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Authors: Šprem, Nikica, Madi, Ivan, Biondić, Dario, and Janječić, Mihael

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RESEARCH PAPER

Unimodal activity pattern of stone marten in a Mediterranean island habitat

Nikica ŠPREM, Ivan MADI, Dario BIONDIĆ and Mihael JANJEČIĆ*

University of Zagreb, Faculty of Agriculture, Department of Fisheries, Apiculture, Wildlife Management and Special Zoology, Zagreb, Croatia; e-mail: mjanjecic@agr.hr, nsprem@agr.hr, dbiondic@agr.hr

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Abstract. Camera traps were deployed over 12 months (2022-2023) to examine the locomotor activity patterns of stone martens (*Martes foina*) in a Mediterranean habitat on the island of Dugi Otok, Croatia. Activity levels were calculated, and intersessional differences were tested. Trap rate was compared between seasons and three types of vegetation cover (open areas, dense vegetation areas and cultivated areas). Temperature and relative humidity data were collected using data loggers placed in the study area, and the correlation between the number of events was calculated. The differences between the independent events depending on the moon phase were tested. A total of 416 independent events involving stone martens were recorded. A unimodal locomotor activity pattern was found for the stone marten on this island, and the patterns remained relatively consistent, with predominantly nocturnal activity. Activity levels in winter were significantly higher than in other seasons. Trapping rates were lower in open areas. There was no significant correlation between the independent events and average temperature and relative humidity. The phases of the moon did not influence the number of independent events. This study identifies new perspectives on the locomotor activity of stone martens in a Mediterranean island habitat and serves as a starting point for further research.

Key words: activity patterns, Adriatic Sea, camera traps, island ecosystem, *Martes foina*, non-invasive methods

Introduction

Mediterranean ecosystems are inherently heterogeneous due to human intervention in the landscape and climatic fluctuations. Wildlife responses to this variability result in a strategy of complementary utilisation of multiple resources provided by land cover, with a net increase in individual fitness (Santos & Santos-Reis 2010). Virgós et al. (2000) pointed out the importance of mosaic habitats for carnivore species compared to forest-only habitats, and similar patterns have been observed in other Mediterranean regions (Sacchi & Meriggi 1995, Rondinini & Boitani 2002).

Activity level, i.e. the proportion of time an animal is active, is a behavioural and ecological metric that can provide indicators of energy, search effort and risk exposure (Rowcliffe et al. 2014). Animal activity patterns are shaped by evolution but are further refined by flexible responses to the environment. Predation risk and resource availability are environmental cues that influence behavioural decisions that drive predator and prey activity surges. Depending on their local importance, they can be strong enough to override the endogenous regulation of the animal's circadian clock (Monterroso et al. 2013).

The stone or 'beech' marten (*Martes foina*) is a small carnivorous mammal widespread throughout Europe and particularly active at night due to improved opportunities to catch prey than during the day. Another reason for this behaviour is anthropogenic

* *Corresponding Author*

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pressure and the experience of avoiding human presence. The activity of stone martens depends mainly on characteristics such as climate, topography, availability, and abundance of prey (Dudin & Georgiev 2016). Most members of the marten family living in northern latitudes are less active in winter than in summer and reduce their activity even in extremely cold winter weather conditions (Pauli et al. 2022). Strong winds may also contribute to reduced activity (Zielinski 2000). Considering the high energy requirements of martens, especially in winter, considerable energy savings can be achieved by reducing activity. In some mustelids, activity can increase energy expenditure by up to six times the basal metabolic rate (Karasov 1992). Deprivation of activities associated with reproductive behaviour reduces activity, though some mustelids also show less territorial behaviour (Monterroso et al. 2014). In contrast to the pine marten (*Martes martes*), the stone marten enlarges its territory in winter to compensate for the reduced availability of food in its habitat at this time.

For small carnivores, the most important factors influencing their activity patterns are access to prey, competition with other small animals, and interspecific competition with large carnivores (Bischof et al. 2014, Mori et al. 2022). Most small predators share their habitat with larger predators, which increases the likelihood of disruptive competition and predation within the niche. Therefore, larger predators trigger a 'landscape of fear' in small carnivores, forcing small carnivores to alter their activity patterns to reduce encounters with larger carnivores without compromising prey capture (Ritchie & Johnson 2009).

Data collected using camera traps are increasingly used to study temporal patterns in species and community ecology, including species activity patterns and niche partitioning. These temporal insights are valuable from an ecological perspective and provide insight into human-induced changes in species behaviour and interactions and the resulting effects on niche partitioning and community structure. The increase in studies based on temporal analyses using cameras provides new ecological and applied insights (Frey et al. 2017). Since there is scarce information about stone marten locomotor activity, especially in a Mediterranean island ecosystem without large carnivores, this study aimed to determine the daily and seasonal activity pattern of this small carnivore species using camera traps.

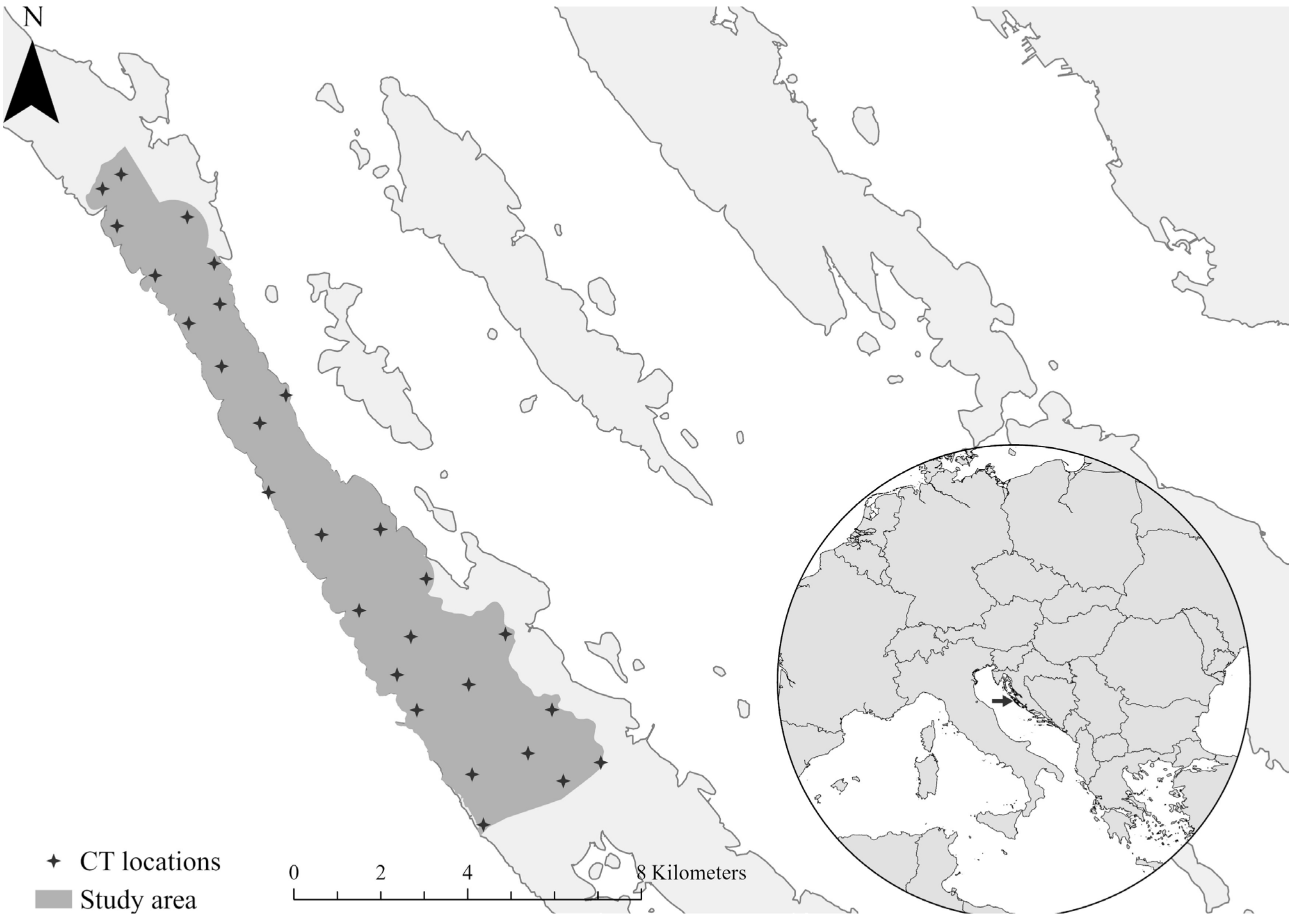

Fig. 1. Study area borders and the camera trap locations.

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Material and Methods

Study area

The study was carried out on the island of Dugi Otok, located in the central part of the Adriatic Sea (43°57′56′′ N, 15°06′24′′ E). The altitude ranges from 0 m to 338 m. The total study area was 3,577 ha, of which 3,016 ha is forest land, 6 ha of arable land, 32 ha of meadows, 391 ha of pastures and 132 ha of unfenced herbaceous plantations. Figure 1 shows the map of the study area and the locations of the camera traps. Land cover on the northern part of the island is predominantly scrub and degradation stages of holm oak (*Quercus ilex*) forests with myrtle (*Myrtus communis*), while in the southern part of the island, Aleppo pine (*Pinus halepensis*) forests with holm oaks occur (Vukelić 2012). According to the Köppen classification, the climate is the Csa type, moderately warm and rainy with hot summers and mild winters, and occasional cold spells. Most of the rainfall occurs in the winter months. The dry season is in the warm season (Šegota & Filipčić 2003).

The stone marten is the only carnivorous species present in the study area, with only recent records (within the last two years) of golden jackal (*Canis aureus*) in very low density (N. Šprem, unpublished data). Besides carnivores, there are also several other species of large mammals, including European mouflon (*Ovis gmellinin musimon*), feral goats (*Capra hircus*), feral sheep (*Ovis aries*), axis deer (*Axis axis*) and wild boar (*Sus scrofa*) (Šprem et al. 2023). Based on the official game management plan, the estimated minimum number of individuals of European mouflon, feral goats, feral sheep, axis deer and wild boar is 82, 96, 105, 65, and eight individuals, respectively. Several prey species, such as house mice (*Mus musculus*), brown rats (*Rattus norvegicus*) and some bird species, can be found on the island. There are also several birds of prey, such as the Eurasian eagle owl (*Bubo bubo*), the long-eared owl (*Asio otus*), the common buzzard (*Buteo buteo*), the peregrine falcon (*Falco peregrinus*) and the short-toed snake eagle (*Circaetus gallicus*). The island is sparsely populated (approximately 14.5 inhabitants per km^2), but in summer, there is more human activity due to tourism. According to the Croatian hunting law, hunting is allowed all year round, but only as individual hunts (group hunts are not allowed). According to the hunting management plan, hunting takes place on a maximum of 40 days per year (N. Šprem, unpublished data).

Data collection

The study was carried out with 27 Dörr Snapshot Mini 12 MP HD camera traps installed for 12 months (10 March 2022 to 28 March 2023) according to the instructions of the ENETWILD Consortium (2021). The cameras were placed at predetermined locations in a uniform spatial distribution in grid form (1.5 × 1.5 km). They were active 24 h a day and took a photo every second until the animal left the area. The camera traps were placed on trees about 50 cm above the ground, with at least 10 m of sparse or no vegetation in front of them. The maximum distance between camera traps was 1.5 km. Each observed animal was considered an independent record if there were more than 90 sec between the two photos.

The cameras were inspected, checked, and maintained regularly to replace batteries and memory cards. The batteries and memory cards were replaced three times, on June 14, September 19 and December 21, 2022, i.e. on average every three months. Due to forest fires, malfunctions and false triggering, there were fluctuations between the camera trapping days during the study. Data on moon phases (first quarter, full moon, third quarter, new moon) were obtained from the Croatian Hydrological and Meteorological Service. To record temperature and relative humidity, six Tinytag Plus 2 – TGP-4500 data loggers (Tinytag, Gemini Data Loggers Ltd.) were installed stepwise according to altitude throughout the study area (one data logger per 60 m altitude). The first data logger was placed at a height of 1 m above sea level. The data loggers took one temperature and relative humidity measurement per hour and were active throughout the study. Each data logger was mounted on the pole in the shade of the vegetation at approximately 1 m above ground with a white plastic cap as additional radiation protection.

Data analysis

We performed the analysis on the complete set of recorded photos and sets of images divided into seasons based on the month of capture: spring (April-June), summer (July-September), autumn (October-December), and winter (January-March). Data acquisition from photographs was performed independently with partial assistance of artificial intelligence in the Agouti software, and data processing was performed in 'R' software (R Core Team 2023). Stone marten activity level (proportion of the day that the animal is active) was estimated from captured photos using the 'activity' package in

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R software (R Core Team 2023), fitting the von Mies kernel as the circular normal distribution (Meredith & Ridout 2014, Rowcliffe 2023). To account for the circularity of time, the solar time at which each photo was taken was converted to radians ranging from 0 to 2π, representing a circular random variable. Based on the simulation performed by Ridout & Linkie (2009), several smoothing parameters (0.5 to 2) were plotted against the original data points. Based on visual inspection, we selected a smoothing factor value of 1.5. The standard error was estimated by non-parametric bootstrapping (999 bootstrap iterations). An activity probability distribution was then created from fitted activity models to illustrate the activity pattern (Fig. 2). Camera trapping days were calculated for each season, and the trap rate was calculated as the quotient between the total number of independent records and the camera trapping days. Seasonal activity levels were compared using the Wald test, as suggested by Rowcliffe et al. (2014). Trap

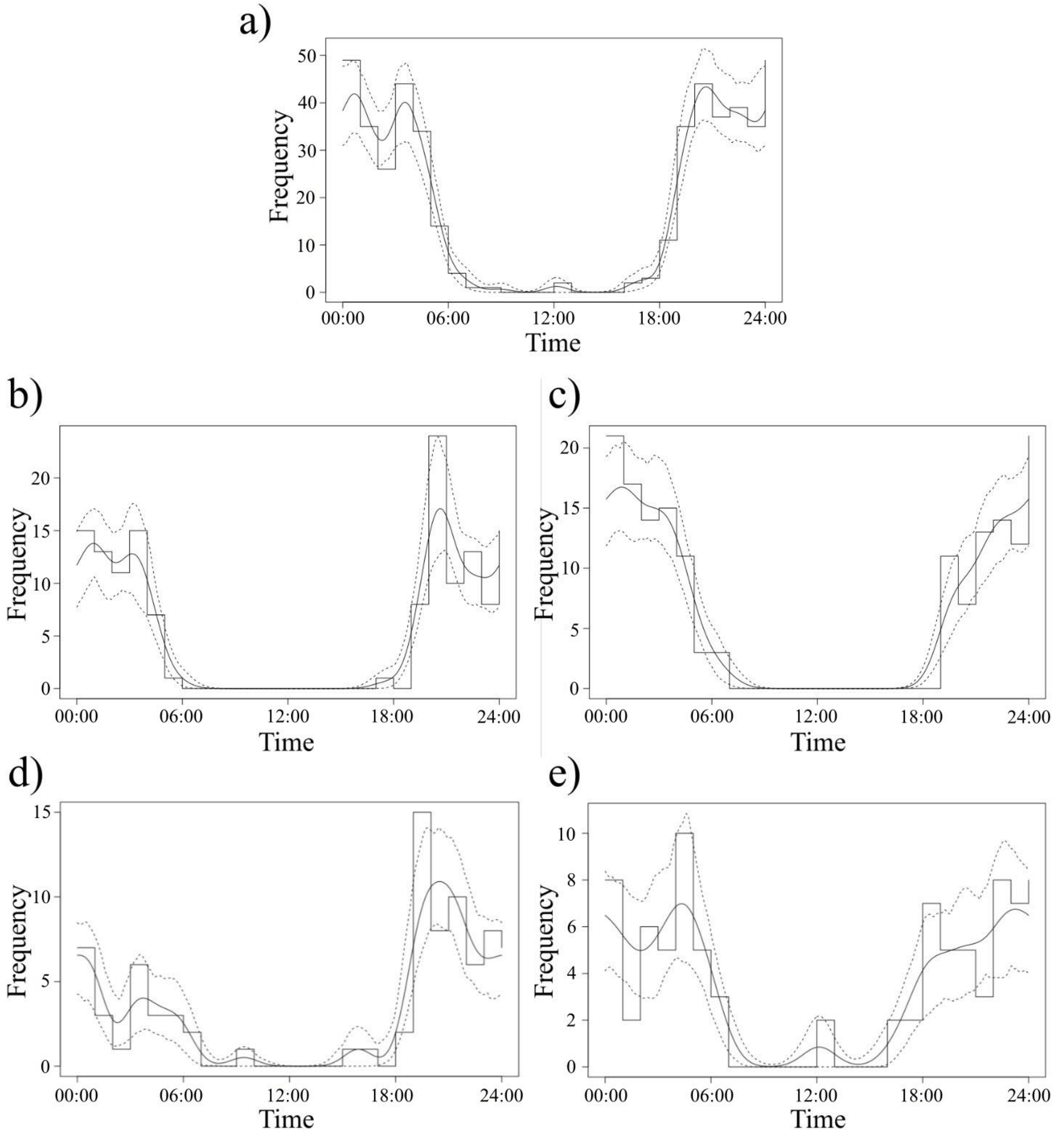

Fig. 2. Kernel density estimates (1.5 smoothing factor) of daily activity pattern and number of photos (frequency) for stone marten (*Martes foina*) on Dugi Otok Island, Croatia during: a) overall study period (12 months), b) spring, c) summer, d) autumn, and e) winter. The curve represents the pattern of relative activity over the day (activity pattern). The area under this curve is proportional to the total amount of time allocated to activity (activity level).

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Table 1. Seasonal activity level (%) of stone marten (*Martes foina*) on Dugi Otok Island, Croatia. SE – standard error, LCL – lower control limit (2.5%), UCL – upper control limit (97.5%).

	Spring	Summer	Autumn	Winter
Activity level	31	35	29	48
SE	4	3	4	5
LCL	22	27	22	31
UCL	35	38	36	51

Table 2. Two-sided *P*-values corresponding to the Wald test for activity level difference.

	Spring-Summer	Spring-Autumn	Spring-Winter	Summer-Autumn	Summer-Winter	Autumn-Winter
P-values	0.14	0.65	1.67^{-9}	0.54	5.22^{-6}	8.92^{-11}

rates were calculated for each season, and differences between them were tested using the Kruskal-Wallis test. Buffer zones of 30 ha were established around each camera trap, corresponding to the reported home range of the stone marten (Santos & Santos-Reis 2010). The habitat type in the buffer zones was determined using Corine land cover 2018. Habitat types with similar characteristics were classified into three main categories according to CLC standard levels and vegetation cover characteristics (Box & Fujiwara 2013): open areas (natural grasslands and sclerophyllous vegetation), cultivated areas (olive groves and complex cultivation patterns), and areas with dense vegetation (broad-leaved forest and transitional woodland-shrub). The overall trap rate was calculated for each category, and the significance of pairwise comparisons was estimated using the Wald test. The average daily temperature and relative humidity were calculated as the mean values recorded by all data loggers in the study area. The correlation between the average temperature, the number of observations, and the correlation between the relative humidity and the number of observations were calculated as Spearman's rank correlation coefficient. The total number of observations per moon phase was recorded, and the differences were tested using one-way ANOVA.

Results

The total number of camera trapping days was 6,717; 1,453 in spring, 1,296 in summer, 1,925 in autumn and 2,043 in winter. The stone marten was photographed in 416 independent records: 126 times in spring, 133 times in summer, 77 times in autumn and 80 times in winter. According to the probability density function shown in Fig. 2, the stone martens were most active between 18:00 and 06:00 (Fig. 2a). In spring, the peak of the marten activity curve was recorded between 19:00 and 04:00 (Fig. 2b), while the rest of the day, i.e. between 05:00 and 18:00, there was almost no activity. In summer, the peak of the marten activity curve was between 23:00 and 04:00, while no activity was recorded between 07:00 and 18:00 (Fig. 2c). While some daytime activity was recorded in the autumn (Fig. 2d), the peak of the marten activity curve was between 18:00 and 24:00, with lower density values (activity) between 00:00 and 06:00. In winter, stone marten activity started earlier, around 16:00, with a peak in the activity curve between 18:00 and 06:00 (Fig. 2e). Finally, stone martens on the island of Dugi Otok show a unimodal locomotor activity pattern, with predominantly nocturnal activity. The activity level (proportion of time the animals are active) was highest in winter and significantly different from all other seasons ($P < 0.05$). The activity levels in spring, summer and autumn were not statistically significantly different. The activity level values for the individual seasons are shown in Table 1, and the results of the Wald test are shown in Table 2. The seasonally calculated trap rate was 0.087 (spring), 0.103 (summer), 0.040 (autumn) and 0.039 (winter). There was no significant difference between the trap rates ($P < 0.05$) in the different seasons. The trapping rate in cultivated areas with dense vegetation and open areas was 0.089, 0.076 and 0.019, respectively. The trap rate differed significantly ($P < 0.05$) between open and cultivated areas and between open areas and areas with dense vegetation. There was no statistically significant difference between cultivated areas and areas with dense vegetation. A moderate negative correlation (–0.37) was found between average temperature and trap rate in spring. No significant correlations were found during the rest of the study period, with an overall correlation of 0.05 for temperature and –0.15 for humidity. The phase of

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the moon did not affect the trap rate ($P < 0.05$): 25.72% of all detections occurred at the new moon, 23.08% in the first quarter, 22.60% at the full moon and 28.61% in the third quarter. European mouflon, feral goats and sheep, axis deer, wild boar, golden jackals, house mice, brown rats and domestic cats were recorded during the study period. The number of independent events for each species and the type of activity are shown in supplementary data in Table S1.

Discussion

The stone marten is known to be a primarily nocturnal species that forages mainly at night (Delibes 1983, Herrmann 1994), which was confirmed by the results of this study. Comparing the activity patterns of stone marten recorded in this study with the reports of Linck et al. (2023), there were no significant differences in activity patterns.

Mori et al. (2022) reported that pine martens were active at dusk and dawn most of the year, and daytime activity increased when females gave birth. On Elba Island (Italy), where large carnivores are absent, the pine marten was observed 125 times in the spring/summer period (April to July), 103 times in the late summer/autumn period (September to November), and 64 times in the winter/spring period (January to April) (Mori et al. 2022). Comparing activity periods in Mori et al. (2022) with the results of the present study, the trap rate of pine martens does not differ significantly from the trap rate of stone martens. For both species, the frequency of observations was higher in the warmer seasons and decreased in the winter months. This observation can be explained as an adaptation of the stone marten to the cold, i.e. its reduced activity is related to energy conservation in cold conditions (Monterroso et al. 2014, Pauli et al. 2022). Roy et al. (2019) reported that martens showed a nocturnal activity pattern (85%) with two activity peaks, between 21:00 and 23:00 and between 01:00 and 03:00. Looking at the activity of the stone martens on Dugi Otok Island throughout the year, stone martens had only one peak during night hours. The same unimodal activity pattern of stone marten was recorded in an agricultural habitat, while a bimodal activity pattern was recorded in the mountains in Bulgaria (Petrov 2022). The unimodal activity pattern could be due to predation by other species, which was confirmed in a study by Šprem et al. (2015) on chamois (*Rupicapra rupicapra*). The activity of stone martens was closely related to rodent activity on the island, as they showed a purely nocturnal and unimodal activity pattern throughout the year (see Fig. S1). Similarly, Roy et al. (2019) observed that the temporal pattern of marten activity is closely related to the activity of the woolly rabbit (*Lepus oiostolus*), resulting in a strong temporal overlap, which could facilitate marten predation. Monterroso et al. (2013) showed that carnivores do not entirely follow the activity pattern of European rabbits (*Oryctolagus cuniculus*) despite higher energy intake. It is assumed that these systems have likely evolved in such a way that a certain level of activity favours the survival of the entire prey population in times of high risk, while the availability of sufficient prey prevents predators from following them altogether. The trapping rate in open areas was significantly lower, which is consistent with the studies of Fonda et al. (2021), in which stone martens preferred wooded areas, and Santos & Santos-Reis (2010), in which stone martens mainly used forests, riparian vegetation and orchards, and sometimes meadows and other open areas.

In the study by Vilella et al. (2020), stone marten and common genet (*Genetta genettas*) showed an irregular pattern of activity, with two distinct peaks in spring and summer. Also, the European badger (*Meles meles*) and the European wildcat (*Felis silvestris*) showed a consistent pattern with a peak of activity between 21:00 and 00:00. In terms of variations in daily activity patterns, red fox (*Vulpes vulpes*) and marten were the only animals to show significant seasonal differences. However, these shifts were not in the same direction: while the red fox started and reduced its activity earlier in fall and winter, the marten increased its activity around dawn (Vilella et al. 2020). The present study shows that activity levels increased in winter, which could be influenced by the length of daylight and night (Fig. 2e), as shown in the study by Vilella et al. (2020). In the study by Pauli et al. (2022), stone martens even become more diurnal to save energy. This shift in activity time combined with a longer nighttime might be responsible for increased activity levels during the winter.

The phase of the moon is a known factor affecting predator activity, especially during periods of high visibility, when prey reduce their activity to minimise predation risk, while predators increase their activity in search of prey (Penteriani et al. 2013). This study supported this hypothesis, as stone martens were more active at times of better visibility (third quarter). Similar results on the moon trap rate were recently confirmed for golden jackals in Croatia (Šprem et al. 2024).

The stone marten has several natural enemies on the island of Dugi Otok, especially birds of prey and,

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more recently, a mesocarnivore species, the golden jackal, which was recorded several times during the study period at only four different camera traps (Table S1). It is assumed that the stone marten is prey for larger carnivores such as red fox, wildcat, and lynx (*Lynx lynx*) (Janicki et al. 2007). Tsunoda et al. (2018) stated that habitats with terns, stone marten, and badgers avoid the terns, and are active only at night when terns are not active. Zhao et al. (2020) observed that small carnivores avoid entirely areas where the North China leopard (*Panthera pardus japonensis*) is present in all seasons. Similarly, Suraci et al. (2016) showed that small carnivores avoid certain areas or spend much less time there in the presence of large carnivores. In the study conducted by Giannatos et al. (2010), remains of stone martens were found in golden jackal scats. Although the remains of marten were not very numerous (only 3.2%), this is evidence that they can be prey for golden jackals, raising special attention to their coexistence on Dugi Otok Island. The study by Ferretti et al. (2023) also shows that larger carnivores can prey on smaller carnivore species, but when the main prey species are abundant, negative interactions with smaller carnivores are limited. A further increase in golden jackals on Dugi Otok could lead to behaviour interference and interspecific competition with the stone marten.

Camera traps have proven to be a successful tool for monitoring small carnivore species, such as the stone marten. This study opens new perspectives on the locomotor activity pattern of stone martens in a Mediterranean island habitat and serves as a starting point for further research to test the hypothesis on the possible influence of a newly arrived mesocarnivore (golden jackal), where an intra-guild effect was confirmed as a strategy (Ferretti et al. 2020). Long-term monitoring of activity could also illustrate any impact of climate change on the stone marten in the Mediterranean.

Author Contributions

N. Šprem conceptualised the framework and wrote all drafts of the manuscript. M. Janječić conducted the statistical analyses. I. Madi and D. Biondić obtained and arranged raw data. All authors read, corrected, and approved the manuscript.

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Supplementary online material

Table S1. List of species, number of independent events, and type of activity.

Fig. S1. Kernel density estimates (1.5 smoothing factor) of daily activity pattern and number of photos (frequency) on Dugi Otok Island, Croatia for: a) house mice (*Mus musculus*) and b) brown rat (*Rattus norvegicus*).

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