Thesis of the Doctoral (Ph.D.) dissertation

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Department of Wildlife Biology and Management

Monitoring the Occurrence and Distribution of Large and Medium-Sized Carnivores in Georgia

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Title: Monitoring the Occurrence and Distribution of Large and Medium-Sized Carnivores in Georgia.

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1. BACKGROUND OF THE WORK AND ITS AIMS

1.1. Study Background.

Carnivore species that have been persecuted throughout the last few decades have been documented to be increasing in numbers and range, occurring in previously unsuitable areas in Europe (e.g. Ripple et al., 2014). Legal protection of wolves, bears, and lynx, successful conservation initiatives such as the EU's Habitats Directive, as well as the efforts for restoring the landscapes and creating favourable habitats for these species have all played a significant role in recovering the carnivore populations. Species adaptability and climate change have also been recognized as critical contributing factors to the expansion in range, as they alter ecosystems and allow carnivores to extend their ranges into previously uninhabitable areas. This trend is also visible in the Caucasus region. Georgia once held large populations of red deer, wild boar, chamois, mouflon, ibex and other ungulate or carnivore species whereas today, many of the most common species are experiencing a strict decline (Zazanashvili & Mallon, 2009).

The expansion of native and alien carnivore species both have distinct impacts on local ecosystems and local and rural human communities. On the one hand, the return of native predators like wolves has been shown to play a significant part in promoting ecosystem functionality by controlling populations of herbivores, thereby preventing overgrazing and promoting forest regeneration and its economic value (Blanco & Sundseth, 2023). However, the lack of effective management of these species often conflicts with the activities of local human communities, particularly in rural areas where livestock depredation can lead to economic losses for farmers. On the other hand, alien species often disrupt local ecosystems in more harmful ways. The raccoon for instance, preys on native species, especially the small game species that are most vulnerable to predation; at the same time it can outcompete for resources, leading to declines in native populations.

The planned species for investigation include medium and large-sized carnivores: grey wolf, golden jackal, and raccoon. Local hunters and farmers in Georgia have become increasingly concerned about the rapidly increasing populations of golden jackals and wolves, as well as the potential impact these species may have on small game and domestic animals. Although in Georgia raccoons have not generated significant complaints due to their currently low population numbers, there is strong evidence suggesting that these species could soon become invasive (Kalandarishvili & Heltai, 2019). By studying their current distribution, we can gain a clearer understanding of the situation and make more accurate future predictions.

The results of this thesis will lay the foundation of a viable management plan for carnivore species in Georgia. As of the time of writing, all essential data for adequate and sustainable management is missing, and a considerable lack of research concerning the ecology of large carnivores in Georgia can be seen. Therefore, the outcomes of this study will directly inform the drafting process of the National Biodiversity Strategy by the Ministry of Environmental Protection and Agriculture of Georgia.

1.2. Aims and Objectives of the Study

The main aim of the research is to understand the presence and, where possible, estimate the minimum population size of native as well as introduced species of large and medium-sized carnivores, namely the wolf, golden jackal, and raccoon in Georgia. The research will be focused on four major topics listed below.

1. **General Systematic Literature Review**

<u>Objective 1: Investigate the general impact of canids on livestock damages.</u>
1.1 Which canid species is causing the most damage to livestock based on the current scientific literature?
1.2 Which livestock species are most affected by the canids?

<u>Objective 2: Investigate the impacts that increasing carnivore population has on domestic prey.</u>
2.1 Which European countries report the highest number of cases of the damages inflicted by canids?
2.2 Which canid species is causing the most damage to domestic animals in Europe?
2.3 What are the most frequently used conflict mitigation methods in Europe against carnivore damage?

2. **Understand the public attitude towards neighboring wildlife**

Objective 3: Understand the extent of the Human-Carnivore conflict in Georgia.

3.1 Are the studied species a nuisance to the local communities? If so, what type of problems are they causing?

3.2 What is the most common method used by the local communities to mitigate and prevent the damages?

3.3 What are the significant factors that need to be considered in management effort concerning these carnivore species?

3. **Monitoring carnivore species on the local and country level**

Objective 4: Understand the coexistence between wild canids, domestic species and humans in a semi-urbanized environment.

4.1 What are the possible factors that encourage their occurrence in the semi-urban area?

4.2 How do large and medium-sized carnivores interact and coexist with domestic animals and humans in semi-urbanized areas in Georgia?

4.3 Are there seasonal differences in the occurrence of large and medium-sized canids in semi-urban areas?

4. **Estimating minimum population size and growth of the golden jackal**

Objective 5: Investigate the population size of golden jackals in Georgian regions.

5.1 What is the minimum population size of the golden jackal on county and country level? Furthermore, which factors influence its occurrence in different regions of Georgia?

5.2 What regions do these species occupy and what type of habitats are they mostly found in?

1.3. Hypotheses

With regards to the general impacts of carnivores on wild and domestic prey species in Europe and consequently in Georgia, following hypotheses have been developed.

- **H_1 - Wolves consume the highest proportion of livestock due to their larger body size and pack-hunting behavior and show preference for larger domestic animals.** In contrast, **golden jackals**, having more omnivorous feeding habits, primarily target medium- or small-sized domestic species such as goats, sheep, and poultry. **Stray**

dogs consume the least livestock, as their diet mainly consists of anthropogenic food sources due to their close association with human settlements.

- **H_2 - The human-carnivore conflict in Georgia is most severe in rural areas,** where livestock depredation is prevalent, leading to increased reliance on lethal control methods such as trapping and shooting.
- **H_3 - Wolf and golden jackal are present throughout all the regions of the country** including in the semi-urban areas in significant numbers which presumes their coexistence through space and time.
- **H_4 - Alien species like raccoon are present in semi-urban areas** in Georgia and are having potential conflicts with same-sized mammals.
- **H_5 - The distribution and occurrence of the golden jackal are significantly influenced by environmental variables and interspecific competition.** Specifically, golden jackals preferentially inhabit agricultural landscapes due to high resource availability while actively avoiding areas with high competition from wolves.

2. MATERIALS AND METHODS

2.1. Off-Site Studies

2.1.1. Literature Survey

I performed the general literature review on diet analyses of the grey wolf, golden jackal, and stray dog using two major platforms to retrieve publications: **Web of Science** and **Scopus** using the combination of the following keywords: Total Search = ((“*Grey wolf*” OR “*Canis lupus*”) AND (“*diet*” OR “*food*” OR "*feeding*") AND (“*livestock*” OR “*domestic*”)). All the articles that used the keywords in the article title, abstract, and keywords sections were included in the analyses, as well as all the publication dates and geographical regions. Non-English papers were also included given that at least the abstract was available in English. Publications whose titles and abstracts lacked any indication of livestock predation were excluded, as it was assumed that their research focus was not on livestock.

I found 71 papers for grey wolves, 22 for golden jackals, and only 4 for stray dogs. Nine involved data about more than one canid species.

The information and metadata derived from the papers were the year of publication, the country where the study was conducted, the studied canid predator(s), and the livestock species consumed (categorized into cattle, pig, sheep, goat, horse, and donkey, poultry if specified). Those cases when distinct livestock species cannot be identified or reported only in groups (e.g., “*cattle, sheep, and horse*” together) or referred only as “*livestock*” in the articles were categorized as “not specified”.

The most commonly used indices expressing the diet composition of the canid species of interest in the related studies were the frequency of occurrence (%O) and percentage of biomass (%B). The frequency of occurrence of livestock was expressed as the percentage of scats or stomachs containing the livestock item considered. The percentage of biomass is estimated by weighing the dry food remains within a sample (dry matter remains from scat or stomach) and then multiplying this mass data by an appropriate conversion factor. When observing the consumption of the livestock species, it is critical to look at both the %O and the %B data. The %O indicates the individual variability of feeding habits of the carnivores, while the %B shows the actual food intake from different diet components.

Only studies that performed stomach content analyses or scat analyses for the diet composition were included in the statistical analysis. Papers reporting data from multiple sites or repeated measures were analyzed as independent studies. Each reported carnivore-livestock pair was handled separately as a unique observation, i.e., a case when one of the prey species of interest was examined about its consumption of any livestock.

A non-parametric Kruskal-Wallis test was performed on the %O or %B data in R to verify statistical differences in the reported livestock consumption of the studied canid species and to find the most consumed livestock species groups for each carnivore. The overall livestock consumption of canid species was compared by taking the minimum and maximum values of the reported %O data and the summarised %B data per study.

The Dunn post hoc test was implemented for pairwise comparisons, which is ideal for groups with unequal numbers of observations (Zar, 2010). The p-value adjustment was performed using the Holm-Bonferroni method, and the 95% confidence intervals were calculated for the mean rank differences. When two groups were compared, the Mann-Whitney U test was used.

2.2. Studies Conducted in Georgia

Georgia is a part of the Caucasus Ecoregion noted as one of the 34 most diverse and threatened biodiversity hotspots, which implies high conservation priorities. The country also contains 66 officially designated Emerald sites (similar to Natura 2000 sites in the EU). The lowlands are characterized mainly by more humid subtropical weather, which results in moderately hot summers and moderately cool winters. The mountainous area has milder weather, and the climate is characterized by moderately warm summers and moderately cold winters.

This research was carried out with the Wildlife Agency of the Ministry of Agriculture and Environmental Protection of Georgia. For our study, we selected seven regions for the bioacoustics survey (Adjara, Imereti, Kakheti, Kvemo-Kartli, Racha Lechkhumi, Samegrelo and Samtskhe-Javakheti). For the camera trap study, we selected the Ponichala Nature Reserve near Tbilisi.

The questionnaire survey among the rural residents was carried out in all regions throughout Georgia except South-Ossetia and Abkhazia.

2.2.1. Citizen Science

For research purposes, to understand the presence of large and medium-sized carnivores in Georgia and understand the extent of the Human-Carnivore conflict in Georgia, a total of 2,000 surveys were distributed to the residents. The respondents were chosen randomly with regard to the demographics, but all living in rural areas.

The survey asked the following ten questions in a multiple-choice format:

1. Which carnivore species have you seen most in your region? (*Wolf, Golden jackal, Brown bear, other unnamed)*.
2. Which of the carnivore species have you heard or seen attack domestic livestock the most? (*Wolf; Golden jackal; Brown bear; other unnamed)*.
3. Which of the carnivore species have you heard or seen to attack or disturb humans the most? (*Wolf; Golden jackal; Brown bear; other unnamed)*.
4. During which season(s) are the attacks by carnivore species on domestic livestock (including poultry) most prominent? (*Spring; Summer; Autumn; Winter)*.
5. Which of the carnivore species would you note as the most problematic species to occur in your region? (*Wolf; Golden jackal; Brown bear; other unnamed).*
6. Which of the carnivore species have you heard of or seen that causes damage to personal property or to personal belongings, for example: car, house, garden, etc.? (*Wolf; Golden jackal; Brown bear; other unnamed)*.
7. Once you identify a carnivore-induced disturbance upon your property and/or belongings, what is the typical action you would undertake to deal with the consequence? (*Call the emergency services; filling a complaint to the local authority; self-prevention; no reaction)*.
8. What is the most frequently noted type of damage that you have either experienced yourself or heard of that was done by the carnivore species? (*predation on Domestic animals; predation on Domestic birds; consumption of crops or any local produce; other)*.

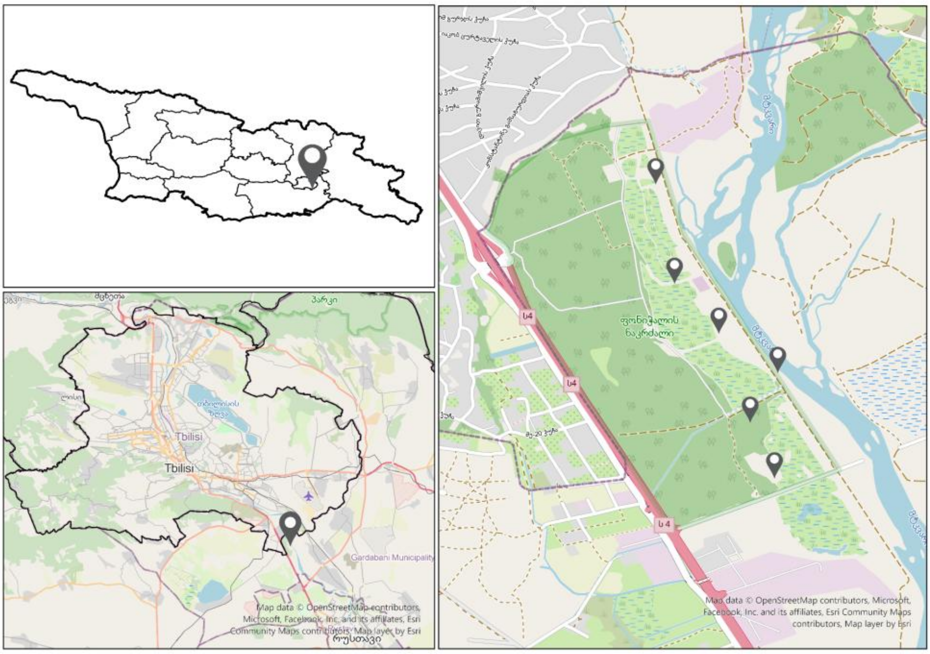
9. In your opinion and personal experience, what is the most effective prevention method for the damage induced by carnivore species? (*Electric fencing; guard dogs; hunting; other)*.
10. Which carnivore species have you sighted the most in the past year? (*Wolf; Golden jackal; Brown bear; other unnamed)*.

I primarily used a descriptive statistical approach to evaluate the demographic distribution of respondents and their attitude toward local carnivores from several aspects. The final data was only available in regionally aggregated format which limited the capacity of conducting a more detailed statistical analysis.
Where possible for statistical testing, I used the Chi-Square test for independence to reveal whether there is any association between the location of the respondents by region and their answers to the most crucial questions of the survey.

2.2.2. Camera Trapping

Ponichala Nature Reserve is a protected area renowned for its ecological importance and recreational opportunities. The area lies along the banks of the Mtkvari River, which occasionally floods the Park area creating more of a fragmented habitat. During arid years, it provides an easier passage for the animals. The area is diverse in riparian forests, meadows, and semi-arid landscapes. The climate in this region is semi-arid, with hot summers and mild winters shaping the park's ecosystem. The reserve is an important biodiversity hotspot, especially for species adapted to riparian and semi-arid conditions. It supports multiple mammals, including foxes, hares, and hedgehogs. Bird species are particularly abundant, with migratory and resident species. Amphibians and reptiles are also common due to the park's wetlands and warm climate.

The way cameras are mounted is to study mammal presence in the semi-urbanized area of Ponichala Nature Reserve (3.5 km^2) and see how wild mammal species coexist with domestic animals and human presence (Map 1), the cameras were set systematically. As the subject of the study is the animal population within a studied area, the cameras were mounted in spots where targeted species are likely to pass. The camera trapping was conducted in two study periods, referred to as "Seasons" in the thesis. Season 1 ran from the 1st of December 2020 to the 16th of March 2021 (204 total trap nights), and Season 2 was marked from the 5th of October 2021 to the 15th of December 2021 (218 total trap nights). In total, there were 422 camera trap nights.



Map 1. Location of camera trap stations

A total of six passive infrared cameras were used to detect mammal species, mainly golden jackals; furthermore, the presence of raccoon, red fox, wild cat, European badger, and stone marten was also anticipated. The cameras were mounted at an average height of 60-70 cm from the ground and operated non-stop after deployment and checked every 4-5 weeks.

The cameras were placed 340 m apart on average, with minimum and maximum distances of approximately 285-532m. Images were manually labelled by the corresponding time and date. Species were identified after visual inspection of the images; none of the detections were excluded due to false or ambiguous identification. A threshold of 30 minutes was used to separate temporally independent detections based on the review of Sollmann (2018).

Most of the analyses were performed in R software using Chris Beirne's technical material from WildCo Lab (Beirne, 2023). The efficiency of detections was expressed in a detection rate form: the number of detections were generalized to detections per 100 camera trap days to allow comparisons.

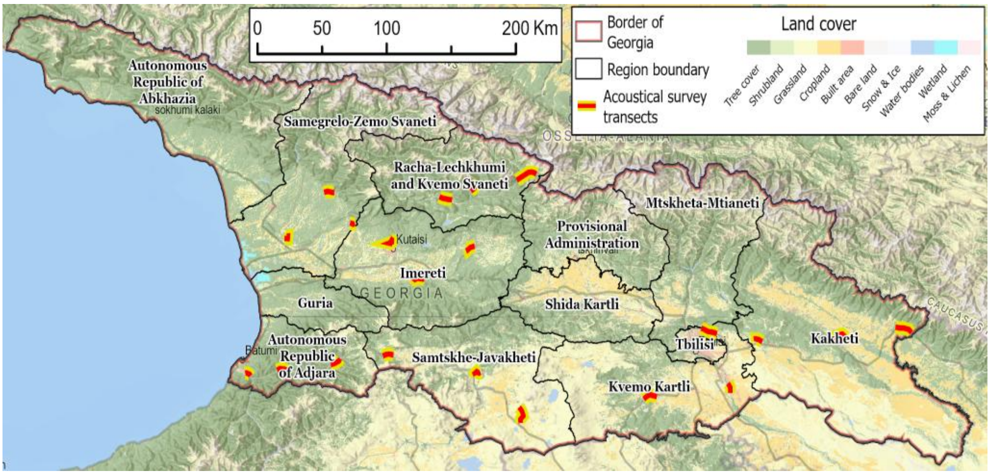
Based on the corresponding timestamps, the diel activity patterns of the occurring species were also visualized with a nonparametric kernel density function to estimate species' activity as a continuous distribution over the wrapped 24-hour cycle. This method allowed intra-species comparisons by evaluating seasonal differences in activity, just as contrasting the daily activity cycle of a species pair. The activity cycles of a species between seasons and between species are statistically compared by calculating the coefficient of overlap ($\hat{\Delta}_4$), which estimates a symmetrical overlapping coefficient between two kernel density functions using a total variation distance function (Frey et al., 2017).

The spatiotemporal co-occurrence of detected species was evaluated by implementing a joint species distribution model under a Bayesian framework with Gibbs Markov chain Monte Carlo (MCMC) sampling. The joint species distribution model can be visualized for different species pairs in a matrix, where colours denote the magnitude of co-occurrence of a species pair. These values range -1 to +1, where -1 indicates that the species were unlikely to occur in the same time and place, while +1 means the opposite. By this method, we can get more insight into the habitat use and the potential niche-segregation of the detected mammal species.

2.2.3. Bioacoustics Survey

Bioacoustical surveys were conducted in 7 regions of Georgia to represent all common environmental features in the country, including the variability of land cover and elevation. The bio-acoustic stimulation has already been successfully used in golden jackal research throughout Europe (e.g. Szabó et al., 2009). The howls are most of the time quite distinguishable from other canids, as a result of which this non-invasive method is a great asset in determining the territorial groups and, indirectly, single individuals.

For this study, seven regions were selected: Adjara (2,880 km^2), Imereti (6,516 km^2), Kakheti (11,310 km^2), Racha (2,893 km^2), Samegrelo (7,468 km^2), Samtskhe-Javakheti (6,413 km^2) and Kvemo Kartli (6,527 km^2). In every region, we established three 10km long transects with five broadcasting points on each to survey for the golden jackal (21 transects and 105 points in total, Map 2). The survey was conducted between June and November 2021.



Map 2. The location of transects for bioacoustical surveys in the seven regions and Georgia's dominant land cover types. Land cover data was obtained from the ESA Worldwide Land Cover Mapping (Zanaga et al., 2022).

There is no actual data for the abundance of golden jackals or wolves in these regions, nor information on the density of other carnivores that may compete for resources in the studied areas. Therefore this study can provide essential information about the species spatiotemporal dynamics.

To provoke jackals' response along the transects of the study area, we used a calling survey method that combined acoustic and visual observations of jackals after stimulation with playback howls by following the methods of (Giannatos et al., 2005). With a mean distance of 1.8 km (min-max: 0.62 to 3.3 km), the broadcasting points were established along these transects where the pre-recorded jackal howls were played using a megaphone. The call that was used for broadcasting was 30 seconds in duration and was recorded in Georgia as well. Following every 30-second broadcast, we kept a 3-minute pause to observe potential responses. In case of no response, the procedure of broadcasting and pausing was repeated five times per individual station; once a response was registered, we determined the direction of the call using a compass. In addition to the howls, we collected data on the weather, and if the wolf responded instead of the golden jackal, we recorded that as well.

My first goal was to estimate the individual density of golden jackals across the seven studied regions of Georgia. To effectively determine the individual density, each recorded vocal response was interpreted as evidence of a distinct social group within the detection area. A single vocal response represented a single individual, whereas multiple responses were assumed to be a group of four individuals as it was the most widely reported group size (e.g. Trbojević et al., 2018). This group-size assumption provides a basis for calculating population density across multiple spatial scales.

Based on other studies (Acosta-Pankov et al., 2018), we determined the maximum human hearing distance on windless nights in open terrain with no background noise at 1.8 – 2 km. In light of this, the population density estimates were calculated at three detection areas around the testing site with a radius of 1 km, 1.5 km, and 2 km buffer areas. By using this three-level approach, we aimed to represent the variation and restrictions in detection ability. The density estimates from each of these scales were then extrapolated across the entire area of the sampled region, enabling a broader assessment of the regional population. This extrapolation involved calculating the average density per square kilometer and applying it to the total surveyed area.

To project population growth, based on the extrapolated density estimates, assumptions were made about the sex composition and reproductive behavior of the population.

- For sex ratio, we assumed a balanced sex ratio, with 50% of the individuals of the population female, a common assumption in carnivore population studies (Csányi & Sándor, 2024).
- To model reproductive potential, two reproductive activity levels were assumed: a **Low Reproductive Population Rate** where 35% of the female population was thought to be reproductively active and a **High Reproductive Population Rate** where 65% of the female population was assumed to be reproductively active (Vlasseva et al., 2020).

These assumptions allowed the estimation of potential breeding females, which directly influenced the population growth projections:

- It was assumed that each reproductively active female gave birth to an average of five pups per breeding cycle, based on typical litter sizes reported for golden jackals and the pups' 50% survival rate (e.g. Stoyanov 2012).

- An estimate of the annual population growth was generated by multiplying the estimated number of active females by five. This value served as the projected increase in population size under each reproductive scenario. Hunting pressure was not included in the model for analyses, as the harvest efficiency in Georgia is low which would add further uncertainties to my estimation if the hunting pressure were incorporated.

My second goal was to evaluate and analyze the underlying environmental factors influencing jackal occurrence. For this purpose, detections registered at the broadcasting points were coded into a presence/absence (1/0) form independent of how many jackal howls were heard at each point. I used the widest area of detection with a radius of 2 km (12.57 km^2) to calculate the percentage cover of land cover types, the mean value of elevation, and the terrain ruggedness index, which functioned as covariates. In addition, the sampling points' distance from the nearest settlement and the actual weather conditions (mean temperature and total precipitation) were also utilized as explanatory variables, just as the registered wolf howls along the transect. Since wolves were also detected during the surveys by "responding" to the calls sometimes, their potential competition with jackals must be considered in jackal occurrence modeling.

For modeling golden jackal occurrence in the function of the covariates mentioned above, I implemented a generalized linear mixed model (GLMM) in R. The presence/absence of jackal (based on responses to playback calls) was used as a dichotomous response variable. The set of explanatory variables were selected with a stepwise selection method during model fitting. All explanatory variables were scaled and filtered for multicollinearity. The survey transects, and their corresponding regions were added as random effects. The best model version was selected with likelihood ratio tests.

Predictions were made using the best model to explain the relationship and magnitude of the suitable explanatory variables on jackal occurrence probability. These predictions were generalized and visualized in a 10 × 10km UTM grid covering Georgia. In addition, the predictive process and the created map were updated with the direct visual detections of wolves reported by the Ministry of Environmental Protection and Agriculture of Georgia. These reports functioned as weights when predictions were calculated at a regional scale.

3. RESULTS

3.1. Literature Review

Most of the studies (84%) were based on scat samples, while the studies based on stomach samples were 16%. The 97 studies used for analyses originated from 29 countries.

The impact of wolves on livestock was the most studied topic worldwide among the three canids: 71% of the papers (75 articles out of 105) were related to wolves. Especially Italy (N=13), Spain, and Pakistan (both N=7) gave place for these types of studies. Still, a significant number of articles originated from India, Iran, Poland, Portugal, the USA (all N=4), and Mongolia (N=3). Most jackal studies were conducted in Bulgaria and Pakistan (N=6 and 4, respectively). The query found more than one golden jackal-related study on livestock consumption in Hungary, India, and Serbia (N=3). The stray dog diet was scarcely studied worldwide and almost disappeared in this context.

3.1.1. Total Livestock Consumption by Canid Species

Considering all observations (N=423), we found that the wolf (N=300 observations) was the most frequently reported canid species that consumed livestock, followed by the golden jackal (N=104) and stray dog (N=19, Figure 1).

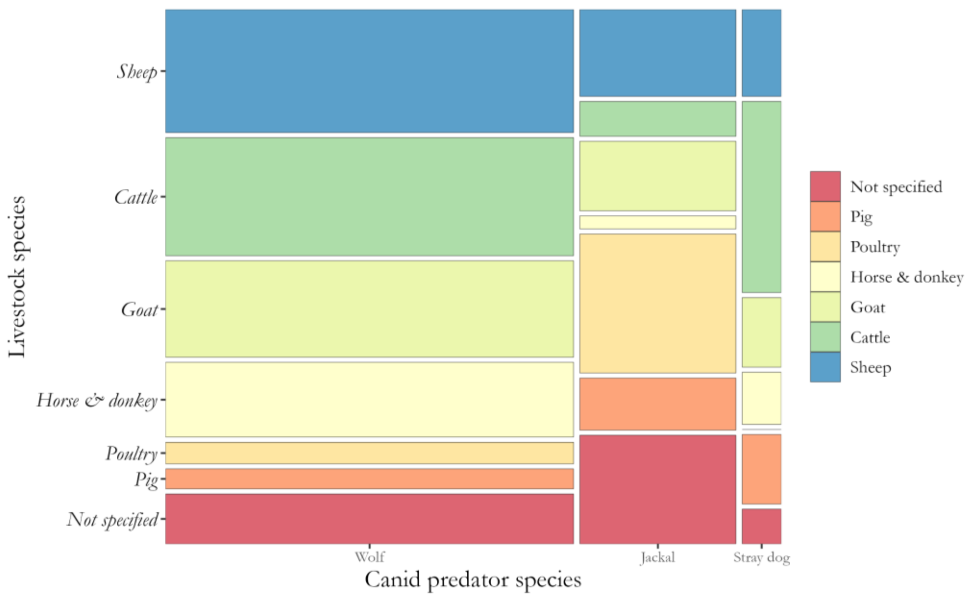


Figure 1. The relative distribution of livestock species reported as consumed by the canid species of interest in the articles. The height and width of each rectangle represent the relative proportion of the contrasting categories, i.e., how many times each livestock-carnivore pair occurred in the studies (number of observations).

We found that the overall livestock consumption was significantly different among canid species when maximal consumption rates were compared based on the frequency of occurrence data (Kruskal-Wallis test: H(2)=17.2, p=0.002). The Dunn post hoc test revealed a significant difference between wolf (%O median = 32, interquartile range = 57) and jackal (%O median = 9.9, IQR = 23.4, p=0.002, Table 1). The minimal consumption rates were statistically similar among canids (H(2)=1.4, p=0.8).

Table 1. Mean rank difference and their 95% confidence intervals for the significant pairwise comparisons. %O - frequency of occurrence data; %B - percentage of biomass data. **Bold** text indicates which group had higher mean rank scores in the comparison.

				95% Confidence interval		
group	metric	comparison	mean rank difference	lower	upper	p
livestock	max. %O	jackal vs. wolf	-28.15	-49.76	-6.53	0.003

wolf	%O	horse/donkey vs. cattle	-44.07	-86.49	-1.64	0.03
wolf	%O	horse/donkey vs. goat	-58.64	-102.27	-15.02	0.001
wolf	%B	**cattle vs. poultry**	51.18	7.79	94.57	0.008
wolf	%B	**cattle vs. sheep**	31.03	2.53	59.52	0.021
jackal	%O	horse/donkey vs. pig	-49.83	-94.91	-4.76	0.017
jackal	%O	**pig vs. sheep**	28.37	1.32	55.41	0.031
jackal	%B	**pig vs. poultry**	22.02	5.48	38.58	0.001

No %B data was reported in the case of stray dogs. Therefore, the comparison was made between wolf and jackal only, but no difference was revealed between them for the total biomass data (Mann-Whitney test: $U=394$, $p=0.51$). The median was above 50% for jackals and under 25% for wolves. However, we have to consider that potential scavenging was frequently reported in the relevant studies: 3 out of 5 for jackals (60%) and 14 out of 31 studies for wolves (45%).

3.1.2. Consumption of Various Livestock Species by Canid Species

Sheep (N=91, 22% of observations) and cattle (N=84, 20% of observations) were the most frequently reported livestock species consumed the most by canids. Goats were the third most reported species (N=77, 18% of observations). Horse and donkey (N=52, 12% of observations), poultry (N=44, 10% of observations), and pigs (N=25, 6% of observations) were less often mentioned.

The reported %O data significantly differed among livestock species groups in the wolf's diet ($H(5)=19.42$, $p=0.002$). Based on 300 reported observations, the %O of equines (mostly horse and donkey, median = 3.6, IQR = 11) was significantly less from cattle (median = 12, IQR = 15.6, p=0.03) and goat (median = 10.2, IQR = 23.2, p=0.001, Table 1).

Significant differences were also revealed in the %B data for wolves based on 129 observations (H(5)=18.3, p=0.003), where the consumed biomass of cattle (median = 16.8, IQR = 46.4) was significantly higher than that of poultry (median = 0.1, IQR = 10.1, p=0.008) and sheep (median = 4.9, IQR = 9.5, p=0.019, Table 1).

Regarding to jackal (N=104 observations) %O data (H(5)=15.8, p=0.007), the consumption of pig (median = 18, IQR = 31.7) was significantly higher than equines (median = 1, IQR = 0.8, p=0.018) and sheep (median = 3.4, IQR = 4.8, p=0.03). Pairwise comparisons on %B data (N=45 observations) revealed statistical difference between pig (median = 57.8, IQR = 28.1) vs. poultry (median = 3.2, IQR = 3.5, p<0.001) consumption (H(4)=15.67, p=0.004).

The %O data of stray dogs' livestock consumption showed no difference between livestock species. Testing on biomass data was impossible due to the lack of adequate data.

3.2. Citizen Science

With 2000 individual surveys distributed across the country, we received 947 survey responses (47% response rate) documenting the perspectives of the local communities. The surveys were conducted in Mtskheta-Tianeti (response rate of the region: 25.3%), Tbilisi (36.8%), Guria (98.9%), Samtskhe-Javakheti (31.3%), Kakheti (96.2%), Lower Kartli (85.7%), Adjara (17%), Imereti (81.8%), Svaneti (19.8%), Lower Svaneti (14.3%), and Inner Kartli (13.2%). The majority of the respondents were male (77%) between the age interval of 35-44. The most active age groups of the respondents were 35-44 (28.2%) and 45-54 (26%); the majority of the respondents had a high school degree (34.02%), and only a few were post-graduates (11.49%). It is essential to highlight that since the respondents could select multiple answers, I expressed the percentages per question based on the total number of answers. Therefore, the results presented are not the reflection of the respondents but of the answers per individual question.

We collected 1,756 answers for **Question 1**, which asked about **the carnivore species they have sighted the most in their respective regions**. 49% of the answers identified the *golden jackal* as the species that were encountered the most often, followed by the *wolf* (40%), *brown bear* (4%), and *other* carnivore species (6.8%). Similarly, for **Question 10**, for which we collected 1,687 answers and asked **which of the carnivore species the local respondents have sighted the most in the past year**, 49.7% indicated that the *golden jackal* was the most sighted species, followed by the *wolf* (38.2%), *other* carnivores (6.3%), and *brown bear* (5.6%).

Question 5, to which we collected a total of 1,713 answers, asked about **the most problematic carnivore species that occur in their respective regions** 49.6% of the answers identified the *golden jackal* as the most problematic carnivore, followed by 40.5% of the responses identifying the *wolf*, while only 4.6% noting the *brown bear*. Similarly, for **Question 2**, for which we collected 1,725 answers, *golden jackals* (47%) and *wolves* (47.3%) were **the most noted species the respondents have seen or heard attack domestic livestock in their region**. In contrast, the *brown bear* only accounted for 5% of these attacks. When asked in **Question 3** if **any of these species were seen to have attacked or in any way disturbed humans**, out of 1,359 total answers, 47.3% and 44% noted that *golden jackal* and *wolf*, respectively, were the carnivores that disturbed or otherwise caused local communities discomfort.

The generally most sighted carnivore species, golden jackal was indeed commonly reported in Samegrelo (67%), Guria (54%), Kakheti (52%), Kvemo Kartli (52%); while only 2% of respondents found it problematic in Racha Lechkhumi. Instead, reports about wolves reached the 50% of responses here, just like it was registered in Adjara (56%). This regional variability was also captured by the independence test both for golden jackal ($\chi^2 = 43.6$, df = 10, $p < 0.001$) and grey wolf ($\chi^2 = 54.9$, df = 10, $p < 0.001$).

Reported attacks on domestic livestock had higher regional variability for golden jackal (min. 0% in Racha - max. 60% in Adjara) than wolf (min. 29% in Kvemo Kartli - max. 51% in Racha). Answers on both species were non-independent by region (jackal: $\chi^2 = 71.5$, df = 10, $p < 0.001$; wolf: $\chi^2 = 29$, df = 10, $p = 0.001$). It is important to note that 49% of the answers reported bears as primary predators of livestock after wolves (51%) in Racha Lechkhumi, and none of the answers reported golden jackal here.

Distribution of answers on Question 3 can be described with almost the same pattern. Observed or known attacks on humans had much higher range regarding golden jackal (min. 0% in Racha - max. 66% in Adjara) than wolf (min. 28% in Adjara - max. 55% in Guria). Racha Lechkhumi also had the highest reported bear attacks (52%) before wolves (48%). The distribution of answers were significantly associated with the regions surveyed (jackal: $\chi^2 = 69.1$, df = 10, $p < 0.001$; wolf: $\chi^2 = 51$, df = 10, $p < 0.001$).

Question 8, for which we collected 2,056 responses, showed that *domestic birds* (39.4%) and *livestock* (38.5%) were **the most frequent types of damage inflicted by carnivores that local respondents had either experienced** themselves or heard about from another source. *Harvest destruction* was also noted as damage caused by carnivore species, as indicated by 18% of the responses. However, **Question 6** further explored **the damage carnivores inflicted on personal belongings**; for example, cars, houses, and gardens. According to the 1,605 responses received, 48.8% indicated damage caused by *golden jackals*, 40.1% by *wolves* and 4.6% by *bears*, while 6.4% of the damages were attributed to *other* carnivore species.

Besides these characteristic species, the reported frequency of *other species* was notably high in Tbilisi (20%). Due to the specifications of the questionnaire the exact species can be only assumed in this case, but racoon might be a decent guess in this highly urbanized region.

Afterward, the questionnaire asked **what measures the locals undertake once the damage has been inflicted** to rid themselves of the disturbance from the large carnivores in the future. Out of 938 answers we gathered for **Question 7**, 41.1% of the answers indicated that they take *no action* against the problem carnivores. In contrast, 35.1% indicated that they *take matters into their own hands* to eliminate the individual. Only 12.8% noted that they had *filed a report to the local authority*, and 11% indicated they had *called the emergency services* for further assistance. Those responses that chose *no action* mainly originated from Tbilisi (76%) and Kakheti region (63%); while none of the respondents answered with *no action* in Adjara, Samegrelo, Racha-Lechkhumi and Shida Kartli.

To further understand the personal opinion of the local communities regarding **the best method to prevent these damages in the future** out of 1,037 answers for **Question 9**, 83.1% of the local communities noted *hunting* to be the most effective method of managing the large carnivore populations followed by *guarding dogs* (14.3%), and *other methods* (2%). All respondents from Racha-Lechkhumi, Samegrelo and Shida Kartli voted for *hunting* without exception (100%); and even the lowest value in this regard among the regions was way higher than 50% (min. 69% in Adjara). The answers were not independent of the regions ($\chi^2 = 62.3$, df = 7, $p < 0.001$).

3.3. Camera Trapping

Throughout the study, 897 images were taken, and 203 provided a definite and well-identifiable image of at least one individual of the target species of interest. On average, the cameras recorded 25.41 images per day, with 5.81 detections of the target species daily. Most detections were registered in February for season 1 (58 detections/100 trap days) and in November for season 2 (50 detections/100 trap days).

The cameras detected six frequently occurring mammal species in the Ponichala Nature Reserve (Figure 2). The majority of them were captured by each one of the cameras. Still, surprisingly, the free-ranging domestic species, namely dogs and cats, were the ones who were only detected by five cameras out of the six deployed (Figure 2 right). Despite some unclear detection, where the detected cats have a similar appearance to wildcats, these detections were identified as domestic cats due to the proximity of the city and the highly urbanized environment. The golden jackal was the most frequently observed species, recorded on 56 occasions in total (Figure 2 left). The second most common species was the raccoon (36 independent detections), an alien species present throughout Georgia. Free-ranging dogs and cats were only the 3rd (N=31) and 4th (N=29) most common species, respectively. Elusive and well-adapted species such as the stone marten and red fox were the least common mammals in the study area, with 14 independent detections each (Figure 2 left), however, they still appeared in every camera trap site.

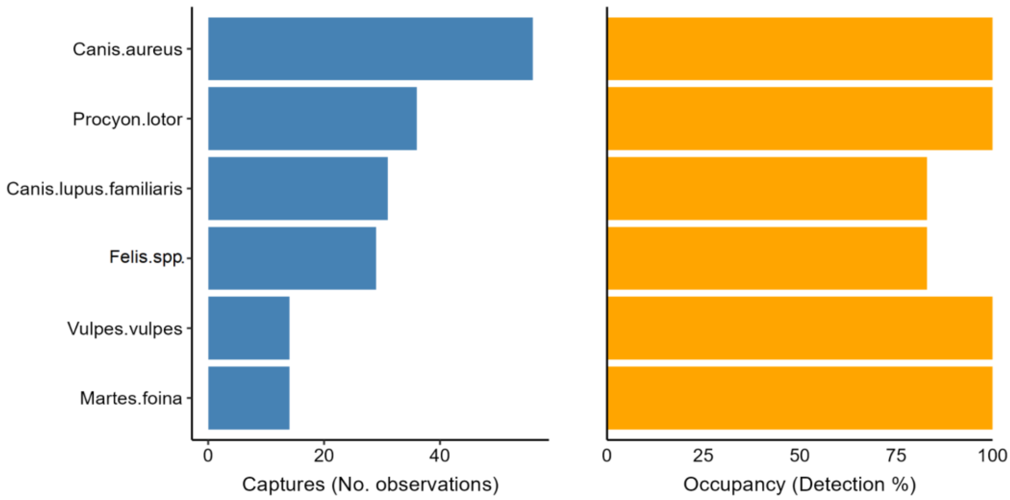


Figure 2: The total count of images per detected species (left) and the occurrence rate of the detected species (right) in the Ponichala Nature Reserve.

3.3.2. Spatial Distribution of Detections

Besides their high detection rate, golden jackals were frequently captured by the camera traps positioned in the northern part of the study area. The detections gradually decreased southbound from a maximal detection rate of 19.7 to 6.2 /100 trap days. On the contrary, cameras situated on the southern side of the Nature Reserve registered the bulk of the stray dog detections from a 9.9 to 11.3 detection rate, without any detection in the middle area. Dog appearance was much lower in the northern part of the study site (3.9 - 5.5 detection/100 trap days).

The presence of raccoons was especially high at one camera (detection rate: 18.3), placed closest to the riverbed while the species appeared less frequently at the other camera trap sites, even though it used the whole area of the Nature Reserve.

Cats actively used the inner-middle parts of the study area but were completely missing from those camera trap images that recorded the highest number of stray dog , stone marten , and red fox detections.

Stone marten also occurred in every location where camera traps were set up, and they were active in the north (max: 5.3 /100 trap days) and the southern parts (max: 6.3 /100 trap days) of the study site.

During the study, red fox detections concentrated on the southern side of the study area, with a max. detection rate of 6.3 ; still, they also appeared before all camera traps.

3.3.3. Temporal Distribution of Detections

Monthly detections

Cameras recorded almost the same number of individuals of foxes in both seasons (6 vs. 8 individuals in total); while cat detections were much higher in the second season (11 vs. 25 individuals in total). There were months without any detections regarding these species: Specifically March and December 2021 for red foxes and December 2020 and October 2021 for cats.

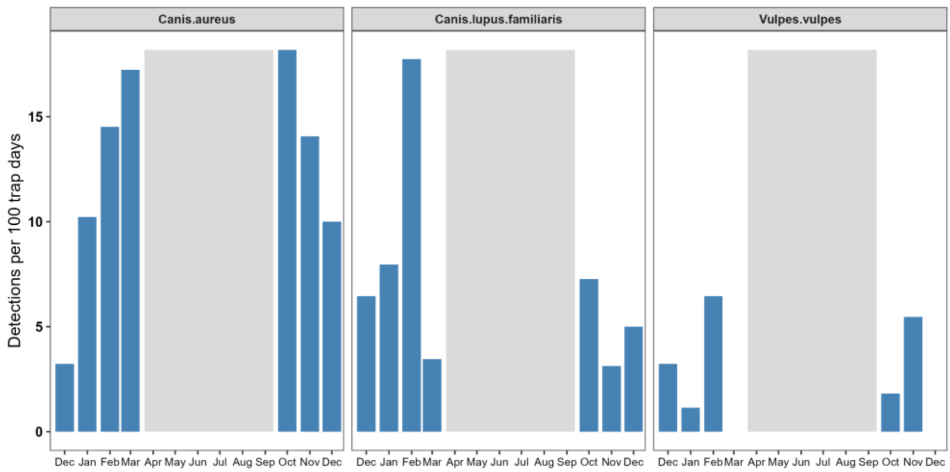


Figure 3: Monthly detection rates of golden jackal (left), dog (middle), and red fox (right) during the camera trapping in the Ponichala Nature Reserve. The grey blocks indicate the period when cameras were inactive.

The most common species, the golden jackal, provided an exceptional trend during the study, differing from any other registered species (Figure 3 left). Due to the technical pause of the camera trapping, the continuously increasing detection rate could not be monitored in the spring and summer of 2021. However, a peak in their activity can be undoubtedly presumed during that period, which could be the highest among the detected mammals (Figure 3 left). Altogether, 27 independent detections were registered in season 1 and 35 detections in season 2.

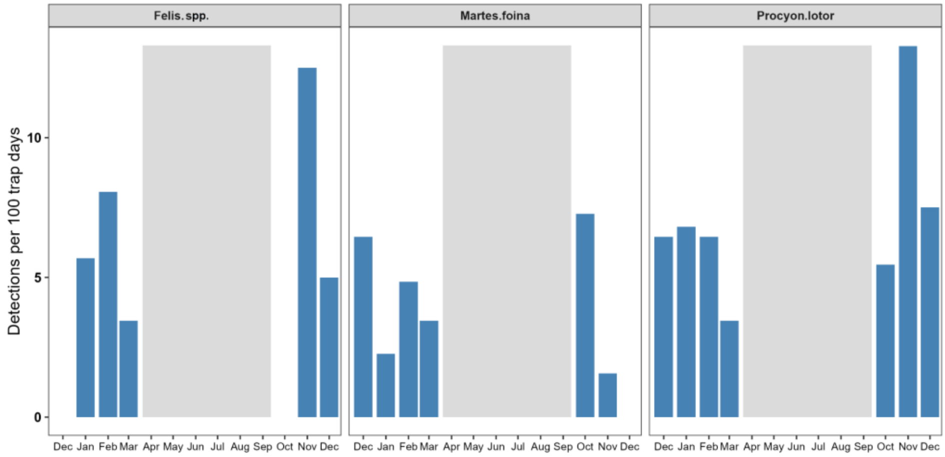


Figure 4: Monthly detection rates of cat (left), stone marten (middle) and racoon (right) during the camera trapping in the Ponichala Nature Reserve. The grey blocks indicate the time period when cameras were inactive.

The monthly detection of free-ranging dogs rates remained seemingly unaffected from golden jackals in season 1 (21 independent detections) than in season 2 (15 individuals). Stone marten and raccoon had nearly random or stagnating detection rates in season 1. They became more variable in season 2, resulting in a complete decline in stone marten detections (Figure 4 middle) and indicating the highest registered peak in raccoon's temporal activity (Figure 4 right). This increase provided the third highest registered detection rate (13.3 detection /100 trap days) after golden jackals and stray dogs.

Daily activity

I focused on analyzing those species' diel activity cycles whose presence caused notable differences or similarities with others. These were the contrasting space use of golden jackal and dog and the racoon and cat.

Contrasting the diel activity cycles of golden jackal and free-ranging dogs, an apparent shift can be observed between them (Figure 5). The highest activity of golden jackal was registered between 6 a.m. and 12 a.m. with an elongated peak activity. Dog detections got more intensive when jackal presence decreased, in the early afternoon from 1 p.m. to 5 p.m. Another but less intensive peak period was registered in the first half of night-time, just right after the jackal detections started to decrease, indicating an approximately 1-1.5 hour lag in peak activities between the two species.

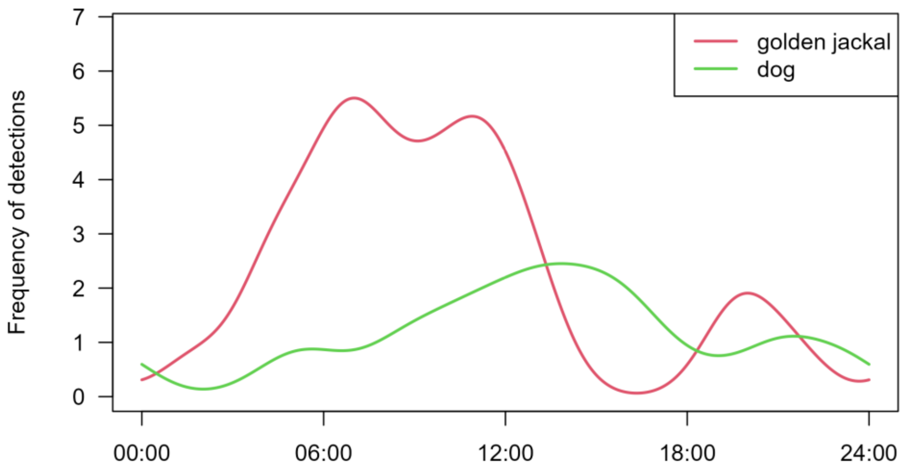


Figure 5: Kernel density estimation of the diel activity of golden jackal and free ranging dogs based on camera trap data.

The $\hat{\Delta}_4$ coefficient confirmed a significant but low overlap between the activity cycles ($\hat{\Delta}_4 = 0.6$, $p = 0.001$), since the probability of encounters between the species gradually increased during the first half of the day (Figure 5), and only the peak activity periods were segregated.

By comparing the raccoon and cat activity cycles, the $\hat{\Delta}_4$ coefficients of overlap confirmed a significant but weak overlap between them ($\hat{\Delta}_4 = 0.59$, $p = 0.006$). The most distinct pattern of their activity is related to the specific and differing nocturnal behaviour. Namely, raccoons were the most active during the night around 2 a.m. and 5 a.m. and their frequency of detection peaked around max. 1 individual during daylight. Cats appeared at the highest rate around 7 a.m. and 1 p.m. at the cameras, and their activity was dropped before nightfall , suggesting a rather diurnal behavior.

Despite the potential co-occurrence, it seemed when one member of this species pair followed a consistent and stable activity cycle, the other one's presence was quite disturbed and vice versa.

3.3.4. Species Co-occurrence

Based on the joint species distribution model, the association strength was the highest for the dog-racoon pair ($r = 0.33$). At the same time, it remained positive but rather indifferent for the dog-red fox ($r = 0.16$) and the golden jackal-stone marten pairs (r = 0.12). The spatiotemporal contrasts between golden jackal and dog occurrence were also emphasized in the matrix (r = -0.29), predicting that these two species are likely to avoid each other.

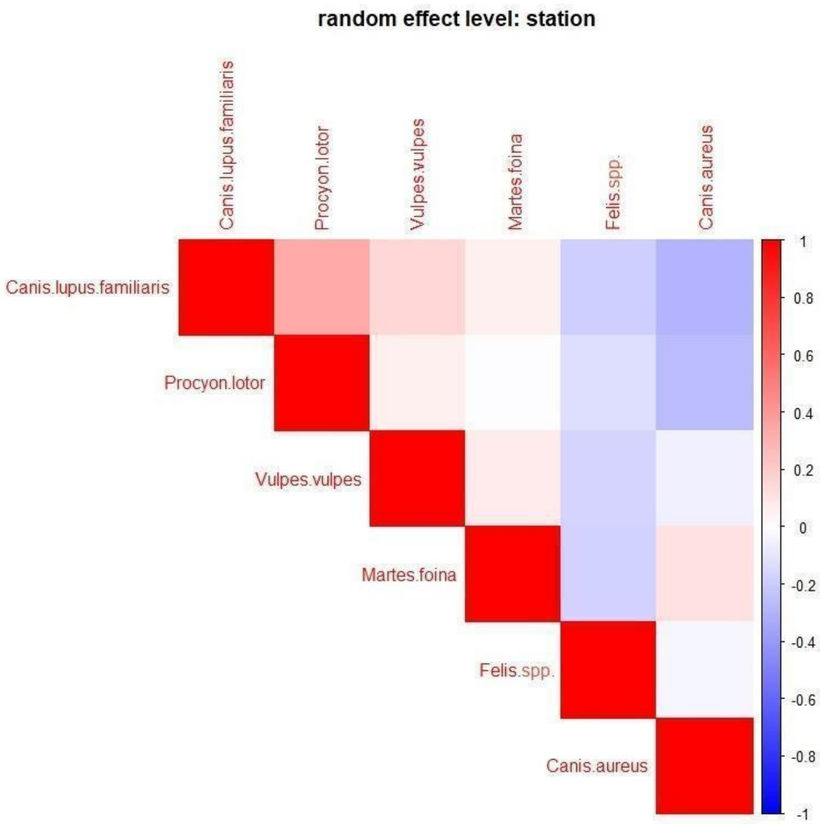


Figure 6: Species co-occurrence in the study area at both study seasons, based on the joint species distribution model. The color gradient ranges from red (positive association/co-occurrence) to blue (negative correlation/ avoidance). White cells indicate indifferent relationship. The scale on the right shows values from -1 to 1, where 1 (deep red) indicates a strong positive association (species tend to appear together). In contrast, -1 (deep blue) notes strong negative association (species tend to avoid each other) than expected under the independence hypothesis.

The cat was generally the most reluctant species based on the model's predictions (r_{mean} = -0.14), avoiding interactions with other species. Its lowest association was predicted with a stray dog (r = -0.18), while surprisingly, the highest value was estimated with another canid, the golden jackal (r = -0.04), indicating an indifferent relationship towards this species.

3.4. Acoustic Survey

3.4.1. Response Intensity and Estimated Population Parameters

The distribution of responses varied across regions, with some showing higher responses from individuals, while in others, we recorded high group responses. The mean number of individual responses was 3.42 ± 1.9, while the mean number of no responses was 3.14 ± 2.54. Group responses were higher, averaging 6.85 ± 4.56. Wolf responses were lower than the golden jackal, with an overall mean of 1.5 ± 2.29.

The highest number of individual responses was recorded in Adjara (n=7), and the lowest was observed in Kakheti (1). However, in Kakheti there were the highest number of group responses (12), whereas Racha and Samtskhe-Javakheti had the lowest group participation. The highest number of wolf responses was recorded in Racha (6), which is much higher than other regions, where wolf responses ranged from 0 to a maximum of 3. The highest number of no responses was found in Samtskhe Javakheti (7) and Racha (6) regions.

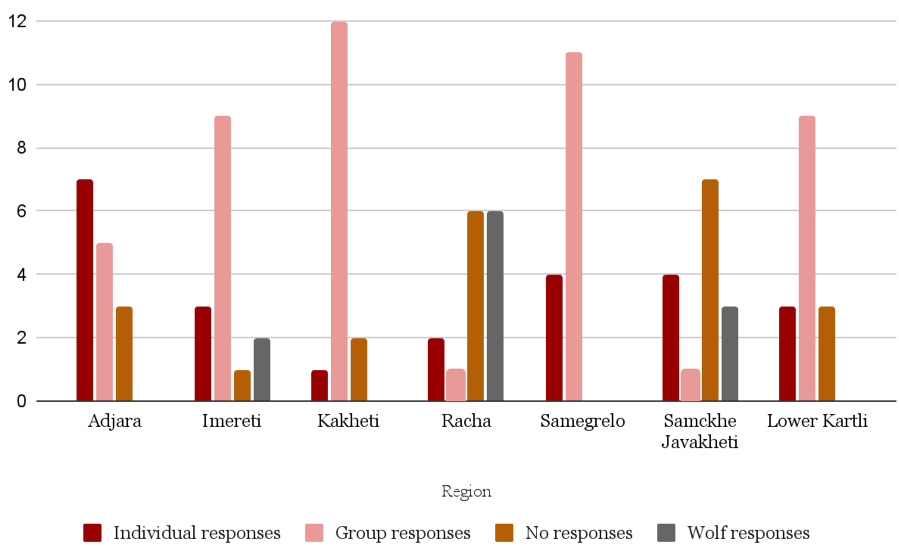


Figure 7: Number of detected responses per region in all calling stations of each transect.

Population density estimates were reflected over the three different detection radii (1 km, 1.5 km, and 2 km). I generally expressed this metric for the buffer zone of 1.5 km and provided estimates for the 1 and 2 km buffers in parentheses, indicating that there is some uncertainty in detection distance (±

500 m). Kakheti was shown to have the highest estimated density of 0.46 individuals per km² (1.04 for 1 km and 0.26 for 2 km buffer zones). Similarly, the regions of Samegrelo displayed relatively high density estimates of 0.45 (1.02 - 0.25) individuals per km². However, Racha showed the lowest estimated density with 0.06 (0.13 - 0.03) individuals per km², indicating a much lower presence of jackals in this region. In other regions, such as Kvemo Kartli and Imereti, results noted an intermediate density estimate, while Samtskhe-Javakheti demonstrated relatively low densities.

Based on these density estimates, population growth under two reproductive scenarios were estimated for low reproductive rate (35% of females reproducing) and high reproductive rate (65% of females reproducing). In both scenarios, an average of five pups per female was assumed, with a 50% pup survival rate. Based on these assumptions, under the low reproductive rate scenario, Kakheti showed the population growth potential with 2286 (5148 - 1286) juveniles, respectively. Racha, being one of the most mountainous regions, showed the least population growth potential, with only 72 (161 - 40) pups across the three buffer zones. The same conclusion holds true for the scenario with high reproduction rate of the females. Kakheti and Samegrelo are the regions with highest potential population density while Racha and Samtskhe Javakheti are the lowest .

3.4.2. Modeling Golden Jackal Occurrence in Function of Environmental Variables

As it can be seen from Figure 8, the absolute values of jackal responses were seemingly lower in those regions where wolves responded to the playback calls. Therefore the average jackal response rates were much lower in regions where wolves also responded to the calls. These areas were mainly mountainous regions like Racha (jackal: 0.2 ± 0.41, wolf: 0.4 ± 0.51, elevation: 1110 ± 430 m) and Samtskhe Javakheti (jackal: 0.33 ± 0.49, wolf: 0.2 ± 0.41, elevation: 1553 ± 282 m).

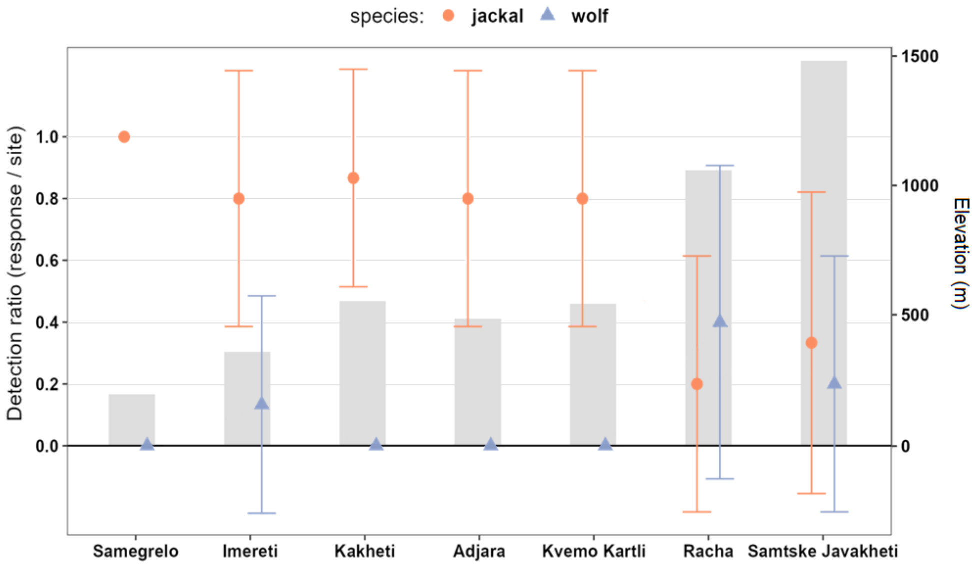


Figure 8. Detection ratio (broadcasting points with response divided by all broadcasting points) of the golden jackal (orange circle) and grey wolf (blue triangle) in different regions of Georgia based on the bioacoustic survey. Grey bars represent the mean elevation of sampling sites per region arranged in an ascending order.

Forest and related woody vegetation was the dominant land cover type on most broadcasting sites throughout the sampled regions). Its mean cover was similar independent of jackal response (with response: 65 ± 28%; without response: 62 ± 35 %). Grassland and meadow was the second most common land cover category; its cover was less variable around sites with jackal responses (17 ± 15%) than without it (26 ± 25%). Cropland area cover was highly variable by the actual region and degree of urbanization (with response: 9 ± 17%; without response: 8 ± 16%); while the other land cover types remained under 5% in the 2 km buffer area of the broadcasting stations most of the time.

None of the cover variables was eligible to provide significant explanatory power to the fitted model in predicting jackal occurrence.Similarly, the other environmental variables,like the Terrain Ruggedness Index, distance from the nearest settlement, total daily precipitation and daily mean temperature:) were considered not significant.

Only elevation (likelihood ratio test: $\chi^2 = 17.1$, $p < 0.001$) and the detected wolf presence on transects provided adequate significance levels in the model.

The latter one only had a weak association, but the likelihood ratio test indicated that wolf detections can still have adequate explanatory power ($\chi^2 = 3.4$, $p = 0.05$) that resulted in the final model below (Table 2).

Table 2. The results of the generalized linear mixed model examining the effects of elevation and wolf presence on golden jackal responses to the bio-acoustical survey. Variables were scaled before fitting. The coefficients and their corresponding confidence intervals are expressed in odds ratios, the exponentiated form of the default log of the odds output of the model. Transect and region were added as random effects to the model.

		95% Confidence Interval			
	Estimate	lower	upper	z value	p
Intercept	2.94**	1.46	5.95	3	0.002
Elevation	0.31**	0.13	0.7	-2.8	0.005
Wolf presence on transect	0.52	0.25	01.09	-1.73	0.084
Variance of random effects: by transect = 1.001; by region = 1.717 ** p<0.01					

The model predicted a gradual decrease in the occurrence probability in the elevation increase function (Figure 9). The relationship is almost linear, increasing uncertainty at higher elevations, indicating that other latent variable(s) may also affect jackal presence.

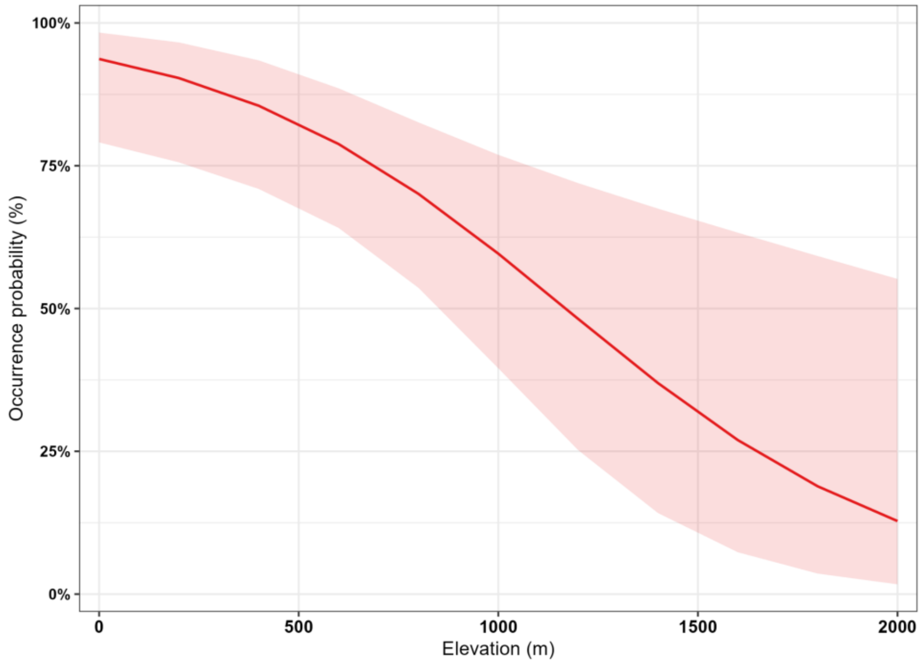


Figure 9. The estimated occurrence probability of golden jackal in function of elevation predicted by the fitted model.

One of these could be the presence—more precisely, the co-occurrence—of wolves in these habitats (Figure 10), which negatively affected jackal occurrence, but the errors gave high uncertainty to this factor. On the other hand, its effects were more pronounced in mountainous areas, where it can significantly alter the habitat use of the golden jackal.

By combining the elevation data obtained from the Digital Elevation Model (Robinson et al., 2014) and data from the Agency of Wildlife on the direct observations of wolf presence in Georgia 2021, the fitted model (Table 2) was used to predict and extrapolate golden jackal occurrence throughout the country. Extrapolations were created at the 10 × 10 km UTM grid scale .

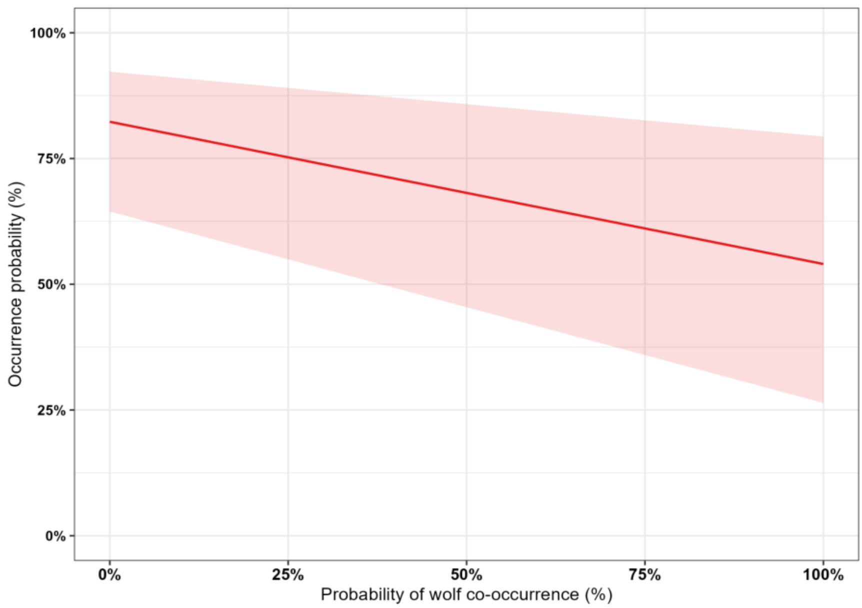


Figure 10. The estimated occurrence probability of golden jackal in function of wolf presence predicted by the fitted model.

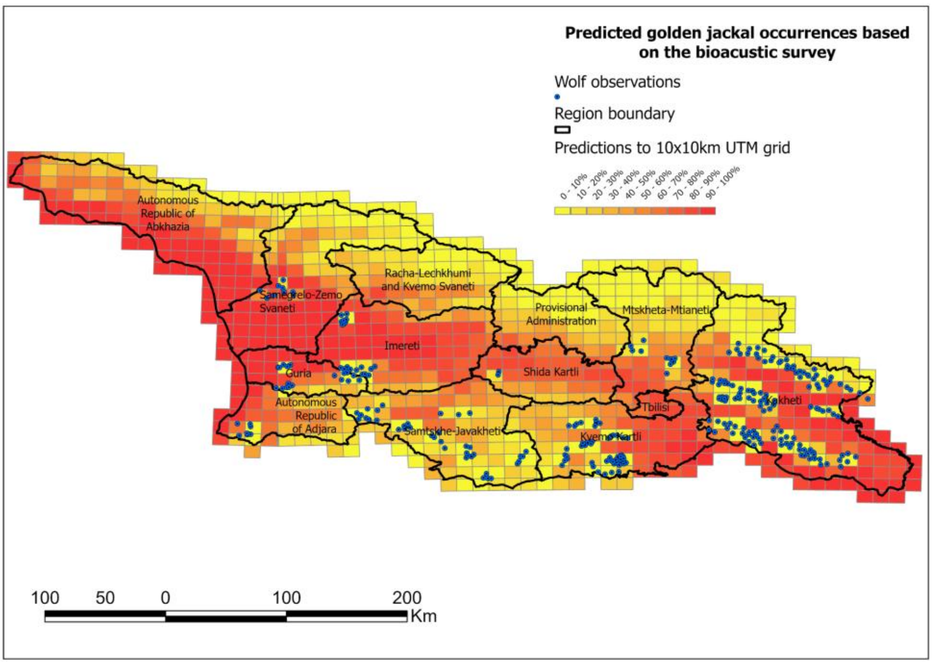


Figure 11. The estimated occurrence probability of golden jackal in Georgia based on the fitted model. Elevation and wolf presence, as significant variables, were used to create model predictions which were generalized onto the 10 × 10 km UTM grid.

4. DISCUSSION

4.1. Literature Review

The literature review addressed Research Objectives 1. and 2. which aimed to investigate the general impact of canids on livestock damages and understand the impacts of increasing carnivore population on domestic prey. The results of the systematic review align with **H_1** and find that wolves consume the highest proportion of livestock and prefer larger domestic animals. Golden jackas primarily target medium- or small-sized domestic species and showed the highest consumption of pigs, while stray dogs consume the least livestock, as their diet primarily consists of anthropogenic food sources due to their close association with human settlements.

Overall, the predation and/or consumption of domestic livestock varies regionally and heavily influenced by wild prey availability and livestock management practices. In southern European countries (e.g., Greece and Portugal), where natural prey is scarce, wolves frequently prey on livestock (Papageorgiou et al., 1994; Vos, 2000; Torres et al., 2015; Janeiro-Otero et al., 2020).

Prey vulnerability is one of the most critical factors that promotes livestock depredation. For example, in Spain's Cantabrian Mountains, the replacement of sheep and goats with free-ranging beef cattle—assumed to be less vulnerable—led to a rise in wolf predation. In Ávila, wolves kill over 1,600 calves annually due to high cattle density, low wild prey availability, and insufficient protective measures (Blanco et al., 2021b). Similarly, in Portugal, free-ranging cattle systems experience more wolf attacks than semi-confined systems (Pimenta et al., 2018), and comparable trends are observed in the USA and Italy (Breck et al., 2004; Dondina et al., 2015).

Wolves in Portugal and Greece have also shown preference for goats over sheep, largely because goats graze farther from human settlements, often unattended and in rugged terrain, whereas sheep are managed in tighter, more protected flocks (Torres et al., 2015; Iliopoulos, 2009). Policy changes have further impacted carnivore diets. The EU Regulation 1774/2002 (later repealed by Regulation 1069/2009) required the removal of livestock carcasses from fields, reducing scavenging opportunities and potentially pushing carnivores to hunt live domestic animals instead (Lagos & Bárcena, 2015).

Golden jackals show significant dietary flexibility influenced by social behavior and seasonality. Individually, they hunt small prey (rodents, birds), but when paired during the breeding season, they can target medium or large animals (Mahmood et al., 2013; Jhala & Moehlman, 2004). Jackals show the highest preference for pigs, especially in Serbia during winter when pig remains are discarded after seasonal slaughter (Ćirović et al., 2014; Penezić, 2015). Similar behaviour was observed in Greece and Israel, where illegal waste dumps near settlements provide reliable winter food, drawing jackals closer to human communities and increasing conflict (Giannatos et al., 2005; Rotem et al., 2011).

In contrast, in Greece, jackals often consume goats alongside pigs (Lanszki et al., 2009; Giannatos et al., 2010), while in Israel, poultry dominates their livestock diet (Lanszki et al., 2010). Generally, cattle and horses are too large and risky for jackals to hunt. Their broad dietary preferences—ranging from plant matter and reptiles to garbage—reflect high adaptability and explain their relatively low reliance on livestock (Lanszki et al., 2006, 2010; Giannatos et al., 2010).

Unlike the predation habits of wolves and golden jackals, livestock predation by stray dogs is poorly studied. While some reports suggest that stray dogs may consume more livestock than wolves (Echegaray & Vilà, 2010), most evidence indicates that their diet mainly consists of anthropogenic food sources, including household waste and roadkill. Unlike wolves and other canid predators, stray dogs are closely associated with human settlements and typically live near farms. This proximity to humans explains why most of their diet consists of anthropogenic food sources (Vanak & Gompper, 2009; Carrasco-Román et al., 2021).

4.2. Citizen Science

The citizen questionnaire addressed Research Objective 3 which aimed to understand the extent of the Human-Carnivore conflict in Georgia. The results align with $\mathbf{H_2}$ and find that human-carnivore conflict in Georgia is most severe in rural areas, where livestock depredation and crop raiding are prevalent, leading to increased reliance on lethal control methods such as trapping and shooting.

Historically, Georgian rural communities coexisted with carnivores through traditional knowledge on livestock management, predator deterrents, and community monitoring (Kikvidze & Tevzadze, 2014). However, given that Georgia has experienced some significant socio-economic changes with regards to urbanization, agricultural practices, and rural economy transformations, traditional knowledge which was essential for coexistence gradually declined. With younger generations migrating to the cities and rural lifestyles evolving, the transmission of ecological knowledge has diminished leaving communities less prepared to manage interactions with carnivores, resulting in increased livestock predation and more frequent conflicts.

To gather insight on Research Question 3.1 (*Are the studied species a nuisance to the local communities? If so, what type of problems are they causing?)*, survey question Q8 (2056 responses) showed that the most damage done by the carnivores is on poultry and livestock. Kopaliani et al. (2009) argue that the lack of wild prey, human encroachment, and absence of barriers to carnivore movement have led to carnivores adapting to human presence. Similarly, Q1 (1756 responses) and Q10 (1688 responses) indicate that jackals and wolves are the most frequently sighted carnivores, with similar trends in carnivore attack reports (Q2, 1725 responces).

While these sightings may suggest population growth, Kopaliani et al. (2009) attribute frequent wolf attacks on livestock to the rise of synanthropic wolves—those adapted to human environments—driven by ecological and socio-economic factors. Kopaliani et al. (2009) identified waste accumulation near settlements as a key driver of wolf synanthropization in Georgia, with landfills being primary attractants for carnivores like jackals and wolves. The camera trap study confirmed similar behavior in golden jackals (see Chapter 4.3).

Vulnerable livestock and scarce wild prey further attract predators. Notably, areas maintaining traditional farming practices report fewer wolf attacks, even when adjacent to disturbed regions. Environmental changes also play a a major role in determining the carnivore distribution. In Mtskheta-Tianeti, Guria, and Adjara, rewilded landscapes—such as restored forests and abandoned tea plantations—create corridors between villages and forests, offering shelter to carnivores and increasing human-wildlife interactions. These factors likely explain why Q2 (1725), Q5 (1713), and Q6 (1606) responses identified jackals and wolves as the most problematic species.

After investigating Research Question 3.2 (*What is the most common method used by the local communities to mitigate and prevent the damages?*) it was clear that while survey question Q9 (1037 responses) did not have a high response rate, it showed that the most common methods of predation prevention are hunting and using guard dogs. Kikvidze (2014) found that many new livestock farmers owned small dogs, which were ineffective against nocturnal wolf attacks. Small dogs often hide or follow their owners, offering little protection. In contrast, larger dogs, though kept at home during the day, actively guard livestock at night, making breed and size key factors in livestock protection.

To address Research Question 3.3 *(What are the major factors that need to be considered in management effort in relation to these carnivore species?),* it is first important to understand the timing of the conflict. Winter and autumn were shown to be when the highest damage occurred, as shown by the Q4, this is unlike other European regions where livestock are kept indoors during these seasons. This suggests a need for more research into winter-specific risk factors in Georgia. Some questions (e.g., Q7 with 938 responses) had low response rates, potentially due to discomfort or perceived irrelevance. Most respondents relied on self-prevention or took no action; only a minority contacted authorities (hotline: 10%, official complaint: 12%). Trust in institutional response appears low—only 18% of requested predator harvests were fulfilled between 2015–2020.

4.3. Camera Trapping

The results of the camera trapping study addressed Research Objective 4, which sought to understand the coexistence between wild canids, domestic animals, and humans in semi-urbanized areas. The results partially support **H_3** confirming golden jackals in semi-urban zones, though no wolves were detected in Ponichala Nature Reserve. Nevertheless, wolf presence elsewhere cannot be ruled out, as citizen questionnaires reported them as problematic species near the settlements. **H_4** is also partially supported as raccoons, an alien species, were detected and showed potential conflict with similarly sized animals, especially cats, based on overlapping seasonal activity cycles. Still, raccoons coexisted with golden jackals and other non-target species, offering insights into their spatiotemporal dynamics.

Regarding the Research Question 4.1 (*What are the possible factors that encourage their occurrence in the semi-urban area?*), the study found that golden jackals were the most frequently detected species, consistent with their adaptability to anthropogenic landscapes (Šálek et al., 2014; Tsunoda & Saito, 2020). Detection was highest in the north, near a deserted land patch—likely a key feeding site—complementing the Forest-Park area used for breeding. This type of spatial preference aligns with findings that jackals thrive in semi-natural habitats with moderate human disturbance (Ćirović et al., 2014).

Topography was another factor that influenced the jackal occurrence. Ponichala Reserve is bordered by the Mtkvari River and surrounded by urban areas. Occasionally, the Reserve becomes fragmented due to flooding during wet years. During arid years, the river levels are low providing an easy passage for the animals between the forest patches. While jackals can disperse from the southern rural area into the Nature Reserve, the roads and highways pose a significant risk of vehicle collisions. Therefore, swimming across the river cannot be ruled out as a possible way into the park, especially during severe droughts with low water levels. However, golden jackals still occurred in the park areas in the year 2021, which was the wet year when the river flooded the passageways. This again highlights their high adaptability, and due to the abandoned land patch, jackals found a way to establish a stable population here.

In contrast, raccoons showed a broad distribution, especially near the riverbed, consistent with their preference for riparian habitats (Sanderson, 1987). As a non-native species in Georgia, their potential ecological impacts warrant concern.

The study also offered insights into Research Question 4.2 *(How do large and medium-sized carnivores interact and coexist with domestic animals and humans in semi-urbanized areas in Georgia?).* The study showed that the stay dogs mainly occupied southern park areas and rarely overlapped with jackals. For Research Question 4.2 (interactions with domestic animals and humans), stray dogs mainly occupied southern park areas and rarely overlapped with jackals. As both species are opportunistic feeders (Vanak & Gompper, 2009; Giannatos et al., 2010), resource competition and territoriality (Font, 1987;

Comazzi et al., 2016) may drive this spatial and temporal separation. In addition, dogs typically appeared in small groups, while jackals were solitary or in pairs. Jackals, typically monogamous and forming smaller family groups during the breeding season, may avoid areas dominated by larger or more aggressive dog packs to reduce conflict.

Raccoons were the second most observed species, peaking in November 2021 when cat activity also rose. While the space use was rather similar between the two species, they differed in their temporal activities. The results confirmed raccoons' nocturnal activity, whereas cats were mainly detected around 7 a.m. and 1 p.m., and their activity dropped before nightfall. This suggests cats were likely domestic, but further research is needed. It occurred as one of these species followed a consistent and stable activity cycle while the other one's presence was quite disturbed. It is possible that the species first probed for the presence of others and then decided if they would stay in the area. The statistical analyses proved no significant competition between stone marten and raccoons

Cats were detected to occur mostly in the inner parts of the study area and were absent in areas where dogs, martens, and foxes were most active, likely avoiding potential competition or predation—especially if kittens were present (Krauze-Gryz et al., 2012; Rodríguez et al., 2020).

Despite the technical pause in camera trapping which prevented monitoring of the steadily increasing detection rate of golden jackals during the spring and summer of 2021, the results still offered insights into Research Question 4.3 *(Are there seasonal differences in the occurrence of large and medium-sized canids in semi-urban areas?).* Golden jackal activity likely peaked during spring due to increased food and human presence. high tolerance towards anthropogenic disturbance, which has allowed populations to become established in human-modified landscapes (Šálek et al., 2014; Tsunoda & Saito, 2020), where they show high utilization of anthropogenic foods (Ćirović et al., 2014).

Detection rates for stone martens and raccoons were nearly random in season 1 but became more variable in season 2. As a result, the stone marten detections declined entirely, while raccoons reached their peak temporal activity. This increase in raccoon detections represented the third-highest recorded rate, following golden jackals and stray dogs. This may be due to the low number of these species in the area or the cameras themselves. Authors like Gompper et al. (2006) argue that tack plates are more effective and have higher Probability of Detection (POD) for observing and studying smaller mammal species like martens and weasels than camera traps. However, for mid-sized carnivores both methods show similar efficiency, as confirmed by Shamoon et al. (2017) in Mediterranean agricultural settings. Since small carnivores were not the study's target, track plates were not used.

4.4. Bioacoustic Survey

The bioacoustic survey addressed Research Objective 5 and investigated the population size of golden jackals in Georgia. Results partially align with $\mathbf{H_5}$, which predicted that environmental variables and interspecific competition significantly influence the distribution and occurrence of the golden jackal. Specifically, golden jackals preferentially inhabit lower elevation areas due to potentially greater resource availability while actively avoiding areas with high competition from larger carnivores.

In addressing Research Question 5.1 (*What is the minimum population size of the golden jackal at the county and country level?).* The reproduction growth model estimated 3,638 individuals under the assumption of low reproductive rates in golden jackal females and 6,756 individuals under the assumption of high reproductive rates within a 2 km radius buffer zone across the seven surveyed regions. However, these projections should be interpreted cautiously, as additional population assessment research is necessary to accurately determine the various ecological and environmental factors that significantly influence reproductive success and must be considered for more precise predictions.

No land cover variables, such as forest cover, grasslands, and croplands were found as significant factor that defined jackal occurrence in any specific region despite initial expectations. This aligns with the international literature that suggests that jackals exhibit considerable ecological plasticity, adapting to various habitats (Šálek et al., 2014; Tsunoda & Saito, 2020). While land cover preference wasn't confirmed, the preference for lower elevations may imply an indirect selection for lowland habitats with higher prey availability and lower predation risks.

The Generalized Linear Mixed Model (GLMM) showed reduced occurrence of jackals at higher elevations. The results showed that the probability of golden jackal occurrence is the highest along Georgia's NW - SE central line. These areas are between 0 and 1200 m above sea level with a mean of 415 ± 323 m elevation, dominated by a mix of land types, mostly croplands, and grasslands, which are divided by forests or less dense woody vegetation near to waterfowls. The absence of jackals at higher elevations may result from lower prey availability or unsuitable habitats. Although no specific land cover type was favored, the preference for lower elevations likely reflects a tendency toward lowland habitats with better prey access and lower predation risk.

Interestingly, UTM cells with over 70% probability of golden jackal occurrence were primarily located near rivers and featured diverse land cover types. Rivers Rioni, Kura, and Alazani create mixed environments that disrupt continuous forest cover, likely supporting higher jackal presence. While this study couldn't confirm specific vegetation preferences, international literature noted that the mixed habitats are most occupied by the golden jackals (Stoyanov, 2012; Šálek et al., 2014; Tsunoda & Saito, 2020).

Although land cover preferences were not the primary focus of the study, the findings highlighted the need for finer-scale habitat analysis. Future research should include prey availability, wolf competition, and human disturbance to inform conservation strategies. The bioacoustic survey revealed regional differences in jackal and wolf presence. Individual jackal responses were highest in Adjara, while group responses peaked in Kakheti, suggesting stronger social structures and potentially higher growth rates in that region—patterns consistent with Moehlman's (1987) findings on increased pup survival in social groups.

Population estimates indicate that jackal densities are highest in the low-lying regions of Kakheti and Samegrelo, and lowest in the high-elevation regions of Racha and Samtskhe-Javakheti. This variation may be linked to climate, habitat, and prey availability (Acosta-Pankov et al., 2018). The fact that Racha, the region with the highest elevation, exhibited the lowest growth potential of golden jackals could suggest that wolves may be preying on juvenile individuals, especially since this region had the highest mean wolf detection rate. While reproductive projections provide insight into potential growth scenarios, these results should be interpreted cautiously and warrant further investigation. A broader range of factors influencing jackal population growth must be considered.

A key finding is the negative relationship between golden jackal and wolf responses, which is also indicated by the fitted model. For example, wolves were present in the region of Imereti where the average elevation was less than in Racha or Samckhe Javakheti; it is plausible to assume that wolves also occur in the other areas of lower elevations that did not respond to the jackal howl playbacks. However, wolf spatial presence needs further investigation. While it is reasonable to conclude that the lack of wolf responses is due to low numbers or absence of wolves from the area, assuming some aspects of competition is also sensible. For example, regions with higher wolf detections, such as Racha and Samtskhe-Javakheti, corresponded to lower jackal detections. Jhala and Moehlman (2004) suggest an interspecific competition, where wolves, as apex predators, may suppress jackal populations through direct predation or competitive exclusion in the shared habitats. The only exception is the Kakheti region, where the significant number of wolf detections strongly modified the predicted occurrence of golden jackals (Figure 11). Any other regions outside of this axis got gradually decreasing estimates of occurrence due to the lack of acoustical surveys in the northern side of the country on the one hand (see Map 2) and the high reported direct observations of wolves along the southern border on the other hand.

It has been observed in many areas that jackals generally tend to avoid wolves. For example, its range in Europe has significantly and quickly expanded from the Balkan Peninsula to central and western countries (Arnold et al., 2012; Rutkowski et al., 2015) in which the wolf, acting as a dominant competitor, is absent (Newsome et al., 2017; Tsunoda & Saito, 2020). The jackal range expansion is often mirrored with the decline in wolf distribution (Krofel et al., 2017). However, the opposite is true in other regions, where jackals benefit from scavenging on wolf kills (Boitani et al., 2018) and successfully coexist with wolves. A similar relationship is seen with red foxes and coyotes in North America (Levi & Wilmers, 2012; Wikenros et al., 2017). The distribution area overlap of wolves and jackals increased from about 7.1% during 1950–1970 to 22.7% in central Europe after 2000, with wolves reclaiming historical ranges and jackals colonizing new areas (Krofel et al., 2017).

No proof of a specific environment was found regarding Research Question 5.2 (*What regions do these species occupy, and what type of habitats are they mostly found in?*). Further research is needed to investigate the environmental factors that encourage and promote golden jackal occurrence in Georgia and its implications for the interaction with human settlements.

5. CONCLUSIONS AND RECOMMENDATIONS

The literature review revealed a few shared conclusions about livestock damage and human-wildlife conflict in Europe (**H_1**). This study highlights that the dietary habits of wolves, golden jackals, and stray dogs are heavily affected by regional variations, especially aspects such as prey availability, livestock management practices, and anthropogenic factors. Wolves in Southern Europe, where natural prey is less abundant, rely more on domestic livestock, leading to increased conflicts with farmers. Furthermore, free-ranging livestock is the most difficult to protect and it is the most vulnerable to wolf predation. This is particularly evident in countries like Spain, Portugal, and Italy, where free-ranging husbandry practices make cattle and goats more susceptible to predation. In the EU, there are many fine-scale differences in human-wildlife conflict. A few large carnivore individuals can produce great damage when the environmental, social, and economic systems predispose to it, whereas large populations can make a limited impact in different circumstances. The availability of natural prey, landscape characteristics, and protection measures shape the incidence of damage to livestock, making it crucial to develop region-specific management strategies.

The study found that the local communities struggle to coexist with the large carnivores (**H_2**) and face continuous damage during winter and autumn. The local communities, who frequently experience damage to their livestock and poultry by golden jackals and wolves, often reserve the opportunity to eliminate the problem individually due to the lack of trust in the local authorities. Incorporating large-sized dogs and bulls in the herds is an effective way to reduce damage to livestock significantly; however, introducing more modern techniques, such as electric fences and other physical barriers, is also effective in helping mitigate the risks associated with increased cattle numbers. By addressing these management gaps, it may be possible to reduce the impact of wolf predation and enhance the sustainability of livestock husbandry in the region. Moreover, some baseline recommendations have been made to address the issues of carnivores. Firstly, it is essential to agree on defining the "problem causing" carnivores and then document every case of such individuals. Secondly, removing any possible attractants and implementing preventive measures is crucial. Personally, conducting a lethal removal of problem individuals should be the last resort. Thirdly, communication regarding carnivore management needs to be adequately established and performed with the local communities and the general public. It is imperative to highlight the necessity of not feeding and approaching the carnivore, as this action creates the risk of carnivores becoming accustomed to humans.

The findings of this study have important implications for the management of golden jackal populations in semi-urban areas as well. The observations showed that the urbanized environment doesn't negatively affect the golden jackal's presence but instead provides them with an ideal refuge to establish viable populations (**H_3**). In addition, given the lower social tolerance towards wolves, the urbanized areas can keep the wolves away from the vicinity, facilitating a higher appearance of the golden jackals. The camera trap survey can also confirm this assumption, where the golden jackals were the most commonly detected species in an area close to the capital city. High priority needs to be attributed to managing the golden jackal population in urban areas as there is a high possibility for interference with humans. Further, raccoons were found to prefer more riparian habitats (**H_4**). This raises concerns over their effect on the native species and habitats. More research is needed to investigate the impact of alien species on native ecosystems and develop a dedicated management plan before alien species become invasive.

Based on the population growth predictions, the highest densities observed in Kakheti and Samegrelo suggest that these regions may require more active management to mitigate potential human-wildlife conflicts, particularly in agricultural areas (**H_5**). Conversely, in regions with low densities, such as Racha and Samtskhe-Javakheti, conservation strategies should focus on maintaining habitat connectivity and minimizing competitive pressures from wolves. It is still important to note that the predictions should be handled carefully in areas where no bioacoustics surveys were made, especially in Abkhazia, South Ossetia, and North-Mtianeti.

Georgia has an active need for effective policy frameworks that support the preservation and integration of traditional ecological knowledge in wildlife management. Encouraging policymakers to consider the socio-cultural dimensions of wildlife conservation and involve local communities in developing and implementing management plans is essential. This inclusive approach could lead to more sustainable and effective solutions for addressing wolf-human conflicts. Consequently, a multifaceted approach is the only way to address these human-wildlife conflict cases effectively. Education and outreach programs are crucial elements that help improve the understanding of wolf behavior and ecology, potentially reducing unfounded fears and misconceptions.

Most importantly, authorities need to foster coexistence, which, for it to be successful, needs to involve collaborative efforts between wildlife conservationists, local communities, and government authorities. Through this process, policies need to be developed to consider the needs of both human and wolf populations. Tackling the underlying causes of conflict and fostering collaborative, well-informed strategies may alleviate tensions, paving the way for a more balanced coexistence between humans and carnivores.

6. NEW SCIENTIFIC RESULTS

- **Livestock Predation** (*Research Objectives 1 & 2*)**:** Wolves strongly prefer larger domestic livestock, specifically cattle and goats. Golden jackals primarily target medium- or small-sized domestic species, with a notable preference for pigs. Stray dogs consume the least livestock, as their diet relies heavily on anthropogenic food sources, but more research is needed to understand livestock consumption by stray dogs.
- **Species Distribution and Damage** (*Research Objective 3*)**:** Golden jackals and wolves are the most sighted species in remote rural areas. During the winter and autumn, these species cause the most damage to livestock and domestic fowl.
- **Conflict Mitigation** (*Research Objective 3*)**:** Based on the surveys, guard dogs and lethal control methods are the most widely utilized methods to prevent carnivore conflicts. In spite of their widespread use, the effectiveness of these methods requires further research to develop effective mechanisms to respond to human-carnivore conflict and promote coexistence.
- **Golden Jackal Ecology:**
  - Golden jackals do not avoid semi-urban areas, as these locations offer refuge with abundant food and minimal predator presence. They can disperse regardless of natural barriers such as rivers (*Research Objectives 4*).
  - The occurrence of golden jackals is negatively correlated with elevation. Golden jackals are most abundant in regions with lower elevations, like Kakheti and Samegrelo, and least abundant in areas of higher elevations, like Racha and Samtskhe-Javakheti (*Research Objective 5*).
  - Areas with a more than 70% probability of golden jackal occurrence contained various land cover types, mainly near rivers. Jackal populations form more substantial social groups in certain areas (e.g., Kakheti), possibly leading to higher reproductive success (*Research Objective 5*).
- **Species Interactions and Habitat:**
  - Golden jackals and wolves exhibit spatial separation: high wolf density regions have lower jackal presence. Wolf responses to

jackal playbacks varied, suggesting potential competitive interactions or territorial avoidance in some areas (*Research Objective 5*). The camera trap study revealed an absence of wolves in the semi-urbanized area where jackals were present in high numbers, suggesting jackals are more adaptive to urbanized environments (*Research Objective 5*).

- Similar avoidance was observed between golden jackals and stray dogs, as well as between raccoons and cats, likely due to dietary overlap and territorial disputes. Raccoons prefer riverine habitats, raising concerns about competition with native species. Raccoons and cats showed particular avoidance in their seasonal activity cycles (*Research Objective 4*)

7. LIST OF PUBLICATIONS

Publications

Kalandarishvili, A., Feher, A., Katona, K. (2024). Differences in livestock consumption by grey wolf, golden jackal, coyote and stray dog revealed by a systematic review. Hystrix, the Italian Journal of Mammalogy, 35(1), 0. https://doi.org/10.4404/hystrix-00672-2023

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