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Map of livestock density in Central Apennines: a standardised protocol

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DATA PAPER

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Abstract

Effective ecosystem management requires a deep understanding of how human activities, such as livestock farming, impact ecological dynamics. Livestock farming influences vegetation structure, nutrient cycling, and wildlife behaviour, yet there are limited standardised methods for estimating livestock grazing pressure on a local scale. Here we developed a standardised protocol for mapping livestock density at cadastral sheet resolution, and we tested it in a mid-mountain area of Central Apennines, Italy. The protocol combines municipal grazing data related to seasonal high-altitude pasture with interviews and geospatial mapping to create fine-scale livestock distribution maps. We focused on different livestock species and we produced a separate map for each: cattle, sheep, goats, and horses. Our protocol addressed a critical gap in conservation research by providing a robust framework for quantifying grazing pressure. These data are crucial for understanding livestock-wildlife interactions and informing ecosystem management strategies on local territory.

Introduction

The sustainable management of ecosystems requires a comprehensive understanding of the different elements and processes that interact within a territory, particularly the relationship between human activities and ecological dynamics. Livestock farming, one of the main anthropogenic activities impacting terrestrial ecosystems, plays a significant role in altering nutrient cycles, leading often to biodiversity loss, habitat degradation, and soil erosion (Gordon 2018). Livestock farming significantly influences vegetation structure, primary productivity, and overall ecosystem services (Li et al. 2021). Livestock presence can have negative influence on wildlife behaviour, with cascading effects on biodiversity (Briske et al. 2011). For instance, the conversion of land for grazing reduces the availability of native vegetation, which impacts wild herbivores and small mammals by limiting their food resources and protective cover (Foley et al. 2005, Schieltz and Rubenstein 2016). Moreover, the increased overlap between livestock and wildlife due to habitat fragmentation enhances the risk of predation, competition, and pathogen transmission (Ekernas et al. 2017, Jori et al. 2021). Grazing is characterised by a variety of factors such as timing, frequency, duration, season, and intensity (Briske et al. 2011, Schieltz and Rubenstein 2016). The intensity of grazing, defined as the amount of grazing per unit of primary productivity (Bouwman et al. 2005, Haberl et al. 2007, Petz et al. 2014), is the most crucial factor influencing changes in ecosystems (Schieltz & Rubenstein, 2016). While grazing generally reduces vegetation quantity, in some cases it can improve plant quality by stimulating regrowth, benefiting certain herbivore species through a facilitation process (Fraser et al. 2014, Schieltz and Rubenstein 2016).

Intensively managed grasslands and arable lands for livestock feed generally support low biodiversity (Newbold et al. 2015), while extensive grazing helps maintaining landscapes diversity by preventing shrub encroachment and reforestation (Rook and Tallowin 2003). Together with traditional agriculture, extensive grazing is essential for preserving many Europe's semi-natural habitats, which have been shaped over millennia and host many threatened species (Halada et al. 2011, Malek et al. 2024b). Due to their low carrying capacities in terms of climatic, soil and terrain conditions, semi-natural habitats often suffer from overgrazing, which leads to an alteration of vegetation states (Kosmas et al. 2016, Pulido et al. 2018, Sartorello et al. 2020). At the same time, many European semi-natural habitats have declined over the past 50 years due to land abandonment, making them some of the most threatened ecosystems (Falcucci et al. 2007, IPBES 2018, EEA 2020, Quaranta et al. 2020). While in fact land abandonment initially has beneficial effects on biodiversity for up to 30 years, then this positive effect decline over the years, due to forest encroachment and a consequent reduction in species richness, particularly in mountainous areas (MacDonald et al. 2000, Plieninger et al. 2014, Sartorello et al. 2020).

In Italy, less productive and mountain areas have undergone extensive land abandonment, especially in the Alps and Apennines (Mazzoleni et al. 2004, Chauchard et al. 2007, Primi et al. 2024). In central Italian Apennines, grazing pastures and marginal meadows contribute to the preservation of open habitats. Without grazing, these areas are encroached upon by shrubs and woodlands, reducing landscape heterogeneity (Falcucci et al. 2007, Ponzetta et al. 2010). Here, the shift from open habitats to woodlands has significant ecological impacts, including a decrease in biodiversity, especially for species that rely on ecotonal and transitional zones (Argenti et al. 2000, Silver et al. 2000). Among these, there are species such as roe deer, or passerines which occur on traditional farming and pastoral systems (e.g., rock sparrow (*Petronia petronia*), ortolan bunting (*Emberiza hortulana*), red-backed shrike (*Lanius collurio*)) (Caballero et al. 2009). Conversely, the increase in forest cover is driving the expansion of large carnivores in many areas of Europe, including the Apennines (Pereira and Navarro 2015, Cimatti et al. 2021). Central Apennines is home to the relict and critically endangered Marsican bear population (*Ursus arctos marsicanus*) (Ciucci and Boitani 2008). Following land abandonment and forest recover, habitat availability has increased also for this charismatic carnivore, but the population is still under threat largely due to limited environmental connectivity leading to dispersal-related mortality and especially direct human persecution (Ciucci and Boitani 2008, Falcucci et al. 2008). In this context, understanding the distribution and intensity of anthropogenic activities in Central Apennines, including grazing, is crucial for preserving the habitat of the bear and for other species inhabit this area as well as predicting and preventing human-wildlife conflict.

The interaction between agricultural activities and wildlife has a long and often conflictual history in central Apennines. For instance, bear-related damages have been reported on livestock (51%), domestic poultry (18%), beehives (16%), and crops and fruit trees (15%) (Ciucci and Boitani 2008). Despite the protected area’s long-standing compensation program, illegal shootings of wolves and bears have continued, suggesting that the underlying societal conflict remains unresolved (Posillico et al. 2004).

Despite grazing's importance for certain aspects of biodiversity conservation, uncertainties remain about its optimal management. Understanding grazing patterns is essential for mitigating biodiversity loss and guiding conservation efforts.

As grazing intensity is a function of livestock density (Abdalla et al. 2018), the quantification of the latter is often used to calculate grazing pressure. There are several works providing livestock density estimates at global (Gilbert et al. 2018) regional (Malek et al. 2024b, 2024a) and national levels (Kolluru et al. 2023, Liu et al. 2024). However, the resolution of these datasets is not sufficient to represent grazing intensity at a scale which is useful for local management, i.e., below the level of municipality. This generates a substantial gap in the scientific literature regarding standardised methods for estimating grazing intensity in terms of livestock density at a local scale. The difficulty in collecting fine-scale livestock density data results in most studies focussing on livestock grazing presence, ignoring its intensity (e.g., Kothmann et al. 2009, Andriuzzi and Wall 2017, Filazzola et al. 2020).

Here we present density maps for different categories of livestock (i.e., cattle, sheep, goats and horses) in an area of Central Apennines, derived using a standardised protocol of data collection and mapping. The protocol was applied in central Italy in a mid-mountain area adjacent to national parks. These maps may provide key information for the management of a territory (Hadjigeorgiou et al. 2005) constituting a valuable tool for the in-depth study of the relationships between livestock, habitats and wildlife.

Methods

Our study was conducted on a 218.75 km² area which correspond to two ecological corridors identified to enhance movements of the Marsican brown bear (*Ursus arctos marsicanus*) in Central Apennines, Italy (Ciucci et al. 2016, Ministero dell'Ambiente e della Sicurezza Energetica & ISPRA 2016) (Fig. 1).

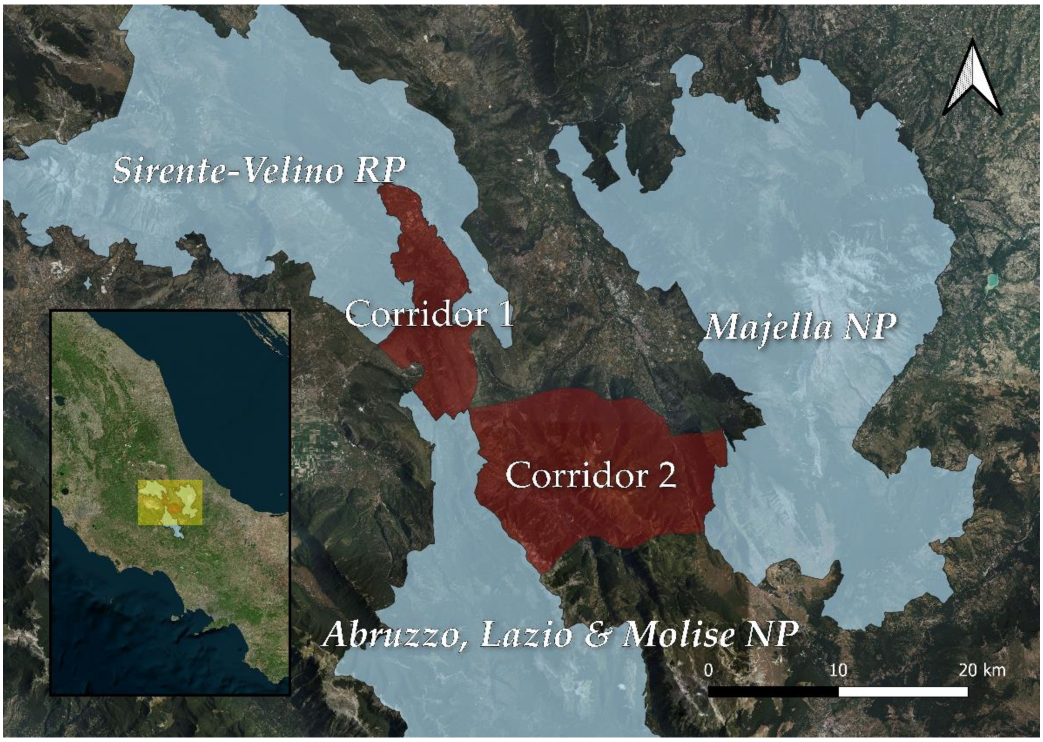

Figure 1: Map of the study area, corresponding to two ecological corridors for the Marsican brown bear.

Corridor 1 spans between the Sirente Velino Regional Natural Park and the Abruzzo, Lazio, and Molise National Park (ALMNP), while Corridor 2 connects ALMNP with the Majella National Park. These corridors facilitate movement for Marsican brown bears, but are also an important habitat for other mammal species, such as roe deer, red deer, wild boar, and porcupine (Dragonetti et al. 2024). Extensive livestock grazing is common in these areas, where cattle and horses roam freely, while sheep and goats are guarded by shepherds and dogs and are sheltered at night.

With this protocol, we collected and mapped livestock densities on a fine scale based on data collected from individual municipalities. We requested from the municipal offices of our study area the data on the number of livestock heads for each municipal pastureland in 2023. We implemented this data with farmer interviews, and we calculated livestock load and densities. Finally, we geolocated the pasturelands in a GIS environment and integrated them with livestock load data to create livestock distribution maps (Fig. 2).

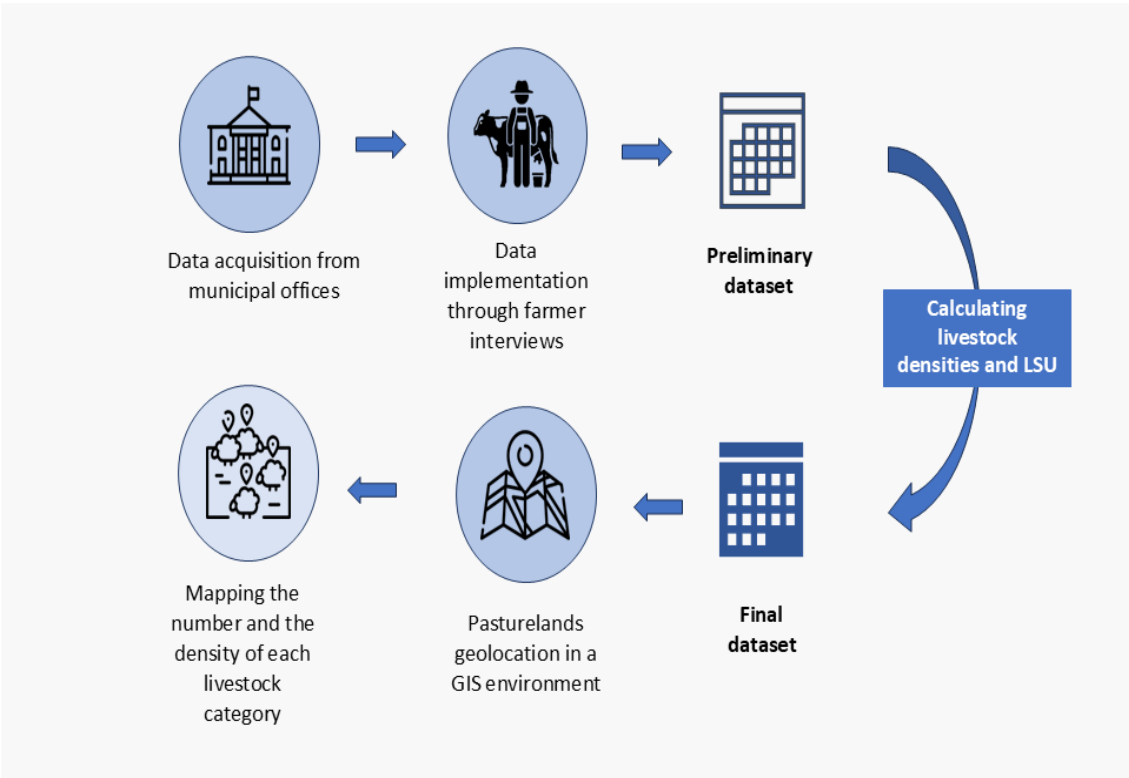

Figure 2: Graphic framework of methods adopted to collect and map livestock densities.

Data collection

As required by the legislation in force in Italy, municipal lands are entrusted to farmers in annual or seasonal concession under the "*fida pascolo*" system, regulated by *Legge 16 giugno 1927, n. 1766* and *Regio Decreto 6 febbraio 1928, n. 332* (Ministero della Giustizia 1927, 1928). This system regulates the allocation of municipal pasturelands to both resident and, in some cases, non-resident farmer applicants, who pay a fee for the exercise of the common grazing rights. Both the fee and the amount of land allocated vary based on the number of livestock heads owned by the applicant. Land boundaries are defined on the Italian cadastral map, which is divided into cadastral sheets (i.e., cadastral map sections that depict a specific area of a municipality) and particles (i.e., individual, numbered land parcels with the same type of crop within a cadastral sheet) as established by the Massedaglia Law, *Legge 1° marzo 1886, n. 3682* (Ministero della Giustizia 1886, Zonetti 2017).

Thus, we investigated livestock densities and geographic distribution by focusing on municipal grazing lands, excluding livestock held in farms with private pasturelands. We identified 15 municipalities that fall entirely or partially within our study area: Villalago, Secinaro, Scanno, Rocca Pia, Pettorano sul Gizio, Pescina, Ortona dei Marsi, Introdacqua, Goriano Sicoli, Gagliano Aterno, Cocullo, Castelvecchio Subequo, Castel di Ieri, Bugnara, Anversa degli Abruzzi. We then requested municipal offices to provide public documents pertaining to the civic use of grazing on municipal properties. Data obtained from the municipal records included both the cadastral sheets and particles assigned to each livestock farm and the number of livestock heads for each farm in the municipality. Data quality varied across municipalities, and some datasets lacked complete animal category breakdowns or livestock distribution in cadastral sheets or particles. To address data gaps and inconsistencies, we conducted additional interviews with farmers. Interviews and on-site visits to livestock farms also provided data on the exact location of pastures, in terms of cadastral sheet, as well as exact animal numbers by species (i.e., cattle, sheep, goats, horses) and age class, essential for calculating the total grazing pressure. We conducted these interviews anonymously, and we only provide aggregate data to protect the identity and location of each farm (Appendix S1).

At the end of the data collection, we obtained a comprehensive database with the following details: municipality, farm's identification code (anonymised), cadastral sheet, cadastral sheet area assigned to the farm (hectares), number of farm-raised cattle >24 months, number of farm-raised cattle 6-24 months, number of farm-raised cattle <6 months, number of farm-raised sheep/goats >12 months, number of farm-raised horses >6 months (Table S1). Our preliminary dataset details, for each cadastral sheet in a municipality, the land area allocated to a specific farm, as well as the corresponding livestock number of each farm in that municipality, categorised by species and age.

Mapping livestock density

Using the QGIS software (QGIS.org 2023), through the GIMP plugin (Motta 2020) we vectorized in the map of the Cadastral Cartography available as Web Map Service (WMS) from the Italian national territory on the *Agenzia delle Entrate* website (Agenzia delle Entrate 2023). We manually selected the cadastral sheets falling entirely or in part in the study area, and exported each cadastral sheet selected in

GIMP in shapefile format. Finally, we merged all the polygons into a single layer, creating a vector map of the cadastral sheets of the study area (Fig. 3).

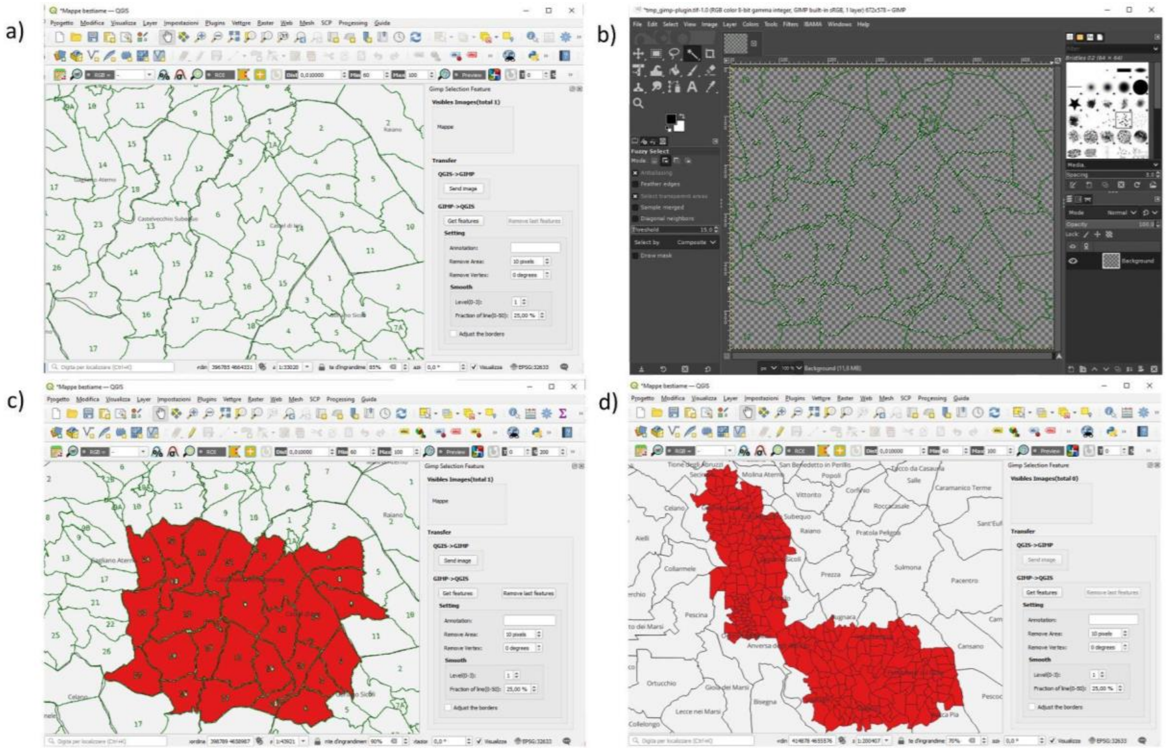

Figure 3 - a) Detailed view of the area of interest. The image is then sent with the command "send image" to GIMP b) On GIMP the cadastral sheets were selected with the "magic wand" tool c) With the command "Get features" the selected items on GIMP are loaded in QGIS, vectorialised and a new layer is created d) Resulting map of all the cadastral sheets of the entire study area.

We selected the sheets intended for "fida pascolo" to calculate the total surface of the grazing areas used by each one of the farms. We had four types of information to combine: the total number of livestock heads, for each livestock category, associated with each farm *i* in a municipality *m* (L_{im}), the areal coverage of each farm's pasture in a municipality ($Area_{im}$), the areal coverage of each farm's pasture in a cadastral sheet s ($Area_{is}$), the areal size of each sheet ($Area_s$).

We then calculate the density D_s (n livestock/ha) of each category of livestock for each cadastral sheet in a municipality, assuming a homogeneous distribution of livestock within each sheet. This was done according to a proportional allocation process, as follow:

Eq. 2

$$D_s = \sum_{i=1}^{n} \frac{L_{im}}{Area_{im}} \times \frac{Area_{is}}{Area_s}$$

In the case of Gagliano Aterno municipality, we only had information on which cadastral sheets were grazed, but not on the number of livestock grazing for each sheet. Therefore, we calculated the overall density for the entire grazed area of the municipality. Then, for each livestock category, we simply divided the total number of livestock heads (L_i) of each farm *i* by the total grazed area of the municipality ($Area_{gm}$), as follow:

Eq. 3

$$D_m = \sum_{i=1}^{n} \frac{L_i}{Area_{gm}}$$

To calculate the total grazing pressure, we used the LSU (Livestock Unit) conversion factor. The LSU has the purpose of synthetically expressing the livestock load, so that the environmental impact of different farmed animals can easily be compared. We referred to the conversion values of the Commission Implementing Regulation (EU) 2016/669 (European Commission, 2016) (Table 1), as these were the same coefficients used by the municipalities. Finally, we associated these densities of each livestock category to the vector map of the cadastral sheets of the study area.

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Table 1 - *Conversion rates of free and semi-free ranging animals to livestock units referring to the European Commission Implementing Regulation 2016/669.*

	Conversion rates of animals to livestock units (“LSU”)	
	Bulls, cows and other bovine animals over two years and equine animals over six months	1 LSU
	Bovine animals from six months to two years	0.6 LSU
	Bovine animals below six months	0.4 LSU
	Sheep and goats	0.15 LSU

We compared our total livestock unit (LSU) data at the municipal level with that of Malek et al. (2024a), which calculated LSUs for each European administrative unit. Additionally, we compared our total LSUs at the cadastral sheet level with Malek et al. (2024b) LSU estimates for semi-natural or managed grazed areas, aggregating their data at the cadastral sheet level (Fig. S1 and S2). In doing both comparisons, we excluded horses from our total LSU, as the other datasets do not consider equines. We verified the correlation between our data and data from both studies (Spearman test).

Results

We obtained a shapefile of grazing pressure, divided into eight livestock categories at cadastral sheet resolution (LSU, LSU density, equines, equines density, cattle, cattle density, sheep+goats and sheep+goats density; Fig. 4). The shapefile attribute table contains 11 columns, each indicating the number and density of each type of livestock listed above, for each sheet of each municipality.

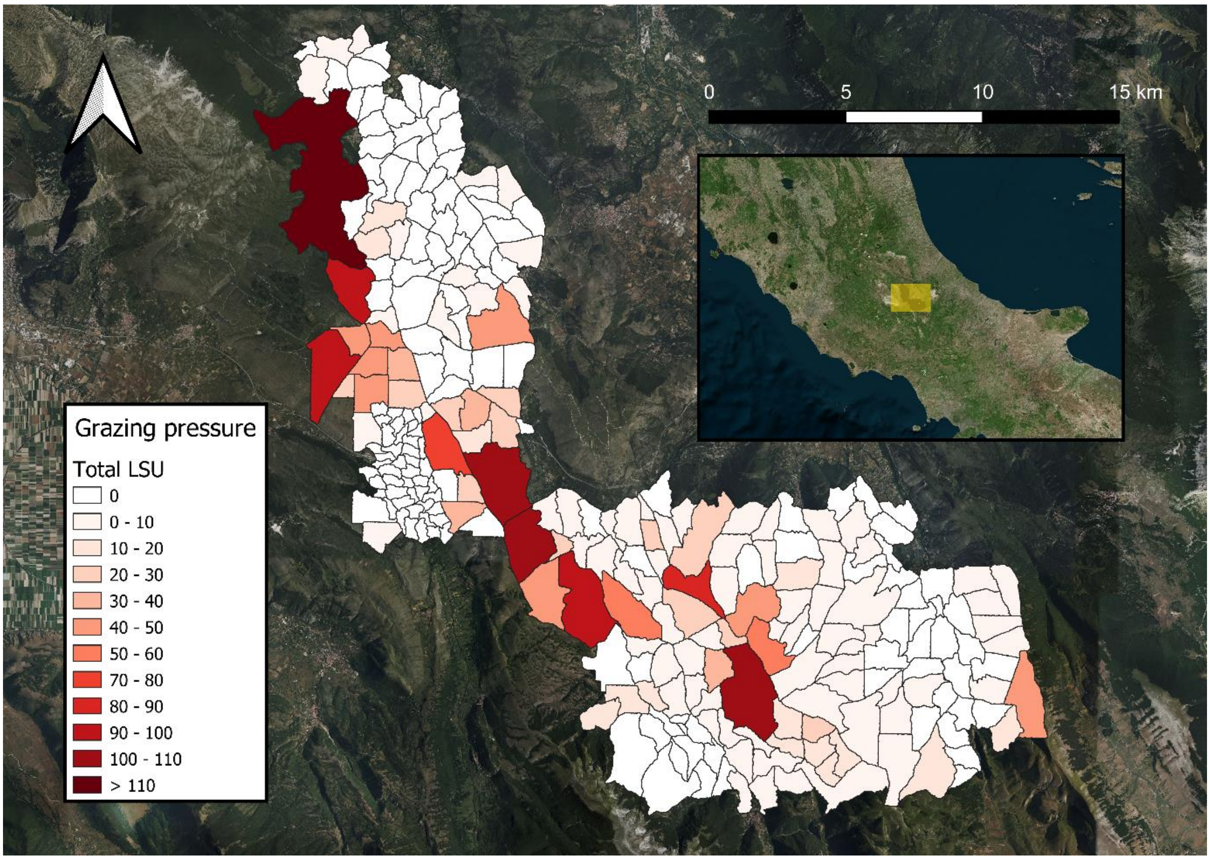

Figure 4 - Map of total grazing pressure in each cadastral sheet, in terms of livestock unit (LSU).

We found that Corridor 1 is generally more grazed than Corridor 2, both in terms of absolute numbers and relative density. Among the municipalities with the highest LSU counts, Gagliano Aterno ranked first (461.8 LSU), followed by Ortona dei Marsi (373.2 LSU), Anversa degli Abruzzi (350.7 LSU) and Scanno (295.2 LSU). Regarding cattle, Gagliano Aterno showed the highest numbers (366 cows), followed by Ortona dei Marsi (204) and Cocullo (166). However, in terms of cattle density, Ortona dei Marsi has the highest grazing intensity (2.03 cattle/ha in grazed cadastral sheets), followed by Scanno (0.96 cattle/ha).

For sheep and goats, Anversa degli Abruzzi showed the highest values (1,173 animals with a density of 8.21 individuals/ha in grazed cadastral sheets), followed by

Bugnara and Pescina in terms of absolute numbers, but with Scanno ranking third in terms of density (5.38 individuals/ha). Regarding equines, Ortona dei Marsi has both the highest number (117 individuals) and the highest density (1.62 individuals/ha), followed by Scanno and Gagliano Aterno.

When comparing our data with Malek et al., 2024a and Malek et al., 2024b, we found our estimates being generally higher than those extracted from both studies, except for some municipalities (i.e., Pescina, Pettorano sul Gizio, Ortona dei Marsi, Scanno), which showed higher values in the comparison study of Malek et al., 2024a (Fig. S2). This was due to the methodological differences and the use of different coefficients for LSU calculations. Overall we found a moderate correlation between our values and the ones extracted from Malek et al. 2024a (Spearman = 0.47, p = 0.08), but a weak correlation with Malek et al. 2024b (Spearman = 0.14, p = 0.02).

Discussion

Many studies simply compare 'grazed' to 'ungrazed' conditions and the measures of grazing intensity at a local scale come in different forms, almost always generalised without a distinction between different types of livestock, thus making the comparison across studies difficult (Briske et al. 2011, Schieltz and Rubenstein 2016). In order to compensate for this lack of standardisation of grazing pressure measurements, and to obtain precise information on the actual distribution of free and semi-free ranging livestock, the introduction of a well-structured protocol for mapping grazing pressure with a standardised data collection method represents an important tool in this sense.

It is important to point out that the preliminary data collection method may vary across different countries, as the legislation in force may require the registration of individual livestock on different databases and regulate grazing activity in different ways. Based on the level of data accessibility, information on the distribution and actual size of the grazing livestock load may be completed and refined with specific interviews at livestock farms or by consulting different databases. In any case, the applicability of this protocol is linked to the processing and subsequent mapping of this data according to a precise map unit, selected based on the precision of the data collected and the spatial resolution desired. Another limitation pertains to the limited temporal validity of the results obtained with this protocol as well, as the concession of municipal lands to farms is annual and may change from year to year (at least in Italy). In order to overcome the problems related to the different spatial resolutions of the collected data, we decided to assume a homogeneous distribution of livestock within the farms, and to group the data provided at the resolution of cadastral particles within the related cadastral sheets. This assumption allowed us to use data with different spatial precision but might not necessarily hold because food resources for grazing animals may not be equally distributed in the territories granted to the farms or because some animals, such as sheep and goats, may move in herds, concentrating the grazing pressure in specific areas.

We compared our grazing assessment with two previous studies conducted at a larger spatial scale (Fig. S1, S2), and identified key differences. Our analysis revealed differences in both calculation methods and final data, which are reflected in the applicability of the dataset. For instance, both of Malek's studies excluded horses from their grazing assessments, a livestock category which could significantly influence grazing dynamics in many areas.

We excluded livestock held on private grazing lands from our analysis because this data was unavailable from the WMS of the “Agenzia delle Entrate” nor by individual municipalities. Private grazing lands constitute only a small portion of the total grazing area within our study region, hence any underestimation of grazing intensity is likely small in our case. However, we acknowledge that private and grazing could be an element of higher importance, and deserving deeper investigation, if transferring our framework to other areas.

Mapping grazing intensity allows us to quantify livestock pressure on ecosystems, which can then serve different purposes. Our data can support conservation strategies that help local communities, their activities, and wildlife to coexist. Our study can be used in combination with land-cover maps, to obtain a further finer grazing allocation and thus a more accurate density estimates actual pasturelands in each cadastral sheet (i.e., mapped at a higher resolution than we did here). By identifying areas where human activities occur in natural and semi-natural environments, and evaluating the biodiversity conditions, it is possible to identify and promote sustainable agriculture and pastoralism practices.

This knowledge is particularly relevant for our study area in the central Apennines, identified as a corridor for the Marsican brown bear. Here, we identified municipalities such as Scanno or Gagliano Aterno as areas that need an assessment of potential overgrazing, together with the monitoring of the interactions between pasture activity and natural systems. In this sense, our study is a useful tool to preserve bear’s suitable habitats from excessive disturbance and degradation. Additionally, our work is a useful tool to assess eventual zoonotic risks, as there is increasing interest in examining the impact of livestock-borne pathogens on the bear's health (Fico et al. 2019), and more in general the risk of a two-way pathogen transmission between farmed and wild animals. Our study is also critical to support conservation strategies of many other species living in these areas, including those living in ecotonal semi-natural environments, shaped and maintained by extensive grazing (Dragonetti et al. 2024).

Considering the influence that livestock has on the temporal and spatial behaviour of wildlife (Schieltz and Rubenstein 2016), in pathogen transmission (Jori et al. 2021) or on changes in vegetation structure and cover (Augustine and McNaughton 1998), accurate mapping of grazing livestock is an important tool in land management planning and biodiversity conservation.

Data Availability

All maps are available in GeoTIFF format and are freely accessible in the Zenodo repository: https://zenodo.org/records/14832257.

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