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Landscape Analysis and Coastal Planning: Ría de Arosa (Pontevedra, Spain)

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Abstract: Coastal areas are fundamental enclaves for economic and recreational development, attracting a large population worldwide. However, these factors have generated significant pressure on the coastal landscape, requiring territorial management strategies to protect and control its degradation. The coastal landscape, composed of abiotic and biotic elements, plays a crucial role in human well-being and the conservation of the natural environment. This study focuses on the southeast area of the Ría de Arosa, on the western coast of Galicia, known for its unique geomorphological features such as estuaries. The main objective is to generate high-resolution thematic maps for territorial planning and conservation of the natural and cultural landscape. Using methodologies based on geographic information systems, various factors of the natural environment will be analyzed to obtain objective results, presenting cartography of landscape units, along with quality and fragility landscape maps. In addition, active strategies are proposed such as multiple land uses or the development of geotourism to preserve, exploit, and manage the landscape better. This work contributes to better understanding the vulnerability of the coastal landscape and provides practical tools for its sustainable management in a context of accelerated global change.

Keywords: landscape units; landscape quality; landscape fragility; coastal planning; GIS

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1. Introduction

Coastal areas are currently presented as perfect enclaves for the development of human activities, both economic and recreational [1,2]. The rapid development of society in recent decades, along with the historical relationship based on the benefits they provide to humans, allows for a high population concentration in these sectors [3]. Additionally, it is estimated that the number of inhabitants will increase in the coming years. Other factors, such as the wide range of tourist offerings provided by these sectors, contribute to the same direction of population density growth [2,4].

The development of inadequate infrastructure in different coastal areas that have experienced an increase in urbanized areas has led to the need for the development of coastal land management strategies [4]. These measures should focus on protecting ecosystems and ensuring proper control of human activities and infrastructure that cause significant landscape degradation [5,6]. Furthermore, the current context of global change makes coastal areas particularly vulnerable to extreme weather events and variations in sea level [7,8]. This implies that territorial management and proper landscape protection become of special interest.

The landscape integrates the set of abiotic natural elements (rocks, water, air) and biotic elements (flora and fauna) that interact directly with humans [9,10]. It is subject to constant change because of the effects generated by external geological agents and anthropogenic action [11]. The landscape constitutes an element whose level of conservation and authenticity directly influences the naturalness of the environment, which is essential for generating wellbeing in the population [6,12]. This reinforces the initial need to implement a series of conservation measures supported by adequate territorial planning [11–14].

The southeast area of the Ría de Arosa is part of the western coast of Galicia (Figure 1). This entire sector presents a very characteristic landscape, whose main elements are the estuaries. The term "ria" refers to an estuary generated by an ancient coastal river valley that has been flooded by the sea during the Quaternary period. Its origin is linked to fracture systems that describe a block relief (horst and graben) with submerged and emerged areas [13–15]. The emerged coastal areas present a multitude of structures associated with various morphogenetic systems (coastal, lithostructural, fluvial. . .) because of the number of processes that have acted on the area.

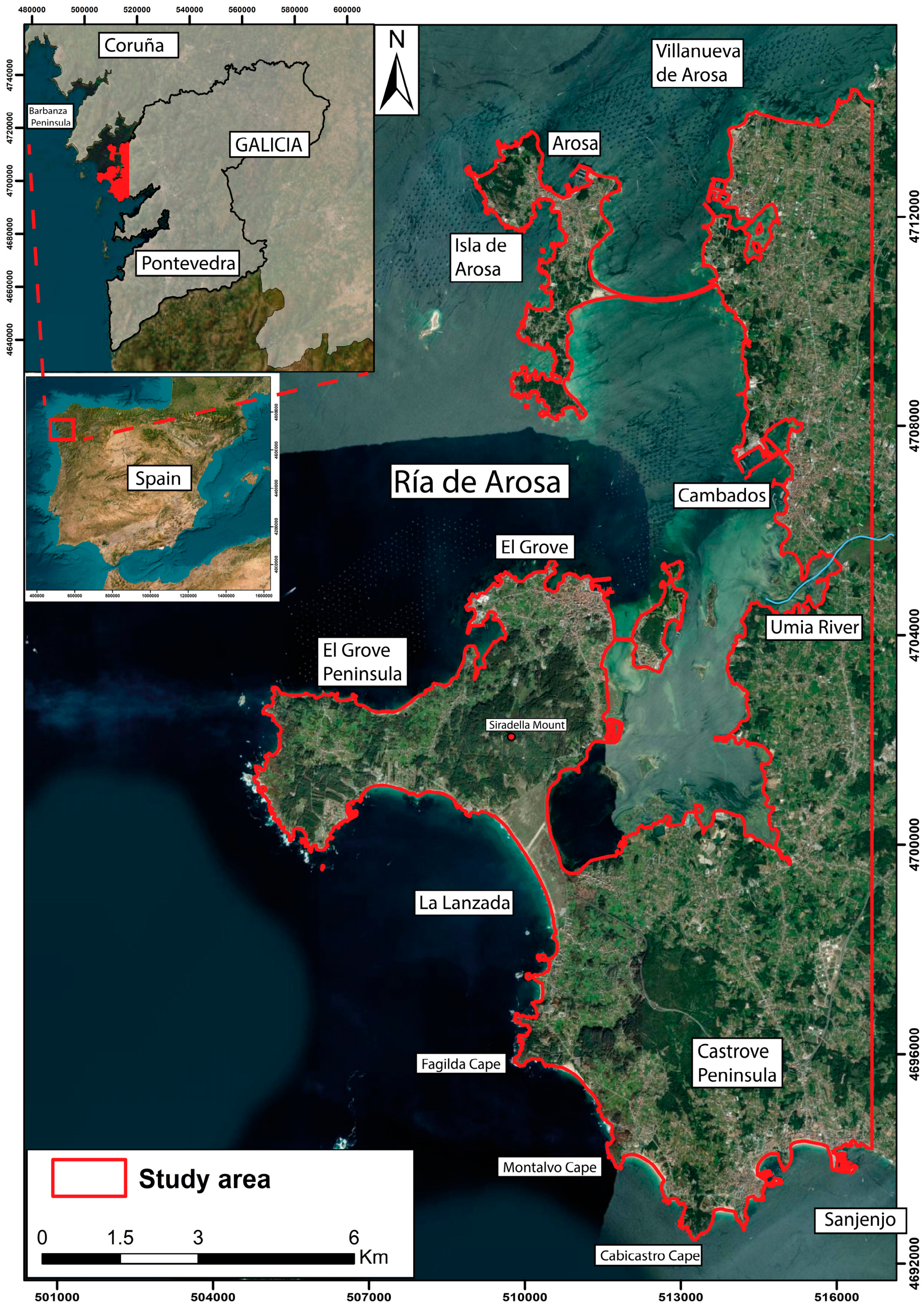

Figure 1. Location map of the study area (in red) within the province of Pontevedra in Galicia.

The objectives of this study focus on analyzing both the landscape units and the quality and fragility of the landscape in the southeast area of the Ría de Arosa. The aim is to examine the landscape from two perspectives: intrinsic and extrinsic. This involves evaluating the visual perception of the landscape from any point in the territory (intrinsic) and within specific landscape units (extrinsic), as well as investigating the landscape's susceptibility to changes and disturbances both globally and within individual landscape units. Additionally, the study aims to develop specific assessment tools to measure both the quality and fragility of the landscape from both perspectives and to propose differentiated conservation and management strategies adapted to the needs of each landscape unit and its natural environment. Ultimately, this study aspires to contribute to the knowledge and understanding of the interaction between the landscape and the natural environment, offering new perspectives on its long-term conservation and management [12,16,17]. This methodology enables the acquisition of objective and quantitative data on landscape quality and fragility [12,17–20]. It combines both direct and indirect methods. Direct methods are based on fieldwork, where data collection and in situ recognition of the physical environment are carried out. Indirect methods rely on techniques such as geographic information systems (GISs), photointerpretation, or consultation of thematic maps (geomorphological, geological, vegetation, etc.). For this study, multicriteria analysis with ArcGis 10.8 is particularly important, as it is successfully used in current environmental studies for territorial planning, landscape analysis, or geological risks [21–23]. Additionally, the process of defining landscape units, crucial for obtaining results, makes this methodology highly versatile. It demonstrates significant adaptability across different types of landscapes to be analyzed. Moreover, data integration and individual analysis of each factor allow for quick updates and the generation of updated results with high resolution.

Study Area

The study area is in the northwest of the province of Pontevedra (northwest Spain), on the southeast coast of the Ría de Arosa (Figure 1). This estuary is the largest of the Rías Bajas, with its northern area belonging to the province of La Coruña and its southern area to the province of Pontevedra. Overall, the study area covers approximately 9600 ha and includes the Galician municipalities of Cambados, El Grove, and Isla de Arosa, as well as parts of the municipalities of Sangenjo, Meaño, Ribadumia, and Villanueva de Arosa, where a total of 57,358 people reside. Climatologically, it is in a continental zone with Mediterranean influences that result in mild and humid average annual conditions [24]. The oceanic effect is the main factor influencing mild temperatures and abundant precipitation. An average annual precipitation of approximately 1455 mm is recorded, with a summer average temperature of 19.3 °C and 9 °C in winter [25].

Geologically, this zone is situated in the northwestern section of the Iberian Massif, particularly within the Galicia–Trás-os-Montes Zone. From a geological perspective, this area is part of the internal region of the Variscan mountain-building event. It is distinguished by a combination of different allochthonous domains resting upon a foundation of Paleozoic metasediments and granite formations. From a geomorphological standpoint, there are several well-defined geomorphological units grouped into different morphogenetic systems. Various Quaternary units can be discerned, which constitute the morphogenetic deposits of different depositional agents. These units are situated atop the Variscan basement. The structural conditions and transitional nature of the area allow for the development of various morphogenetic systems, with lithological characteristics shaping the distinctive and specific relief of the Galician coastal zone, including the Ría de Arosa, and influencing the area's morphogenesis [15].

2. Materials and Methods

The landscape analysis from an indirect perspective requires the development of a systematization method that generates objective and quantitative results. This assessment is directly supported by the constituent elements of the landscape. The results obtained through a direct approach are considered subjective as they are based on perceptual and aesthetic components of the environment [1].

A methodology is presented from a direct perspective, which consists of the creation of three distinct thematic maps: landscape unit analysis, landscape quality, and fragility (Figure 2) [12,17].

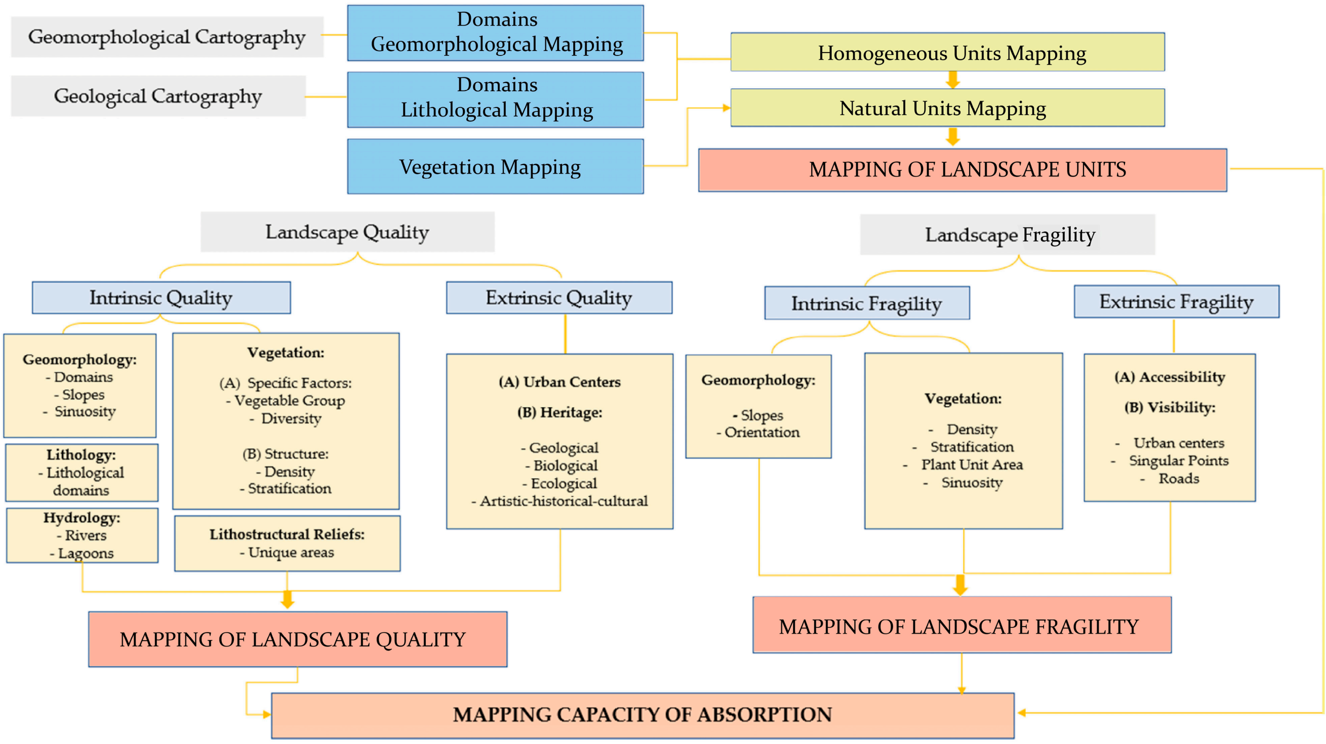

Figure 2. Methodological scheme of Section 2. Modified from [17].

2.1. Mapping of Landscape Units

Firstly, to generate the cartography of landscape units, detailed photointerpretation work (both current and historical) is required, which, along with the use of geomorphological and geological maps, allows for the delineation of different natural units. Geomorphology and geology, from a lithological point of view, represent the most prominent abiotic components. The former, based on the geomorphological map, simplifies the relief forms by grouping them into geomorphological domains. These domains are adapted depending on the different areas that can be differentiated in the terrain under study. The use of this indirect approach allows subdivision into comparable units, which facilitates the detailed description of each unit using direct observation methods. In the case of lithology, derived from the geological map, a synthesis is made into lithological units that have an impact on the landscape [12,26].

Once the geomorphological and lithological units are determined, an on-site analysis is necessary to describe and classify in more detail the previously defined units. GIS geoprocessing techniques allow the integration of both cartographies to obtain the map of homogeneous units, which groups the values of both cartographies into new polygons. Criteria such as representativeness or similarity are considered for the designation of these units [12,19,26]. This conditions smaller portions with greater dispersion to be included within larger and more notable units. Those that constitute parts of the terrain with homogeneous characteristics are grouped within those that show greater relevance from the perspective of perceptual impact.

Finally, the implementation of the vegetation factor is required, which represents the biotic components of the landscape. This cartography is reclassified based on the physiognomy of the unit and crossed with the cartographic data modeled in the previous step to generate the landscape unit cartography. For this, it is necessary to refine the number of units based on the criteria described in the previous paragraph.

2.2. Mapping of Landscape Quality and Fragility

The landscape quality and fragility mapping is obtained through the weighted overlay analysis (WOA) of the multicriteria analysis. WOA is a GIS technique that combines, through weighted summation, the information represented in multiple layers (factors) to obtain a composite result. Specific weights are assigned based on the relative importance or representativeness of each factor and are superimposed to perform an analysis of interrelated data. It demonstrates usefulness in environmental and urban studies where multiple factors interact [21]. In this case, the intrinsic maps, which show greater landscape notoriety, are assigned a weight of 60%, while the extrinsic maps receive a value of 40%. Both intrinsic and extrinsic maps are also calculated based on WOA. Equal values are assigned to the different factors that compose them, since they present similar representativeness and relative importance. This study implements specific evaluation criteria for each parameter into which these factors are divided (geomorphology, lithology, vegetation. . .). These criteria are defined based on detailed knowledge of the study area through field work or photogrammetry, personal communication with local experts in various disciplines (geology, botany, soil science, cultural heritage. . .), as well as a bibliographic review of the evaluations found in studies that develop the same or similar methodology [9,17,26–28]. For example, in the case of geomorphology, values are assigned based on the perceptual prominence of the morphologies, assigning higher values to ridges, scarps, and domes than to beaches and coastal bars. Thus, the methodology ensures rigor in the assessment, guaranteeing a comprehensive and objective evaluation of the landscape. This provides a solid basis for evaluating landscape quality and fragility, facilitating the understanding of the results and their applicability in territorial planning and the sustainable management of natural and cultural landscapes.

2.2.1. Mapping of Intrinsic Landscape Quality

The mapping of intrinsic landscape quality allows the recognition of areas of the territory that present greater singularity and interest, facilitating the implementation of different protection and conservation strategies. It is divided into the following factors:

1. Geomorphological factor: Geomorphology is responsible for the expression of the terrain. Therefore, this factor is considered the most important or one of the most important. Areas of the territory that show greater perceptual relief, where peaks, ridges, escarpments, or domes are found, are considered to have greater positive value than others. Surfaces of abrasion, terrace areas, or pediments, where the topographic contrast is not as pronounced, do not reach such high values. To properly analyze all parameters encompassed by this factor, it is subdivided into three different factors:

a. Geomorphological domains: They mark the spatial arrangement of relief units and the contrast they generate compared to adjacent areas. The evaluation is established based on the topographic contrast generated by the higher areas compared to the topographically lower and smoothed areas. The values in Table 1 indicate the weighting of this parameter.

Table 1. Assessment of Geomorphological Domains for Landscape Quality.

Geomorphological Domains	Value
Ridges, hills, inselbergs, and summits	10
Alluvial fans and slopes	8
Glacis and pediments	6
Marine terraces and surfaces	4
Dunes, beaches, marshes, and valley floors	2
Urban centers and anthropic infrastructures	0

b. Slopes: In this case, the use of the 1 × 1 meter grid slope raster layer allows us to identify with detail the continuous variations in relief. This allows us to assess them based on their greater visual prominence and naturalness, as shown in Table 2. High values correspond to areas with steeper slopes, while those with steeper slopes represent areas of less prominence and naturalness.

Table 2. Assessment of slopes for Landscape Quality.

% Slope	Value
>60	8
30–60	6
15–30	4
5–15	2
0–5	0

c. Sinuosity: This parameter calculates the greater or lesser curvature exhibited by the terrain lines. To obtain the value, an index must be applied that relates the area and the perimeter of the polygons defined between the contour lines (at 20-m equidistance). Using a GIS field calculator, the following operation is performed: perimeter × perimeter/area [28]. Areas with higher sinuosity values receive a higher weighting, as indicated in Table 3.

Table 3. Assessment of sinuosity for Landscape Quality.

Sinuosity	Value
8	High
4	Medium
0	Low

2. Lithological factor: The spatial distribution of different rock outcrops in the area reflects significant variations in the landscape due to their heterogeneous coloration. Rocks enriched in leucocratic minerals exhibit a higher perceptual value than those enriched in melanocratic minerals, as shown in Table 4 [26].

Table 4. Assessment of lithological chromatism.

Lithology	Value
Early granites (enriched in feldspar phenocrysts)	6
Late granites	4
Metamorphic rocks (slates and shales)	2
Conglomerates, gravel, sand, silt, and mud	0

3. Hydrological factor: An environment in which water bodies (rivers, lakes, or reservoirs) are represented adds value to the landscape. When assessing, it is considered that river courses (value 4) have a greater positive impact due to their linear and mobile nature of water (visual and acoustic influence) compared to ponds or reservoirs (value 2) [26].
4. Morphostructural factor: The presence of unique reliefs from a perceptual point of view is directly associated with residual reliefs composed of granitic and metamorphic rocks. These reliefs consist of inselbergs or granitic domes (especially Monte de Siradella, in the El Grove Peninsula) or the metamorphic relief found in Monte Faro. These areas receive a value of 10 [26].
5. Vegetation factor: The variability presented by vegetation from a compositional and structural perspective necessitates its consideration in landscape quality studies.

a. Specific composition: It is studied based on two factors: grouping and vegetation diversity. Vegetation grouping indicates the ecological value of each plant community, which is influenced by the dominant species as shown in Table 5 [26]. As for diversity, an area that presents a greater number of plant species, resulting in a reduction in monotony, receives a higher weighting. This is represented in Table 6.

Table 5. Assessment of the Plant Grouping.

Plant Grouping	Value
Tree formations	8
Bush or shrub formations	6
Subshrub formations	4
Grasslands, crops, and fallow	2
Not vegetated	0

Table 6. Assessment of Plant Diversity.

Plant Diversity	Value
3 plant species	6
2 plant species	4
1 plant species	2
No plant species	0

b. Vegetation structure: It is defined based on horizontal structure or density and vertical structure or stratification. The number of elements present within a defined area is known as density. Its value is determined by the percentage of covered cover fraction (CCF), as indicated in Table 7. Variations within the vertical structure of plants affect the perception of landscape quality, so woody tree formations (greater height) receive a higher weighting than herbaceous grasslands (lower height) (Table 8).

Table 7. Assessment of Plant Density.

% CCF	Value
>40	4
<40	2
0	0

Table 8. Assessment of Plant Stratification.

Plant Stratification	Value
Woody strata (tree formations)	6
Shrub strata (shrub and subshrub formations)	4
Herbaceous strata (grasslands, crops, and fallow)	2
Not vegetated	0

The intrinsic landscape quality of vegetation (ILQV) is obtained from the weighted overlay analysis (WOA) of the 4 parameters with equal value of which it is composed. Values obtained are reclassified to facilitate the compression of information into five groups (Table 9).

Table 9. Values of the Intrinsic Landscape Quality of Vegetation.

ILQV	Value
Very High	21–24
High	16–20
Medium	10–15
Low	6–9
Very Low	0–5

Finally, to know the values of the mapping of intrinsic landscape quality (ILQ), Equation (1) is used [12,17]:

$$\text{ILQ} = \sum \text{Geomorphological factors} + \text{Lithology factor} + \text{Hydrology factor} + \text{Structural relief factor} + \sum \text{Vegetation factors} \quad (1)$$

2.2.2. Mapping of Extrinsic Landscape Quality

The mapping of extrinsic landscape quality (ELQ) is associated with elements that have an anthropogenic origin or are part of the historical, cultural, or natural heritage.

Urban centers' landscape quality in relation to rural landscapes is evaluated, considering that in many cases, they generate morphologies and highlights that enhance their visibility. In this section, their presence is considered positive, and a value of 2 is assigned by calculating an influence area of 100 m around the urban centers and urbanized areas.

The landscape quality generated by heritage considers the added value of these enclaves within the perceptual framework. They allow documenting the history and culture of a region (historical–cultural heritage) or show natural singularities that must be preserved due to their condition as "irreplaceable heritage" (natural heritage). Geological heritage assesses "geosites" described in the area with a weight of 10 over the rest (value 0) [29]. In the case of natural and ecological heritage, special protection areas are considered as follows: Protected Natural Spaces have a value of 6; Protected Wetlands and Special Protection Areas for Birds (ZEPA) have a value of 4; finally, Areas of Community Interest are valued at 2.

Cultural heritage, where enclaves of artistic–cultural importance are found, is valued based on its respect for the landscape. Thus, churches, bridges, castles, hermitages, etc., are valued at 6, and roads, paths, or highways are valued at 2.

Once all the cartographies are obtained, the mapping of extrinsic landscape quality (ELQ) is calculated using Equation (2) [12,17].

$$\text{ELQ} = \text{Landscape quality of urban centers} + \text{Landscape quality of geological heritage} + \text{Landscape quality of ecological heritage} + \text{Landscape quality of cultural heritage} \quad (2)$$

$$\text{MLQ} = 0.6 * \text{intrinsic landscape quality} + 0.4 * \text{extrinsic landscape quality} \quad (3)$$

To generate the mapping of landscape quality (MLQ), both intrinsic and extrinsic cartographies must be added. Since the mapping of intrinsic quality represents the part that gives the landscape greater prominence, it is given greater weight in the calculation compared to the mapping of extrinsic quality (Equation (3)) [12,17].

2.2.3. Mapping of Intrinsic Landscape Fragility

Not all landscape components have the same capacity to respond to disturbances in the natural environment, especially concerning different human activities. Therefore, it is considered that a landscape is more fragile when it shows a higher susceptibility to change when subjected to these impacts. This reason relates various anthropogenic activities directly to the degree of fragility. High values are considered negative for the landscape, while areas where values are lower are considered positive for the development of human activities. To calculate fragility, two different cartographies composed of various factors are used: mapping of intrinsic and extrinsic landscape fragility.

The mapping of intrinsic landscape fragility (ILF) analyzes various factors present in the natural environment, including geomorphology, landscape units, and vegetation.

1. Geomorphological factor: Evaluates fragility based on the morphological characteristics of the terrain.

a. Slopes: It is considered that not all anthropogenic activities generate the same degree of fragility depending on the slope. The gradual increase in this parameter increases the visibility of landscape modification. Areas with steeper slopes result in higher fragility values (Table 10). The same reclassification is used as for the pending factor of intrinsic landscape quality.

Table 10. Assessment of slopes for Landscape Fragility.

% Slope	Value
>35	8
20–35	6
15–20	4
5–15	2
0–5	0

b. Orientations: The variation in luminosity generated between sunny and shady areas directly affects fragility. Areas with a north orientation (sunny side) are more illuminated and therefore have a lower adaptation to landscape variation compared to areas oriented towards the south (shady side) (Table 11).

Table 11. Assessment of Orientations against Landscape Fragility.

Orientation	Value
North	6
East	4
West	2
South	0

2. Area factor of landscape units: The size of landscape units represents their ability to absorb impacts because of the difficulty in modifying them. All landscape unit areas are calculated and reclassified into quartiles, where smaller units receive a weight of 6 due to their very high fragility. Larger areas are assigned a value of 0 as they are considered to have very low fragility.
3. Vegetation factor: Within this factor, the following factors are analyzed:

a. Vegetation density: Areas with a higher concentration of plant species are more stable against possible disturbances. These areas exhibit greater resistance to modifications caused by external processes. Higher fragility values correspond to areas with lower vegetation density (see Table 12).

Table 12. Assessment of Vegetation Density versus Landscape Fragility.

Density	Value
High	8
Medium	4
Low	0

The Landscape Quality Density values are inverted and multiplied by two.

b. Vegetation stratification: Fragility of a landscape in relation to vegetation stratification indicates that areas with lower values exhibit greater vulnerability compared to areas with higher values (see Table 13).

Table 13. Assessment of Vegetation Stratification against Landscape Fragility.

Stratification	Value
Very High	6
High	4
Low	2
Very Low	0

The Landscape Quality Stratification values are reversed.

c. Area of vegetation units: Larger areas are better at mitigating landscape impacts. Larger areas will result in lower susceptibility. All areas are calculated and grouped into quartiles, which are valued in Table 14.

Table 14. Assessment of Vegetation Unit Areas against Landscape Fragility.

Area of Vegetation Unit	Value
Very High	6
High	4
Low	2
Very Low	0

d. Sinuosity of vegetation: The sinuosity index (perimeter x perimeter/area) is applied to vegetation units to evaluate their edge effect. The higher the sinuosity, the greater the sensitivity to landscape disturbance of the unit (see Table 15).

Table 15. Assessment of Vegetation Sinuosity versus Landscape Fragility.

Sinuosity	Value
Very High	8
High	4
Low	2
Very Low	0

Relating all the factors, the mapping of intrinsic landscape fragility (ILF) is obtained using Equation (4) [10,15]:

$$\text{ILF} = \text{Geomorphological fragility mapping (slopes + orientation)} + \text{Area factor of landscape units} + \sum \text{Vegetation fragility factors} \quad (4)$$

2.2.4. Mapping of Landscape Extrinsic Fragility

In the second step, the mapping of extrinsic landscape fragility must be calculated, where anthropogenic elements are of particular interest. To do this, the accessibility and visibility factors are analyzed.

1. Accessibility factor: Areas close to urbanized sectors or access infrastructures (such as roads and pathways) are more fragile than areas where access is more complex or that are directly inaccessible [30]. To analyze the most fragile areas, the influence areas within 500 m of main roads and urbanized areas of the territory must be calculated. Areas within the defined 500 m influence area are considered easily accessible and assigned a value of 4, while areas outside are considered difficult to access and assigned a value of 0.
2. Visibility factor: Different anthropogenic elements are considered: population centers, main roads, and singular points. Visual basins are calculated for all of them in a GIS, and visible points are assigned a value of 4. The visual basin of population centers is determined from the centroid of the polygon. The “Mirador Alto” (High Lookout, Mount of Siradella) and the “Mirador Golo” (Golo Lookout) are chosen as singular points. These points offer the best perspective of the study area.

The four cartographies obtained are integrated to generate the mapping of extrinsic landscape fragility (ELF) (Equation (5)) [12,17].

$$\text{ELF} = \text{Accessibility factor} + \sum \text{Visibility factors} \quad (5)$$

In summary, the mapping of landscape fragility (MLF) was generated by combining and weighting all the obtained layers. Intrinsic fragility is more relevant as it affects the vegetative structure and determines the capacity to absorb human activities in each area of the territory. On the other hand, extrinsic fragility reflects the inverse perception of an external observer regarding specific landscape units. Although important, it has less influence than intrinsic fragility, which defines the visible characteristics of each unit. This process was carried out using geographic information system (GIS) techniques and applying Equation (6) [12,17].

$$\text{MLF} = 0.6 * \text{Intrinsic landscape fragility} + 0.4 * \text{Extrinsic landscape fragility} \quad (6)$$

3. Results

3.1. Cartography of Landscape Units

The elaboration of the landscape unit cartography allows for the analysis of the landscape through its different components. For this study area, a total of 15 landscape units are recognized (Figure 3). In this section, the different units will be described, which are based on geomorphological, geological (lithology), and biological factors (Figure 4A–O).

Areas of the territory representing the most abrupt morphologies and creating a greater perceptual prominence are dominated by hills, ridges, or summits. In these locations, the lithostructural component is highly relevant. In the case of being composed of granitoids, typical granite landforms develop. Significant domestic structures (inselbergs) are recognized throughout the study area, with the most prominent ones located on the El Grove Peninsula. Associated with these morphostructures, three units are described:

1. A. Ridges, summits, and hills in granitoids with tree formations: These areas are either fully vegetated or partially vegetated by tree formations. These large granite structures evidence a singularity from an evolutionary perspective of relief (scientific interest) and lend a special naturalness to the landscape. This imparts a particular vividness and beauty to the landscape. They represent a significant area in total and are mainly concentrated in the El Grove Peninsula (Mount Siradella) and the NW sector of Arosa Island (Figure 4B).

1. B. Ridges, summits, and hills in granitoids with treeless formations: These areas are entirely dominated by abiotic components (geomorphology and lithology). Here, factors such as chromaticism are more relevant. These areas with diffuse boundaries evidence variability in granite morphologies, indicating greater relief evolution. Domes with a higher degree of degradation are distinguished, where boulders and systems of joints, as well as rocky outcrops, are manifested (Figure 4C).

1. C. Ridges, summits, and hills in granitoids with grasslands, crops, and fallow: These comprise the most evolved granitic zones with less pronounced surfaces. The generalized smoother morphology of the relief results in the unit having a lesser impact from a perceptual standpoint. Areas with slight soil developments are established, allowing for the implementation of crop areas, which almost entirely cover the rocky bed (Figure 4D).

In the central area of the Castrove Peninsula, where the peaks of Monte Faro or Trincheras are located, there are the largest outcrops of metamorphic rocks. Associated with a unit from a lithostructural geomorphological standpoint, two units are differentiated:

2. A. Ridges, summits, and hills in metamorphic rocks with tree formations: These areas of the territory show a greater impact of their slopes compared to the much smoother adjacent unit areas. The biotic factor in this case is quite significant, concentrating numerous woody plants that represent extensive forested areas of pine and eucalyptus (Figure 4F).

2. B. Ridges, summits, and hills in metamorphic rocks with mixed formations, treeless areas, and cropped and fallow grasslands: The density of the biotic factor decreases to the point where certain areas are entirely treeless or covered by small patches of shrub or cultivation. In this area, lithologies create a greater prominence, especially in areas where the ridges are manifested, as these lithological alignments attract more attention. The area where these units are best represented is in the SW coastal area, with relevance in Noalla and the capes of Cabicastro, Montalvo, or Fagilda (Figure 4E).

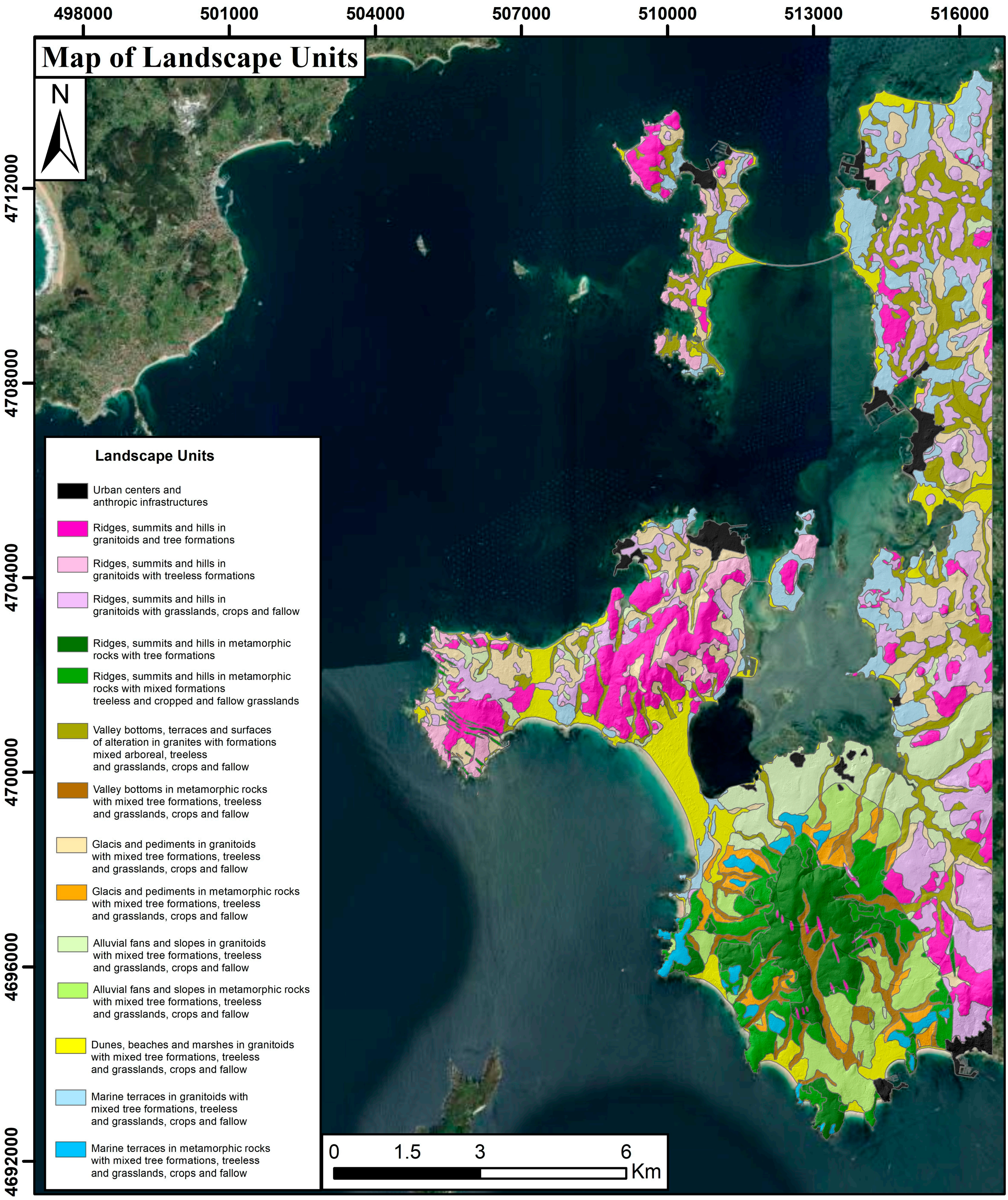

Figure 3. Cartography that shows the 14 units that characterize the landscapes of the SE margin of the Ría de Arosa.

Figure 4. (**A**) Coastal urban landscapes: Arosa Island. (**B**) Ridges and summits on granites with tree formations: El Grove Peninsula. (**C**) Hills on granites with treeless formations: Reboredo. (**D**) Hills on granites with grasslands and crops: Castrelo. (**E**) Hills on metamorphic rocks with grasslands and crops: Noalla. (**F**) Summits and ridges on metamorphic rocks with tree formations: Monta Faro. (**G**) Valley bottoms on granites: Tragove. (**H**) Valley bottoms on metamorphic rocks: Barrantes. (**I**) Glacis and foothills on granites with mixed formations: Rouxique. (**J**) Glacis and foothills on metamorphic rocks: Aios. (**K**) Alluvial slopes and fans on granites in mixed formations: A Gandara. (**L**) Alluvial slopes and fans on metamorphic rocks: Coirón. (**M**) Dunes, beaches, and marshes on granites: Tómbolo de La Lanzada. (**N**) Marine terraces on metamorphic rocks: Cabo Fagilda. (**O**) Marine terraces on granites: Hermitage of La Lanzada.

The presence of the fluvial morphogenetic system predominates throughout the SE area of the Ría de Arosa. Within this morphogenetic system, different landscape units are distinguished:

3. A. Valley bottoms, terraces, and alteration surfaces in granites with mixed arboreal and treeless areas, and grasslands, crops, and fallow formations: These comprise various deposits and morphologies associated with active and abandoned watercourses. In the case of the drainage network established in areas dominated by granitoids, there is a slight difference depending on variations in slopes. From a landscape value perspective, these areas provide great naturalness and aesthetic value. The drainage network superimposed on granite domes exhibits greater incision (El Grove Peninsula). This fact gives the observer a sense of closed landscape, resulting from the existence of visual barriers, which is amplified by the higher concentration of trees. The coastal area along the entire NE strip of the study area, where small systems of river terraces and alteration surfaces (typical of a morphogenetic system) are established adjacent to these alluvial zones, shows less visual impact. In these areas, the slopes are much gentler, and the surfaces are dominated by crops and pastures, a consequence of the incipient development of soils (Figure 4G).

3. B. Valley bottoms, terraces, and alteration surfaces in metamorphic rocks with mixed tree formations, treeless areas, and grasslands, crops, and fallow: These sectors are mainly dominated by shrub areas and crops, with patches of low tree density. The incision shows a progressive decrease, leading to a gradual loss of the sense of a closed landscape as we move away from the central areas of the Castrove Peninsula where the headwater zones are located (Figure 4H).

Areas covered by pediments and alluvial fans correspond to the terrain inflections that connect prominences with flat surfaces. It is here where variations in slopes occur because of the smoothing of the relief caused by the accumulation of fluvial and, in some cases, gravitational deposits. Two units linked to these morphologies are described:

4. A. Glacis and pediments in granitoids with mixed tree formations, treeless areas, and grasslands, crops, and fallow: Typically found spatially in areas adjacent to granite domes and ridges. They smooth the relief compared to the steep slopes of these dome-shaped and castellated structures. This results in less visual prominence for the observer, implying a relative loss of landscape value. These areas vary in terms of vegetation but are mainly dominated by cultivation and extensive pastures (Figure 4I).

4. B. Glacis and pediments in metamorphic rocks with mixed tree formations, treeless areas, and grasslands, crops, and fallow: Represent a small part of the total surface. They are concentrated covering the metamorphic substrate more with the flatter areas of the coastal sector. Like the previous case, these areas are mainly dedicated to pasture and cultivation (Figure 4J).

The morphologies that create the greatest contrast from a perceptual standpoint compared to the steeper areas are alluvial fans and slopes. They are associated with the lower limits of mountain fronts and cover large areas of the territory. This breadth gives the observer a sense of distance, creating a panoramic space.

5. A. Alluvial fans and slopes in granitoids with mixed tree formations, treeless areas, and grasslands, crops, and fallow: Found mainly in small portions of land at the foot of the granite domes of the El Grove Peninsula and to a greater extent in the extensive territory on the northern coastal front of the Castrove Peninsula. Generally, grass and cultivated areas are established, but isolated woody plant species can also be found (Figure 4K).

5. B. Alluvial fans and slopes in metamorphic rocks with mixed tree formations, treeless areas, and grasslands, crops, and fallow: Cover extensive areas at the feet of small mountainous areas of metamorphic rocks in the northern and mainly southern part of the Castrove Peninsula. Biotically, they are areas of pasture and cultivation, but isolated woody plant species can also be found (Figure 4L).

Given the coastal location of the study area, the coastal morphogenetic system is of relevance. For the purposes of landscape units, forms associated with constructive processes (such as beaches, tombolos, dune systems) and destructive processes (such as marine terrace systems and abrasion surfaces) will be differentiated. A total of three units are described:

6. A. Dunes, beaches, and marshes in granitoids with mixed tree formations, treeless areas, and grasslands, crops, and fallow: Constructive morphologies are associated with a marine environment (beaches, coastal bars, tombolos, spits), transitional environments (marshes), and finally, aeolian environments (dune systems). Areas closest to the coastline, subject to cyclical flooding, are entirely treeless, while older dune systems may have shrub vegetation and, in some cases, trees (Figure 4M).

6. B. Marine terraces in granitoids with mixed tree formations, treeless areas, and grasslands, crops, and fallow: These represent structures associated with erosive (destructive) processes that create flat abrasion surfaces. They are distributed along the portion of land closest to the coast, but occasionally, some are found in more inland areas, reflecting a more complex evolution of the territory. Biologically, they present variable plant species (trees, shrubs, and even crops and pastures) (Figure 4O).

6. C. Marine terraces in metamorphic rocks with mixed tree formations, treeless areas, and grasslands, crops, and fallow: These are in areas near the coast in the southern part of the study area, where outcrops of metamorphic rocks are found. A good example is the flat surface described at Cape Fagilda. Biologically, they exhibit diversity in plant species (trees, shrubs, and even crops and pastures), but grasses dominate (Figure 4N).

3.2. Mapping of Landscape Quality and Fragility

Mapping of landscape quality allows us to know the most important areas from the point of view of their uniqueness (abiotic and biotic). To understand it better, it is necessary to describe the results of the mapping of intrinsic and extrinsic quality in parts.

To obtain the intrinsic quality map, the factors presented in the previous section are analyzed separately (Figure 5A–G). The sum of all these factors (Equation (1)) allows us to obtain the final map (Figure 5H). The values on the map are reclassified into five classes: very low, low, medium, high, very high. The values of very high and high quality are concentrated in areas with the highest relief, which are found in the inner parts of the Castrove and El Grove Peninsulas. These are territories where forms associated with lithostructural relief stand out, such as dome-shaped domes, ridges, and summit areas (Mount Siradella, Montefaro, Trincheras). High values of intrinsic landscape quality are also found on Arosa Island. Areas of low intrinsic quality are located on the tombolo of La Lanzada, urban areas, and in those points where there is a higher concentration of abrasion surfaces (marine terraces). These surfaces typically have a gentle morphology and are filled with poorly consolidated deposits (conglomerates, gravels, sands, silts, and clays).

In the case of landscape extrinsic quality, anthropogenic (urban centers) and heritage factors (geological, ecological, or historical–cultural) are considered (Figure 6A–D). The extrinsic landscape quality is reclassified again into five classes, from very low quality to very high (Figure 6E). The highest-quality zone is found on the tombolo of La Lanzada. In this area, ecological protection features, such as the Umia–El Grove Intertidal Complex, and geological heritage features are concentrated. Associated with the combination of a "geosite" and ecological protection zones, we obtain very-high- and high-quality values in the southern part of Arosa Island and in the northern coastal area of the Castrove Peninsula. Areas of very low landscape quality are found where there are no protection or heritage features. Examples of this are the NE coastal flank and the interior of the Castrove Peninsula.

The weighted sum of these maps (Equation (3)) allows us to obtain the landscape quality map (Figure 7). The areas of highest quality are concentrated in the mountainous sectors located in the interior of the El Grove and Castrove Peninsulas. High values are obtained on Arosa Island. Low values stand out in the Lanzada tombolo, the NE area of the coast where the municipalities of Villanueva de Arosa and Cambados meet. Similarly, the metropolitan areas of El Grove, Portonovo, and Sangenjo also record low values.

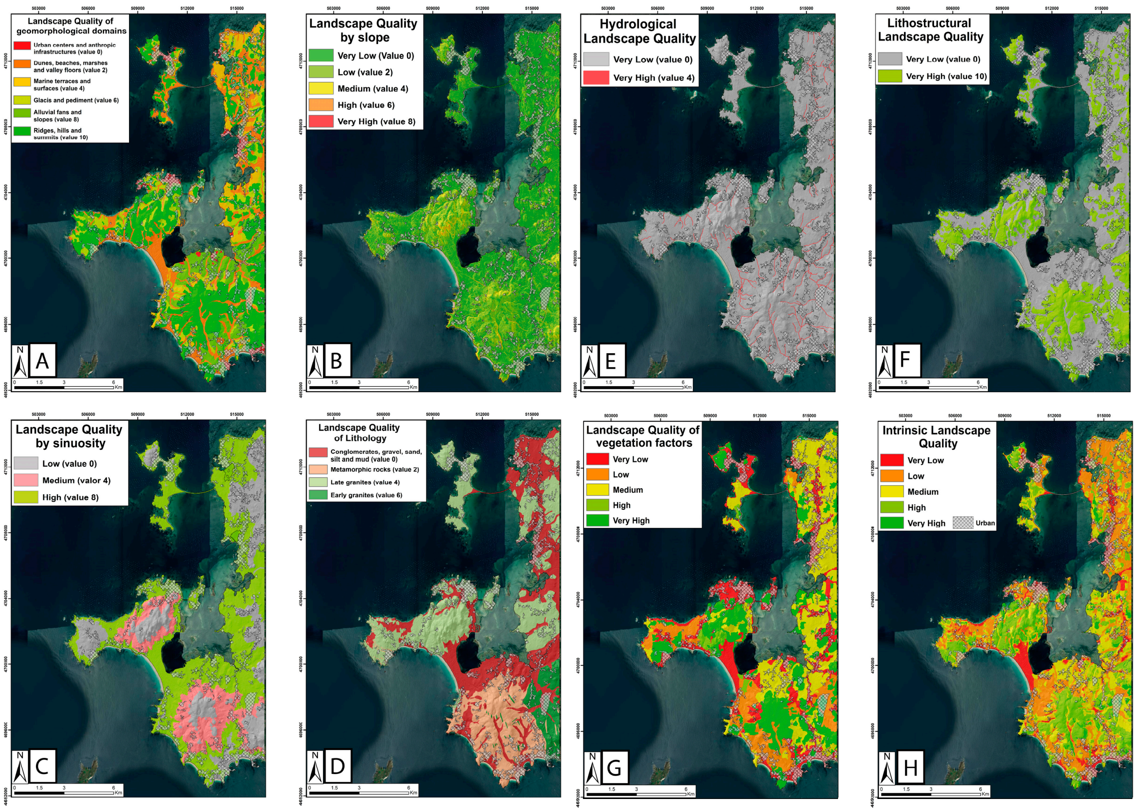

Figure 5. Quality cartographies of intrinsic factors: (**A**) Geomorphological Domains; (**B**) Slopes; (**C**) Sinuosity; (**D**) Lithology; (**E**) Hydrological; (**F**) Lithostructural; (**G**) Vegetation; (**H**) Intrinsic Landscape Quality.

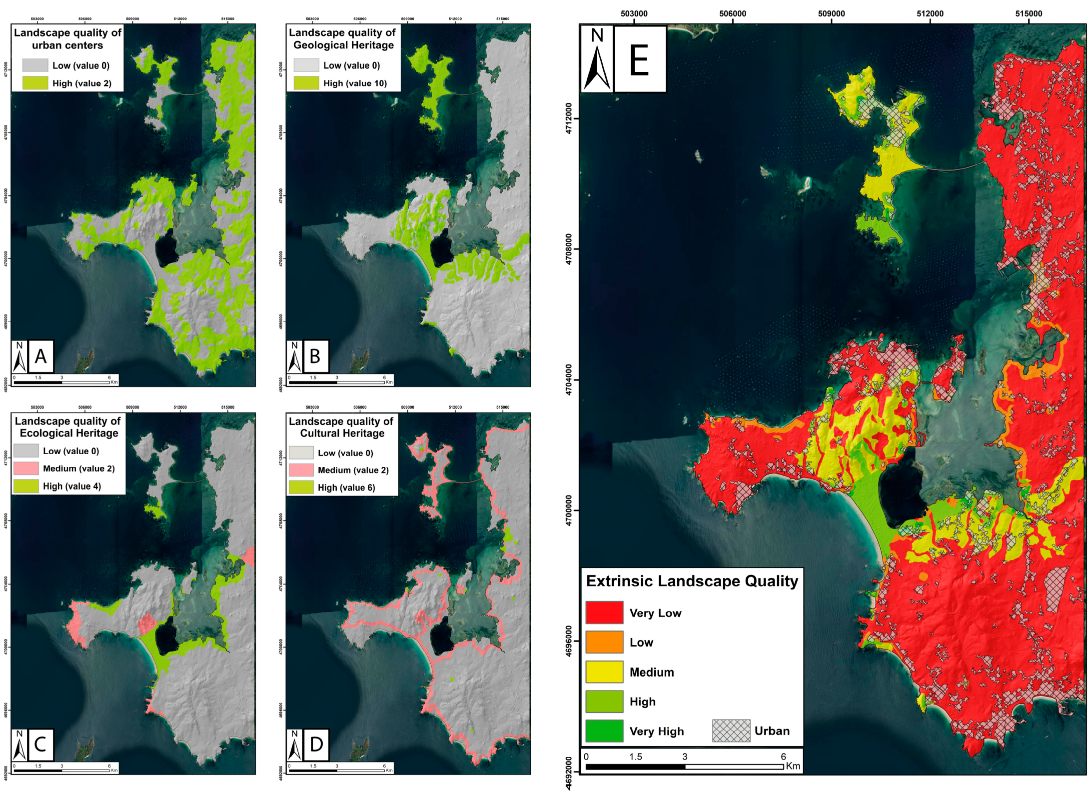

Figure 6. Extrinsic Quality cartographies: (**A**) Urban Centers; (**B**) Geological Heritage; (**C**) Ecological Heritage; (**D**) Cultural Heritage; (**E**) Extrinsic Landscape Quality.

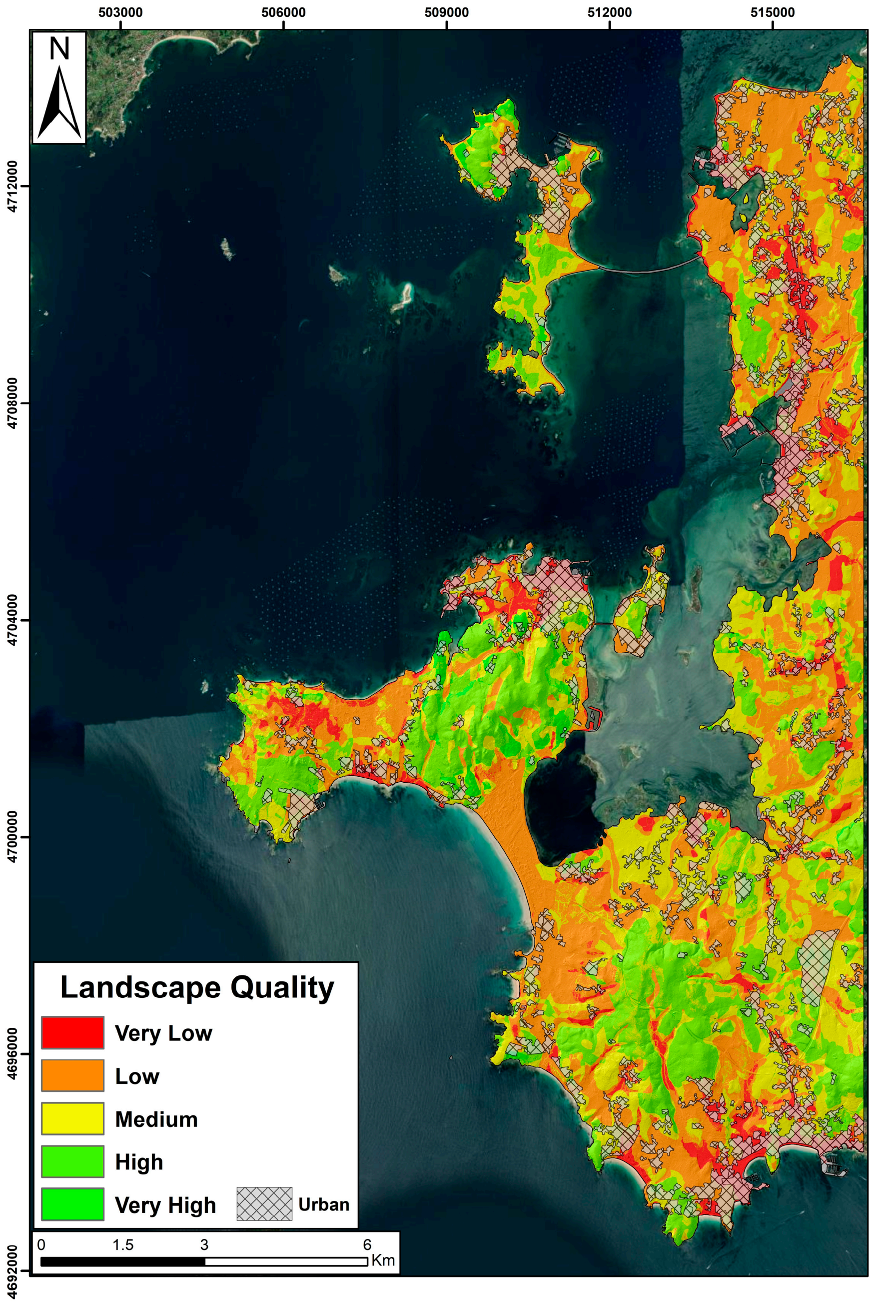

Figure 7. Mapping of Landscape Quality of the SE margin of the Ria de Arosa.

Fragility mapping aims to find the areas of the territory in which the landscape is susceptible to certain actions or impacts. To do this, it is necessary to first analyze the cartographies of intrinsic and extrinsic fragility.

The seven factors (geomorphological, lithological, and biological) described above are integrated (Equation (4)) to obtain the intrinsic fragility map (Figure 8A–G). The result is reclassified to facilitate comprehension into five classes ordered from lower to higher fragility (Figure 8H). Not many areas of very high fragility are recorded, and the few that exist are concentrated around coastal areas where the steepest cliffs are located. Areas of high fragility are more representative and, like those of higher value, are concentrated around the boundaries of coastal transitional zones. They stand out among all the coastal boundaries of Arosa Island. Medium and low values are the most represented, while the lowest values are found in the mountainous areas of the interior peninsulas.

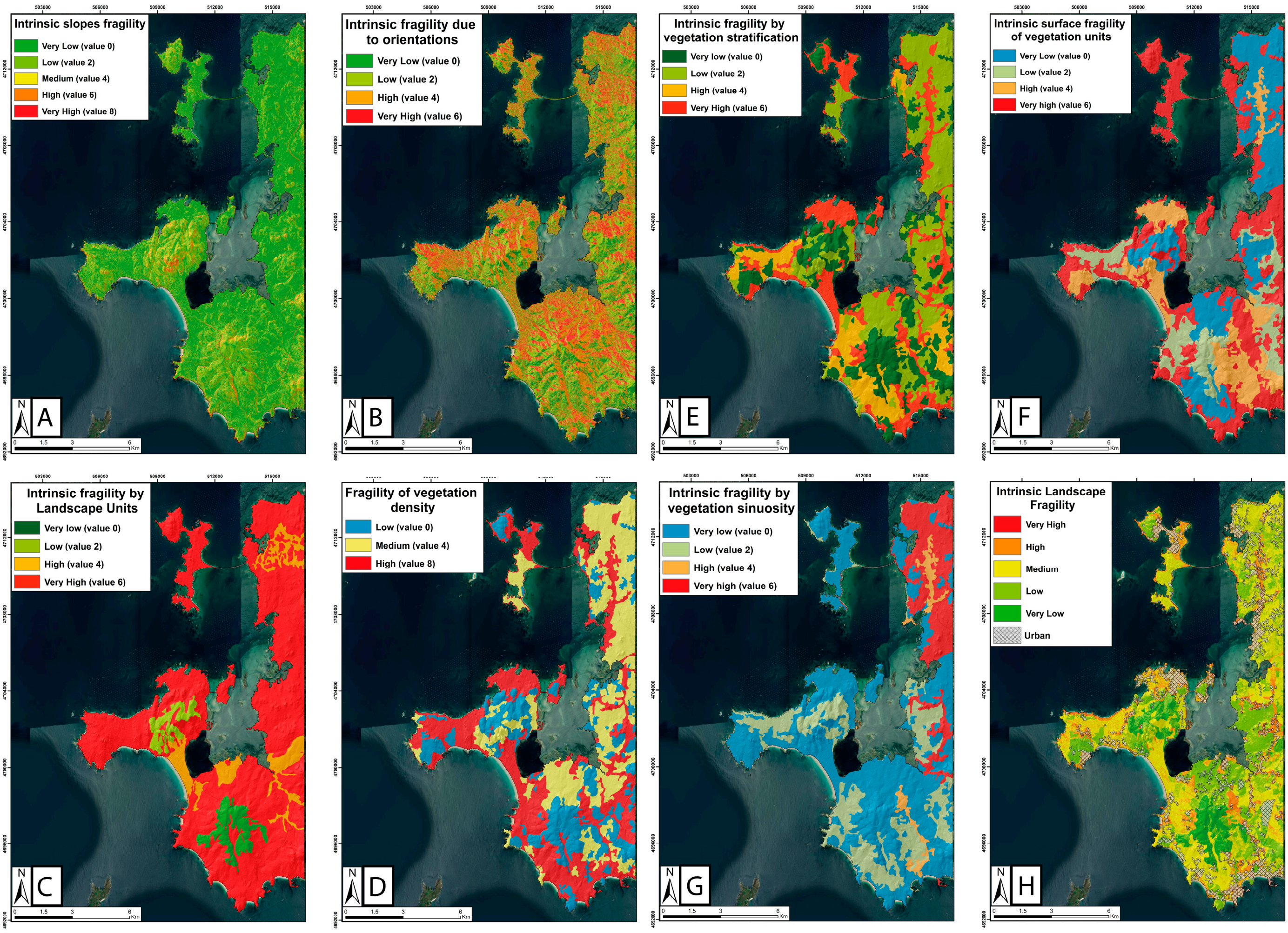

Figure 8. Quality cartographies of intrinsic factors: (**A**) Slopes; (**B**) Orientations; (**C**) Landscape Units; (**D**) Vegetation Density; (**E**) Vegetation Stratification; (**F**) Vegetation Units; (**G**) Vegetation Sinuosity; (**H**) Intrinsic Landscape Fragility.

The sum of the visibility and accessibility factors (Figure 9A–D) generates the final map of extrinsic fragility (Figure 9E). In this map, many areas dominated by very high and high fragility values are found. These values coincide with the topographically lowest areas, where urbanized sectors and higher visibility are concentrated. This significantly reduces the absorption capacity against an impact. In contrast, areas with low and very low values are those at higher elevations where access is more restricted and show a higher number of blind spots. The western area of Arosa Island shows a clear dominance of low values of extrinsic fragility.

By the weighted sum of the intrinsic and extrinsic fragility maps, the fragility map is obtained, which is reclassified into five classes ordered according to their higher or lower fragility (Figure 10). Following the coherence of the results from previous fragility maps it can be observed that very high and high values are mainly distributed around coastal areas. These are accentuated in parts where urbanized areas are found. Similarly, sectors of lower fragility are in the mountainous areas of the El Grove and Castrove Peninsulas, coinciding with residual granitic reliefs (domes, ridges, summits) and metamorphic reliefs.

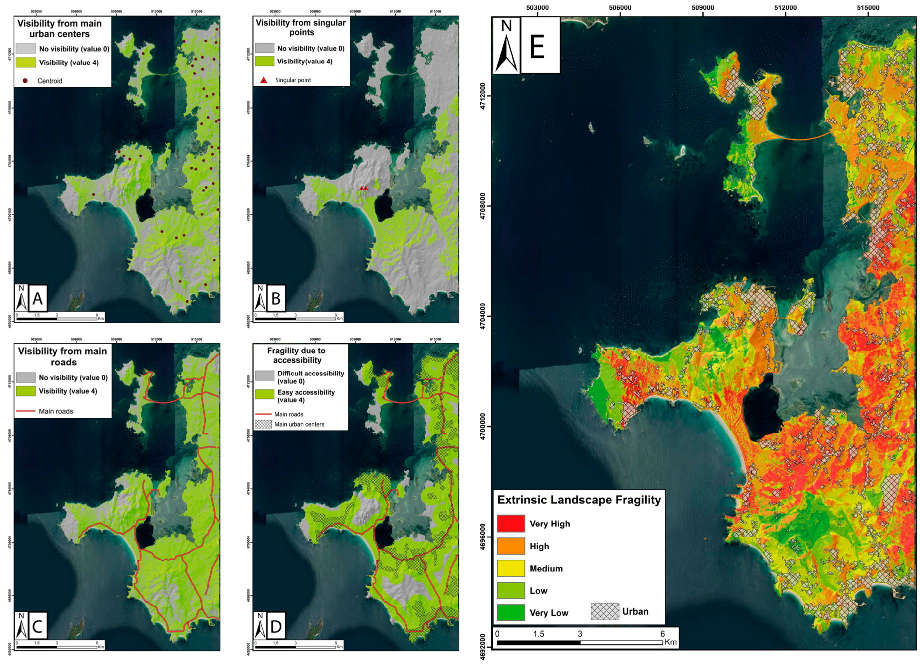

Figure 9. Extrinsic Fragility Factors. Visibility: (**A**) Urban Centers; (**B**) Singular Points; (**C**) Main Roads; (**D**) Accessibility; (**E**) Extrinsic Landscape Fragility.

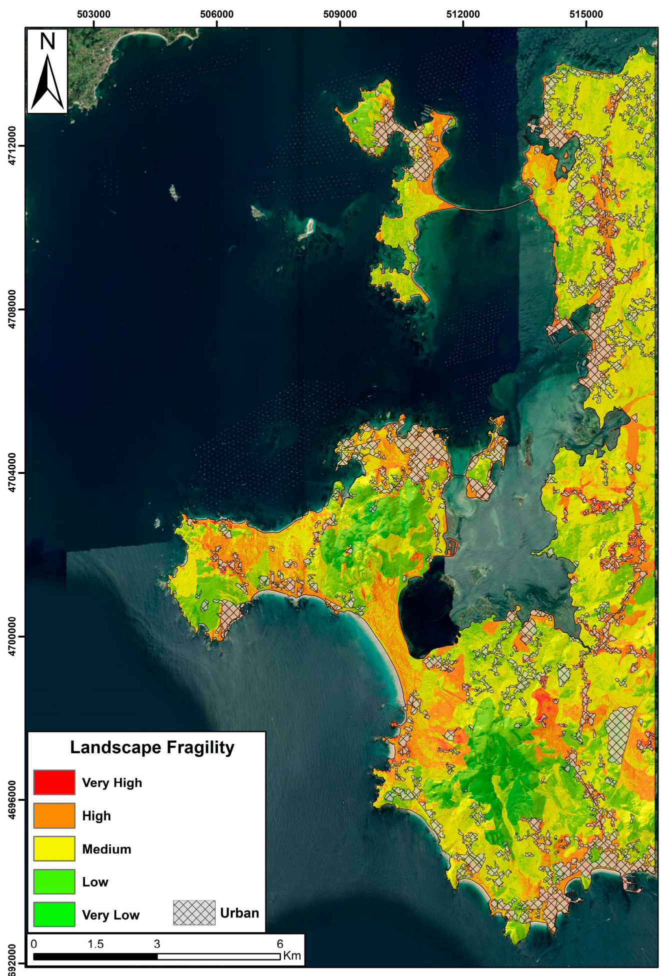

Figure 10. Mapping of Landscape Fragility of the SE margin of the Ria de Arosa.

4. Discussion

4.1. Development and Validation of Cartography

The presented cartographies are developed from a methodology that starts from an objective point of view, analyzing quantifiable parameters that do not depend on an individual's perception [12,17]. To conduct a good landscape analysis, we believe that opting for a multidisciplinary approach is essential, one that relates the different components of the environment, both abiotic (geomorphology or lithologies) and biotic (plant or faunal species), as well as sociocultural factors. All these factors are responsible for shaping the characteristic landscape of the region. The modeling aims to be used as an easily accessible tool, capable of generating up-to-date and high-resolution results (in this case, working with a cell size of 1×1 m). Working with a smaller pixel size allows for better space efficiency and better data detail compared to using a larger cell size. It is intended that the different factors can be updated based on new information generated as a result of variations in the environment. Sudden disturbances in the environment, such as a significant loss of vegetation due to a fire, can affect the quality and fragility factors of the environment to varying degrees. Therefore, this methodology can be of great utility and assistance in understanding the landscape impact of an event in an area.

The development of field campaigns as direct methods of result validation is one of the indispensable requirements to guarantee the veracity of the generated results [31,32]. During these campaigns, strategic observation points of the different landscape units are selected for image capture using cameras or drones, aiming to increase resolution or correct possible errors. The GIS data obtained in this work proved to be of adequate detail and representativeness.

4.2. Interactions between Landscape Quality and Fragility for Urban Planning

The areas corresponding to the highest values of landscape quality align very well with those of lower fragility. Summit areas, hills, and ridges, where residual reliefs and the greatest variations in altitude are found, best maintain this relationship (internal areas of the El Grove and Castrove Peninsulas). Arosa Island, along its western and southern flanks, also presents very-high- and high-quality values alongside areas of low or very low fragility. These areas, broadly speaking, tend to coincide with vegetated (tree or shrub species) and non-urbanized zones. Land uses are dedicated to non-anthropogenic activities.

On the other hand, it is observed that areas of lower landscape quality predominantly coincide with those of high or very high fragility. Urban areas, where the most important municipalities are concentrated, record the most antagonistic values of these factors (low or very low quality and high or very high fragility). Anthropized areas are concentrated in locations most suitable for building and with better connection to the sea. These places are spatially very exposed due to gentle topographic contrasts (marine terraces, glacis, or alluvial fans) and sparse vegetation (deforested or cultivated areas).

Ideal locations for future projects of urban expansion or other anthropogenic activities with high impact will be those where the values of lower landscape quality coincide with those of lower fragility. These are the areas that have the greatest absorption capacity. The southwestern flank of the Castrove Peninsula or the northwestern coastal area, near the municipalities of Villanueva de Arosa or Cambados, are the areas that present the best absorption capacity. However, the Lanzada tombolo or the summit and hill areas are not advisable as they present lower absorption capacity values. An especially sensitive area due to its high fragility is the tombolo and the adjacent area to the south of it.

4.3. Conservation Strategies Applied to the Landscape

Conservation of the landscape can be addressed through both passive and active strategies, which require a detailed study of the environment. In the case of passive strategies, the development of social awareness through environmental education for the conservation of the abiotic and biotic environment is fundamental [33,34]. This process should target various levels of society with the local population, initially, but a goal should be to reach those who formulate land management policies [35,36].

Proper land planning, oriented towards landscape conservation through the cartographies presented here, facilitates territory management even more within the current context of rapid global transformation. The most modern techniques for preserving the biotic environment, which are proving to be more effective, are based on land use through multiple uses [37–39]. These methods, based on ecosystem services, provide better protection of biodiversity and increased benefits compared to traditional intensive techniques [36,40]. The low quality and high fragility shown by grassland and crop areas in the study area open the door to the development of these techniques with the aim of gaining naturalness and reversing these values.

The abiotic environment, composed of geomorphology, geology, and hydrology, is particularly sensitive to landscape impacts due to its unique and irreplaceable nature. Furthermore, restoration and rehabilitation campaigns are highly complex and costly, and due to the degree of landscape degradation, they may be ineffective [41]. The identification of areas most vulnerable to landscape impacts (where absorption capacity is lower) offered by these cartographies allows work to be performed in smaller and more affected areas. This is very positive as it significantly reduces the cost of a restoration and/or rehabilitation project.

Finally, the use of geotourism as a tool for geoconservation of the landscape has been gaining ground in recent years [42]. Geotourism promotes the value of geological, biological, and cultural heritage together, enabling a better understanding and appreciation of the environment [43].

5. Conclusions

The detailed study of the landscape on the southeastern margin of the Ría de Arosa has provided a comprehensive and valuable insight into the environment. Below are the main conclusions and recommendations derived from the study:

1. The methodology presented allows for a thorough analysis of the landscape quickly by combining abiotic, biotic, and sociocultural aspects. The multidisciplinary approach is emphasized as key to better understanding the complexity of the landscape and guiding conservation and territorial planning strategies.
2. There is a close relationship between landscape quality and fragility in the study area, with high-quality areas coinciding with those of lower fragility and vice versa.
3. The landscape quality and fragility maps developed in this study are useful tools for territorial planning and management. They provide high-resolution and up-to-date information on the spatial distribution of areas based on their quality and fragility, facilitating the identification of priority areas for conservation and sustainable landscape management.
4. Various landscape conservation techniques are proposed based on the study's findings. These strategies include both passive approaches, such as social awareness through environmental education, and active approaches, ranging from territorial planning to restoration and rehabilitation techniques. This underscores the need to adopt adaptive and proactive approaches to address the challenges of landscape conservation in a context of accelerated global change, both environmental and social.

In summary, the study contributes to a better understanding of the landscape in the southeastern margin of the Ría de Arosa and provides practical tools for its conservation and management [8]. However, there is a recognized need to continue researching and developing conservation strategies in response to the rapid and constant evolution of the environment.

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