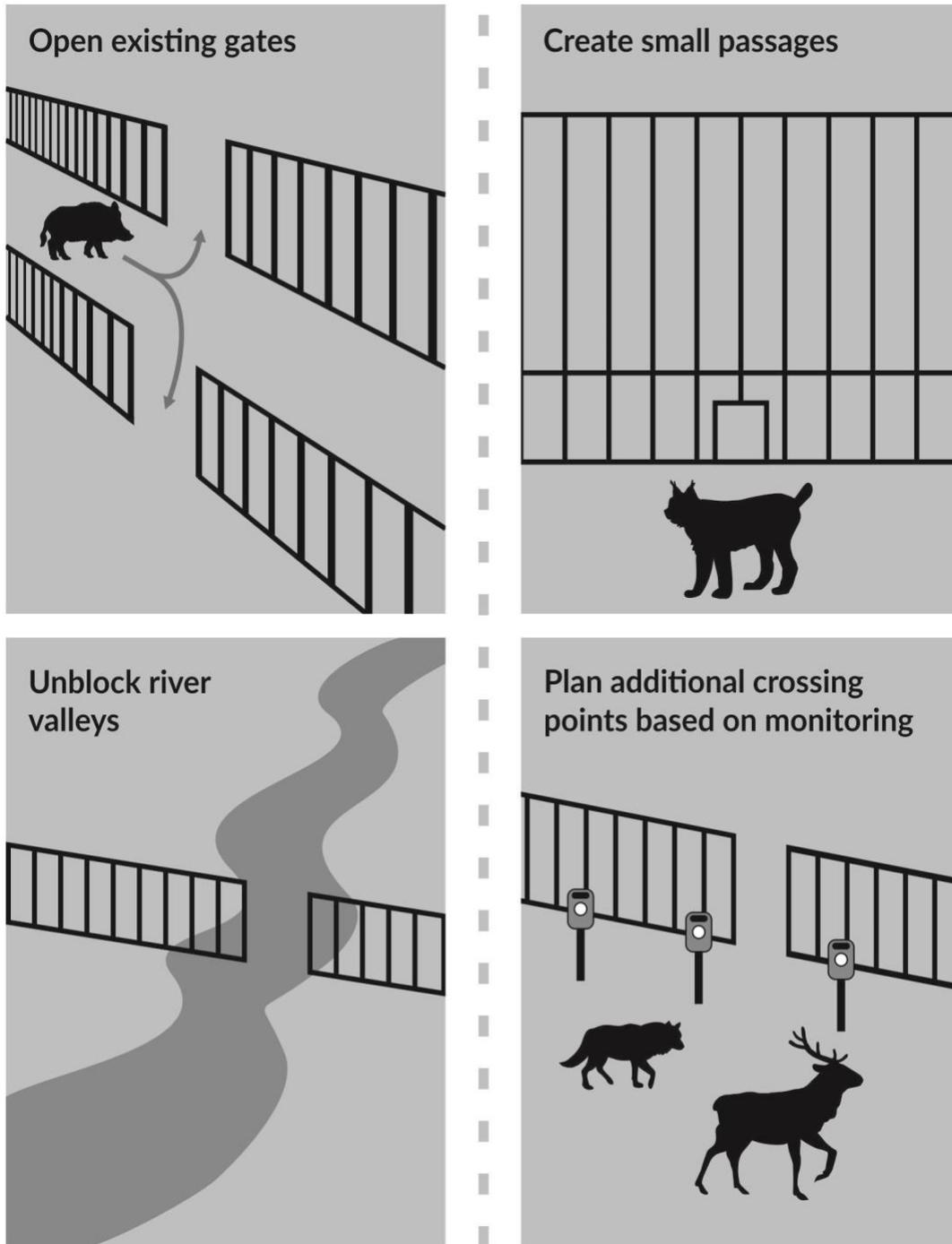


232 **FIGURE 2 Fenced Narewka River (left), one of seven transboundary rivers in Białowieża**
233 **Forest, and one of the 24 gates (right) installed in Poland’s 186-km barrier to enable**
234 **wildlife movement (of those, 9 such gates are in Białowieża Forest, which is bisected by the**
235 **border for 53.4 km).**
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FIGURE 3 Bull bison observed in late August 2025 standing on the other side of Poland's main barrier.



242
 243 **FIGURE 4 Proposed multi-faceted approach to support wildlife movement currently**
 244 **constrained by border barriers. Upper left illustrates the opening of gates/doors/other**
 245 **segments of barriers to release animals trapped in between both countries' barriers and**
 246 **encourage transboundary movement. Lower left illustrates unfencing of rivers/streams to**
 247 **enable movement along water courses, known to be used as corridors by wildlife, and**
 248 **especially important under the documented climate warming and ongoing droughts in**
 249 **Białowieża Forest. Upper right shows creation of passages that can accommodate lynx and**

250 **other small to medium animals (modeled on passages in the US-MX border barrier**
251 **through which similar species such as bobcats pass); these openings do not compromise the**
252 **barrier's security purpose. Lower right represents monitoring during which wildlife is**
253 **observed and their behavior and response to the barrier analyzed (Xu et al., 2021), to**
254 **evaluate the effectiveness of the proposed approaches as well as improve and optimize**
255 **additional ways to restore wildlife movement through, for example, virtual fencing which,**
256 **together with video monitoring, may be in line with the goals of border authorities.**
257

258 *Lynx and moose as priority species*

259 Lynx and moose are two priority species for restoring connectivity between Poland and Belarus.
260 There are very few lynx on the Polish side of the border and their genetic diversity is the lowest
261 in the species range (Lucena-Perez et al., 2020). The border fence further isolates this population
262 by preventing movement of lynx and exchange of genes with eastern populations. Moreover,
263 according to telemetry data, the same individuals occupied territories located on both sides of the
264 Polish-Belarusian border; therefore, the fence splits this population and its habitat in Białowieża
265 Forest into two parts. Such a division significantly changes the spatial organization of the
266 population and reduces by half the size of suitable and available areas for the lynx living on both
267 sides of the forest, which may have a serious negative impact on the survival of this isolated
268 Polish population of the species in the long-term (Schmidt et al., 2024 and references therein).
269

270 Moose living on the Polish side of Białowieża Forest are part of a larger and genetically-distinct
271 population of the species inhabiting north-eastern Poland and western Belarus. The south-
272 western border of the continuous moose population runs through Poland, and the density of the
273 species in Poland is one of the lowest in the European range of the species (Jensen et al., 2020).
274 Until now, there has been extensive gene exchange among populations of the species living on
275 the European mainland. The new, impermeable barrier stops the exchange of moose individuals
276 and their genes and isolates the Polish population from the rest of the Eastern European
277 population, the only external source population for moose in Poland (Niedziałkowska et al.,
278 2016).
279

280 *Foreseen challenges and conditions*

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

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

297
298 Several conditions we foresee as necessary for restoring transboundary wildlife movement
299 include a binding agreement to not exploit wildlife passages for reasons that may impact either
300 country’s national security. This formal bilateral agreement may also be beneficial to delineate
301 wildlife border passage placement, joint patrolling and close monitoring of passages, harmonized
302 management of large mammals, and other joint management (diseases, invasive species, fires).
303 The agreement necessitates willingness to modify existing infrastructure, use of science to assess
304 risks and harmonize management, as well as precaution in the planning of additional fortification
305 to avoid further habitat degradation, blockage of animal movement, and deviation from recent
306 UNESCO recommendations (UNESCO, 2024) by, e.g., opting against additional roads and road
307 upgrades (features of Poland’s “Shield East” plan).

308

309 **3 ADDRESSING SHARED URGENCY AMID POLITICAL DISCORD**

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

321

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

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