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ORIGINAL ARTICLE

How much Eurasian beaver activity is there in Italy? Using field signs to monitor and map a returned species

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Abstract

After centuries of widespread extinction, the Eurasian beaver *Castor fiber* has recolonised most of its former extent of occurrence, following international and national protection laws, reintroduction programmes, and unauthorized releases. Beavers provide valuable ecosystem services and multiple benefits to native biodiversity, though their activity may trigger conflicts with humans, especially in highly modified landscapes. Therefore, it is important to monitor their range-expansion, particularly at the early stages of the colonization process. This study quantifies beaver presence in Central and Northern Italy, where reproduction was first detected in recent years after five centuries of absence. A mix of techniques including both direct and indirect signs of presence was adopted to assess the occurrence and status of beavers in the area, retrieving data for the application of density estimators and, thus, population estimates. We document that at least 16 reproductive events occurred between 2021 and early 2023, with at least 55 areas of activity, located across three rivers of Central Italy, corresponding to a minimum of 40 individuals. Seven to ten individuals (in at least 5 areas of activity) were also recorded in Northern regions, in continuity with the populations occurring in neighboring countries beyond the Alps. Given the fast range expansion by the species and the potential for conflict with human activities, alongside the efficiency and applicability of our approach, this type of beaver field survey should be adopted by wildlife managers and policy makers both in areas of established presence but also in potential expansion areas, to develop management plans and to figure out opportunities this returning native species may bring.

Keywords Eurasian beaver · Field sign · Population monitoring · Restoration · Mammal densities · Italy

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Introduction

Monitoring wildlife populations is key to inform conservation and management decisions and enable effective actions, particularly in light of human-wildlife conflicts and global change (Vallecillo et al. 2021). Wildlife population counts are particularly important for species experiencing range-expansions which may affect human activities (e.g., the wild boar *Sus scrofa* and the grey wolf *Canis lupus*: Galaverni et al. 2016; Ferretti et al. 2021), for invasive alien species (e.g., ring-necked parakeets *Psittacula krameri* and Siberian chipmunks *Eutamias sibiricus* in Europe: Pârâu et al. 2016; Nerva et al. 2021), for threatened species (e.g., the Italian endemic Sardinian long-eared bat *Plecotus sardus*: Ancillotto et al. 2021), as well as to monitor the success of reintroductions (e.g., Bertolero et al. 2007; Moseby et al. 2018). Undertaking any population monitoring survey can be challenging, especially - for example - those existing at low densities over a large area or in areas hard to be reached (e.g., Buckland et al. 2000; Gargioni et al. 2021). Thus, all data on wildlife population size are based on local estimates following standard methods and species-specific presence signs of the target species (e.g., field signs, contacts by means of camera-traps, and capture-mark-recapture; Karanth 1995; Thompson et al. 2010; Galaverni et al. 2016; Ferretti et al. 2021), that most reliably provide good proxies of population size.

The Eurasian beaver, *Castor fiber* Linnaeus was once present in a large part of the Palaearctic, ranging from Portugal to Mongolia, throughout all suitable riparian habitat types (Halley et al. 2021). In Medieval times, this rodent underwent a severe population decline, due to both hunting (e.g., for fur, meat, and castoreum), and to habitat loss (Halley and Rosell 2002; Campbell-Palmer et al. 2016). Since 1920, legal protection together with official and unofficial reintroduction events and natural spread triggered the recovery of the species in most of its original range (Halley et al. 2021).

In Italy, Salari et al. (2020) reported that Eurasian beavers occurred in the Early Pleistocene in central and northern Italian regions. Records from Tuscany date back to early Medieval times (i.e., around 700–1000 AD), whereas the Eurasian beaver may have persisted in the eastern Po plain forests up to 1500s, and up to 1954 in Alto Adige (Salari et al. 2020). Reintroductions occurred in the last century in neighboring countries (Austria and Switzerland) between the 1970s and the 1990s, promoting the recolonisation of most of these countries (Halley et al. 2021). In 2018, the first confirmed Eurasian beaver was reported in North-Eastern Italy (Tarvisio, Friuli Venezia Giulia) - followed by a second and a third individual in 2023 - probably as a result of natural dispersal from Austria (Pontarini et al. 2019).

Beavers are relatively secretive mammals, mainly being active during night hours and usually being found in hard-to-monitor environments such as well-preserved rivers (Mori et al. 2022a). Nonetheless, despite such difficulties in observing and thus directly monitoring the species, beavers are rather conspicuous inhabitants of riverine habitats, providing plenty of indirect signs of their occurrence represented by dams, lodges, and gnawed tree trunks. As such, Eurasian beavers are excellent candidates for the application of indirect count methods to assess their population size and/or spread (Campbell-Palmer et al. 2021). Beaver field signs have been confirmed by wildlife technicians and provincial police in three river basins of Central Italy since March 2021, where they are believed to have been present since 2018–2019 (Mori et al. 2021; Pucci et al. 2021). Further individuals have been reported in Southern Regions (at least 3–4 individuals: Abruzzo, Molise, and Campania), though no evidence of breeding has yet been documented (Capobianco et al. 2023).

The Eurasian beaver is listed within the Annexes II and IV of the Habitats Directive (92/43/EEC: Genovesi et al. 2014; Stoch and Genovesi 2016). Despite this, unauthorized releases even of protected species, including beavers, are currently against national recommendations for reintroductions (Presidential Decree 357/1997, amended by Presidential Decree 102/2019; Decree of the Ministry of the Environment of 2 April 2020) - with concerns raised by public administrations questioning if this has occurred in the specific case of central Italian beavers (Bertolino et al. 2023). Beavers can provide remarkable ecosystem services to riverine environments (Campbell-Palmer et al. 2016; Grudzinski et al. 2022), thus potentially representing a positive driver of habitat restoration and "rewilding" (Grudzinski et al. 2022). Recent studies investigating nature-based solutions have shown the multiple benefits that the return of the beaver can bring (Brazier et al. 2021) including biodiversity and habitat enhancement (Law et al. 2016), attenuation of storm flow (Westbrook et al. 2020; Puttock et al. 2021), drought, and wild-fire resilience (Fairfax et al. 2023).

Beaver eradication following unofficial releases has been proposed in other countries (Román and Aguilar-Gómez 2023), though removal has been ineffective for naturalized populations, as it is expensive and can be inefficient unless highly coordinated and well-funded (e.g., the Spanish case: Mori et al. 2021; Román and Aguilar-Gómez 2023; Treves and Comino 2023; Serva et al. 2024a). Campbell-Palmer et al. (2021) have shown that spatial extent and environmental impact of beavers can be quantified via distinctive field signs (e.g., gnawing activity intensity on wood trunks, dams, lodges, and road-killed animals), by which it is possible to estimate the number of beaver 'areas of activity'.

Eurasian beavers are highly territorial and actively defend core areas including their food resources, shelter, as well as wintering and breeding sites (e.g., burrows or lodges), mostly following waterbody shorelines (Rosell et al. 1998). Territory size varies greatly within and amongst beaver populations (Wilsson 1971; Nolet and Rosell 1994; Herr and Rosell 2004; Hamšíková et al. 2016), ranging from 1 to 7 km of riverbank length (mean ± SD, 3.7 ± 1.7 km) (Herr and Rosell 2004; Campbell et al. 2005; McClanahan et al. 2020). Overlap between different territories is on average less than 2.5%, with a maximum of 10%, depending on local population density, habitat heterogeneity, and local food availability (Herr and Rosell 2004).

Aim of this work has been to determine the spatial distribution of Eurasian beavers in Italy and to determine the number of beaver areas of activity, by applying an easily replicable approach based on indirect signs of presence.

Materials and methods

Field sign surveys

In Central Italy, beaver field sign surveys were conducted between December 2021 and January 2023, once per astronomical season (autumn, winter, spring, and summer), by combining walking and kayaking according to riverbank accessibility. Surveys focused on rivers, small water courses, ponds and lakes where beavers have been previously reported (Umbria and Tuscany regions: Mori et al. 2021; Pucci et al. 2021; Fig. 1a). These areas were

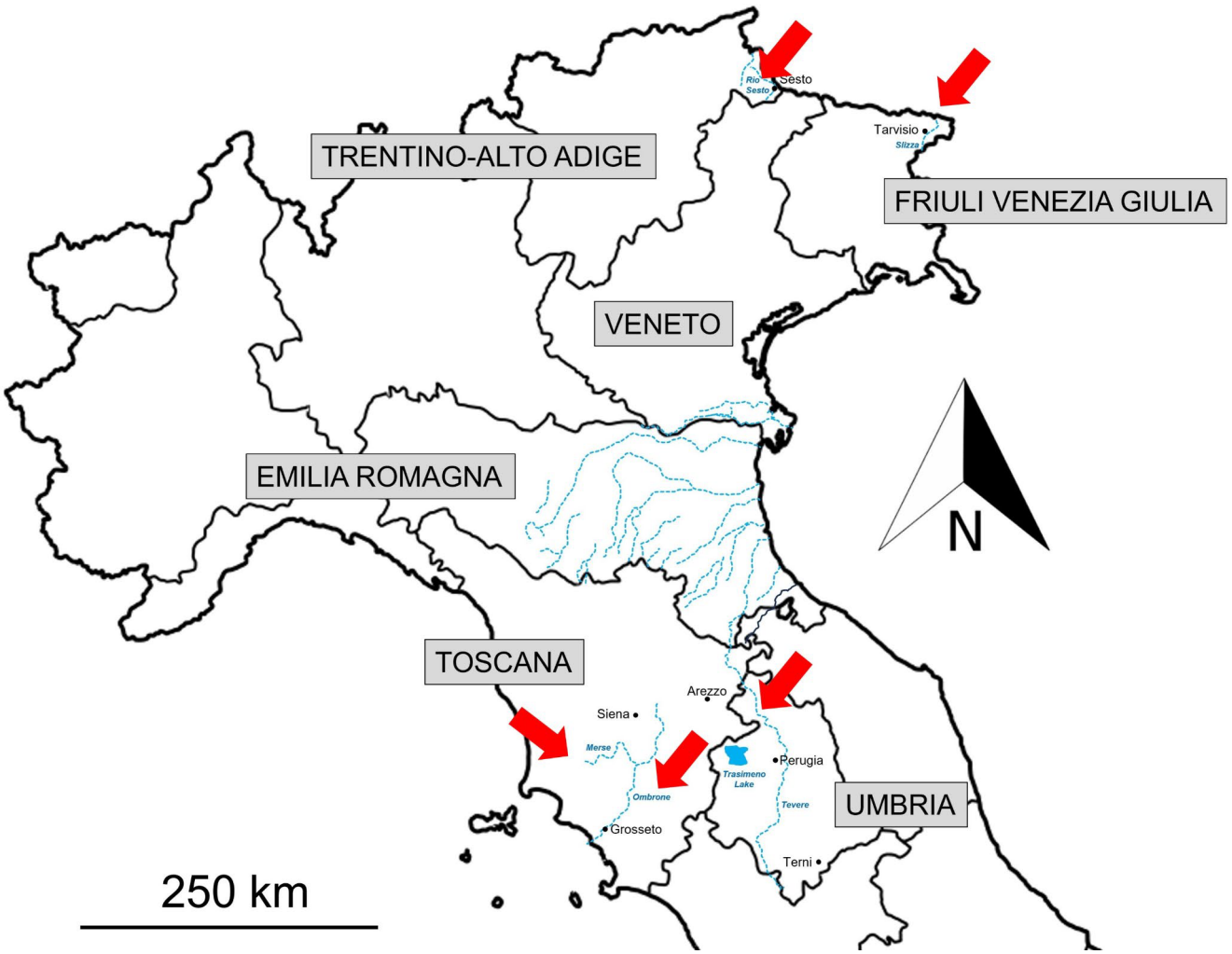


Fig. 1 **a**) rivers and other water bodies surveyed for beaver presence signs in Central (Tuscany and Umbria) and Northern Regions (Emilia Romagna and Veneto). Systematic surveys occurred in Tuscany and Umbria, whereas only suitable areas were visited in Emilia Romagna and Southern Veneto; **b**) rivers and other water bodies systematically surveyed for beaver presence signs in NorthEastern regions (Friuli Venezia Giulia and Trentino-Alto Adige). Red arrows show rivers with confirmed beaver presence; river network created by one of the author (AV)

systematically investigated and all rivers were traveled to search for signs of presence. Where necessary, i.e. in three cases, we asked for permissions to Regional Councils (Tuscany) and local landowners in Umbria and Tuscany.

Signs of active beaver presence were also undertaken in the adjacent northern Italian regions (Emilia-Romagna and Southern Veneto), to investigate potential natural colonization from the Alps (Leoncini and Viviano 2023). In this area, the watercourses selected for the survey were identified following a meeting with the regional Public Administration, focusing only on those with persistent water throughout the year (Leoncini and Viviano 2023), and in areas characterized by a high environmental suitability for beavers, at least potentially (Falaschi et al. 2023; Serva et al. 2023a).

As for Tuscany and Umbria, a standardized survey on the whole water bodies of beaver presence was also conducted in the extreme North-Eastern Italian regions (Trentino-Alto Adige and Fruli Venezia Giulia: Fig. 1b).

All signs of beaver presence were included in a global dataset with the coordinates (latitude and longitude) recorded using GPS devices (Garmin) with an XY resolution of +/- 10 m, the number and the type of presence sign (recent gnawed trunks, camera-trapping, road-kills, lodges, dams and scent marking sites), following Campbell-Palmer et al. (2021).

Analysis of survey data and identification of 'areas of activity'

Beaver areas of activity can be defined using different methods e.g., scent mound mapping as indicators of borders of areas of activity (Campbell et al. 2005), movement data from radio-tagged individuals (Campbell et al. 2005; Graf et al. 2016), riverbank length assessed as Minimum Convex Polygon or kernel estimates (Herr and Rosell 2004), or patterns of beaver field sign density (Fustec et al. 2001; Trentanovi et al. 2023). We are aware that so many methods may produce different or biased estimates of beaver population size, due to limited sample size (e.g., radio-tagged individuals often under-represent the distribution/behaviour of the total population: Lovari and Rolando 2004) or to excessive approximations (e.g., point transects over long rivers may underestimate the numbers of areas of beaver activity). However, Campbell-Palmer et al. (2021) suggested the use of beaver field-signs as a highly reliable method to estimate beaver territories over large areas.

Typically, early-colonizing family units of beavers select the highest quality habitat (Nolet and Rosell 1994, 1998; Horníček et al. 2021). In expanding beaver populations, areas of activity are increasingly close to each other, while territorial behaviors (e.g., inter-individual aggression and scent marking) increase in numbers (Hartman 1995; Rosell and Nolet 1997). In spring, scent marking increases and new areas of activity are formed by dispersing subadults (Hartman 1997).

Estimation of areas of activity from survey data

We used an automated classification approach to estimate the numbers and distribution of beaver activity areas, based on the location of recorded signs and a kernel density estimation analysis (hereafter, KDE), identifying spatially explicit clusters of beaver activity (Campbell-Palmer et al. 2018, 2021). We used a five-points methodological workflow, summarized in Fig. 2.

We used XY coordinates where beaver signs of presence were detected to create a kernel density raster for each survey season using the {spatialEco} R package (Evans 2021). Weights were applied to the points based on their effort category class (in four levels) to give greater prominence to areas of high feeding effort (Fryxell and Doucet 1991). Low, medium, and high classes had weights of 1, 1e + 03 and 1e + 06 respectively. A fourth low threshold value of 1e-10 was used to remove areas of extremely low density, increasing the chance of disentangling between coincident regions of high-density signs. These specific weights and low threshold limits were chosen following local knowledge of locations of beaver areas of activity to increase the chance of distinguishing coincident regions of high-density foraging (Graham et al. 2022). High-density foraging areas were considered to describe the core areas of beaver activity (Campbell-Palmer et al. 2021). When an activity region intersected either a dam, it was flagged for a further confirmation.

We used unmistakable field signs (lodges/dams, sightings, cuttings, and droppings) as confirmatory signs, adding a further layer of confidence to estimations where signs were recorded (Campbell-Palmer et al. 2021). Road-kills were also considered as a sign of presence, but they may also represent dispersal sites, without any other actual occurrence. Presence/absence of beaver signs in each area of activity was flagged giving a further layer of information for expert interpretation (e.g., Campbell-Palmer et al. 2018; Trentanovi et al. 2023; Fig. 2). Beaver foraging signs can be roughly aged by the degree of regrowth on woody vegetation and by the discolouration of the stumps, which become darker after a few months since cutting (Pucci et al. 2021; Juhász et al. 2023). Only some local natural processes (e.g., oxidation by environmental pollution, gnawing by other large rodents and extreme events such as wildfires, storms and floods) may affect the aging of foraging signs (e.g., see Wohl 2019; Mori et al. 2022b). Moreover, gnawed trunks are long lasting features in the environment and allow estimating previous presence (Campbell-Palmer et al. 2021).

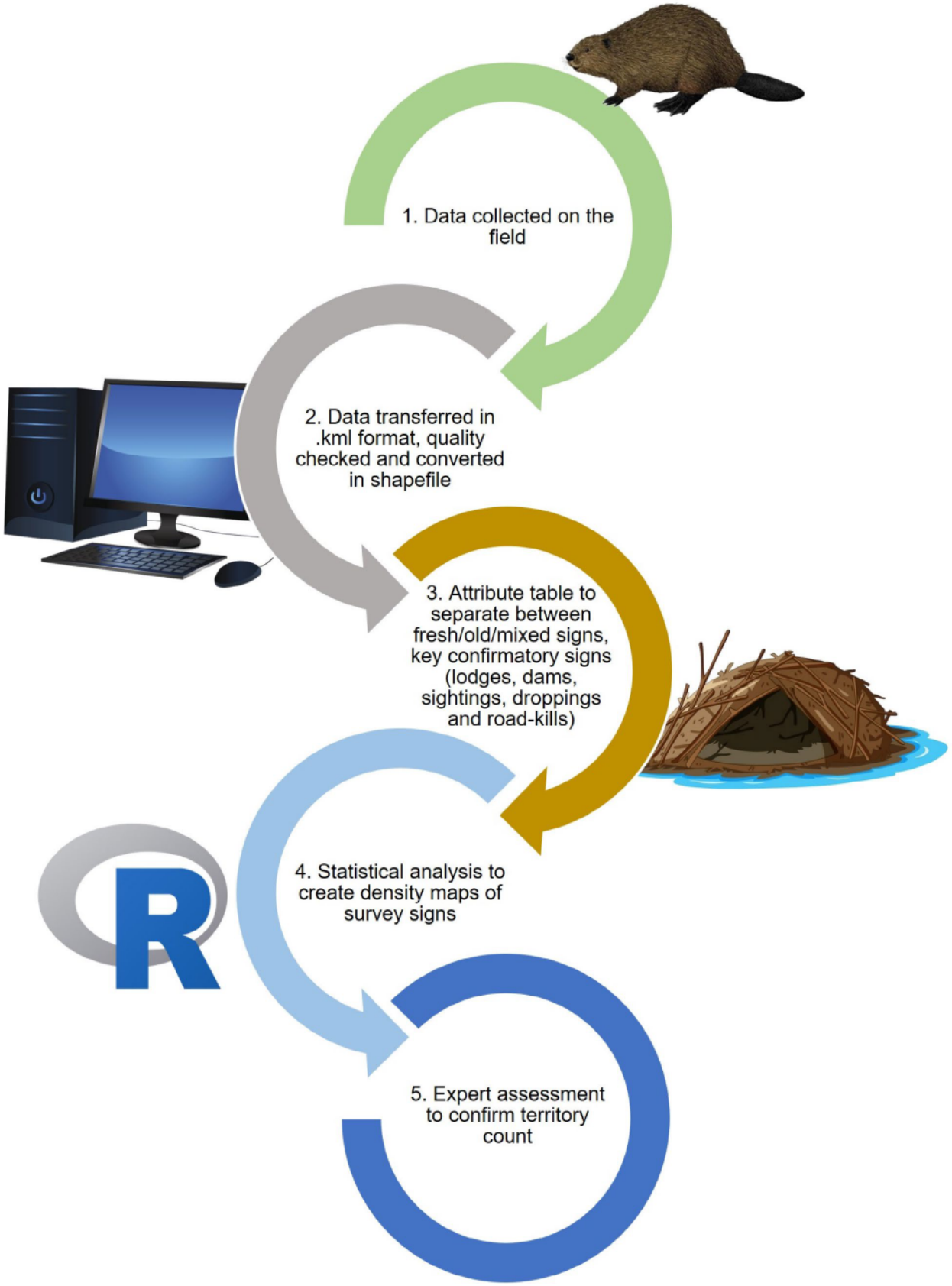


Fig. 2 Methodology for identifying beaver areas of activity in Italy, adapted from Campbell-Palmer et al. (2021)

We also traveled several river-transects, to search for beaver signs of presence through a kayak. Where survey transect data was collected but exact locations of associated recorded signs were not reported, the start point of the transect has been mapped. To allow further analysis of this data, for all points, the type of survey (point *versus* transect) has been recorded in the attribute table under 'survey'. Additionally, under 'sign' in the attribute table comments from the field survey team regarding sign types/observations along transects have been recorded.

To allow integration of transect data where some uncertainties existed, 'sign' data were analysed and where possible the presence of beaver sightings has been extracted (Y/N) and recorded under the 'Individual' attribute. Similarly, the presence of a key confirmatory sign i.e., dwelling or dam, as used in the beaver tools methodology, has been extracted and recorded under 'dwelling_dam'.

To allow integration of the number of signs from transects into the KDE 'heat mapping approach', we weighted each presence record by the numbers of signs recorded per transect, and these records were merged and used for the KDE. To account for uncertainty in exact location of a recorded sign along a transect, a search radius of 1.0 km was used in KDE, i.e., at every area in the KDE results, all signs within 1.0 km are considered and the more signs implied a higher density, following Campbell-Palmer et al. (2021), to get comparable results. All polygons extracted from KDE analysis have been described as 'areas of activity' rather than territories.

We adopted 10 km square grids to visualize beaver activity areas across the study area; such relatively low resolution was selected to both account for uncertainty and secure the population against potential poaching by not disclosing exact locations. Where a grid cell contains (i) fresh or mixed beaver signs (ii) a confirmatory sign and (iii) a beaver sighting, it is graded 3 or green, i.e., high confidence; where (i) and either (ii) or (iii) are recorded, it is graded 2 or orange, i.e., medium confidence; where only (i) is recorded, it is graded 1 or red, i.e., low confidence.

To conclude, we identified a "reproductive event" in all contexts where at least a lactating female (i.e., with evident nipples) and/or a kit (smaller in body size with respect to other individuals) was directly observed and/or camera-trapped (Mori et al. 2022a).

Results

Field work data from Northern and Central Italy

We retrieved evidence of the occurrence of beavers from two rivers of North-Eastern Italy (Slizza and Rio Sesto rivers, Friuli Venezia Giulia and Trentino Alto Adige regions respectively), by both camera traps and presence signs derived from systematic surveillance.

We traveled a total of 347.21 km of water courses along six rivers with suspected beaver presence in Central Italy (Ombrone, Merse, Cerfone, and Tevere), and 21 further river basins where the Eurasian beaver was not present. The occurrence of beavers was confirmed for two river basins in Central Italy (Ombrone-Merse and Cerfone-Tevere: Fig. 3a). Throughout the investigated regions, we confirmed a 75% overlap between sightings (both living individuals and road-kills) and dam/dwelling areas (Fig. 3b).

Most field records consisted in cuttings, followed by lodges and dams, and road-killed individuals. Few ($N=4$) direct sightings are related to videos by fishermen. One road-killed juvenile was also found in the Marche region, though no field sign was recorded in these areas (Fig. 4).

In Central Italy, we identified 55 areas of activity, counting for at least 40 individuals (as 40 out of 55 showed recent signs of presence, and 15 included only old gnawed trees). Beaver reproduction was confirmed 16 times in 7 of these areas between 2021 and early 2023 (Fig. 5a). We mostly recorded mixed old and recent signs of presence both in Northern and in Central Italy (Fig. 5b). Only old signs of presence were recorded in northern Tuscany (Arno River, Arezzo Province) and in Emilia Romagna, where no recent activity signs were retrieved to indicate current beaver presence (Fig. 5b).

After our field work, in late 2023, at least two individuals apparently settled at three sites between the Toce river and Lake Maggiore (provinces of Verbano-Cusio-Ossola, Piedmont, and Varese, Lombardy); several single records of Eurasian beavers were also confirmed for Southern Italy (Aterno river in Abruzzi, Volturno river in Molise and Campania) from 2022 to 2023 (Fig. 6). Moreover, in June 2024, the first reproduction in North-Eastern Italy (Tarvisio, Friuli Venezia Giulia) was recorded through camera-trapping.

Discussion

We here present an updated picture of the current distribution of the Eurasian beaver in Italy based on standardized robust methods, thus providing a key tool for conservation and management of the species in Italy and elsewhere, besides also representing a repeatable exercise applicable to estimating population size of other elusive species. Our approach provides only indirect estimations of population size in terms of numbers of individuals, yet the social structure of *C. fiber* and its known ecology and spatial behavior well fit with considering centers of activity - as defined by direct and indirect presence signs - as a valuable and

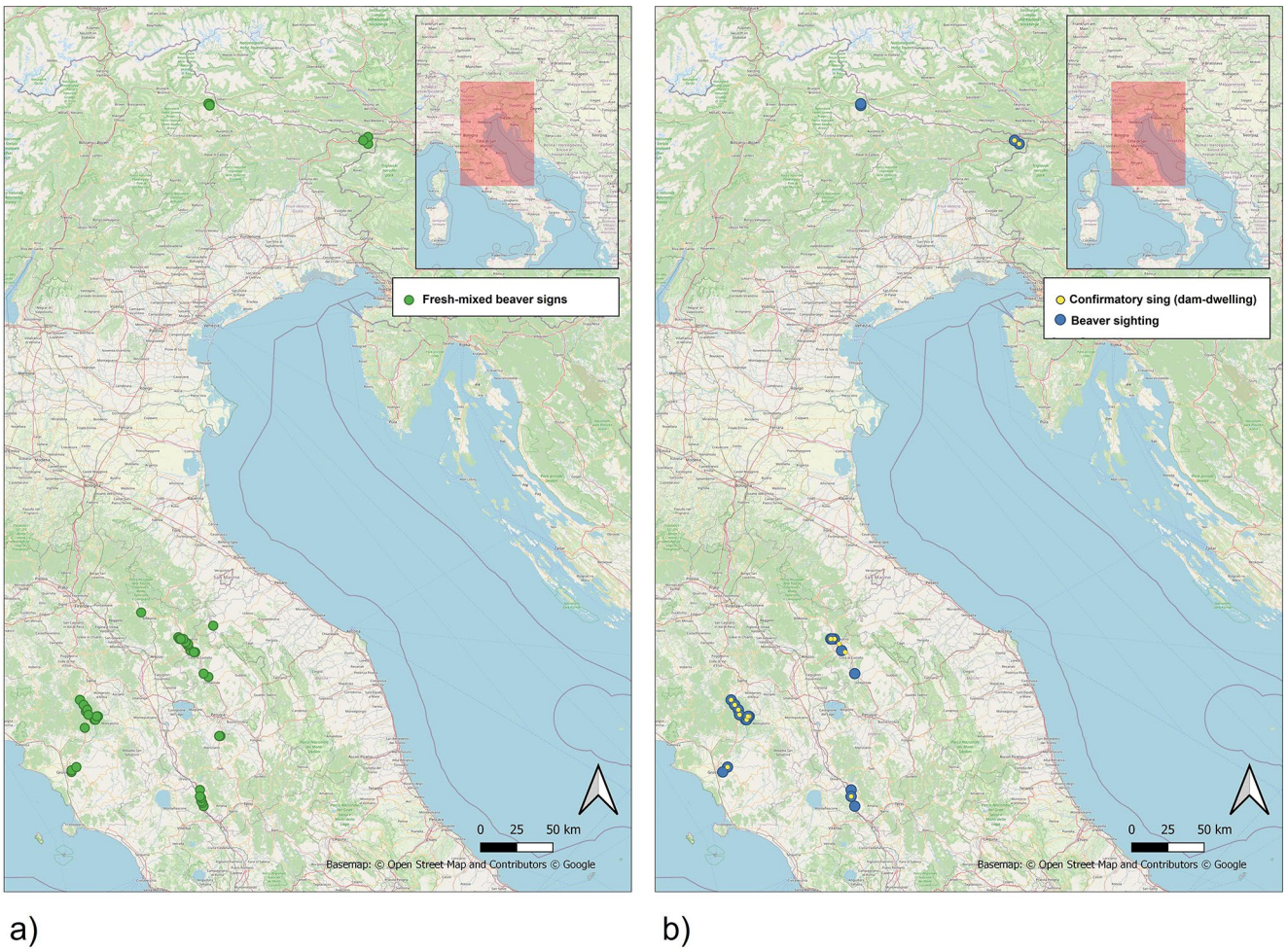


Fig. 3 **a**) fresh and mixed age beaver field sign distribution across Italy; **b**) beaver sightings overlaid with confirmatory field signs of either a dam or a dwelling in Italy

efficient unit for monitoring and managing the species and its habitats. Where key recorded confirmatory signs (i.e., dwellings, dams or sightings of beavers, kits or lactating females, i.e., with evident nipples) overlapped with areas of evident gnawing activity, it is highly likely that actual beaver territories are present (Campbell-Palmer et al. 2021).

Moreover, applying a classification approach to age the indirect presence signs of the species also allow to estimate timing of settling by individuals in the above-mentioned centers of activity, in support of more direct records such as observations or road-kills. Concurrent evidence of both fresh and mixed signs may suggest the occurrence of resident families and/or single individuals, whose presence has been confirmed by camera trapping along three monitored rivers (Mori et al. 2021, 2022a, b). Therefore, rivers with confirmed beaver reproduction in Central Italy (Tevere, Merse, and Ombrone) are currently showing population increase, and a clear expansion towards southern sections of the occupied rivers. Interestingly, such expansion fits well with the predicted species' suitability as estimated by modeling exercises (Falaschi et al. 2023; Serva et al. 2023a). In the specific case of the Tevere, Merse and Ombrone rivers, closest sites along different hydrographic systems feature shortest distances of approximately 100 km, a distance unlikely to be crossed by a beaver without signs of its presence in between, suggesting independent introduction events, since the species usually does not disperse over such long-distances (Rosell and Campbell-Palmer 2022; but see Saveljev et al. 2002; Šimůnková and Vorel 2015). Active dispersal by the species is though clearly evident from our results: the isolated records of individuals (e.g., road-killed) at sites located between known areas of activity both within our study area (e.g., in Latium, Marche and Umbria regions) as well as between Italy and neighboring countries (e.g., a juvenile found in Coccau, i.e. at the border with Austria) may possibly indicate potential range expansion pathways to be monitored in the future. These areas are overlapping with the main dispersion pathways identified by connectivity studies on the Eurasian beaver in Italy (Falaschi et al. 2023; Serva et al. 2024a). Besides, several of these isolated

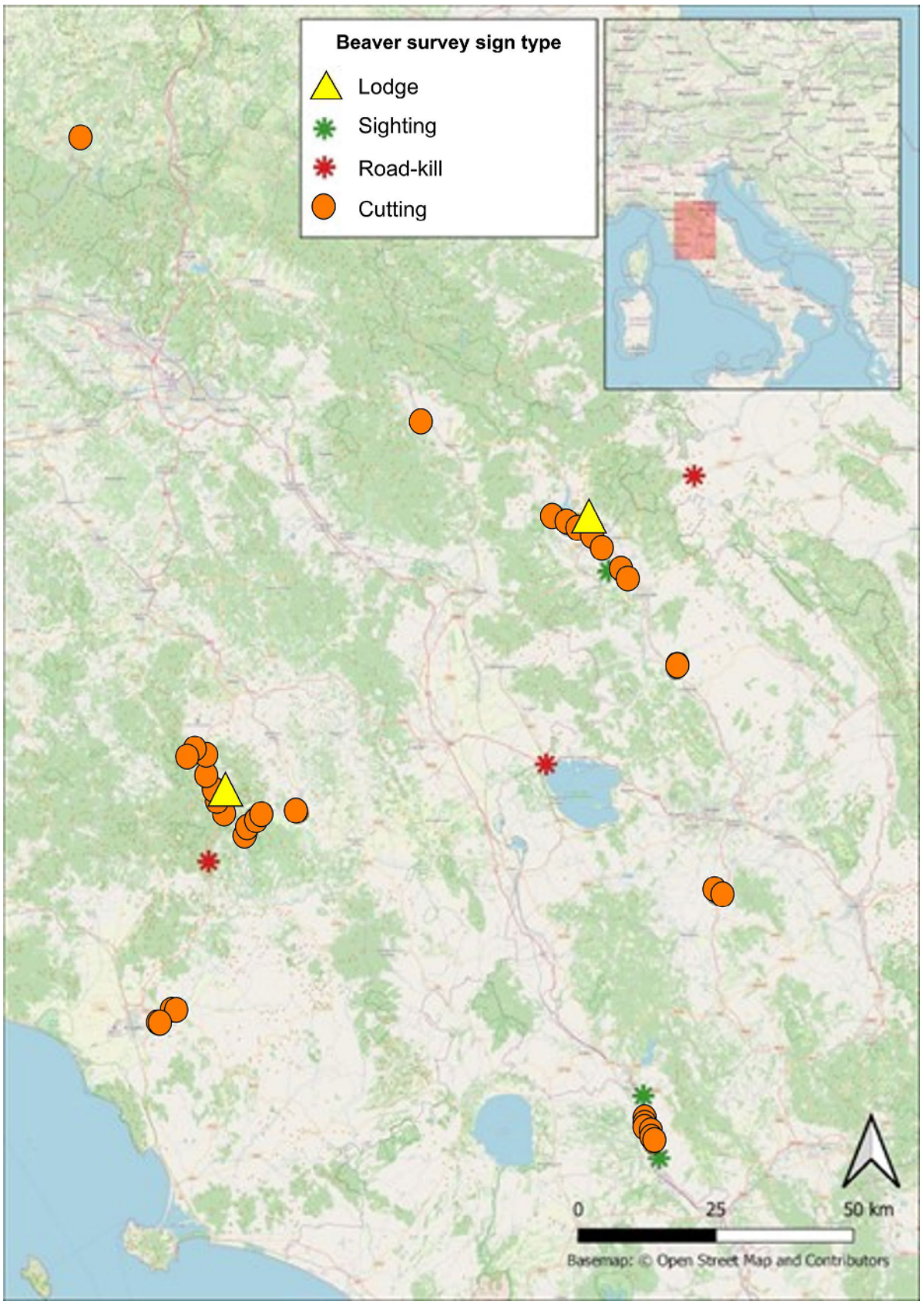
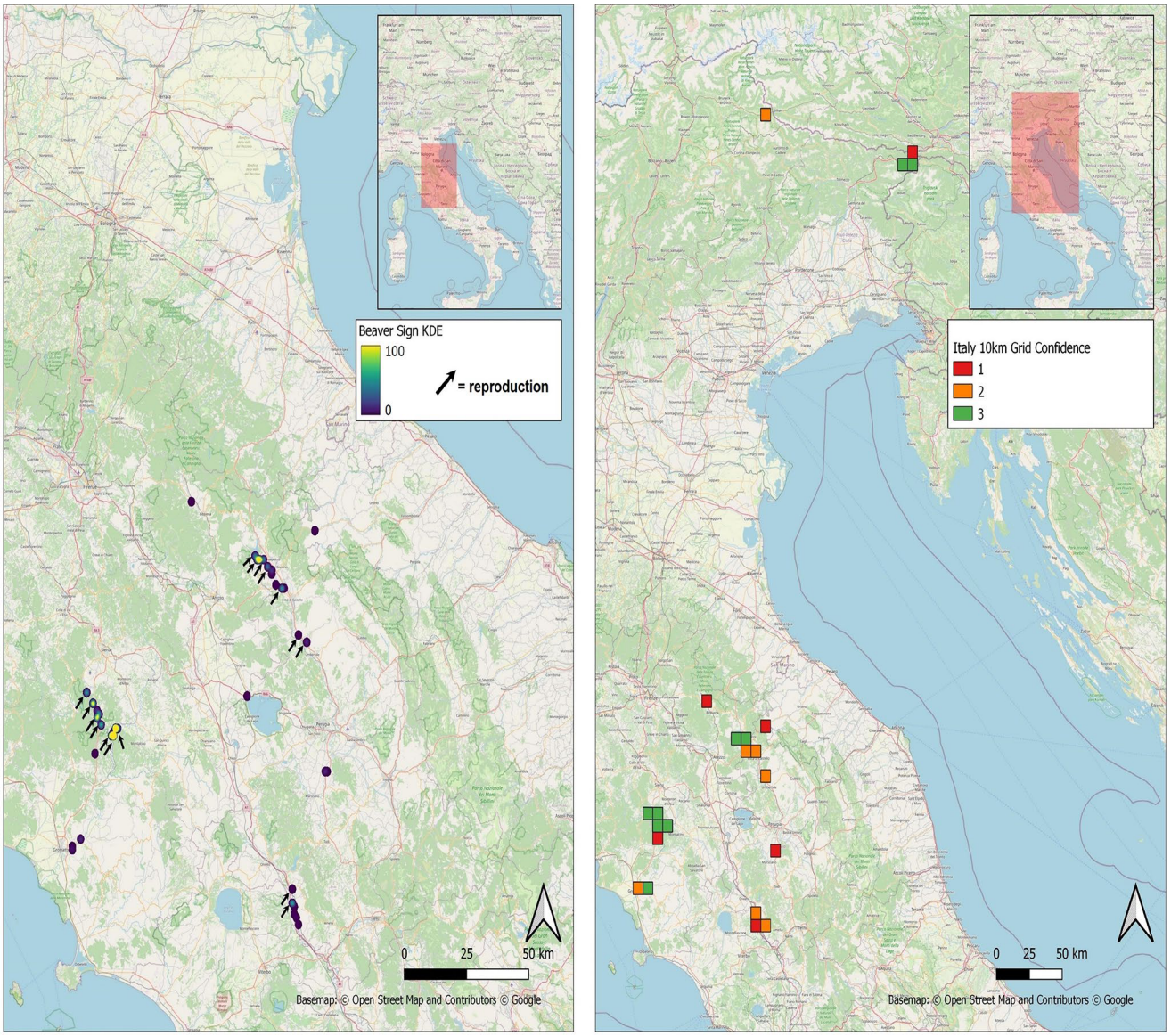


Fig. 4 Type and location of beaver field signs collected during our survey in Central Italy. Further road-kills were detected after this survey in Northern Latium (Pisciarello, Viterbo) and in Northern Umbria (Promano, Perugia: Turillazzi et al. 2024)



a)

b)

Fig. 5 **a**) areas of beaver activity across Central Italy, as defined by kernel density estimates. Black arrows highlight kit sightings; **b**) beaver activity across Italy using 10 km grid confidence. Cell colors indicate data reliability. green: high confidence, supported by (i) fresh or mixed beaver signs (ii), a confirmatory sign, and (iii) direct observation; orange: medium confidence, supported only by (i) and either (ii) or (iii); red: low confidence, where only (i) is recorded it is graded 1 or red, i.e., lower confidence

records (road-kills, direct observation, camera trapping) were though not supported by any further evidence of presence (e.g., gnawed tree trunks), strongly suggesting that - at least in some cases - these represent failed introduction or dispersal events, and thus do not indicate the actual stable occurrence of the species in such areas (Mori et al. 2021; Turillazzi et al. 2024). Moreover, recent reports from Southern Italian regions (Campania, Abruzzo, and Molise: Capobianco et al. 2023) suggest the potential occurrence of at least 3–4 individuals, yet whether such records represent novel illegal introduction events, or whether any individuals established in the area, is yet to be ascertained. Conversely, fresh signs of presence (trunk cutting and gnawing, burrowing) and camera-trapping confirmed the occurrence of two or three Eurasian beaver individuals at the border between Piedmont and Lombardy, between the Toce river and Lake Maggiore, where further monitoring is ongoing in order to ascertain the origin and spatial movements of this area of activity.

Fig. 6 Current distribution of the Eurasian beaver in Italy. Yellow squares are areas of activity. Purple lines show Italian regional borders

Despite the remarkable genetic similarity with Central and Southern European populations (Attili et al. 2023), the distance and the lack of presence signs for over 500 km between the main European populations and reproductive nuclei of Central Italy strongly suggest local unofficial releases rather than natural colonization (Pucci et al. 2021; Bertolino et al. 2023), as also confirmed by connectivity analyses (Falaschi et al. 2023; Serva et al. 2024a). Given the local high appreciation of beavers (Viviano et al. 2023), future monitoring should be recommended to ensure healthy and genetically viable populations with viable connectivity throughout the landscape (Treves et al. 2020, 2022; Serva et al. 2023a, 2024a).

Conclusions

Our work provided the first extensive beaver population survey across Italy, including both naturally expanding and probably introduced individuals. In addition to three southern regions (Capobianco et al. 2023), beavers are known to occur in at least four northern Italian regions (Friuli Venezia Giulia, Trentino-Alto Adige, and a small area

between Piedmont and Lombardy) and two central ones (Tuscany and Umbria), with single records from three other regions (Emilia Romagna, Marche, and Latium), suggesting a potential expansion (Falaschi et al. 2023; Serva et al. 2024a). The same method (KDE) could be applied to depict the distribution of other native and alien species, which are currently expanding their range in Italy (e.g., Boscherini et al. 2019; Cunze and Klimpel 2022; Mori et al. 2024; Shanefelt 2023; Serva et al. 2023b, 2024b).

Given the inclusion of *C. fiber* in the Annexes II and IV of the Habitats Directive, monitoring should be conducted adopting tried and tested management approaches from neighboring European countries to coexist with beavers, minimize potential management conflicts, and benefit from the ecosystem services/nature-based solutions that beavers can provide (Brazier et al. 2021). Besides the current position of Italian institutions suggesting that the illegally reintroduced Italian beavers should be culled timely (Bertolino et al. 2023), the comparable case from Spain – where beavers were as well illegally released in 2003 (Halley et al. 2021; Calderòn et al. 2022) - suggests a reasonable debate between protection and removal of beavers. In facts, the European Commission has expressed a favourable opinion on the presence of Eurasian beavers in Spain, thus discouraging removal actions, due to both the disadvantageous tradeoffs between expected costs and results of potential eradication campaigns, as well as to the historically native origins of the species in Mediterranean countries (Salari et al. 2020), and to its inclusion within Annexes II and IV of the Habitats Directive (Calderòn et al. 2022).

Finally, by applying a relatively simple and easily replicable methodological approach, we provide the first comprehensive assessment of the spatial distribution of *C. fiber* in Italy, combined with an approximated evaluation of population size - estimated to count at least 40 individuals - of the species, both key aspects required in case of either legal protection (e.g., for the reporting as required by art. 17 of the Habitats Directive) or management of the species in Italy.

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Author contributions EM, AV, RCP and RN conceived the study and wrote the first draft. RN and AP analyzed the data. EM, AV, FL, MS, LA, RP, AM, GM and GT collected field data. AV, RP, GT and FL organized the dataset. All authors participated in writing the MS and approved the final version.

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Data availability Datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Conflict of interest Authors declare no competing interests.

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