IMPACT OF WHEEL TRACK EROSION ON THE BRIȚEI *CROCUS HEUFFELIANUS* FIELD

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Abstract. Impact of wheel track erosion on the Briței *crocus heuffelianus* field. This study examines the impact of off-road vehicle traffic and associated "floral tourism" on the population of *Crocus heuffelianus* within the Briței floral field. As social media-driven tourism increases, sensitive ecosystems face new anthropogenic pressures that threaten the long-term viability of rare botanical species. The analysis is based on aerial imagery captured via UAV across three sample areas in May 2021. Photogrammetric reconstruction of the UAV imagery into high-resolution digital surface models (DSMs) enabled the quantification of floral coverage, the extent of habitat fragmentation, and the direct mechanical footprint of wheel-track erosion on the *C. heuffelianus* population. The findings reveal a significant *C. heuffelianus* prevalence, with floral cover ranging between 15,9% and 26,0% (average 20,1%). However, habitat fragmentation varied significantly, reaching a peak of 5,41 m^2/100 m^2 in the most disturbed plots. High fragmentation indices (4 m^2/100 m^2) and direct spatial coincidence between vehicle trajectories and dense floral clusters resulted in a 2,8% loss of total floral area. Total population estimates exceed 30 million specimens, yet wheel-track erosion and associated soil compaction are responsible for a total loss of over 900000 individuals.

Keywords: wheel track erosion, off-road tourism, habitat fragmentation, *Crocus heuffelianus* damage and loss

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1. INTRODUCTION

The degradation of natural environments due to motorized off-road tourism has become an increasingly prevalent global phenomenon. Beyond immediate ecological disturbances, this activity facilitates the progressive loss of natural and semi-natural habitats, leading to subsequent declines of various biodiversity components including flora elements which, in many instances, constitutes the primary aesthetic and touristic appeal of the landscape. The present study aims to quantify the physical impacts of motorized off-road vehicles within the Briței *Crocus heuffelianus* field, assessing the extent of habitat fragmentation and the loss of specimen caused by these anthropogenic pressures.

2. ECOLOGY, DISTRIBUTION AND CONSERVATION STATUS OF *CROCUS HEUFFELIANUS* IN ROMANIA

In Romania six species of the genus *Crocus* are known, amongst which *Crocus banaticus* and *Crocus heuffelianus* are the most widespread in the country (Anastasiu et al., 2021). *Crocus heuffelianus* is a perennial geophyte and European endemic species distributed across the Alpine-Carpathian-Balkan region. The species exhibits a spring phenology with flowering occurring between March and May, after snowmelt. Ecologically, *C. heuffelianus* is frequent and occasionally abundant across a broad altitudinal gradient, extending from the sessile oak belt to subalpine elevations. Its habitat preferences include meadows, glades, forest edges, and riparian woodlands (Sârbu et al, 2013). It settles preferably on open habitats and prefers bright light during its flowering period in early spring, but it can also grow in broad-leaved forests. Requires consistent moisture during the spring growth phase which is provided by snowmelt (Mihaly & Kricsfalusy, 1997). In Romania we may find them for ex. in Făgărași, Maramureș, Rodnei, Harghita, Șureanu and Bihor Mountains, this latter being the topic of this article. Each spring, following the snowmelt, extensive carpets of *Crocus* species emerge. Their visual impact is such that it defies description (Székely, 2023).

The above-ground biomass of *C. heuffelianus* persists for a brief vegetative period of approximately three months. The prominent purple flowers emerge contemporaneously with the leaves, arising directly from the subterranean corm. The root system initiates development in autumn (at shallow soil depths), persisting through winter frosts to remain functional during the spring growth phase. Consequently, the phenological strategy of *C. heuffelianus* is characterized by early spring flowering followed by a prolonged summer-to-winter dormancy (Mihaly & Kricsfalusy, 1997). Since it lacks an above-ground stem, it also ripens its fruit underground and this makes it so vulnerable against wheel track or footpath erosion and (over)grazing. Although the livestock do not graze the flowers, they cause soil compaction, which inhibits the maturation of the crop (Höhn, 2000).

Law No. 49/2011, which ratifies Emergency Government Ordinance No. 57/2007 on the protected areas and values, does not list *Crocus heuffelianus* as a protected species (in Romania), still according to management plans of the protected areas, Natura 2000 data forms (2020) recommendations and generally conservation ethics emphasizes that any damage should be avoided to plants, as disturbing the corms and the habitat poses a threat to the population.

3. STUDY AREA

The study area encompasses tree study plots of the Briței *C. heuffelianus* field, situated in the Bihor Mountains, north of the Padiș Plateau. While colloquially referred to as Briței crocus field it actually lies beneath the Briței Peak (the site specifically occupies the slopes surrounding and beneath Briței Peak) extending eastwards toward Piatra Tâlharului and reaches southwest the ridge overlooking the headwaters of Someșul Cald River. The total extent of the *Crocus heuffelianus* habitat comprises approximately 2,7 km², characterized by a distribution ranging from sporadic occurrences to high-density floral clusters.

The studied area lies at an altitude at about 1600–1700 m, where a relatively cool and humid (pluvial) climate prevails. The mean annual temperature being approximately 2–4°C, the mean precipitation can reach 1400 mm annually (at Stâna de Vale Meteorological station) (Bleahu and Bordea, 1974). The first snow arrives usually in the second part of November (Copernicus Browser, 2015–2025) and it lasts until mid-May, sometimes (like 2025) late April, snow melting being the key factor of blooming.

Approximately third of this field lies within the boundaries of the Apuseni Nature Park and the ROSCI0002 Apuseni Natura 2000 site, designated under the EU Habitats Directive and it is integrated in the ROSPA0081 Apuseni–Vlădeasa Natura 2000 site designated under the EU Birds Directive.

The crocus field represent a significant seasonal tourist destination, characterized by high visitor density during the flowering period. This phenological phenomenon creates a unique natural spectacle that serves as a primary pull factor for the area in the blooming period. Tourism generates a substantial digital footprint, extensive social media activity and coverage on tourism platforms that lead to an annual increase of tourists and in addition to backpackers, there has been a notable rise in motorized tourism (4-wheel drive cars, motorbikes, quads, etc.) that led to growing human impact on biodiversity and specifically on *Crocus heuffelianus*.

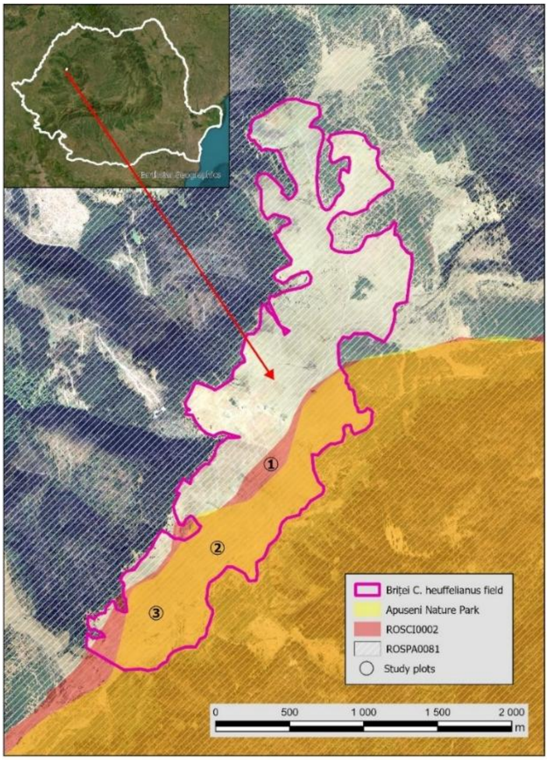

Fig. 1. Wheel track erosion on the Briței C. heuffelianus field

Fig. 2. Study areas on the Briței C. heuffelianus field

4. DATA AND METHODS

The primary objective of this study is to assess the impact of intensified off-road tourism on the habitat of *Crocus heuffelianus* during its flowering period and all over the year. The research quantifies the extent of habitat degradation caused by the formation of wheel tracks. The analysis is based on aerial imagery captured via Unmanned Aerial Vehicles (UAVs) across three sample areas in May 2021. These images were processed into orthophotos using Agisoft Metashape Professional photogrammetry software, and subsequent spatial analyses were conducted within the ArcGIS 10.8 and ArcGIS Pro Geographic Information System (GIS) environment. The spatial resolution of the resulting orthophotos was 3,68 cm/pixel. The total extent of the three sample areas is 1,28 km^2, comprising study plot 1 (0,38 km^2), study plot 2 (0,45 km^2), and study plot 3 (0,45 km^2).

While the Random Forest (RF) algorithm classified the majority of wheel tracks as bare soil, manual vectorization was subsequently employed to refine the actual boundaries of the tracks. This method was necessary to distinguish between areas where intermittent water flows had disrupted soil integrity from the ones where off-road vehicles caused linear erosion and to include tracks that had induced soil compaction without resulting in the total loss of vegetative cover.

Habitat fragmentation was assessed employing a methodology adapted from the concept of drainage density (D_d) used in hydrology and geomorphology. While drainage density is traditionally defined as the ratio of total channel length to total basin area (typically expressed in km/km^2 or m/m^2), habitat fragmentation in this study was calculated as the ratio of the total surface area of wheel tracks to the total area within a 100 m^2 grid (expressed in m^2/100m^2). Mean habitat fragmentation for the entire plot area was calculated using the same ration and is similarly expressed m^2/100 m^2.

C. heuffelianus cover was quantified using an identical approach, ensuring consistency across all spatial metrics.

Flower density was calculated using the quadrat method, within 1x1 m quadrats. To determine the required number of quadrats, a running mean was plotted until the estimate stabilized, as described in the sampling protocols by the Interagency Technical Reference (1999) and by Barker (2001). Running average and standard deviation curves smoothed out at about 14 measurements (out of 20), when percentage change in density was +/- 2%. A mean density of 163 flowers per m^2 was derived and utilized for subsequent calculations.

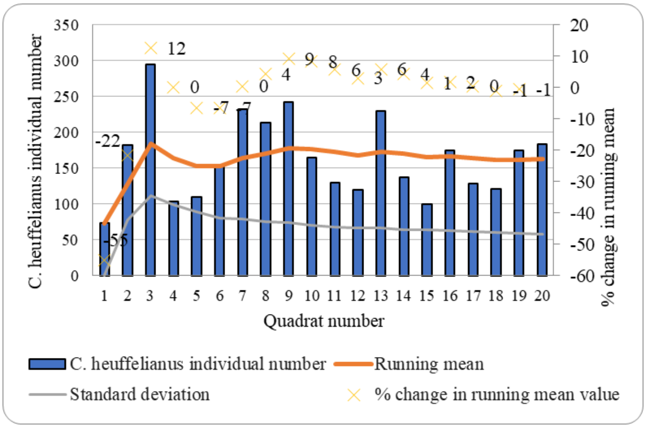

Fig. 3. Running mean analysis of C. heuffelianus population density across sequential quadrats

5. RESULTS

5.1. Spatial distribution and environmental determinants of *C. heuffelianus* habitats

The initial phase of the investigation focused on the spatial identification and delimitation of areas within the potential range of *Crocus heuffelianus*. To isolate the primary habitat, the study area was constrained to an alpine meadow, utilizing vectorized boundaries to exclude large woody and shrub-dominated vegetation units where crocus occurrences were merely sporadic. Consequently, the total area of the three sample sites was narrowed to 1 km², encompassing study plots 1, 2, and 3, with respective areas of 0,35 km², 0,26 km² and 0,39 km². This grassland matrix, characterized by consistent *C. heuffelianus* presence, served as the starting point for subsequent analyses.

Floral clusters were identified using the Random Forest (RF) algorithm, a supervised machine learning technique. This model was selected for its proven efficacy, with previous studies demonstrating accuracies exceeding 90% (Gogul et al., 2017; Sivaraj et al., 2024). The RF algorithm enabled the classification of the environment into six distinct categories: grass, *C. heuffelianus* clusters, soil, snow, rocky terrain, and small bushes. Solitary flowers and very low density floral clusters could not be identified as such by the model because of the relatively low of resolution of the orthophotos. Bushes, snow, and rocky patches were excluded as these represent environmental „noise” or unsuitable substrates that do not support the *C. heuffelianus* niche. Bare soil surfaces – often conforming to the geometry of wheel tracks or natural linear erosion – were retained and identified as *C. heuffelianus* habitat because the disturbance (water/wheels) is mechanical rather than a change in soil type or morphology of the relief. The potential area of crocus habitat was calculated by aggregating grassy areas, crocus clusters, and bare soil (table 1). The inclusion of bare soil is justified by the fact that these areas, though currently disturbed by wheel tracks or intermittent watercourses, represent potential habitats where the original vegetation cover was destroyed.

The primary matrix for potential expansion consists of grassland, which covers more than 70% of the area (average 72.9%). The variation in grassy cover is minimal, ranging only from 71,6% in plot 1 to 75,1% in plot 2. While certain

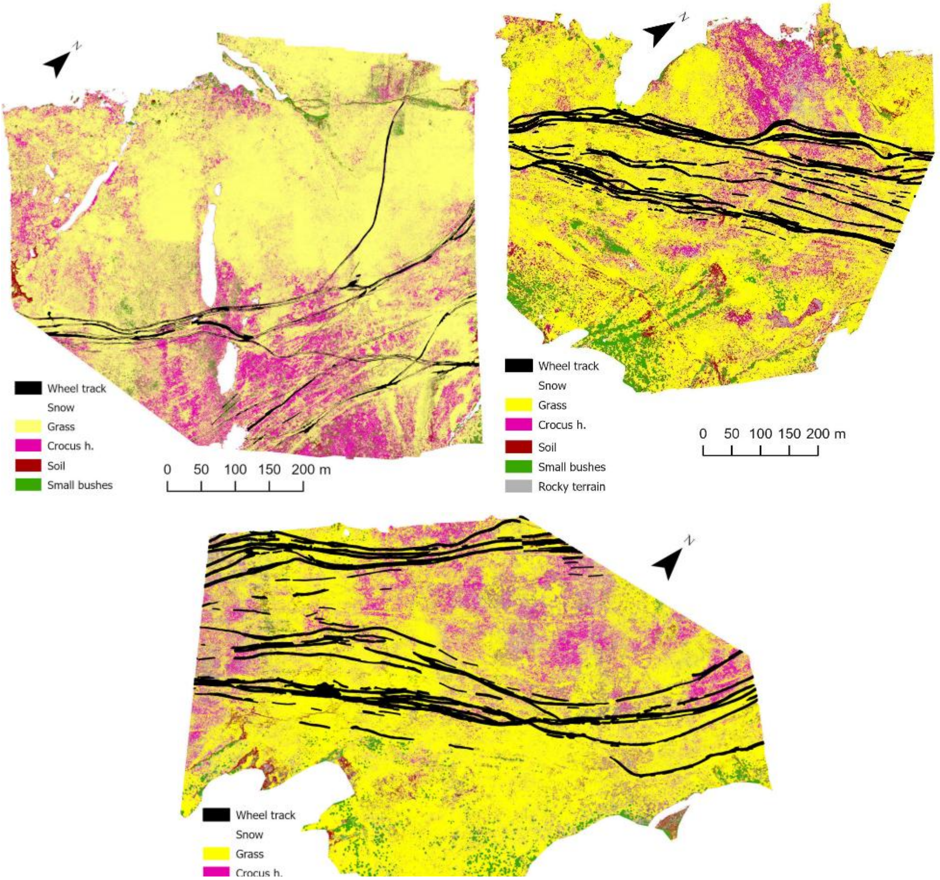

Fig. 4 Spatial distribution of C. heuffelianus and wheel tracks on plot 1 (upper left), plot 2 (bottom) and plot 3 (upper right)

terrains were initially categorized as lacking *C. heuffelianus* cover, these suitable habitats are actually more expansive. The true extent of these areas remained unrecognized because the sporadic presence of flowering individuals led to their exclusion from primary distribution maps.

Table 1. C. heuffelianus distribution across the study plots

Study plot	*C. heuffelianus* habitat (m^2)	Grass %	Bare soil %	Crocus clusters %
1	326557	71,6	2,4	26,0
2	228323	75,1	9,0	15,9
3	359004	71,8	9,7	18,5
Total/Average	913884	72,9	7,0	20,1

C. heuffelianus prevalence across the three study plots varied between 15,9% and 26%, with an average of 20,1%. This represents a significant abundance for a specialized alpine species, still it is important to note that while the overall presence of the species is more widespread, this study specifically focused on areas densely covered by *C. heuffelianus* categorized as floral clusters.

While *Crocus heuffelianus* typically favors southern exposures, analysis across the three designated study plots revealed no consistent correlation between floral distribution and slope aspect. The only uniform characteristic across all sites was the preferential distribution of individuals on flat terrain, which accounted for 19%, 35%, and 9% of the population in plots 1, 2, and 3, respectively.

Plot 3 demonstrated a strong affinity for high-insolation areas, with 82% of floral clusters situated on south (S) and southwest (SW) facing slopes. Similarly, plot 2 showed a moderate preference for these aspects (52%). Conversely, plot 1 displayed an inverse distribution, with 51% of floral clusters localized on cooler, shaded northern (N), northeastern (NE), and eastern (E) exposures. This observed lack of strong aspectual correlation may be attributed to the low topographic inclination of the study sites. In high-altitude, open meadow ecosystems with minimal slope gradients, the variation in incident of solar radiation between different exposures is significantly attenuated. Consequently, the relative thermal and light energy income across these plots remains relatively uniform, diminishing the selective pressure for southern-facing microsites.

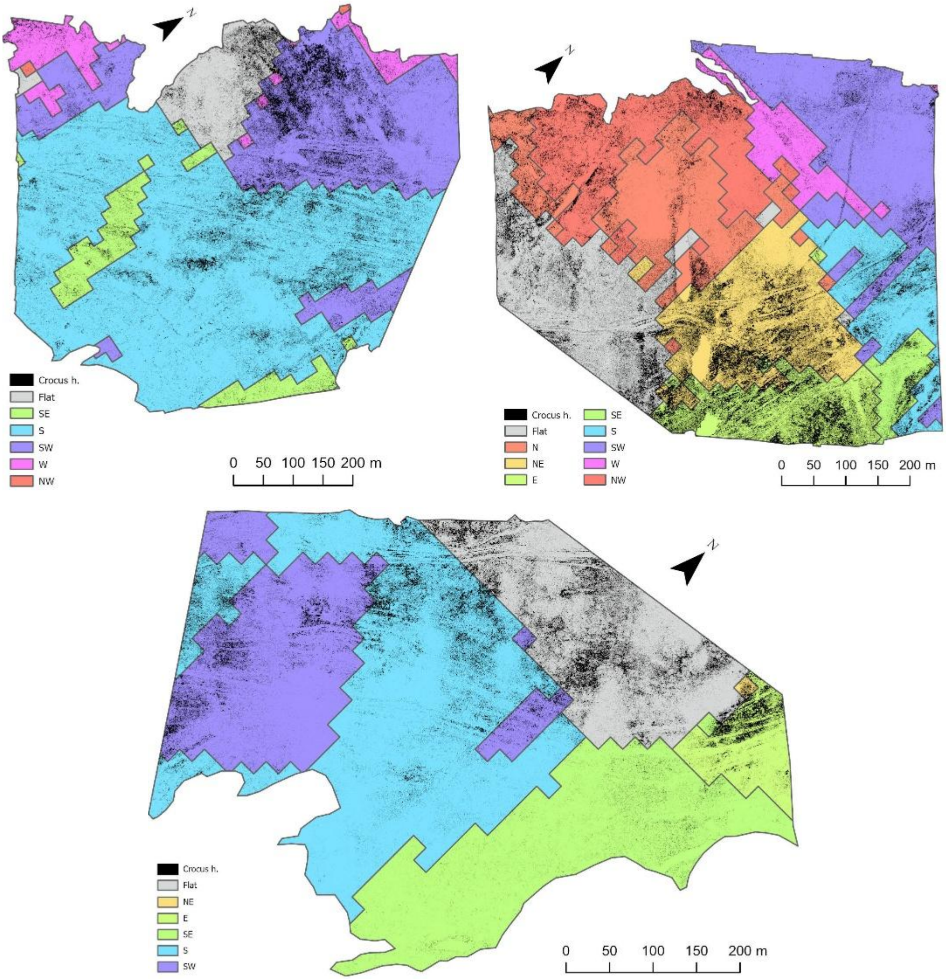

Fig. 5. Distribution dynamics of C. heuffelianus along slope aspect on plot 1 (upper left), plot 2 (bottom) and plot 3 (upper right)

The gradient of the slopes colonized by *C. heuffelianus* exhibits minimal variation, with the study area characterized predominantly by gentle terrain. The mean slope across the three sample plots is 6,19°. Spatial analyses of floral distribution reveal a distinct preference for nearly level or gently sloping areas, which account for 75%, 80%, and 74% of occurrences in plots 1, 2, and 3, respectively. Areas categorized as sloping represent the secondary distribution zones (22%, 19%, and 25%), whereas steeper gradients exhibit only negligible or non-existent occurrences. These findings are consistent with the species' requirement for wet conditions during the spring growth phase; such moisture is typically provided by snowmelt, which is insufficient on steep slopes where accelerated melting and rapid surface runoff prevent adequate soil saturation.

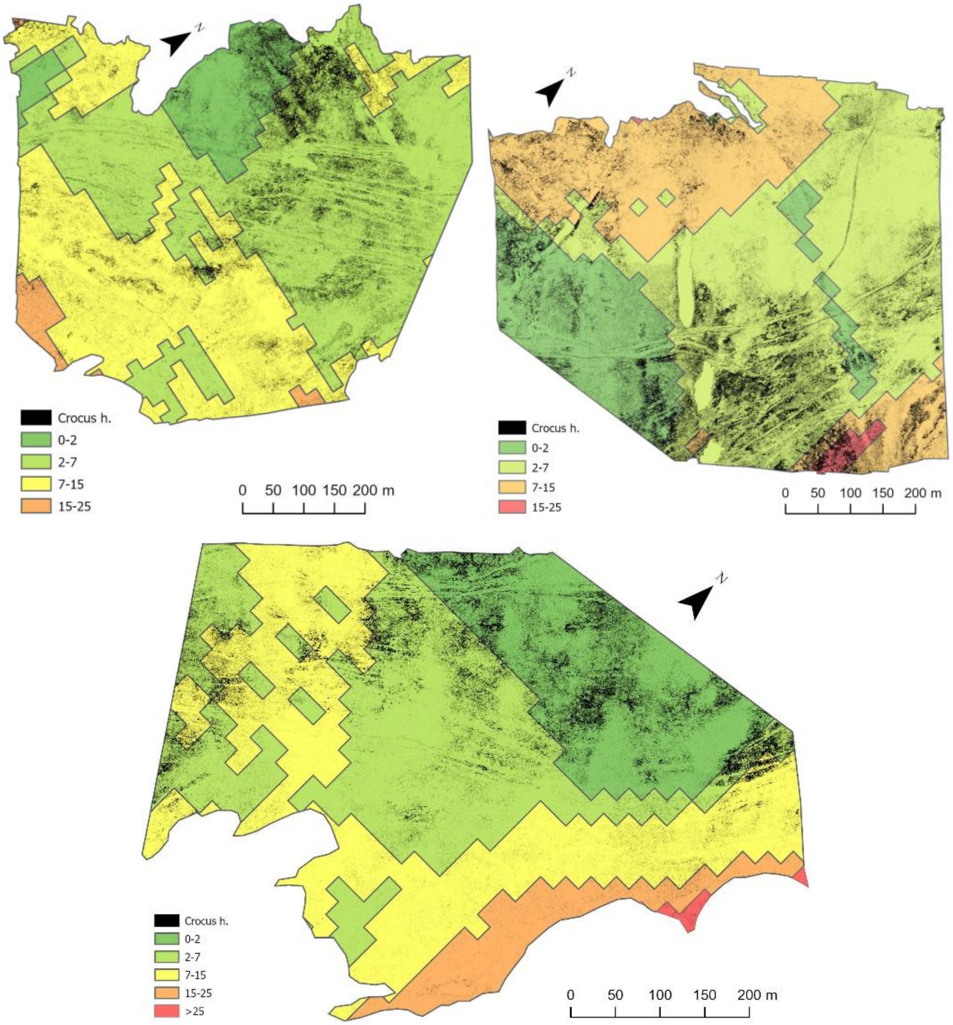

Fig. 6. Distribution dynamics of C. heuffelianus along slope gradients on plot 1 (upper left), plot 2 (bottom) and plot 3 (upper right)

5.2. Impact of habitat fragmentation and wheel-track disturbance on *C. Heuffelianus* floral cover

Quantifying the spatial extent of wheel tracks allowed for the assessment of habitat fragmentation – specifically the dissection of the landscape caused by these anthropogenic linear features. The intersection of vehicle tracks with floral clusters results in significant specimen damage or loss. Frequent use of wheel tracks over floral clusters leads to total destruction of the vegetation and severe soil compaction, which crushes the corms. However, where tracks are used only occasionally, the soil is not fully compacted. In these cases, *C. heuffelianus* can survive as long as the physical damage does not extend deep enough to impact the corm itself. In the present study, floral loss and damage are analyzed collectively, as the increased frequency of track usage inevitably leads to deep-soil compaction that eventually compromises the viability of the corms.

Table 2. Mean C. heuffelianus cover, mean habitat fragmentation and floral loss or damage across the study plots

	Mean *C. h.* cover $m^2/100\ m^2$	Mean habitat fragmentation $m^2/100\ m^2$	*C. h.* loss or damage by wheel tracks (%)
Plot 1	26	3,06	3,0
Plot 2	15,9	5,41	1,9
Plot 3	18,5	3,54	3,5
Average	20,11	4,00	2,80

Although there is pretty high degree of structural similarity across the three study plots Plot 1 stands out with the highest mean flower coverage (26 $m^2/100\ m^2$) and the lowest impact of the wheel tracks.

Observations from Plot 1 indicate a lower frequency of wheel tracks; however, these features exhibit greater width and more advanced erosion. Spatial analysis of the tracks reveals that although they have a low habitat fragmentation (3,06 $m^2/100\ m^2$), they intersect directly with floral zones. This overlap results in the mechanical degradation of approximately 3% of the total floral coverage. This suggests that even a few poorly positioned tracks in a meadow can cause significant damage if they bisect flower colonies.

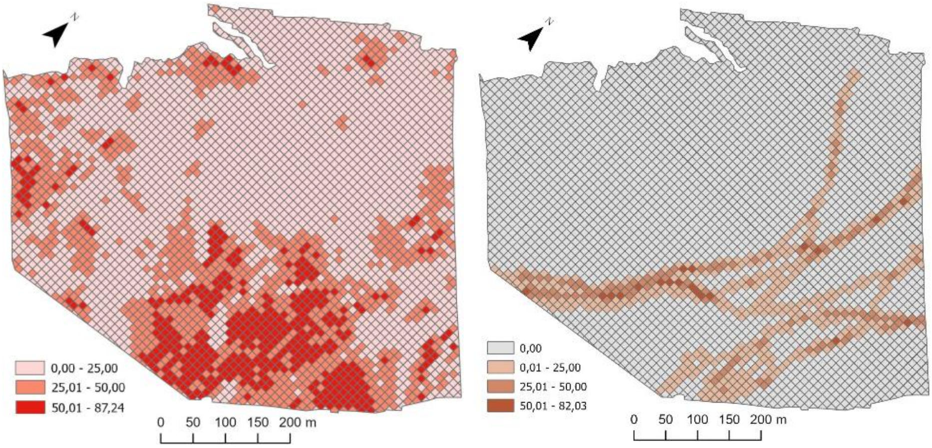

Fig. 7. Spatial analyses of floral cover classes (left) and habitat fragmentation(right) (expressed in %, in 100 m^2 quadrats) on plot 1

Conversely, in plot 2 mean floral coverage has the smallest value (16 m^2/100 m^2), both the frequency and the total surface area of the tracks are significantly higher than in plot 1 and 3, and it correlates with the highest degree of habitat fragmentation (5,4 m^2/100 m^2). However, spatial analysis indicates that these trajectories bypass the primary, high coverage *Crocus heuffelianus* clusters; consequently, the degree of fragmentation within the specific floral zones causes smaller damage, resulting in the lowest (1,9%) structural disruption to the crocus-covered areas.

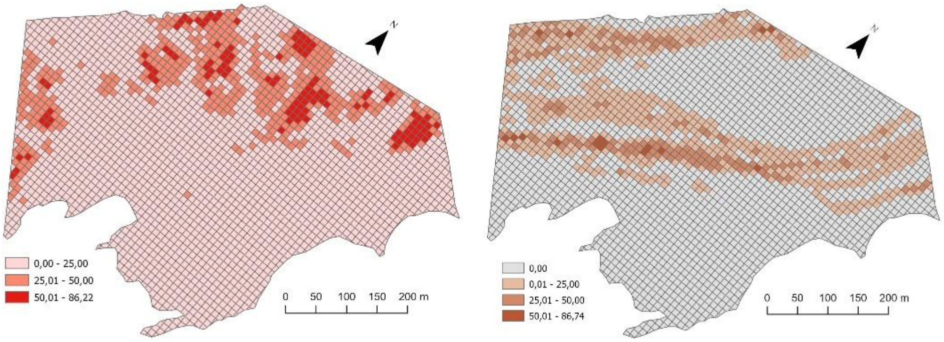

Fig.8. Spatial analyses of floral cover classes (left) and habitat fragmentation(right) (expressed in %, in 100 m^2 quadrats) on plot 2

Plot 3 exhibits intermediate values across the three plots regarding both mean floral coverage (18,5 m^2/100 m^2) and mean habitat fragmentation (3,5 m^2/100 m^2).

Nevertheless, it demonstrates the most significant impact in terms of spatial overlap, with 3,5% of crocus population affected by mechanical disturbance. The total area of vehicular tracks intersecting floral clusters reached 2299 m^2; this substantial footprint suggests that traffic is extensively dispersed throughout the plot, precluding the possibility of the population avoiding anthropogenic damage.

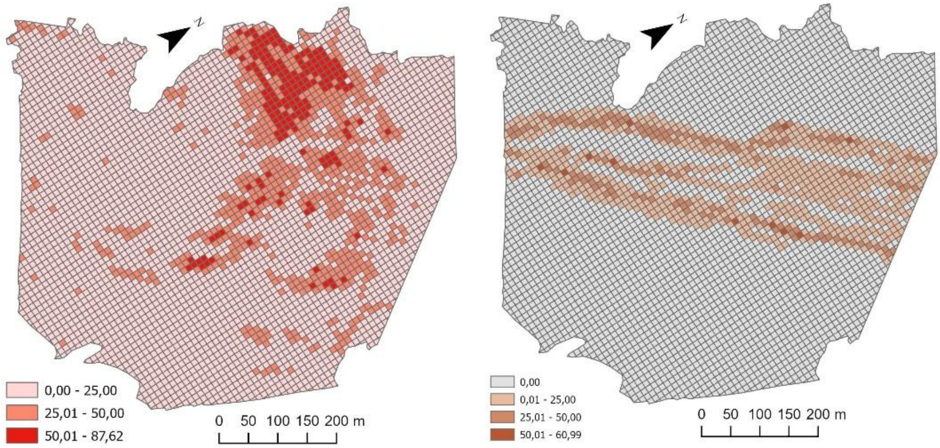

Fig. 9. Spatial analyses of floral cover classes (left) and habitat fragmentation(right) (expressed in %, in 100 m^2 quadrats) on plot 3

5.3. Quantification of *C. heuffelianus* damage and loss

Crocus density was assessed using 20 randomly selected 1x1 m quadrats, within which every individual specimen was recorded. The observed densities ranged from 73/m^2 to 295/m^2, with a mean flower density of 163 *C. heuffelianus*/m^2.

Utilizing a mean density of 163 specimen/m^2, the estimated population of *C. heuffelianus* within the designated high coverage area was calculated to be approximately 30 546 502 individuals. While the total population across the broader Briței field significantly exceeds this number, the scope of the current analysis was restricted to densely covered zones.

Table 3. Quantifying floral loss and damage induced by wheel-track erosion in c. heuffelianus populations

	Crocus specimens	Crocus specimens damaged or lost by wheel track erosion
Plot 1	13 834 187	411 991
Plot 2	5 902 923	114 825
Plot 3	10 809 392	374 709
Total	30 546 502	901 525

The quantification of specimen loss and damage resulting from vehicular erosion was extrapolated from the previously calculated wheel track area, yielding consistent loss or damage across the three study plots: 411 991 specimens in plot 1, 114 825 in plot 2 and 374 709 in plot 3, respectively. Off-road vehicular activity led to the mechanical destruction of an estimated 901 525 specimens, corresponding to an aggregate mortality or damage rate of approximately 2,95%.

6. DISCUSSION

The observed distribution of *C. heuffelianus* across the study plots suggests a strong correlation between habitat integrity and species coverage. The findings regarding the impact of anthropogenic disturbance reveal that while the area is naturally prone to crocus, erosion from wheel tracks inhibit *C. heuffelianus* growth by breaking up or compact the soil.

The increased surface area of wheel tracks correlates directly with the volume of vegetation cover removal and/or compacted soil. As noted by Höhn (2000), soil compaction inhibits the maturation of the corm (bulbotuber) and the development of the underground organs. By quantifying the area of these tracks, we can better estimate the loss of vegetation and the vulnerable zones where water infiltration is restricted and mechanical resistance prevents the upward emergence of buds in early spring. Sprouts and juvenile individuals exhibit the highest vulnerability to soil compaction, as their corms and root systems are still rudimentary and situated at shallow soil depths. This lack of structural maturity and vertical displacement makes these early-stage geophytes particularly susceptible to mechanical stress and desiccation, ultimately driving to population decline. Because root development begins in autumn, the period of environmental sensitivity extends well beyond the flowering period. The lack of above-ground structures in the dormant period prevents the spatial delimitation of the population by the public, making the avoidance (even if intended) of these areas practically impossible outside the flowering season.

Consequently, fragmentation of the area should be viewed not just as a spatial division of the population, but as a significant loss (an average of 4 m^2/100 m^2) of viable subterranean habitat.

Still, data suggest that habitat fragmentation is not the only source of species loss in this context, rather the high values of fragmentation and the spatial overlap between vehicular trajectories and floral clusters determines the survival rate. Plot 2 proves that tourism may coexist with sensitive geophytes if the activity is geographically restricted to the periphery of floral „hotspots".

Field observations reveal that many off-road tours specifically target the densest floral areas rather than avoiding them. In pursuit of "spectacular" social media content, vehicles are driven straight through the flower beds. This behavior likely accounts for a significant, though currently unquantified, proportion of the total destruction (>900000 specimens) observed within the *C. heuffelianus* population."

Given that the study area serves as a primary transit corridor crossing the main ridge of the Bihor Mountains, we recommend the designation (during the flowering season) of a single, restricted route, complemented by the installation of landscape-integrated camouflaged barriers to protect the remaining floral clusters. The implementation of these measures would be significantly facilitated by a border extension of both the Nature Park and the ROSCI0002 Apuseni Natura 2000 site to ensure that the entirety *C. heuffelianus* population receives formal protection.

References

1. Anastasiu, P., Comanescu, P., Urziceanu, M., Calotă, A. (2021): Distribution of the Crocus Species in Romania, Acta Horti Botanici Bucurestiensis, nr. 47, p. 67-104
2. Barker, P. (20001): A Technical Manual for Vegetation Monitoring, Resource Management and Conservation Division, Department of Primary Industries, Water and Environment, Hobart, 79 p.

3. Bleahu, M., Bordea, S (1974): Bihor-Vlădeasa: Ghid turistic, Editura pentru Turism, București, 118 p.

4. Gogul, I. Kumar, V.S. (2017): Flower species recognition system using convolution neural networks and transfer learning. Fourth International Conference on Signal Processing, Communication and Networking (ICSCN), IEEE, India, p. 1-6

5. Höhn M. (2000): A Kárpáti sáfrány (C. heuffelianus), Erdélyi Nimród, https://web.archive.org/web/20131004212739/http://erdelyinimrod.ro/html/archivum/153

6. Interagency Technical Reference (1999): *Sampling Vegetation Attributes*. BLM/RS/ST-96/002+1730, National Business Center, Denver, Colorado, 164 p.

7. Mihaly, A., & Kricsfalusy, V. (1997). Population biology and ecology of *Crocus heuffelianus* HERB. (Iridaceae) in Ukraine, *Linzer biologische Beiträge*, *29*(2), p. 641–681

8. Sârbu, I, Ștefan, N, Oprea, A (2013): Plante Vasculare din România: Determinator ilustrat de teren, Editura Victor B Victor, București, 1320 p.

9. Sivaraj, M., Thanappan, R., & Sharma, A. K. (2024): A Comparative Analysis of AI Methods for Flower Classification and Chemical Fingerprint Creation, *International Research Journal of Multidisciplinary Technovation* 6 (6), p. 241-60, https://doi.org/10.54392/irjmt24617

10. Székely Árpád (2023): A Kárpátok virágoskertje: Növény ritkaságok és botanikai csemegék a Magas-Tátrától a Retyezátig, Árkánia Könyvesbolt, Székelyudvarhely, 280 p.

11. ***Lege nr. 49 din 7 aprilie 2011pentru aprobarea Ordonanţei de urgenţă a Guvernului nr. 57/2007 privind regimul ariilor naturale protejate, conservarea habitatelor naturale, a florei şi faunei sălbatice, https://faolex.fao.org/docs/pdf/rom203885.pdf

12. ***Ordonanță de urgență nr. 57 din 20 iunie 2007 privind regimul ariilor naturale protejate, conservarea habitatelor naturale, a florei și faunei sălbatice, https://legislatie.just.ro/Public/DetaliiDocument/294533

13. ***ROSCI0002 Apuseni Natura 2000 standard data form, 2020, https://www.mmediu.ro/app/webroot/uploads/files/Formulare_standard_SCI.pdf

14. ***Ordin privind aprobarea Planului de management integrat al Parcului Natural Apuseni și al ariilor naturale protejate integrate, Monitorul oficial al României, Nr. 1071, p. 3-1163

15. ***Snow data, Copernicus Browser, browser.dataspace.copernicus.eu/