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To cite this article: L. Stendardi, C. Dibari, M. Bassignana, M. Bindi, L. Brilli, P. Choler, E. Cremonese, G. Filippa, A. Piccot & G. Argenti (2022): Pasture areas in the Gran Paradiso National Park, Journal of Maps, DOI: [10.1080/17445647.2022.2120835](https://doi.org/10.1080/17445647.2022.2120835)

To link to this article: <https://doi.org/10.1080/17445647.2022.2120835>



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Pasture areas in the Gran Paradiso National Park

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ABSTRACT

Mountain pastures are essential for maintaining biodiversity and local economies. Despite the great value and fragility of these ecosystems, an up-to-date overview of extent and type of alpine pastures is lacking in many areas of the Alps. In this study, the interpretation of ancillary information combined with expeditious field campaigns, and the harmonization of classification methodologies allowed us to: (1) define the spatial extent of mountain pastures; (2) identify the non-grazeable percentage in these areas; (3) Characterize and map pasture types within the Gran Paradiso National Park (Italy), where 4596 ha of grazeable areas were mapped. Among the 13 categories identified, the three most represented in the park are Bare thermophile grasslands (38%), *Nardus* swards (20%), and Alpine intermediate grasslands (18%). The maps obtained in this study are useful for animal management during the grazing season, and have the capability of geographically assessing potential forage availability through modeling and remote sensing data.

ARTICLE HISTORY

Received 27 February 2022
Revised 26 August 2022
Accepted 30 August 2022

KEYWORDS

Mountain pastures;
mapping; classification;
pasture types; grassland;
Alps

1. Introduction

Mountain pastures are complex semi-natural systems located in the subalpine and alpine belts, displaying a wide variety of sizes, shapes, and elevational zones (Nettier et al., 2017; Peringer et al., 2013). They are also among the richest mountain ecosystems in terms of species thanks to extensive human management (animal grazing) over the centuries (Kampmann et al., 2008; Nicod et al., 2019) and climatic gradient (Kikvidze et al., 2011; Moser et al., 2005). In all major mountains of Europe, livestock farming systems rely on high-elevation grasslands to feed the herds. Ordinarily, animal grazing is performed during the summer season, linking lowland and mountain agroecosystems (Herzog et al., 2005; Herzog & Seidl, 2018). Furthermore, besides contributing to biodiversity conservation and fodder provision for domestic and wild herbivores (Dumont et al., 2007), pastoral resources help in maintaining the cultural value of the typical mountain landscape (Peringer et al., 2013). Moreover, whenever integrated in a sustainable development strategy, pastures may represent a boost for local economy and tourism (Lamarque et al., 2011). However, mountain pastures are acknowledged as very vulnerable to both climate and land use changes especially in the Alps (Craine et al., 2011; Dibari et al., 2020; Oliver et al., 2015). Therefore, the identification of appropriate approaches/methods to

obtain reliable up-to-date mapping and vegetation classification of alpine pasture resource has become increasingly important.

The classification and mapping of pasture areas has several limitations. Data collected in the field are the most valuable for classifying grassland types (Peel & Green, 1984). However, these types of surveys over large areas are often very expensive and time consuming. For instance, linear floristic surveys, such as those proposed by Daget and Poissonet (1971), are costly and difficult to obtain on a large scale.

A complementary approach is offered by remote sensing (Boschetti et al., 2007; Schino et al., 2003; Tuellet, 1989) that can produce useful information not only for grassland characterization but also for their rational management (Ali et al., 2016). For example, a high resolution (10 meters) map of grasslands at the European level has been made available by the Copernicus programme (HRL). Although remote sensing may produce maps with a high estimation accuracy (Cingolani et al., 2003; Crabbe et al., 2020), the validation – also called ‘accuracy assessment’ – is often affected by the limited availability of ground truth data (Xie et al., 2008). Moreover, in a mountain environment where pastures are often fragmented, the spatial resolution of satellite sensors can lead to mixed pixels, which in turn results in biased classification estimates (Cingolani et al., 2003; Lu & Weng,

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Supplemental map for this article is available online at <https://doi.org/10.1080/17445647.2022.2120835>.

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2007). Obtaining a method that allows the concurrent exploitation of available maps, remotely sensed data and field data is therefore a promising alternative to deliver a very accurate product on a large scale basis and at reasonable costs (Dibari et al., 2016). Furthermore, though the use of a universal pasture classification methodology would be preferable, it is often hard to implement it due to the local peculiarities. A harmonization and integration phase of different methodologies is therefore crucial in order to compare and analyse pasture systems over wide territories (De Càceres & Wiser, 2012; Mucina, 1997).

This study focuses on the mountain pastures of the Gran Paradiso National Park (GPNP), located in the Italian Western Alps. The pastoral data available at this relevant alpine protected area represent a flagship example of the above-mentioned limitations of alpine pastures information systems currently available at local, regional, national, and alpine scales: (i) available GPNP grassland classification studies are limited to few select areas (Bornard et al., 2006; Cavallero et al., 2007); (ii) each of these studies applies a different methodology in the classification legend adopted. Thus, having an accurate, harmonized, and updated map based on a single classification system is therefore pivotal for the monitoring of mountain pastures in these vulnerable areas and to program their rational and sustainable management over large territories (Dibari et al., 2016).

Here, we developed grassland maps by combining ancillary data (e.g. habitat maps, orthophotos visual interpretation) with data collected in the field without phytosociological surveys, during the 2018 and 2019 summer seasons and by using a harmonized classification method. The main objective of this investigation is to derive a methodological framework to create an up-to-date pasture map of the GPNP, at a reasonable cost, through an expeditious field survey method not based on linear floristic investigation, with the aim of developing a solid and comprehensive knowledge base to support the development of pasture management plans over a large area (8022 ha in total), and in particular, to:

- (1) Identify the actual extent area of pastureland and the amount of grazeable/ungrazeable areas using a method that incorporates both ancillary data and field data;
- (2) Classify the pastures according to the dominant vegetation types under a harmonized classification approach in order to assess the pastoral value of the grazed areas.

2. Materials and methods

2.1. Study area

Gran Paradiso National Park (GPNP) lies between 45°25' and 45°45'N and between 7° and 7°30'W in

the Western Italian Alps (Figure 1), covering two administrative Italian regions: Aosta Valley and Piedmont. The total surface is 71,044 ha, with elevations ranging from 800 m to 4061 m a.s.l. at the Gran Paradiso peak. The park has a varied morphology characterized by high elevations and narrow valleys and grasslands with an average elevation around 2000m a.s.l. Though the climate of area is typical alpine, the morphology determines highly heterogeneous micro climatic conditions caused by steep morphological gradients and highly variable slopes and aspects. This, together with the range of elevations and different lithological conformations, split between acid gneisses in the east and limestone schists in the west (Tiberti et al., 2010), results in a great richness of plant species and relevant habitats (Baumann et al., 2016; Hoffmann et al., 2019). Pastures, which are situated between forests, shrublands, debris, bedrock and glaciers, are characterized by a highly fragmented surface (Ranghetti et al., 2016). Particularly in the Piedmont part of the GPNP, summer transhumance has seen a progressive decline, causing a reduction in the extent of pastures (Fleury et al., 2001), resulting in the invasion of pasture areas by shrubs and loss of biodiversity (Cavallero et al., 1997).

2.2. Methodology and data sets

The outline of the work is described in Figure 2, while the list of the ancillary data and remote sensing data used in our project is described in Table 1.

Habitat Map, produced by interpreting aerial photographs and other supporting cartography (geological map, map of forest types) at a scale of 1:10,000 with in-depth studies also at a larger scale, therefore not by means of vegetation surveys carried out in the field. Starting from this simplified cartography, photo-interpretation was used to confirm the polygons and add or remove any herbaceous areas that differed from the Habitat Map. Subsequently, for each polygon, the homogeneous surfaces were identified based on differences perceptible from orthophotos visual interpretation (color and density of the plot, presence, and nature of extraneous elements such as rocks and boulders, shrubs and trees, etc.) and eventually an initial estimate of the non-grazeable areas was made. The classes shown in Table 2 were selected to qualify the non-grazeable areas. All the grasslands that could potentially be reached and grazed by domestic herbivores were considered as 'Net pasture area'. In addition, areas located in steep surfaces were masked out, as well as areas that could not be reached by animals due to natural constraints. The fieldwork was carried out during the summers 2018 and 2019, verifying the presence/absence of pasture abscribing the relative percentage of non-grazeable areas and identifying the pasture types in the

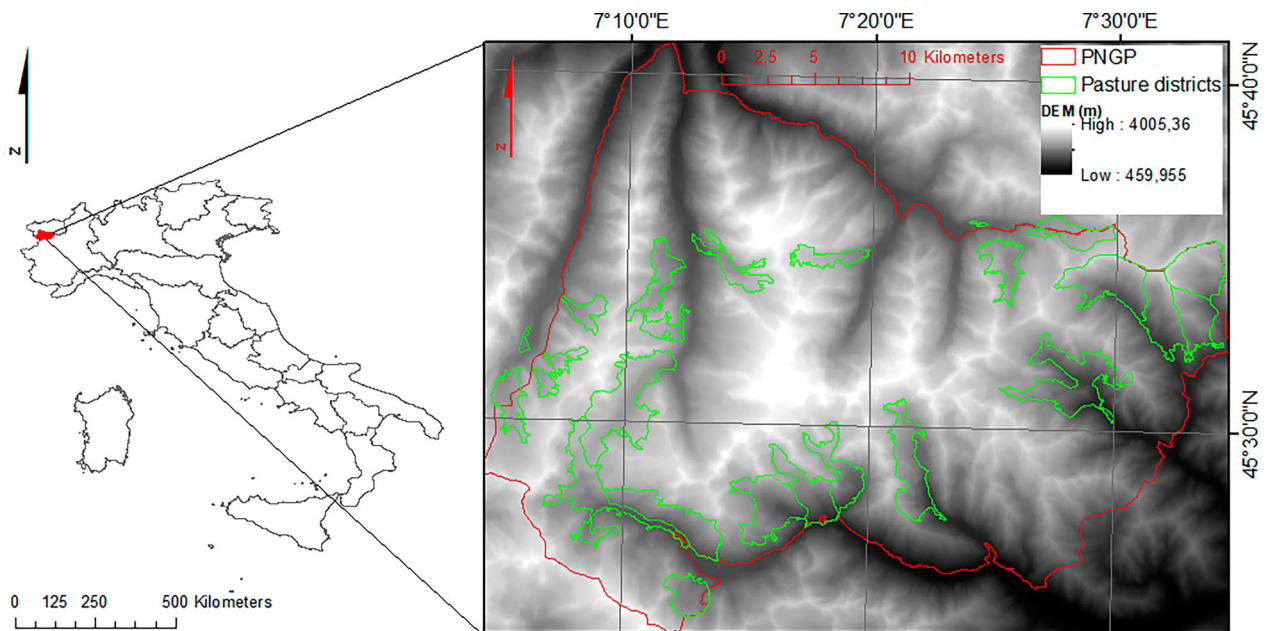


Figure 1. Digital Elevation Model map of Gran Paradiso National Park with pastoral districts defined for fieldwork (in green).

field through a visual assessment. This is an undoubtedly more expeditious method than the linear floristic survey proposed by [Daget and Poissonet \(1971\)](#), which could not be applicable, effectively and at a reasonable cost, on such large areas. The areas were inspected and the precise pasture type was identified and assigned to each polygon, based on the alpine pasture typologies proposed by [Bornard et al. \(2006\)](#) for Aosta Valley and by [Cavallero et al. \(2007\)](#) for Piedmont. Where two categories coexisted within one single polygon and could not be distinguished, their relative coverage (as percentage) within the area was recorded.

With the aim of harmonizing the different typologies, then, the 22 pastoral types of the classification by [Bornard et al. \(2006\)](#) and the 92 types of that of [Cavallero et al. \(2007\)](#) were grouped into 13 common categories, defined as a result of similarities in the floristic composition. The field campaign was carried out by six technicians expert in pasture classification, dividing the study area into 23 pasture districts ([Figure 1](#)) to simplify the planning of field work. To achieve a consistent mapping, pasture outside the park but in continuity with park's grasslands were also included. Auxiliary and support tools, both electronic (tablets,

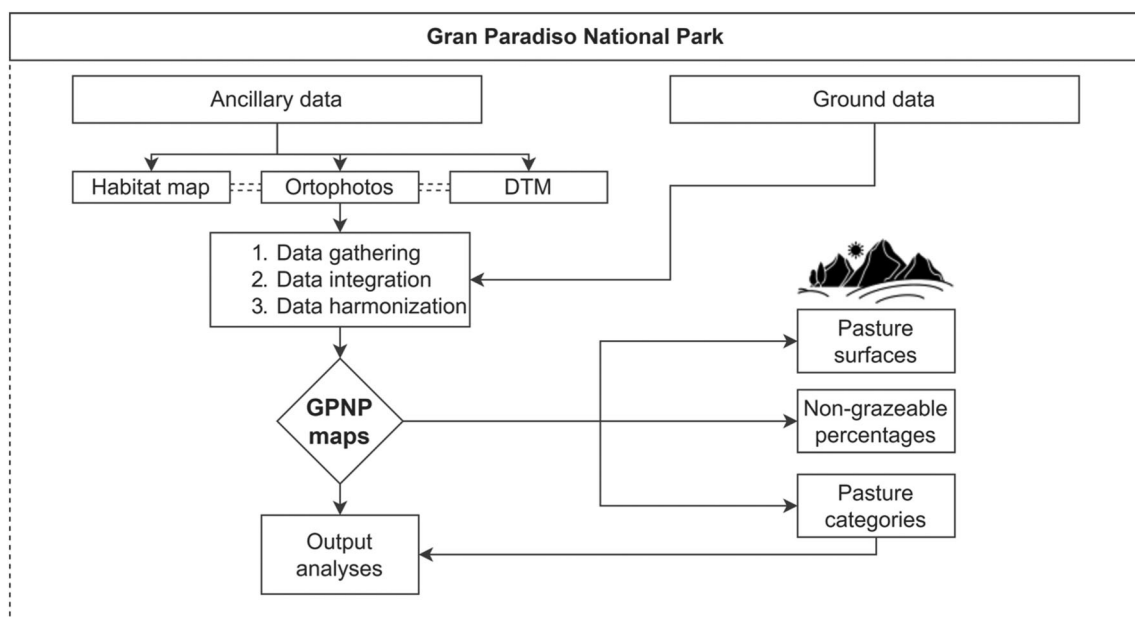


Figure 2. Diagram of the proposed framework that involves the simultaneous use of pre-existing data and data collected in the field to develop, after a phase of integration and harmonization, grazing maps of the GNP.

Table 1. Ancillary data used in this work.

Data	Year	Resolution (m)	Approx. Error (m)	Area	Source
Orthophoto	2009–2011	5	±0.30	Piedmont	Regione Piemonte – A1613B – Sistema informativo territoriale e ambientale – Metadata
Digital Terrain Model (DTM)	2009–2011	5	±0.30	Piedmont	Regione Piemonte – A1613B – Sistema informativo territoriale e ambientale – Metadata
Territorial Reference Database of \\\ Piedmontese Autorit�e (BDTRE)	2018	5	±1	Piedmont	Regione Piemonte – A1613B – Sistema informativo territoriale e ambientale – Metadata
Orthophoto	2012	0.2	±0.10	Aosta Valley	Sistema delle conoscenze territoriali – Regione Valle d’Aosta – Metadata
Infrared Orthophoto	2012	0.2	±0.10	Aosta Valley	Sistema delle conoscenze territoriali – Regione Valle d’Aosta – Metadata
Digital Terrain model (DTM)	2008	10	±0.50	Aosta Valley	Sistema delle conoscenze territoriali – Regione Valle d’Aosta – Metadata
Regional Technical Map (CTRN)	2003	2.5	±1	Aosta Valley	Sistema delle conoscenze territoriali – Regione Valle d’Aosta – Metadata
Habitat map	2005	5	±1	Total area	Sistema delle conoscenze territoriali – Regione Valle d’Aosta – Metadata
Orthophoto	2012	0.5	±0.10	Total area	Geoportale Nazionale
GDD	2004–2019	20	±2	Total area	Calculated from temperature maps (Silvestro et al., 2013; Silvestro et al., 2015) combined with snowmelt maps (Gascoin et al., 2019)
DAH		20	±1	Total area	Calculated from dem with SAGA-GIS (B�hner & Antoni�, 2009)
DEM		30	±2	Total area	From the Shuttle Radar Topography Mission (native spatial resolution 30 m (Farr et al., 2007))

handheld GPS, mobile phones) and paper-based (maps), were used in the field.

To allow an analysis of the value of these categories in terms of grazing supply, the Potential Stocking Rate (PSR) of each category was derived from the Pastoral Value (PV), a parameter that is calculated from botanical composition and that is directly linked to forage value of pasture vegetation and to its potential stocking rate (Argenti & Lombardi, 2012). In this way, the PSR is expressed in terms of $LU \cdot d \cdot ha^{-1}$, i.e. the number of Livestock Units (equivalent to an adult dairy cow) that can be maintained on a hectare of pasture for a given number of days of grazing (Bornard et al., 2006).

Through the complementary use of ancillary data analyses and information obtained from the outdoor interpretation, three products were developed:

- (1) a map of the presence/absence of grassland (Map 1)
- (2) a map with the percentages of non-grazeable areas (Map 2)
- (3) a map with the 13 pasture categories (Map 3)

Finally, we examined the distribution of elevation (DEM), Diurnal Anisotropic Heating (DAH) and Growing Degree Days (GDD). The DAH represents an approximation of the radiative heating potential of a given pixel based on its slope and aspect (B hner

& Antoni , 2009) while the GDD is calculated on air temperature $>0^{\circ}C$ cumulated from snow melt date until day of the year 270, a late fall date when temperature is expected to no longer affect plant development (Choler et al., 2021). Analysis was performed for each of the 13 pastoral categories (Map 3 in Figure 3) together with testing of significant differences between pastures using a partition of variance and a Tukeys Honest Significant Difference (Tukeys HSD) post-hoc test. This was performed by randomly selecting homogeneous pixels subsets (i.e. 1000 pixels from each category) from the categories with a percentage of presence above 1%, for a total of 8 categories.

3. Results

In PNGP, 8022 ha of pastures were identified; 4596 ha were classified as ‘net grazing’ area (the area actually grazeable by animals).

Total pasture areas are displayed in Map 1 of Figure 3; Map 2 in Figure 3 shows the percentage of non-grazeable areas within each polygon while Map 3 in Figure 3 illustrates the 13 grazing categories identified. Table 3 gives the correspondences between the two vegetation typologies based on the literature and the 13 pasture categories defined in our study. Each category is associated with an alphanumeric code. In addition, the categories are briefly described, providing the indicator species and the Potential Stocking Rate. We found that (see Table 4): only 21% of pastures are represented by herbaceous and open areas utilized for domestic grazing. Most grasslands have non-grazeable surfaces ranging from 20% to 50% of their total area. As for the pasture categories, shown in Figure 4, the three most represented in the GPNP

Table 2. Non-grazeable classes adopted.

Percentage of the grass cover	Applied class of Non-grazeable
Between 95% and 100%	0%
Between 80% and 95%	20%
Between 50% and 80%	50%
Between 50% and 20%	80%
Less than 20%	100%

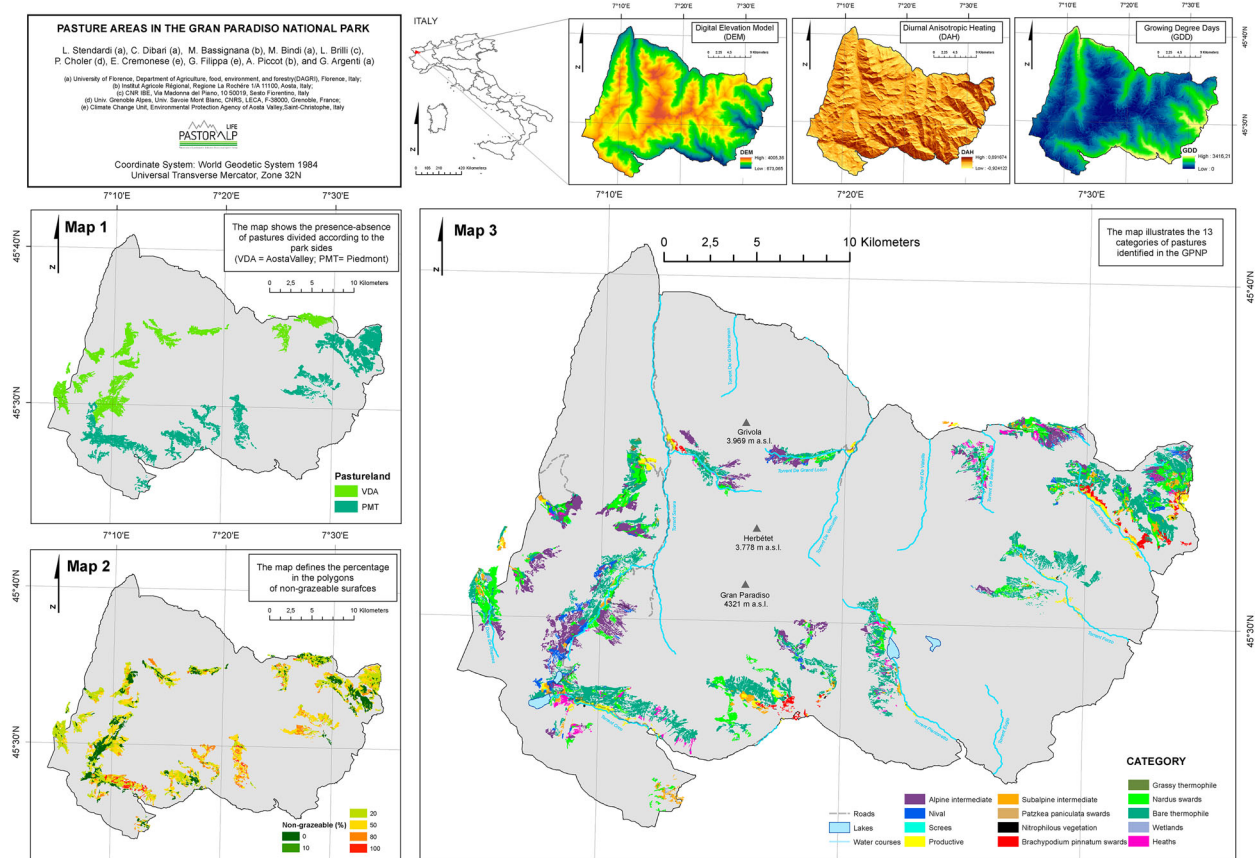


Figure 3. Map 1 shows the sence-absence of pastures divided according to the park sides (VDA = Aosta Valley; PMT = Piedmont), Map 2 defines the percentage in the polygons of non-grazeable areas, Map 3 illustrates the 13 categories of pastures identified in the GPNP (for the de-codification of categories, refer to Table 3).

are Bare thermophile (SA-III) grasslands (38%), *Nardus* swards (SA-II) (20%) and Alpine intermediate (A-I) grasslands (18%). The Subalpine intermediate (S-II), Productive (S-I), Nival (A-II) grasslands, *Brachypodium pinnatum* swards (S-V) and Heaths (SAV) have percentages ranging approximately from 1.5 to 6%. The remaining categories are all below 1%. The grasslands dominated by *Festuca luedii* (SA-III) constitute about 26% of all the mountain pastures studied.

Graphs (a), (b), and (c) in Figure 5 show the box-plots of DEM, DAH, GDD values for each category, with the letters obtained from the Tukey's HSD (Honest Significant Difference) after modeling an ANOVA permutation in which the categories are indicated. As for the top plot, that deals with the elevation of pastoral category, not surprisingly, in both regions, Alpine intermediate (A-I), Scree (A-III) and Nival (A-II) categories were found to be most prevalent at higher elevations (Figure 5(a)), while at lower elevations *Brachypodium pinnatum* swards (S-V), and Productive (S-I) categories are dominant. The other categories follow a similar gradient on both sides of the Park, and are located at higher altitudes on the Aosta Valley side. The absence or nearly, of the *Patzkea paniculata* swards (S-III) in the two regions should be noted.

Based on Tukey's HSD we have no significant difference between Alpine intermediate (A-I) and Nival (A-II) category in the Aosta valley region, while in Piedmont region both *Nardus* swards (SA-II) – Bare thermophile (SA-III), and *Brachypodium pinnatum* swards (S-V) – Productive swards (S-I) share a similar elevation range.

As for the values taken from the DAH layer, in Figure 5(b), the highest values are represented by the category *Brachypodium pinnatum* swards (S-V) and Grassy thermophile (SA-I). The lowest values are instead the categories Heaths (SA-V), Nival (A-II) and Scree (A-III); *Patzkea paniculata* swards (S-III) for the Aosta Valley side of the park. Here the Tukey's HSD test found a similarity between Productive (SI), Subalpine Intermediate (S-II) and Alpine intermediate (A-I), as well as between Nival (A-II) and *Nardus* swards (SA-II), which also shares similar DAH ranges with the previous group. Even in Piedmont region, Alpine intermediate (A-I), Productive (S-I), Subalpine Intermediate (S-II) are not statistically different; the latter two also share with Productive (S-I) similar DAH values.

Graph (c) in Figure 5 represents the Growing Degree Days in each category: on both administrative regions of the park, *Brachypodium pinnatum* swards (S-V) resulted the highest values, followed by the Productive swards ones (S-I). In contrast, the Alpine

Table 3. Table of the 13 pasture categories.

Altitudinal zone	Category code	Category Name	Aosta Valley types (Bornard et al., 2006)	Piedmont types (Cavallero et al., 2007)	Description	Indicator species	Potential Stocking Rate (LSU*d/ha)
Subalpine belt	S-I	Productive	S3	8, 56, 57, 59	Very tall (over 50 cm) and dense vegetation in rich soil	<i>Dactylis glomerata</i> , <i>Trisetaria flavescens</i> , <i>Bromopsis erectus</i> , <i>Poa pratensis</i>	85–130
	S-II	Subalpine intermediate	S2	52, 53, 54, 60, 64	30–50 cm high, dense grassy patches in medium-rich soil	<i>Festuca gr. rubra</i> , <i>Agrostis capillaris</i> , <i>Phleum alpinum</i> , <i>Alchemilla xanthochlora</i>	55–105
	S-III	Patzkea paniculata swards	S6	26	Very tall (over 50 cm), very dense vegetation dominated by <i>Patzkea paniculata</i>	<i>Patzkea paniculata</i> , <i>Festuca gr. rubra</i> , <i>Carex sempervirens</i>	30–45
	S-IV	Nitrophile vegetation		67, 69	Herbaceous formations dominated by nitrophilous species	<i>Rumex alpinus</i> , <i>Blitum bonus-henricus</i>	15–55
	S-V	Brachypodium pinnatum swards	S5	3, 25	Medium height (20–30 cm), dense vegetation, dominated by <i>Brachypodium pinnatum</i>	<i>Brachypodium pinnatum</i> , <i>Carex sempervirens</i> , <i>Festuca ovina</i>	25–35
Subalpine and Alpine belt	SA-I	Grassy thermophile	S4, A3	11, 40	30–50 cm high, very dense vegetation on sunny slopes	<i>Helictotrichon parlatorei</i> , <i>Onobrychis montana</i>	10–80
	SA-II	Nardus swards	S1, A8	29, 30, 32, 41, 47, 48, 49, 61	Medium height (20–30 cm), dominated by <i>Nardus stricta</i>	<i>Nardus stricta</i> , <i>Carex sempervirens</i> , <i>Festuca gr. rubra</i> , <i>Trifolium alpinum</i>	20–45
	SA-III	Bare thermophile	SA1, SA2, SA3, A1, A2	13, 17, 19, 24, 46, 50	Vegetation in medium-steep south-facing slopes	<i>Festuca luedii</i> , <i>Festuca violacea</i> , <i>Sesleria caerulea</i> , <i>Festuca ovina</i>	5–40
	SA-IV	Wetlands	ZH	81, 86	Very wet areas with temporary or permanent excess of water	<i>Eriophorum</i> spp., <i>Ranunculus aconitifolius</i> , <i>Caltha palustris</i> , <i>Carex nigra</i>	0–35
	SA-V	Heaths	L1, L2, L3	90, 91, 92	Vegetation with a shrub and herb layer	<i>Rhododendron ferrugineum</i> , <i>Vaccinium uliginosum</i> , <i>Arctostaphylos uva-ursi</i> , <i>Juniperus communis</i> , <i>Kalmia procumbens</i>	0–15
Alpine belt	A-I	Alpine intermediate	A4, A5,	21, 22, 33, 35, 36, 37	Sparse vegetation in the alpine belt	<i>Carex curvula</i> , <i>Carex myosuroides</i> , <i>Festuca halleri</i> , <i>Trifolium alpinum</i>	5–25
	A-II	Nival	A9, A10	72, 74, 75, 76, 77, 79	Sparse vegetation in the alpine and nival belt	<i>Alopecurus alpinus</i> , <i>Alchemilla pentaphyllea</i> , <i>Salix herbacea</i> , <i>Plantago alpina</i>	0–30
	A-III	Scree	E	70	Areas with more than 50% of the surface occupied by stones and rocks	<i>Dryas octopetala</i> , <i>Achillea nana</i> , <i>Salix retusa</i> , <i>S. reticulata</i> , <i>S. serpyllifolia</i>	0–5

Note: For each category, the correspondences of pasture types between vegetation typologies, the description, the main species and the Potential Stocking Rate are indicated. The alphanumeric code used for each category was defined according to: (1) Altitudinal belt: subalpine (S), subalpine and alpine (SA) and alpine (A); (2) Potential stocking rate: in descending order for each altitudinal belt. Therefore, the first letter gives an indication of the elevation level, while the number follows the productivity order.

intermediate (A-I), Scree (A-III) and Nival (A-II) categories feature the lowest number in terms of GDD. In the Aosta Valley Bare thermophile (SA-III), Wetlands (SA-IV), Nardus swards (SA-II), and Heaths (SA-V) have GDD values below 1000, while they are always above 1000 on the Piedmont side. Grassy thermophile

(SA-I) and Subalpine intermediate (S-II) swards have similar values on both sides, though with different dynamic ranges. On the contrary, the Nitrophile vegetation (S-IV) shows a difference in GDD between Piedmont and Aosta Valley, with reduced values in the latter one. In terms of the analysis of variance, on both sides of the park, there are no categories that share the same number of GDDs all exhibiting statistical differences.

Table 4. Gross surface in hectares and percentage of GPNP grasslands divided by non-grazeable classes.

Non-grazeable class	Gross Area (ha)	Gross Area (%)
0%	1552.82	19.36
20%	2152.42	26.83
50%	2385.95	29.74
80%	623.94	7.78
100%	1306.98	16.29

4. Discussion

Rural depopulation and reduction in livestock farming levels is one of the main drivers of changes in alpine

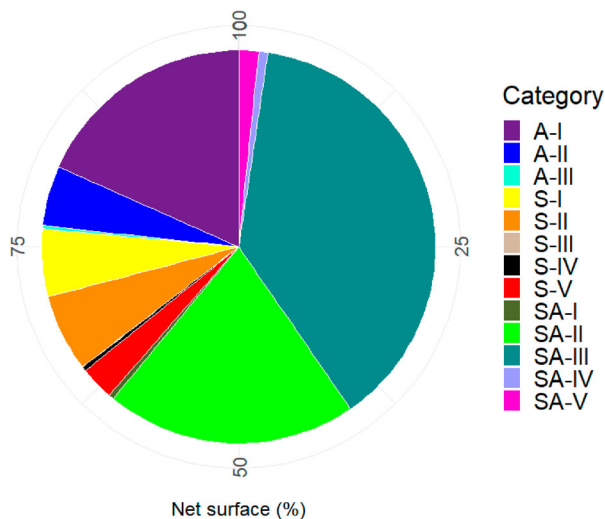


Figure 4. Contribution (%) of each pasture category to the net grazeable surface of the GPNP (for the de-codification of categories, refer to Table 3).

grassland ecosystem function and dynamics (Dirnböck et al., 2003) as occurring in a large part of European mountain areas (Lasanta et al., 2017; Probo et al., 2016). Thus providing an up-to-date mapping of pastures, such as the one presented in our study, allows not only to have an assessment of the presence of pastures, but also to obtain a solid basis to monitor changes affecting these ecosystems and, in turn, support grazing management along the season. This proves to be of critical importance as also highlighted by Malfasi and Cannone (2021).

Furthermore, by obtaining the total extension of the pasture areas, our study enabled the determination of the area actually grazeable by the animals (net surface). Below the treeline, undergrazing or pasture abandonment lead to natural encroachment processes that gradually convert subalpine pastures into shrublands and finally into forests (Laiolo et al., 2004).

To this end, our product, Map 2, is innovative and multi-functional. On one hand, it allows to establish the potential grazeable areas, and on the other hand, it could be effectively applied for the validation of satellite classification products, and used also for predicting changes under future climate scenarios, when coupled with modeling approaches.

Promoting methodological standardization in the classification of vegetation is of primary importance (De Cáceres et al., 2015; De Cáceres & Wiser, 2012; Giupponi & Leoni, 2020). The classification of grassland plant communities through their attribution to a set of vegetation types is an approach aimed at speeding up the fieldwork, which allows large areas of mountain meadows and pastures to be mapped more rapidly. In several cases, the classification key to determining vegetation types is based on a combination of orographic and physiognomic characters,

which reduce the need for the operator to possess in-depth botanical skills (Bassignana et al., 2004). Essentially, the typologies of permanent grasslands are conceived as operational tools, in the context of what we could define as a ‘technology transfer’ to the extension services and agricultural technicians operating in mountain areas, to evaluate the feeding potential and sustainable animal stocking rate on pasture areas. In this sense, they differ from purely botanical and phytosociological classifications such as, for instance, that of Rodwell (1998). This approach had an intense development in various areas of the Alps, especially between the years 1990 and 2000 (Argenti & Lombardi, 2012; Bornard et al., 2006; Cavallero et al., 2007; Joulet, 1999; Ziliotto, 2004). In several cases, the classification of the main pastoral types was associated with their mapping on the territory of the respective area of validity (Cavallero et al., 2007; Ziliotto et al., 2004). In other cases, however, this step was not made, or only partially. The composition of permanent grassland plant communities depends mainly on the characteristics of the physical environment associated with those of pastoral use (Bornard et al., 2004). Therefore, it cannot be excluded that the types may change over time, for example because of changes in the climatic context or pastoral practices or even, in some cases, for the spread of invasive alien species (Viciani et al., 2020). However, the dynamics of change in the composition of plant communities can be considered rather slow (Brau-Noguè, 1996) and we assume that the use in the field of a typology several years after its conception is, in itself, a further validation of its effectiveness. Therefore, even though we recognize limitations in our study related to the use of ancillary data, the sampling campaign allowed us to verify and possibly update information directly in the field.

Based on this type of expeditious classification, we developed a harmonized pasture classification method to be adopted across the entire Gran Paradiso National Park, which was taken as a case study.

Our results (Map 3) allowed us to highlight the most three abundant categories in the park (about 75% of the total grassland). The thermophile grasslands (SA-III) dominated by *Festuca luedii* represent about a quarter of the surveyed pastureland. This species is typical of xero-thermal patchy pastures on south-facing slopes (Wallossek, 1999) and offers a low-quality forage to domestic herbivores (Ziliotto et al., 2004). However, in winter it is a fodder resource for alpine ungulates, such as chamois (La Morgia & Bassano, 2009). This category is located in the Aosta Valley side above 2300 m a.s.l. with an average of approximately 800 GDD and a DAH slightly above 0. On the other hand, in the Piedmont area, we found the category at lower elevations, with DAH higher than 0.25 and more than 1000 GDD.

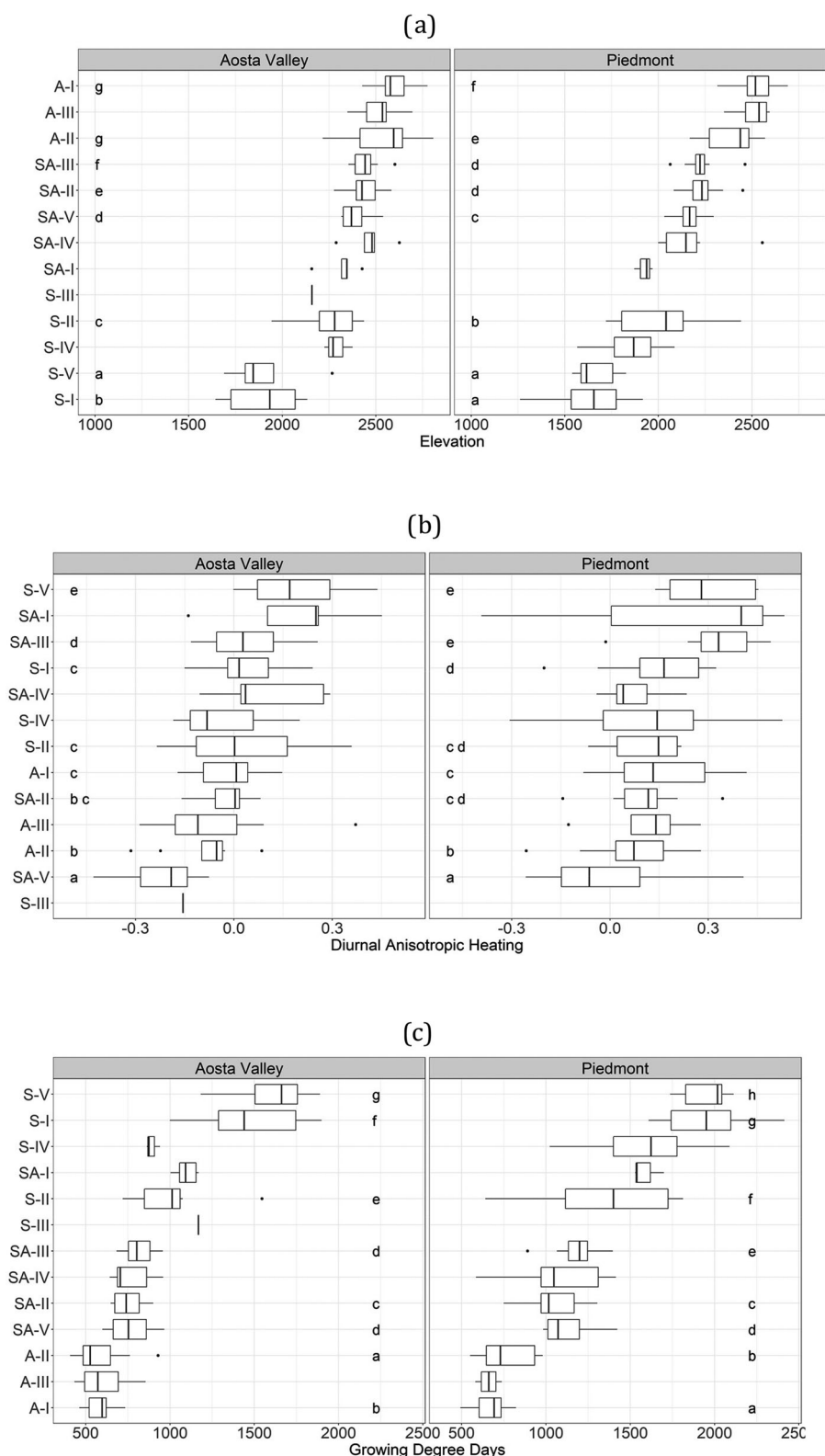


Figure 5. Boxplot graphs of extracted values for each category based on DEM, DAH and GDD layers. Tukey HSD (honest significant difference) graphs derived from one-way ANOVA test applied to pasture categories for different information layers. The IDs of the grazing categories are shown on the y-axis and can be viewed in the [Table 3](#). On the x-axes are the values for DEM, DAH, and GDD. Next to the boxplots of the 8 selected categories are letters derived from Tukey's HSD test. Boxplots sharing the same letter are not statistically different.

Furthermore, a highly represented category in the park is the *Nardus* swards (SA-II), which in accordance with ([Kurtogullari et al., 2020](#)), is found at high elevations (around 2300 m a.s.l. on both sides). Its abundance is determined by acidification and soil

nutrient impoverishment, associated with selective grazing, as livestock prefer to feed on grass with a higher nutrient content avoiding unpalatable grass, such as matgrass ([Parolo et al., 2011](#)). Also this category results to have higher GDD requirements on

the Piedmont side. The third most common category, Alpine intermediate (A-I), is located above 2500 m a.s.l. on average and with GDD always below 1000. The plant communities belonging to this category, are mostly dominated by *Festuca halleri*, *Carex curvula*, and *C. myosuroides* species which are most commonly found on siliceous substrate (Puşcaş et al., 2008). Although its elevation range varies from 2000 to 3000 m a.s.l. on wind-swept scree and snow-rich slopes (Wallossek, 1999), in the GPNP this category is limited to high elevations and with a rather narrow range.

From the analysis of variance, we showed that there are statistically significant similarities between the categories in both elevation and diurnal anisotropic heating values. Nevertheless, the results are very different in the two sides of the park. This could highlight the complex nature of the distribution of pastoral categories, which is not only driven by morphological or climatic factors but also it is the result of the interplay between multiple factors such as grazing stock and livestock species (Meisser et al., 2014; Probo et al., 2014), soil type (Ferrè et al., 2020), and microbial communities (Praeg et al., 2020). On the other hand, the analysis of the growing degree days shows that, both in Aosta Valley and in Piedmont, each category has peculiar values, not statistically related.

Finally, our analysis showed that most pastures in the GPNP have low agronomic value, determined by the presence of species with medium to low Potential Stocking Rate values. This should be taken into account as determining management strategies for grazing cattle.

In conclusion, with our study, we were able to produce up-to-date maps of the GPNP pastures. The presented method proved to be expeditious and cost-effective, significantly reducing the time spent in the field and allowing to map on large scales. In addition, this work is of critical importance for the calibration and validation of products derived from remote sensing data, as highlighted in the study carried out by Filippa et al. (2022). The advantageous aspects of our study are based on two key points: first, the possibility of employing well-trained experts to carry out the field work; second, the possibility of using classifications of the park's grasslands found in the literature as a basis for our harmonization process.

5. Conclusion

The monitoring of mountain pastures is a key factor in revealing the changes affecting these ecosystems, in understanding their dynamics and in conceiving appropriate responses to these challenges. The maps we produced in this study show the distribution of pasture types in the Gran Paradiso National Park, their net grazeable areas and the percentage of non-

grazeable areas. In addition to pasture management purposes, this characterization allows to obtain information on the ecological characteristics of plant communities, evaluating the relationships between environment and management. Furthermore, these data have a great exploitation potential from a remote sensing point of view. Future work could use our maps in classification and validation of satellite products (e.g. comparison with the Copernicus Grassland product). Moreover, future studies should consider additional aspects to develop an integrated analysis of the variance of the category. Finally, in order to apply the working methods to other study areas, it is recommended to take into account the training of personnel for field surveys and the presence of pasture classifications in the literature as a baseline.

Software

In the field, QField GNU Public License (GPL) Version 2 was used on a tablet media. The pasture types map was created using the open-source software QGIS. The map layout was carried out with ESRI ArcGIS 10.8.1 while R-4.1.0 was used for map analysis.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This work was supported by the LIFE PASTORALP project "Pastures vulnerability and adaptation strategies to climate change impacts in the Alps" (LIFE16 CCA/IT/000060), co-funded by the European Union's LIFE Programme, Climate change adaptation action sub-programme. <https://www.pastoralp.eu/home/>.

Data availability statement (DAS)

The material presented in this article is freely available on request by contacting the corresponding author.

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