


Spatiotemporal activity of the pine marten *Martes martes*: Insights from an island population

Emiliano Mori¹ | Ettore Fedele² | Ilaria Greco³ |
Margherita Giampaoli Rustichelli³ | Alessandro Massolo^{4,5} | Silvia Miniati³ |
Francesca Puppo⁶ | Giacomo Santini³ | Marco Zaccaroni³ 

¹National Research Council—Research Institute on Terrestrial Ecosystems—Via Madonna del Piano 10, Sesto Fiorentino, Italy

²Department of Genetics, University of Leicester, Leicester, UK

³Department of Biology, University of Florence, Sesto Fiorentino, Italy

⁴Ethology Unit, Department of Biology, University of Pisa, Pisa, Italy

⁵UMR CNRS 6249 Chrono-environnement, Université Bourgogne Franche-Comté, Besançon, France

⁶Tuscan Archipelago National Park, Locality Enfolà, Livorno, Italy

Correspondence

Marco Zaccaroni, Department of Biology, University of Florence, Via Madonna del Piano, 6, 50019, Sesto Fiorentino (FI), Italy.

Email: marco.zaccaroni@unifi.it

Abstract

Behavioral interference and interspecific competition shape the spatiotemporal behavior of carnivores, where intra-guild predation has been recorded as a strategy to limit competition. Very often, disentangling the effect of intra-guild effects from other ecological processes is challenging, if not impossible. This work aimed to assess the spatiotemporal behavior of the pine marten *Martes martes* in an island ecosystem without any intra-guild predation. Using an intensive camera-trap survey on Elba Island, Italy, we estimated occupancy, detection probability, and locomotor rhythms of the species. The pine marten occurred throughout the study area, showing a tendency to avoid urban areas during the high tourist season. Occupancy was higher in colder months and lowered in autumn, following opposite fluctuations of recorded human presence. Conversely, the detection probability remained low throughout the year, confirming the pine marten elusiveness. With other studies conducted in sympatry with other carnivores or predators, Elba Island martens showed locomotor ground activity mostly at dawn and dusk throughout the year, with an increasing diurnal locomotor activity in spring, when cubs are present. The spatiotemporal behavior of the pine marten in Elba island did show little variation across seasons. It was similar to those reported where potential predators were present, suggesting the intra-guild predation not playing a significant role in shaping the spatiotemporal activity of pine martens.

KEYWORDS

activity rhythms, island ecosystem, *Martes martes*, occupancy modeling, wildlife camera-trapping

1 | INTRODUCTION

Behavioral interference and interspecific competition represent two forces shaping the spatiotemporal behavior of many species (e.g., Ferretti et al., 2011; Garcia-Olaechea &

Emiliano Mori and Ettore Fedele contributed equally to this work.

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Hurtado, 2020; Merchant & Nagata, 2011; Mori, Bagnato, et al., 2020; Mori, Sangiovanni, & Corlatti, 2020). It is particularly evident in carnivores, where intra-guild predation has been recorded as a strategy to limit competition (Donadio & Buskirk, 2006, Ferretti et al., 2020; Palomares & Caro, 1999; for reviews). Avoidance of the dominant competitor can be exerted through spatial or temporal niche partitioning or through a shift in the diet, which may limit aggression triggering (Durant, 2000; Monterroso et al., 2013). The assessment of spatiotemporal behavior of wild carnivores is crucial for their conservation and management, particularly when involving rare and elusive species (Botts et al., 2020; Lucentini et al., 2007; Merson et al., 2019; Srivathsa et al., 2014). Competition between pine marten *Martes martes* and stone marten *Martes foina*, two closely related, very similar European carnivores, has been widely studied through radio-tracking (Wereszczuk & Zalewski, 2015), molecular analyses (Monterroso et al., 2016; Posluszny et al., 2007; Rosellini et al., 2008), snow-tracking (Goszczyński et al., 2007) and camera trapping (e.g., Balestrieri et al., 2019; Gazzola & Balestrieri, 2020; Monterroso et al., 2016; Rosellini et al., 2008; Torretta et al., 2017). When these martens live in sympatry with several other carnivore species (e.g., the red fox *Vulpes vulpes* and the European badger *Meles meles*), stone martens are mostly nocturnal, whereas pine martens show a cathemeral or diurnal pattern (Fonda et al., 2017; Monterroso et al., 2014; Mori & Menchetti, 2019; Torretta et al., 2017). Zalewski (2001) showed that, in Central Europe (Białowieża Primeval Forest), the activity rhythms of the pine marten change seasonally, with daytime bouts increasing when cubs are present and with strictly nocturnal habits in winter. Where large competitors (e.g., the lynx *Lynx lynx*, the red fox, and large-sized raptors) are present, avoidance of daylight may result from predation risk perception by martens (Drew & Bissonette, 1997; Zalewski, 2001). Because of their semi-retractable claws, pine martens widely use trees and canopies ranging throughout woodland areas, whereas tree cavities are required for reproduction and resting sites (Birks et al., 2005). Accordingly, this species is typical of forest environments and sloping terrains, whereas being only rarely detected in human settlements (Boitani et al., 2003; Mergey et al., 2011). Conversely, the stone marten seems to be common in plain ecosystems, open habitats, and human settlements (Boitani et al., 2003; Herr et al., 2010; Vergara et al., 2016).

Islands (Sardinia, Sicily, Elba Island, and Minorca) offer a unique occasion to study the ecology of the pine marten, where the carnivore guild is built up by a low number of species (Clevenger, 1992, 1995; Loy

et al., 2019; Mitchell-Jones et al., 1999). Particularly, the absence of other carnivore species (apart from few domestic dogs *Canis lupus familiaris* and cats *Felis catus* within and in the surroundings of human settlements, that is, where pine martens are a sporadic occurrence: cf. Vergara et al., 2016) makes Elba an ideal study area to research the spatiotemporal behavior of the pine marten in a situation of virtually no intra-guild predation (De Marinis & Masseti, 1993a, 1993b). In this context, the human presence is presumably the primary source of disturbance for the pine marten; thus, directly affecting its spatiotemporal distribution on the island.

Our work aimed to investigate the locomotor activity patterns of the pine marten on Elba to assess its fine-scale activity rhythms in the absence of potential predators. Moreover, we estimated its probability of detection (p) and occupancy (ψ) in this area concerning anthropogenic and environmental factors. Given the biological requirements of this small carnivore species (Balestrieri et al., 2019; Clevenger, 1992; Gazzola & Balestrieri, 2020), we will expect that: (1) martens would become more nocturnal to avoid overlap with disturbance by humans; (2) their presence will decrease with increasing human disturbance and (3) its occupancy will increase when associated with increasing vegetation density. In addition, drawing from the findings of Zub et al., 2018 (and cited works), we tested (4) whether, due to the semi-arboreal habits of the species, the type of vegetation (forested vs. non-forested areas) could have any potential effect on detection. Finally, owing to the peculiarity of the study area, which is characterized by the presence of Mount Capanne—a mountainous relief reaching an elevation of 1019 m asl—we analyzed the effects of elevation on the occupancy (5), which has been shown to affect habitat selection operated by the species (Zub et al., 2018).

2 | MATERIALS AND METHODS

2.1 | Study area

Our study has been conducted within the Tuscan Archipelago National Park (hereafter, TANP) on Mount Capanne, located on the western side of Elba island (42°46'20.4"N, 10°10'14.4"E), Central Italy (Figure 1).

A Mediterranean climate characterizes the area (annual mean temperature: 16.5°C; mean annual rainfall: 95 mm), with dry summers and mild winters and sporadic snowfall events on the top of Mount Capanne (1016 m asl). The area is largely covered by woodlands on the northern slopes and several types of maquis and garrigues on the southern slopes. Patches of pine plantations (*Pinus* sp. and *Pseudotsuga menziesii* [Mirb.] Franco) are also present

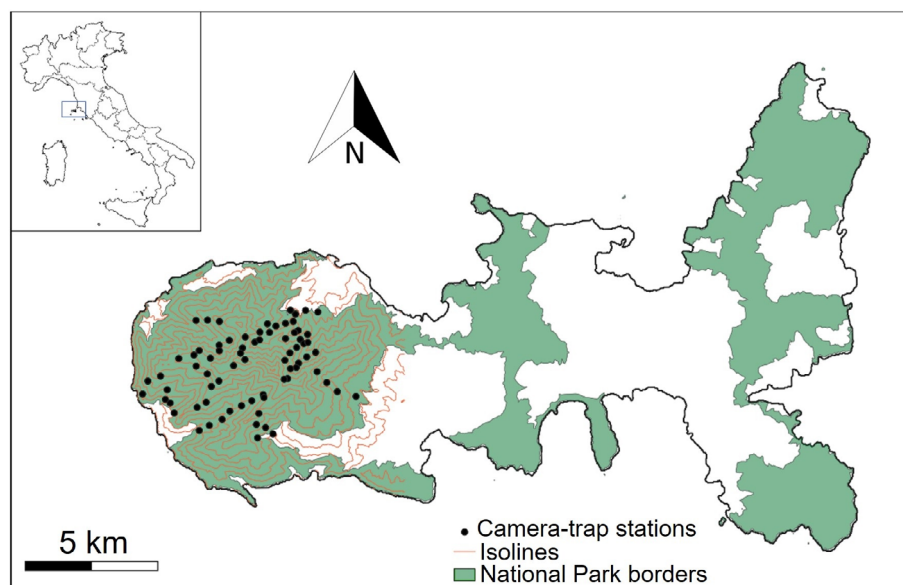


FIGURE 1 Distribution of camera traps used to estimate occupancy by pine marten, in a protected area in Elba Island, Italy, from April 2018 to April 2019 [Color figure can be viewed at wileyonlinelibrary.com]

along the mountain slopes, as a result of reforestation events in the 1950s. Thus, five major macrohabitats were present (cf. Greco et al., 2021): holm-oak woods *Quercus ilex* L., chestnut groves *Castanea sativa* Mill., pine plantations, low Mediterranean maquis characterized by *Salvia rosmarinus* Schleid., *Lavandula stoechas* L. and *Cistus* spp., Mediterranean maquis with vegetation >1 m characterized by strawberry trees *Arbutus unedo* L. and tree heath *Erica arborea* L. (hereafter “tall maquis”) (Foggi et al., 2006; Meriggi et al., 2016). Human settlements and cultivations occur outside the borders of the TANP, with a dominance of orchards and vineyards, and a major paved road connecting villages around the park borders. Terrestrial mammal species occurring within the park include several small rodents and shrew species, the wild boar *Sus scrofa*, the European mouflon *Ovis aries*, the Apennine hare *Lepus corsicanus*, the European brown hare *Lepus europaeus* and the pine marten as the only wild Carnivore species (Greco et al., 2021; Loy et al., 2019).

2.2 | Camera-trap sampling design

For this study, we used camera-trap bycatch data from a survey conducted to monitor large-sized ungulates on the island (Greco et al., 2021). Three different brands of camera-traps (i.e., Ltl Acorn—Shenzhen, Guangdong, China; Spromise—Shenzhen, Guangdong, China; and U-way—Atlanta, Georgia, USA) were arrayed in the study area during three sampling periods: 7th April–15th July 2018 (spring–summer); 1st September–18th November 2018 (late summer–autumn) and 18th January–8th April 2019 (winter–spring). Thus, camera-trap data covered an entire solar year. The sampling design consisted of four

consecutive arrays of 20 camera traps for a duration of 18 days (on average) each per season. In doing so, a total of 80 predefined camera trap stations could be sampled within the seasonal time frames. Camera traps operated in picture mode throughout. Due to the dense vegetation and the harsh terrain, camera-traps were placed along trekking trails, about 20 m off-trails, and separated by at least 500 m between one another (Figure 1). Every camera-trap was secured to trunks at about 50 cm from the ground, pointing to the trail, without the use of baits or lures. During our visits to the camera trap stations, we recorded percentages of tree cover (plants taller than 5 m; this was recorded in percentage classes over a radius of 10 m from the camera trap station), shrub cover (plants less than 5 m in height; this was recorded in percentage classes over a radius of 10 m from the camera trap station), grass cover (herbaceous plants; this was recorded in percentage classes over a radius of 10 m from the camera trap station), elevation (recorded using Garmin GPS Etrex 32X), and mountain aspect (see Greco et al., 2021).

2.3 | Occupancy models

Camera-trap photographs were classified using the dedicated open-source software Wild.ID (Fegraus & MacCharty, 2016). We extracted raw detection indices of the pine marten (i.e., the number of independent events with 30 min interval) and the naïve occupancy (proportion of sites occupied by the target species on sites sampled).

Spatial variation in occupancy and detection probability was estimated using a static single-species single-season occupancy model (MacKenzie et al., 2002) for

each sampling period. We used single-season models to evaluate potential variations in environmental and anthropogenic variables affecting the occupancy and detection probability between sampling periods instead of estimating dynamic parameters. In addition, as eight camera traps were moved between study periods, we could not guarantee complete consistency across sites

(see *Camera-trap sampling design*). A binary string (1, detection of pine marten; 0, non-detection) was filled for each camera-trap site and each sampling occasion (MacKenzie et al., 2006), building matrices of the site (i) by survey (j), with a resolution of 1 day.

We computed occupancy models on the software R (version 3.6.1., R Foundation for Statistical Computing,

TABLE 1 List, definition, and predicted effect of covariates used in modeling detection and occupancy of the pine marten across sites

Covariate	Definition	Type	Expected effect
Detection			
Camera trap Model	Make of camera trap	Categorical	Unknown as different models may perform differently
Grass cover (%)	Herbaceous vegetation cover in 10 m radius	Continuous	Negative as it may conceal the species
Shrub cover (%)	Shrub vegetation cover in 10 m radius	Continuous	Unknown and dependent on the season
Tree cover (%)	Arboreal vegetation cover in 10 m radius	Continuous	Negative as the pine marten may move in the high branch and evade the camera trap
Occupancy			
Distance to settlement	Distance (m) from camera trap to the closest human settlement	Continuous	Positive as the pine marten tends to avoid forms of human disturbance
Elevation	Elevation (m) of camera trap above the sea level	Continuous	Unknown and dependent on the season and the region (see Zub et al., 2018)
Mountain side	North or South side of Mount Capanne	Categorical	Unknown as both sides may be suitable habitat for the pine marten
Artificial surfaces	Square meters covered in artificial surface according to the Corine Land Cover Classification System (level 1)	Continuous	Negative as the pine marten tends to avoid forms of human disturbance
Agricultural areas	Square meters covered in agricultural surface according to the Corine Land Cover Classification System (level 1)	Continuous	Negative as the pine marten tends to avoid forms of human disturbance
C.L.C. 311	Square meters covered in broad-leaved forest according to the Corine Land Cover Classification System (level 3)	Continuous	Positive as the habitat is suitable for the pine marten
C.L.C. 312	Square meters covered in coniferous forest according to the Corine Land Cover Classification System (level 3)	Continuous	Positive as the habitat is suitable for the pine marten
C.L.C. 313	Square meters covered in mixed forest according to the Corine Land Cover Classification System (level 3)	Continuous	Positive as the habitat is suitable for the pine marten
C.L.C. 323	Square meters covered in sclerophyllous vegetation according to the Corine Land Cover Classification System (level 3)	Continuous	Positive as the habitat is suitable for the pine marten
C.L.C. 324	Square meters covered in transitional woodland-shrub according to the Corine Land Cover Classification System (level 3)	Continuous	Positive as the habitat is suitable for the pine marten
C.L.C. 332	Square meters covered in bare rocks according to the Corine Land Cover Classification System (level 3)	Continuous	Negative as the habitat may not be suitable for the pine marten

Abbreviation: C.L.C., cover classification system.

Vienna, Austria: cran.r-project.org) by using the package “unmarked” (Fiske & Chandler, 2011). We included the effects of the following covariates in the detection analysis (see Table 1): (1) camera-trap model, as trigger speed may affect the probability to record the target species (Rovero et al., 2013); (2–4) grass, shrub, and tree cover to study the effects of different vegetation structures on the locomotion and hence detectability of the species. For the analysis of the occupancy, we investigated the effects of the following covariates (see Table 1): (1) distance to the closest human settlement; (2) elevation, (3) habitat type (measured in square meters using QGIS and the Corine Land Cover Classification System over an area of 100 m radius with center on the camera trap point); (4) side of Mount Capanne (i.e., North or South). Numerical covariates were standardized to have mean zero and unit variance and were then checked for collinearity using Pearson's rank correlation (Rovero & Zimmermann, 2016).

Starting with a “null” model that is excluding all covariates (Mori, Sangiovanni, & Corlatti, 2020), we then focused on the effect of the covariates on the detection (p) holding occupancy probability constant across camera stations, as per the recommendations of MacKenzie et al., 2006 (see MacKenzie et al., 2002, 2006; Johnson et al., 2020). Hence, constant occupancy models (i.e., models with constant occupancy probability) were ranked using Akaike's Information Criterion (AIC). Conditionally on the best detection model (i.e., the covariates structure for p bearing the lowest AIC, see Burnham & Anderson, 2002), we then assessed the effects of covariates on the occupancy probability for the pine marten, keeping the covariate structure for p fixed, across sampling sites (Burnham & Anderson, 2002; Johnson et al., 2020; Niedballa et al., 2015). Covariates that exhibited collinearity >0.6 (see Table 2) were not included in the same models. Candidate models were then ranked using the information-theoretic approach described by Burnham and Anderson (2002), whereby the top model set would include all those with $AIC < 2$ from the best-supported models. When top-ranked models could not be distinguished (i.e., with a difference between each model's AIC and the lowest AIC lower than 2; Burnham & Anderson, 2002), we used the package “AICcmodavg” (Mazerolle & Mazerolle, 2019) to average them and derive predictions for Ψ and p .

2.4 | Patterns of locomotor activity rhythms

Analyses were conducted on total-year and seasonal scales (spring–summer, late summer–autumn, and winter–early spring). We defined as “activity” the cumulative time animals spend outside shelter sites, that is,

TABLE 2 Collinearity (Pearson's r) between covariates for each season

Collinear relations	Pearson's r	p -value
Spring–summer		
Distance to settlement—artificial surfaces	−0.70	0.012
Distance to settlement—elevation	0.77	0.003
Elevation—agricultural areas	−0.70	0.012
C.L.C.324—agricultural areas	0.68	0.014
C.L.C.324—elevation	−0.63	0.028
C.L.C.332—elevation	0.60	0.040
C.L.C.323–C.L.C.311	0.74	<0.001
Grass cover %–Shrub cover %	0.77	0.003
Grass cover %–Tree cover %	−0.75	0.005
Shrub cover %–Tree cover %	−0.97	<0.001
Summer–autumn		
Distance to settlement–artificial surfaces	−0.75	0.003
Distance to settlement–Elevation	0.85	<0.001
C.L.C.324–Agricultural areas	0.66	0.014
C.L.C.311—C.L.C.323	−0.74	0.004
C.L.C.311—C.L.C.332	−0.60	0.032
Grass cover %—shrub cover %	0.87	<0.001
Grass cover %—tree cover %	−0.84	<0.001
Shrub cover %—tree cover %	−0.97	<0.001
Winter		
Distance to settlement—artificial surfaces	−0.70	0.008
Distance to settlement—elevation	0.86	<0.001
C.L.C.311—C.L.C.323	0.86	<0.001
Grass cover %—shrub cover %	0.87	<0.001
Grass cover %—tree cover %	−0.88	<0.001
Shrub cover %—tree cover %	−0.98	<0.001

moving (Lashley et al., 2018). For all marten photographs, we reported the date and the solar hour. Detections of pine martens occurring at the same site within less than 30 min were removed from the dataset to limit pseudo-replication bias (Meredith & Ridout, 2014). We estimated the patterns of activity of the pine marten and their 95% confidence intervals (hereafter, CIs) with the R 3.6.1 package “overlap” (Meredith & Ridout, 2014). We performed a Hermans–Rasson test to evaluate whether a random activity pattern was exhibited over 24 h (Landler et al., 2019). We estimated the coefficient of overlapping (Δ) between temporal activity patterns of all pairwise season combinations (spring–summer, late summer–autumn,

TABLE 3 Number of events and naïve occupancy of the pine marten during the three sampling periods (period 1, spring–summer [April–July]; period 2, late summer–autumn [September–November]; period 3: winter–early spring [January–April]) in a protected area in the Elba Island, Italy, from April 2018 to April 2019

Species	Number of events			Naïve estimate of Ψ		
	Period 1	Period 2	Period 3	Period 1	Period 2	Period 3
Pine marten	125	103	64	0.54	0.45	0.50

TABLE 4 Model selection and ranking of the best occupancy models for pine marten, in a protected area in the Elba Island, Italy, from April 2018 to April 2019

Sampling period	Model	n. Pars	AIC	Δ AIC	AIC w_i
Spring–summer (April–July)	p (tree cover %) $\sim \psi$ (C.L.C 313 + C.L.C 323)	5	511.19	0.00	0.127
	p (tree cover %) $\sim \psi$ (C.L.C. 323)	4	511.63	0.44	0.102
	p (tree cover %) $\sim \psi$ (artificial surfaces + C.L.C. 323)	5	511.92	0.74	0.088
	p (tree cover %) $\sim \psi$ (C.L.C. 311)	4	512.69	1.50	0.060
	p (tree cover %) $\sim \psi$ (C.L.C. 311 + C.L.C. 332)	5	512.84	1.65	0.056
	p (tree cover %) $\sim \psi$ (artificial surfaces + C.L.C. 311)	5	512.92	1.74	0.053
	p (tree cover %) $\sim \psi$ (C.L.C. 311 + C.L.C. 313)	5	513.13	1.94	0.048
	p (1) $\sim \psi$ (1)	2	521.58	10.39	0.001
Late summer–autumn (September–November)	p (camera model) $\sim \psi$ (artificial surfaces)	5	551.01	0.00	0.220
	p (camera model) $\sim \psi$ (artificial surfaces + C.L.C. 332)	6	551.15	0.14	0.210
	p (camera model) $\sim \psi$ (artificial surfaces + C.L.C. 323)	6	552.62	1.59	0.100
	p (camera model) $\sim \psi$ (artificial surfaces + C.L.C. 313)	6	552.77	1.76	0.093
	p (camera model) $\sim \psi$ (artificial surfaces + C.L.C. 311)	6	552.98	1.97	0.084
	p (camera model) $\sim \psi$ (artificial surfaces + Agricultural areas)	6	553.00	1.99	0.083
	p (1) $\sim \psi$ (1)	2	566.58	15.57	$9.3e^{-5}$
Winter–early spring (January–April)	p (shrub cover %) $\sim \psi$ (artificial surfaces)	4	431.28	0.00	0.130
	p (shrub cover %) $\sim \psi$ (artificial surfaces + C.L.C. 332)	5	431.95	0.66	0.091
	p (shrub cover %) $\sim \psi$ (C.L.C. 332 + Distance to settlement)	5	432.35	1.07	0.075
	p (shrub cover %) $\sim \psi$ (artificial surfaces + Agricultural areas)	5	432.51	1.23	0.069
	p (shrub cover %) $\sim \psi$ (artificial surfaces + C.L.C. 311)	5	432.57	1.28	0.067
	p (shrub cover %) $\sim \psi$ (artificial surfaces + C.L.C. 312)	5	432.83	1.55	0.059
	p (shrub cover %) $\sim \psi$ (artificial surfaces + C.L.C. 313)	5	432.89	1.60	0.057
	p (shrub cover %) $\sim \psi$ (artificial surfaces + C.L.C. 323)	5	432.95	1.66	0.055
	p (shrub cover %) $\sim \psi$ (artificial surfaces + C.L.C. 324)	5	433.16	1.87	0.050
	p (shrub cover %) $\sim \psi$ (artificial surfaces + Elevation)	5	433.22	1.93	0.048
	p (1) $\sim \psi$ (1)	2	446.48	15.19	$6.4e^{-5}$

Note: Below are reported the estimates of occupancy (ψ) and detection probability (p), number of parameters (i.e., n Pars), AIC, Δ AIC, AIC w_i . Bold highlights the best models (i.e., those with Δ AIC < 2) reported together with the null model.

Abbreviation: C.L.C., cover classification system.

and winter–early spring). The coefficient of overlapping ranges between 0 (no overlap) and 1 (total overlap: Meredith & Ridout, 2014). We calculated the Δ_4 estimator

if the smallest sample of each pairwise comparison was >75 records, Δ_1 if at least one of the samples of each pairwise comparison was <75 records (Meredith &

Ridout, 2014). The 95% CIs of the coefficient estimator were computed using 10,000 bootstrap replicates (Mori, Bagnato, et al., 2020; Mori, Sangiovanni, & Corlatti, 2020). Overlap was considered as “intermediate” with Δ included

between 0.50 and 0.75, as “high” with $0.75 < \Delta < 0.90$, as “very high” with $\Delta > 0.90$ (Mazza et al., 2020).

3 | RESULTS

3.1 | Camera trap data

We obtained a total of 292 independent records for the pine marten (spring–summer, $n = 125$; late summer–autumn, $n = 103$; winter–early spring, $n = 64$) in a total sampling effort of 3457 camera-trap days (Table 3). Seasonal naïve occupancy values are also reported in Table 3. Other species reported on the island were: wild boars (*S. scrofa*), mouflons (*O. aries*), and very few hares (*L. europaeus*), as well as scattered domestic cats (*F. catus*) and dogs (*Canis familiaris*) (Greco et al., 2021).

TABLE 5 Seasonal occupancy (ψ) and detection (p) probabilities (along with their SE) of the pine marten during the three sampling periods, from April 2018 to April 2019

Sampling season	Occupancy (ψ) \pm SE	Detection (p) \pm SE
Spring–summer (April–July)	0.71 \pm 0.15	0.15 \pm 0.04
Late summer–autumn (September–November)	0.61 \pm 0.11	0.11 \pm 0.03
Winter–early spring (January–April)	0.80 \pm 0.08	0.07 \pm 0.02

TABLE 6 Parameter estimates for each sampling period from the averaging of the best occupancy models for pine marten, from April 2018 to April 2019

Sampling period	Model	Estimate	SE	Z	p (Z)
Spring–summer (April–July)	ψ C.L.C. 323	−0.39	0.41	0.95	0.342
	ψ C.L.C. 313	−0.54	30.4	0.02	0.986
	ψ artificial surfaces	−0.11	0.25	0.43	0.668
	ψ C.L.C. 311	0.24	0.37	0.65	0.513
	ψ C.L.C. 332	0.04	0.18	0.25	0.801
	p tree cover %	−0.48	0.14	3.48	<0.001*
Late summer–autumn (September–November)	ψ artificial surfaces	−1.83	0.80	2.67	0.0234
	ψ C.L.C. 332	−0.10	0.24	0.44	0.66
	ψ C.L.C. 323	−0.02	0.12	0.19	0.851
	ψ C.L.C. 313	0.02	0.11	0.14	0.888
	ψ C.L.C. 311	0.01	0.10	0.06	0.955
	ψ C.L.C. agricultural areas	−0.01	0.12	0.03	0.977
	p Camera model (Spromise)	0.87	0.37	2.32	0.021*
p Camera model (U-way)	−0.31	0.52	0.58	0.559	
Winter–early spring (January–April)	ψ artificial surfaces	−1.60	1.03	1.56	0.118
	ψ C.L.C. 332	0.08	0.34	0.24	0.808
	ψ C.L.C. 323	2.85	13.3	0.21	0.830
	ψ Distance to settlement	9.85	47.3	0.21	0.835
	ψ Agricultural areas	−0.04	0.18	0.22	0.823
	ψ C.L.C. 311	−0.04	0.20	0.21	0.832
	ψ C.L.C. 312	0.03	0.32	0.10	0.920
	ψ C.L.C. 313	0.38	7.37	0.05	0.958
	ψ C.L.C. 324	0.01	0.18	0.07	0.943
	ψ elevation	0.01	0.13	0.06	0.949
	p shrub cover %	0.50	0.16	3.15	0.002*

Abbreviation: C.L.C., cover classification system.

*Significant p -values.

3.2 | Occupancy models

Top-ranked models (with $\Delta AIC < 2$) are displayed in Table 4, alongside the null model for each season.

The pine marten appeared to be present over the entire extent of the sampling area, with relatively high overall occupancy and mean seasonal occupancy that fluctuated across periods (Table 5). Higher mean occupancy values were reported during winter-early spring ($\psi \pm SE = 0.80 \pm 0.08$), whereas a lower occupancy probability was found during late summer-autumn ($\psi \pm SE = 0.61 \pm 0.11$). Conversely, detectability was low throughout the year (spring-summer, $p \pm SE = 0.15 \pm 0.04$; late summer-autumn, $p \pm SE = 0.11 \pm 0.03$; winter-early spring, $p \pm SE = 0.07 \pm 0.02$). Of all the covariates being considered, only artificial areas (e.g., urban fabrics and roads) were found to significantly associate with the occupancy of the species in the summer period. Conversely, covariates associated with detection varied throughout the year (Table 6).

In spring-summer, the study of covariate influence on detection probability resulted in p being negatively associated with tree cover in the 10 m around the camera trap ($\beta \pm SE = -0.48 \pm 0.138$, $p < 0.001$). No significant effect on the species occupancy was recorded for the first season.

In late summer-autumn association, a positive was found between p and the camera model Spromise ($\beta \pm SE = 0.87 \pm 0.375$, $p = 0.021$) while holding occupancy constant. This model was then used to explore the combination of covariates best explained the *M. martes* occupancy in the study area. We averaged six occupancy models that ranked $< 2 \Delta AIC$; this resulted in the extent of habitat calculated in squared meters, within 100 m radius from the camera trap, covered in “artificial surfaces” being negatively correlated with the occupancy of the species ($\beta \pm SE = -1.82 \pm 0.804$, $p = 0.023$).

In winter, a positive correlation was found between the percentage of shrub cover in the 10 m radius around the camera trap and the detection probability of the

TABLE 7 Averaged model estimates confidence intervals (5% and 95%) for pine marten, from April 2018 to April 2019

Sampling period	Model	5%	95%
Spring-summer (April-July)	ψ C.L.C. 323	-1.95	-0.11
	ψ C.L.C. 313	-92.4	88.9
	ψ artificial surfaces	-0.99	0.11
	ψ C.L.C. 311	0.02	1.07
	p tree cover %	-0.71	-0.25*
Late summer-autumn (September-November)	ψ artificial surfaces	-3.15	-0.50*
	ψ C.L.C. 332	-0.93	0.09
	ψ C.L.C. 323	-0.30	0.67
	ψ C.L.C. 313	-0.36	0.64
	ψ C.L.C. 311	-0.45	0.56
	ψ agricultural areas	-0.65	0.58
	p Camera model (Spromise)	0.25	1.48*
Winter-early spring (January-April)	p Camera model (U-way)	-1.17	0.56
	ψ artificial surfaces	-3.30	-0.28
	ψ C.L.C. 332	-0.56	1.87
	ψ C.L.C. 323	-30.0	61.7
	ψ distance to settlement	-95.7	286
	ψ agricultural areas	-1.09	0.27
	ψ C.L.C. 311	-1.29	0.36
	ψ C.L.C. 312	-1.33	2.13
	ψ C.L.C. 313	-37.6	47.3
	ψ C.L.C. 324	-0.90	1.27
	ψ elevation	-0.69	0.94
p Shrub cover %	0.24	0.76*	

Abbreviation: C.L.C., cover classification system.

*Significant p -values.

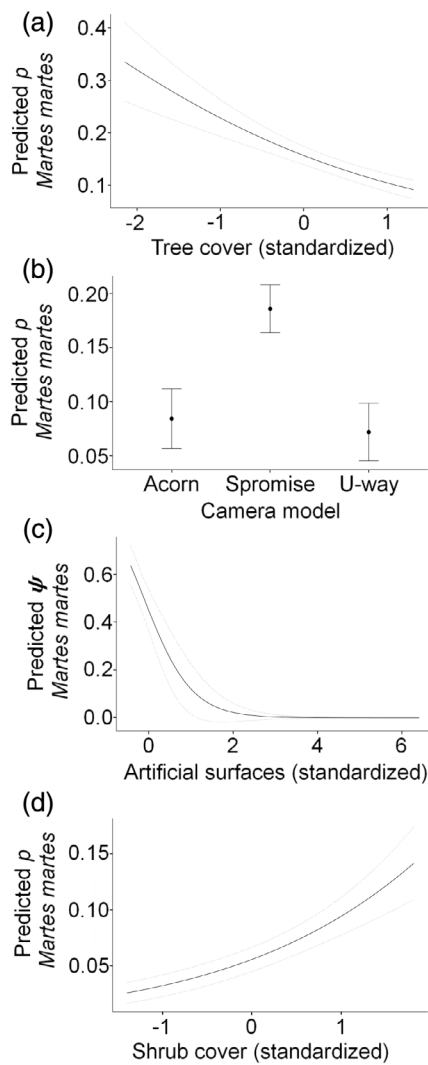


FIGURE 2 Covariates significantly affecting the detection and the occupancy of the pine marten, during the three sampling periods from April 2018 to April 2019; (a) covariates affecting the detection in spring–summer (April–July); (b) covariates affecting the detection in late summer–autumn (September–November); (c) covariates affecting the occupancy in late summer–autumn (September–November); (d) winter–early spring (January–April)

species ($\beta \pm SE = 0.56 \pm 0.156$, $p < 0.001$). In addition, 10 occupancy models were equally supported (with $\Delta AIC < 2$) and were therefore averaged. However, none of them tested significant and were thus excluded from the analysis. Confidence intervals for the estimates are displayed in Table 7. The results are represented in Figure 2.

3.3 | Patterns of activity rhythms

A nonrandom activity pattern was exhibited throughout the year, peaking at dawn and dusk (Hermans–Rasson test: $R = 257.9$; $p < 0.001$; Figure 3).

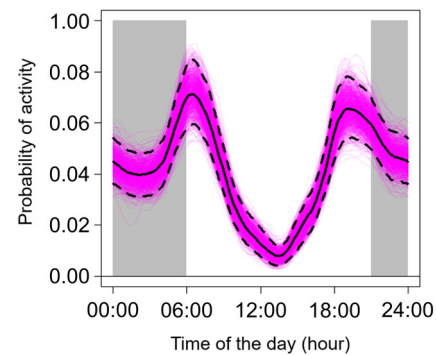


FIGURE 3 Patterns of activity rhythms of the pine marten, during the three sampling periods from April 2018 to April 2019. Lines represent Kernel density estimates of activity throughout the 24-h cycle ($n = 486$ independent records). Purple lines represent bootstrap estimates, and dashed black lines represent 95% CIs [Color figure can be viewed at wileyonlinelibrary.com]

Pairwise interseason overlaps were all high ($\Delta > 0.75$; Figure 4; Table 8). Pairwise interseason differences were not significant, that is, both analyzed sets of circular observations come from the same distribution (all $p > 0.05$).

4 | DISCUSSION

This work represents the first assessment of the spatio-temporal behavior of the pine marten in the absence of other wild mammalian carnivore competitors. The pine marten is the only wild carnivore occurring in Elba island, where the only disturbance we are aware of is represented by humans. Accordingly, although this carnivore is strictly protected in Europe, poaching events may occur, as *Martes* species are reported to exert several damages to poultries and game species (cf. Pilot et al., 2007). Other mammals detected with our camera trap survey include wild boar, mouflons, and very few hares, along with few individuals of domestic cats and dogs (Greco et al., 2021). In general, domestic cats and dogs may represent a threat to martens. Domestic carnivores were detected only scattered and in the proximity of roads and towns, that is, in areas usually avoided by pine martens (Balestrieri et al., 2019; Viviano et al., 2021; Wereszczuk & Zalewski, 2015). Thus, we also may suggest that the presence of cats or dogs affects pine marten's spatiotemporal behavior, leading to their avoidance of these areas (see Viviano et al., 2021). However, data were too few to investigate any effect. Overall, the pine marten was found to occupy almost every habitat in the study area, except highly anthropized areas in summer when tourism reaches its peak. Therefore, we can conclude that the species tend to avoid areas with high human disturbance. In addition, we found that mean occupancy varied

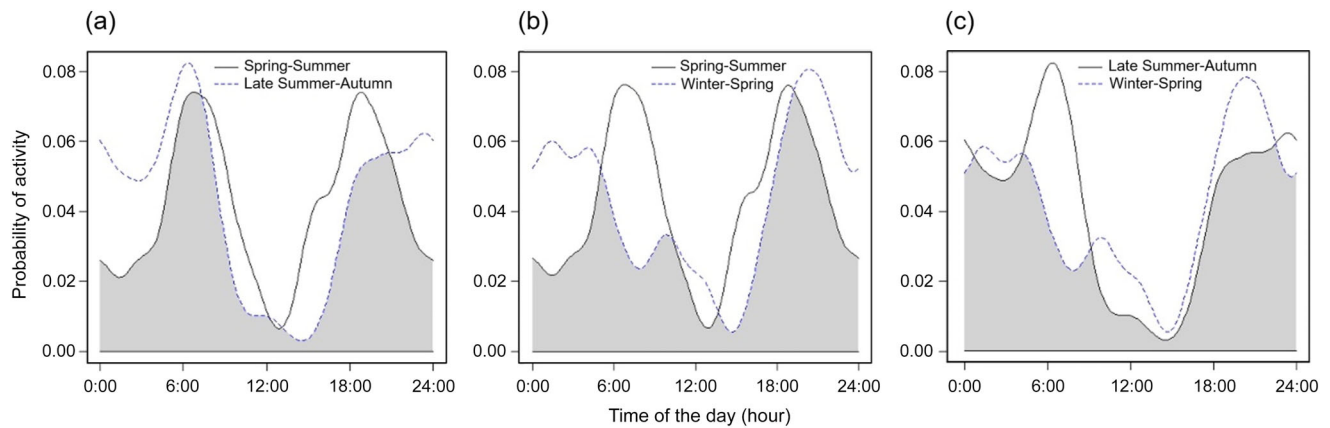


FIGURE 4 Inter-seasonal activity patterns of the pine marten inferred through camera trapping, from April 2018 to April 2019; (a) spring–summer/late summer–autumn; (b) spring–summer/winter–early spring; (c) late summer–autumn/winter–early spring; spring–summer = April–July, late summer–autumn = September–November, winter–early spring = January–April [Color figure can be viewed at wileyonlinelibrary.com]

TABLE 8 Coefficients of temporal overlap and 95% relevant confident intervals of inter-seasonal activity patterns of the pine marten, from April 2018 to April 2019

Time periods	Δ_4	CIs (95%)
Spring–summer—late summer–autumn	0.77	0.70–0.85
Spring–summer—winter–early spring	0.73	0.65–0.84
Winter–early spring—late summer–autumn	0.82	0.72–0.89

Note: spring–summer = April–July, late summer–autumn = September–November, winter–early spring = January–April.

between sampling periods, with the estimated lower mean occupancy value during late summer–autumn. In this season, the interiors of Elba Island are frequented by people searching for mushrooms and chestnuts. Conversely, during the winter season, when the human presence on the island is low, we estimated a higher mean value of the pine marten occupancy probability. In fact, following a reduction in anthropogenic pressure, the pine marten increases its area of occurrence to cover different environments. In addition, the relatively low occupancy recorded in the spring–summer period seems to be in line with the expected reduced home range due to the presence of the cubs that forces adult females to range mostly in the surroundings of the den; thus, reducing the detectability and site-use intensity of the species (Bartolommei et al., 2016; Boitani et al., 2003). These results corroborate the findings of a similar study conducted in continental Tuscany by Balestrieri et al. (2019). The authors conclude that the pine marten tends to avoid human settlements and urbanized areas (Mergery et al., 2011). On this island,

small hamlets and villages are virtually inhabited throughout the year, only receiving a large influx of tourists in summer; this could explain the absence of a significant correlation between distance to human settlement and the occupancy of the pine marten.

On the other hand, the relatively low estimates for the species probability of detection are likely to be the result of both the well-studied elusiveness of the species (see Lucentini et al., 2007), but also of a possible caveat in the study design, which was initially intended for the study of larger-bodied animals (e.g., *S. scrofa* and *O. aries*; see Greco et al., 2021). Indeed, the positioning of the camera traps is to be considered suboptimal for researching the occupancy of semi-arboreal species (Yugerson, 1950; Zalewski, 1997). A camera trap set designed specifically for targeting pine martens will help to overcome these possible limitations. However, any fault in the design (e.g., height of the camera trap from the ground and settings such as triggering speed and sensitivity) is de facto consistent throughout the study area. With this in mind, we were still able to carry out a basic yet robust analysis of covariates that can affect the detection of the species in the Mount Capanne area of Elba Island. In particular, the negative effect of tree cover on the detectability of the pine marten during the spring–summer period can be explained by the presence of thicker vegetation that conceals the species movements. In addition, the presence of nesting bird species during this season may allure the pine marten to move in the high branches in search of prey; hence, evading the range of the camera traps positioned lower on the tree trunk. Conversely, when the vegetation is scarcer in winter, there exists a positive correlation between the shrub cover and the species detectability.

Our analyses showed that ground activity rhythms of the pine marten in the absence of potential predators

were similar across seasons, with significant peaks at dawn and dusk and a sharp decline in activity in the central hours of the day. At the same latitude in continental Italy, where a guild of carnivores also including red foxes, stone martens, western polecats *Mustela putorius*, least weasels *Mustela nivalis*, European badgers, and wild cats *Felis silvestris*, pine martens showed a similar activity trend, but with lower peaks in the early morning (Mori & Menchetti, 2019; Viviano et al., 2021). As well, both Fonda et al. (2017) and Torretta et al. (2017) detected the same activity peaks in the early morning and around sunset, respectively, in the Carnic Prealps (North-Eastern Italy) and Liguria (North-Western Italy), both areas characterized by a rich carnivore guild. A slight increase in diurnal activity has been detected in spring, in line with all previous studies on the activity of pine martens (Clevenger, 1992; Fonda et al., 2017; Monterroso et al., 2014; Torretta et al., 2017; Zalewski, 2001). Bouts of diurnal activity may represent a female prerogative in early spring when nights start to be shorter concerning the winter months and when cubs are present (Zalewski, 2001). Patterns of locomotor activity detected in our work did not reflect any remarkable difference with areas characterized by a rich carnivore guild (e.g., Gazzola & Balestrieri, 2020; Goszczyński et al., 2007; Torretta et al., 2017; Wereszczuk & Zalewski, 2015). Zwijacz-Kozica et al. (2017) suggested that feral domestic cats may occupy a very similar ecological niche with respect to wild cats. However, in Central Italy, the presence of free-ranging domestic cats and dogs was very scattered and occurred only in the surroundings of human settlements (i.e., where pine martens are a rare occurrence: Vergara et al., 2016); thus, not affecting marten behavior (see Viviano et al., 2021).

To the best of our knowledge, this is the first study that has assessed both spatial and temporal behavior of the pine marten using presence/absence data obtained from a camera-trap survey. Identifying martens using camera traps is challenging where both pine and stone marten occur; thus, discarding a high number of records that cannot be identified at the species level (see Mori, Bagnato, et al., 2020; Mori, Sangiovanni, & Corlatti, 2020). Conversely, the pine marten is the only carnivore on Elba island; thus, facilitating species identification from camera-trap records.

The assessment of interspecific interactions is a key topic in behavioral ecology, despite being little studied amongst small carnivores concerning large ones (Palomares & Caro, 1999). Our work showed that the spatiotemporal behavior of the pine marten did not differ in the presence or absence of wild mammalian competitors, is always recorded as a diurnal/crepuscular species typical of densely vegetated areas, mostly avoiding human settlements (cf. Balestrieri et al., 2019).

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CONFLICT OF INTEREST

The authors declare no conflicts of interest.

AUTHOR CONTRIBUTIONS

Marco Zaccaroni, Giacomo Santini, Francesca Puppo, and Alessandro Massolo designed the study; Marco Zaccaroni directed the project; Ilaria Greco supervised the fieldwork, processed the experimental data, and together with Margherita Giampaoli Rustichelli and Silvia Miniati collected the data; Emiliano Mori and Ettore Fedele performed the analysis and drafted the manuscript, with the contribution of Ilaria Greco. All the authors revised the various drafts of the manuscript.

ORCID

Marco Zaccaroni  <https://orcid.org/0000-0002-3588-6476>

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