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The Ecological Impacts and Modeling of the Beaver Dam Distribution: A Study on Habitat Characteristics and Environmental Factors in Romania

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Abstract: Beavers (*Castor fiber* L.) are recognized as keystone ecological engineers who shape freshwater ecosystems by modifying hydrology, sediment dynamics, and biodiversity. Although beaver populations have recovered across Europe, including Romania, understanding the environmental factors driving their dam distribution remains limited. This study aimed to (i) characterize the physical and compositional features of beaver dams in the Râul Negru basin, Romania, (ii) model the environmental variables influencing the dam distribution using MaxEnt, and (iii) evaluate the implications for broader conservation strategies. Over a five-year survey covering 353.7 km of watercourses, 135 beaver families were identified, with an estimated population of 320–512 individuals. The dam dimensions showed strong correlations with the river slope, channel width, and wetness index. Predictive models based on LIDAR data achieved over 90% accuracy, outperforming SRTM-based models. The results reveal that topographic wetness, flow accumulation, and valley morphology are the strongest predictors of dam presence. These findings contribute to proactive beaver management strategies, highlighting areas of potential future expansion and offering data-driven guidance for balancing ecosystem restoration with human land use, contributing to the development of conservation strategies that balance ecosystem engineering by beavers with human land-use needs in Romania and across Europe.

Keywords: Eurasian beaver; dam distribution; habitat modeling

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1. Introduction

The European beaver (*Castor fiber* L.) is the largest rodent in Europe, being a predominantly nocturnal species with a semi-aquatic lifestyle and a herbivorous diet [1,2]. Once a well-distributed species, by the end of the 19th century, the Eurasian beaver was on the brink of extinction, surviving in only eight isolated regions across France, Germany, Norway, Belarus, Ukraine, Russia, Mongolia, and China [1,3]. It is estimated that the total population of beavers at that time was approximately 1,200 individuals [4]. Thanks to large-scale conservation efforts, including legal protection, habitat restoration, and translocations, the species has shown a remarkable comeback, reaching a population size of approximately 1.2 million individuals by 2020 [5,6]. Notable reintroduction efforts of the Eurasian beaver include Sweden [7], Scotland [8,9], Great Britain [10,11], the Netherlands [12], and Romania.

In Romania, this species disappeared in the 19th century due to excessive hunting and habitat loss [13]. Through conservation efforts, 182 beavers were reintroduced from Germany between 1998 and 2003 into the Olt, Mureș, and Ialomița river basins [14]. Occupying the same habitats as the previous native populations, over the past two decades, the species has adapted and slowly spread in both number and range, even reaching Bulgaria through the Danube River [15]. This expansion raises concerns about the impact that beavers will have in the future and their negative impact on ecosystems [16,17].

A major challenge for conservation biology is facilitating coexistence between humans and wildlife [18,19]. Human–wildlife conflicts typically occur when wildlife encroaches on human habitats or activities, leading to competition for resources, damage to crops or property, or threats to safety [20]. Most conflicts arise due to an overabundance of certain species [21–23]. In Romania, human–wildlife conflicts are on the rise, primarily driven by large carnivores [24] and ungulates [25], while the current beaver expansion is a potential future issue. The growing number of conflicts involving beavers further complicates the situation, particularly given the already low levels of social acceptance for wildlife interactions in the country. Beavers are often referred to as ecosystem engineers due to their dam-building behavior, which modifies hydrological regimes, sediment transport, and local biodiversity [26–28]. Their presence may increase wetland complexity and habitat heterogeneity but can also lead to flooding, tree loss, and disruption of water management systems [29,30]. Assessing the dual role of beavers—as keystone species and as potential nuisance animals—is fundamental for sustainable ecosystem management and conflict mitigation.

The current understanding of the spatial distribution and environmental determinants of beaver dams, especially in Central and Eastern Europe, remains fragmented. Previous studies often focused on localized habitat preferences or ecosystem responses without integrating predictive spatial models. Therefore, this study aimed to (i) characterize the physical and compositional features of beaver dams in the Râul Negru basin, (ii) model the environmental variables influencing the dam distribution using MaxEnt, and (iii) evaluate the implications for broader conservation strategies in Romania and Europe. By combining empirical fieldwork with high-resolution geospatial analysis, this study addresses critical knowledge gaps and supports data-driven wildlife management.

2. Materials and Methods

2.1. Study Area

This study was conducted within the Râul Negru basin, a significant tributary of the Olt River in Romania, covering an area of 2349 km^2. Originating from the Vrancea Mountains at an altitude of 1260 m, the Râul Negru flows through the Târgu Secuiesc depression, receiving waters from 22 tributaries. The catchment area has an average value of 32 km^2, and flow rates vary between 2 and 10 l/s/km^2. Slopes in the valleys range from 4% to 10%, with multiannual flow rates generally below 20 m^3/s. The area was selected due to its established beaver population and relatively uniform distribution across the tributaries.

2.2. Population Survey and Estimation

Between 2013 and 2018, field surveys covered 353.7 km of watercourses to identify the beaver presence. The surveys involved locating feeding traces, tracks, paths, trails, lodges, and dams using GPS devices. Active lodges were the primary indicator for population estimates, with family size multipliers used to calculate individual numbers (the average size of a beaver family being considered 2.8 in Romania). This method provided an estimate of the number of families and total individuals inhabiting the basin.

For modeling, the following features were collected or calculated: annual rainfall, potential evapotranspiration, land use, valley width, dam presence points, and the DEM. The DEM was used in both SRTM format (shuttle radar topography mission), which has a spatial resolution of 30 m × 30 m at the pixel level, and in LIDAR format (light detection and ranging), with 0.5 m × 0.5 m/pixel. Additionally, the model included a series of variables calculated using the ArcGIS 10.5 software: flow accumulation, the topographic humidity index, and valley depth.

2.3. Dam Measurement and Characterization

Each identified dam was measured for its length (inner contour upstream), width (base thickness), and height (using a gauge fixed at the riverbed downstream). Photographs were taken to document its shape (straight, S-shaped, concave, or convex) and material composition (woody debris, mud, stones, sand, and anthropogenic waste). Additionally, the riverbed width, stream slope, and catchment area at each dam location were recorded. The SAGA GIS 2.3.2. software was used to calculate the stream power index and convergence index based on digital elevation models (DEMs) [31,32].

2.4. Environmental Data Collection and Preparation

The environmental predictors for the modeling included annual rainfall, potential evapotranspiration, land use, valley width, and DEMs (SRTM: 30 × 30 m; LIDAR: 0.5 × 0.5 m resolution). The derived variables included flow accumulation, the topographic wetness index (TWI), and valley depth using ArcGIS tools. The flow rates and maximum flow speeds were obtained from measurements by the Olt River Basin Administration.

2.5. Statistical and Spatial Analysis

All recorded and calculated features were centralized in a Microsoft Excel database. The descriptive statistics (mean, median, standard deviation, minimum, and maximum values) were calculated using RStudio 12.1 packages. The correlations between dimensional features (length, width, height, and material composition) were analyzed, and the datasets were checked for outliers and collinearity. The spatial distribution of the dams was analyzed using the Spatstat package in R to determine the distribution patterns (clustered, random, or dispersed).

2.6. Predictive Habitat Modeling

A species distribution model was developed using the MaxEnt 3.4.1 software [33], suitable for presence-only data. Approximately 30–50 presence points were used to maximize the predictive power [34,35]. The environmental variables included flow accumulation, the topographic wetness index, valley depth, channel width, land use, soil type, precipitation, and evapotranspiration. The model performance was compared between the DEM sources (SRTM vs. LIDAR), evaluating the prediction accuracy. Response curves were generated to visualize the relationship between the environmental variables and dam occurrence likelihood. The MaxEnt algorithm makes predictions based on presence points, not absence points, with the principle that a distribution with maximum entropy is the best approximation of an unknown distribution because it takes into account what is known while avoiding assumptions about what is unknown [36].

3. Results

3.1. Population Characteristics of Râul Negru

It was found that within the Râul Negru basin, there were 135 families in 2018 (Table 1), which was approximately 10% more than the number evaluated in the surveys from June

2013. In the year 2018, the estimated number of individuals in the Râul Negru basin ranged between 320 and 512 individuals.

Table 1. Estimated population characteristics of Eurasian beavers (Castor fiber) in the Râul Negru basin.

Feature	Estimated Number of Families	Minimum Number of Specimens	Maximum Number of Specimens	Population Density (Individuals/km)
Total	135	320	512	0.39

3.2. Dam Characteristics

Based on the dimensional characteristics (Table 2), the volume of the beaver dams was calculated, with the smallest dams being 0.2 m^3 and the largest being 85.1 m^3. To construct these dams, beavers primarily used plant materials, but they also incorporated other materials, such as mud, stones, sand, and sometimes even waste from human activities. The predominant material used in construction was timber, specifically remnants of woody material with varying diameters (1–30 cm) resulting from foraging.

Table 2. Dimensional features and material composition of beaver dams recorded in the Râul Negru basin.

Dimensional Feature	Average	Standard Deviation	Minimum	Maximum
Length (cm)	621.59	320.29	103	1857
Width (cm)	96.8	50.52	30	321
Height (cm)	106.77	45.58	38	305
Proportion of plant material (%)	59.73	18.91	20	90
Mud proportion (%)	40.27	18.91	10	80

The results reveal that dams with small lengths are characteristic of irrigation channels and small tributaries, which often do not exceed 4 m in width, while larger dams are typical of natural or artificial watercourses with a riverbed width greater than 4–5 m.

The highest spatial density of the dams (the spatial density of the beaver dams was calculated as the ratio between the number of dams and the length of the analyzed river segment) was recorded at levels of 2.9–7.3, while the lowest density was at levels of 0.5–0.8. The spatial distribution of the dam density appeared to be closely linked to the habitat quality, particularly the stream width and slope. The average dimensions of the dams were representative of three of the measured characteristics (length, width, and height), with the series of values for these characteristics showing a normal distribution. It was observed that there was a distinct and significant positive correlation between the length, width, and height of the dams. Higher correlation coefficient values could be observed between the height of a dam and its width (0.54), as well as between the height of a dam and its length (0.41). Regarding the shape of the dams, in water sectors with a riverbed width of less than 3–4 m, the shape of the dams was most often straight. In sectors with a greater riverbed width, where the dams were longer, meandering dams with irregular shapes (such as S-shaped, concave, or convex dams) appeared.

The identified dams were built on small- to medium-sized watercourses, with the width of the streambed ranging from 0.9 to 7.5 m. Approximately 78% of the measured dams were located in areas where the width of the streambed was between 2 and 6 m. Regarding the slope of the terrain, 92% of the measured dams were located in areas with a slope between 0 and 5%, 5% of the dams were in areas with a slope of 5–20%, and only 3% were in areas with a slope of 21–35%. The average slope in the basin of the Râul Negru was approximately 6%.

3.3. Predictive Distribution Models for Beaver Dams in Râul Negru Basin

The topographic wetness index had the greatest influence on the beavers' preference for building dams, with values of approximately 0.55, contributing 55.7% to the construction of the model (Figure 1). The parameter with the least influence (0.30) and a contribution of 21.7% to the construction of the model was the valley depth.

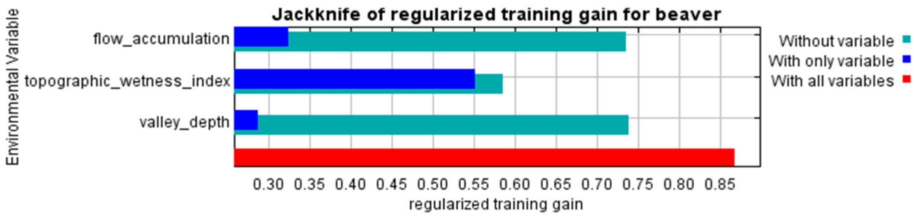

Figure 1. Parameters used in the model and their relative influences.

The MaxEnt prediction (Figure 2) revealed that dams were predominantly found in areas where the flow accumulation was approximately 900 cm^3/s, the topographic moisture index ranged from 3.85 to 25.64, and the valley depth was less than 361.67 cm.

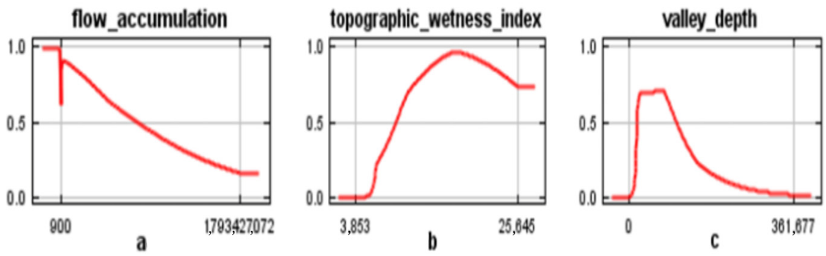

Figure 2. Response curves showing the influences of (**a**) flow accumulation, (**b**) topographic wetness index, and (**c**) valley depth on the likelihood of beaver dam presence.

Based on the modeling of dam position predictions in the basin of Râul Negru, where conditions are suitable for beavers to build dams (Figure 3), it was found that both digital elevation models achieved a support level exceeding 85% (85.6% for SRTM and 90.5% for LIDAR), which suggested a nearly perfect match. Still, the SRTM model delivered data with a lower accuracy, as some predicted points did not align with the watercourse, whereas the LIDAR model demonstrated a higher accuracy, with all predicted points located along the river. A significant relationship was identified between height and composition, with a directly proportional relationship with the vegetation composition (0.21) and an inversely proportional relationship with the silt composition (−0.21).

In the development of the model for predicting the distribution of beaver dams (Figure 4) in the Râul Negru basin, additional variables considered included channel width, land use category, potential evapotranspiration, average annual precipitation, and soil type. The channel width contributed the most to the model (83.6%), while the soil type had no contribution (0%). The remaining variables included in the analysis had contribution percentages below 6%. Although no presence of dams was recorded based on the field data in the Râul Negru area, the modeling indicated that beavers may have constructed dams in the upper part of the river. This may be due to the fact that in that area, the channel width was less than 6 m, the flow rate and speed were at a minimum, and the terrain slope was below 5%.

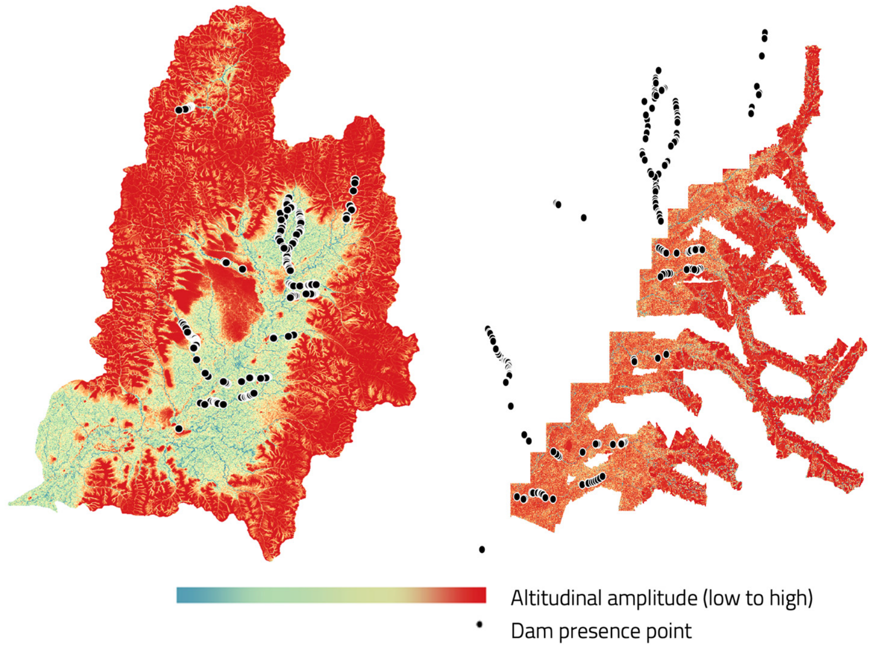

Figure 3. Spatial predictions of beaver dam distribution based on (**left**) SRTM-derived DEM and (**right**) LIDAR-derived DEM for the Râul Negru basin.

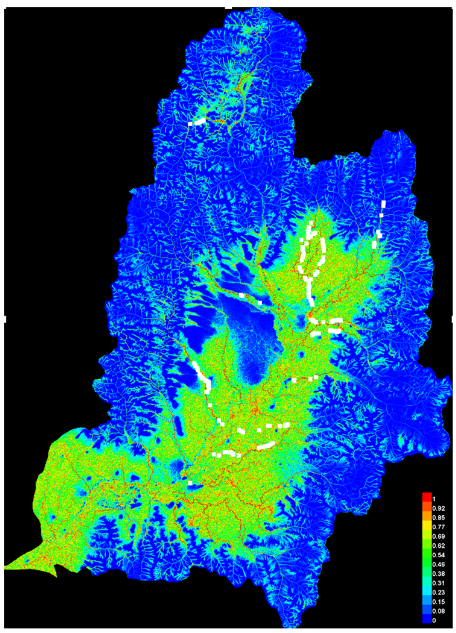

Figure 4. Predicted suitability map for beaver dam construction across the Râul Negru basin based on MaxEnt modeling and environmental variables.

Based on the response curves (Figure 5), each of these environmental parameters provided different information regarding the likelihood of the presence of beaver dams. The response curves show that the probability of dam occurrence was higher in areas with channel widths ranging from 0 to 132.68 cm, an average annual precipitation between 546.96 and 635.50 mm, potential evapotranspiration values between 785.28 and 952.59, valley depths of up to 333.79 cm, and a topographic moisture index ranging from 4.02 to 24.18.

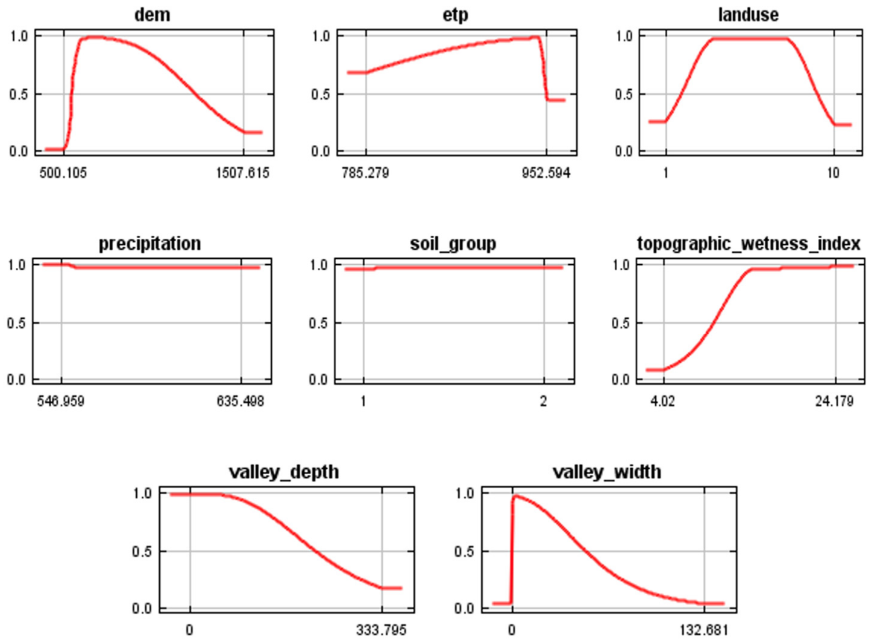

Figure 5. Response curves for channel width, annual precipitation, potential evapotranspiration, valley depth, and topographic wetness index influencing beaver dam occurrence probability.

4. Discussion

As one of the few regional studies combining field ecology with predictive modeling of beavers, this study represents an innovative approach to studying beaver ecology. In Romania, and especially in the Râul Negru basin, approximately two decades after the first reintroduction actions of beavers in 1998 [37], the species has entered a phase of exponential expansion, with the population increasing at a rate of 20% per decade. In this context, the territories reclaimed by beavers are becoming increasingly vast, so the current range is much more extensive compared with that during the reintroduction period. The observed density of 0.39 individuals/km closely mirrors populations in central Russia [38], suggesting optimal environmental conditions. In Bavaria, the density identified was much higher, at 1.15 individuals/km [39], while in Poland, the densities can exceed 6 individuals/km^2 [40]. A very similar species, the North American beaver (*Castor canadensis* L.), has a higher density of 0.5–0.6 colonies/km (1.8 individuals per colony) in the Green River, Utah [41]. The spatial distribution of dams across various tributaries demonstrates a successful recolonization process underpinned by suitable hydrological and morphological conditions [42,43].

From the analysis of the ten environmental characteristics, this study identified clear patterns linking dam characteristics (e.g., size and shape) with topographic and hydrological variables. Meanwhile, the geographical position of dams had limited influence on their structural features, similar to the findings in a related species of beaver (*Castor canadensis* L.) from North America [44]. There was a strong inverse relationship between the shape and spatial position of the dams, particularly regarding coordinates in the north direction and altitude, as was found in similar studies [45,46]. Nonetheless, dam shape exhibited a notable inverse correlation with altitude and northing, though this pattern may reflect the uniform hydromorphological profile of the Râul Negru basin rather than a causal effect.

The composition of mud and the composition of vegetation are highly correlated due to their antagonistic nature (the two characteristics are represented as percentages, such that the % silt composition + % vegetation composition = 100%). In other words, an increase in the height and length of a dam leads to an increase in the proportion of plant material and a decrease in the proportion of silt. However, since this relationship was not statistically significant, it was anticipated that other factors (e.g., the abundance of materials and local conditions) may also influence the proportions of materials in the dam. The slope of the terrain measurement was similar to those reported in Sweden, where the vast majority of dams are distributed in areas where the slope is between 1 and 4% [47]. The terrain slope is a limiting factor for the construction of beaver dams [48,49]. In the study conducted by Macfarlane in 2017 [43], it was noted that the species did not build dams where the slope exceeded 23%, and very rarely have dams been reported on land with a slope between 17% and 23%, which is also confirmed by our findings.

Speed and flow, along with the width and depth of the river, the distance to woody vegetation, and the height of the bank, are some of the most important factors in the construction of beaver dams [42]. Additionally, beavers sometimes inhabit larger rivers (as is the case with the Râul Negru), but they will only build seasonal dams during periods of low flow, a fact also noted in the research conducted by Castro et al. in 2015 [50].

The ecological niche model developed using MaxEnt provided reliable predictions of the dam distribution, with both the SRTM and LIDAR-based models achieving a strong performance (AUC > 85%). The LIDAR-derived model, with a spatial resolution of 0.5 m, demonstrated a superior predictive accuracy compared with the 30 m resolution of the SRTM-based model. This difference highlights the importance of precision in modeling fine-scale habitat features, particularly in riparian ecosystems where subtle microtopographic variations influence beaver site selection. However, MaxEnt's reliance on presence-only data introduces a potential limitation: areas predicted as highly suitable may not reflect actual occupancy due to non-environmental constraints, such as territoriality, dispersal barriers, or anthropogenic disturbances. Additionally, while MaxEnt is highly effective in identifying environmental correlates, it does not inherently capture temporal dynamics or changes in population behavior over time.

Beyond the local findings, this study contributes to broader conservation strategies by highlighting how predictive modeling and dam characteristic analysis can support landscape-level decision making. In Romania, where rewilding initiatives are gaining traction, the expansion of beaver populations presents both ecological opportunities and socio-economic challenges. The model identified suitable habitats in the upper reaches of the Râul Negru basin, where no dams are currently present. These "hotspots" highlight potential areas of future expansion and serve as valuable inputs for conservation planning. By integrating predictive modeling with real-time field monitoring, stakeholders can prioritize high-risk areas for early interventions, such as infrastructure reinforcement, riparian buffer creation, or proactive stakeholder engagement. This approach could significantly reduce future human–wildlife conflicts while supporting the ecological functions of beaver presence.

The study findings advocate for the use of spatial modeling in wildlife management frameworks, and especially in beaver management. Predictive tools, particularly when enhanced with high-resolution geospatial inputs, can inform long-term landscape planning and species coexistence strategies, and can prepare scientists for the adoption of adaptive management. The documented habitat preferences and dam construction patterns can inform regional habitat suitability maps and guide future reintroduction or connectivity projects. In the context of Romania and Eastern Europe, where beaver populations are rapidly expanding [5,51], such tools are not only beneficial but essential to balance biodiversity conservation with human land-use priorities [52–54]. Ultimately, integrating such empirical models into conservation planning can help policymakers move from reactive conflict management toward proactive ecosystem design, enhancing the coexistence between humans and this keystone species.

5. Conclusions

The presence and expansion of Eurasian beavers in Romania signal both ecological recovery and a growing need for adaptive wildlife management. This study demonstrated that high-resolution spatial data, combined with ecological modeling, can effectively predict dam distribution and identify future conflict zones. Moving forward, conservation efforts should be proactive rather than reactive, integrating ecological, hydrological, and social dimensions. Importantly, collaborative strategies between researchers, land managers, and local communities will be essential to mediate human–wildlife interactions. As European landscapes continue to change under both anthropogenic and climatic pressures, the Eurasian beaver may serve as both a management challenge and an emblem of ecosystem recovery.

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