

POTENTIAL IMPACTS ON NATURE CONSERVATION AND TOURISM FROM THE BORDER BARRIER IN THE BIALOWIEZA FOREST

*Pawel Mickiewicz^{ID}, Anna Kiepas-Kokot^{ID}

West Pomeranian University of Technology Szczecin, Poland

*Corresponding author's email: pmickiewicz@zut.edu.pl

Abstract

The aim of this study is to determine the potential effects of migration restrictions at the Polish-Belarusian border on the objects of protection residing in protected areas and the nature tourism implemented on their basis. The migration restrictions discussed in the paper include the border barrier and the prohibition of temporary stay in border areas. The key rationale for undertaking this analysis are the specific legal conditions under which the border barrier was created, which exclude standard impact assessment procedures for projects that may have a significant impact on the wider environment, and thus the unrecognised potential impacts of its creation and operation. The specific legal and factual conditions resulting from the course of the border barrier through naturally valuable areas, including those under nature protection, and at the same time constituting the state and EU border - subjected especially in recent years to migratory pressure - force increased activity of services, which puts pressure on natural resources. On the other hand, the introduced temporary bans on staying in the border area have the effect of minimising the movement of other people, including tourists. The authors of the study aimed to identify the effects of the introduced migration restrictions on the natural resources (values) and, consequently, on the tourism carried out on their basis. The identified effects were arranged according to the problem tree technique, from the direct effects on people and animals to the more far-reaching, indirect consequences.

Keywords: border barrier, EU border, migration, nature tourism.

Introduction

A prerequisite for the proper functioning of animal populations, especially those with high individual mobility, is the presence of their preferred habitats and the ability to migrate between refuges. Migration is also a prerequisite for effective nature tourism, based on the values of the environment explored in the modes of migration, often carried out in the areas of nature protection, such as national parks. However, migration does not only have a naturalistic form – there is an increasingly emphasized need to decrease the value of migration in connection with the threat posed by politically and economically motivated - migratory movements of people between the borders of countries and their unions. The implementation of migration barriers for people, both physical and organizational, result in difficulties in natural migration. This applies to both animal migration, desirable due to the need for sustainability and stability of ecosystems, and human migration - aimed at learning about natural values and constructing environmental awareness. Restricted natural migration can become both a destabilizing factor for migratory animal populations and a general factor degrading natural resources and values. Thus, in view of the need for human migration barriers, limiting their negative effects on the environment becomes a key challenge. Although the achievement of environmental and political goals (in terms of internal security) seems to collide - the needs in this realm should determine adequate actions. In turn, these actions, should result from an assessment of the effects of the introduced changes, to the extent its possible, based on the environmental principle of foresight and precaution.

Materials and Methods

The aim of the study is to indicate the direction and mechanism of potential impact of human migration

restrictions introduced on the Polish-Belarusian border (border barrier and prohibition of temporary stay in border areas) – on the protected species: The European bison (*Bison bonasus*), wolf (*Canis lupus*), and lynx (*Lynx lynx*), and, thus on the potential for nature tourism associated with the presence of these animals in the restricted area.

The key rationale for undertaking this analysis are the specific legal conditions for the creation of the border barrier, which exclude standard environmental impact assessment procedures, and thus the unrecognized potential effects of its creation and operation. The border barrier in question runs through naturally valuable areas, including those under nature protection and at the same time constituting the state and EU border - subjected to migration pressure, which forces increased activity of state services, which puts pressure on natural resources. On the other hand, the introduced temporary bans on staying in the border area may result in minimizing the movement of other people, including tourist traffic, both due to actual restrictions and psychological barriers.

The authors of the paper, for the purposes of this article, understand the concept of nature tourism as tourism aimed at learning about the natural values of areas covered by various forms of nature protection. In particular, the paper pays attention to faunal tourism aimed at animal species under species protection, implemented within the boundaries of the Bialowieza National Park. These animals have a significant impact on the natural values of the area and thus shape its touristic attractiveness.

Based on the available data and literature on the subjects of the study, the potential effects of migration restrictions introduced on the Polish – Belarusian border were identified. The identified effects of the environmental problem, which undoubtedly is the introduction of technical and organizational migration

restrictions along the Polish – Belarusian border, were arranged according to the criterion of mechanism and scope into direct and indirect effects, considering the causal relationships existing between them (corresponding to the problem tree analysis).

The study developed a theoretical model with a cascade structure of the potential effects of the introduction of physical (technical) and organizational migration restrictions on the Polish – Belarusian border, which allowed for a systematic presentation of the mechanisms of the impact of migration barriers on ecosystems and related socio-economic aspects. The developed model presents a system of cause-and-effect connections resulting from the introduction of migration restrictions. The main elements of the model include feedback (health and population, economic and ecological) that amplify the negative consequences for the ecosystem and local communities.

For the quantitative data presented in Tables 1 and 2 we performed linear regression (ordinary least squares) to assess long-term trends. Abundance of European bison, lynx and wolf (years 2000–2023) and numbers of tourists in Polish national parks, including Białowieża NP, for the years 2019–2023, were regressed on calendar year. For each species/series we report the slope (annual change), coefficient of determination (R^2) and p-value testing H_0 : slope = 0. Analyses were carried out in Python (SciPy) at significance level $\alpha = 0.05$.

Given the theoretical nature of this study and its explicit aim to construct a conceptual cascade model of impacts on European bison, wolf, lynx and nature tourism, no advanced inferential statistics beyond trend analysis were applied; regression served to illustrate the direction and strength of observed changes. Instead, model construction relied on qualitative synthesis of literature, problem-tree analysis and expert findings (IOŚ-PIB 2024), ensuring a systematic mapping of cause–effect relationships in line with the study objectives.

To build the model, a hierarchical ordering of causes and effects was made, indicating the resulting relationships. The main initiating factor (root cause) that leads to the first level of consequences was identified. Then, the subsequent consequences generated by the first level of effects were identified, creating a logical sequence of relationships. The model uses dependency flowcharts to visualize the flow of information and the impact of changes on subsequent levels of the system (Sterman, 2000). Feedback was also included in the developed model (their reinforcing nature leading to self-reinforcing effects was indicated (Meadows, 2008). In practice, cascade models are used in systems analysis, ecology, economics and crisis management, where it is necessary to predict the effects of changes in each ecosystem or social structure (Epstein, 2006).

The identified potential effects of the analysed problem were verified by the results of the first

signalling research on the actual impact of the border barrier on natural resources, two years after its creation presented in the expert opinion titled '*Oddziaływanie zapory granicznej na granicy polsko-białoruskiej na Obiekt Światowego Dziedzictwa 'Białowieża Forest' - Ssaki i rośliny inwazyjne*' (Schmidt et al., 2025).

Legal conditions of migration restrictions on the Polish – Belarusian border

The border barrier, which purpose is to secure the state border (which is also the external border of the EU), also against illegal crossing, was established under the provisions of the Law of October 29, 2021, on the construction of state border security. According to Article 6 (1) of this law, separate regulations, including, among others, the Law of April 27, 2001, do not apply to the investment (*Environmental Protection Law and the provisions of the Act of October 3, 2008, on providing information on the environment and its protection, public participation in environmental protection and environmental impact assessments*). Information on the construction, safeguards and technical parameters of the barrier is not public and is not subject to release under separate regulations (Article 7). This means that an assessment of the project's impact on the environment was not conducted during the implementation of the barrier. However, the unique legal conditions for the implementation of the barrier do not result in the abolition or reduction of the general principles of nature protection under the Law of April 16, 2004, on Nature Protection. The goals, principles and forms of nature protection still apply - with the understanding that achieving these goals may be difficult and may require modifying the way they will be achieved.

In addition to the technical border barrier, migration restrictions include a temporary ban on staying in the border zone, which is imposed periodically based on the authorization set forth in Article 12a of Law on State Border Protection of October 12th, 1990. According to this provision, in the event of a need to ensure security or public order in the border area in connection with a threat to human life or health, or property, resulting from crossing the state border in violation of the law or attempting to do so, or a justified risk of committing other criminal acts, a temporary ban on staying in a specific area in the border area adjacent to the state border constituting an external border within the meaning of the Schengen Borders Code may be imposed. The last (fifth) restrictions, regarding the temporary ban on abiding in a particular area within the border zone between the state and Belarusian Republic border, were introduced by the Minister of Internal and Administrative Affairs on March 6, 2025, and were fully enforced on March 10, 2025, for 90 days (Dz.U. 2025 poz. 281).

Barrier effect on nature

The created border barrier between Poland and Belarus is about 187 kilometres long and takes the form of an approximately 5-meter-high steel fence set on a concrete foundation dug into the ground to a depth of

1 meter. The barrier runs through the dense forest complex of the Bialowieza Forest. Its transboundary location makes it interfere with the network of major ecological corridors of pan-European importance, crucial for large mammals. Major corridors are the most important migration and migratory routes for species in the country and at the same time provide habitat and population connectivity on a continental scale. Interference with the course of such corridor means reducing the connectivity of habitats and populations of which animals use it.

In addition to the long and practically continuous border barrier built by Poland, the barrier effect is also due to its connection with the barrier created by Lithuania and Latvia, which cumulatively isolates animal populations migrating through the Belarusian territory. In addition, since the 1980s, there has already

been a border fence on the Belarusian side, the so-called 'sistiema', the offset of which from the course of the border has resulted in the creation of natural enclaves between the Polish border and the Belarusian 'sistiema', with no possibility of human entry (except for Belarusian border services). Poland's construction of a border barrier across the state border line has deepened the isolation of these enclaves. The degree of this isolation will be determined by the possible ability of animals to overcome all these terrain obstacles and the existence of alternative routes of movement.

Population of large mammals under species protection

Over the past nearly quarter century, the estimated abundance of bison, lynx and wolves in Poland has increased significantly: 4-fold, 2-fold and nearly 5-fold (Table 1), respectively.

Table 1

Changes in the abundance of bison, lynx and wolf in Poland in 2000-2023

Species	Number of animals in years						
	2000	2005	2010	2015	2020	2022	2023
Bison*	715	901	1,224	1,553	2,316	2,603	2,820
Lynx*	285	231	285	390	580	558	630
Wolf**	1,086	800	770	1,484	3,530	4,328	5,046

According to Environmental Protection (2020, 2021, 2022, 2023, 2024); *estimates of the Directorate-General for the Environment - not based on field work carried out according to a single methodology but collected periodically once a year from the same sources; **abundance indicated according to data from the Bison Pedigree Book.

Only a small part of the national population of bison, lynx and wolves occurs in Poland's national parks, and this occurrence is spatially unevenly distributed. Jamrose's (2008) study based on observations by national park field staff shows that wolves and lynxes are found in roughly half of Poland's 23 parks, but bison are found in only two of them (Bialowieza and Bieszczady). Data published by the Central Statistical Office (2024), on the other hand, show that in 2023 less than 8% of bison individuals occurred in their territory (210 individuals), with a significant majority (154 individuals) in Bialowieza National Park. Slightly higher (9%) was the share of individuals occurring in Polish national parks in the lynx population (59 individuals), of which only 2 individuals were recorded in Bialowieza National Park. Only 5.5% of the wolf population in Poland occurs in national parks (28 individuals), of which 19 individuals were recorded on the territory of the Bialowieza Park. On the other hand, in Podlaskie Voivodeship in 2023, there were 1,269 bison (45% of the national population), 52 lynx (8%) and 290 wolves - 6% of the national population (Environmental Protection, 2020, 2021, 2022, 2023, 2024).

Based on data from CSO (Environmental Protection, 2020, 2021, 2022, 2023, 2024), a linear model of species abundance against year was fitted. Results show highly significant positive trends for all three species:

- **European bison:** slope = 81 individuals/year, $R^2 = 0.98$, $p < 0.001$

- **Lynx:** slope = 15 individuals/year, $R^2 = 0.90$, $p = 0.003$
- **Wolf:** slope = 244 individuals/year, $R^2 = 0.93$, $p < 0.001$

These strong, statistically significant increases confirm the rapid post-2000 recovery of protected large mammals in Poland and underscore the potential for border barriers to disrupt otherwise expanding populations.

Migration needs of protected migratory animals

Migrations play an essential role in the functioning of animal populations, as they enable the exchange of individuals necessary for population sustainability. Contact between individuals and species is carried out using ecological corridors (Bernatek, 2011), whose functions are limited by: excessive narrowing, cutting with anthropogenic fragments, environmental fragmentation, or simplification of the landscape structure of the area (Korytarze, 2011).

Long-distance migration of individuals is a prerequisite for the proper functioning of wolf and lynx populations. The average size of the territory of wolves is about 230 km^2 and that of lynxes is about 100 km^2 (Jędrzejewski et al., 2004). The reappearance of the wolf in Kuyavia and Pomerania is undoubtedly the result of migratory behavior characteristic of this species. The animals most likely arrived here from the Bialowieza Forest using the north-central corridor starting there (Kaminski et al., 2011). However, while useful areas for wolves and lynx are plentiful in

Poland, numerous migration barriers hinder their recolonization (Jędrzejewski et al., 2004).

Lynxes move exclusively through forested areas during their migrations (Jędrzejewski et al., 2004), which has to do with the way these cats hunt. They need cover to be able to get closer to their prey and carry out a successful attack (Schmidt & Kowalczyk, 2012). Thus, an essential feature of the environment that enables lynxes' permanent existence is the continuity of forest complexes, which ensures adequate numbers and maintains high genetic diversity in the population (Schmidt & Kowalczyk, 2012). The abundance and condition of predators is also determined by the availability of a food base (Jędrzejewski et al., 2004). The lynx is a typical carnivore. Its food can be a variety of animal species, but it is dominated primarily by large ungulates - roe deer and deer (Schmidt & Kowalczyk, 2012).

In turn, the free roaming bison populations living in both parts of the Białowieża Forest were formed at different times and developed independently of each other. Crossing the border strip was recorded relatively rarely, and after the construction of a fence along the border on the Belarusian side in 1980, both populations developed in complete isolation. Migrations of bison in the eastern part took place in the eastern direction towards fields, meadows and small forests. In the Polish population, during the early period of restoration, the bison migrated westward towards fields of rapeseed, winter crops or corn. Until the late 1970s, both populations occupied relatively small acreages, located in the centre of both parts of the Forest (Kraśiński et al., 2016).

The natural effects of migration restrictions

The state border itself is an obstacle for animals, primarily bison and deer, which negatively affects the gene pool and narrows the gene base of the population (Paszko & Sialverstava, 2022). In addition, the border barrier built by Poland results in a full physical ecological barrier with the disruption of ecological connectivity, which can lead to effects at individual, habitat and species level. The significant barrier effect is due to the construction used and its parameters, probably completely preventing the movement of terrestrial species. As a result of the existence of the barrier, there is habitat fragmentation and isolation of local populations, restriction of the use of individual areas (for obtaining food, seeking shelter, access to breeding sites). The inhibition of the possibility of free movement across the barrier (including local migrations, long-distance migration, and dispersal of individuals) results in a lack of colonization of new habitats and range expansion, the range of gene flow decreases, and the genetic variability of local populations is reduced, leading to their weakening and gradual disappearance.

With the previously identified complete isolation between the bison populations on the Polish and Belarusian sides, Poland's construction of a new border barrier does not seem to be as critical for

achieving the species' conservation goals as in the case of the wolf and especially the lynx. The built border barrier limits the influx of new wolf and lynx individuals from the east, enriching the gene pool of these populations. The barrier causing the effect of their isolation is a factor aggravating the already existing problems of development and even preservation especially of those species in which, as in the case of the bison - the gene pool is poor, and thus, migration (in addition to inbreeding) is a key source of its sustainability.

In terms of long-term environmental effects - the barrier physically divides the site into smaller patches and the dividing line follows the state border - regardless of natural conditions, it causes effects that vary with the natural values of the site and their sensitivity to change. The introduced physical (technical) division of the land, at the level of effect, hinders or prevents the penetration and contact with each other of individuals of the same species and species dependent on each other, residing in fragmented habitats creating the so-called ecological barrier effect. At the level of impact on individual animal species, fragmentation and isolation limit the availability of the food base and gene flow that determines genetic variation within a population and thus its stability and sustainability. As a consequence, there may be a quantitative reduction and, in extreme situations, extinction of local populations and a reduction in biodiversity. This is particularly true for the area located between the border barrier on the Polish side and the '*sistiema*' on the Belarusian side (the total area of cut off areas on the Belarusian side is about 50 km²). Areas of natural value located on the Polish side of the border barrier remain functionally linked to areas to the south, north and west.

The wolf and lynx populations isolated by the border barrier may rapidly reduce local populations of wild ungulates, which in the long term may endanger themselves - due to the depletion of the food base. In the case of wolves in such a situation, there may also be increased killing of livestock. However, assuming the trend of migration of the wolf located on Polish territory towards the western borders and greater freedom of movement in this direction, the population of wild ungulates does not appear to be threatened.

Disruption of corridor functions in extreme cases leads to isolation, manifested, among other things, by a decrease in disease resistance and ability to adapt to changes in the environment (Paszkiwicz, 2021). Isolated populations may experience overcrowding, and this, already recorded in the Białowieża Forest, is a likely cause of the high intensity of lungworm in resident bison resulting from the significant accumulation of invasive larvae of the disease-causing parasite (Demiaszkiewicz et al., 2009).

The wolf's high ability to overcome terrain obstacles (thus, it is not excluded that also barriers through animal crossings, or places devoid of them) and the limitation of its migration towards Belarus, where it is

exterminated - as a result of the creation of another barrier on the border - should not affect the reduction of its numbers and inhibit the growth of its population. Moreover, it could be argued that the border barrier (also due to its design) will reduce the possibility of shooting wolves that would attempt to migrate eastward from the EU area and the possibility of injury if they become entangled in the wires of the concertina 'sistiema' (nevertheless, for wolves migrating from the east, it will provide an additional barrier effect). Thus, the primary direction of spatial expansion of the wolf will be westward, and the primary factor limiting its numbers is likely to be mortality caused by collisions with vehicles on roads.

The border strip and the fence running along it on the eastern side prevent bison migration. On the northeastern side, the Siemianowka reservoir is a migration obstacle, and on the western side the barrier is the 20,000-strong town of Hajnowka and villages, settlements and farmland. The area of the Ładzka Forest, which could provide a link between the Białowieża Forest and the Knyszyn Forest, is only occasionally visited by bison. This situation indicates the high degree of isolation of the Białowieża Forest from other large forest complexes in Poland and the poor development of ecological corridors in its vicinity. The development of the population and thus counteracting the overabundance of bison requires the maximal improvement of existing and potential ecological corridors (Kraśniński et al., 2011). The separation of the two bison populations (western and eastern) is historically determined and their definitive

separation by a barrier functioning since 1980 on the Belarusian side indicates that the new barrier created on the Polish side - is not the first significant restriction of transboundary migration of these animals, but affects the shifting of the boundary of land availability on both sides and creates an enclave between the existing barriers with a hitherto undocumented function in the existence of this species.

Tourism in the Białowieża National Park

Białowieża National Park occupies the central part of the Białowieża Forest, more than 40% of which is within the administrative boundaries of Poland and the remainder of which is in Belarus. In addition to its unique natural value, an additional attraction appealing to domestic and foreign tourists to the Białowieża Forest region was, until recently, the possibility of visiting the areas on the other side of the state border with Belarus, thanks to the Białowieża-Pererorov border crossing, opened in 2005 – and allowed crossing without a visa, with simplified clearance (Rąkowski, 2022). After the outbreak of the migration crisis on the Polish – Belarusian border and the creation of the border barrier, this became impossible. Moreover, the creation of the barrier coincided with the start of a full-scale war in Ukraine (2022). At the same time, this was the year with the lowest rates of nature tourism realized in the Białowieża National Park in 2019-2023 (Table 2). Comparing the number of tourists in 2022 to 2019 (before the Covid-19 pandemic), the scale of decline reached 50%, practically recovering in the following year.

Table 2

Changes in the number of tourists in national parks in Poland in 2019-2023

	2019	2020	2021	2022	2023
Number of tourists in Poland's national parks					
Thousand people	14,149.7	13,411.3	16,068.2	16,031.0	15,554.5
Persons/ha	44.5	42.2	50.5	50.4	48.9
Number of tourists in the Białowieża National Park					
Thousand people	173.5	158.2	142.0	97.0	144.0
Persons/ha	16.5	15.0	13.5	9.0	14.0

In our research, a trend-analysis to tourist numbers was applied. For all Polish national parks combined a non-significant upward trend was observed (slope = +543 000 visitors/year, $R^2 = 0.51$, $p = 0.17$), reflecting COVID-19 and geopolitical fluctuations. In Białowieża NP, data reveal a slight but non-significant decline (slope = -12 000 visitors/year, $R^2 = 0.44$, $p = 0.22$), consistent with 2022's lowest attendance since 2019 and partial recovery in 2023.

Although the tourism trends did not reach statistical significance ($p > 0.05$), the observed decline in Białowieża NP visits in 2022 and the slower recovery in 2023 correspond to the overlapping effects of barrier construction, temporary stay bans, and the war in Ukraine.

Rakowski's (2022) analysis shows that, despite numerous

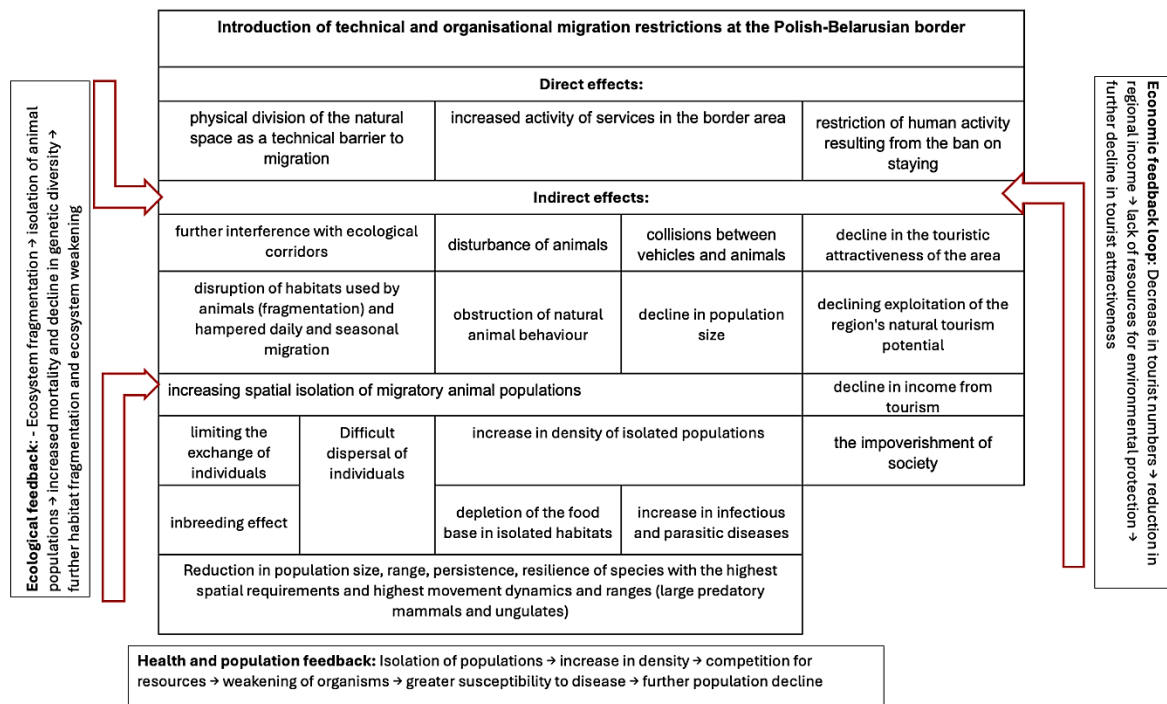
reservations about the representativeness of the CSO's data on tourism in national parks, it can also be used as some measure of the size and dynamics of tourist traffic in the Białowieża Forest region. Based on these data, he showed that the traffic is characterized by significant fluctuations: from 82,300 in 2007 up to 248,700 in 2017. Rakowski (2022) emphasizes that the decline in the number of visitors in recent years has certainly been influenced by the Covid-19 epidemic that began in our country in the spring of 2020, and the migration crisis on the Belarusian border that began in 2021, as well as the restrictions on staying and moving in border areas introduced due to this crisis and the construction of a fence on the Belarusian border. With an awareness of the vast yet untapped tourism potential of the regions, Rakowski (2022) sees numerous threats to the

development of tourism due to the specifics of the location, in connection with the migration crisis, the construction of the barrier and the war in Ukraine, while he also links the threats to the natural environment of the Białowieża Forest itself to the barrier. The current state of knowledge on potential influence of migration restrictions on the Polish-Belarusian border on nature and tourism allows modelling of potential

consequences, as displayed in Figure 1. The direction, mechanism and the scale of these consequences require monitoring and consequently implementing actions which limit their negative influences. Furthermore, it cannot be ruled out that the proposed model fully exhausts the list of potential consequences of the enforced migration restrictions.

Figure 1

Model of potential consequences of introducing technical and organizational migration restrictions on the Polish – Belarusian border



The model above shows the cascading effects of migration restrictions, which lead to a weakening of both the ecosystem and the local economy.

Feedback makes the negative effects accumulate over time, amplifying the initial problems. The ecological imbalance also affects people, especially communities that depend on ecotourism and the region's natural resources.

The first results of a study conducted by the EIA-PIB (2024) on the actual impact of the border barrier two years after its construction show measurable effects on the distribution and movement of mammals (especially bison and deer), confirming the identified potential effects of the introduced migration restrictions. In addition, the impact of the border barrier on the occurrence of invasive plant species in the Białowieża Forest and increased concentrations of foxes, raccoons and domestic cats near the border have been proven. The authors of this research link the increased activity of small predators near the border strip to the presence of permanent military posts on the border, which are a source of food waste, which can promote the spread of diseases carried by wild and domestic mammals.

The most worrisome conclusion of the EIA-PIB study (2024), is that the barrier will significantly contribute to deepening the isolation of the Białowieża lynx population and its exposure to further loss of genetic variability and threats to its sustainability.

Conclusions

The aim of this study was to indicate the direction and mechanism of potential impacts of migration restrictions introduced at the Polish–Belarusian border on three protected species (European bison, wolf and lynx) and on nature tourism dependent on their presence.

Currently, there is no indication that the technical and organisational barriers on the Polish-Belarusian border will be removed or reduced, which allows us to assume that their effects and impacts will be long-term.

Our qualitative, cascade-model analysis—grounded in problem-tree methodology and expert findings—demonstrates that both physical (steel fence) and organizational (temporary stay bans) migration barriers generate pronounced ecological barrier effects. These include:

1. **Habitat fragmentation** and isolation of local wildlife populations, leading to reduced gene flow and weakening of population resilience.

2. **Altered migration dynamics**, with wolves and lynx diverted to alternative routes and bison confined to enclaves, exacerbating genetic bottlenecks.

3. **Decline in tourism** within Białowieża National Park, as restricted access and perceived security risks discourage visitors—thereby undermining both conservation funding and local livelihoods.

These conclusions address directly the study’s aim by tracing the causal pathways through which migration restrictions affect both wildlife and tourism.

They highlight the necessity of:

- **continuous monitoring** of animal movements and tourist flows,
- **adaptive management** to mitigate negative ecological and socio-economic outcomes,
- **policy measures** that reconcile border-security needs with the conservation of transboundary ecological corridors.

Future research should build on this theoretical framework by incorporating empirical field studies and, where appropriate, quantitative analyses to validate and refine the proposed cascade model.

References

- Bernatek, A. (2011). *Koncepcja korytarzy ekologicznych w planowaniu przestrzennym na szczeblu wojewódzkim [The concept of ecological corridors in spatial planning at the provincial level]*. Uniwersytet Jagielloński. <https://journals.pan.pl/Content/96676/mainfile.pdf>
- Demiaszkiewicz, A. W., Pyziel, A. M., Lachowicz, J., & Kuligowska, I. (2009). Robaczycza płucna żubrów w Puszczy Białowieskiej [Bison lungworm in the Białowieża Forest]. *European Bison Conservation Newsletter*, 2, 112–118. https://www.researchgate.net/publication/333190580_Robaczycza_płucna_zubrow_w_Puszczy_Białowieskiej
- Epstein, J. M. (2006). *Generative Social Science: Studies in Agent-Based Computational Modeling*. Princeton University Press. <https://doi.org/10.1515/9781400842872>
- Główny Urząd Statystyczny. (2020). *Ochrona środowiska 2020 [Environmental protection 2020]*, GUS. https://stat.gov.pl/download/gfx/portalinformacyjny/pl/defaultaktualnosci/5484/1/21/1/ochrona_srodowiska_2020.pdf
- Główny Urząd Statystyczny. (2021). *Ochrona środowiska 2021 [Environmental protection 2021]*, GUS. https://stat.gov.pl/download/gfx/portalinformacyjny/pl/defaultaktualnosci/5484/1/22/1/ochrona_srodowiska_2021.pdf
- Główny Urząd Statystyczny. (2022). *Ochrona środowiska 2022 [Environmental protection 2022]*, GUS. https://stat.gov.pl/download/gfx/portalinformacyjny/pl/defaultaktualnosci/5484/1/23/1/ochrona_srodowiska_2022.pdf
- Główny Urząd Statystyczny. (2023). *Ochrona środowiska 2023 [Environmental protection 2023]*, GUS. https://stat.gov.pl/download/gfx/portalinformacyjny/pl/defaultaktualnosci/5484/1/24/1/ochrona_srodowiska_2023_korekta_gugik.pdf
- Główny Urząd Statystyczny. (2024). *Ochrona środowiska 2024 [Environmental protection 2024]*, GUS. https://stat.gov.pl/download/gfx/portalinformacyjny/pl/defaultaktualnosci/5484/1/25/1/ochrona_srodowiska_2024.pdf
- Jamrozy, G. (2008). Ocena występowania i tendencji zmian liczebności dużych i średnich ssaków w polskich parkach narodowych [Assessment of the occurrence and trends in the number of large and medium-sized mammals in Polish national parks]. *Sylwan*, 2, 36–44. <https://doi.org/10.26202/sylwan.2006158>
- Jędrzejewski, W., Nowak, S., Schmidt, K., & Jędrzejewska, B. (2002). Wilk i ryś w Polsce – wyniki inwentaryzacji w 2001 r. [Wolf and lynx in Poland – inventory results from 2001]. *Kosmos*, 51(4), 491–499. <https://kosmos.ptpk.org/index.php/Kosmos/article/view/1496/1475>
- Kamiński, B., Fiederevicz, J., & Grajewski, S. (2011). Wilk (*Canis lupus L.*) w Puszczy Bydgoskiej i jego wpływ na populację dziko żyjących zwierząt kopytnych [The wolf (*Canis lupus L.*) in the Bydgoszcz Forest and its impact on the populations of wild ungulates]. *Infrastruktura i Ekologia Terenów Wiejskich*, 2, 247–260. PAN, Oddział w Krakowie. <https://agro.icm.edu.pl/agro/element/bwmeta1.element.dl-catalog-37687ff0-c847-4e82-8e55-da3164783c81/c/Kaminski.pdf>
- Korytarze ekologiczne w województwie mazowieckim, ze szczególnym uwzględnieniem korytarza ekologicznego Wkry [Ecological corridors in the Masovian Voivodeship, with particular emphasis on the Wkry ecological corridor]. (2011). *Mazowsze. Analizy i Studia*, 4(45). https://biblio.modr.mazowsze.pl/Biblioteka/Ekologia/mais_45_www.pdf
- Kraśniński, Z. A., Olech, W., Perzanowski, K., Bielecki, W., & Bereszyński, A. (2011). Operat ochrony żubra (*Bison bonasus*) w Białowieskim Parku Narodowym [Conservation plan for wisent *Bison bonasus* in Białowieża National Park]. *European Bison Conservation Newsletter*, 4, 101–116. <https://smz.waw.pl/wydawnictwa/biuletyn4/zu13.pdf>
- Kraśniński, Z., Kraśnińska, M., & Raczyński, J. (2016). Żubry nizinne i nizinno-kaukaskie w Puszczy Białowieskiej [Lowland and lowland Caucasian bisons in the Białowieża Forest]. *Chrońmy Przyrodę Ojczystą*, 72(2), 100–109. <http://rcin.org.pl/Content/144293>
- Meadows, D. H. (2008). *Thinking in Systems: A Primer*. Chelsea Green Publishing. <https://research.fit.edu/media/site-specific/researchfit.edu/coast-climate-adaptation-library/climate-communications/psychology-and-behavior/Meadows-2008.-Thinking-in-Systems.pdf>

- Paszkiewicz, R. (2021). *Znaczenie korytarzy migracyjnych bieszczadzskich żubrów w aspekcie ochrony zdrowia tych zwierząt* [The importance of migration corridors of the Bieszczady European bison in terms of protecting the health of these animals]. *European Bison Conservation Newsletter*, 13, 95–102. <https://smz.waw.pl/wp-content/uploads/2021/09/09-Paszkiewicz-R.-Znaczenie-korytarzy-migracyjnych-bieszczadzskich-zubrow-w-aspekcie-ochrony-zdrowia-tych-zwierzat.pdf>
- Paszko, P. & Sialverstava, S. (2022). *Podział Puszczy Białowieskiej i problemy jej ochrony jako wspólnego dziedzictwa Polski i Białorusi* [The division of the Białowieża Forest and the problems of its protection as a common heritage of Poland and Belarus]. In Marozau W. A. & Wołkowycki D. (Eds.) *Lasy przyszłości. Wyzwania współczesnego leśnictwa* (pp. 113–118). Oficyna Wydawnicza Politechniki Białostockiej. <https://pb.edu.pl/oficyna-wydawnicza/wp-content/uploads/sites/4/2022/12/Lasy-przyszlosci.pdf>
- Rąkowski, G. (2022). *Turystyka w regionie Puszczy Białowieskiej w kontekście zarządzania dobrem światowego dziedzictwa Białowieża Forest* [Tourism in the Białowieża Forest region in the context of managing the Białowieża Forest World Heritage Site]. Instytut Ochrony Środowiska – Państwowy Instytut Badawczy. <https://ios.edu.pl/wp-content/uploads/2022/12/bf-ekspertyza-turystyka-w-regionie-puszczy-bialowieskiej-w-kontekscie-zarzadza.pdf>
- Schmidt, K. & Kowalczyk, R. (2012). Zrozumieć rysia [Understanding the lynx]. *Akademia Magazyn PAN*, 2(30), 16–19. <https://journals.pan.pl/dlibra/publication/145773/edition/127017/content>
- Schmidt, K., Kowalczyk, R., Kołodziej-Sobocińska, M., Niedziałkowska, M., Tokarska, M., Żmihorski, M., & Nowak, K. (2025). *Oddziaływanie zapory granicznej na granicy polsko-białoruskiej na Obiekt Światowego Dziedzictwa 'Białowieża Forest'* [Impact of the border barrier on the Polish-Belarusian border on the World Heritage Site 'Białowieża Forest' – Mammals and invasive plants]. Instytut Ochrony Środowiska – Państwowy Instytut Badawczy. https://www.researchgate.net/publication/387958072_Oddziaływanie_zapory_granicznej_na_granicy_polsko-białoruskiej_na_Obiekt_Swiatowego_Dziedzictwa_Białowieża_Forest#fullTextFileContent
- Sterman, J. D. (2000). *Business Dynamics: Systems Thinking and Modeling for a Complex World*. McGraw-Hill Education. https://www.researchgate.net/publication/44827001_Business_Dynamics_System_Thinking_and_Modeling_for_a_Complex_World
- Ustawa z dnia 12 października 1990 r. o ochronie granicy państwowej* [Act of 12 October 1990 on the protection of the state border], (Dz.U. z 2025 r. poz. 184). <https://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WDU19900780461>
- Ustawa z dnia 16 kwietnia 2004 r. o ochronie przyrody* [Act of 16 April 2004 on nature protection], (t.j. Dz.U. z 2024 r. poz. 1478 ze zm). <https://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WDU20240001478>
- Ustawa z dnia 27 kwietnia 2001 r. Prawo ochrony środowiska* [Act of 27 April 2001 - Environmental Protection Law], (Dz.U. z 2024 r. poz. 54 ze zm). <https://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WDU20010620627>
- Ustawa z dnia 29 października 2021 r. o budowie zabezpieczenia granicy państwowej* [Act of 29 October 2021 on the construction of state border security], (Dz.U. z 2023 r. poz. 1390). <https://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WDU20210001992>
- Ustawa z dnia 3 października 2008 r. o udostępnianiu informacji o środowisku i jego ochronie, udziale społeczeństwa w ochronie środowiska oraz o ocenach oddziaływania na środowisko* [Act of 3 October 2008 on the provision of information on the environment and its protection, public participation in environmental protection and environmental impact assessments], (Dz.U. z 2024 r. poz. 1112 ze zm). <https://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=wdu20081991227>