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Cumulative Spatial and Temporal Analysis of Anthropogenic Impacts in the Protected Area of the Gran Paradiso National Park in the NW Alps, Italy

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Abstract: Anthropogenic threats are responsible for habitat degradation and biodiversity decline. The mapping of the distribution and intensity of threats to biodiversity can be useful for informing efficient planning in protected areas. In this study, we propose a cumulative spatial and temporal analysis of anthropogenic impacts insisting on an alpine protected area, the Gran Paradiso National Park. The applied methodology starts with the construction of a spatial and temporal dataset of anthropogenic impacts and normalization based on relative intensity. The impacts analyzed include overgrazing, helicopter flights, road networks, built-up areas, worksites, derivations and discharges, sports activities, and dams and hydroelectric power plants. Each impact was assigned a weight based on its temporal persistence. Threats maps obtained from the collected, normalized, and weighted geodata are thus obtained. Finally, the risk map is calculated by combining the impact map with the vulnerability map, estimated through the methodology outlined in the Green Guidelines of the Metropolitan City of Turin. The risk map obtained was cross-referenced with the Park's cartography to highlight any critical issues to specific habitats. Results show that most of the territory falls in low-risk (63%) or no-risk (35%) areas. However, there are some habitats that are totally or nearly totally affected by some degree of risk, although different to zero, such as the "Lentic waters with aquatic vegetation [incl. cod. 3130]", the "Lentic waters partially buried", the "Mountain pine forests (*Pinus uncinata*) [cod. 9430]", and the "Mixed hygrophilous woods of broad-leaved trees [incl. cod. 91E0]". This study highlights both the potential of these analyses, which enable informed management and planning of the fruition of protected areas, and the limitations of such approaches, which require in-depth knowledge of the territory and ecosystems and how they respond to threats in order to refine the model and obtain realistic maps.

Keywords: anthropogenic impacts; pressions; threats; land use; vegetation; geographic information system; protected area

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1. Introduction

The landscapes of the Alps are strongly shaped by geomorphological complexity that deeply changes from the bottom of the valleys up to the rocky walls and the peaks determining different soil structures and profiles [1–3].

The history of human land use in the Alps testifies to the adaptability of humans to the harsh geomorphology and the capability of living for millennia with sustainable, low intensity use of soil, plant, and water resources [4–8]. Traditional land use for agriculture, forestry, and pasture shaped the vegetation and landscapes enhancing plant, fungal, and animal biodiversity in grasslands and forests, leading to the typical landscapes of the

Alps, characterized by an equilibrium between natural ecosystems and human-shaped agro-forestry-pastoral systems along the elevation gradient, with a prevalence of natural ecosystems at high elevation and an increase in human-shaped habitats at lower elevations.

Changes in the use of energy and technologies since the beginning of the last century and the increasing number of tourists changed this equilibrium, with an increasing length of roads, new buildings, dams and other hydroelectric power plants, ski facilities, mountain huts, bivouacs, mountain bike and climbing activities, and helicopter flights. These relatively recent land uses have important impacts on soil, vegetation, and animals and threaten biodiversity conservation in different ways.

Several studies demonstrated that disturbances sensu Grime [9], that is, every mechanical event removing or destroying plant biomass, cause increasingly persistent damage to vegetation and consequently to other groups of organisms as elevation increases since disturbing vegetation where plant species are subjected also to stress causes a very slow or impossible recovery of the vegetation cover [10–13]. This is one of the reasons why the Italian framework law (L. 394/1991) on protected areas distinguishes four zone types (A, B, C and D from higher to lower elevations) with different protection levels, from wilderness areas to areas of economic promotion.

The Gran Paradiso National Park (GPNP), founded in 1922, is the oldest Italian National Park and one of the oldest in Europe. GPNP is also a core area of the Natura 2000 network. Management activities have always been aimed at the conservation of nature and traditional uses of the land such as grazing livestock, which is important for the conservation of biodiversity and traditional landscapes.

Management plans were realized and applied in order to limit human impacts on biodiversity but at the same time to maintain the traditional land uses which enhance plant and animal diversity conservation. From the first years of the GPNP, the work of a distinguished group of park guards and other office dependents allowed them to monitor a high amount of data on wild and raised animals, vegetation communities, land uses, tourism, and other activities carried out in the park. Data collected must be elaborated and represented spatially and temporally to be used for the environmental risk assessment and future management plans.

Cumulative anthropogenic impact analysis is a widely used methodological approach to assess the combined effects of human activities on the environment [14–18]. This approach is critical for understanding the impacts of multiple stressors on ecosystems and for making informed decisions about resource management and conservation.

Different methodologies are employed depending on the scale and specific goals of the analysis. One key attempt to give a standardized methodology was provided by Halpern et al. [19], who conducted a global-scale analysis in the marine environment. Marine and freshwater environments are the areas where these methodologies have found greater implementation [15,16,20–38] than studies in terrestrial settings, for which there are fewer examples of application [39–43]. Conceptual models, such as the DPSIR (Drivers, Pressures, State, Impact, and Response) framework [14], are often used to identify the pathways through which impacts occur and to identify the most significant sources of impact [17]. Quantitative methods, such as ecological models or other analytical tools, are used to estimate the effects of different human activities on ecosystem components. In addition, multicriteria decision analysis (MCDA) is a useful tool for assessing trade-offs among different management options [44–46]. The use of these methodologies can help identify data gaps, provide information on the scale and scope of cumulative impacts and help developing effective strategies to mitigate or avoid adverse impacts while promoting sustainable planning.

In summary, the methodologies used are varied and context-specific, but they all have in common the goal of understanding the cumulative impacts of human activities on the environment. These approaches are critical to making informed decisions that promote the health of ecosystems and the provisioning of their services.

The primary goal of this study is to provide a first attempt to assess how much the activities involving anthropic frequentation can interact with the conservation objectives of the protected area and, in this sense, to provide an easily replicable methodology that can be configured as a useful management tool. This paper reports on a specific approach to a method for ecological and environmental risk assessment, which leverages the potential of geographic information systems (GIS) for processing related geo-spatial data.

This need arises from the fact that the intensity of disturbance on the park territory varies spatially and temporally, and the use of GIS, together with the unique opportunity of a vast availability of data on the use of the territory, offers a powerful analysis tool.

The assessment of anthropic pressures is based on a cumulative spatial and temporal analysis in four main phases: the identification and mapping of the pressures, the estimation of the value of the pressures present, the estimation of the vulnerability of the territory, and finally, the risk assessment based on the previous two factors.

The methodology used is based on a study conducted by ENEA (Italian National Agency for New Technologies, Energy and Sustainable Economic Development) for CMTo (Metropolitan City of Turin). The Metropolitan City of Turin in 2014 wanted to define and use a methodology to analyze territories' ecological network and set procedures for its improvement from larger to local scale. Methodology is included in the Guidelines of Green System in "Provincial Territorial Coordination Plan" [47].

The methodology to assess the ecological networking of the territory starts from land use cartography. Territory analysis was performed starting from the assignment of «attribute values» concerning ecological features/evaluation criteria for each 97 land use typologies. Values of naturality, relevance for conservation, pressure on surroundings, fragility, and irreversibility were assigned to each land-use typology. For the large-scale analysis of ecological network, the Land Cover Piemonte legend and cartography were chosen as a basis, comprising 97 land use typologies (5 levels).

This study was carried out as part of the Interreg ALCOTRA GEBIODIV project—Managing biodiversity areas by harmonizing the management methods of Alpine protected areas.

2. Materials and Methods

2.1. Study Area

The study area (Figure 1) is the Gran Paradiso National Park (GPNP), an alpine protected area that extends over 710 km^2 in the North–West of the Italian Alps, between the regions of Piedmont and Aosta Valley, and presents a complex topography with numerous valleys and peaks up to over 4000 m a.s.l. The climate is alpine-continental type, with rigid winters and short summers and persisting snow above 2000 m a.s.l. from October/November until June. The GPNP is the first national park established in Italy, in 1922, in favor of the conservation of the ibex (*Capra ibex*). The Park Authority has been active in the area for 100 years, conducting numerous monitoring and research activities and collecting a huge amount of environmental data. The park territory has been influenced both in the past and in the present by human activities, which are concentrated in the valley floors in the winter and rise to high altitudes in the summer for tourists and pastoral activities [48].

2.2. Workflow

The geospatial dataset was built by collecting information layers from various sources, such as national and regional geoportals, regional environmental protection agencies (ARPA) websites, GPNP archives, and collaborative websites for sharing sports itineraries. Additional layers were obtained by using available orthoimages (Figure S1). All impacts were then normalized based on the relative intensity, where available, and weighted based on the temporal persistence of the impact itself. The cumulative impact map was then retrieved by summing all the impacts. The vulnerability map was estimated applying the LGRE methodology. Finally, the risk map was obtained by combining impact and vulnerability maps (Figure 2). More detailed information can be found in the following paragraphs.

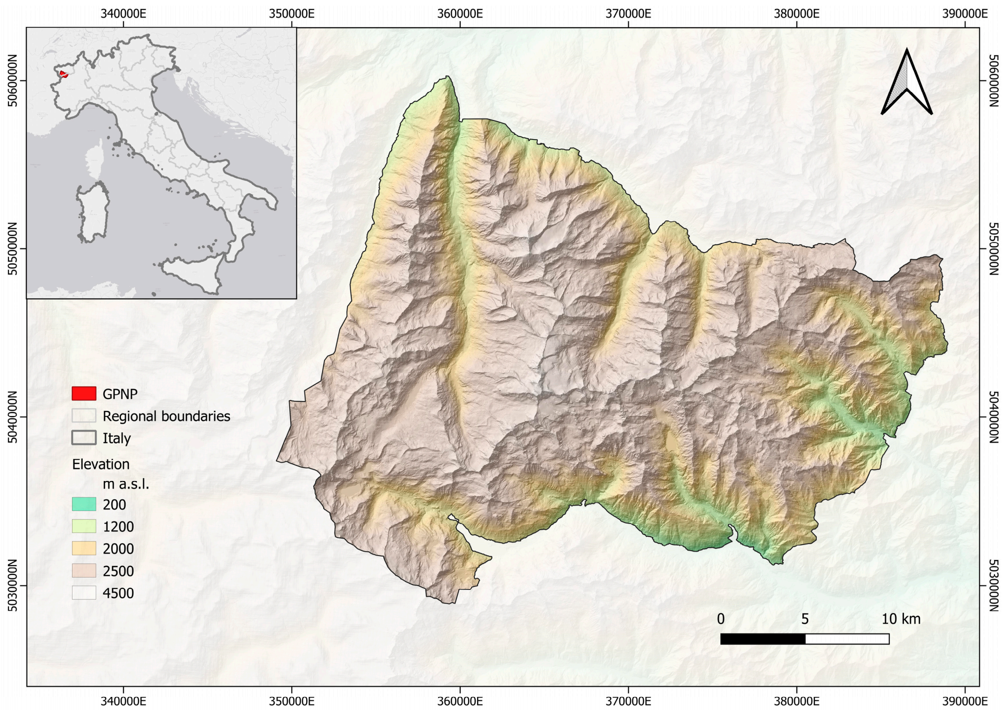

Figure 1. Study area.

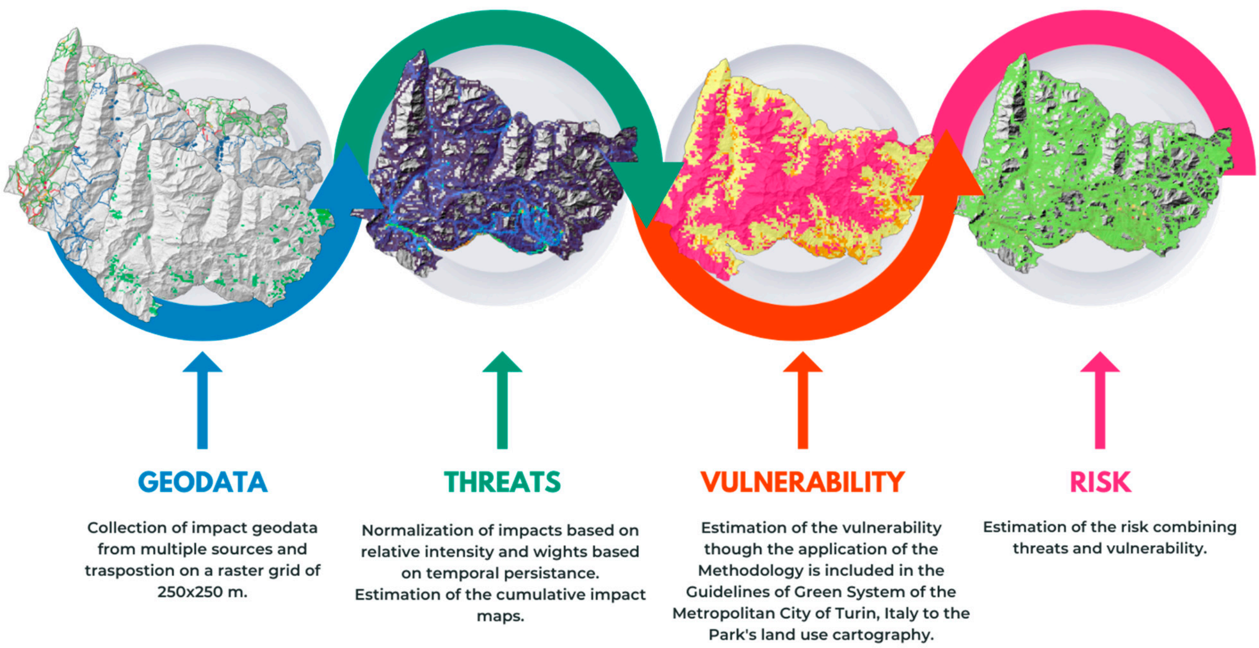

Figure 2. Flow chart of the assessment procedure adopted.

All geodata were resampled on a 250 m $\times$ 250 m grid, spanning the whole GPNP area. Table 1 reports the dataset constructed and its time span covered.

Table 1. Anthropogenic impacts geodata collected.

Anthropogenic Impact	Geodata	Source	Temporal Range	References
Tourism and sports	Pathways	Park Aosta Valley Geoportal OSM	2020	[49–69]
	Mountain huts	Park OSM Gulliver and Questionnaires for the intensity	2020	
	Bivouacs	Park OSM Gulliver and Questionnaires for the intensity	2020	
	Ski facilities	Park	2020	
	Alpine skiing Climbing Bouldering Equipped crag Alpinism Mountain bike Icefalls climbing Steep skiing Canyoning Snowshoeing	Gulliver and Questionnaires for the intensity	2020 2020 2020 2020 2020 2020 2020 2020 2020 2020	
Overgrazing	Overgrazing sites	Park	2000–2018	[70–78]
Worksites	Construction sites	Park	1980–2020	[79,80]
Helicopter flights	Flight routes	Interviews Park	2010–2020	[80–82]
Road traffic	Road traffic	Piedmont Geoportal OSM ARPA Aosta Valley	2019 2020 2018	[83–90]
Derivation and discharge	Derivation/discharge	Park	2020	[91–95]
	Derivation/intakes from surface water Discharge from production settlement Urban sewage discharge	Piedmont Geoportal	2018	
Built-up	Urbanized generic	Imperviousness (Copernicus) OSM	2020 2012	[79,96–99]
	Dams	AGEA 2012 orthophoto	2020	
	Hydroelectric power plants	Piedmont Geoportal	2019	

2.2.1. Interviews and Questionnaires

In the period between August and September 2020, interviews were carried out with the managers of 11 mountain huts located in the GPNP. The aim of the interviews was on one hand to collect information on spatial distribution and relative intensity (such as number of tourists, number of kettles, or frequency of flights) of the impacts, and on the other, to investigate the managers' perception of the impacts on the environment.

In addition, a questionnaire designed to collect information from tourists about their frequency of visiting and sports practice in the GPNP was compiled and distributed online. The questionnaire, distributed through a Google form, was freely filled out during the period between 1 August 2020 and 30 November 2020. A focus on the use of refuges and bivouacs and major trails and the conducted recreational activities was made. The questionnaire was promoted through the GPNP social media accounts (on Facebook and Instagram) and through a series of posters displayed in accommodation facilities (mountain huts, hotels, etc.) and other commercial activities in the area. A total of 314 questionnaires were filled out.

2.2.2. Worksites

The “Worksites” layer is considered useful to represent the impacts deriving from building interventions on the GPNP area [82]. The layer was obtained starting from the intervention authorization document provided by the GPNP, containing data relating to the works carried out in the last 40 years (1980–2020). A detailed analysis of each intervention was carried out resulting in a selection of the most significant interventions in terms of potential impacts on the landscape. The selection of interventions from the database was made arbitrarily, and minor interventions, e.g., gutter repair, were discarded, while new construction or other interventions with significant material movement and soil remodeling were retained. Those data containing geolocation information, also obtained with the help of input from shelter managers during the interviews, were included in a geospatial layer and considered in this study.

2.2.3. Derivations and Discharges

The point layer “Derivation and discharge” derives from the merge of different layers: (a) the shapefile provided by GPNP containing information on intake and discharge points on surface waters; (b) “Urban wastewater discharge”, “Discharge from the production site” and “Intake on surface water extracted” from the Water Resources Information System of the Piedmont Region (http://www.regione.piemonte.it/siriw/cartografia/mappa.do;jsessionid=71FF3621806243A7E72EB83D4BD22BC4.part212node12, accessed on 10 October 2020, accessed on 15 December 2019). The different point shapefiles were merged with no distinction since no information on the amount of intake or discharge was available.

2.2.4. Dams and Hydroelectric Power Plants

The dams were identified, at a detail scale up to 1:100, based on the photointerpretation of the most recent available orthophoto, acquired in 2012 and accessible through the Ministry of the Environment and the Protection of the Territory and the Sea—National Geoportal (http://wms.pcn.minambiente.it/ogc?map=/ms_ogc/WMS_v1.3/raster/ortofoto_colore_12.map&service=wms&request=getCapabilities&version=1.3.0, accessed on 10 October 2019).

The hydroelectric power plants layer was obtained from the geoportal of the Piedmont Region. Information on the hydroelectric power plants in the Piedmont area of the GPNP was supplemented with Lillaz hydroelectric power plant, located near the boundaries of the park in the Aosta Valley Region.

2.2.5. Imperviousness

The “Built-up” layer was derived from two datasets: the “Degree of Imperviousness”, distributed by the Land monitoring services of Copernicus (https://land.copernicus.eu/pan-european/high-resolution-layers/imperviousness/status-maps/imperviousness-density-2018, accessed on 29 November 2019), and the “building footprint” node of OpenStreetMap (OSM).

The “Degree of Imperviousness” is a thematic product that shows the sealing coverage in the range 0–100% for the period 2018, at a resolution of 10 m. This layer, created through the application of machine learning algorithms of the sealed soil directly from satellite images, resulted as inadequate in the case of sparse urban fabric; thus, this limit has been bridged by introducing the OpenStreetMap (OSM) layer with sparse buildings. This last layer is created not automatically, like the imperviousness layer, but through digitization by volunteer operators. The OSM layer, on the other hand, returns a polygon layer with the footprint of the building. Finally, the sealed ground was brought back to the grid at 250×250 m based on the percentage of sealed cells.

2.2.6. Road Network

The road network layer includes four types: local road, secondary extra-urban road, urban neighborhood street, and farm road [79]. The layer derives from the merge of the “Average Daily Traffic 2019” (ADT2019) from the regional geoportal of Piedmont (Geoportal Piedmont, https://www.geoportale.piemonte.it/geonetwork/srv/ita/catalog.search#/metadata/r_piemon:face619f-b974-4ed7-b0a1-ec6f42f9f0d9, accessed on 17 July 2020), and from the "road network" node acquired from OSM regarding the Aosta Valley side.

ADT2019 includes additional attributes of the linear component of the traffic graph, related to vehicular mobility (https://www.geoportale.piemonte.it/geonetwork/srv/ita/catalog.search#/metadata/r_piemon:face619f-b974-4ed7-b0a1-ec6f42f9f0d9, accessed on 25 July 2020). The average daily traffic value represents the number of vehicles that transit on the road element on average daily, in the reference year. It is distinguished by the type of vehicle, light or heavy, and expressed as number of vehicles per day. The "light" category includes all vehicles up to 3.5 t and 9 passengers, while the "heavy vehicles" category includes vehicles with a higher weight.

The most recent data available for the Aosta Valley were acquired from the Report on the State of the Environment (RSA) 2018–FLU_EM_001 (https://www.arpa.vda.it/en/relazione-stato-ambiente/archivio-rsa/xiii-relazione-sullo-stato-dell-ambiente-2018/1309-rsa-2018-flussi-di-materiali/rsa-2018-emissioni/3373-flussi-di-traffico-autoveicolare-fluem001, accessed on 23 August 2020), reporting on the motor vehicle traffic flows. The main routes of the regional road network are clustered into different categories characterized by different average daily traffic values for light and heavy vehicles. This information was merged and standardized in the final geodata reporting all the data into classes (Table 2).

Table 2. Conversion of the mean daily traffic into classes.

Vehicles Number	Class
0	0
0–100	1
100–200	2
200–500	3
500–1000	4
1000–2000	5
2000–3000	6
3000–10,000	7
>10,000	8

2.2.7. Helicopter Flights

The starting information was contained in a shapefile owned by the park, of a punctual type, inherent to flights carried out in the period 2010–2019 by multiple actors.

Using the information "protocol number" and "route", it was possible to define the routes followed by the individual flights. Each section was reconstructed, with the aid of a digital terrain model (DTM), calculating the path at minimum cost (slope and crossing on slope) in R environment [100], using the "*leastcostpath*" package [101], between the points of each section, arriving to obtain a reconstruction as realistic as possible of the route traveled by helicopters. Where the routes were not indicated, the single point was kept. We therefore arrived at two shapefiles, one of linear type, representing the routes flown over by helicopters, to which the information obtained from the interviews was added, and one of punctual type, relating to the data in which it was not possible to find information on the route traveled. Both files retain all original information, including the year when the flight occurred and overall days of flight.

2.2.8. Tourism and Sport Activities

The geospatial data related to tourism and sport activities have been obtained by combining information coming from different sources including data collected with the interviews of tourists and refuge managers. The following layers were produced:

1. *Mountain huts and bivouacs*: this layer contains the precise data of the location of mountain huts, bivouacs, hunting lodges, and park rangers' lodges, digitized based on the orthophoto of 2012 with the help of various sources, such as the Gulliver site,

OpenStreetMap, and the park website. The attributes considered concern name, type (mountain huts, bivouacs, hunting lodges, and park rangers' lodges), municipality, region, and specific fields relating to the frequency of visits by tourists obtained with the data collected through the interviews. It reported the number of people who visit the refuge at least three times a year, more than once but less than three times a year, and never, derived from the tourist interviews. Moreover, the geodata reports the annual estimate of people who visit the refuge in summer and winter obtained through interviews with refuge managers.

2. *Pathways*: the geodata of the pathways were provided by the Park. To this were added the pathways that were absent in the first geodata of the data bank of the Aosta Valley path network, made public through a dedicated geo-navigator (https://catastosentieri.regione.vda.it, accessed on 28 August 2020), and from OSM. The information in the attribute table was subsequently standardized as much as possible. The attribute table is organized in a series of generic fields: id, num. section, name, municipality, length, min altitude, max altitude, the difference in height, section, average slope, typology, paving, gutters, edges, walls, state, signs, digressions, pastures, parks, classification, hunting roads, and royal mule tracks. In addition, two specific fields related to tourist attendance were available: a field already present in the geodata provided by the park and therefore only related to that part of the paths and a field containing the information derived from the questionnaire for tourists. They contain information only for the paths present in the initial geodata provided by the park, on which the questionnaire was built.
3. *Sport activities*: the information relating to sports was taken from the Gulliver website (https://www.gulliver.it, accessed on 12 December 2020), an outdoor community where users share information on itineraries where they can practice different types of sports. On this platform it is possible to set geographic filters by sporting activity. Each itinerary in Gulliver's database was then digitized, where the description was clear enough to allow a correct location or the track was downloaded, when available, resulting in the following geodata: climbing, bouldering, equipped cragging, trekking (i.e., pathways), mountain biking, canyoning (summer sports), alpine/steep skiing, snowshoeing, icefalls climbing (winter sports). The shapefile relating to the skiing facilities was provided by the park, and no changes have been made.

2.2.9. Overgrazing

The "Overgrazing" geodata was produced starting from the Excel database provided by park with the information about the area covered by pastures between 2000 and 2018. Databases for every year were merged and a unique identifier was created for each pasture, combining the id and "year". Subsequently, the records without references to the grid cells were deleted in case of incomplete or absent geographical indications or were completed with reference cells in case of sufficient information was provided. The final database was processed in R to report each pasture data within the selected grid cell to obtain a shapefile for each individual pasture, subsequently merged into a single geodata in which the pastures are layered. Through geoprocessing, the total area of each pasture was then calculated. Grazing activity, if well managed, does not in itself constitute an impact but, on the contrary, is desirable for the maintenance of biodiversity. On the other hand, if it is poorly managed it constitutes a negative impact. For this reason, it is useful to weight the impact of pastures where overgrazing has occurred and exclude all other grazing activities. No applicable methods have emerged from the scientific literature to estimate the grazing capacity of the pastures on a large scale, so we made use of the gray literature and of the regulations deriving from local management policies, such as the Rural Development Plans of Piedmont and the Aosta Valley. Overgrazing events were identified as those above the threshold of 0.5 livestock units per hectare per year (LU/ha/year) indicated for alpine pasture zoning for the Aosta Valley side and 0.6 for the Piedmont side.

2.2.10. Forest Cuts

Through the interviews, it was not possible to obtain any data relating to forest cuts because this information does not concern mountain hut managers. The only data available are in the intervention authorization file of the park, from which it is possible to filter, among all the intervention types, e.g., fencing or building repair, the forest cuts, for a total of 44 forest cutting operations. The permission database was deemed valid because illegal cutting is implausible given the surveillance by the park authority. However, only 6 interventions report sufficient information for correct geo-localization. In the other cases, due to the partial description of the place of intervention, it was not possible to digitize this data. Given the partiality of the information relating to the "Forest cuts" geodata, it was decided to completely exclude this pressure factor from the analysis.

2.3. Estimate of the Threats Value

2.3.1. Normalization and Weighting of Threats Intensity

All the quantitative data related to specific threats have been normalized by considering the ratio of each threat intensity with respect to its maximum value. This procedure resulted in a standardized scale of 0–1. If no quantitative information is available, the value assigned is 1 to consider the presence of the specific threat and 0 in the case of absence (Table 3).

Table 3. Methodology adopted for the normalization of impacts.

Impact	Intensity Factor	Value	Formula
Dam	Presence	1	-
Helicopter flight	Annual days of flights	dayMax	[(day/dayMax) + 1]/ 2 × 1/(YY − year)
	Year	YY = yearMax + 1	
	Presence	1	
Worksites	Presence	1	[1 + (day/dayMax)]/ 2 × 1/(YY − year)
	Day of stay	dayMax	
	Year	YY = yearMax + 1	
Derivation and discharge	Presence	1	-
Hydroelectric power plants	Presence	1	-
Built-up areas	Density (from 0% to 100%)	D/100	(D + 1)/2
	Presence	1	
Road traffic	Average daily light vehicle traffic (L)	LmaxValue	[T + (L/LmaxValue) + (H/HmaxValue)]/3
	Average daily heavy vehicle traffic (H)	HmaxValue	
	Road type (T)	Farm road = 0.25 Neighborhood urban street = 0.5 Local road = 0.75 Suburban road = 2	
Overgrazing	(Livestock Units/Area) × (Days of stay/365)	ValueMax	Value/ValueMax/(YY − year)
	Year	YY = yearMax + 1	
	Presence	1	
Mountain huts	Attendance	Fmax	1 + (freq/Fmax)/2
Bivouacs	Presence	1	
Pathways	Attendance	Fmax	1 + (freq/Fmax)/2
	Presence	1	

Table 3. *Cont.*

Impact	Intensity Factor	Value	Formula
Canyoning	Presence	1	-
Climbing, bouldering	Presence	1	-
Equipped cragging	Presence	1	-
Alpinism	Presence	1	-
Mountain bike	Presence	1	-
Alpine and steep ski	Presence	1	-
Skiing facilities	Presence	1	-
Snowshoeing	Presence	1	-
Icefalls climbing	Presence	1	-

In the literature, no impact values were found to express quantitatively the different sources of pressure. In similar studies, the analysis of pressures was carried out by using weights of individual impacts inferred through expert evaluation. In this study, the assignment of a weight value for each impact was based on the temporal frequency of the impact itself: constant impacts over time have a value of 1, e.g., dams and hydroelectric plants, while 0 is considered for impacts that do not persist at all, e.g., winter bivouacs. Intermediate values represent intermediate persistence times considered over the day and/or year by type (Table 4). For example, worksites have a limited duration in the annual time but high daily in the time of occurrence, and thus 0.8 was assigned. In contrast, bouldering is an activity that lasts a few hours during the day and presumably does not occur every day, so it was assigned the value 0.2.

Table 4. Weights of each impact in relation to temporal persistence and potential pressure generated.

Impact	Weight	Motivation
Dam	1	Persistent impact, impact on watercourse and proxy of constant human presence
Helicopter flights	0.5	Limited impact over time
Worksites	0.8	Impact limited in time but involving high disturbance (noise, material transport, human presence)
Derivation and discharge	1	Impact persistent on watercourse
Hydroelectric power plants	1	Persistent impact, proxy for constant anthropogenic presence
Built-up areas	1	Persistent impact, proxy of constant human presence
Road traffic	0.5	Impact not constant over time, proxy for human presence
Overgrazing	0.5	Impact on wildlife (competition for pasture) and on habitat
Summer tourism and sports		
Mountain huts	1	Persistent human disturbance over time in summer
Bivouacs	0.2	Values assigned based on the results of the questionnaire addressed to tourists
Pathways	0.5	
Canyoning	0.2	
Climbing	0.2	
Bouldering	0.1	
Equipped cragging	0.2	
Alpinism	0.2	
Mountain bike	0.5	
Winter tourism and sports		
Snowshoeing	0.2	Values assigned based on the results of the questionnaire addressed to tourists
Icefall climbing	0.2	
Alpine and steep skiing	0.2	
Ski facilities	0.2	
Mountain huts	0.2	Occasional human disturbance in winter
Bivouacs	0	Negligible human disturbance in winter

2.3.2. Cumulative Analysis of Threats

The cumulative analysis was performed summing all the impacts that persist for each cell of the analyzed area (on a 250 m × 250 m grid).

2.4. Vulnerability and Risk Assessment

The vulnerability is inferred using the ecological-environmental assessment values of the fragility parameter assigned to the legend classes of the Land Cover Piemonte (LCP) 2010 cartography, translating them into the land-use cartography of the park (see Table S1). The approach adopted for the level of fragility assignation is based on expert evaluation as reported by the Ecological Network methodology developed by the Metropolitan City of Turin and ENEA [102]. The levels of fragility, defined as the inverse of resilience, were assigned through expert knowledge considering the following criteria:

- Level 1: land-use classes characterizing both natural environments with very low resilience and semi-natural environments with significant anthropic determinism that are easily impacted (e.g., rocky areas, artificial water basins, areas with sparse vegetation).
- Level 2: natural and semi-natural land-use classes which can be considered poorly resilient with respect to the pressures deriving from anthropic disturbance (e.g., areas with shrub vegetation in natural evolution, pastures).
- Level 3: natural land-use classes with good resilience (e.g., climatic tree formations).
- Level 4: all the land-use classes with total anthropogenic determinism (e.g., most of the crops and the types of artificial land use).

The 4 levels of fragility were converted on a scale from 0, for artificial and agricultural areas, to a maximum of 1, for highly vulnerable land-use types.

To associate the classification of the GPNP cartography with the Piedmont Land Cover classification (LCP) [103], and, thus, to translate the fragility values associated with the latter, we proceeded by comparing the correspondence between the two cartographies in a GIS environment. Both the land-use layers were made at an analysis scale of 1:10,000, and, in some cases, up to 1:2000 as regards the park map. The park map was created through an analysis of the vegetation starting from aerial photogrammetric surveys (years 2005–2012), identifying the different polygons and attributing them to the different subgroups (and in some cases to more detailed classifications) with the help of the geological map and the forest typology map; the direct knowledge of the vegetation of the territory, organized in the databases of the park's botanical service, is also of great importance for the attribution. LCP, released in 2010, derives from the harmonization and integration of data present in archives and maps already existing in the Piedmont Region, following specific analyses and processing in the final data feed. The scales of analysis and the reference years of the source data are superimposable; therefore, it is possible to make a comparison, albeit indicative, between the two maps. For each type of land cover in the park cartography, the correspondence with the land cover surfaces of LCP, found through a spatial analysis, is shown in the Supplementary Materials. For example, the cartography class of the "Fir trees" park overlaps by 90% with the LCP class "3121-Fir trees", which is associated with a fragility value of 3, by 8% with the LCP class "3124-Woods of larch and/or stone pine", with a fragility value of 3, and by 2% to the class "2310-Stable meadows and pastures", with a fragility value of 2.

Finally, by combining the impact map with the vulnerability, it is possible to obtain the risk map by using the following equation:

$$\text{Risk} = \text{Vulnerability} \times \text{Threat} \tag{1}$$

The conservation value was not considered in the Equation (1) because, since this is an area protected both on a national and European level (Special Protection Area), the conservation value is to be assumed maximum in any case.

3. Results

Figure 3 shows the results of the methodologies applied to assess, respectively, the cumulative impacts (top), vulnerability (middle), and risk (bottom) on the GPNP area.

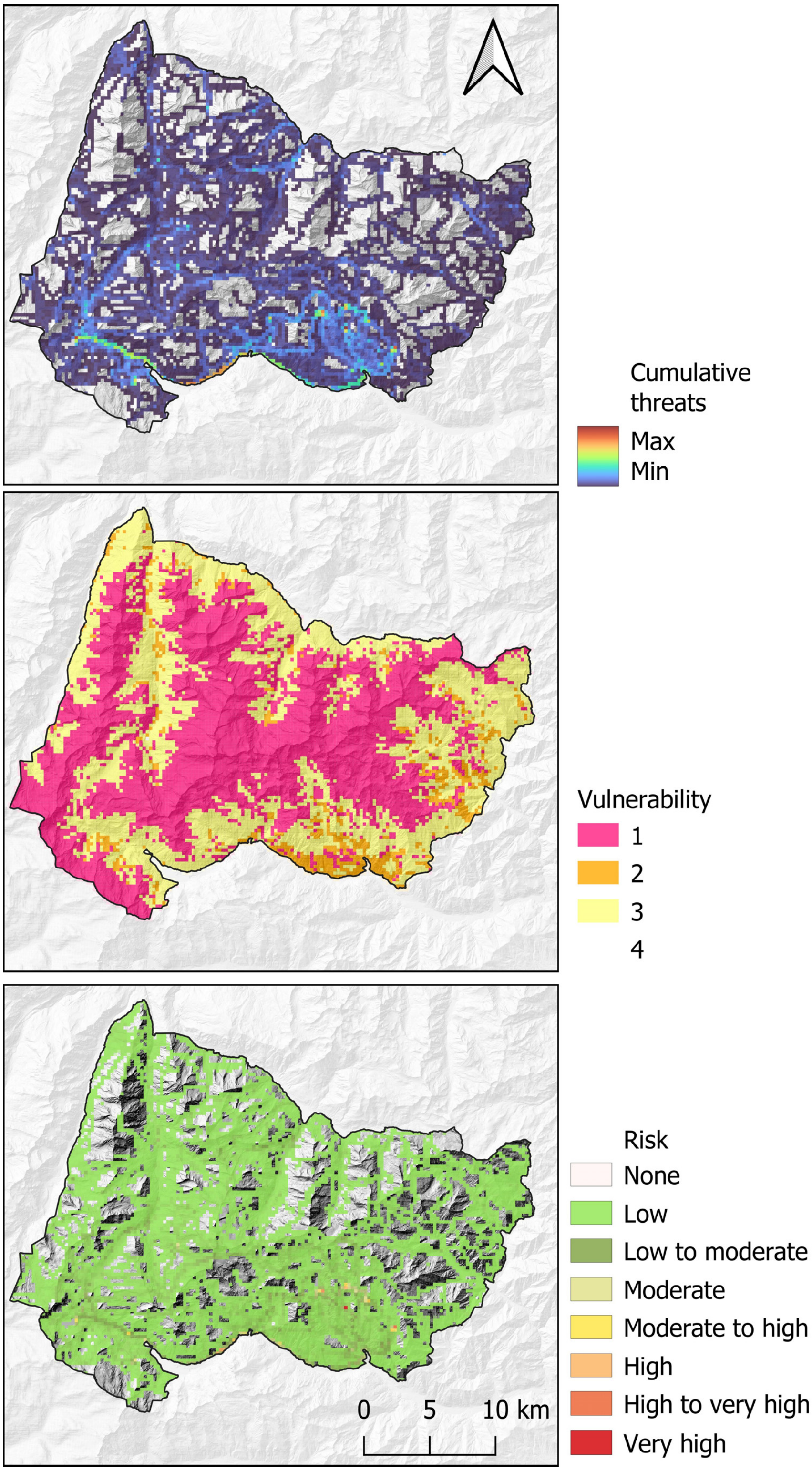

Figure 3. (**Top**): Map of estimated cumulative threats. (**Center**) Estimated vulnerability map of the Park. Level 1 represents the highest vulnerability, while level 4 represents non-vulnerable areas. (**Bottom**) Map of the estimated risk.

High values indicate areas where multiple pressure factors overlap. The threat values range from 0 to 8.6. The vulnerability values range from 0 to 4. The risk values obtained were divided into the following risk classes: 0 = no risk; 0–1.5 = low risk; 1.5–3 = low to moderate risk; 3–4.5 = moderate risk; 4.5–6 = moderate to high risk; 6–7.5 = high risk; 7.5–8 = high to very-high risk; >8 = very-high risk. The risk map obtained shows that most of the park's territory (63%) falls into areas with low risk, followed by areas with no risk (35% of the territory), i.e., with no anthropogenic activity insisting on those areas. These two classes together cover about the 98% of the park. The remaining 2% is distributed among the other classes (Table 5).

Table 5. Extension of the risk classes estimation in the park.

Risk Class	Area (ha)	Percentage (%)
None	24,489	35
Low	44,573	63
Low to moderate	1136	1.6
Moderate	282	0.4
Moderate to high	49	0.07
High	47	0.07
High to very high	35	0.05
Very high	13	0.02

Overall, most of the habitat surfaces are, as a result, affected by the low-risk or no-risk classes (Figure 4). However, no habitat typology is completely unaffected by threats. On the other hand, "Lentic waters with aquatic vegetation [incl. cod. 3130]" and "Lentic waters partially buried" fall entirely in the low-risk class. Additionally, the habitats "Mountain pine forests (*Pinus uncinata*) [cod. 9430]" and "Mixed hygrophilous woods of broad-leaved trees [incl. cod. 91E0]" are almost entirely in the low-risk class, with respectively only 1 and 2% in the no-risk class. Following this, we found "Montane grasslands [incl. cod. 6520]" and "Chestnut groves [incl. cod.9260]", "Marshes with small acidophilic sedges [cor. 54.4]", "Pioneer herbaceous vegetation of alpine watercourses [incl. cod. 7240*]", "Herbaceous riparian vegetation of watercourses [incl. cod. 3220]", and "Woody riparian vegetation of watercourses [incl. cod. 3230 and 3240]" with less than 10% at no risk. The only vegetation type that falls more than half in the no-risk class is the "Transitional peat bogs [cod. 7140]" with 58%, followed by the "Calcareous and calc-scists cliffs" and the "Siliceous cliffs", both with 45%, and the screes, "Siliceous screes" and "Calcareous and calc-scists screes", with, respectively, 42 and 40%. The other vegetation types are included for a range between 10 and 40% in this class. The low-risk class is the most represented; in fact, most of the surfaces fall into this category. The other risk classes affect smaller portions of the park's territory.

The low to moderate class affects the 13% of the "Reforestation" areas, and the 9% of "Chestnut groves [incl. cod.9260]", followed by the 8% of "Hydrophilous tall herb communities of the Alpine plain [cod. 6430 p.p.]", the 7% of "Montane grasslands [incl. cod. 6520]", and under 6% to 0% of the other vegetation types. The 22% of "Chestnut groves [incl. cod.9260]" falls in the moderate risk class. The moderate-to-high-risk class is almost empty, affecting 2 to 0% of the different land cover types, as well as the high-, the high-to-very-high and very-high classes. The "Lentic waters" are the land cover type most affected by risks, with 3% in the very-high risk, 4% in high risk, 5% in moderate risk, 6% in low to moderate risk, and the rest in low- or no-risk classes. This is due to the presence of the dams and hydroelectric plants that require this land cover type.

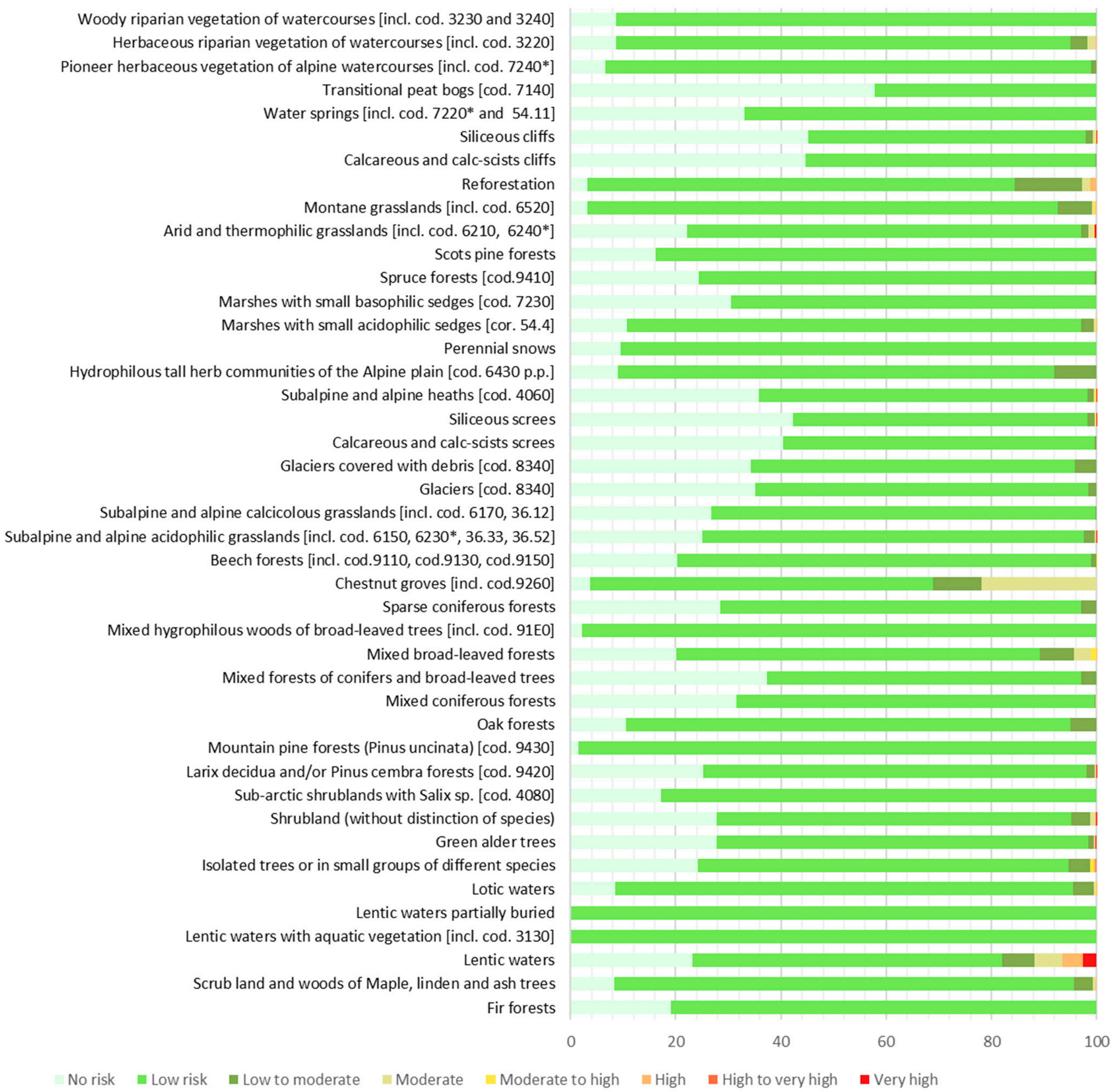

Figure 4. Quantitative distribution of the vegetation and habitat types for risk classification.

4. Discussion

Through a preliminary analysis, the park's managers have identified the stressors that insist on the study area: helicopter flights, worksites, forest cuts, grazing and other agro-pastoral activities, tourist impact (tourism entities and sports activities on trails and shelters), road traffic, stream uptake and derivation, dams and hydroelectric plants, and urban fabric and infrastructure.

The information available regarding the location and intensity of the threats identified was collected and digitized from various sources, including through the conduct of interviews, and stored in a geodatabase.

At this stage, the pressure "Forest cuts" were excluded from the analysis due to the lack of data. Pressures were normalized in a range between 0 and 1 based on their intensity and weighted based on the temporal frequency of the impact itself. Starting from the park's land-use/land-cover cartography, a vulnerability map was then extracted, expressed in a range between 0 (no vulnerability) and 1 (maximum vulnerability) using the methodology proposed by ENEA and the CMTo for the Green Guidelines.

Finally, by combining the pressure maps and the vulnerability map, the risk map was calculated on a grid of the park of 250 × 250 m. The risk map, therefore, represents the additive sum of the values of the multiple pressures, normalized and weighted, which reside in each cell, multiplied by the vulnerability value of the corresponding habitat types.

The values of the risk map have been divided into eight risk level classes. The classes represent the spatial concentration of pressure factors as a general disturbance on habitat and animal species and are therefore indicative of areas in which disturbance types present in the park territory are co-present.

Overall, the analysis highlights good management of the activities in the park, evidenced by the absence of environmental emergencies in terms of habitats subjected to high pressures, as also found by other studies [40].

The activities that determine anthropic frequentation are spread throughout the territory, and there are few areas completely free of pressure factors. Nevertheless, there are no habitats characterized by a significant percentage extension in high-risk areas. The type with a non-negligible percentage in areas with a moderate to high risk level is the "Lentic waters" class, which, however, includes both natural and artificial water basins, created by the presence of dams, while the other classes present negligible levels of risk.

Finally, it should be noted that some natural environmental typologies fall 100% in areas with a different level of risk; however, the risk is not zero, e.g., the "Lentic waters with aquatic vegetation [incl. cod. 3130]" and the "Lentic waters partially buried". Additionally, for the most falling in some risk class there are the "Mountain pine forests (*Pinus uncinata*) [cod. 9430]", the "Mixed hygrophilous woods of broad-leaved trees [incl. cod. 91E0]", the "Montane grasslands [incl. cod. 6520]", "Chestnut groves [incl. cod.9260]", "Marshes with small acidophilic sedges [cor. 54.4]", "Pioneer herbaceous vegetation of alpine watercourses [incl. cod. 7240*]", "Herbaceous riparian vegetation of watercourses [incl. cod. 3220]", and "Woody riparian vegetation of watercourses [incl. cod. 3230 and 3240]".

The methodological approach used has already found many applications in natural areas, especially in marine and coastal areas; however, there are no guidelines for the construction of the pressure factor dataset or the related threat estimate. This method is therefore still under development and demonstrates the need to deepen the study of decision support tools and specific methodologies to support planning in parks and nature reserves and is crucial for effective protected area management [104].

The impact geodatabase was constructed with data from multiple sources, with different temporal coverage, collected and harmonized. Some represent a snapshot of a specific moment in which the data was acquired while others span 20 years (from 2000 to 2020). However, the heterogeneity of the data used does not represent a limit for the analysis thanks to the normalization and harmonization in the grid at 250 × 250 m. On the contrary, gaps in the stressor geodatabase are a common problem affecting cumulative impact analysis both on large [105] and fine scales [15]. In this study, for example, forest cuts or, in general, areas where it was not possible to geolocate impacts, made the starting database non-exhaustive. Thus, although an operational tool for park managers would require further studies, the present work represents a useful preliminary analysis aiming to highlight gaps in both available data and methodological approach.

This study represents a first attempt to map the risks occurring in the park territory for habitat and species. Overall, a cumulative impact analysis can provide valuable insights into the potential effects of multiple stressors on ecosystems. However, it is important to recognize the limitations of this approach and to use caution when interpreting the results of the analysis. One of the key limitations of a cumulative impact analysis is that the interactions between different stressors are often non-additive. This means that the combined effect of two or more stressors is not simply the sum of their individual effects. Instead, the interaction between the stressors may result in a synergistic effect that is greater than the sum of their individual effects. Alternatively, the interaction may result in an antagonistic effect that is less than the sum of their individual effects [15]. Another limitation of a cumulative impact analysis is that the response of vegetation communities to stressors is often non-linear. This means that the magnitude of the stressor and the response of the ecosystem is not necessarily linear. Instead, the response of the ecosystem may be exponential, logarithmic, or exhibit other complex patterns. These non-linear responses can make it difficult to predict the effects of stressors on habitats [15,106]. In a future deeper analysis, these shortcomings should be considered to obtain a more realistic risk map.

In the same way, the vulnerability weights associated with each stressor/habitat combination should be considered in a future improvement of the present study, in which they were assumed to be all equal. These weights are used to reflect the relative vulnerability of different habitats to different threats. However, there is limited knowledge on specific interactions between most stressor/habitat combinations [106], so this point is still tough. Another key challenge is in determining the threshold at which the functionality of an ecosystem is compromised. This threshold will vary depending on the specific ecosystem being studied and the stressors that are impacting it. However, determining this threshold can be challenging, particularly when there is limited information available on the long-term effects of multiple stressors on ecosystems [15].

Finally, one of the significant limitations of a cumulative impact analysis is the challenge of validating the predictions made by the analysis. This is particularly challenging when the analysis is based on complex models that incorporate multiple stressors and non-linear responses. Ground truth data require long-term monitoring of ecosystems to assess the accuracy of the predictions made by the analysis. However, such monitoring can be expensive and time-consuming, making it challenging to validate the results of a cumulative impact analysis [16].

5. Conclusions

The present study, based on a cumulative multi-pressure assessment model generated by anthropogenic attendance, is proposed as a support methodology for decision-makers and planners in the analysis of the current areas at risk of deterioration and can be used to identify management priorities in the study area.

To adapt this method to other study areas, the pressure considered should be selected specifically based on an in-depth knowledge of the territory and of the threats present as well as the availability of the data. However, the weights for threats and vulnerability could be quantified based on an expert evaluation or on the basis of studies conducted on the relationship between specific threat/habitat combinations.

A possible future development of this study is the comparison with the map of impacts and risks obtained with the map of land cover changes that have occurred to highlight any correlations and, subsequently, use the data obtained to refine the vulnerability weights for each stressor/habitat combination, which is also useful for modeling future land cover and habitat change scenarios using software such as InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs) [107] and integrating climate change models not captured by this study. Furthermore, it would be desirable to enrich the datasets of the pressure factors used with threats for which no data were found in this study, such as forest cuts and the distribution of invasive alien plant species.

Finally, spatial threat propagation models based on pressure-factor-specific simulations could be included to refine the model, which was assumed to be linear in this study.

In summary, despite the above uncertainties, this study, the results of which confirm the effectiveness of the park's protection policies, is significant for assessing the ecological risk present in the GPNP based on the cumulative pressure analysis method and can provide valid support for territorial protection and management.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/land12061124/s1, Table S1: Transcoding between the legend of the park cartography and the legend of Land Cover Piemonte 2010. Figure S1: Impacts of geodata mapped in this study.

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