

Title page

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Supporting wildlife movement amid the rise of border infrastructure

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- 2 environmental peace-building, wildlife border passages, ecological connectivity

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

19
20 **Preserving ecosystems in a fenced world**
21 Fences are among the most pervasive and prevalent human-made structures, exceeding the road
22 network at least tenfold (Jakes et al. 2018). Border fences, often erected in transboundary
23 landscapes of conservation importance (Liu et al. 2020), are particularly impassable (Zhuo et al.
24 2024; Lei & Wang 2025; Sennett & Chambers 2025). Such barriers are often built without
25 environmental impact assessments, exempted from various laws in the name of national security
26 (Nowak et al. 2024), and have an intensive construction phase followed by a prolonged phase of
27 modification (Trouwborst et al. 2016). They are usually long, fortified with sharp elements,
28 floodlights, alarm systems, associated with linear infrastructure such as roads, and continuous
29 military, patrol, and maintenance activities (*ibid.*). Restricted access is usually imposed,
30 impeding scientific data collection and monitoring, while mitigation may be challenging without
31 compromising a border fence’s intended purpose of keeping out people.

32
33 Such fences are being constructed even in the few (11%) terrestrial transboundary areas where
34 nature protection exists on both sides of a border (Zhang et al. 2025). They thus hinder cross-
35 border conservation of wildlife, including peripheral taxa whose continued occurrence in one
36 country depends on ecological connectivity with another (Thornton et al. 2017). Restricting
37 animal movement cuts off gene flow and population viability, nutrient flow, seed dispersal, can
38 exacerbate human-wildlife conflicts, and can be deadly if animals become entangled (Pokorný et
39 al., 2017) or entrapped (Harrity et al. 2024). Animals may learn to avoid fenced areas, forfeiting
40 resources or access to habitat (Jones et al. 2019; Xu et al. 2021), and hindering future
41 connectivity restoration potential. Blocking animal movement has important consequences for

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

44
45 There is urgent need to mitigate the ecological effects of border barriers in transboundary
46 regions, and reconnect habitats and wildlife populations even in militarized natural areas. Among
47 possible solutions are peace parks, e.g., a Greater Himalayan Peace Reserve was recently
48 proposed as a diplomatic tool to safeguard one of the most biodiverse regions in the world
49 (Pandit 2025). Peace parks have a nearly 100-year history. In 1924, the Kraków Protocol
50 between Poland and then Czechoslovakia led to parks like Pieniny International Landscape Park.
51 Around the same time, Rotary Club members in Canada and the United States initiated the
52 creation of the world's first official peace park, Waterton-Glacier International Peace Park
53 (1932), honoring ecological continuity on the formerly unsevered lands of the Blackfoot
54 Confederacy (*Niitsitapi*) and strengthening US-Canada relations (Quinn 2012). Peace parks have
55 since been proposed in areas of long-standing military conflict such as Siachen Glacier at the
56 India-Pakistan border on the basis that a peace park would reduce costs—human, economic, and
57 environmental (Biringer & Cariappa 2012). A related approach recently proposed is “ecological
58 peace corridors” (Cazzolla-Gatti 2025), intended to “provide safe passages for migratory species
59 and support the natural movement patterns of wildlife” in conflict zones.

60
61 Under scenarios of ongoing human conflicts and/or when peace parks or corridors are not
62 possible, a smaller-scale approach is that of “wildlife border passages”. For instance, the
63 Kazakhstan Border Service of the National Security Committee agreed to pilot 32 passages for
64 ungulates in the border fences along Kazakhstan's state border with Uzbekistan and
65 Turkmenistan. The passages, monitored with camera traps, provided evidence that a number of
66 species are using them, including urial sheep (*Ovis vignei*), goitered gazelle (*Gazella*
67 *subgutturosa*), kulan (*Equus hemionus*) and caracal (*Caracal caracal*) (Pestov et al. 2020). To
68 strengthen conservation efforts in this critical transboundary hotspot, in 2024, Kazakhstan,
69 Turkmenistan and Uzbekistan, within the frame of the Convention on the Conservation of
70 Migratory Species of Wild Animals Central Asian Mammals Initiative, signed a Memorandum
71 of Cooperation for Wildlife Conservation on the Ustyurt Plateau (“the Ustyurt Memorandum”)
72 and agreed to a 2025-2030 Roadmap to the Ustyurt Memorandum, reinforcing the commitment
73 of all three countries to protecting migratory wildlife, their habitat, and connectivity, and
74 signaling to the international community that the Ustyurt Plateau is one of their conservation
75 priorities.

76
77 Another example comes from the US-Mexico border, where, in 164 km of border wall, 13 small
78 openings (sized 21.5 x 27.8 cm) at the base of the bollard barrier accommodate species such as
79 coyotes (*Canis latrans*), bobcats (*Lynx rufus*), and javelinas (*Pecari tajacu*) (Harrity et al. 2024).
80 In addition, on a seasonal basis, larger floodgates are opened during heavy rain and through
81 these, black bear (*Ursus americanus*) and deer can pass. Researchers have encouraged the US

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

86

87 Białowieża Forest as a case study

88 An example of nature protection on both sides of an international border is Białowieża Forest, in
89 the Polish-Belarusian borderland, recognized as a transboundary UNESCO World Heritage Site
90 (WHS) in 1992, and extended in 2014 (currently covering 1,418.85 km², Fig. 1). Białowieża
91 Forest is exemplary in its naturalness and preservation of ecological processes, often described as
92 Europe's last primeval lowland forest (Jaroszewicz et al. 2019), historically characterized by not
93 less than 70% canopy cover (Latałowa et al. 2016), and long-term field studies (Broughton et al.
94 2025). Białowieża Forest is inhabited by megafauna such as European bison (*Bison bonasus*),
95 moose (*Alces alces*), red deer (*Cervus elaphus*) and grey wolf (*Canis lupus*), which may already
96 be adversely affected by international border fencing (Nowak et al. 2024).

97

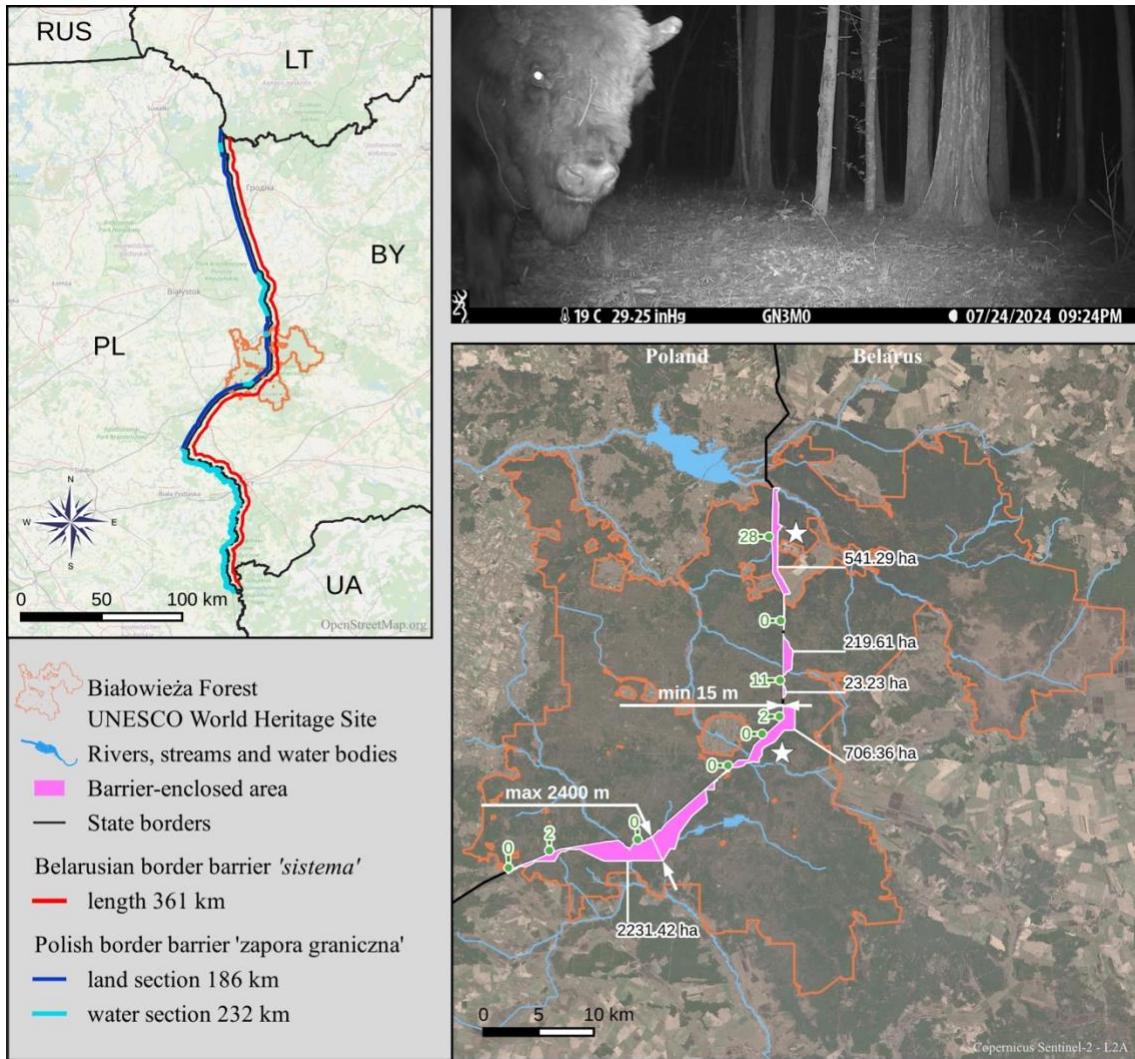
98 After World War II, Białowieża Forest, which was entirely located in Poland, became
99 transboundary when the new borders of Europe were drawn and the forest was divided between
100 Poland and Belarus (then part of the Soviet Union). Prior to 1981, animals moved freely across
101 some parts of the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

113

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

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

125



126
127 Fig. 1: Barriers on the Poland-Belarus border (upper left) and the habitat pockets created
128 by the barriers in Białowieża Forest (lower right). The entire barrier-enclosed area from
129 the tri-border of Ukraine (UA), Belarus (BY) and Poland (PL), to the border with
130 Lithuania (LT), has an area of 155 km² (upper left); therefore, a quarter of such fenced
131 habitat lies within Białowieża Forest where the narrowest (15 m) and widest (2.5 km)
132 intervals between the barriers are found (lower right). Pockets of habitat in between the
133 barriers in Białowieża Forest range in size from 23 ha to 2231 ha. On the basis of limited
134 data, the northern part of Białowieża Forest appears to be most promising for restoring
135 bison transboundary movement in that the most bison were detected in the northernmost
136 site in 2023-2024 in 7,466 camera trap days along the border (Nowak et al. 2025). Further,
137 in two sample areas (indicated with a white star on the map, in the north and center),

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

142

143 *Multi-faceted approach to support wildlife movement*

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

159

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

167

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

170

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

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

180 3) Unfence (permanently or at least seasonally) selected fragments of riverine areas as they
181 are known to function as natural corridors for wildlife (e.g., Sánchez-Montoya et al.
182 2023); during initial planning phases of the border barrier, rivers were to remain
183 unfenced. If unfencing is not possible (for security reasons), installing floodgates (as in
184 the US-Mexico border wall) or a double door/gate system similar to corrals used to pen
185 and guide farm animal movement may be an option;

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

192
193 First, animals in the fenced area between barriers of Poland and Belarus should be liberated with
194 possible use of drones or involvement of trained personnel from both sides to get information on
195 the species trapped (where and how many) and to encourage animals to leave the entrapped area.
196 Preventing re-occupation by wildlife of the fenced-in area may require additional modification of
197 existing infrastructure, e.g., gates that are one-way or unidirectional allowing animals to exit a
198 space but preventing them from returning.

199
200 Secondly, wildlife movement across the entire WHS should be improved. One drawback is that
201 animals are already learning about barriers and may take time to learn about openings. For that, it
202 is important to act soon and for border passages to be considered and constructed together with
203 any further fortification. Ultimately, if movement of wildlife is to span the entire Białowieża
204 Forest and beyond, this will require sustained cooperation and sufficient political will.

205
206 Third, intensive, systematic and joint monitoring of wildlife passages and evaluation of their
207 effectiveness will be required for each of the above. This would help restore cooperation
208 between different stakeholders (scientists, border guard, managers) and bilateral transboundary
209 cooperation. Restoring wildlife movement is consistent with recommendations in UNESCO's
210 recent report (2024) that, "it would be important to restart the transboundary cooperation process
211 at the technical and scientific level...including the development of urgent mitigation measures to
212 address the impact of the border barrier" (UNESCO 2024). If the two neighboring countries
213 cannot discuss solutions directly, then a third party such as UNESCO or IUCN can mediate
214 dialogue, as explicitly suggested in the UNESCO report. Another possible intermediary might be
215 the Peace Parks Foundation.

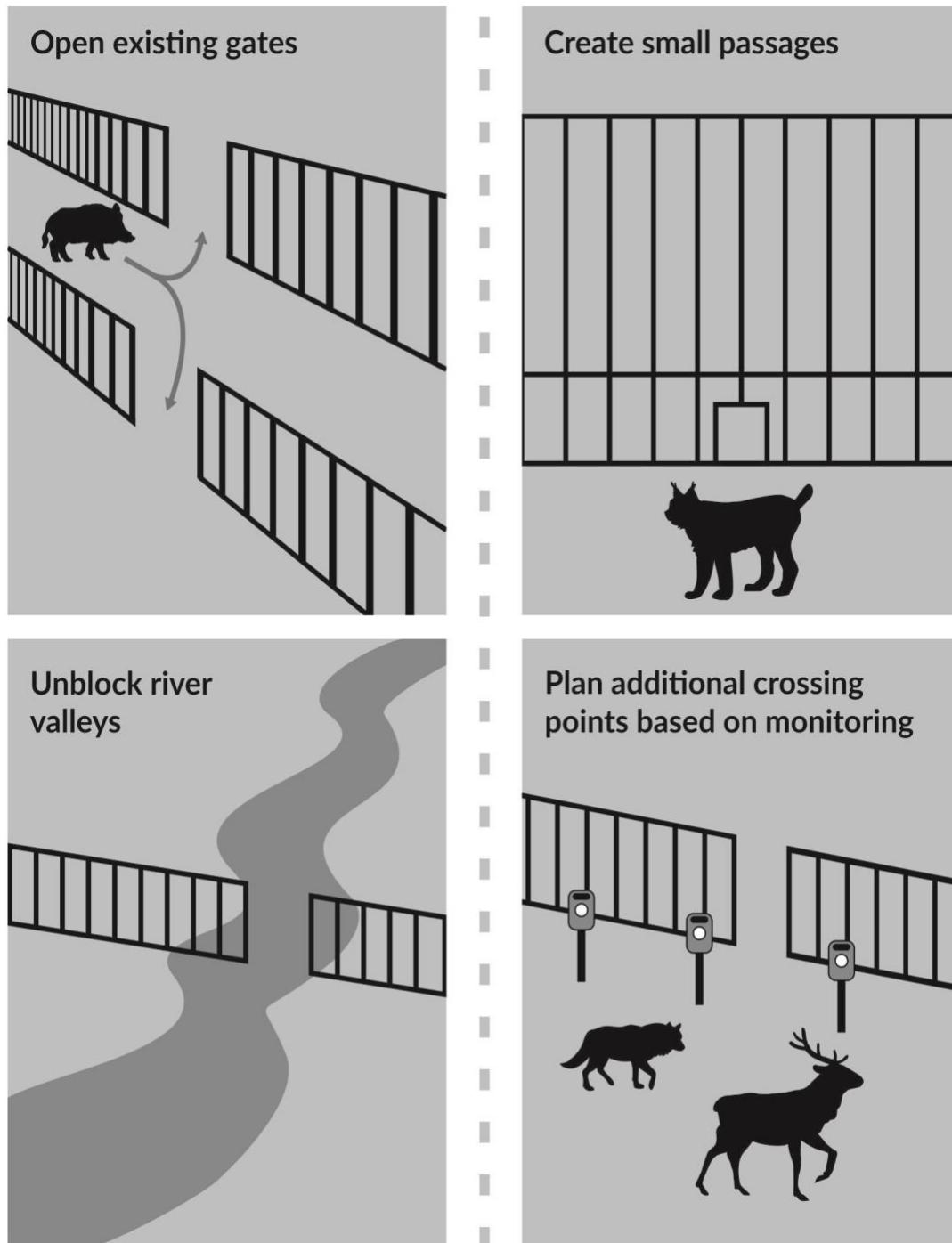
217 There is an imperative to develop “prototypes” of wildlife border passages, and evaluate their
218 effectiveness, as was done decades ago for animal road crossing structures. This “experiment”
219 will be of high relevance in the current global situation of growing border infrastructure and
220 militarization.

221



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

226



227

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

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

242

243 *Lynx and moose as priority species*

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

254

255 Moose living on the Polish side of Białowieża Forest are part of a larger and genetically-distinct
256 population of the species inhabiting north-eastern Poland and western Belarus. The south-
257 western border of the continuous moose population runs through Poland, and the density of the
258 species in Poland is one of the lowest in the European range of the species (Jensen et al. 2020).
259 Until now, there has been extensive gene exchange among populations of the species living on
260 the European mainland. The new, impermeable barrier stops the exchange of moose individuals
261 and their genes and isolates the Polish population from the rest of the Eastern European
262 population, the only external source population for moose in Poland (Niedziałkowska et al.
263 2016).

264

265 *Foreseen challenges and conditions*

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

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

282

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

293

294 **Addressing shared urgency amid political discord**

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

306

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

313

314

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