Cats and clouds: how a citizen camera-trapping project boosts wildcat (Felis silvestris) conservation

Sara Savazza1 · Paolo Rossi1 · Nicola Rebora1 · Fabrizio G. Lioy2 · Donato Franculli2 · Andrè Roveyaz1 ·

Alfredo Bruno1 · Antonio Sicuro1 · Giuseppe Dino1 · Erica La Placa1 · Lorenzo Gaudiano3 · Luciano Cicognani4 · Franca Monti4 · Gianluca Serra1 · Giovanni Gallipò5 · Vanessa Draksler1 · Claudio Vecchietti1 · Lorenzo Filoni6 · Andrea Cairone1 · Egzon Krodaliu1 · Alex Nardone1 · Fabio Dartora7 · Maurizio Scotti1 · Filippo Rimassa1 · Carlo Vecchiolli1 · Simone Calandri1 · David Francescangeli1 · Girolamo Parretta8 · Simone Giosso1 ·

Ludovica Barbieri1 · Daniele Ecotti9 · Federico Piolanti1 · Gianni Piolanti1 · Stefano Comazzi10 · Stefano Filacorda11 · Clayton K. Nielsen12· Stefano Anile1

Abstract

The European wildcat is an elusive small carnivore species whose distribution, behavioural ecology and interactions with domestic cats are scantly known. However, the use of camera-trapping is steadily increasing in wildlife studies as well as citizen science, with the latter setting the basis for a large source of robust data. Here we provide an overview of our efforts to create an independent network, named Piccoli Fototrappolatori Indipendenti (Little Independent Camera-trappers, here- after PFI), of citizen scientists who are contributing with the goal of a deeper understanding of wildcat ecology. We engaged 31 volunteers who collected domestic cats, putative hybrids (hereafter hybrids) and wildcats' detections at 503 locations throughout Italy from 11/04/2006 to 24/10/2022. So far, this dataset hosts 312 images and 1015 videos (1327 detections) which were morphological examined and standardised, leading to 123, 137 and 1016 detections of domestic cats, hybrids and wildcats, respectively. We documented the expansion of the wildcat towards Northern Italy, with the first camera-trapping records from the Western Alps (Val D'Aosta) and from the Northern Apennines (Liguria), as well as the detection of kink- tailed wildcats in new regions. Moreover, we observed behavioural differences among cat types, with domestic cats marking at a lower rate and with hybrids being less elusive than wildcats at night. Further research and efforts are needed to better explore the conservation consequences of our findings, as well as to investigate the full potential of citizen science combined with camera trapping which are promising tools in wildcat conservation.

Keywords Felis silvestris · Citizen science · Camera-trapping · Behaviour

Introduction

The European wildcat (*Felis silvestris*), hereafter only wild-cat, is an elusive, solitary, small felid (body weight: 3–5 kg)(Macdonald and Loveridge 2010) that is ranked as Least Concern in the IUCN© red list of threatened species, but whose population trend is unknown in the last assessment (Bastianelli et al. 2021; Gerngross et al. 2022). Wildcat distribution extends from the Iberian Peninsula to the Cauca-sus and from Sicily to Scotland (Nowell and Jackson 1996)with largely fragmented populations at national, regional andlocal scales. Thus, several wildcat populations are isolated from other populations and hence exposed to extinction riskdue to habitat fragmentation (Anile et al. 2019; Gil-Sanchezet al. 2020), hybridization with domestic cats (*Felis catus*) (Mattucci et al. 2013, 2016) transmission of pathogens (Millán and Rodríguez 2009), road kills (Klar et al. 2009) and likely inbreeding depression (Lioy et al. 2022). In this context, crucial information to preserve wildcat such as its current distribution and its behavioural ecology are lack- ing throughout its range, including Italy (Lozano and Malo 2012; Lozano et al. 2013) where national investigations date back to the last century (Ghigi 1911; Ragni 1972; Cagnolaro et al. 1976; Pavan 1981).

In Italy, three geographically distinct wildcat populations were identified in the Eastern Alps, in Central and Southern Italy, and in Sicily (Mattucci et al. 2013), but this distri- bution needs to be revised. Indeed, from the early 2000s a northwards expansion was suggested by records in Pesaro Apennines (Ragni 2003; Santolini et al. 2010), Foreste Casentinesi National Park (Agostini et al. 2008) and Mugello (D. Berzi, pers. comm.). Moreover, although this species was thought to be extinct since the 1980s in the north-west of the Italian Peninsula (Ragni et al. 2012), recent sightings in Liguria provided some evidence of early recolonization of this area (Velli et al. 2015; Gavagnin et al. 2018; Loy et al. 2019). Furthermore, an ecologically isolated wildcat popu- lation is present in Gargano National Park (Agostini et al. 2008; Gaudiano et al. 2022), but has been poorly studied.

Obtaining large and robust datasets to study cryptic solitary species such as the wildcat can be expensive, time consuming and logistically challenging, particularly across wide geographical areas. Indeed, a notable survey effort is required to detect this species because of its low popula- tion densities (Anile et al. 2014; Gil-Sanchez et al. 2015), preference for forested habitats which offer shelter (Sunquist and Sunquist 2002) and its primarily nocturnal activity pat- tern (Daniels et al. 2001; Germain et al. 2008; Lazzeri et al. 2022). In the last 2 decades the development of camera- trapping has greatly expanded our knowledge about rare and nocturnal species (Lazzeri et al. 2022), including the wild- cat. For instance, its caching behaviour was observed via camera traps in two recent studies (Krofel et al. 2021; Ruiz- Villar et al. 2020) as well as the re-capture of a wildcat after over 9 years (Anile et al. 2020), in addition to the description of the first morphological anomalies for this species such as cowlicks, kinked-tails and brachyura (Lioy et al. 2022). Another recent study documented wildcats using tempo- ral segregation to avoid coexisting predators (Vilella et al. 2020). Interestingly, by-catch data (Mazzamuto et al. 2019) from camera-trapping surveys targeting other species (e.g. Comunicato 629 Ufficio Stampa Provincia Autonoma di Trento 2018) are increasingly recorded, or they are collected by recreational camera traps thanks to the increasing popu- larity of this activity among enthusiasts (Sheil et al. 2013; McShea et al. 2016). These cost-effective data offer not only a valuable source of georeferenced wildcat detections (Campbell et al. 2021; Lasky et al. 2021; Mukherjee et al. 2021), but also considerable information about behaviours, activity pat- tern and interaction with other mesocarnivores.

A potential solution to collect data over large spatial scales is citizen science (Bonney et al. 2009) which can be defined as the contribution of volunteers in scientific pro- jects. This umbrella term includes a great variety of collabo- rative arrangements (Heigl et al. 2019) from simple upload of presence-only data to a total volunteer engagement by contributing, learning and sharing project goals (Kays et al. 2021; Zulian et al. 2021). Some studies further highlight the benefits of a direct dialogue between researchers and volunteers and the resultant knowledge exchange, and the ability to share rewarding experiences with others (Lasky et al. 2021; Mukherjee et al. 2021).

In recent studies, citizen science and camera-trapping have been successfully employed to monitor small cat species (Campbell et al. 2021; Mukherjee et al. 2021), wildcats in Italy included (Sforzi 2021; https://www. museonaturalemaremma.it/gatto-selvatico-italia/). Indeed, camera-trapping is largely used to carry out field surveys around the world (Anile and Devillard 2020). Moreover, camera traps are valuable tools to engage the public through a rewarding activity which does not require a high level of training thanks to a fairly simple functionality (Parsons et al. 2018), although the scientific approach can only be guaranteed thoroughly data quality check and screening by the principal investigator (McShea et al. 2016). A well-planned citizen science camera-trapping project can therefore quickly gather a large amount of data (Caravaggi et al. 2017; Anile et al. 2020; Green et al. 2020) which might be lost if not examined and collected into a complete dataset aiming to reach a deeper knowledge of the species or system. Clearly, georeferenced detections of wildcats may further contribute to assess the distribution of this species at fine and coarse scales (Anile et al. 2009; Wuest et al. 2021) which is crucial for evaluating how wildcat popula- tions respond to landscape modifications and to human dis- turbance, as well as for establishing a systematic scientific approach at the national level for monitoring wildcat popu- lations and promoting conservation programmes. Addition- ally, direct observations in nature could enhance further investigations about both behavioural repertoire and activ- ity patterns of this elusive species (Ghaskadbi et al. 2016), a field of investigation which remains largely unexplored. Indeed, the usage of camera traps can provide a wide range of information (e.g. the behaviours shown as well as the time length a subject is recorded by video, hereafter named visitation time) which can then be used for performing occupancy, time to event, activity and ethogram analyses. Videos and pictures recorded by camera traps allow not only the distinction of wildcats, domestic cats and hybrids (Velli et al. 2015) through the morphological examination of the markings system of the coat pattern and its varia- tion (Ragni and Possenti 1996; Kitchener et al. 2005), but also to attain individual identification (Eichholzer 2010; Ballesteros-Duperon et al. 2014).

In this paper, we describe our citizen science camera-trapping project (PFI project, Piccoli Fototrappolatori Indipendenti—Small Independent Camera-trappers) which is a network of volunteers-based wildcat detections and associated camera data (i.e. coordinates, start and retrieval date), either opportunistic or systematic, collected throughout Italy and standardised for subsequent scien- tific analysis (i.e. effort, scale, time and independence time between detections are accounted for). We report our first results, which have documented an expansion of the wildcat distribution range as well as a different mark- ing frequency (Berteselli et al. 2017) and visitation time between wildcats, hybrids and domestic cats in the wild. We further discuss the goals achieved thus far and how this project can be further implemented to fully exploit the potential role of citizen science in combination with camera-trapping. Overall, we aimed to create an independ- ent network of citizen scientists to involve volunteers in conducting meaningful science and helping to increase knowledge about wildcat distribution, ecology, and hybrid- ization throughout Italy.

Methods

Study area

Cat detections were collected throughout Italy. Cameras were deployed in Sicily, in the Gargano promontory, along the Apennines, and in the Alps (Mont-Blanc region, Belluno province, Carnic Alps and Pre-alps and Carso; Fig. 1). Sicily is the largest island of Italy, and it is characterised by the typ-ical Mediterranean climate, with mild winters, short warm rainy spring and fall season, and a long dry summer, with the exception of high altitudes, where snow cover is com- mon during winter. The Gargano promontory is an isolated mountain massif located in Sud-Eastern Italy (Apulia) and it is dominated by a beech (*Fagus sylvatica*) forest, in spite of low altitudes (150–830 m a.s.l.). The Apennines are a long mountain chain, mostly contiguous for ~ 1200 km, extending along the Italian

Peninsula, with prevailing broad-leaved for- ests, and are characterised by short and snowy winters, and warm summers. Coniferous woodlands are widespread in the Alps and the climate is marked by snowy late autumn, winter and spring seasons (Bransford 2009). Overall, a great variety of habitats (e.g. coniferous and broad-leaved forest, rocky and cliff areas, riverbeds, creeks, ponds and grass- lands) were sampled.

Volunteer recruitment

Starting 11 February 2021, potential volunteers were directly reached by targeting recruitment efforts to recreational cam- era-trapping groups and amateur camera trappers' associa- tions on social media. Potential volunteers were asked to contribute towards the PFI project by sharing videos or photos with wildcats (*Felis silvestris*), domestic cats (*Felis catus*) and potential hybrids between the two species (*Felis silvestris* x *Felis catus*) (Kitchner et al. 2017). Addition- ally, volunteers were asked to provide their own e-mail in order to join a Google group (https://www.groups.google. com) where project information and news are shared. The project manager provided real-time feedback and assistance for data submission, consistency and integrity, while also keeping volunteers engaged by addressing questions about the project. We calculated the acceptance ratio (i.e. the ratio between contributors and potential volunteers expressed as percentage) in order to verify whether future actions (e.g. a website hosting the project as well as a webinar reporting data about the project) would positively impact this metric; responses were classified into 3 levels (i.e. yes, no and n.a.) with the latter level indicating an absence of response to our request.

Camera-trapping surveys

Volunteers autonomously placed camera traps of various brands and models but were asked to choose among the fol- lowing 3 levels of camera placement, corresponding to: (1) random, in case of absence of animal trails; (2) trail, espe- cially nearby junction of trails; and (3) target, in the pres- ence of potential den, bait (i.e. valerian tincture—*Valeriana officinalis*—placed on a stake in front of the camera) or prey remains (Ruiz-Villar et al. 2020; Krofel et al. 2021). Cam- eras were set at variable height and angle to the path, tied to a tree or another support. Volunteers were instructed about optimal camera trapping settings (i.e. camera orientation with respect to the trail and/or camera height from the ground) for maximising wildcat detections (Anile et al. 2014) whenever this information was required; otherwise, camera trapping settings were chosen by volunteers.

The camera trap brands and models, the camera operational mode (i.e. videos/images or both), the delay time used as well as the deployment and retrieval dates were recorded. Anytime the day length of cam-era activation was less than 1 day (i.e. the camera was active only during certain hours of the day), we recorded the hours of activation per day: this value was then used to properly scale the number of camera trap-nights (i.e. effort) accumu-lated at these cameras (Anile and Devillard 2015). When- ever the deployment or retrieval dates were not available, we parsimoniously assumed that cameras were active from the day before and the day after the detections, while also labelling them as "truncated". We removed non-independent detections at the same camera if separated by a threshold of 10 min. Detections were further classified according to light conditions (i.e. sunrise, day, sunset, night). To include detec- tions that had an NA in the time field into our framework, we replaced the time with "00:00". This expediency was necessary as the software used for managing the data (see further) was not capable of handling unknown time format; this subset of detections will be discarded when perform- ing temporal analysis. For each detection, and whenever it was feasible, the species status of the cat was assessed (i.e. domestic cat, hybrid, wildcat, only cat if the assessment was not possible) by the project manager based exclusively on the coat marking system proposed by Ragni and Possenti (1996) and further developed by Kitchner et al. (2005). Individuals showing clear anomalies in the typical wildcat coat mark- ing system (e.g. white patches across the body, dorsal line continuing throughout the whole tail, poorly defined stripes on the shoulders, the typical domestic cat coloration over the back of the ears) were identified as putative hybrids (Lioy et al. 2022; Gaudiano et al. 2022; Fig. 2). Furthermore, we closely inspected the tails of the cats to detect kinks over the tail, as this anomaly might be related to inbreeding depres- sion (Roelke et al. 1993; Johnson et al. 2010).

Marking behaviour (i.e. scratching, defecating, spray-ing and rubbing; Stanton et al. 2015) was also recorded as a binary factor (i.e. 0/1) and the distribution of the detections, filtered to ensure that only one adult cat with certain status (i.e. domestic cat, hybrid or wildcat, hereafter dc, hy and wc, respectively) was depicted in the video, was compared across the three different cat types using the χ^2 test ($\alpha = 0.5$ through- out). We used visitation time (Krauss et al. 2018; Cozzi et al. 2022), as a proxy of an animal's shyness displayed in front of the camera. Indeed, it is known that animals may sense cam- era traps by detecting noises, odours or lights, and respond with different behaviours, ranging from avoidance to device investigation (Meek et al. 2016). A Kruskall-Wallis rank sum test was performed to assess whether visitation time differed among cat types and between light conditions, with sunrise and sunset detections ranked as day and light due to the rela-tively low occurrence of detections during these specific light periods. If significant differences were found, then pair-wise comparisons were performed with a post-hoc Dunn's test for multiple comparisons to assess which groups behaved dif- ferently (Zar 2010).

Data storage

For each volunteer, two data files (namely, the cameras and the detections files) were allocated. The camera file included information for each camera trap: (1) camera ID (unique id for each camera location, usually the first letter of the name and surname—hereafter N and S -, followed by a number indicat-ing the device); (2) camera location (random, trail or target); (3) camera set-up (video or photo); (4) camera deployment and retrieval date; (5) and (6) start and end date of each camera malfunctioning or inactivity period; (7) Google Maps (https://www.google.it/maps) coordinates; (8) camera manufacturer and model; (9) general description of the habitat type (e.g. forest, meadow, river, agricultural field); and (10) site (region, province, municipality). The detection file contained informa- tion about each detection: (1) provider (name and surname); (2) detection number; (3) camera ID; (4) time and date (dd/ mm/yy hh:mm:ss format); (5) number of cats; (6) cat type (wildcat/domestic cat/hybrid); (7) cat age (juvenile/sub-adult/ adult); (8) cat sex (male/female); (9) cat ID (univocal number); (10) running time of the video and time the subject itself wasrecorded; (11) light condition (night/day); and (12) additional notes. To ensure data integrity, each video or photograph was renamed with the following fields: detection number, date and time (yyyy_mm_dd_hh_mm) and camera ID (e.g. 1_2018_08_23_01_40_NS1.AVI).

Data were shared through three different ways: (1) videos/ photos were directly sent to the project manager who then filled the files (odt. Format) and asked for any missing infor- mation from the volunteers; (2) videos/photo and camera and detection files were uploaded and shared using Google Drive(https://drive.google.com/drive) and filled in by volunteers;

(3) alternatively, volunteers could have filled in two Google Forms (https://www.docs.google.com/forms), corresponding to the camera and detection file. All new detections recorded and uploaded were checked by the project manager. The *R* software (R version 4.0.2) was used for extracting and merging the data, while also performing quality checks (e.g. camera deployment and retrieval was consistent with the detections recorded at each camera, no duplicate names and coordinates existed across the camera ID). Mapping and data analysis used the following *R* packages: *camtrapR* (Niedballa et al. 2016), *tidyverse* (Wickham 2016), *ggplot2* (Wickham et al. 2019) and *shiny* packages (Chang et al. 2017). Finally, a Shiny app including information about the project and an interactive map of current detections was developed and published online (https://pfiproject.shinyapps.io/pfi_app/).

Results

Data reporting and contact response

As of 24/10/2022, we asked 98 potential contributors to join our network and we obtained 10 negative responses, 49 positive responses (of which only 30 had actually contributed to the project) and 39 potential contributors did not reply to our request, leading to an overall accept- ance rate of 30.6%. PFI citizen scientists had cumulatively deployed camera traps at 503 unique sites across the Ital- ian Peninsula (Fig. 2) and Sicily for 41.506 camera trap- nights during 11/04/2006 to 24/10/2022. After removing 187 duplicates, we collected 1327 detections (312 images and 1015 videos) unevenly distributed among cat types (dc = 123, hy = 137, wc = 1016). Species identification was not possible for 51 detections. In addition, we corrected 20 detections that had an NA in the date time field by replac- ing the time with “00:00”.

Each volunteer managed their own camera traps at dif- ferent locations (range = 1–61) for a variable period of deployment. The distribution of the sightings was dom- inated by records from southern Italy (Sicily, Calabria, Basilicata and Apulia) with 618 observations, followed by northern Italy (Emilia Romagna, Veneto, Friuli Venezia- Giulia, Liguria and Aosta Valley) with 466 and central regions (Lazio, Umbria, Abruzzo, Toscana and Marche) with 243 (Table 1). Wildcat detections were distributed across its near-historical range, with the addition of recent recolonized areas located in the Occidental Alps (Aosta Valley) and Northern Apennines (Liguria) (Gerngross et al. 2022); domestic cat and hybrid detections were col- lected across all the Italian regions.

Finally, 36 wildcats showing a kink in the tail were recorded in more regions than those previously found (Lioyet al. 2022) (Table 2).

Behavioural differences among cat types

We found different marking frequencies across the three cattypes (X-squared = 6.119, df = 2, *p*-value = 0.047) (Table 3), with domestic cats marking with a lower frequency compared to wildcats (Fig. 3). Visitation times varied significantly between cat types (X-squared = 18.154, df = 2, *p*-value < 0.001) during night (X-squared = 15.718, df = 2, *p*-value < 0.001) and between hybrids and wildcats (*p*-value = 0.001) (Fig. 4). Visitation rates did not differ among species during day time (X-squared = 3.526, df = 2, *p*-value = 0.172).

Discussion

During the first 20 months of the PFI project, we estab- lished a network of citizen scientists aiming to increase our knowledge on the wildcat ecology and conservation status in Italy. Several models of citizen science exist, ranging from simple sighting data upload to a practical and captivated involvement of volunteers (Heigl et al. 2019; Lasky et al. 2021; Mukherjee et al. 2021). We opted to facilitate a direct dialogue between citizens and researchers, starting from the beginning of the project. Our main objective was to create a pool of trained citizen scientists consciously involved in the process of doing research focused on European wildcat. We targeted recruitment efforts, using social networks, to the great number of existing recreational camera-trapping groups and amateur camera trappers' associations. Cam- era trap technology has rapidly advanced, thereby revolu- tionising the study of rare, elusive and nocturnal species worldwide, including wildcats (Can et al. 2011; Kilshaw and Macdonald 2011; Anile et al. 2012; Kilshaw et al. 2014; Kilshaw et al. 2016; Gil-Sánchez et al. 2020; Fonda et al. 2021), while becoming affordable and popular among the public (McShea et al. 2016). Indeed, almost one-third of the people and associations responded positively and actually contributed to the project, reaching 31 volunteers recruited from Northern Italy to Sicily. Another advantage offered by camera-trapping is that pictures and videos are readily storable with associated metadata (i.e. time record of an animal's detection; days of the camera being functional and active) (Bowler et al. 2022). More detailed metadata increases the value of data, especially when dealing with unstructured surveys (Isaac and Pocock 2015). For this reason, volunteers were asked to share not merely occurrence data but also other crucial information to allow standardisation, such as days of activity and camera placement type. Furthermore, datasets including videos (rather than just pictures) are preferable in citizen science projects, since videos have a higher classification accu- racy (Green et al. 2022). Thus, volunteers are more likely to spontaneously provide additional information about subjects (i.e. age and sex), resulting in higher participation, critical thinking and engagement (Green et al. 2022).

Our approach yielded 1016 wildcat detections distributed across the near-historical range of this species, consisting of Sicily (within the northern part of the island and the Mt. Etna Regional Park), Garagano Massif, Apennine ridge from Calabria to Romagna, and the North-East (Belluno province, Carnic Alps and Pre-alps, Julian Alps and Pre-alps and Fri- ulian Morainic Hills) (Pierpaoli et al. 2003; Lapini 2006; Velli et al. 2015; Fonda et al. 2021; Gaudiano et al. 2022). In addition, we recorded novel occurrences and a reproduc- tive event (see Supplementary Information) in the Northern Apennines (Liguria) documenting the possible recolonization of the north-western Italian peninsula, in accordance with other recent findings (Gavagnin et al. 2018; Loy et al. 2019). We also reported the first wildcat detections in the Western Alps (Valle D'Aosta), which may be the sign of the colonisation of a new territory from ecologically connected Alpine areas. This finding is further corroborated by the detection of a wildcat in the nearby territory of the Savoia in France after 100 years of absence (R. Cousin, pers. comm. 2022; https:// www.leparisien.fr/savoie-73/biodiversite-le-chat-sauvage- de-retour-en-savoie-28-05-2022). The wildcat range expan- sion may be explained by the natural regeneration of forested areas in the Alpine range during the twentieth century as well as the drastic drop of carnivore species persecutions under the Berne Convention (Appendix II, 1979) and the European Habitat Directive 92/43/EEC (Appendix IV, 1992), which have led the resurgence of declining wildcat popula- tions across Europe (Easterbee et al. 1991; Weber et al. 2010; Say et al. 2012).

However, our data have to be considered carefully, since range expansion and population health are not synonymous in ecology. Indeed, populations may be fragmented and thus exposed to inbreeding and local extinction (Kenney et al. 2014). Recently, the first detections of morphological abnor- malities (i.e. brachyuria, kinked tails and cowlicks), poten- tial indicative of inbreeding depression, have been docu- mented in five wildcat populations in Italy (Sicily, Basilicata, Apulia, Friuli Venezia-Giulia and Umbria; Lioy et al. 2022). We recorded wildcats with kinked tails in three additional regions than those previously found (Calabria, Abruzzo and Veneto), highlighting the need of an extensive investigation into the genetic associations of these abnormalities across Italy. Another crucial threat to wildcat conservation we iden- tified is the widespread detection of domestic cats, with the consequent hybridization which may result in genetic extinc- tion through introgression (Rhymer and Simberloff 1996; Allendorf et al. 2010; Ellstrand et al. 2010; Nussberger et al. 2018). We found domestic cats shared much of wildcat range, with the obvious consequence that hybrids were also detected. In addition to range expansion many other factors can affect domestic cat introgression into wildcat habitat. For example, local domestic cat colonies can be a dramatic source of feral cats if neutering policy is not respected (see Legge Quadro 281/91). Even when neutering policy is respected, there might be a bias into this method such that it usually affects only females. This practise might hence increase the number of domestic male cats ranging into wildcat habitat looking for potential females in oestrus. The population dynamics of domestic cats, hybrids and their behavioural interactions with wildcats is of considerable importance with surprisingly few hard data across Europe (Nussberger et al; 2018; Beugin et al. 2020; Lepczyk et al. 2022). Our project hence provides the opportunity, the occurrence and the interactions among the three cat types, which are essential to consider in the context of wildcat genetic integrity (Matias et al. 2022).

Cat behaviours were investigated at two levels: marking frequency and visitation time. In wildcats, olfactory com- munication plays a crucial role, mainly in territory adver- tisement (MacDonald 1980; Mellen 1993). We detected a different marking frequency among cat types, with domestic cats marking at a lower rate; this result is in line with the findings of Berteselli et al. (2017), although their study was conducted in a captive environment. This outcome might be explained by the fact that wildcat home ranges are on average five-fold wider than domestic cats (Fitzgerald and Karl 1986; Anile et al. 2017) and thus requiring wildcats to mark for territorial defence much more often than domestic cats (Feldman 1994; Lozano 2010; Beugin et al. 2016). Our findings in the wild have critical implications toward the use of bait lure during camera trapping surveys which are largely employed in the study of elusive species (Buyaskas et al. 2020), and may enhance domestic cat marking behav- iour, promoting intra- and interspecific contact and disease transmission (Millán and Rodríguez 2009; Mills et al. 2019). We detected a different visitation time between the three cat types, with hybrids being more active than wild- cats at night. The variations of behavioural ecology in hybrids have been already reported for other carnivore species (Monzon et al. 2014), and they might be linked to gene introgression from domestic to wild type. Indeed, a comparative whole-genome study on wildcats and domes- tic cats revealed a positive selection in the latter of many genes associated with behaviour, diet, sensory processes, and reward (Montague et al. 2014). Thus, introgression of domestic traits into the wildcat population may led to adaptations to human-dominated environments, with hybrids being more inclined to explore domestic cat range but also sharing at least a part of their territory with wild- cats and thus playing a key role in upcoming hybridization events (Kilshaw et al. 2016; Beugin et al. 2020). Further investigations are needed to clarify the conservation con- sequences of these differential behaviours among the three cat types, reported here for the first time.

Understanding wildlife distribution and behavioural ecology is crucial for implementing effective conservation policies to protect threatened species (Cianfrani et al. 2010). Given the lack of both a national wildcat monitoring plan in Italy (Lioy et al. 2022) and information on the conserva- tion status of the wildcat in the majority of its range, citizen science represents a promising source of data, especially by using camera traps. In addition, the amount of data that can be collected and processed efficiently could be max- imised by the integration of citizen science and novel pro- cedures, such as machine-based classification of species, individuals and behaviours, which is significantly improv- ing wildlife conservation worldwide by reducing human bias (Nipko et al. 2020; Duggan et al. 2021; Whytock et al. 2021; Pereira et al. 2022). Finally, our results show how free-roaming domestic cats share wildcat distribu- tion range (but see Gil-Sanchez et al. 2015 for contrast- ing results), highlighting the importance of implementing science-based management of feral cat populations and an effective assessment of hybridization range.

Supplementary Information The online version contains supplemen- tary material available at https://doi.org/10.1007/s10344-023-01670-6.

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