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Map of livestock density in Central Appenines: a standardised protocol

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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. 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 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). Additionally, livestock presence disrupts wildlife behaviour and can have cascading effects on biodiversity, yet the research on this interaction remains limited and often yields conflicting results (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 and pathogen transmission (Ekernas et al. 2017, Jori et al. 2021). 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 (Schieltz and Rubenstein 2016).

Grazing is characterised by a variety of factors such as timing, frequency, duration, season, and intensity (Briske et al. 2011, Schieltz and Rubenstein 2016). Intensity in particular is the most crucial factor influencing changes in ecosystems (Schieltz & Rubenstein, 2016). However, defining grazing intensity varies across studies, and inconsistencies in what constitutes 'moderate' grazing, along with the different impacts

of various livestock types, make comparisons difficult. This generates a substantial gap in the scientific literature regarding standardised methods for estimating grazing intensity in terms of livestock density. 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). The presence of wildlife species and free-grazing livestock in the same mountainous region, especially near protected areas, necessitates a spatial analysis of both livestock and wildlife distribution to develop conservation and coexistence strategies.

In this work, 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

The study was conducted on a 218.75 km² area which correspond to two ecological corridors identified for 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).

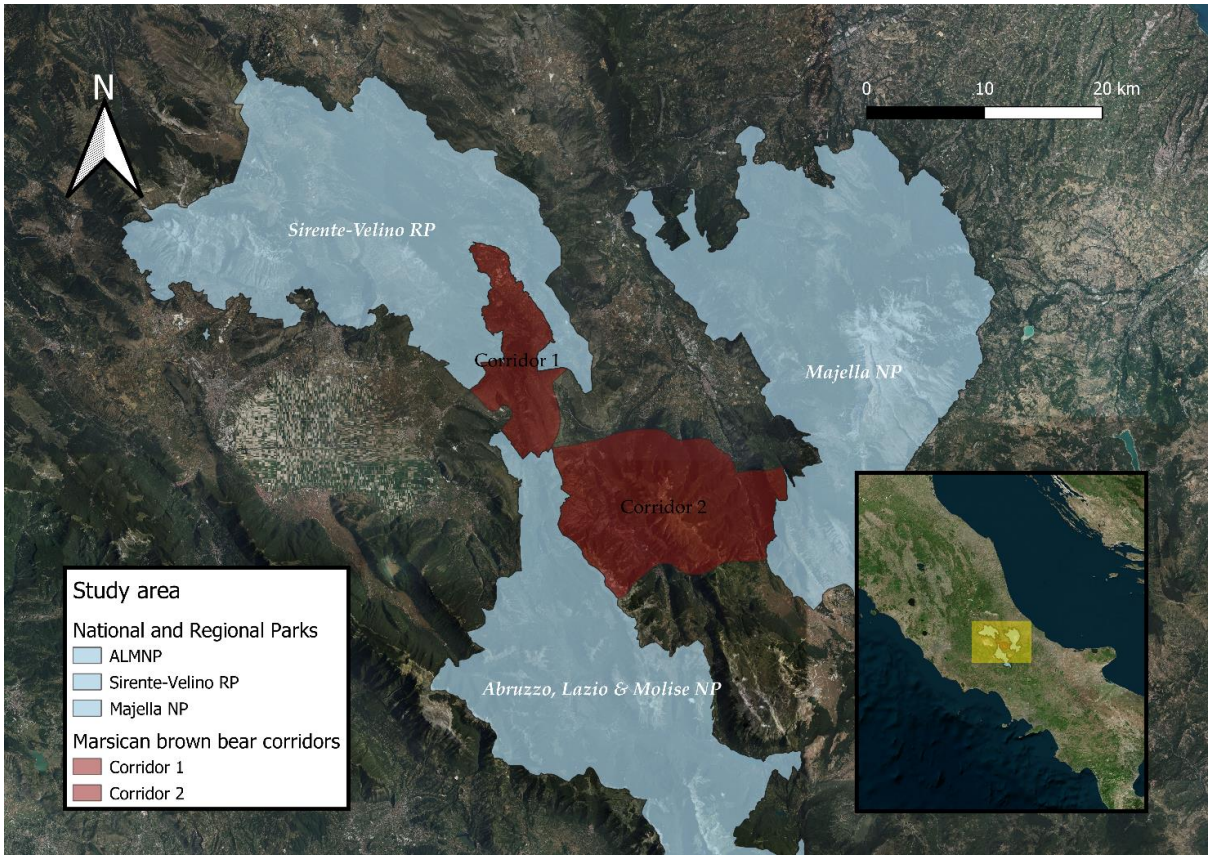
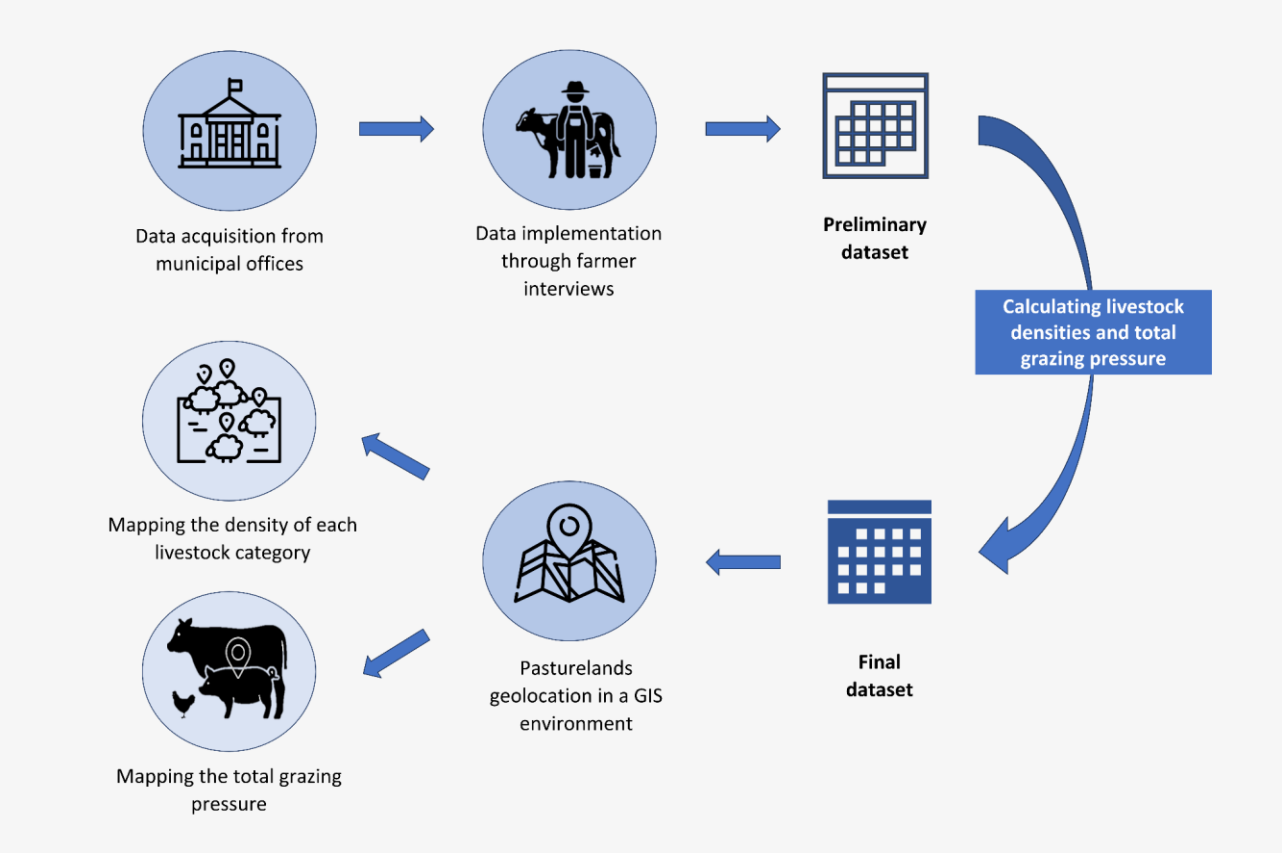


Figure 1: Map of the study area, corresponding to two ecological corridors for the Marsican brown bear.

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

98 calculated livestock load and densities. Finally, we geolocated the pasturelands in a
99 GIS environment and integrated them with livestock load data to create livestock
100 distribution maps (Fig. 2).
101



102 *Figure 2: Graphic framework of methods adopted to collect and map livestock*
103 *densities.*
104

105 Data collection

106 As required by the legislation in force in Italy, municipal lands are entrusted to farmers
107 in annual or seasonal concession under the "*fida pascolo*" system, regulated by *Legge*
108 *16 giugno 1927, n. 1766* and *Regio Decreto 6 febbraio 1928, n. 332* (Ministero della
109 Giustizia 1927, 1928). This system regulates the allocation of municipal pasturelands
110 to both resident and, in some cases, non-resident farmer applicants, who pay a fee for

111 the exercise of the common grazing rights. Both the fee and the amount of land
112 allocated vary based on the number of livestock heads owned by the applicant. Land
113 boundaries are defined on the Italian cadastral map, which is divided into cadastral
114 sheets (i.e., cadastral map sections that depict a specific area of a municipality) and
115 particles (i.e., individual, numbered land parcels with the same type of crop within a
116 cadastral sheet) as established by the Massedaglia Law, *Legge 1° marzo 1886, n.*
117 *3682* (Ministero della Giustizia 1886, Zonetti 2017).

118 Thus, we investigated livestock densities and geographic distribution by focusing on
119 municipal grazing lands, excluding farms with private pasturelands. We identified 15
120 municipalities that fall entirely or partially within our study area: Villalago, Secinaro,
121 Scanno, Rocca Pia, Pettorano sul Gizio, Pescina, Ortona dei Marsi, Introdacqua,
122 Goriano Sicoli, Gagliano Aterno, Cocullo, Castelvecchio Subequo, Castel di Ieri,
123 Bugnara, Anversa degli Abruzzi. We then requested municipal offices to provide public
124 documents pertaining to the civic use of grazing on municipal properties. Data
125 obtained from the municipal records included both the cadastral sheets and particles
126 assigned to each livestock farm and the number of livestock heads for each farm in
127 the municipality. Data quality varied across municipalities, and some datasets lacked
128 complete animal category breakdowns or livestock distribution in cadastral sheets or
129 particles. To address data gaps and inconsistencies, we conducted additional
130 interviews with farmers. Interviews and on-site visits to livestock farms also provided
131 data on the exact location of pastures, the seasonality of livestock practices, as well
132 as exact animal numbers by species (i.e., cattle, sheep, goats, horses) and age class,
133 essential for calculating the total grazing pressure. We conducted these interviews
134 anonymously, and only provide aggregate data to protect the identity and location of
135 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 L. 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). In order to work on a map at cadastral sheet resolution, in GIMP we manually selected the cadastral sheets falling entirely or in part in the study area. We then 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).

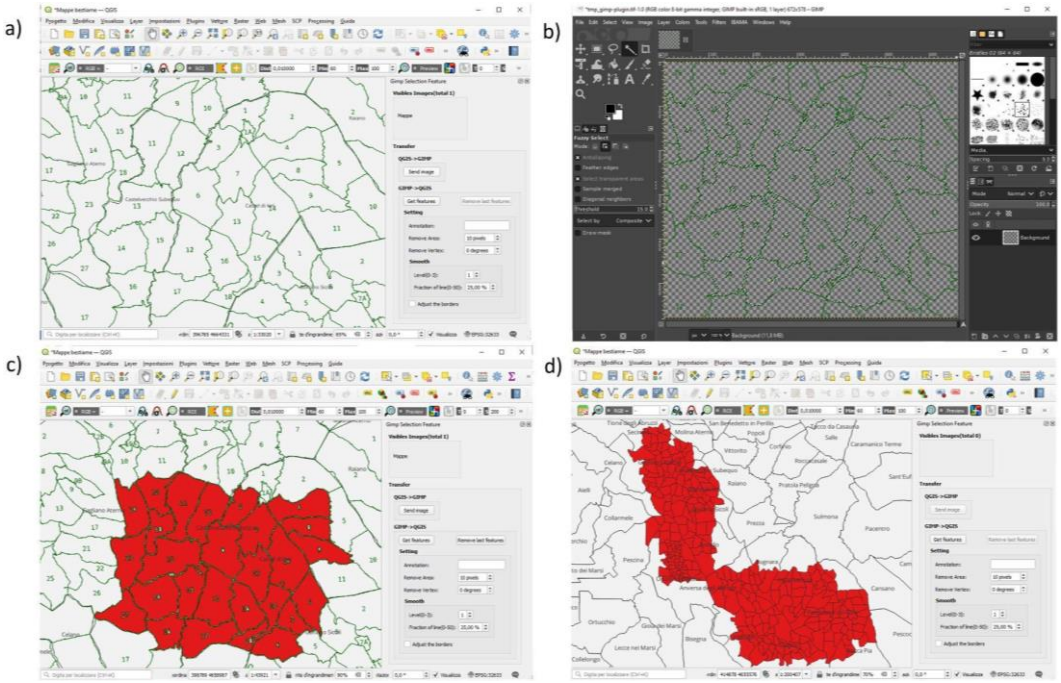


Figure 3 - a) Detailed view of the area of interest. The image is then sent with the command "send image" to GIMP b) On GIMP the cadastral sheets were selected with the "magic wand" tool c) With the command "Get features" the selected items on GIMP are loaded in QGIS, vectorialised and a new layer is 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 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 combined this information to calculate the density D_s of each category of livestock (i.e., sheep + goats - aggregated, cattle and horses) for each cadastral sheet of each

170 municipality, assuming a homogeneous distribution of livestock within each sheet. This
171 was done according to a proportional allocation process, following Equation 1:

172 Eq. 1

173 $$D_s = \sum_{i=1}^{n} \frac{L_{im}}{Area_{im}} \times \frac{Area_{is}}{Area_s}$$

174 In the case of Gagliano Aterno municipality, we lacked precise data on the
175 geographical positioning of the pasture areas within the municipal cadastral sheets.
176 Thus, for each livestock category, we simply divided the total number of livestock
177 heads (L_i) of each farm *i* by the total area of the municipality ($Area_m$), as shown in eq.
178 2:

179 Eq. 2

180 $$D_m = \sum_{i=1}^{n} \frac{L_{im}}{A_m}$$

181 To calculate the total grazing pressure, we used the LSU (Livestock Unit) conversion
182 factor. The LSU has the purpose of synthetically expressing the livestock load. It
183 considers the quantity and quality (e.g., nitrogen content, phosphorus) of the
184 wastewater so that the environmental impact of different farmed animals can easily be
185 compared. For the precise conversion values we referred to the Commission
186 Implementing Regulation (EU) 2016/669 (European Commission, 2016) (Table 1).

187 Finally, we associated these densities of each livestock category to the vector map of
188 the cadastral sheets of the study area.

189

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

Results and Discussion

We obtained a digital map in ESRI shapefile format of grazing pressure, divided into eight categories (LSU, LSU density, equines, equines density, cattle, cattle density, sheep+goats and sheep+goats density) at cadastral sheet resolution (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.

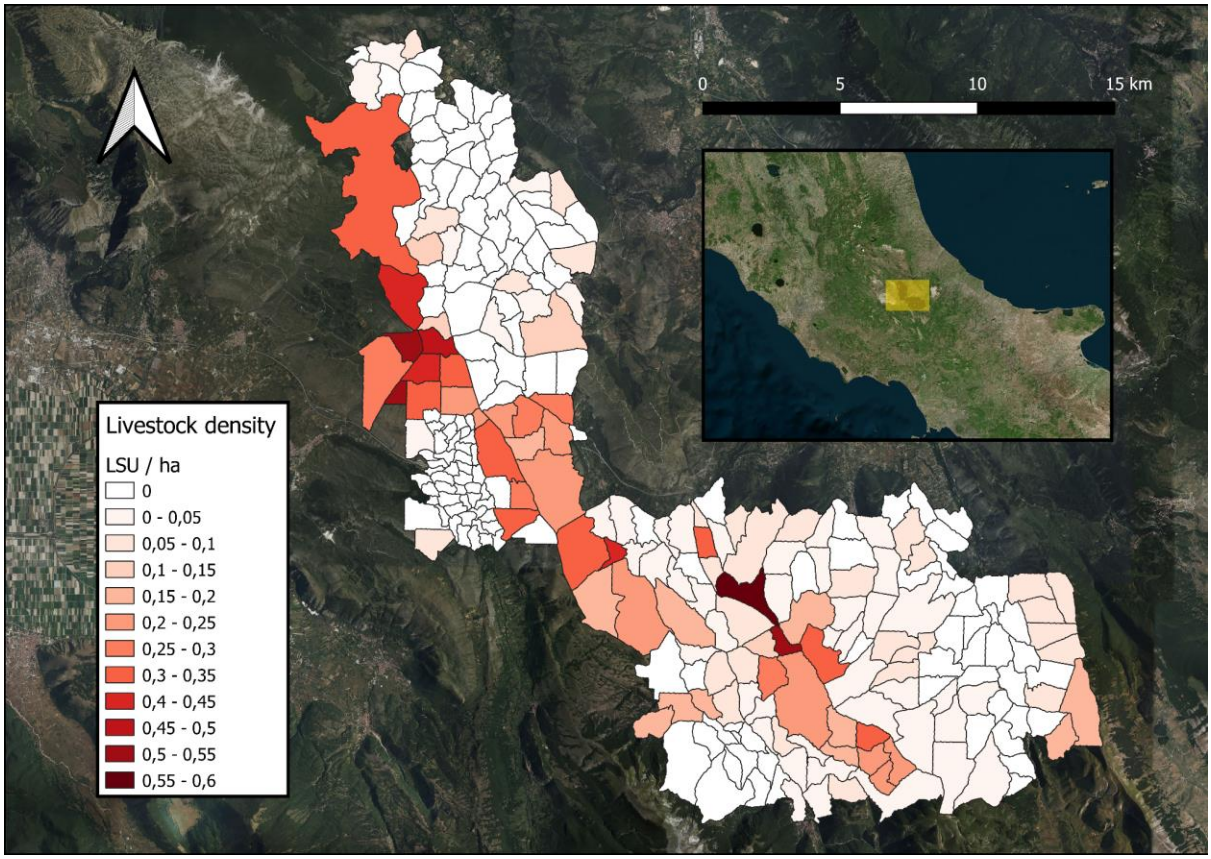


Figure 4 - Map of total grazing pressure in each cadastral sheet, in terms of livestock unit (LSU).

Many studies simply compare 'grazed' to 'ungrazed' conditions and the measures of grazing intensity 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.

Mapping grazing intensity allows us to quantify livestock pressure on ecosystems, which can then serve different purposes. For instance, grazing pressure (total and from specific livestock) can be used as a variable for modelling wildlife occupancy, or density. 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 can become 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/13986495.

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Supporting Information

Table S1: *Sample of the initial dataset used to calculate and map livestock densities, relatives to cadastral sheets 11 and 12 of Anversa degli Abruzzi municipality. The first four columns (in green) provide information on the cadastral sheets assigned to each farm according to the "fida pascolo" legislation. The following five columns (in orange) indicate the number of animals of each livestock category owned by each farm and distributed in all the cadastral sheets.*

Municipality	Livestock farm	Cadastral sheet	Cadastral sheet area assigned to the livestock farm (hectares)	Farm-raised cattle >24 months	Farm-raised cattle 6-24 months	Farm-raised cattle <6 months	Farm-raised sheep/goats >12 months	Farm-raised horses >6 months
ANVERSA DEGLI ABRUZZI	Farm 1	11	133,5554	0	0	0	1762	6
ANVERSA DEGLI ABRUZZI	Farm 1	12	39,7782	0	0	0	1762	6
ANVERSA DEGLI ABRUZZI	Farm 2	11	52,568	0	0	0	70	0
ANVERSA DEGLI ABRUZZI	Farm 3	11	32,274	27	24	2	25	37
ANVERSA DEGLI ABRUZZI	Farm 5	11	20	12	7	9	41	17

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340 **Appendix S1:** *Template of an anonymous interview with livestock farmers.*

341

Interviewer:	Date:
Farm's identification code:	
Municipality:	

342

343

CATTLE		
Land area (hectares):	**Location:**	**Cadastral sheets and particles:**
Number of Cattle <6 months	Free grazing	Period:
	Guided grazing	Period:
	Rotational grazing with fences	Period:
		Number of sections:
		Period per section:
Number of Cattle 6-24 months	Free grazing	Period:
	Guided grazing	Period:
	Rotational grazing with fences	Period:
		Number of sections:
		Period per section:
Number of Cattle >24 months	Free grazing	Period:
	Guided grazing	Period:
	Rotational grazing with fences	Period:
		Number of sections:
		Period per section:

344

345

SHEEP AND GOATS		
Land area (hectares):	**Location:**	**Cadastral sheets and particles:**
Number of Sheep:	Free grazing	Period:
	Guided grazing	Period:
	Rotational grazing with fences	Period:
		Number of sections:
		Period per section:
Number of Goats:	Free grazing	Period:
	Guided grazing	Period:
	Rotational grazing with fences	Period:
		Number of sections:
		Period per section:

346

347

HORSES		
Land area (hectares):	**Location:**	**Cadastral sheets and particles:**
Number of Horses >6 months:	Free grazing	Period:
	Guided grazing	Period:
	Rotational grazing with fences	Period:
		Number of sections:
		Period per section:

348

349

350