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New arrival, new problems? First insights into livestock damages by a colonising meso-carnivore in the Eastern Italian Alps

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Abstract:

Extensive livestock farming in mountainous areas provides important ecosystem services. However, its abandonment causes environmental degradation, and persisting farms face carnivore conflicts. The golden jackal *Canis aureus*, a meso-carnivore colonising the Italian Peninsula, acts as an ecosystem scavenger, but its livestock impacts remain understudied. This study provides the first insights into jackal-attributed livestock damages in Italy. We analysed official claims data (2018–2024) collected from trained personnel in the FVG Region. Within the studied period, $n = 121$ livestock damages (defined as the sum of preyed upon, injured, and missing individuals) were recorded during $n = 53$ attacks. $N = 75$ (62.0%) damages involved sheep, while $n = 42$ (34.7%) involved poultry, the most damaged livestock categories. Most damages ($n = 68$, 56.2%) were observed in the karstland, with an increase in livestock damages observed across years. No significant association between: (i) livestock attacks and habitat features, and (ii) livestock damages and distance from the nearest urban and/or canopy-covered area was observed. Damaged sheep breeds (Comisana, Istriana, Suffolk) and poultry (Leghorn chickens, Muscovy ducks) are FAO-listed as 'Vulnerable' or 'Endangered'. In order to increase herder tolerance towards jackals, post-damage compensation schemes should take into account the conservation status of the damaged livestock breed. The proportional use of available habitats as suitable attack sites, together with the occurrence of attacks also near human settlements, confirms the notable ecological and behavioural adaptability of jackals. The implementation of proper prevention measures is thus a necessary step to enhance long-term human-jackal coexistence.

Keywords: *Canis aureus*, livestock predations, extensive grazing, golden jackal, human-carnivore coexistence.

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Short title

Golden jackal colonisation: livestock damage in Eastern Alps

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1 1 **New arrival, new problems? First insights into livestock damages by a colonising meso-**
2 2 **carnivore in the Eastern Italian Alps**

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9 9 **Running title:** Human-jackal conflicts in North-Eastern Italy

10 10 **Abstract**

11 11 Extensive livestock farming in mountainous areas provides important ecosystem services. However, its abandonment
12 12 causes environmental degradation, and persisting farms face carnivore conflicts. The golden jackal *Canis aureus*, a
13 13 meso-carnivore colonising the Italian Peninsula, acts as an ecosystem scavenger, but its livestock impacts remain
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15 15 official claims data (2018–2024) collected from trained personnel in the FVG Region. Within the studied period, n =
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17 17 53 attacks. N = 75 (62.0%) damages involved sheep, while n = 42 (34.7%) involved poultry, the most damaged
18 18 livestock categories. Most damages (n = 68, 56.2%) were observed in the karstland, with an increase in livestock
19 19 damages observed across years. No significant association between: (i) livestock attacks and habitat features, and (ii)
20 20 livestock damages and distance from the nearest urban and/or canopy-covered area was observed. Damaged sheep
21 21 breeds (*Comisana*, *Istriana*, *Suffolk*) and poultry (*Leghorn chickens*, *Muscovy ducks*) are FAO-listed as ‘Vulnerable’ or
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23 23 into account the conservation status of the damaged livestock breed. The proportional use of available habitats as
24 24 suitable attack sites, together with the occurrence of attacks also near human settlements, confirms the notable
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26 26 necessary step to enhance long-term human-jackal coexistence.

27 27 **Keywords:** *Canis aureus*, extensive grazing, golden jackal, human-carnivore coexistence, livestock predations.

31 29

32 30 **Introduction**

33 31 Extensive livestock practices, when sustainable and properly managed, provide several ecosystem services
34 32 (ESs), defined as benefits contributing to human well-being (MEA, 2005; Battaglini et al., 2014; Haines-Young and
35 33 Potschin, 2018; Pachoud et al., 2020). However, in recent decades, the abandonment of grazing in mountain areas has
36 34 driven environmental degradation, as these practices are key for maintaining ecosystem functioning. Main
37 35 consequences include reduced microbial activity and soil carbon-storage capacity (Oggioni et al., 2020), decreased soil
38 36 stability and water retention with increased risks of landslides and nutrient loss (Raquena Serrano et al., 2024), and
39 37 biodiversity loss, as grazing helps limit biomass accumulation and supports diverse plant and microbial communities
40 38 (Ribeiro et al., 2023). Remaining summer farms (herein, farms) face multiple challenges, including high production
41 39 costs, limited economies of scale, climate change impacts, labour shortages, and, to a lesser extent, livestock predations
42 40 by carnivores in shared landscapes, which may in turn potentially imperil long-lasting human-carnivore coexistence.

43 41 Although some studies have reported the feasibility of human-carnivore coexistence (Carter et al., 2012;
44 42 Schuette et al., 2013), it remains a major global challenge (Woodroffe et al., 2005; Treves et al., 2006; Dickman et al.,
45 43 2011) and is often undermined by human-carnivore conflicts (herein, HCCs). Conflicts arising from livestock
46 44 predations can lead, on the one hand, to the abandonment of livestock practices in conflict-prone areas (Holmern et al.,
47 45 2007) and foster resentment among the most affected groups, particularly livestock owners (Dressel et al., 2015;
48 46 Franchini et al., 2021, 2025a), and, on the other hand, to retaliatory persecution of carnivores (Guerisoli et al., 2017;
49 47 Soofi et al., 2022), which in the most severe cases has resulted in local carnivore extinctions (Breitenmoser, 1998;
50 48 Woodroffe, 2000). Predators play key ecological roles by exerting top-down control on species at lower trophic levels
51 49 (Estes et al., 2011; Ripple et al., 2014), contributing to ecosystem functioning and stability. They can also provide
52 50 indirect public health benefits by limiting spread diseases (Braczkowski et al., 2018), help regulate invasive alien
53 51 species such as the coypu (*Myocastor coypus* - Travain et al., 2025; Belardi et al. 2024), and offer cultural, emotional,
54 52 and recreational value to society (Kellert et al., 1996). Considering the ecological and social benefits provided by both
55 53 livestock systems and carnivores, the development of effective conflict-prevention and mitigation strategies to promote
56 54 coexistence is therefore of primary importance.

57 55 When discussing HCCs, large carnivores are frequently blamed to be responsible for the majority of damages
58 56 (e.g., Guerisoli et al., 2017; Augugliaro et al., 2020; Soofi et al., 2022; Franchini et al., 2025a). However, medium-sized
59 57 carnivores (including meso-carnivores) can also affect livestock grazing systems (e.g., Yom-Tov et al., 1995; Sacks and
60 58 Neale, 2007; McInturff et al., 2021; Torres-Romero et al., 2023; Kalendarishvili et al., 2024). Among these, the golden

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63 59 jackal *Canis aureus* (herein, jackal) is a meso-carnivore that has exhibited a remarkable range expansion across Europe
64 60 over recent decades (Krofel et al., 2017; Spassov and Acosta-Pankov, 2019). This expansion has been driven by
65 61 multiple factors, including: (i) wildlife management practices and land-use changes (Markov, 2012; Krofel et al., 2017;
66 62 Ranc et al., 2026); (ii) the decline in grey wolf *Canis lupus* (herein, wolf) populations across Europe over the past 150
67 63 years (Trouwborst et al., 2015; Krofel et al., 2017; Ranc et al., 2026); (iii) climatic changes (Fabbri et al., 2014; Ranc et
68 64 al., 2026); and (iv) increased use of anthropogenic food resources, as jackals are well adapted to human-modified
69 65 environments and readily exploit food produced or made available by people (Šalek et al., 2014; Ćirović et al., 2016;
70 66 Lanszki et al., 2018; Fenton et al., 2021; Ranc et al., 2026).

71 67 Jackals play a fundamental ecological role as ecosystem scavengers. A study conducted by Ćirović et al. (2016)
72 68 showed that, in Serbia, jackals remove approximately 3,700 tons of animal waste and 13.2 million crop-pest rodents
73 69 annually, thereby providing indirect yet substantial health and economic benefits to humans. In spite of their ecological
74 70 role, jackals are frequently blamed for being responsible for livestock losses by livestock herders (herein, herders) (e.g.,
75 71 Khattak et al., 2021; Shanko et al., 2021; Bashyal et al., 2022), but the impact they may exert on livestock practices
76 72 remains poorly investigated (Yom-Tov et al., 1995; Kalandarishvili et al., 2024). Most studies on jackal feeding
77 73 behaviour have been in fact conducted through the analysis of scats and/or stomach contents (Lange et al., 2021).
78 74 However, a key limitation of these methods is their inability to distinguish between scavenging and predatory
79 75 behaviours (e.g., Torres et al., 2015; Werhahn et al., 2019; Trbojevic et al., 2020).

80 76 In Italy, the species was first recorded in 1984 in the Eastern Alps, with the earliest documented reproductive
81 77 event occurring in 1985 (Lapini et al., 2021), and is most abundant in the Friuli Venezia Giulia (herein, FVG) Region,
82 78 particularly in the karst area located in the South-Eastern portion of the Region (Lapini et al., 2018, 2021; Frangini et
83 79 al., 2025). In the area, the jackal is known for feeding primarily on wild ungulates, followed by small- and medium-
84 80 sized mammals. Birds and fruits are also consumed, with their relative contribution varying according to season
85 81 (Torretta et al., 2021). With regards to livestock predations, the first preliminary local report of livestock attacks by
86 82 jackals appeared in 2014 (Benfatto et al., 2014). However, to the best of our knowledge, scientific studies investigating
87 83 the impact on livestock over multiple years are still largely lacking at both local and national scale.

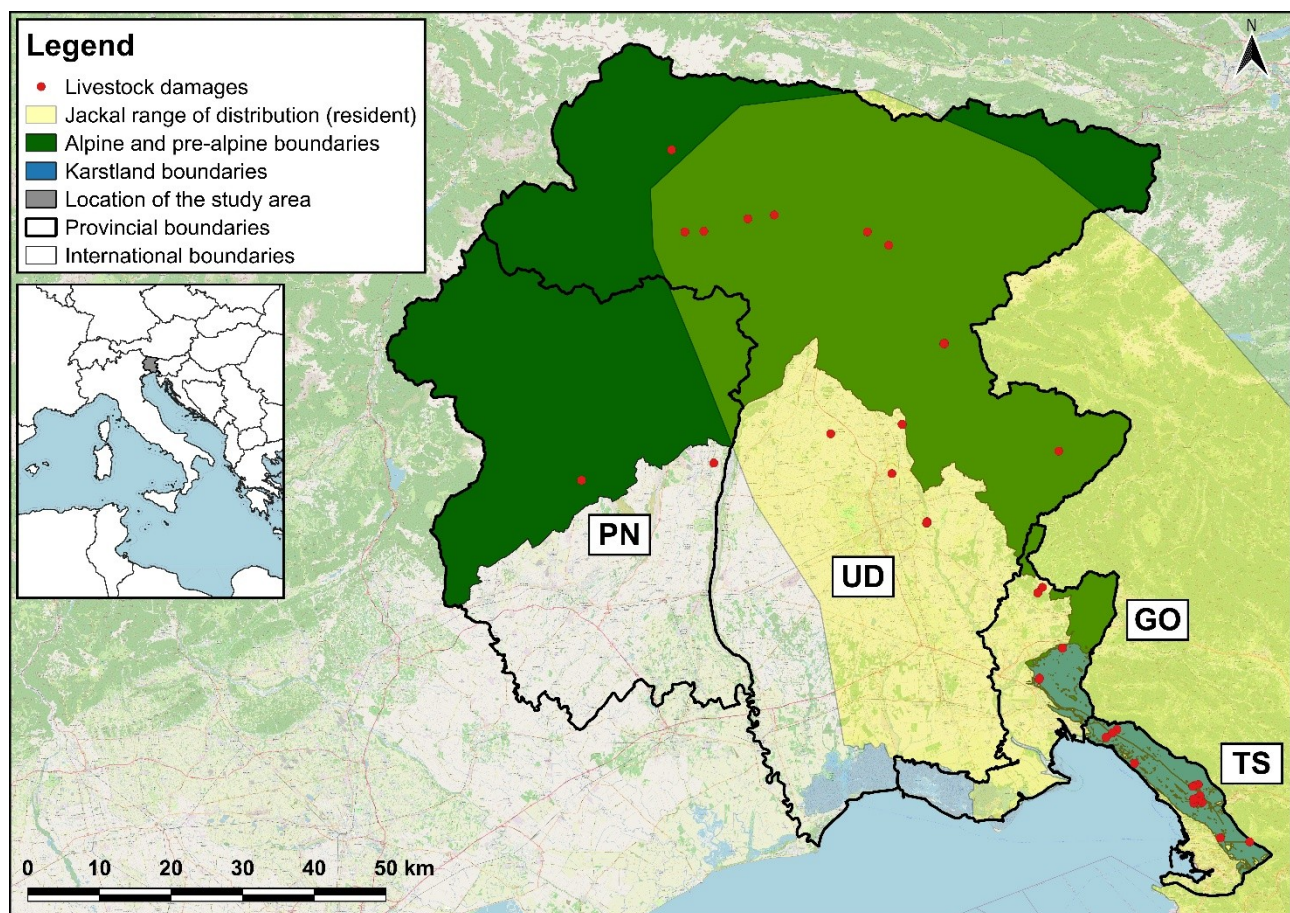
88 84 The purpose of this research was thus to provide the first insights into livestock damages (herein defined as the
89 85 sum of preyed upon, injured, and missing individuals) caused by jackals in the Eastern Italian Alps (and Italy, to a
90 86 broader extent). Specifically, we aimed to: (i) characterise the spatio-temporal distribution of livestock damages. Given
91 87 the higher abundance reached by the species in the karstland compared to other areas (Lapini et al., 2018, 2021;
92 88 Frangini et al., 2025), we predicted that the greatest number of livestock damages would occur in the karstland.
93 89 Additionally, we aimed to (ii) describe the most affected livestock categories and (iii) identify habitat features

96 90 associated with an increased risk of attacks and/or damages on livestock. Given the remarkable ecological and
 97 91 behavioural plasticity of jackals which enables the species to exploit both natural and human-modified environments
 98 92 (Šalek et al., 2014; Ćirović et al., 2016; Lanszki et al., 2018; Fenton et al., 2021; Ranc et al., 2026), we predicted to
 99 93 observe (i) a proportional use of available habitats as suitable attack sites, and (ii) a high occurrence of livestock
 100 94 damages also near urban areas.

102 96 Material and methods

103 97 Study area and adopted livestock breeding system

104 98 The study was conducted in FVG, the North-Easternmost Region of Italy, which covers an area of approximately
 105 99 7,924 km² and has a population density of about 150 inhabitants/km² (Fig. 1).



106 100
 107 101 **Figure 1.** Location of the study area (FVG Region; inset map), jackal range of distribution (IUCN, 2018), and
 108 102 coordinates of livestock damage events (i.e., sum of preyed upon, injured, and missing individuals) within each area.
 109 103 The uncoloured area indicates the lowland territories. Abbreviations (Provinces): PN = Pordenone; UD = Udine; GO =
 110 104 Gorizia; TS = Trieste.

The climate of the Region ranges from Mediterranean along the Adriatic coast, to temperate-humid in hilly and lowland areas, and Alpine in mountainous zones. The average annual temperature is approximately 14.5°C. Precipitation is abundant, particularly in the pre-Alpine belt, where it can reach up to 3,000 mm per year, with the highest rainfall occurring in autumn (approximately 1,200–1,400 mm/year) (Arpa FVG - <https://www.clima.fvg.it/home.php>). Habitat composition varies with elevation: croplands and anthropic areas dominate the lowlands, whereas forests and shrublands are more characteristic of the Alpine, pre-Alpine, and karst landscapes (Poldini et al., 2006). Among plant species, oaks (*Quercus* sp.), larches (*Larix* sp.), beech (*Fagus* sp.), and spruce (*Picea abies*) are most abundant in Alpine and pre-Alpine areas, whereas poplars (*Populus* sp.), hornbeams (*Carpinus* sp.), and ashes (*Fraxinus* sp.) are more common in lowland territories (Poldini et al., 2001).

The Region hosts a diverse mammalian community. Among predators, it includes the brown bear *Ursus arctos* (herein, bear), wolf, jackal, red fox (*Vulpes vulpes*), Eurasian lynx (*Lynx lynx*) (herein, lynx), European wildcat *Felis silvestris*, and Eurasian otter (*Lutra lutra*). Conversely, prey species include the red deer *Cervus elaphus*, wild boar (*Sus scrofa*), roe deer (*Capreolus capreolus*), Northern/Alpine chamois (*Rupicapra rupicapra*), Alpine ibex *Capra ibex*, European brown hare *Lepus europaeus*, and mountain hare *Lepus timidus* (Regional Hunting Plan, 2015).

Livestock husbandry varies according to the geographical area. In Alpine and pre-Alpine Regions, a transhumant system is practiced from May/June to September/October, during which livestock is moved from lower to higher elevations to graze in open grasslands (Orland, 2004; Faccioni et al., 2015). In the karstland, livestock is managed under a rotational grazing system, with animals allowed to roam freely within fenced areas throughout the year, and occasionally enclosed in barns at night, particularly during winter. In contrast, lowland areas are characterised by an intensive livestock system, in which animals are typically kept indoors in barns or allowed to graze freely in the immediate proximity of farms, within either fenced or unfenced areas. The overall number of livestock heads and farms for each livestock category vary according to the area, i.e., alps/pre-alps, karstland, lowland (**Table 1**).

Table 1. Number of livestock heads and farms for each livestock category within the study area (FVG Region) and divided by area (alps/pre-alps, karstland, lowland). Data obtained from the National Institute of Statistics (ISTAT - <https://esploradati.istat.it/databrowser/#/it/censimentoagricoltura>). NA = Not available data.

Livestock category	Indicator	Alps/pre-alps	Karstland	Lowland	FVG
Sheep	Heads	20,067	1,800	1,054	22,921
	Farms	197	58	69	324
Goat	Heads	4,273	738	1,585	6,596
	Farms	198	78	132	408
Poultry	Heads	907,035	250,335	5,462,026	6,619,396
	Farms	305	261	855	1,421

144	Cattle	Heads	22,017	3,104	50,908	76,029
		Farms	500	123	713	1,336
145	Donkey	Heads	NA	NA	NA	NA
146		Farms	NA	NA	NA	NA

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148 131 **Data collection**

149 132 We analysed officially validated claims data collected between 2018 (the first year in which jackal damages on
150 133 livestock were registered) and 2024 by wildlife technicians, university researchers, veterinarians, and members of the
151 134 Forestry Service operating in the FVG Region, and stored in an Excel database. The dataset included information on: (i)
152 135 damage ID, (ii) Municipality, (iii) Province, (iv) date of the attack, (v) responsible predator, (vi) geographical
153 136 coordinates of each attack, (vii) affected livestock category, further divided by sex and age class when available, (viii)
154 137 total number of preyed upon, (ix) injured, and (x) missing individuals per attack, and (xi) compensation amount (Euros -
155 138 €). In the FVG Region, the compensation system for damages caused by carnivores is regulated under Articles 11 and
156 139 39 of Regional Law No. 6/2008 and Regional Decree No. 162/2020. Following the amendment of Article 11 of
157 140 Regional Law No. 6/2008 by Regional Law No. 28/2017, the jackal was included among the carnivore species, together
158 141 with the bear wolf and lynx, eligible for post-damage compensation claims. Claims for compensations must be
159 142 submitted within 72 hours of the discovery of the event, and damages are compensated at 100% of the verified amount.
160 143 Compensation is not provided when: (1) the carcass and elements useful to determine the cause of damage are absent;
161 144 (2) the carcass is present, but elements useful to determine the cause of damage are lacking; (3) the herder is responsible
162 145 for killing the predator; and (4) in cases of illegal grazing.

163 146 The threshold of >10 individuals was adopted following Gazzola et al. (2008) and Franchini et al. (2025b), who
164 147 used a similar definition to identify unusually severe predation events. This cut-off is intended to capture episodes
165 148 characterised by multiple killings or disappearances within a single predation event, which are generally interpreted as
166 149 “surplus killings” and represent ecologically and economically exceptional cases compared to standard single-prey
167 150 predatory events. Livestock attacks were attributed to jackals after *in-situ* inspections conducted by trained personnel
168 151 (i.e., wildlife technicians, Forestry Service members, veterinarians) following standardised protocols established by the
169 152 FVG Regional authorities. The responsible predator was identified based on field evidences such as footprints, scrapes,
170 153 throat and/or rear leg bite marks, and the distance between canine teeth. Considering that stray dogs are extremely rare
171 154 in Northern Italy, particularly in mountainous areas, officially validated claims provided reliable information on jackal-
172 155 related damages. Following the outbreak in the late 1990s of the neurodegenerative disease in cattle known as bovine
173 156 spongiform encephalopathy (BSE), and its human form, variant Creutzfeldt-Jakob disease (vCJD), European Union

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176 157 regulations mandated the removal and incineration of all livestock carcasses to prevent disease transmission (Donázar et
177 158 al., 2009; Margalida et al., 2010). Accordingly, after each *in-situ* inspection, livestock carcasses should be removed in
178 159 compliance with these regulations, also to reduce the likelihood of attracting carnivores near farms.

179 160 **Spatial analysis**

180 161 The spatial analysis was conducted using the QGIS Software (v. 3.40.4; QGIS Development Team, 2025).

181 162 We applied a buffer of 1.9 km of radius around each coordinate representing livestock damage events, in order to
182 163 reproduce the average home-range size of a jackal within a human-altered environment in Central Europe (~ 11 km²;
183 164 Fenton et al., 2021). Within each buffer we calculated the percentage of landscape (PLAND) of each habitat, starting
184 165 from the ESA WorldCover 2021 with a resolution of 10 m (Zanaga et al., 2022 - <https://worldcover2021.esa.int/>),
185 166 derived from Copernicus Sentinel Data, and converted into a shapefile layer. Habitat categories were re-classified as
186 167 follows: 'bare sparse vegetation', 'cropland', 'forest', 'grassland', 'herbaceous wetland', 'shrubland', 'urban area',
187 168 'riverbank'. The distance (m) of each attack (represented by coordinates) from the nearest urban and/or canopy-covered
188 169 area, i.e., forest or shrubland, was calculated in PostgreSQL through *ST_Distance* function
189 170 (<https://www.postgresql.org/docs/14/index.html>).

190 171 **Statistical analysis**

191 172 The statistical analysis was realised through the R Software (v. 4.4.2; R Core Team, 2024) and, for frequentist
192 173 statistics, the level of significance was set at 0.05.

193 174 In the analyses, both frequentist and Bayesian methods were applied: frequentist methods, i.e., Mann-Kendall
194 175 test (Mann, 1945; Kendall, 1975) and Fisher's exact test (Fisher, 1922), were used for descriptive and preliminary
195 176 analyses, while a Bayesian approach, i.e., Bayesian Generalised Linear Model (BGLM; Gelman et al., 2013), was
196 177 implemented for ecological inference. The adoption of a BGLM was motivated by the relatively small dataset available
197 178 for the regression analyses, which consisted of only 53 georeferenced predation events. These events were modelled as
198 179 a function of one categorical predictor (area: karst, alps/pre-alps, and lowland) and two continuous covariates (distance
199 180 to the nearest canopy-covered area and distance to the nearest urban area). Under these conditions, Bayesian estimation
200 181 provides more stable parameter estimates and more robust uncertainty quantification than maximum-likelihood
201 182 estimation, particularly when the number of observations available for model fitting is limited (e.g., Gelman & Hill,
202 183 2006; Filacorda et al., 2022; Franchini et al., 2022, 2025a; Franchini and Guerisoli, 2023; Gelman et al., 2025; Bikembo
203 184 et al., 2026).

206 185 To assess the presence of monotonic trends over time in (i) the overall number of livestock damages, (ii) the
207 186 amount of compensation, and (iii) the number of municipalities affected by livestock damages, we applied the non-
208 187 parametric Mann-Kendall test (Mann, 1945; Kendall, 1975). The test was implemented using the exact distribution of
209 188 the S statistic, which is suitable for detecting short-term temporal trends (Gilbert, 1987; Yue et al., 2002).

210 189 To explore (i) spatial variations in the number of livestock damages across areas (i.e., alps/pre-alps, karstland,
211 190 lowland), and seasons classified as autumn (September 21st – December 20th), winter (December 21st – March 20th),
212 191 spring (March 21st – June 20th), and summer (June 21st – September 20th); and (ii) habitat preferences for attack sites
213 192 compared to overall habitat availability either chi-square test or Fisher's exact test (when expected counts were < 5)
214 193 were used (Fisher, 1922). For post-doc pairwise comparisons between groups, the *pairwise nominal independence*
215 194 *function (pnif)* implemented in the 'rcompanion' R package (Mangiafico, 2024) was used.

216 195 The relationship between the number of livestock damages (response variable) and the distance (m) of each
217 196 attack from the nearest canopy-covered and urban area (covariates) within each area (predictor) was analysed using the
218 197 BGLM (Gelman et al., 2013), with a negative binomial distribution to account for data overdispersion (Zuur et al.,
219 198 2009). The model was fitted with four chains of 2,000 iterations each, including 1,000 warm-up iterations, using the
220 199 *stan_glm* R function from the 'rstanarm' R package (Goodrich et al., 2024). Given the absence of a priori evidence for a
221 200 directional effect of distance from urban or forested areas on damage intensity, weakly informative priors centred on
222 201 zero were specified (Gelman et al., 2025). The strength of the direction of the Bayesian predictors was assessed using
223 202 both the 95% credible interval (95% CI) and the probability of direction (pd), also referred to as the Maximum
224 203 Probability of Effect. The pd ranges from 50% to 100% and represents the probability that a parameter (as described by
225 204 its posterior distribution) is strictly positive or strictly negative (Makowski et al., 2019). A Bayesian regression
226 205 coefficient was considered to have a strong effect when zero lay outside the 95% CI, corresponding to a pd equal to, or
227 206 very close to, 100% (Murphy, 2012). Model *goodness-of-fit* was evaluated using: (i) the R-hat statistic, which measures
228 207 the convergence of the Markov Chain Monte Carlo (MCMC) chains (R-hat \approx 1 indicates good convergence), and (ii)
229 208 the Effective Sample Size (ESS), representing the effective number of independent samples from the posterior
230 209 distribution, with values above 400 considered adequate (Gelman et al., 2013).

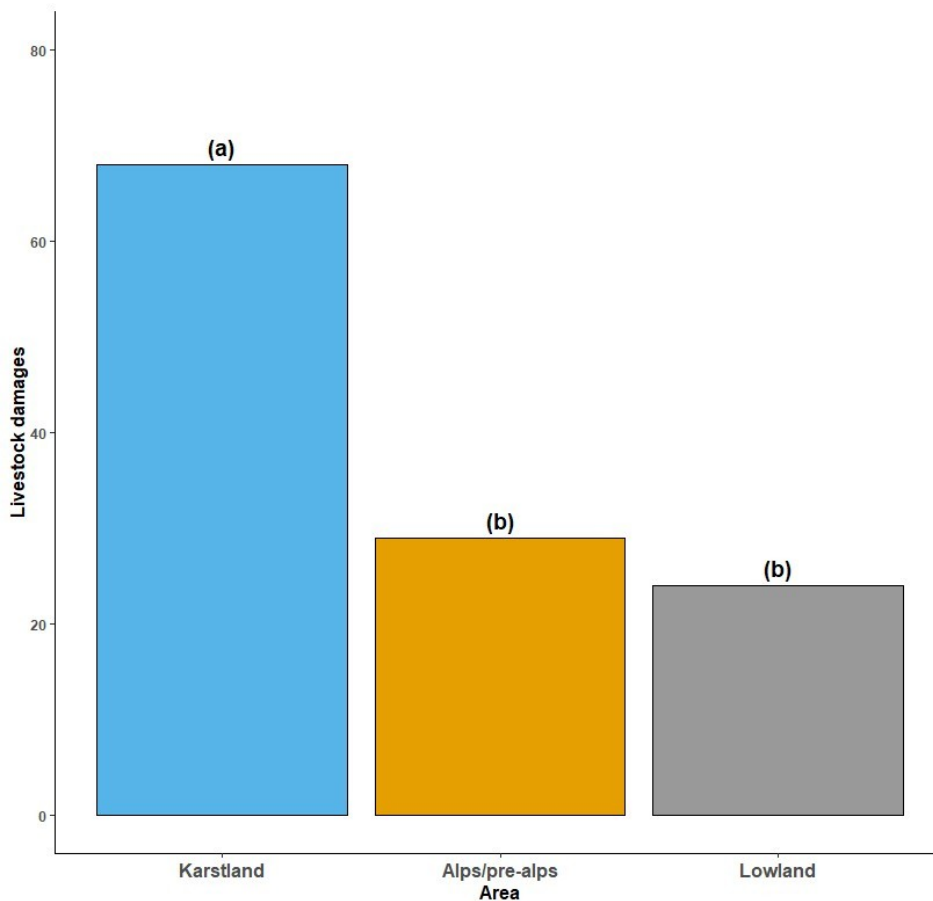
231 210 Prior to model inclusion, multicollinearity among covariates was assessed using the Variance Inflation Factor
232 211 (VIF) via the 'arm' R package (Gelman and Hill, 2006), with $VIF \geq 3$ indicating strong collinearity (Hair, 2014). To
233 212 enhance parameter estimation and priors' interpretability, covariates were standardized using the *mutate_at* R function
234 213 from the 'dplyr' R package (Wickham et al., 2023).

236 215 Results

239 216 **Spatio-temporal distribution of livestock damages**

240 217 From 2018 to 2024, $n = 121$ livestock damages (i.e., sum of preyed upon, injured, and missing individuals) were
241 218 recorded during $n = 53$ attacks by jackals, with an average of 2.3 ± 3.9 (SD) individuals damaged per attack. Of these
242 219 damages, $n = 107$ (88.4%) were attributed to predation, $n = 1$ (0.8%) to injury, and $n = 13$ (10.7%) to missing
243 220 individuals following the attack.

244 221 The majority of livestock damages were registered in the karstland ($n = 68$, 56.2%), followed by the alpine/pre-
245 222 alpine area ($n = 29$, 24.0%), and the lowland ($n = 24$, 19.8%). A significant difference was found in livestock damages
246 223 between areas ($\chi^2 = 43.2$, $p < 0.001$), and specifically between the karstland and the other areas (*pnif*, $p = 0.001$) (Fig.
247 224 2).



248 225
249 226 **Figure 2.** Number of livestock damages (i.e., sum of preyed upon, injured, and missing individuals) within each area.
250 227 Different letters over the bars indicate a significant difference ($p < 0.05$) in pairwise comparisons.

251 228 Most livestock damages were recorded in 2024, followed by 2023 and 2020 (**Table 2**), with a significant
252 229 positive monotonic trend observed across years ($S = 14.0$, $\tau = 0.7$, $z = 2.0$, $p = 0.04$).

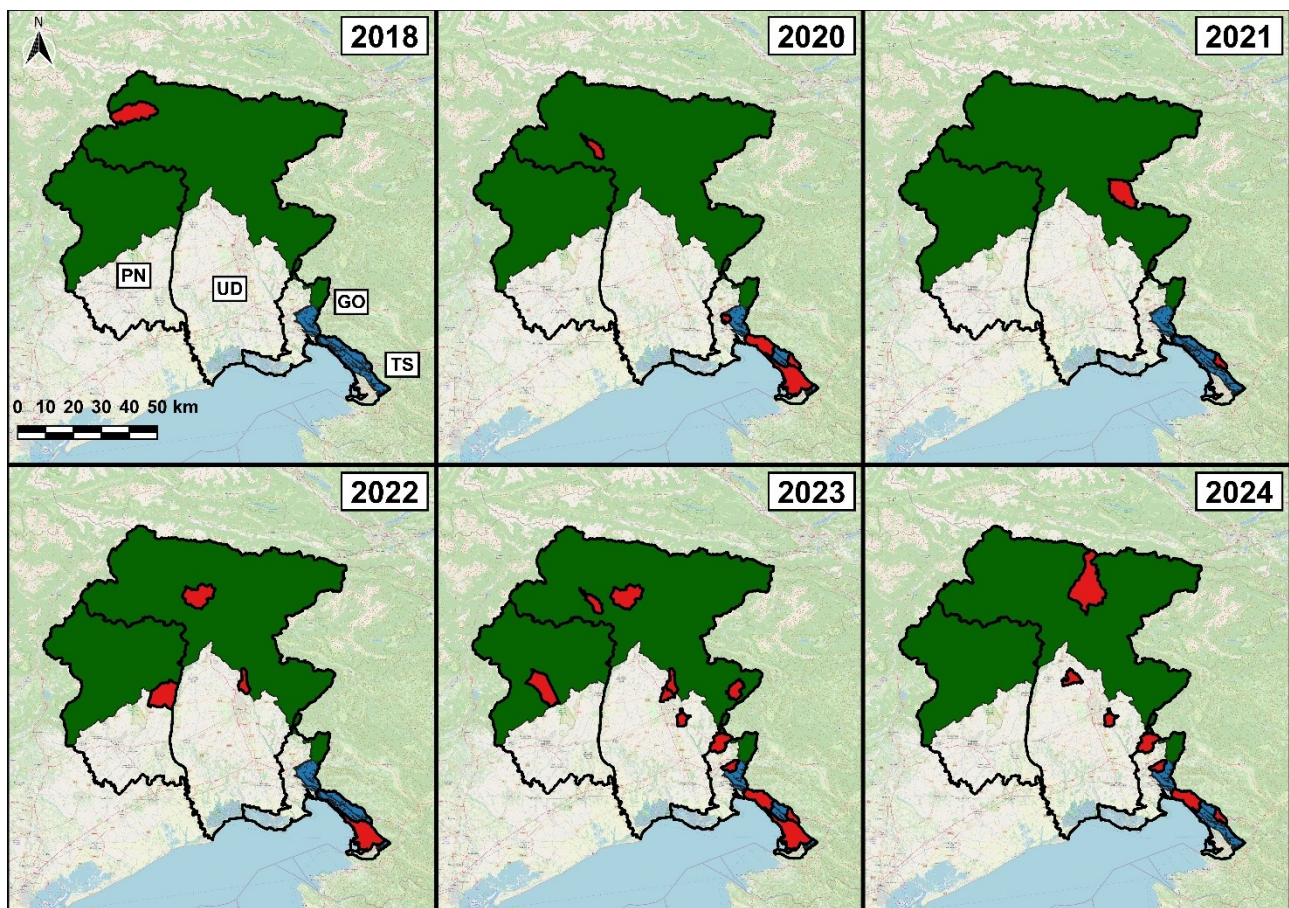
255 230 **Table 2.** Temporal trend in the number of livestock damage events (i.e., sum of preyed upon, injured, and missing
256 231 individuals), post-damage compensations (€), and municipalities affected by livestock damages.

Year	Livestock damages		Compensations (€)		Municipalities	
	n	%	n	%	n	%
2018	2	1.7	0	0.0	1	3.1
2019	0	0.0	0	0.0	0	0.0
2020	23	19.0	2,592	23.0	5	15.6
2021	10	8.3	1,400	12.4	3	9.4
2022	10	8.3	2,416	21.5	4	12.5
2023	30	24.8	2,444	21.7	12	37.5
2024	46	38.0	2,407	21.4	7	21.9
Total	121	100	11,259	100	32	100

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267 233 The highest post-damage compensations were registered in 2023, followed by 2022 and 2024 (**Table 2**), but a
268 234 non-significant positive monotonic trend was observed across years ($S = 8.0$, $\tau = 0.4$, $z = 1.1$, $p = 0.3$).

269 235 The number of municipalities involved into livestock damages was the highest in 2023, followed by 2024 and
270 236 2020 (**Table 2**; **Fig. 3**), with a marginally significant positive monotonic trend observed across years ($S = 13.0$, $\tau = 0.6$,
271 237 $z = 1.8$, $p = 0.07$).



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Figure 3. Temporal variation in the number of municipalities (in red) affected by livestock damage events (i.e., sum of preyed upon, injured, and missing individuals) within each area and across years. The alpine and pre-alpine boundaries were highlighted in green; while the karstland boundaries were highlighted in blue. The uncoloured area represents the lowland. Abbreviations (Provinces): PN = Pordenone; UD = Udine; GO = Gorizia; TS = Trieste.

Affected livestock categories

Most livestock damages were recorded mainly on sheep *Ovis aries*, followed by poultry (various avian species), donkey *Equus africanus asinus*, and cattle *Bos taurus* (**Table 3**).

Table 3. Number of livestock damage events (i.e., sum of preyed upon, injured, and missing individuals) on each livestock category divided by age class. NA = Not available data.

Livestock category	Age class	n	%
Sheep	Adult	47	62.7
	Sub-adult	0	0
	Lamb	28	37.3
	NA	0	0
Total	-	75	100
Poultry	Adult	0	0
	Sub-adult	0	0
	Chick	0	0
	NA	42	100
Total	-	42	100
Donkey	Adult	0	0
	Sub-adult	2	66.7
	Foal	1	33.3
	NA	0	0
Total	-	3	100
Cattle	Adult	0	0
	Sub-adult	0	0
	Calf	1	100
	NA	0	0
Total	-	1	100

With regard to the affected age classes, the majority of livestock damages in sheep involved adult individuals. Conversely, the few damages recorded on donkeys and cattle predominantly concerned juveniles and sub-adult individuals. For poultry, the age class was not identified (**Table 3**).

As for sex, most damages in sheep affected females (n = 44, 58.7%), followed by males (n = 3, 4.0%) and sex-
unidentified individuals (n = 28, 37.3%). Among donkeys, two cases (66.7%) involved females and one (33.3%) an
unidentified sex. In cattle and poultry, the sex of the affected individuals was not reported.

Regarding livestock breeds, most sheep damages involved the *Istriana* breed (n = 38, 50.7%), followed by half-
breeds (n = 17, 22.7%), *Comisana* (n = 4, 5.3%), and both *Sardinian* and *Suffolk* breeds (n = 1, 1.3% each). In 14 cases
(18.7%), the breed was not identified. Among donkeys, two damages (66.7%) involved half-breeds, while in one case
(33.3%) the breed was unidentified. The only cattle damage involved the *Pezzata Rossa* breed. Regarding poultry, nine
damages (21.4%) involved the *Muscovy duck* and four (9.5%) the *Leghorn chicken*, whereas in 29 cases (69.1%) the
breed was not identified.

Considering the average number of livestock individuals affected per attack, poultry experienced the highest
impact (**Table 4**). Indeed, the only surplus damage event (0.2%) was registered on poultry, with 27 affected individuals
(sum of preyed upon, injured and missing individuals) during a single attack.

Table 4. Average number of livestock damages (sum of preyed upon, injured and missing individuals) divided by
livestock category. Abbreviation: SD = standard deviation. The range defines the minimum and maximum number of
damaged individuals during a single attack.

Livestock category	Number of attacks	Livestock damages	Mean	SD	Range
Sheep	44	75	1.7	1.6	1–10
Poultry	5	42	8.4	10.9	1–27
Donkey	3	3	1.0	0.0	1–1
Cattle	1	1	1.0	0.0	1–1

Seasonal variations in livestock damages

In the karstland, the highest livestock damages were registered in autumn (n = 38, 55.9%), followed by summer
(n = 23, 33.8%), spring (n = 5, 7.3%), and winter (n = 2, 3.0%). A significant difference was found in livestock
damages across seasons (Fisher's test, $p < 0.001$). Specifically, between autumn and all the other seasons ($pnif$, $p <$
0.05), as well as between summer and spring ($pnif$, $p < 0.001$), and summer and winter ($pnif$, $p < 0.001$) (**Fig. 4a**).

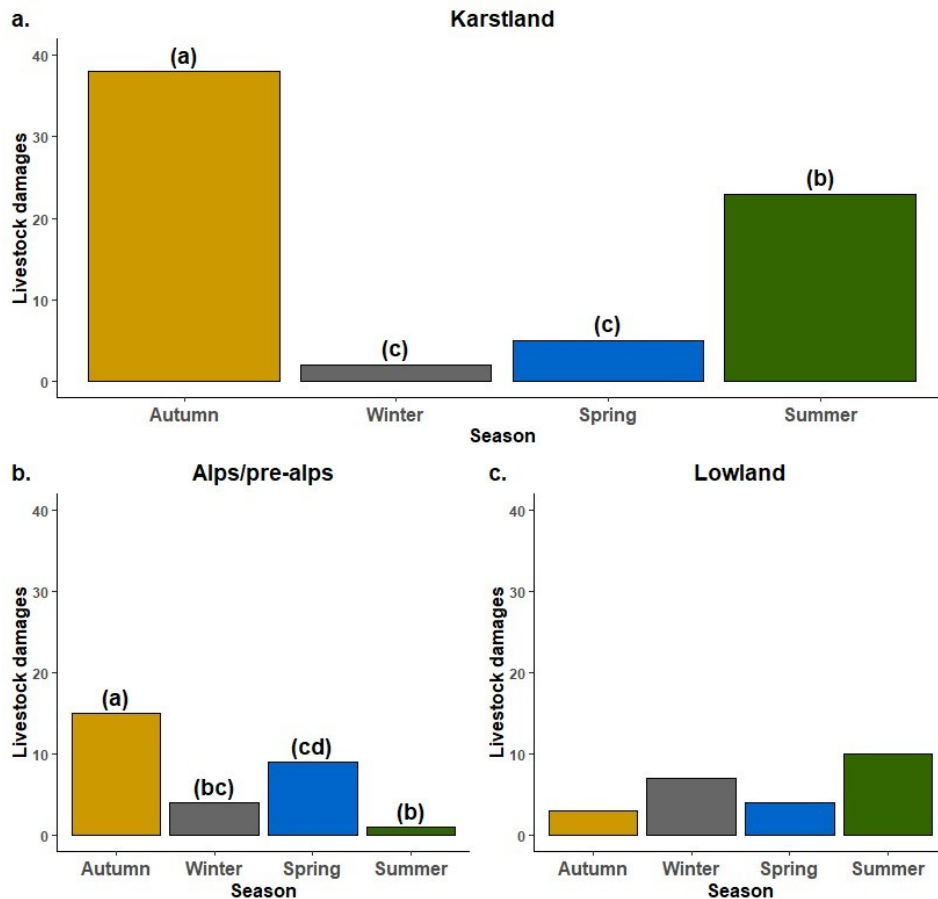


Figure 4. Seasonal variations in the number of livestock damage events (i.e., sum of preyed upon, injured, and missing individuals) across areas: (a) karstland, (b) alps/pre-alps, (c) lowland. Different letters over the bars indicate a significant difference ($p < 0.05$) in pairwise comparisons.

Regarding the alpine/pre-alpine territories, the majority of livestock damages were recorded in autumn ($n = 15$, 51.7%), followed by spring ($n = 9$, 31.0%), winter ($n = 4$, 13.8%), and summer ($n = 1$, 3.5%). A significant difference was found in livestock damages across seasons (Fisher's test, $p < 0.001$). Specifically, between autumn and summer ($pnif$, $p < 0.001$), autumn and winter ($pnif$, $p = 0.01$), and summer and spring ($pnif$, $p < 0.02$) (Fig. 4b).

In the lowland, the highest number of livestock damages was reported in summer ($n = 10$, 41.7%), followed by winter ($n = 7$, 29.2%), spring ($n = 4$, 16.7%), and autumn ($n = 3$, 12.4%). A marginally significant difference was found in livestock damages across seasons (Fisher's test, $p = 0.09$) (Fig. 4c).

Habitat features influencing the likelihood of attacks and damages on livestock

In the karstland, the highest number of attacks on livestock was registered in forests, followed by grasslands (Table 5). In the Alpine/pre-alpine territories, the majority of attacks occurred within forests, followed by grasslands,

351 287 and urban areas; while in the lowland, most attacks were recorded in grasslands, followed by forests, croplands, and
352 288 urban areas (**Table 5**).

353 289 **Table 5.** Percentage of landscape (PLAND) of each habitat calculated within each buffer, along with the number and
354 290 percentage of jackal's attacks on livestock within every habitat.

Area	Habitat	PLAND	Attacks	
			n	%
Karstland	Bare sparse vegetation	0.2	0	0.0
	Cropland	1.1	0	0.0
	Forest	79.7	20	90.9
	Grassland	9.3	2	9.1
	Herbaceous wetland	0.0	0	0.0
	Shrubland	0.7	0	0.0
	Urban area	7.1	0	0.0
	Riverbank	2.0	0	0.0
Total		100	22	100
Alps/pre-alps	Bare sparse vegetation	0.9	0	0.0
	Cropland	5.5	0	0.0
	Forest	71.6	12	75.0
	Grassland	18.4	3	18.8
	Herbaceous wetland	0.0	0	0.0
	Shrubland	0.0	0	0.0
	Urban area	2.0	1	6.3
	Riverbank	1.6	0	0.0
Total		100	16	100
Lowland	Bare sparse vegetation	0.7	0	0.0
	Cropland	32.8	1	6.7
	Forest	27.9	4	26.7
	Grassland	31.3	9	60.0
	Herbaceous wetland	0.0	0	0.0
	Shrubland	0.3	0	0.0
	Urban area	6.5	1	6.7
	Riverbank	0.3	0	0.0
Total		100	15	100

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381 292 With regard to habitat preferences for attack sites compared to overall habitat availability, no significant
382 293 differences were found between observed and expected frequencies in karstland (Fisher's test, $p = 0.5$), alpine/pre-
383 294 alpine areas (Fisher's test, $p = 1.0$), and lowland (Fisher's test, $p = 0.3$).

384 295 In the karstland, attacks occurred between roughly 12 and 455 m from the nearest urban area, and between 0 and
385 296 approximately 11 m from the nearest canopy-covered area. In alpine and pre-alpine areas, livestock attacks occurred at

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distances ranging from 0 to approximately 732 m from the nearest urban area, and from 0 to about 57 m from the nearest canopy-covered area. In the lowland, attacks were recorded at distances ranging from 0 to about 306 m from the nearest urban area, and from 0 to approximately 186 m from the nearest canopy-covered area. However, the results obtained from the BGLM revealed that all the considered covariates/predictors showed no clear tendency towards either a positive or negative direction (Table 6).

Table 6. Effect of the considered covariates/predictors on livestock damage events. Abbreviations: Urban = distance from the nearest urban area (m); Canopy = distance from the nearest canopy-covered area (m); 95% CI = 95% confidence interval; pd = probability of direction; R-hat = index of convergence of the Markov Chain Monte Carlo (MCMC) chains; ESS = effective sample size. Interactions between covariates and predictors are denoted by “:”.

Covariates/Predictors	Median	95% CI	pd	R-hat	ESS
Area	-0.9	-4.5 – 2.6	70.1%	1.0	2634
Urban	0.2	-0.7 – 0.2	84.5%	1.0	2869
Canopy	0.7	-0.5 – 2.0	87.9%	1.0	2444
Area:Urban	0.7	-1.2 – 2.7	76.2%	1.0	2704
Area:Canopy	-3.8	-11.7 – 4.2	84.4%	1.0	2657

Discussion

This research represents the first significant scientific contribution to understanding the impact of jackals on agro-livestock practices in the Eastern Italian Alps. Moreover, it constitutes the first study conducted in Italy on this topic, thereby contributing to fill the existing knowledge gap regarding the species' socio-economic implications in the Italian Peninsula.

In line with our initial prediction, the highest number of livestock damages occurred in the karstland, where jackals reach their greatest abundances (Lapini et al., 2018, 2021; Frangini et al., 2025), most likely due to the high habitat suitability and connectivity values recorded in this area (Torretta et al., 2020; Frangini et al., 2022). The significant positive monotonic trend in livestock damages observed over the years suggests, as reported for other social carnivores like the wolf, either an increase in damages associated with an increasing population trend (Franchini et al., 2025b), or the presence of specific individuals repeatedly attacking livestock (Mayer et al., 2022). Further research incorporating individual behavioural patterns is needed to provide additional insights. Moreover, although not fully significant, the expansion observed in the spatial distribution of municipalities affected by livestock damages supports the ongoing natural colonisation process of the species across the FVG Region (Lapini et al., 2018, 2021; Frangini et al., 2025) and in Europe (Spasov and Acosta-Pankov, 2019; Ranc et al., 2026).

421 322 As for livestock damages, the high number of damages observed on poultry is consistent with the preferred prey
422 323 weight range reported for jackals, i.e., 0–4 kg (Hayward et al., 2017). Moreover, a surplus killing event involving
423 324 poultry was recorded, with 27 individuals killed during a single attack. Livestock species are more susceptible to
424 325 surplus predations when they are confined within artificial environments (e.g., fenced areas) and are unable to escape
425 326 (Jackson, 2015; Akrim et al., 2021; Parchizadeh et al., 2024). This can lead to higher livestock mortality than in free-
426 327 ranging open habitats (Gazzola et al., 2008; Bijoor et al., 2021; Parchizadeh et al., 2024). In this case, it is likely that the
427 328 jackal(s) managed to enter a henhouse or fenced enclosure, resulting in the killing of multiple individuals during a
428 329 single event.

429 330 The predominance of damages on sheep (37% on lambs and 63% on adults), the two cases recorded on sub-adult
430 331 donkeys (one individual that died due to posterior lesions and another that was euthanised the following day as a
431 332 consequence of injuries to the perianal and perivaginal areas), and two single damage events involving a calf and a
432 333 donkey foal, respectively, are consistent with patterns reported for other medium-sized carnivores, such as coyotes
433 334 *Canis latrans*, where predation rates have been shown to increase with the availability of small- to medium-sized
434 335 livestock (e.g., Sacks and Neale, 2007; McInturff et al., 2021; Torres-Romero et al., 2023). Adult sheep, calves, and
435 336 donkey sub-adults or foals fall outside the preferred prey weight range of jackals (Hayward et al., 2017). However, the
436 337 species' social behaviour may provide an explanation. Solitary jackals mainly rely on small-sized prey such as hares,
437 338 birds, or rodents (Kalandarishvili et al., 2024), but when they aggregate into packs their hunting efficiency increases
438 339 markedly (Mahmood et al., 2013), enabling them to successfully prey upon medium- or large-sized ungulates (Jhala and
439 340 Moehlman, 2004). Although we were not able to explore preferences towards specific livestock categories (including
440 341 sex, age class, or breed), approximately 59% of damages on adult sheep involved females. This may suggest that the
441 342 body size of females (larger than lambs but smaller than adult males), combined with ineffective anti-predatory
442 343 behaviour and the absence of defensive weaponry (e.g., horns), may make them more profitable prey for jackals.

443 344 Regarding the livestock breeds involved, approximately 30% of poultry damages affected *Leghorn chickens* or
444 345 *Muscovy ducks*. Among ovines, about 57% of damages involved *Comisana*, *Istriana*, or *Suffolk sheep*. All these breeds
445 346 are classified as either 'Vulnerable' or 'Endangered' of extinction at national or global level by the Food and
446 347 Agriculture Organization of the United Nations (FAO; <https://www.fao.org/dad-is/browse-by-country-and-species/en/>).
447 348 In the context of compensation schemes, one of the most frequent concerns raised by herders is the lack of
448 349 consideration for indirect damages, including the conservation status of the affected animals (Franchini et al., 2025a).
449 350 Therefore, further research aimed at assessing in detail the impact of jackals (and carnivores more broadly) on specific
450 351 livestock breeds is essential for developing more appropriate and equitable compensation policies.

453 352 Regarding seasonal livestock damages, in the karstland the majority occurred during autumn and summer, when
454 353 livestock are left to graze freely within fenced areas and are generally not enclosed in barns at night. In the alpine and
455 354 pre-alpine areas, the higher number of damages observed during autumn and spring coincides with the transhumance
456 355 period (Orland, 2004; Faccioni et al., 2015), when livestock are moved to higher elevations to graze in open grasslands
457 356 and are potentially more exposed to carnivore attacks (Faccioni et al., 2015; Franchini et al., 2025b, 2026).

458 357 In line with our initial predictions, we observed a proportional use of the available habitats as suitable attack
459 358 sites, along with a high occurrence of attacks in close proximity to human settlements. Across all considered areas (i.e.,
460 359 alps/pre-alps, karstland, lowland), approximately 28% of attacks occurred within 50 m of the nearest human building.
461 360 These findings confirm the remarkable ecological and behavioural adaptability of jackals, which allows the species to
462 361 occupy a wide spectrum of habitats (including near human settlements) under diverse climatic conditions across
463 362 different European countries (Arnold et al., 2012; Rutkowski et al., 2015; Trouwborst et al., 2015; Krofel et al., 2017;
464 363 Travain et al., 2024). Furthermore, jackals are known to effectively exploit human-modified landscapes by taking
465 364 advantage of anthropogenic food resources (Šalek et al., 2014; Ćirović et al., 2016; Lanszki et al., 2018; Fenton et al.,
466 365 2021; Ranc et al., 2026).

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468 367 **Research limitations**

469 368 The main limitations of this research are linked to the absence of certain information regarding the adopted
470 369 livestock husbandry system in each area. First, due to privacy restrictions, the lack of data on the location of each
471 370 affected farm prevented us from analysing the distance of each attack from the farm and from identifying potential
472 371 conflict hotspots. Second, the absence of information on the grazing system adopted for each livestock species (e.g.,
473 372 free-ranging, rotational, mixed) did not enable us to determine which husbandry practices are more vulnerable to
474 373 attacks. Third, the lack of data on the total number of livestock reared in each farm (divided by species, sex, age class,
475 374 and breed) prevented us from assessing potential jackal preferences for specific livestock categories. Finally, the
476 375 absence of information on the use of prevention measures, data often unavailable, especially in large-scale studies
477 376 (Oliveira et al., 2021; Singer et al., 2023; Franchini et al., 2025b, 2026), did not allow us to evaluate their effectiveness
478 377 in reducing jackal attacks on livestock. We suggest that, in the future, the inclusion of this information would greatly
479 378 contribute to obtaining a more comprehensive description of jackal-related damages to livestock practices.

480 379 Additionally, the majority of livestock damages, particularly in the karstland and alpine/pre-alpine areas, were
481 380 recorded within forests. However, in these regions, forest environments typically form a mosaic of wooded areas (the
482 381 dominant habitat) interspersed with open grasslands. This fine-scale habitat heterogeneity is generally not captured by

the land cover shapefiles available for habitat analyses. Consequently, it is plausible that some damage events (especially those involving sheep, which avoid forests as feeding areas due to their grazing behaviour) actually occurred in grasslands adjacent to forest patches, but the coarse spatial resolution of the land cover data prevented such distinctions.

Conclusions and future perspectives

Although the impact of jackals on livestock in the FVG Region could be considered low compared to that of other social carnivore species such as the wolf (Franchini et al., 2025b), the continued expansion of the species, particularly in recent years, highlights the need to maintain long-term monitoring in the Region to prevent further potential impacts on livestock practices. In addition, it is important to consider that the classification of livestock damages as “low” should always be contextualised according to livestock availability in each farm. Indeed, some farms may experience higher predation rates than others, consequently suffering greater economic losses (Franchini et al., 2025a). In this regard, collecting detailed information on livestock numbers per farm (including sex, age class, and breed) becomes crucial to accurately assess the socio-economic impact of this meso-predator.

The implementation of proper preventive measures, such as electrified fences, night enclosures, and livestock guardian dogs (LGDs), is essential to reduce or prevent the impact of jackals on livestock. However, the most suitable measure may vary depending on the environmental context and adopted livestock management system, and therefore should be evaluated a priori. For example, in alpine or pre-alpine territories, the installation of electrified fences may not always be practical, particularly in large, steep grasslands or rocky terrains. In such cases, LGDs may be more effective, although their use should also consider the presence of tourism in the area. Conversely, in lowland areas, where animals are kept near farms, night enclosures into barns and/or electrified fences may be appropriate. In the karstland, the consistent presence of dense vegetation can hinder the implementation of electrified fences, while hunting activities may make LGDs impractical due to potential negative interactions with hunting dogs. In these contexts, night enclosures and/or the use of alternative guarding animals, such as donkeys, is suggested. In this research, we observed that sub-adult donkeys and/or foals may occasionally fall prey to jackals. Nevertheless, adult donkeys are effective and widely used guarding animals for protecting flocks against medium- to large-bodied predators (Gese, 2003; Guerisoli et al., 2017). The protective behaviour displayed by donkeys apparently stems from their apparent dislike of dogs (Gese, 2003). However, in order to be effective: (i) one donkey per flock should be used while the other donkeys should be kept away or the animal will bond with them, (ii) females or neutered males should be preferred, as intact males may display aggressiveness towards livestock, (iii) they are more effective in small fenced areas, and (iv) the donkey should

517 412 be introduced to the flock when they became independent to properly bond with the animals (Gese, 2003). The
518 413 advantages linked to the use of donkeys derives from the fact that these animals develop a strong territoriality, they
519 414 quickly bond with the flock (typically in from four to six weeks), and do not require specific feeding. They can in fact
520 415 be penned with the flock and have a longer life expectancy compared to LGDs (Gese, 2003).

521 416 Extensive livestock practices represent a historical and cultural heritage for local communities and are designed
522 417 to meet human needs. Additionally, they provide essential ESs and contribute substantially to biodiversity and
523 418 landscape preservation (Battaglini et al., 2014; Salvador et al., 2017; Pachoud et al., 2020). Similarly, the presence of
524 419 jackals plays a key ecological role as scavengers, reducing the risk of disease spread and thereby indirectly benefiting
525 420 both the environment and human populations (Ćirović et al., 2016). Given their fundamental role in ecosystem
526 421 preservation, effective management and conservation interventions are therefore essential to promote long-term
527 422 coexistence between jackals and human activities in shared landscapes.

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556 449 **Data availability statement**

557 450 The data presented in this study were shared by the Friuli Venezia Giulia Region. Data are not publicly available due to
558 451 privacy reasons.

559 452 **Author contributions**

560 453 MF, SR, and SB conceived the study; SP conducted the kill-site inspections; SR conducted the spatial analysis; MF
561 454 conducted the statistical analysis; MF and SR wrote the first draft of the manuscript; MC and SB supervised the
562 455 research. All authors contributed to reviewing and editing the final version of the manuscript and approve it before
563 456 submission.

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573 466 The authors declare they have no known conflicts of interests to disclose.

574 467 **Generative AI statement**

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577 468 The authors declare that no Generative AI was used in the creation of this manuscript.

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Table 1. Number of livestock heads and farms for each livestock category within the study area (FVG Region) and divided by area (alps/pre-alps, karstland, lowland). Data obtained from the National Institute of Statistics (ISTAT - <https://esploradati.istat.it/databrowser/#/it/censimentoagricoltura>). NA = Not available data.

Livestock category	Indicator	Alps/pre-alps	Karstland	Lowland	FVG
Sheep	Heads	20,067	1,800	1,054	22,921
	Farms	197	58	69	324
Goat	Heads	4,273	738	1,585	6,596
	Farms	198	78	132	408
Poultry	Heads	907,035	250,335	5,462,026	6,619,396
	Farms	305	261	855	1,421
Cattle	Heads	22,017	3,104	50,908	76,029
	Farms	500	123	713	1,336
Donkey	Heads	NA	NA	NA	NA
	Farms	NA	NA	NA	NA

Table 2. Temporal trend in the number of livestock damage events (i.e., sum of preyed upon, injured, and missing individuals), post-damage compensations (€), and municipalities affected by livestock damages.

Year	Livestock damages		Compensations (€)		Municipalities	
	n	%	n	%	n	%
2018	2	1.7	0	0.0	1	3.1
2019	0	0.0	0	0.0	0	0.0
2020	23	19.0	2,592	23.0	5	15.6
2021	10	8.3	1,400	12.4	3	9.4
2022	10	8.3	2,416	21.5	4	12.5
2023	30	24.8	2,444	21.7	12	37.5
2024	46	38.0	2,407	21.4	7	21.9
Total	121	100	11,259	100	32	100

Table 3. Number of livestock damage events (i.e., sum of preyed upon, injured, and missing individuals) on each livestock category divided by age class. NA = Not available data.

Livestock category	Age class	n	%
Sheep	Adult	47	62.7
	Sub-adult	0	0
	Lamb	28	37.3
	NA	0	0
Total	-	75	100
Poultry	Adult	0	0
	Sub-adult	0	0
	Chick	0	0
	NA	42	100
Total	-	42	100
Donkey	Adult	0	0
	Sub-adult	2	66.7
	Foal	1	33.3
	NA	0	0
Total	-	3	100
Cattle	Adult	0	0
	Sub-adult	0	0
	Calf	1	100
	NA	0	0
Total	-	1	100

Table 4. Average number of livestock damages (sum of preyed upon, injured and missing individuals) divided by livestock category. Abbreviation: SD = standard deviation. The range defines the minimum and maximum number of damaged individuals during a single attack.

Livestock category	Number of attacks	Livestock damages	Mean	SD	Range
Sheep	44	75	1.7	1.6	1–10
Poultry	5	42	8.4	10.9	1–27
Donkey	3	3	1.0	0.0	1–1
Cattle	1	1	1.0	0.0	1–1

Table 5. Percentage of landscape (PLAND) of each habitat calculated within each buffer, along with the number and percentage of jackal's attacks on livestock within every habitat.

Area	Habitat	PLAND	Attacks	
			n	%
Karstland	Bare sparse vegetation	0.2	0	0.0
	Cropland	1.1	0	0.0
	Forest	79.7	20	90.9
	Grassland	9.3	2	9.1
	Herbaceous wetland	0.0	0	0.0
	Shrubland	0.7	0	0.0
	Urban area	7.1	0	0.0
	Riverbank	2.0	0	0.0
Total		100	22	100
Alps/pre-alps	Bare sparse vegetation	0.9	0	0.0
	Cropland	5.5	0	0.0
	Forest	71.6	12	75.0
	Grassland	18.4	3	18.8
	Herbaceous wetland	0.0	0	0.0
	Shrubland	0.0	0	0.0
	Urban area	2.0	1	6.3
	Riverbank	1.6	0	0.0
Total		100	16	100
Lowland	Bare sparse vegetation	0.7	0	0.0
	Cropland	32.8	1	6.7
	Forest	27.9	4	26.7
	Grassland	31.3	9	60.0
	Herbaceous wetland	0.0	0	0.0
	Shrubland	0.3	0	0.0
	Urban area	6.5	1	6.7
	Riverbank	0.3	0	0.0
Total		100	15	100

Table 6. Effect of the considered covariates/predictors on livestock damage events. Abbreviations: Urban = distance from the nearest urban area (m); Canopy = distance from the nearest canopy-covered area (m); 95% CI = 95% confidence interval; pd = probability of direction; R-hat = index of convergence of the Markov Chain Monte Carlo (MCMC) chains; ESS = effective sample size. Interactions between covariates and predictors are denoted by “:”.

Covariates/Predictors	Median	95% CI	pd	R-hat	ESS
Area	-0.9	-4.5 – 2.6	70.1%	1.0	2634
Urban	0.2	-0.7 – 0.2	84.5%	1.0	2869
Canopy	0.7	-0.5 – 2.0	87.9%	1.0	2444
Area:Urban	0.7	-1.2 – 2.7	76.2%	1.0	2704
Area:Canopy	-3.8	-11.7 – 4.2	84.4%	1.0	2657

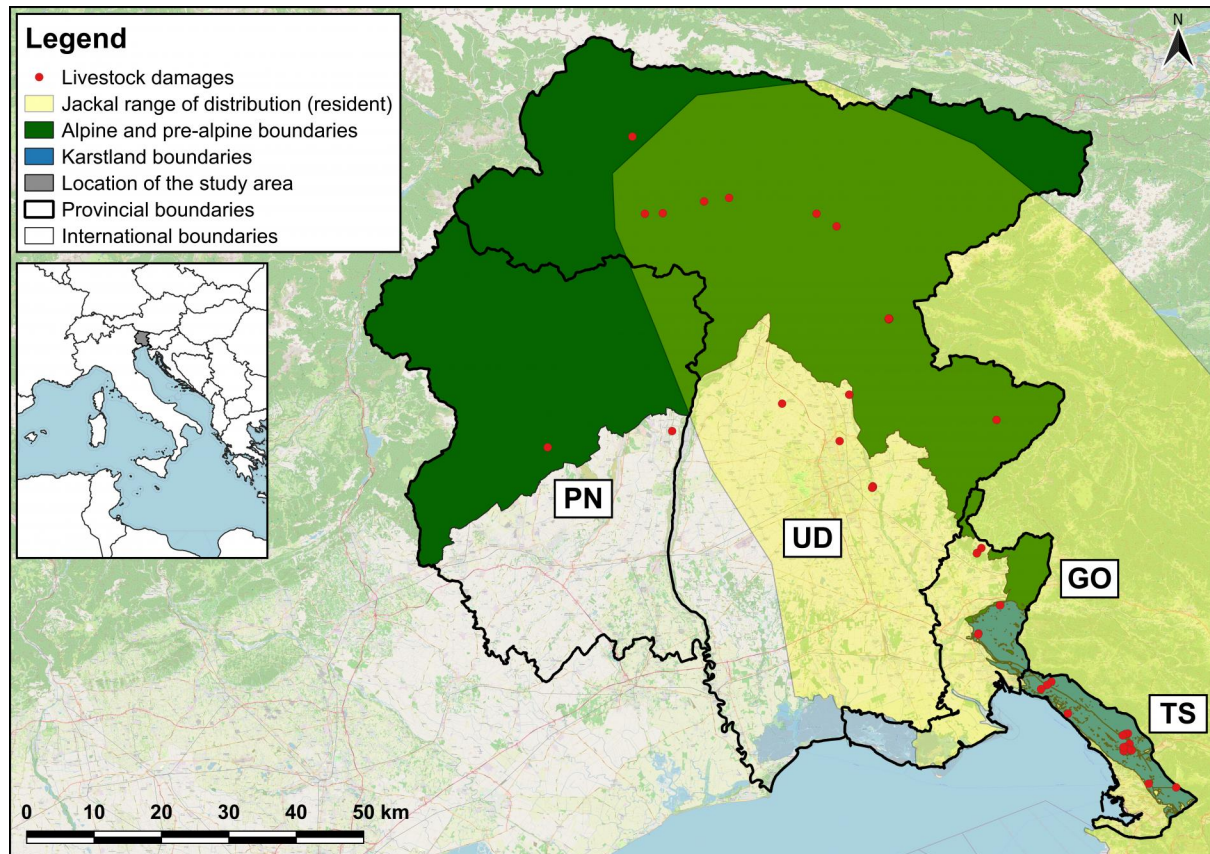
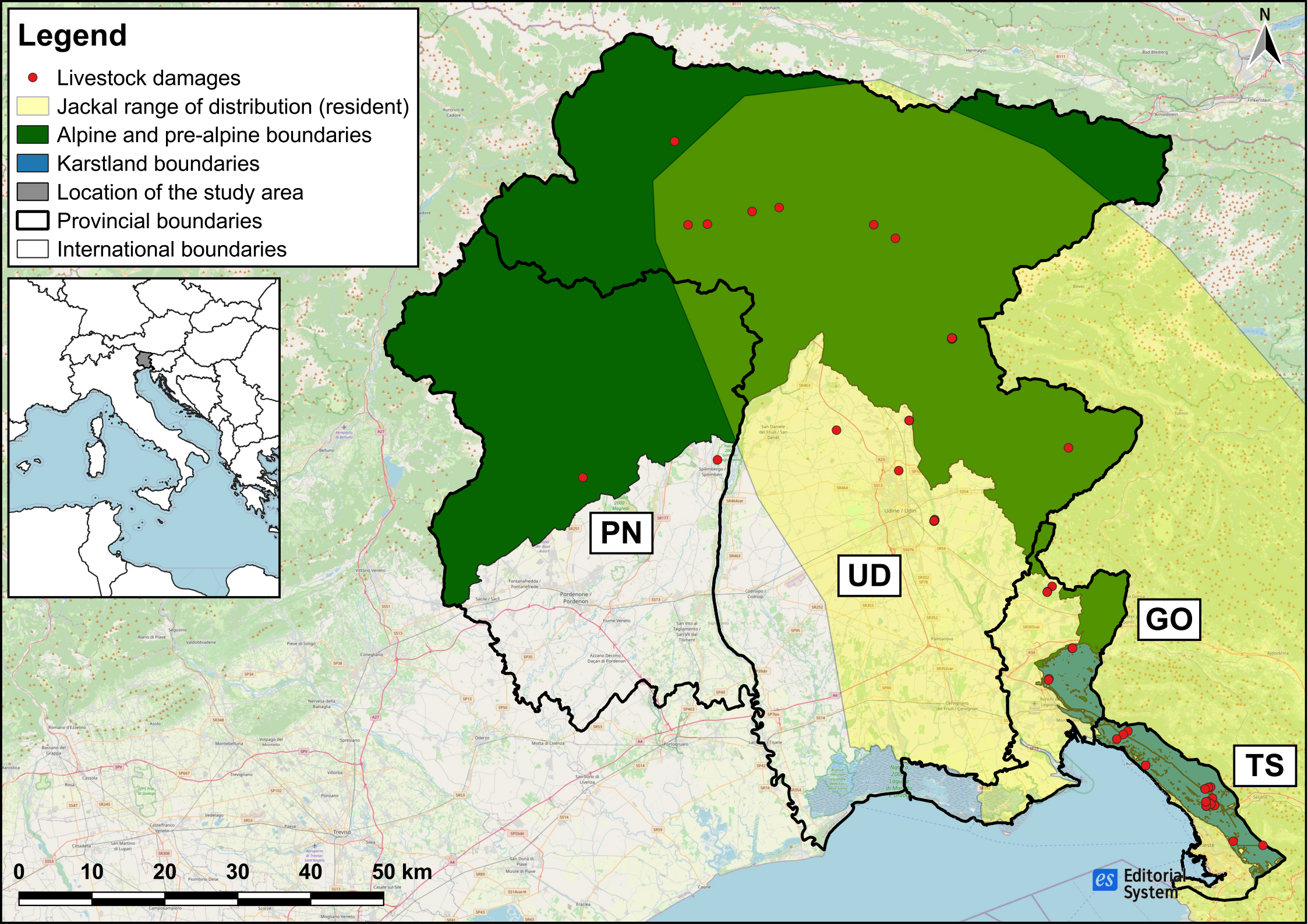
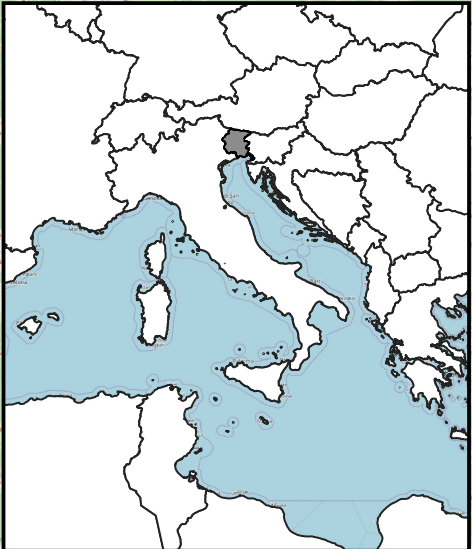


Figure 1. Location of the study area (FVG Region; inset map), jackal range of distribution (IUCN, 2018), and coordinates of livestock damage events (i.e., sum of preyed upon, injured, and missing individuals) within each area. The uncoloured area indicates the lowland territories. Abbreviations (Provinces): PN = Pordenone; UD = Udine; GO = Gorizia; TS = Trieste.

Legend

- Livestock damages
- Jackal range of distribution (resident)
- Alpine and pre-alpine boundaries
- Karstland boundaries
- Location of the study area
- Provincial boundaries
- International boundaries



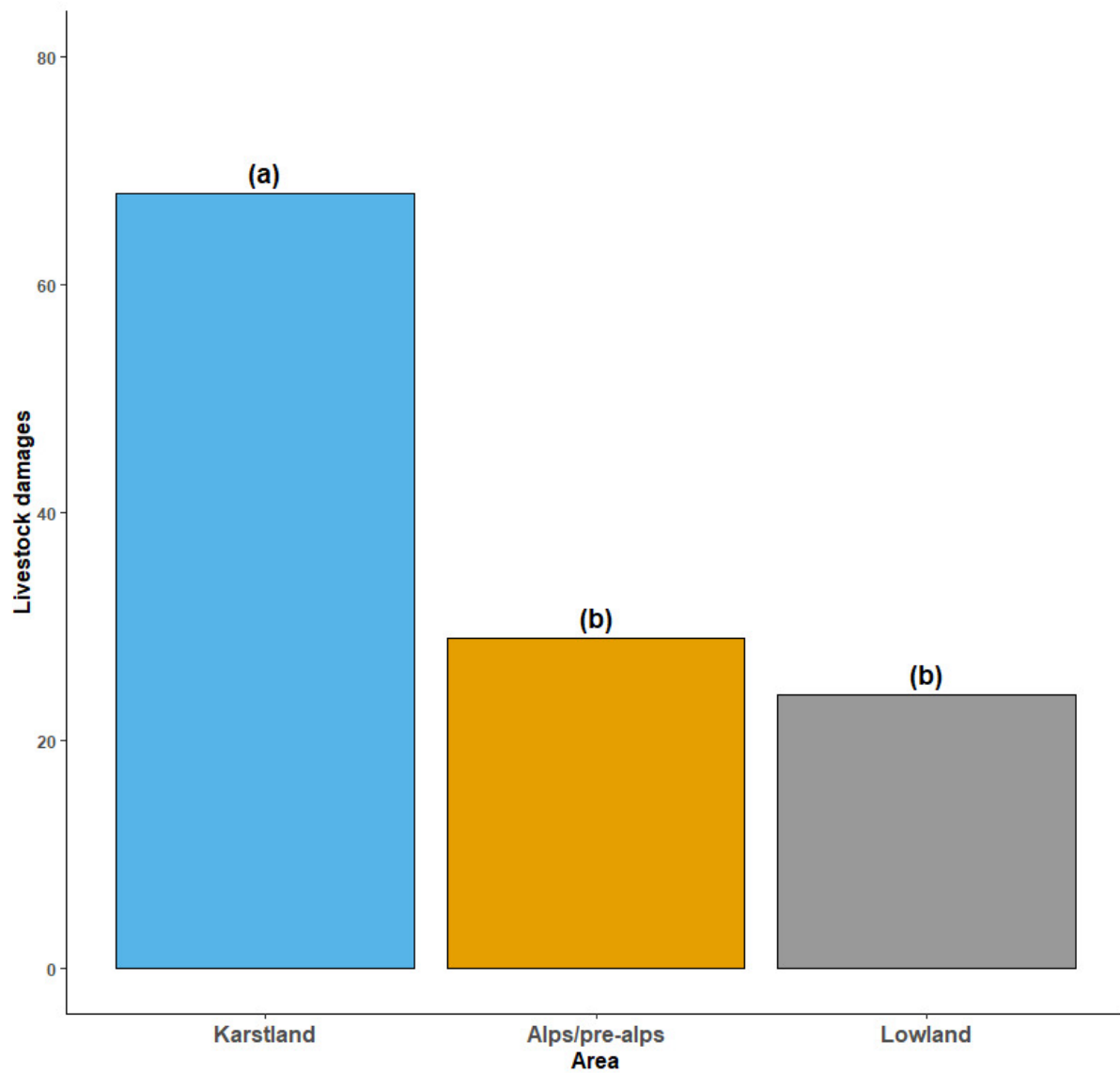
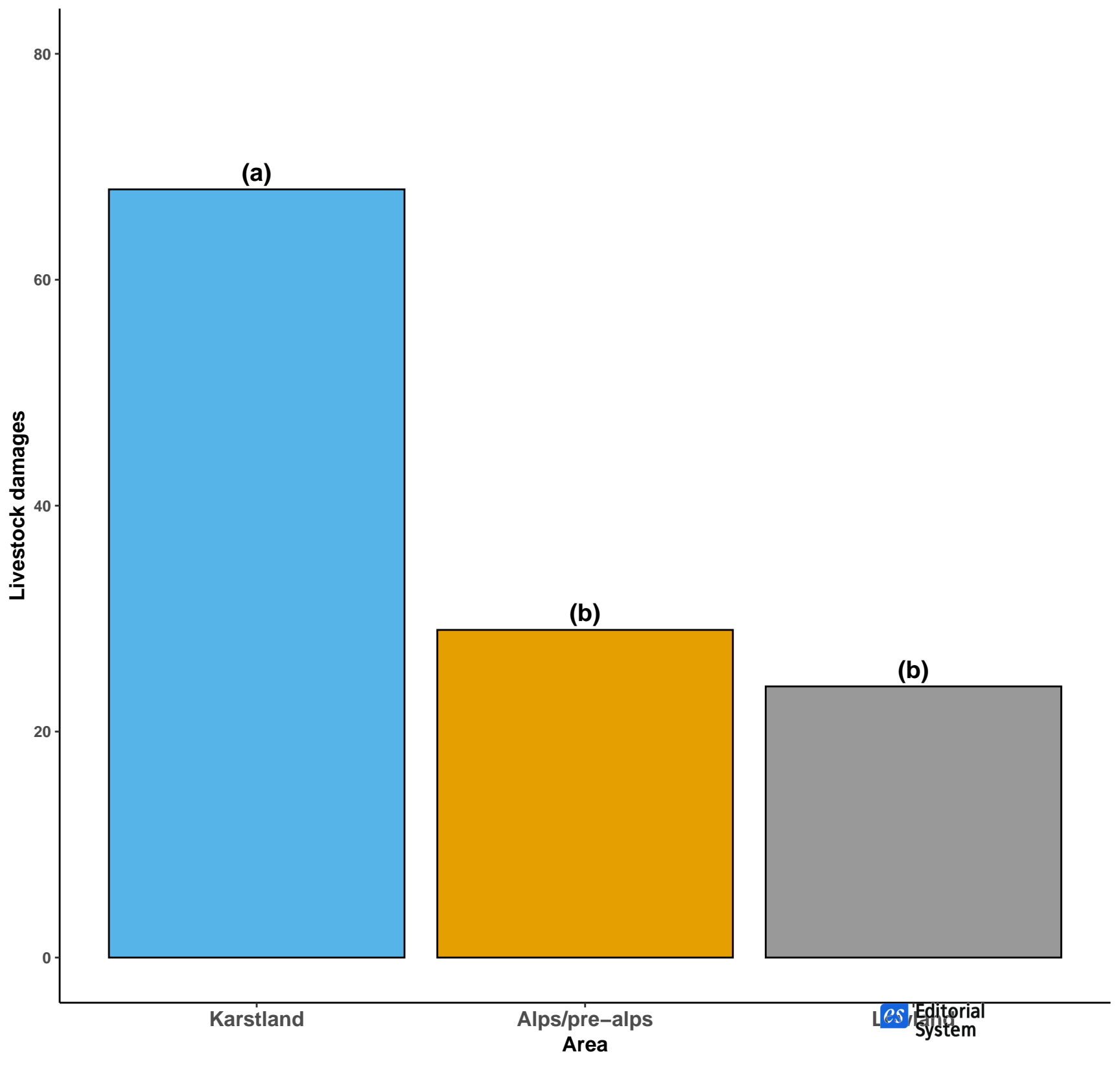


Figure 2. Number of livestock damages (i.e., sum of preyed upon, injured, and missing individuals) within each area. Different letters over the bars indicate a significant difference ($p < 0.05$) in pairwise comparisons.



(a)

(b)

(b)

Karstland

Alps/pre-alps
Area

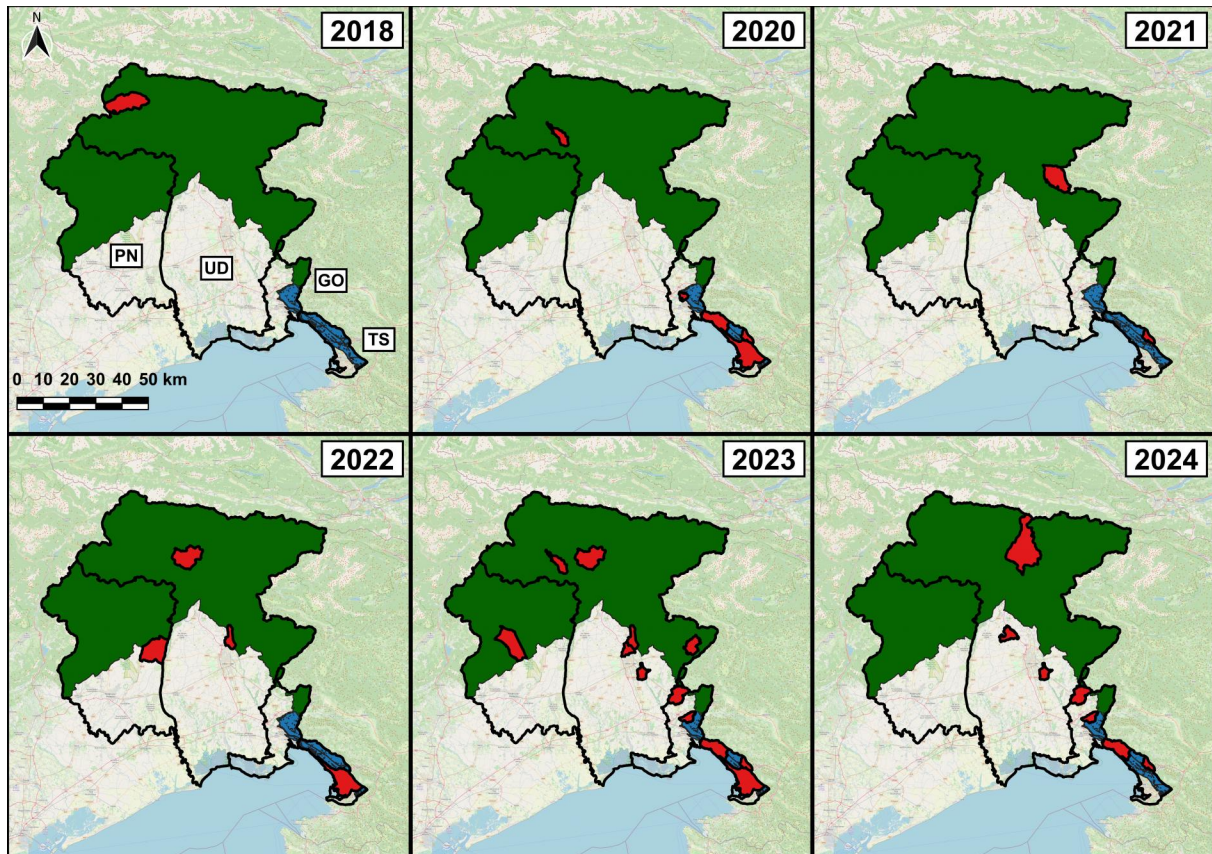
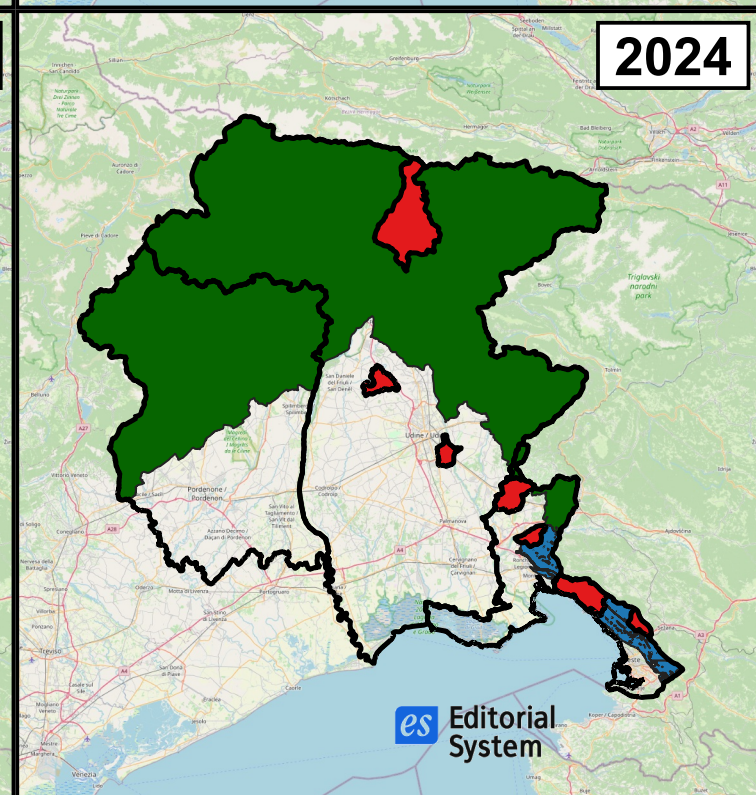
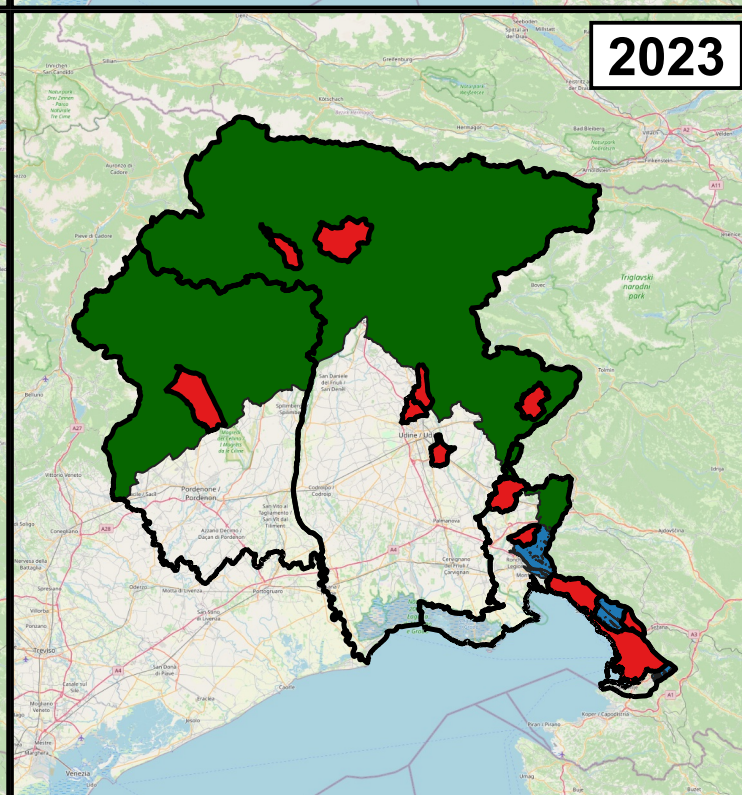
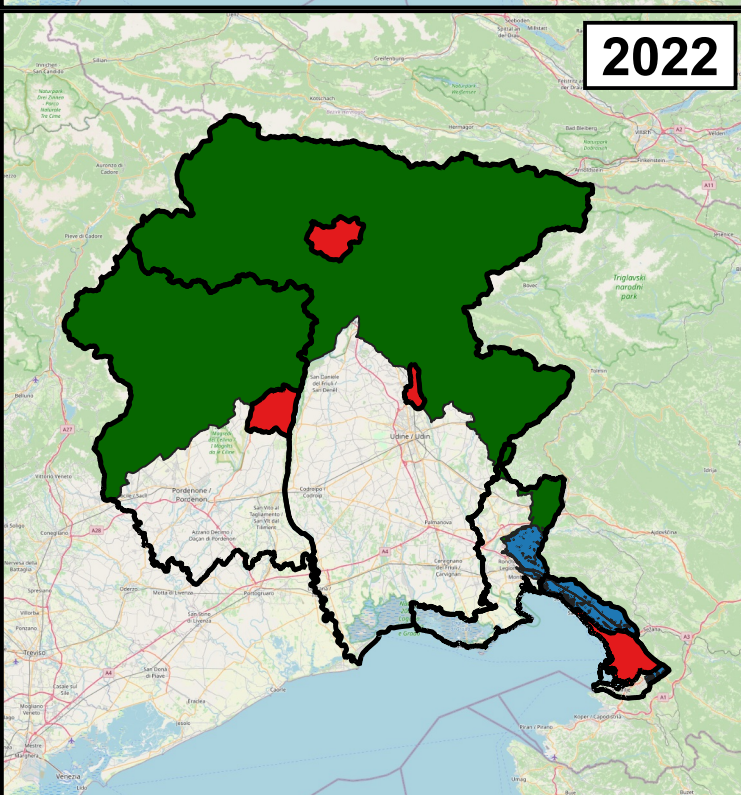
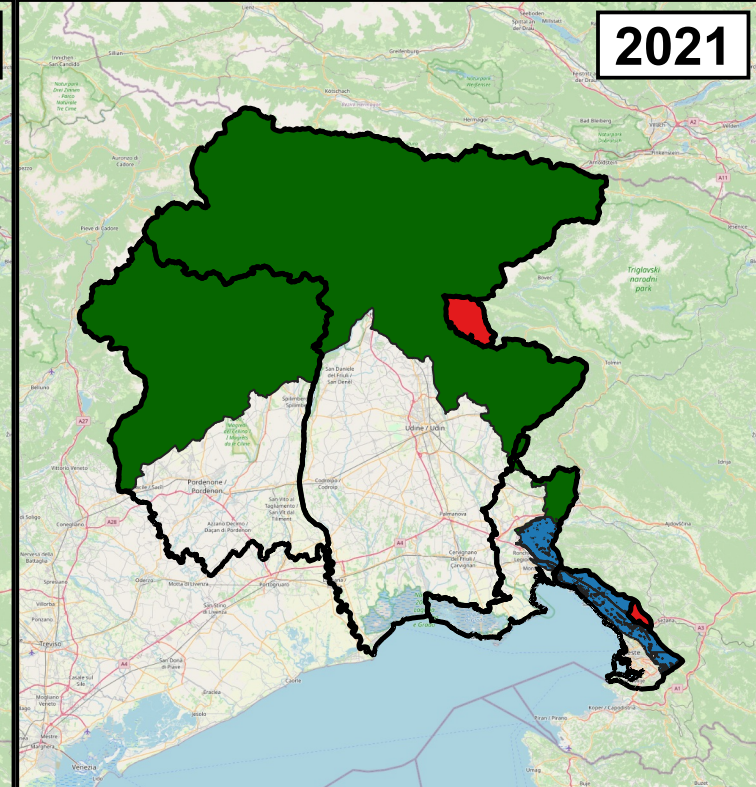
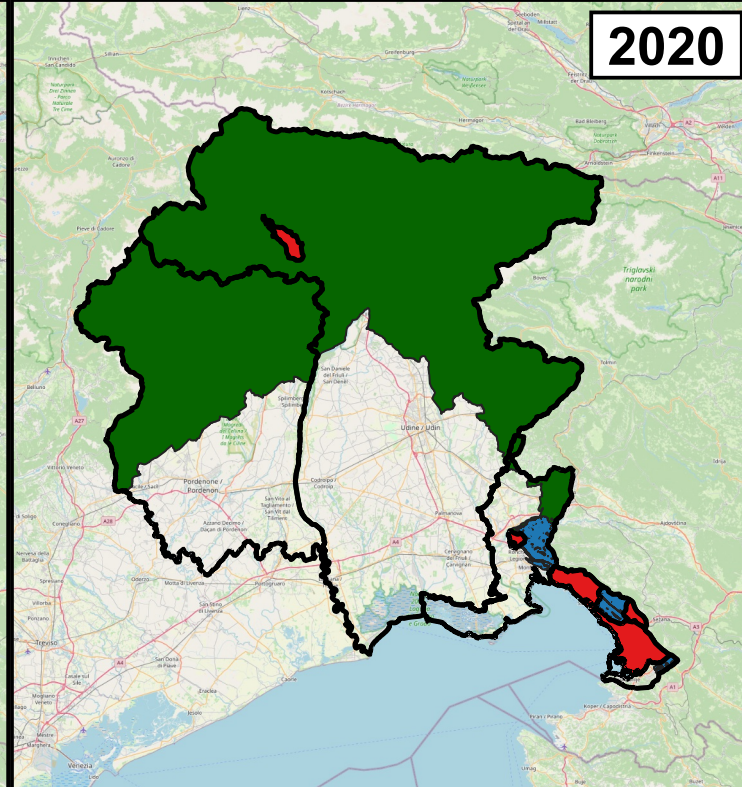
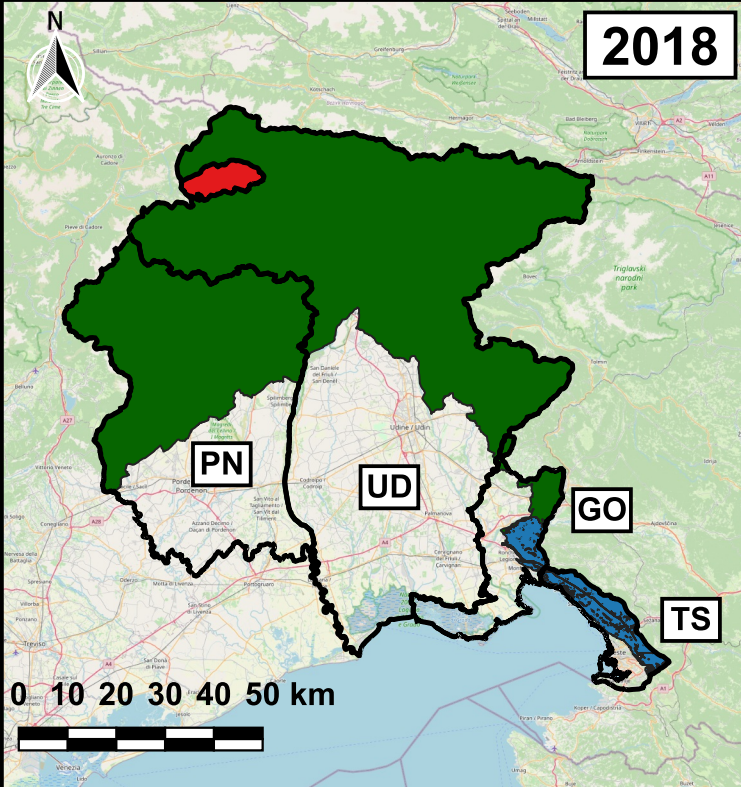


Figure 3. Temporal variation in the number of municipalities (in red) affected by livestock damage events (i.e., sum of preyed upon, injured, and missing individuals) within each area and across years. The alpine and pre-alpine boundaries were highlighted in green; while the karstland boundaries were highlighted in blue. The uncoloured area represents the lowland. Abbreviations (Provinces): PN = Pordenone; UD = Udine; GO = Gorizia; TS = Trieste.



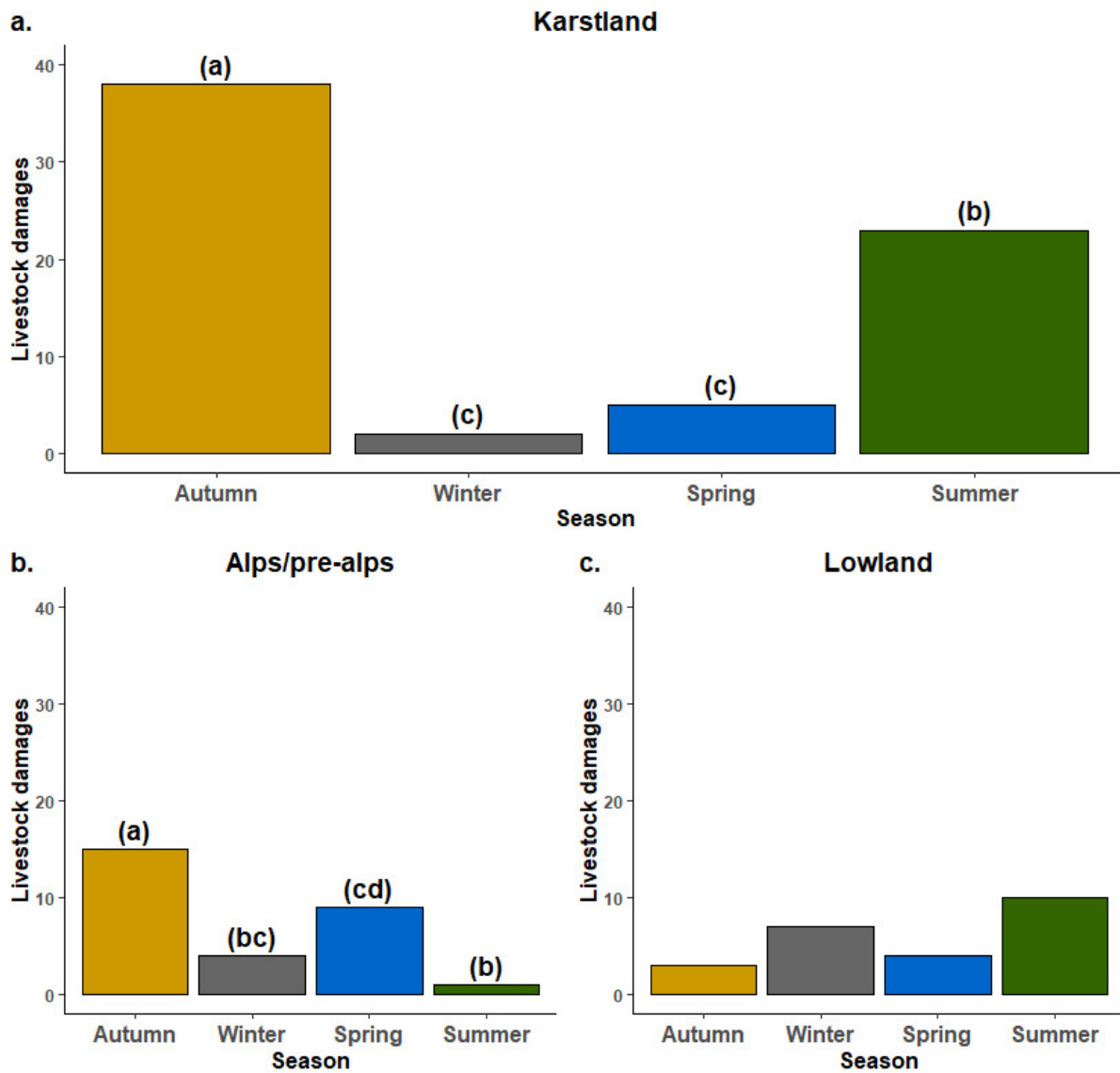
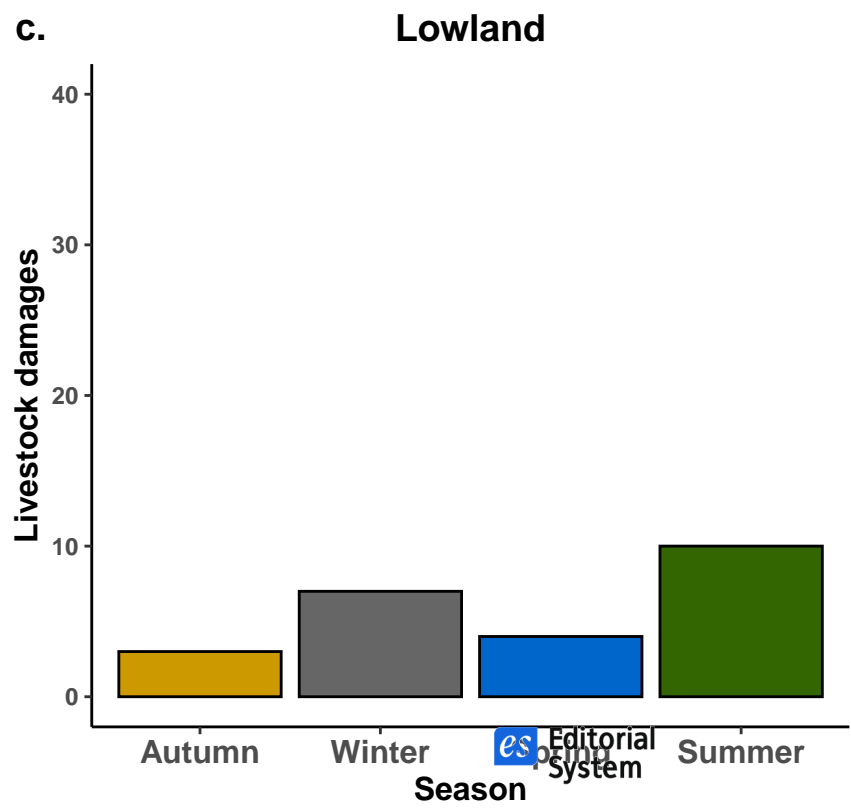
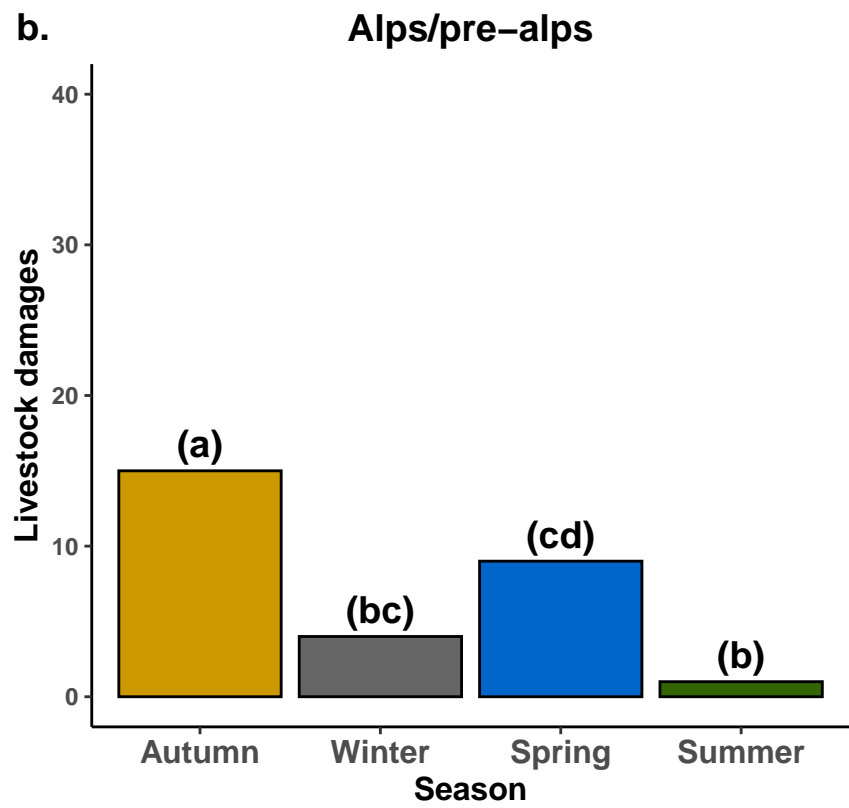
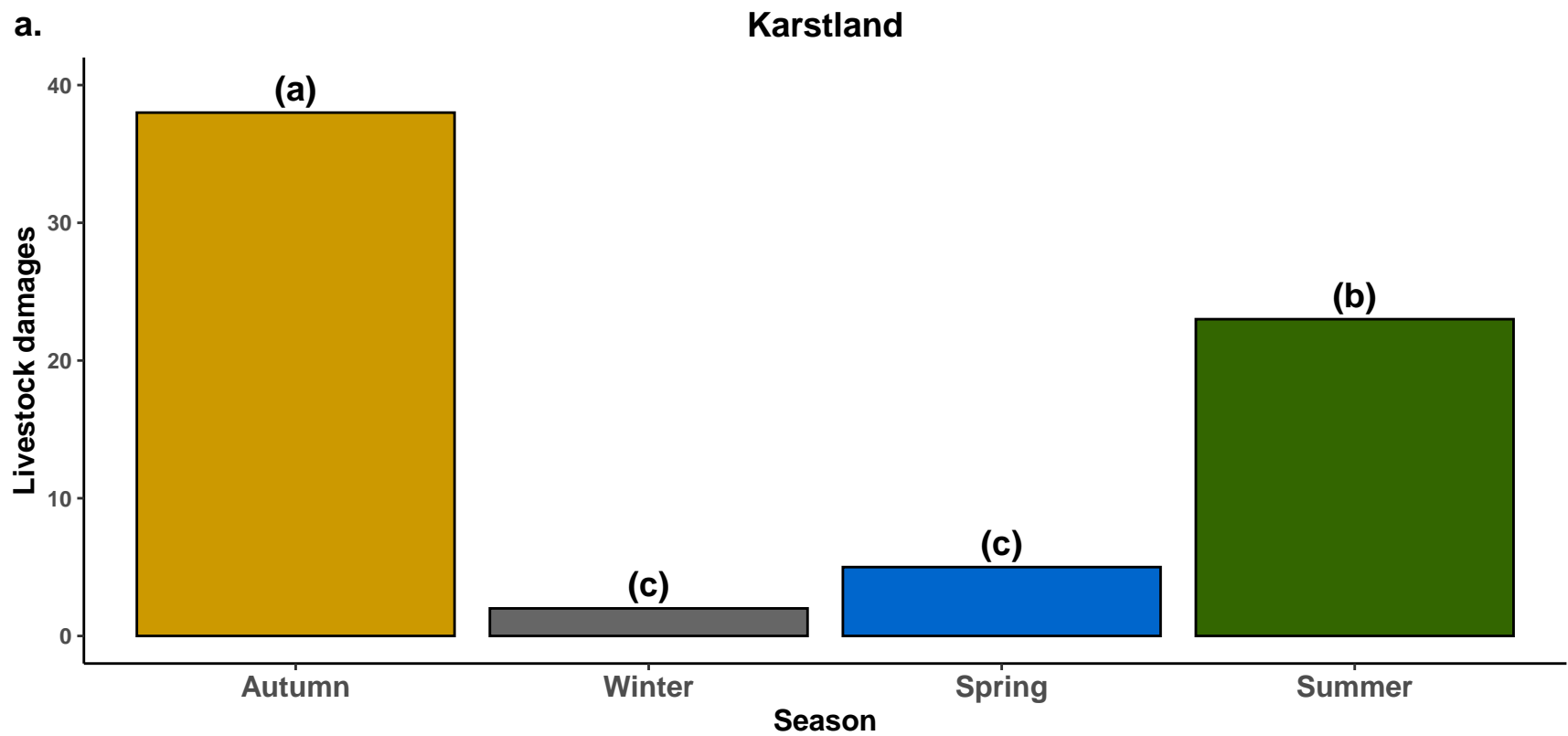


Figure 4. Seasonal variations in the number of livestock damage events (i.e., sum of preyed upon, injured, and missing individuals) across areas: (a) karstland, (b) alps/pre-alps, (c) lowland. Different letters over the bars indicate a significant difference ($p < 0.05$) in pairwise comparisons.



Manuscript body

[Download source file \(1.74 MB\)](#)

Tables

Table 1 - [Download source file \(14.83 kB\)](#)

Table 1. Number of livestock heads and farms for each livestock category within the study area (FVG Region) and divided by area (alps/pre-alps, karstland, lowland). Data obtained from the National Institute of Statistics (ISTAT - <https://esploradati.istat.it/databrowser/#/it/censimentoagricoltura>). NA = Not available data.

Table 2 - [Download source file \(14.51 kB\)](#)

Table 2. Temporal trend in the number of livestock damage events (i.e., sum of preyed upon, injured, and missing individuals), post-damage compensations (€), and municipalities affected by livestock damages.

Table 3 - [Download source file \(14.7 kB\)](#)

Table 2. Temporal trend in the number of livestock damage events (i.e., sum of preyed upon, injured, and missing individuals), post-damage compensations (€), and municipalities affected by livestock damages.

Table 4 - [Download source file \(13.5 kB\)](#)

Table 4. Average number of livestock damages (sum of preyed upon, injured and missing individuals) divided by livestock category. Abbreviation: SD = standard deviation. The range defines the minimum and maximum number of damaged individuals during a single attack.

Table 5 - [Download source file \(16.27 kB\)](#)

Table 5. Percentage of landscape (PLAND) of each habitat calculated within each buffer, along with the number and percentage of jackal's attacks on livestock within every habitat.

Table 6 - [Download source file \(13.91 kB\)](#)

Table 6. Effect of the considered covariates/predictors on livestock damage events. Abbreviations: Urban = distance from the nearest urban area (m); Canopy = distance from the nearest canopy-covered area (m); 95% CI = 95% confidence interval; pd = probability of direction; R-hat = index of convergence of the Markov Chain Monte Carlo (MCMC) chains; ESS = effective sample size. Interactions between covariates and predictors are denoted by “.”.

Figures

Figure 1 - [Download source file \(61.5 MB\)](#)

Figure 1. Location of the study area (FVG Region; inset map), jackal range of distribution (IUCN, 2018), and coordinates of livestock damage events (i.e., sum of preyed upon, injured, and missing individuals) within each area. The uncoloured area indicates the lowland territories. Abbreviations (Provinces): PN = Pordenone; UD = Udine; GO = Gorizia; TS = Trieste.

Figure 2 - [Download source file \(4.34 MB\)](#)

Figure 1. Location of the study area (FVG Region; inset map), jackal range of distribution (IUCN, 2018), and coordinates of livestock damage events (i.e., sum of preyed upon, injured, and missing individuals) within each area. The uncoloured area indicates the lowland territories. Abbreviations (Provinces): PN = Pordenone; UD = Udine; GO = Gorizia; TS = Trieste.

Figure 3 - [Download source file \(24.64 kB\)](#)

Figure 2. Number of livestock damages (i.e., sum of preyed upon, injured, and missing individuals) within each area. Different letters over the bars indicate a significant difference ($p < 0.05$) in pairwise comparisons.

Figure 4 - [Download source file \(4.29 kB\)](#)

Figure 2. Number of livestock damages (i.e., sum of preyed upon, injured, and missing individuals) within each area. Different letters over the bars indicate a significant difference ($p < 0.05$) in pairwise comparisons.

Figure 5 - [Download source file \(77.42 MB\)](#)

Figure 3. Temporal variation in the number of municipalities (in red) affected by livestock damage events (i.e., sum of preyed upon, injured, and missing individuals) within each area and across years. The alpine and pre-alpine boundaries were highlighted in green; while the karstland boundaries were highlighted in blue. The uncoloured area represents the lowland. Abbreviations (Provinces): PN = Pordenone; UD = Udine; GO = Gorizia; TS = Trieste.

Figure 6 - [Download source file \(6.2 MB\)](#)

Figure 3. Temporal variation in the number of municipalities (in red) affected by livestock damage events (i.e., sum of preyed upon, injured, and missing individuals) within each area and across years. The alpine and pre-alpine boundaries were highlighted in green; while the karstland boundaries were highlighted in blue. The uncoloured area represents the lowland. Abbreviations (Provinces): PN = Pordenone; UD = Udine; GO = Gorizia; TS = Trieste.

Figure 7 - [Download source file \(42.76 kB\)](#)

Figure 4. Seasonal variations in the number of livestock damage events (i.e., sum of preyed upon, injured, and missing individuals) across areas: (a) karstland, (b) alps/pre-alps, (c) lowland. Different letters over the bars indicate a significant difference ($p < 0.05$) in pairwise comparisons.

Figure 8 - [Download source file \(4.98 kB\)](#)

Figure 4. Seasonal variations in the number of livestock damage events (i.e., sum of preyed upon, injured, and missing individuals) across areas: (a) karstland, (b) alps/pre-alps, (c) lowland. Different letters over the bars indicate a significant difference ($p < 0.05$) in pairwise comparisons.