Landscape Architecture

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Class-Resolved Land-Cover Resistance of Peri-Urban Green Infrastructure in the Krakow Metropolitan Fringe

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Abstract

Green infrastructure in peri-urban areas may be assessed according to various criteria like green-area quantity, accessibility, or sustainability class. Such indicators prove valuable, however, the difference between convertible and resilient land remains overlooked. This paper studies Krakow's peri-urban fringe based on land-use composition within five sustainability classes defined for each of the 2313 hexagonal cells in the assessment system. The aim was to identify sustainability classes that feature both significant proportion of space and land use configuration that increases vulnerability of green infrastructural assets. Additionally, the effect of a modest arable-permanent grassland land-use exchange is estimated on those two classes that exhibit relatively higher susceptibility to change. The five classes under study have 1095 fields each (which constitutes 47.34% of the total number of fields), while very high and high classes account for 615 fields apiece (totaling 26.59%). Ordinal state is equal to 2.81, while ordinal sustainability burden stands at 0.547. In the very low class, arable land covers 74%, built-up - 11%, permanent grassland - 10% and no forest; therefore, its exposure-resilience ratio comes up to 8.50. For very high class arable land occupies 16%, built-up - 3%, permanent grassland - 18% and forest - 58%; hence, it gets an exposure-resilience ratio equal to 0.25. The low class is primarily responsible for vulnerability since it involves 36.62% of the total number of fields, exposes 73% to conversion and scores the transition-priority value of 0.200. With 20% arable-permanent grassland reallocation, the ratio of the very low class drops from 8.50 to 2.83, and that of the low class decreases from 3.48 to 1.78.

Keywords: peri-urban green infrastructure; arable land; permanent grassland; forest anchors; land-cover resistance; Krakow; exposure-to-resilience ratio

1. Introduction

Fringes of metropolitan areas are dynamic transition landscapes, in which agriculture, settlement, woodland, grassland, transport lines, and protected nature areas coexist within a limited planning horizon. Green performance of metropolitan fringes cannot be judged on the basis of green surface alone. While one large arable block may look open, it could be under high residential or infrastructural pressure and thus be prone to subdivision. On the other hand, a smaller woodland area or grassland complex would offer better sustainability of green land from

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planning point of view. Thus, the question of green land is not merely one of green surface but rather of its planning durability.

The notion of green infrastructure is widely recognised in urban and regional environmental planning because of its dual linkages between ecology and spatial governance. It is defined as a continuous green space network, which performs the functions of supporting ecosystems, increasing biodiversity, ensuring recreational and social well-being, improving the resilience to climate change, and maintaining good health conditions of the population [4, 12, 24]. Landscape ecology gives further weight to this definition by pointing out that ecological function relies on patch and network properties such as composition, edge quality, connectivity, and surrounding-land permeability [6, 23]. These principles are crucial in peri-urban settings, where minor additions to settlements and extensions of transport routes create continuous threats to ecological networks, without reaching significant surface changes first.

The Krakow metropolitan fringe is characterised by presence of arable land, permanent grassland, woodland, built-up surface, water bodies, and protected or semi-protected natural areas. These land-cover categories are not ecologically or planning-wise equivalent and need to be differentiated. While woodlands can be treated as ecological anchors, permanent grasslands can connect and buffer settlement fields. Arable land can provide openness, good farmland, and traditional landscape but within the dynamic metropolitan fringe environment, it can easily convert into other land use. Built-up land represents existing anthropogenic transformation and adds new pressure to nearby farmland. Thus, the task of assessing Krakow metro fringe is to distinguish between green land cover and sustainable green land.

Composite sustainability classes make such differentiation possible because they condense several criteria into meaningful ordinal order. Sustainability classes can reveal the extent of ecological importance of land cover, the strength of human pressure on it, and planning urgency to secure it. A class label in itself, however, does not convey much about the reasons behind the particular class rating. The same class position can be associated with different land cover combinations. Low class with predominance of farmland represents a totally different planning challenge than low class with predominance of settlement. High class rich in forest is obviously more important from ecological standpoint than another high class covered mainly by temporary or weakly protected open spaces. Thus, class interpretation has to take into account land cover types, which are linked to the five sustainability classes.

The assessment offered in this paper maintains the existing calculations and enhances their interpretative power. The purpose of the exercise is to determine the sustainability class that represents the largest vulnerable belt, the class with the highest level of exposure imbalance, and the land cover adjustment that helps improve the weakest classes. The analysis utilises 2313 hexagonal assessment fields and the class-level land cover data from the Krakow Green Neighbourhood Sustainability Index assessment [5]. The number of hexagons is kept deliberately low in order to maintain the class resolution: very low, low, moderate, high, and very high classes are considered as distinct land-cover resistance categories.

The paper offers additional class interpretation to the existing calculations. It reveals the low class as the most vulnerable belt, the very low class as the most imbalanced exposure state, and the very high class as the most ecologically stable retention category. In addition, the assessment shows that limited modification of low classes can result in major improvements in their vulnerability/retention balance. The main conclusion of the paper is that green infrastructure in the Krakow metropolitan fringe needs to be managed in terms of land cover resistance: forest clusters need to be protected, low classes with predominance of arable land need to be controlled, and the permanent grassland category is best for reinforcing weakest open lands.

2. Background

2.1. Green infrastructure beyond surface area

The term “green infrastructure” is not synonymous with all undeveloped land but rather denotes a geographically coherent system of natural and semi-natural components, performing ecological and social functions across urban, peri-urban, and regional territories [1, 4, 24]. While the concept of green infrastructure is important from the point of view of ecology, it adds planning significance because of its multiple functional roles. These include ecological functions, such as provision of wildlife habitat, maintenance of biodiversity, water regulation, and ecological connectivity, and social functions, such as climate regulation, recreation, and cultural values [14, 16]. Green infrastructure also implies spatial continuity of green land. As a matter of fact, any surface can qualify as green, and the Krakow peri-urban fringe has numerous examples. Yet, not all green spaces are ecologically and socially functional and planning-wise reliable.

This problem can be explained by means of landscape ecology. Landscape structure affects ecological functions through such factors as patch and corridor geometry, connectivity, and edge quality [6, 23]. While connectivity can be ensured through appropriate spatial design, ecological functionality requires careful selection of green components. The Krakow assessment can benefit from such selection as it distinguishes between agricultural fields, permanent grassland, woodland, urban parkland, and other open lands. Such differentiation is useful for identifying the elements of the landscape that are suitable as green infrastructure elements.

2.2. Peri-urban conversion pressure

Peri-urban areas combine agricultural persistence and urban sprawl. The process of suburbanisation implies gradual transition of open lands into urban and suburban environments via settlement, industrial activity, infrastructure development, and transport route construction. While the change happens continuously on one side, it is hardly noticeable in aggregate land-cover maps. Yet, it poses serious challenges to ecological functionality and planning sustainability of the land. Several studies of global and European peri-urban areas prove that such conversion negatively affects biodiversity, carbon storage, landscape identity, hydrology, and ecological network structure [2, 20, 25].

In this situation, agricultural fields play an ambiguous role. While providing openness, biodiversity, and productive farmland, agricultural areas can easily undergo transformation, and, hence, cannot be regarded as sustainable open land. Farmland, although providing some benefits, is often vulnerable to residential and infrastructure developments, especially in areas experiencing rapid growth and economic attractiveness of parcel division. Thus, the role of agricultural land in urban-fringe environment needs special consideration.

Another element to be assessed is built-up area. Unlike farmland, it represents completed transformation of green land. In other words, urban fabric records already existing conversions and often adds further pressures to the adjacent open land. In a sense, the combination of agricultural and built-up land represents high vulnerability of green cover. Such vulnerability cannot be reduced or eliminated entirely. It simply points to the places in peri-urban landscapes where agricultural land will sooner or later transform.

2.3. Forest and grassland retention capacity

Forests and permanent grasslands can serve as anchors of green infrastructure in peri-urban areas. While the former represent high ecological value and planning significance, the latter can complement the anchor role of forest areas by linking them and buffering other less resistant elements, such as agricultural land. Unlike forests, permanent grasslands do not represent high structural resistance of land-cover, but they can be created through such practices as establishment of meadows, riparian buffers, and agricultural grass strips. Such grasslands have been shown to improve urban environment significantly, both socially and ecologically [22].

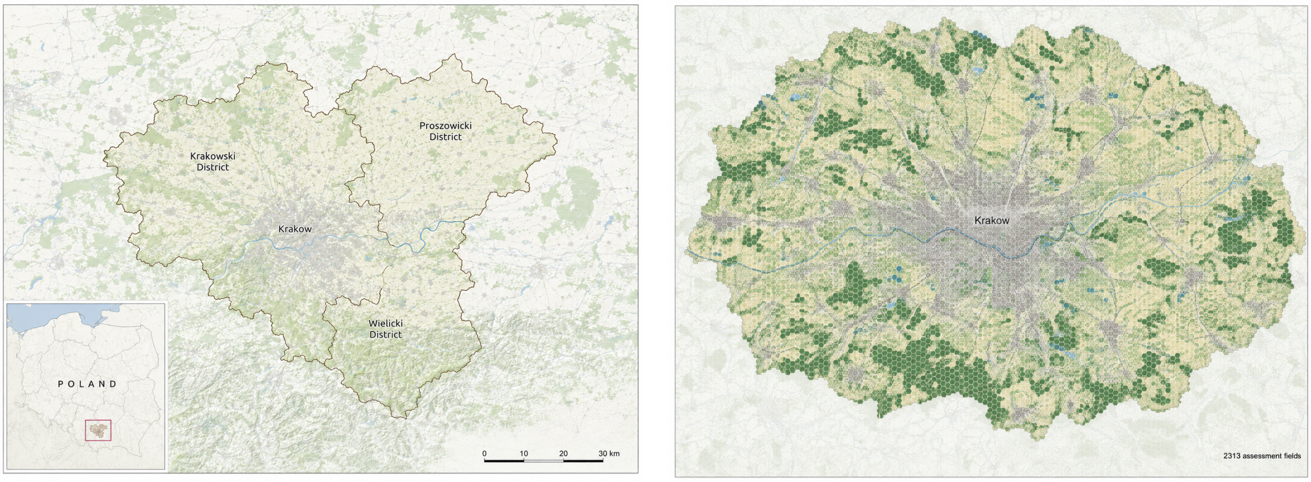
Thus, in terms of the Krakow peri-urban environment assessment, forests will be interpreted as anchor components and grasslands as linkable components of green land. This classification helps interpret the results correctly. The very high class will be interpreted as ecologically stable and sustainable class while other classes, especially those that dominate in arable land, will need grassland addition.

3. Krakow Metropolitan Fringe and Assessment Fields

3.1. Metropolitan setting

This study examines a peri-urban landscape around Krakow located in southern Poland. The total assessment area is 2056 km^2 and includes the Krakowski, Proszowicki, and Wielicki districts. The area is composed of dense urban core, scattered suburban settlements, open agricultural fields, wooded areas, permanent grasslands, water areas, and protected or semi-protected natural areas. The combination of such diverse land cover allows for conducting a class-resolved assessment, which takes into account both ecological stability of the landscape and susceptibility to conversion.

This metropolitan setting is illustrated in Figure 1. The first sub-map presents district boundaries and the second one presents the actual assessment fields.



(a) District context. **(b)** Assessment fields.

Figure 1. Krakow assessment surface.

Paired figures in Figure 1 explain the level of analysis. Hexagonal cells represent standard units for assessment, neither legal parcels nor design lots. They enable reading the metropolitan fringe as a continuous class surface of sustainability structure. The scale used supports strategic priorities, and its application would involve zoning and ownership data.

3.2. Sustainability classes and number of fields

Calculation involves 2313 basic assessment fields and five sustainability classes based on the Krakow Green Neighbourhood Sustainability Index assessment [5]. Classes are denoted very low, low, moderate, high, and very high. They are interpreted as ordered states from 1 to 5 in terms of an ordinal measure of burden. Such ordering does not imply equal distances between the GNSI class intervals but relies on ordering to define the position of the assessment system in terms of the weak to strong sustainability continuum.

Numbers of class fields reported in Table 1 confirm that there is a highly uneven distribution. Together, very low and low classes include 1095 fields, equal to 47.34% of all fields. Moderate class includes 603 fields, or 26.07%. Similarly, high and very high classes contain 615 fields, or 26.59%.

The values in Table 1 identify the low class as a central planning category rather than a marginal condition. It contains 847 fields, more than any other class. Planning attention therefore cannot be confined to the 248 very low fields. A wider low-sustainability belt must be evaluated because its size may produce the greater cumulative conversion risk.

The distribution is visualised in Figure 2. The low class dominates the field count, while high and very high classes form a smaller combined share. The mean ordinal position of 2.81 indicates that the class distribution is pulled downward by low and moderate states rather than upward by retention states.

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Table 1. Sustainability-class distribution.

Sustainability class	GNSI interval	Hexagons	Share (%)	Ordinal state
Very low	−0.81–0.42	248	10.72	1
Low	0.43–0.92	847	36.62	2
Moderate	0.93–1.39	603	26.07	3
High	1.40–1.93	324	14.01	4
Very high	1.94–2.60	291	12.58	5
Total	–	2313	100.00	–

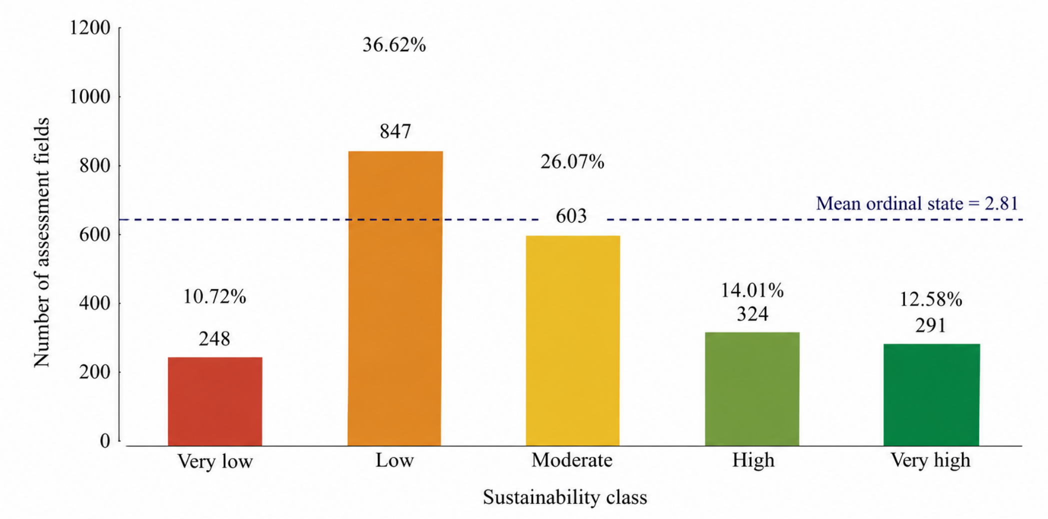


Figure 2. Sustainability-class counts.

Figure 2 distinguishes between class severity and class dominance. While the very low class ranks as the weakest by severity, the low class is the dominating spatial characteristic. The distinction makes it clear why subsequent analyses use both class weakness and class share as well as conversion exposure rather than simply class order.

3.3. Land-cover composition at the class level

There are five land-cover categories that form the basis for interpreting the sustainability classes: arable land, permanent grassland, forest, built-up land, and other land. Conversion exposure comprises arable land and built-up land. The former is regarded as the exposure since it can be converted into built-up land while still being visibly green and convertible, especially compared to forest and permanent semi-natural land within the metropolitan fringe. Ecological resilience includes forest and permanent grassland. The forest represents ecological anchoring and resilience, and the latter represents semi-natural connectivity and an option to enhance agricultural sustainability without closing off space.

The figures for land-cover composition in Table 2 demonstrate significant contrasts among the sustainability classes. The very low class consists of 74% arable land, 10% permanent grassland, no forest, 11% built-up land, and 5% other land. The low class consists of 64% arable land, 18% permanent grassland, 3% forest, 9% built-up land, and 5% other land. Both the moderate and high classes display a more equal land-cover composition than the other two classes, whereas the very high class is characterized by 58% forest cover and 3% built-up land.

The compositional values in Table 2 show that the sustainability gradient is not a simple shift from built-up land to green land. The weaker classes remain strongly green in visual terms because they are dominated by arable land, but that green component has lower resistance. The strongest class differs because forest becomes the dominant cover, not because all non-built land is counted equally.

Table 2. Land-cover composition by class.

Class	Arable land (%)	Permanent grassland (%)	Forest (%)	Built-up (%)	Other (%)
Very low	74	10	0	11	5
Low	64	18	3	9	5
Moderate	42	29	13	9	8
High	43	24	17	8	7
Very high	16	18	58	3	5

The same contrast appears in Figure 3. The broad arable blocks in the very low and low classes and the dominant forest block in the very high class provide the empirical basis for the exposure and resilience calculations.

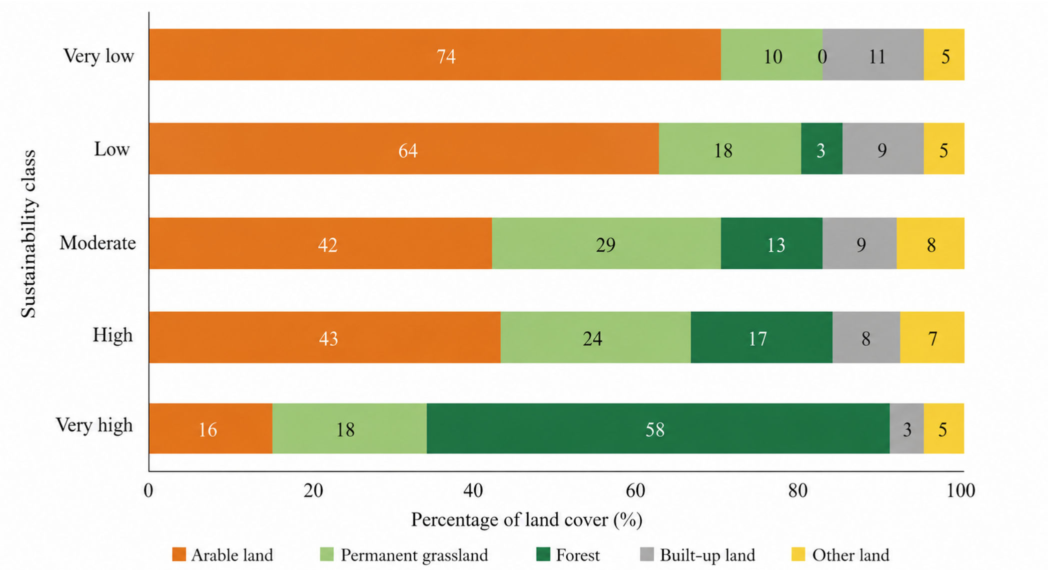


Figure 3. Land-cover composition.

The land-cover bars in Figure 3 make the main contrast visible without adding another classification. Arable land dominates the vulnerable classes, while forest dominates the most secure class. Permanent grassland increases in the middle classes and provides the most practical category for improving the weakest classes without changing the entire agricultural identity of the fringe.

4. Class-Level Indicator Calculation

4.1. Ordinal sustainability burden

The first calculation summarises the class distribution. Let s_j denote the proportional share of class j, where $j = 1, \ldots, 5$ and larger values indicate stronger sustainability states. The mean ordinal state is calculated as

$$\bar{O} = \sum_{j=1}^{5} j s_j . \tag{1}$$

This value locates the centre of gravity of the five-class distribution. It is not a replacement for the GNSI value and does not reinterpret the index intervals. It describes whether the assessment system is concentrated toward weak, intermediate, or strong classes.

Ordinal sustainability burden is calculated as

$$B = \sum_{j=1}^{5} s_j \left(\frac{5-j}{4} \right). \tag{2}$$

A burden value of 0 would mean that all fields are in the very high class. A burden value of 1 would mean that all fields are in the very low class. The actual value expresses how far the observed distribution remains from the strongest possible class arrangement. This is useful for the Krakow fringe because strong forest-rich fields do not cancel the large extent of lower classes.

4.2. Conversion exposure and ecological resilience

Conversion exposure is calculated for each class by summing arable land and built-up land:

$$E_j = A_j + U_j, \tag{3}$$

where A_j is the arable-land share and U_j is the built-up share. The definition captures two distinct drivers of weakness. Built-up land records existing transformation. Arable land records open land that may remain conversion-sensitive under suburban growth.

Ecological resilience is calculated by summing forest and permanent grassland:

$$R_j = F_j + G_j, \tag{4}$$

where F_j is the forest share and G_j is the permanent-grassland share. Forest and grassland do not perform the same role, but both contribute to class-level resistance. Forest provides stronger anchoring; grassland provides a repairable and connective component within agricultural landscapes.

The exposure-to-resilience ratio is calculated as

$$ERR_j = \frac{E_j}{R_j + \epsilon}. \tag{5}$$

The stabilising constant ϵ is set to zero because each class contains at least some forest or permanent grassland. A high value indicates that exposure components dominate. A low value indicates that resilience components are stronger than arable and built-up pressure.

4.3. Priority score and arable-grassland reallocation

The priority score combines class weakness, exposure, and class share. The class weakness coefficient is calculated as

$$W_j = \frac{5-j}{4}. \tag{6}$$

The coefficient equals 1 in the very low class and 0 in the very high class. It decreases stepwise from weak to strong states.

The transition-priority score is calculated as

$$TPS_j = W_j \times \left(\frac{E_j}{100} \right) \times s_j. \tag{7}$$

This calculation identifies classes in which weakness, exposure, and spatial extent coincide. It is necessary because the most imbalanced class is not always the largest planning problem. A small class with severe exposure may require repair, while a larger class with slightly lower exposure may require stronger preventive policy.

The two weakest classes are also evaluated through a 20% arable-grassland reallocation. The adjusted arable and grassland shares are calculated as

$$A'_j = 0.8A_j, \tag{8}$$

$$G'_j = G_j + 0.2A_j. \tag{9}$$

Adjusted exposure and resilience are then calculated as

$$E'_j = A'_j + U_j, \tag{10}$$

$$R'_j = F_j + G'_j, \tag{11}$$

and the adjusted ratio is calculated as

$$ERR'_j = \frac{E'_j}{R'_j}. \tag{12}$$

This calculation represents limited reinforcement of permanent grassland in the very low and low classes. It does not assume full afforestation, removal of agriculture, or change to built-up land. It measures how strongly the weakest classes respond when part of the arable component becomes a more resistant semi-natural cover.

5. Results

5.1. Lower-class burden across the assessment fields

The class distribution reveals a marked lower-state burden. The very low and low classes contain 1095 fields, or 47.34% of the assessment system. The moderate class contains 603 fields, or 26.07%. The high and very high classes contain 615 fields, or 26.59%. These values show that the Krakow fringe contains important retention areas, but the wider class structure is weighted toward weak and intermediate conditions.

The aggregate ordinal indicators in Table 3 show that the mean ordinal state is 2.81, below the threshold between moderate and high states. Ordinal sustainability burden is 0.547, meaning that the distribution remains slightly more than halfway from the strongest possible arrangement. The burden is not caused by the absence of high-value fields. It is caused by the large share of very low, low, and moderate fields in the overall assessment system.

Table 3. Aggregate ordinal indicators.

Indicator	Value
Total basic assessment fields	2313
Very low + low classes	1095 fields; 47.34%
Moderate class	603 fields; 26.07%
High + very high classes	615 fields; 26.59%
Mean ordinal state, $\bar{O}$	2.81
Ordinal sustainability burden, B	0.547

The indicators presented in Table 3 allow the identification of the classes depicted in Figure 2. There are several strong classes covering more than one-quarter of the area, although they do not dominate the system. The number of fields in the two weakest classes is slightly less than half of the total. Such a distribution of classes implies that planning is needed to ensure the preservation of retention anchors against the belt of preventive areas.

5.2. Composition of classes according to land-cover signatures

It should be noted that the weakest classes are not characterized solely by their share of built-up land. The very weak class comprises 74% arable land and 11% built-up area, whereas the weak class comprises 64% arable land and 9% built-up area. Thus, the main indicator of exposure is the presence of arable land rather than settlement in this class. It is important to understand that the danger in these classes lies behind the green background. The land is open, but it has cover that is easier to transform into other forms than forests or grasslands.

Partial rebalancing between exposure and resilience is observed within the two middle classes. The moderate class comprises 42% arable land, 29% permanent grassland, and 13% forest. The high class comprises 43% arable land, 24% permanent grassland, and 17% forest. From these values, it is clear that the moderate and high classes continue to be dominated by agriculture, yet they have a larger share of forest and grasslands compared to the two weakest classes. It is also noteworthy that the composition of the high class differs from the one of the moderate class. The difference lies in the higher proportion of forests rather than in lower exposure.

The very high class has a significantly different structure: it consists of 58% forests, 18% permanent grassland, 16% arable land, and 3% built-up land. The dominance of forests in the composition and the low proportion of transformed land are what makes the very high class a retention anchor.

The synthesis of the green security landscape in Figure 8 begins precisely from the distinction between arable lands and stable land cover, i.e., forest and grassland. It starts from the class comparison shown in Table 4 and illustrated in Figure 3.

5.3. Exposure and resilience ratio

Table 4 presents exposure and resilience indicators for each class. The very low class comprises 85% exposure and 10% resilience, having the exposure to resilience ratio of 8.50. In this respect, there are eight times more exposure components than resilience components. The absence of forests plays a critical role in this class since it is the only source of resilience along with permanent grassland.

The low class comprises 73% exposure and 21% resilience, resulting in an indicator ratio of 3.48. This means that the imbalance is smaller compared to the previous case. Nevertheless, the low class includes many fields, which makes it strategically important despite being a minor component numerically. The moderate class comprises 51% exposure and 42% resilience, giving 1.21 ratio. Similarly, the high class comprises 51% exposure and 41% resilience, providing 1.24 ratio. These two ratios are close, but their compositions vary: the moderate class contains a larger proportion of grasslands than the high class, which, in turn, contains a larger portion of forests. Finally, the very high class includes 19% exposure and 76% resilience, resulting in the 0.25 ratio.

Table 4. Exposure and resilience indicators.

Class	Exposure E_j (%)	Resilience R_j (%)	ERR_j	Interpretation
Very low	85	10	8.50	Critical exposure
Low	73	21	3.48	High exposure
Moderate	51	42	1.21	Transitional balance
High	51	41	1.24	Managed retention
Very high	19	76	0.25	Resilience anchor

The ratios in Table 4 show why class-level composition must accompany class-level rank. Very low and low classes are not simply lower on a sustainability scale; they have exposure-heavy land-cover structures. The very high class is not only higher on the scale; it has a resilience-dominant structure. This difference changes the planning response from undifferentiated green-space preservation to land-cover-specific management.

The balance shown in Figure 4 repeats the same shift from exposure dominance in the weaker classes to resilience dominance in the very high class. It is useful because the moderate and high classes appear close in ratio terms, reminding the reader that their interpretation requires attention to the detailed land-cover shares in Table 2.

This comparison confirms the fundamental finding. Sustainability depends on more than just the amount of green space within the system. It depends on the dominant type of green space in each field – i.e., whether that green space consists primarily of arable land, grasslands, or forest cover. It is these considerations that define both the priority score and the arable-grassland reallocation.

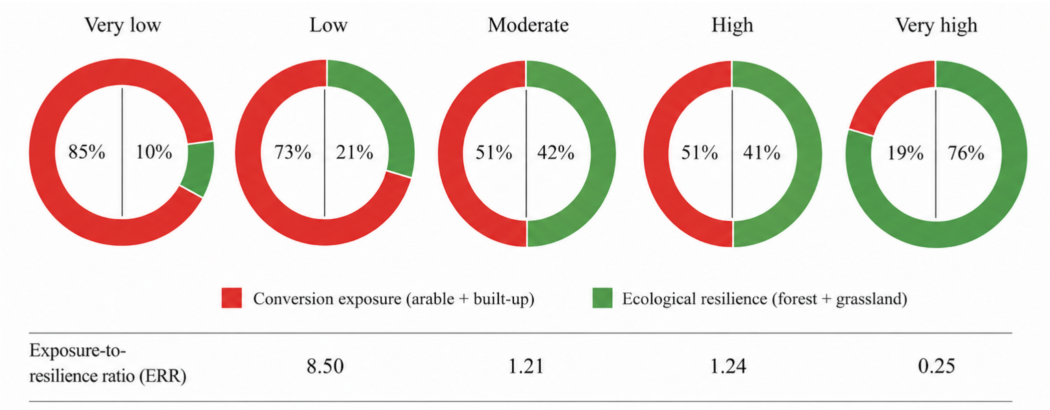


Figure 4. Exposure and resilience.

5.4. Priority belt and arable-grassland reallocation

By changing the perspective, priority redefines the notion of urgency. Although the very low class faces the greatest exposure-to-resilience imbalance, it is still the largest with 248 fields or 10.72% of the total. Its transition-priority score is thus equal to 0.091. The low class comprises 847 fields or 36.62% of the system, which translates into 73% exposure. Given the weakness coefficient of 0.75, its score jumps to 0.200. Thus, this belt is identified as the main vulnerable zone of the Krakow fringe.

The other belts have lower scores. For example, the moderate class has the highest score at 0.067 due to the extent of its vulnerability, while the high class receives a score of 0.018 because it is more stable and occupies less space in the system. Finally, the very high class score is equal to 0.000, since its weakness coefficient equals zero. This score cannot be interpreted as ecological insignificance. It simply indicates that the very high class is not a conversion-prevention priority like the others; rather, it is a conservation priority.

The scores from Table 5 indicate that the low class represents the most critical priority. This finding differs from one that would rely only on ratios. An analysis based on ratio data would prioritize the very low class. The priority score indicates that the more comprehensive low class is the more important metropolitan ring because it includes a higher proportion of exposed fringe areas that are also weak.

Table 5. Transition-priority score.

Class	Class share	Weakness coefficient	Exposure share	Transition-priority score
Very low	0.1072	1.00	0.85	0.091
Low	0.3662	0.75	0.73	0.200
Moderate	0.2607	0.50	0.51	0.067
High	0.1401	0.25	0.51	0.018
Very high	0.1258	0.00	0.19	0.000

The same finding is presented in Figure 5. Priority for the low class is established by its relatively high exposure and larger class membership size. The very low class is imbalanced but smaller. The very high class, having low exposure and lacking any weakness coefficient, represents the conditions under which it should be retained rather than protected from conversion.

The priority space of Figure 5 enables the separation of the issue into compositional severity, which is the very low class, and scale, the metropolitan one, which is the low class. Both must be considered in the planning policy, i.e., focused repair of extreme imbalances, along with preventive control of the whole low-class area.

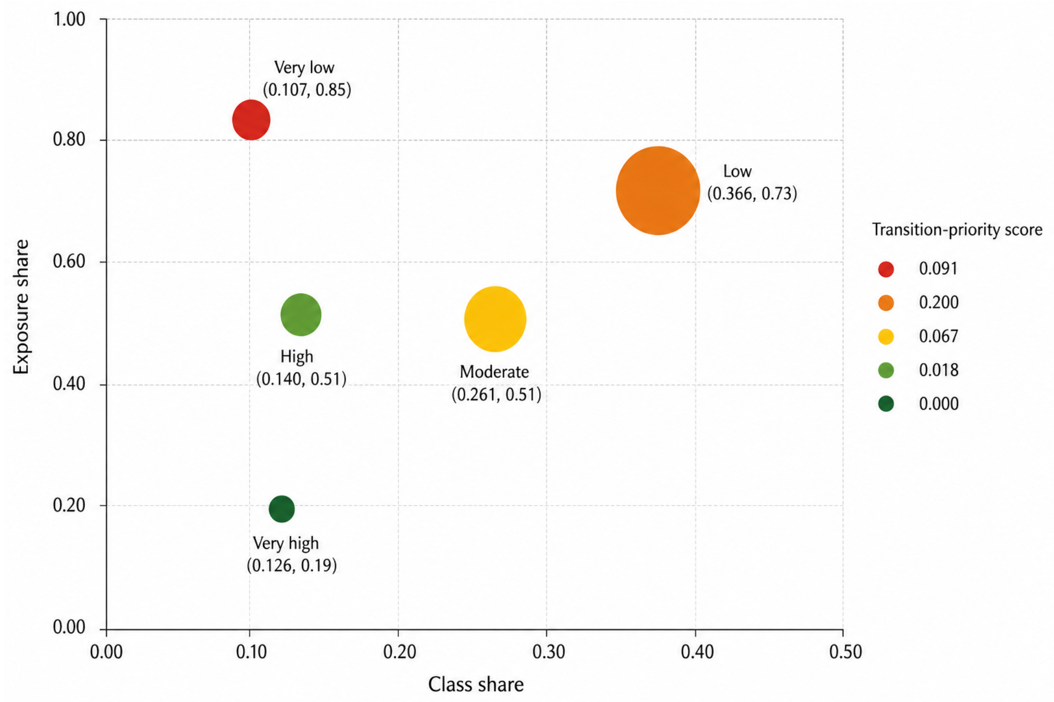


Figure 5. Priority space.

The Table 6 demonstrates an example of how the two classes react to the adjustment of arable/grassland relation. With the very low class, a 20% decrease in arable land leads to 59.2% arable land and 24.8% permanent grassland, against the initial values of 74% and 10% correspondingly; built-up land remains at 11%, while forest land is absent. The exposure is decreased from 85% to 70.2%, the resilience is increased from 10% to 24.8%, and the ratio becomes 2.83, which used to be 8.50. Thus, the field remains exposed, but the imbalances get visibly decreased.

The same adjustment for the low class will make the proportion change from 64% and 18% for the respective arable and permanent grasslands to 51.2% and 30.8% correspondingly, while the amount of forest land will be 3%, built-up land will stay at 9%, and other land will account for 5%. The exposure gets reduced from 73% to 60.2%, the resilience is increased from 21% to 33.8%, and the ratio reduces from 3.48 to 1.78. The effect is less spectacular but more significant, as the low class contains 847 fields.

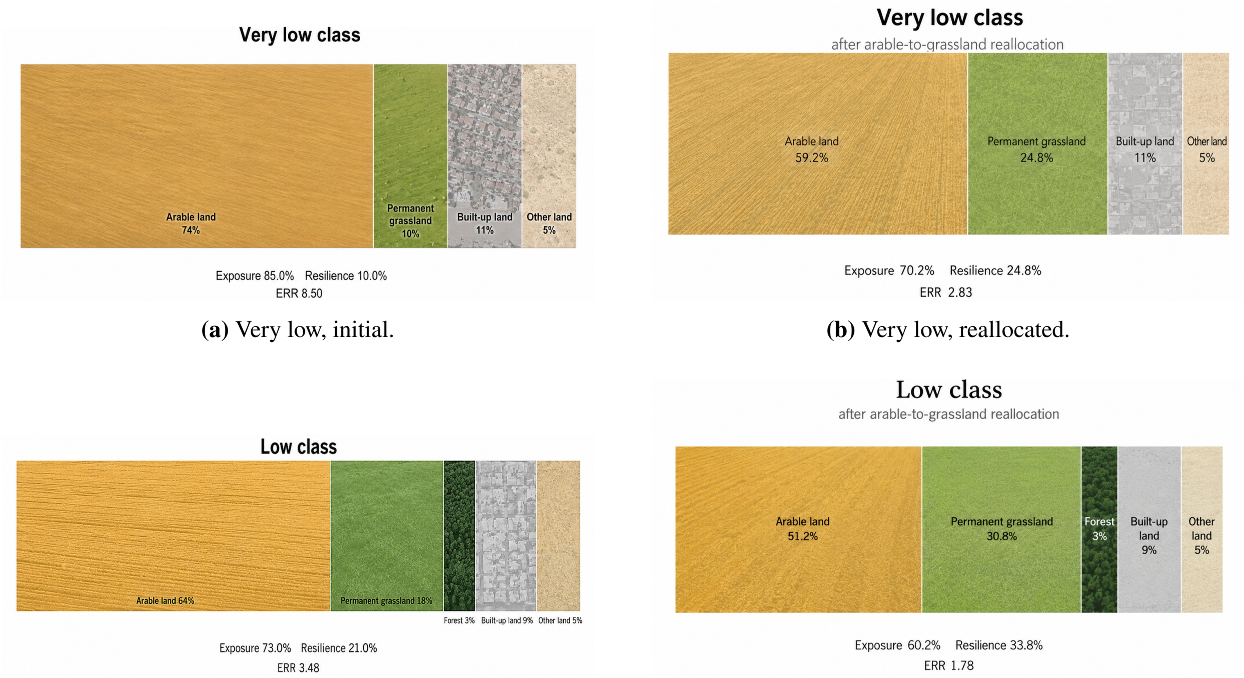
Table 6. Arable-grassland reallocation.

Class	Initial ERR	Adjusted exposure (%)	Adjusted resilience (%)	Adjusted ERR
Very low	8.50	70.2	24.8	2.83
Low	3.48	60.2	33.8	1.78

The adjustment data in Table 6 clearly indicate that the permanent grassland performs a powerful leverage function in the weakest classes. Small reallocation from arable land towards grassland is enough to maintain the agricultural nature of the fringes but has a great effect on improving the exposure/resilience relationship. This finding indicates that field-margin enlargement, meadow buffer zones, riparian grasslands, and small-grassland patches can be effective in weak classes.

Figure 6 shows the results of 20% reallocation from arable land towards permanent grassland among the two weakest classes. In all of them, the share of built-up area stays constant, and the difference comes from the changes in the internal structure of open areas.

The representation of the numerical adjustment through the sequence of the panels illustrated in Figure 6 is given below. The block of arable lands shrinks whereas the block of grassland grows. Nevertheless, the block of settlement-related covers remains unchanged. It becomes obvious that the best opportunity to improve the calculations lies in the alteration of the composition of open lands rather than green land.



(a) Very low, initial. **(b)** Very low, reallocated. **(c)** Low, initial. **(d)** Low, reallocated.

Figure 6. Arable-grassland reallocation.

5.5. Treatment of the class based on the calculated results

Figure 7 illustrates the treatment of the classes based on the calculated results. Very low classes must be repaired as they are arable and exposed with no forest coverage at all. Low classes need some preventive actions since they are exposed and have significant field coverage. The transition between the exposed state and the resilient one should be achieved within the moderate classes since both exposures are similar. High classes require landscape connectivity consolidation because of the forest and arable land cover. Very high fields should be protected as they contain a considerable portion of forest coverage.

As it can be seen in Figure 7, the structure of the treatment converts the calculated ratios into the language of planning and planning activities. Class-based assessment system should not be simplified to one-dimensional ranking. Every class has to be assigned a unique planning responsibility depending on the unique characteristics of extent, exposure, and resilience. Such class-based analysis is the main advantage of this particular type of analysis as it enables differentiation.

5.6. Green presence versus green infrastructure security

It is worth noting that the green presence indicator is not equal to the concept of green infrastructure security. The highest percentage of forest lands is present in the very high class – 58%. In contrast, the lowest green presence occurs in the very low class (26%) and is dominated by arable lands (74%). Thus, the difference between green presence and green infrastructure security becomes obvious.

This fact means that it is impossible to rely on pure conservationist approaches to achieve the desired result in the peri-urban zone. Although the very high class must be conserved as the field with the greatest green presence, the lack of preventive measures in the exposed low-class fields creates the problem of vulnerability of green infrastructure. Moreover, focusing on either extremely high or low class is inappropriate since the latter class includes fewer fields in spatial terms. This leads to the need of implementing at least two different actions – retaining forest components and managing the exposure in the low-class fields.

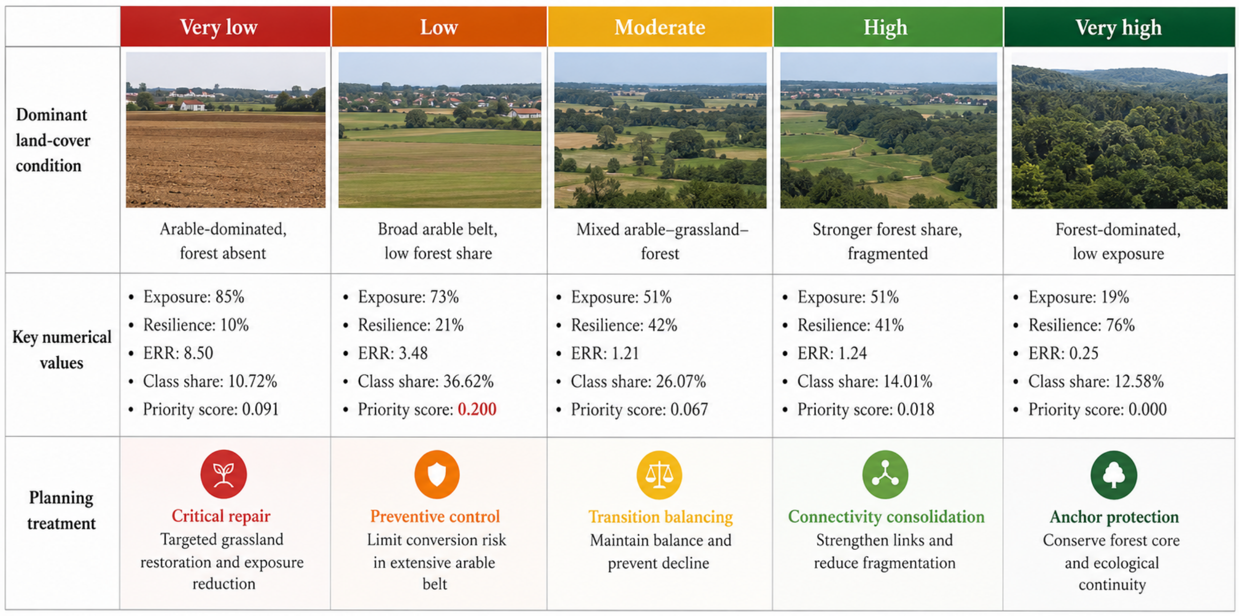


Figure 7. Class treatment.

5.7. Strategic position of the low class

Low classes become significant for green infrastructure planning due to their distinctive features. As it was shown in the previous sections, this class combines three important characteristics: great extent, significant exposure, and considerable weakness. The low class occupies 36.62% of the total number of fields, has exposure share of 73%, and achieves the highest priority score of 0.200. In turn, the very low class, although is even more vulnerable in terms of the exposure/resilience ratio (8.50), occupies smaller share of the fields (10.72%).

In other words, the low class can be regarded as the belt to consider when developing a green infrastructure strategy. This conclusion is interesting strategically speaking because it implies the risk of green-infrastructure insecurity despite the existence of the very low class fields occupying smaller share of the metropolitan fringe. The fact is that the low class possesses a sufficiently large number of fields, meaning that landscape fragmentation in these classes may affect the metropolitan fringe adversely.

Therefore, the implementation of preventive land-use control must be prioritized for these fields as the vulnerability of green infrastructure depends significantly on them.

5.8. Reinforcement of perennial grassland

Based on the conclusions made in the previous sections, it can be stated that the most promising reinforcement option for the peri-urban green infrastructure is perennial grassland. Its advantage consists in the flexibility that allows the grassland component to be introduced into the agricultural landscape without destroying it completely. Calculation showed that reassignment of 20% of arable lands to grassland decreased the very low ratio to 2.83 and the low ratio to 1.78.

These figures prove that the introduction of perennial grassland in the agricultural landscape significantly affects the assessment of the very low and low classes. Practically speaking, this fact indicates the possibility to retain and restore ecological stability of the fields by adding grasslands. Grasslands can be placed as widening field margins, creating meadow strips, implementing riparian buffers and grassed corridors, as well as introducing low-intensity grassland patches near forests and water bodies.

The fact that afforestation cannot serve as a tool for achieving this goal is obvious since it contradicts the agricultural character of peri-urban zones.

It should be mentioned that the current analysis is not a prediction since it measures the impact of the suggested alteration of the class structure. Nevertheless, this fact does not make the obtained ratios meaningless. On the contrary, the significance of the calculation lies in quantifying the improvement of the exposure/resilience ratio due to grassland reinforcement. This makes it possible to convert a broad recommendation to improve ecological conditions into a particular measure of response.

5.9. The role of forest anchors and the surrounding lands

Contrary to the previously considered classes, the high and very high ones should not be perceived as the objects of further intervention since they already provide certain security. Specifically, the very high class includes 58% of forest coverage, 18% of perennial grassland, and 3% of built-up lands, resulting in the exposure/resilience ratio being equal to 0.25. Therefore, it is necessary to retain those fields in their current state.

Nevertheless, forest anchors should have supportive zones in order to perform their functions efficiently. They are played by the moderate and high classes, which, despite having greater agricultural coverage, also include the elements of grassland and forest. Such interpretation stems from the fact that the high and very high classes cannot exist separately in the landscape as they are the sources of landscape connectivity.

Therefore, the high class should be seen not as the example of green-infrastructure security but as a mechanism for landscape connectivity consolidation. Otherwise, the Krakow metropolitan fringe will consist of the separate forest patches surrounded by highly-exposed agricultural lands, which means low green-infrastructure security. This aspect is particularly true for the case under consideration as the landscape is highly fragmented.

5.10. Planning implications for the Krakow metropolitan fringe

Based on the obtained results, it can be stated that the Krakow metropolitan fringe requires a differentiated planning approach regarding green-infrastructure security in fields. In particular, the following actions should be taken: very high fields must be conserved as forest anchors; high classes should be maintained in order to consolidate landscape connectivity; moderate fields should be kept to prevent deterioration of conditions as they already possess sufficient levels of resilience; low fields need preventive land-use control; finally, very low fields should be subjected to reinforcement.

It is also important to note that such differentiation must be undertaken carefully. First, green infrastructure planning should consider the different vulnerability and exposure of different fields. Second, green infrastructure policies should not focus solely on the natural fields and should take into account the majority of exposed agricultural lands. Finally, afforestation cannot be the only way to ensure ecological balance.

(a) Green presence. **(b)** Green security.

Figure 8. Green land and secure infrastructure.

Figure 8 illustrates visually the results of the quantitative analysis carried out in this paper. Accordingly, the green presence relates to the weak and low-class belt that was defined in the course of calculations, while the green security refers to the resistance of fields within the high and very high classes. Such an illustration is a useful tool for translating the outcomes into action plans without any extra calculations.

5.11. Limitations of analytical methods

At first, the current analysis is based on class level, so it does not define the exact parcels, limitations regarding their use, optimal corridors, or potential problems associated with municipal zoning. Also, some important indicators including prices, local demand for the land, road access, soil quality, and protection levels were not included into the analysis. These factors can play an important role in case a specific plan should be created for a certain municipality.

Second, treating arable lands as conversion-sensitive indicates that this type of land is not important for green infrastructure security. However, this assumption is not always true since it can be assumed that agricultural lands are deprived of ecological value. For instance, fields belonging to private owners and requiring soil quality conservation represent a special case of analysis that needs adjustment in terms of local specificity.

Third, the current analysis includes the effect of 20% reallocation of arable lands into permanent grassland. Obviously, the above assumption seems unrealistic since grasslands cannot be simply placed on the fields depending on location. Nevertheless, the calculation still demonstrates how sensitive low and very low fields are to this type of action.

6. Conclusion

This paper intended to find out which classes in the Krakow metropolitan fringe include a considerable part of land with low green-infrastructure security. As was demonstrated, low fields are the most vulnerable belt with 36.62% of all fields and the ratio of exposure to resistance of 0.200. Very low fields have the highest exposure-to-resilience ratio amounting to 8.50. Low exposure-to-resilience ratio was also registered in very low fields accounting for only 10.72% of total field number. Retention capacity was characterized by the ratio of 0.25.

Furthermore, the current analysis revealed that retention capacity in Krakow metropolitan fringe was rather low. Low and very low classes together occupied 47.34% of the area, while high and very high represented only 26.59%. Moreover, the average ordinal value of the state was 2.81 indicating that Krakow metropolitan fringe had poor green-infrastructure security. This conclusion can be confirmed by the burden equal to 0.547.

Finally, the calculation according to the goal of this paper revealed that allocation of 20% of arable lands into grassland resulted in a reduction of exposure to 2.83 for very low fields and 1.78 for low fields. This fact suggests that Krakow metropolitan fringe requires retention measures, preventive actions, and grassland reinforcement.

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