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Aliens in their native country: the case of the Alpine marmot *Marmota marmota* (Linnaeus, 1758) (Mammalia, Rodentia) in the Apennine ridge

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SUMMARY

The distribution of the Alpine marmot released in the Northern Apennines has been largely unstudied. In this note, we summarise the current distribution and the altitude range of the Alpine marmot in the Apennine ridge, 80 years after their first releases. We searched for marmot occurrence on the Apennines (i) on citizen-science platforms and (ii) through a webmail on Sciuridae distribution in Italy. We collected 80 marmot records validated by photos and by field investigations. We showed that Alpine marmots are present on over 70,000 ha in the Apennines, between Emilia Romagna and Tuscany. Most occurrences were recorded between 1600 and 1700 m a.s.l., in lines with other works on this species. Although the introduction of the Alpine marmot in the Apennines appears to have been successful, further molecular and ecological data are needed to assess origins and potential environmental impacts (e.g. on soil stability) of these established populations. This work may represent a description of the current status of this species, to be compared with future monitoring. In turn, updating the distribution of the Alpine marmot in the Apennines in the next years may be useful to assess potential distribution shift towards higher altitudes as a response to local climatic change.

INTRODUCTION

Mountain ecosystems include sensitive environments subject to wide seasonal variations, which require particular adaptations by the species they host (Monge and Leon-Velarde 1991; Inouye et al. 2000). Many mammalian species are shifting their altitudinal distribution towards higher elevations in most mountain environments (e.g., Badgley et al. 2018; Ye et al., 2018; Lovari et al. 2020; Semenzato et al. 2021), providing them with enough food (Stanisci et al. 2015; Evangelista et al. 2016). Therefore, assessing and updating the distribution of mountain mammals is particularly important for taxa adapted to live in altitude prairies, i.e. above the tree line. Given that the tree line is located higher and higher in altitude year by year because of climatic change (Smith et al. 2009), thus reducing prairie cover, prairie-dependent species should be much more sensitive to climatic change and more at risk of local extinction than other species (e.g., Pizzolotto et al. 2014; Lovari et al. 2020).

The Alpine marmot *Marmota marmota* (Linnaeus, 1758) is a large ground-dwelling squirrel (Rodentia, Sciuridae) currently present as a native species throughout the Alpine chain (*M. m. marmota*), Carpathians and Tatra mountains (subspecies *M. m. latirostris* Kratochvíl, 1961). These subspecies have only been defined through morphology, as no genetic analysis is available yet to confirm their reliability (Amori et al. 2011). Several isolated populations are the result of local introduction (i.e. those in the Pyrenees, Massif Central, Jura, Vosges and Apennines) and reintroduction (i.e. Eastern Alps) (Borgo 2003; López et al. 2010; Priori and Scaravelli 2011) events. This rodent is typical of alpine meadows and high-altitude prairies (Armitage 2000; Galluzzi et al. 2017), mostly placed on south-facing slopes at 1200-2800 m a.s.l., although occasionally found at lower and higher altitudes (range, 600-3600 m: Ferri et al. 1992; Armitage 2000). Marmots spend most of night time and all winter months in deep burrow systems, dug in alluvial soil or rocky areas (Pigozzi 1984). The distribution of the marmot in the Pyrenees is well-known (Herrero et al. 1994; Barrio et al. 2013), as well as that in the Alps and in Central Europe (Mitchell-Jones et al. 1999), whereas no updated information is available on its current status and distribution along the Apennine ridge. About 80 individuals of Alpine marmot have been released by the Italian Forestry State Body (CFS) and by private citizens in 16 Apennine localities between 1946 and 1987, and most of these releases were successful (Ferri et al. 1988; Sala et al. 1993, 1994; Tongiorgi et al. 1993). Anecdotal information reports that marmots were introduced to the Apennine ridge to provide the local population of golden eagle *Aquila chrysaethos* (Linnaeus, 1758) with a profitable prey, although we were not able to find any other reliable information explaining these releases. In the early 1990s, introduced marmot populations occurred through seven provinces (Alessandria, Parma, Reggio Emilia, Modena, Bologna, Pistoia and Lucca). Over 1800 den entrances were counted in the province of Modena (although no information is available on how many of them were actually occupied), at 1350-1750 m a.s.l., with a single individual observed at about 500 metres for at least two years (Ferri et al. 1992). Alpine marmots occurred in the Apennine ridge up to Pleistocene (Zimina and Gerasimov 1973), but not in historical times. Therefore, their presence in Apennine regions does not represent a reintroduction, but an actual introduction, also because individuals of both known subspecies (the Alpine one and the Carpathian one) were released in this area (Ferri et al. 1992).

No other study on the distribution of marmots in the Apennines has been published after Ferri et al. (1992). Keeping the knowledge on species distribution constantly updated is necessary for taxa inhabiting mountain peaks in the Apennines. Low mountain peaks (e.g. the Apennines) are reported to be particularly sensitive areas to climatic change (e.g. Smith et al. 2009; Lovari et al. 2020). Furthermore, being the Alpine marmot an introduced species

by humans in this area, its distribution is an essential start point for any management action. Therefore, in this note, we updated the distribution of the marmot in the Apennine ridge with georeferenced records.

MATERIALS AND METHODS

We collected georeferenced records of the Alpine marmot in the Apennine through citizen science projects (iNaturalist: https://www.inaturalist.org; Ornitho: https://www.ornitho.it) and through the "Save Red Squirrels" project, which involved the collection of Sciuridae photos through email (Mori and Menchetti 2014). Photos were validated by the authors and field investigations were carried out in 16 areas, i.e. for records reported with no photo attached. We determined the extent of occurrence of the Alpine marmot in the Apennines in the period 2010-2020, by using the Minimum Convex Polygon (MCP) encompassing all the records (Calenge 2006). The 95% kernel (Ker) method was also calculated, as a more accurate probabilistic estimate of space use (Worton 1989). MCP and Ker estimates were obtained with the software R 3.3.1 (R Core Team 2013), packages ade4 (Dray and Dufour 2007), and adehabitat (Calenge 2006). We also determined the altitudinal range of records of this species.

RESULTS

We collected a total of 80 confirmed observations by citizens to describe the range of the Alpine marmot in our study area (Figure 1; Supplementary Material). The range of the Alpine marmot in the Northern Apennines covers a MCP area of over 70,000 ha in 2010-2020 (47,359 ha for 95% Ker), encompassing three provinces in Tuscany (Massa Carrara, Lucca and Pistoia) and four in Emilia Romagna (Parma, Reggio Emilia, Modena and Bologna). No record from Piedmont (i.e. province of Alessandria) was recorded in our study period, suggesting that the populations originating from individuals released in this area in 1960-1961 may have become extinct (Ferri et al. 1992). Records of Alpine marmot were collected between 1205 and 2123 m a.s.l., with a peak between 1600 and 1700 m a.s.l. (Figure 2).

DISCUSSION

Our work showed that, eighty years after their first release, populations of Alpine marmots translocated to the Apennine ridge have established reproductive groups on 70,000 hectares covering all areas where they have been released apart from the South-Eastern Piedmont. The Alpine marmot is a territorial species living in family groups, showing a limited dispersal ability in such a low timescale (i.e. 80 years) (Walter 1990; Galluzzi et al. 2017), which may explain why a remarkable range expansion after introduction to the Apennines seems to have not occurred. The limited range expansion we recorded may also be due to the scarce habitat suitability of the Apennines for the species (Galluzzi et al. 2017). However, records from Massa Carrara province, where no information on local release is available (Ferri et al. 1992), suggest that some movements from release sites may have occurred. We are aware that collecting data through citizen science may underestimate species distribution (Tiago et al. 2017). However, the marmot is a diurnal, large-sized species, thus widely reported by citizen scientists (Tytar et al. 2017; Milanesi et al. 2020). Therefore, although we cannot rule out that a few further records may occur, we assumed that collected data were exhaustive to describe the distribution of the Alpine marmot in the Apennines.

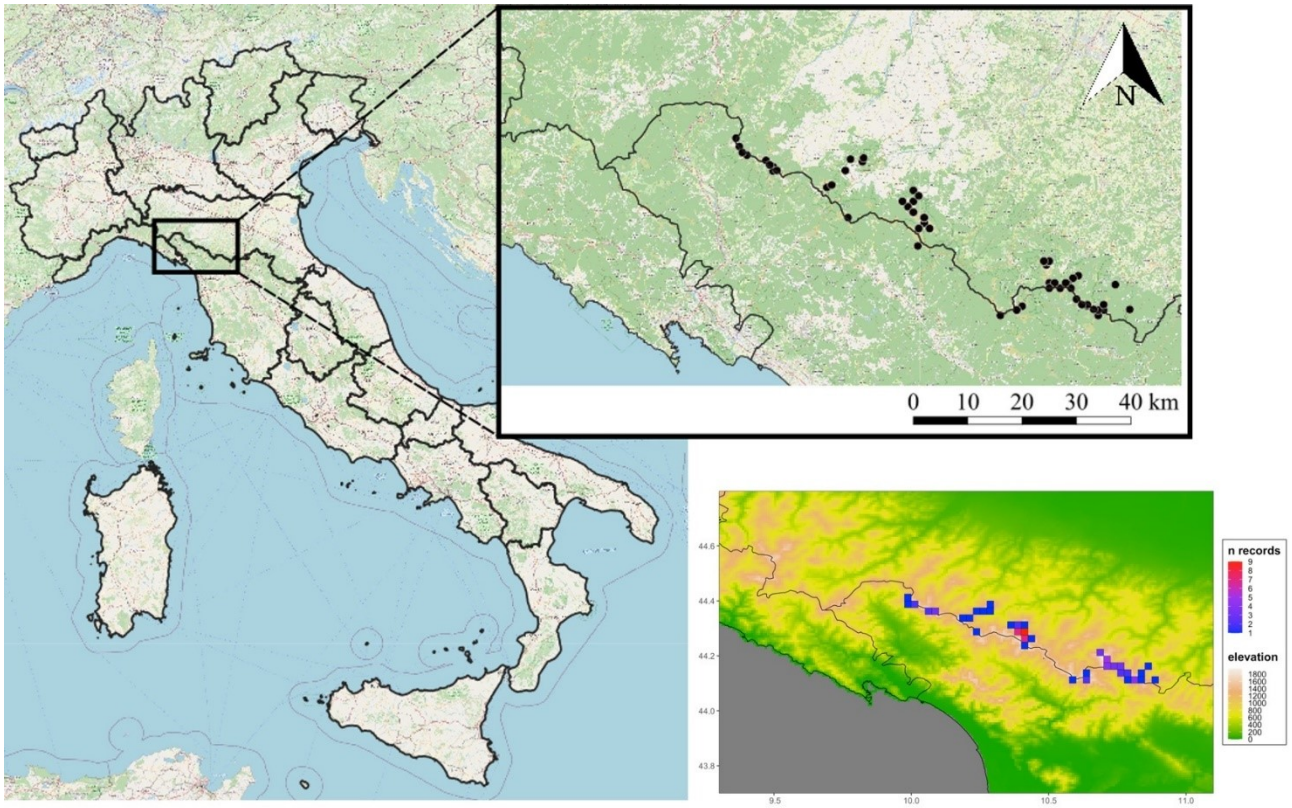

Figure 1. Distribution of the Alpine marmot in the Northern Apennines. Colour intensity of the squares in the heat map is related to the number of marmot records in the same area.

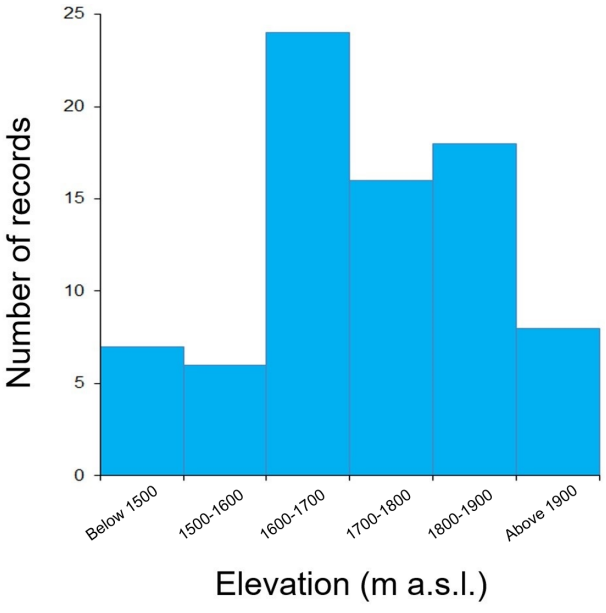

Figure 2. Altitudinal range of the Alpine marmot in the Apennine ridge in 2010-2021.

The Apennines represent the southernmost limit of the distribution of the Alpine marmot, i.e. potentially an area where the species faces the strongest ecological pressure. Marmots have been reported as sensitive species to climatic change, showing decreasing litter size and hibernation periods with increasing environmental temperatures (Herrero et al. 1994; Tafani et al. 2013; Rézouki et al. 2016; Gossmann et al. 2019; Armitage 2013; Cordes et al. 2020; Yoccoz 2020). If marmots reduce their hibernation period by some days, they may emerge from the den when environmental temperature could be suitable, but before food resources would be available (cf. Armitage 2013). Moreover, the reduction in snow cover limits the isolation of the den from cold environmental temperatures in winter, which may increase winter juvenile mortality by increased exposure to cold temperatures (Rézouki et al. 2016). Accordingly, Sala et al. (1997) recorded

population fluctuations in their long-term study on marmots in the Apennines. Given the habitat requirements by this species (i.e. open habitats: Galluzzi et al. 2017), a shift towards higher altitudes should be expected in the next 20 years, following the expansion of scrubland and forest habitats, unsuitable for the Alpine marmot, at altitudes where marmots currently occur. Records above 1900 m a.s.l. in our study area have been recorded since 2016 but never before, suggesting that movements towards higher altitudes may already have started. Unpublished observations made by one of the reviewers of this manuscript on the northern slope of Mount Cimone (Emilia Romagna) showed that, in the mid-1990s, stable and reproductive marmot nuclei were found starting from 1700 m a.s.l., whereas currently the species seems to have settled only over 1850-1900 m a.s.l. At high altitudes, substrate conditions are generally less suitable for burrowing as being mostly covered with screes. Conversely, at lower elevations (i.e., at 1700 m a.s.l.), over the last 25 years, a progressive contraction of the prairie-grassland coverage has been recorded, with the expansion of *Vaccinium* and other shrub species usually avoided by marmots.

The Apennines represent a particularly suitable area to study the effect of climatic change on mammal species, as being relatively old mountains with few peak above 2000 m in comparison to the Alps (cf. Barrio et al. 2013). Therefore, in these mountains, the effects of climatic change should be more rapidly evident than in the Alps. Particularly, changes in precipitation regimes would result in summer droughts, which strongly affect marmot survival (Armitage 2000). Moreover, the expansion in altitude of the tree line would reduce the availability of altitude prairies more rapidly than in the Alps, thus threatening the survival of the local population of Alpine marmot.

Although the marmot has been recorded in the Apennine ridge as a native species in the Late Pleistocene and Early Holocene, its presence in the Apennine ridge represents an actual introduction in an area where it was historically absent (Petronio et al. 2007). Information on the current abundance of Alpine marmots in the Apennines is not available and may require further research. Moreover, the role of the Alpine marmot as an ecosystem engineer should be evaluated in the Apennine ridge, including the environmental effect of burrow systems, as this information could provide pivotal insights for the management of this population and the conservation of mountain meadows.

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