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Research Article

Distribution of the brown bear (*Ursus arctos marsicanus*) in the Central Apennines, Italy, 2005–2014

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Abstract

Despite its critical conservation status, no formal estimate of the Apennine brown bear (*Ursus arctos marsicanus*) distribution has ever been attempted, nor a coordinated effort to compile and verify all recent occurrences has ever been ensured. We used 48331 verified bear location data collected by qualified personnel from 2005–2014 in the central Apennines, Italy, to estimate the current distribution of Apennine brown bears. Data sources included telemetry relocations, scats and DNA-verified hair samples, sightings, indirect signs of presence, photos from camera traps, and damage to properties. Using a grid-based zonal analysis to transform raw data density, we applied ordinary kriging and estimated a 4923 km^2 main bear distribution, encompassing the historical stronghold of the bear population, and including a smaller (1460 km^2) area of stable occupancy of reproducing female bears. National and Regional Parks cover 38.8% of the main bear distribution, plus an additional 19.5% encompassed by the Natura 2000 network alone. Despite some methodological and sampling problems related to spatial and temporal variation in sampling effort at the landscape scale, our approach provides an approximation of the current bear distribution that is suited to frequently update the distribution map. Future monitoring of this bear population would benefit from estimating detectability across a range of environmental and sampling variables, and from intensifying the collection of bear presence data in the peripheral portions of the distribution.

Introduction

Brown bears in the Apennines (*Ursus arctos marsicanus*) survive in a relict and isolated population that is considered critically endangered both at the European (Kaczensky et al., 2013) and the national (Rondinini et al., 2013) level. Although several authors during the past 20 years have retrospectively compiled historical records of bear presence (Febbo and Pellegrini, 1990; Bologna and Vigna Taglianti, 1992; Boscagli et al., 1995), no formal estimate of its distribution is as yet available (Ciucci and Boitani, 2008). This is unfortunate because in addition (or in alternative) to population abundance, a species' distribution provides clear indications of its conservation status (e.g., Harris and Pimm, 2008), and as such is currently contemplated within the IUCN criteria to assess threat categories (Mace et al., 2008).

Isolated from other brown bear populations in the Alps since at least 400–700 years (Randi et al., 1994; Lorenzini et al., 2004), brown bears spanned most of the Apennines in historic times (Carpaneto and Boitani, 2003). Although their distribution started to decline progressively in the 17th century, most of the range reduction likely took place over the past 200 years due to human persecution and changes in land use practices (Febbo and Pellegrini, 1990). Using compilations of historical and recent bear records (Febbo and Pellegrini, 1990; Boscagli et al., 1995; Posillico et al., 2004), Ciucci and Boitani (2008) delineated an approximate extent of occurrence, coarsely differentiating between a core and a peripheral range, the latter including a limited number of erratic bears, mostly males, of little contribution to the dynamics of the whole population. Stable occupancy by adult, reproducing females appeared to be restricted to the core portion of the range (Ciucci and Boitani, 2008).

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Despite long-time protection afforded by national and regional authorities to Apennine bears, and notwithstanding the availability of suitable habitat across a much larger area (Posillico et al., 2004; Falcucci et al., 2009), their distribution did not expand during the recent decades, nor have reproductive nuclei established outside the core. However, the expansion of the range in Apennine bears has long been recognized as a fundamental conservation requirement (Boscagli, 1999; Posillico et al., 2004; Ciucci and Boitani, 2008), based on which the success of any conservation strategy of this relict bear population should be assessed. Indeed, lack of range expansion in Apennine bears prompted renewed conservation efforts and the development of an improved, interregional strategy (Anonymous, 2011). However, the lack of a reliable distribution map to be used as a baseline hinders evaluating in due time the outcome of renewed conservation actions, and does not allow to inform management in areas of recent or imminent range expansion.

Methods to estimate the distribution of wildlife populations are susceptible to both sampling and analytical problems (Buckland and Elston, 1993; Burgman and Fox, 2003; Walker et al., 2008; Gaston and Fuller, 2009), and the task may prove particularly problematic for large carnivores that are elusive, span over large areas, and live at low densities (Thompson, 2004). However, in situations where location data are abundant and are collected according to several, complementary sampling methods, their accumulation over an extended period of time may offer the opportunity to estimate a species' distribution with reasonable accuracy. For example, distribution of the grizzly bear in the Greater Yellowstone Ecosystem has been repeatedly estimated in the last decades using telemetry locations, verified sightings of females with young, locations of bear damages, and bear fatalities (Basile, 1982; Blanchard et al., 1992; Schwartz et al., 2002, 2006; Bjornlie et al., 2014). Traditionally, the method most commonly used to delineate species distributions has been the minimum convex polygon, that is known to be particularly sensitive to outermost location data and susceptible to temporal and spatial variation of sampling effort (Burgman and Fox, 2003). Alternatively, Schwartz et al. (2002, 2006) overlaid fixed-density kernel utilization distributions developed for each source of data (i.e., telemetry locations, verified observations of females with cubs, mortalities, conflicts) to obtain an overall, composite estimate of the distribution of grizzly bears in the Yellowstone ecosystem. This method, however, can be computationally time-consuming and is not ideal for location data that are autocorrelated, such as those acquired through Global Positioning System telemetry (Bjornlie et al., 2014). Based on this, Bjornlie et al. (2014) used a grid-based method to analyze bear locations using ordinary kriging to generate distribution maps of grizzly bears. Kriging is a geostatistical technique that, using a semivariogram model to account for spatial autocorrelation among sample location data, produces a prediction surface over locations with unknown values (Johnston et al., 2001). This method proved less susceptible to differences in the density of location data from different data sources, and offered a more accurate representation of the outer boundaries of the distribution (Bjornlie et al., 2014).

Since the mid 2000s, a renewed attention to the Apennine bear population led to enhanced research and monitoring activity both within the core (Gervasi et al., 2008, 2012; Ciucci et al., 2015a,b) and the peripheral portions of the range (PRSV, 2007; Forconi and Dell'Orso, 2008; Carotenuto et al., 2014; Giangregorio et al., 2014; van Gils et al., 2014). Coupled with the development of noninvasive genetic sampling (Woods et al., 1999), and the widespread adoption of camera trapping (Burton et al., 2015), bear location data collected across the Apennines has been rapidly accumulating.

As formal estimates of the Apennine bear distribution are of critical importance to assess its future dynamics, we followed the approach by Bjornlie et al. (2014) to estimate the distribution of this bear population using verified location data from 2005–2014. In particular, the aims of this work were: (i) to provide a first, formal estimation of the distribution of the Apennine brown bear, both at the population level and separately for adult, reproducing females; (ii) to define a standard protocol to filter and analyze all data available on bear presence to more frequently estimate and update its distribution, and (iii) to discuss the implications of the extent and configuration of the estimated distribution for the conservation of this imperiled bear population.

Materials and methods

Study area

Our 9941 km^2 study area is located in the central Apennines, Italy, in the area where brown bears have been recorded during the last decades (Falcucci et al., 2009). The area is mainly mountainous, with rough topography and elevation up to 2912 m a.s.l. Forests, mostly composed by beech (*Fagus sylvatica*) above 1000 m, cover about 44.6% of the study area, followed by open areas (26%), cultivated areas (18%), and shrubland (10.4%). The climate in the area is Mediterranean montane, with dry summers and cold, snowy winters (Piovesan et al., 2003). At the township level, human density averages 56.4 ($\pm$83.5 SD) people/km^2 (Istat, 2001), and road density averages 1.16 ($\pm$0.67 SD) and 0.50 ($\pm$0.41 SD) km/km^2 for paved and dirt roads, respectively (De Agostini-GeoNext and TeleAtlas road layers, updated to 2003). The study area spans over 5 regional administrations, and hosts several protected areas, among which 4 National and 3 Regional parks, for a total of 4422 km^2 (42.5% of the study area). The Natura 2000 network, as provided by the Italian Ministry of the Environment under the EU Habitats Directive and the Birds Directive, covers about 55.7% of the area, including 134 Special Areas of Conservation and 75 Special Protection Areas. In addition to bears, other large carnivores in the area include wolves (*Canis lupus*), locally reaching densities of 5–6 wolves/100km^2 (Molnar et al., 2015). The bear in Italy has been protected since 1939, whereas the Abruzzo Lazio and Molise National Park (PNALM) has been established since 1923 representing the main historical stronghold of the Apennine brown bear. Verified damages by bears to livestock, poultry, apiaries and crops are compensated by Park Authorities within National and Regional Parks and by Regional governments elsewhere. In 2014, 50 (95% CI: 45–69) bears of all ages have been estimated in the core portion of the range (Ciucci et al., 2015a). During the last decade, a cumulative total of 12 bears have been noninvasively detected in the peripheral portion of the range, including some comprised in the core population (Carotenuto et al., 2014; Giangregorio et al., 2014), although little is known about their fate.

Data sources

Under the provisions of the Ministry of the Environment, we held two workshops in February and April 2015 with researchers, technicians and managers from the agencies that had been involved in monitoring bear presence over the last decade in the central Apennines. Representatives from areas with no recent bear presence but comprised in the historical range of the species (Febbo and Pellegrini, 1990) were also involved. The aim of the first workshop was to define common criteria to ensure reliability of bear presence data, according to which we adopted quality rules to filter single datasets and integrate them into a combined dataset of verified bear presence across the entire central Apennines. In the second workshop we gathered and assembled all available data and ran the analyses. Bear location data from the core portion of the range were generated by a telemetry project conducted in the PNALM from 2005–2010, and a subsequent population monitoring project (Ciucci et al., 2015a,b); these included both VHF- and GPS-locations of 26 bears, as well as sightings and indirect signs of presence (i.e., scats, hair tufts, tracks) collected by qualified research and agency personnel. From these data, to delineate the stable area of occupancy of reproducing female bears, we: (a) filtered VHF- and GPS-locations, as well as DNA-identified (i.e., multilocus genotypes; Ciucci et al., 2015a) hair samples of 7 marked adult female bears known to have produced cubs at least once during 2005–2010, and (b) added all sightings of family groups (i.e., females with cubs and females with yearlings) systematically tallied each year from 2006 to 2014 (Tosoni et al., in press) using standard field procedures (Knight et al., 1995; Keating et al., 2002). We also compiled the few indications of family groups available from the peripheral portion of the range, although these were treated separately as extremely rare and isolated. Bear location data collected or

verified by experienced agency personnel in the peripheral portion of the range comprised VHF locations, direct observations, video clips and/or photo obtained from camera traps, DNA-identified hair samples, scats and other signs of presence, as well as verified damages to human property. Where local bear density made it practical, several agencies adopted noninvasive genetic sampling according to systematic (Woods et al., 1999) and/or opportunistic (Gervasi et al., 2008; De Barba et al., 2010) sampling, locally coupled by opportunistic camera trapping. We did not consider unconfirmed signs of bear presence, including reports that were not verified by experienced personnel, or those whose identification may be subjective or equivocal (e.g., foraging and feeding signs, rolled stones, damaged trees). We also did not consider locations of natural or human-induced bear fatalities (Falcucci et al., 2009).

As sampling effort and distribution varied markedly over time, especially in the peripheral portion of the range, we pooled the data over a 10-year period, reflecting approximate generation time in brown bears (Harris and Allendorf, 1989).

Spatial analyses

We set up a 3 km×3 km grid over the area containing all verified bear locations. Grid cell size was based on mean daily distance travelled by 18 GPS-collared adult bears in the PNALM ($\bar{x}$=2672±1406 SD m; P. Ciucci unpubl. data). To mitigate the effects of the heterogeneity in distribution and effort of sampling, we transformed the raw bear location data by performing a zonal analysis (Bjornlie et al., 2014). We assigned a value of 1 to all grid cells containing ⩾1 observation and 0 to all unoccupied cells and, for each cell, we summed the value of the cell and of the 8 adjacent cells. Therefore, each cell had a value potentially ranging from 0 to 9. After assigning the zonal sum of each cell to its centroid, we used ordinary kriging to develop a predictive surface, including in the range only areas with predicted values ⩾1.0 (Bjornlie et al., 2014). The parameters of the semivariogram were chosen using a jackknife procedure in which one point at time was left out of the analyses and compared to the predicted value. Model goodness was evaluated considering the root mean square error (RMSE). All analyses were performed in the Geostatistical Analyst extension (Johnston et al., 2001) available in ArcGIS 10.3.1 (ESRI ©).

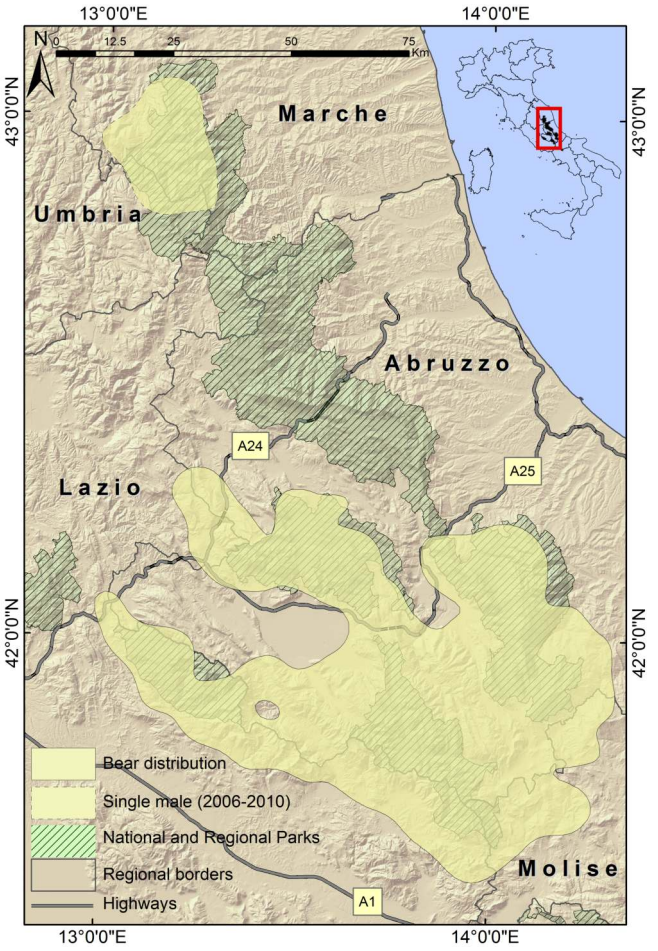

Figure 1 – Brown bear distribution in the Central Apennines, Italy, 2005–2014, estimated using zonal analysis of 48331 verified location data from multiple sources and ordinary kriging.

Results

From 2005–2014, out of 49751 bear location data assembled across the entire central Apennines range, we discarded 2.85% (n=1418) due to missing information, coding errors, non-validated records, or because they referred to equivocal signs of presence. We therefore used for the analyses 48331 verified bear location data that covered 325 grid cells (2925 km^2); these included telemetry relocations (86%), scats and DNA-verified hair samples (11.3%), sightings (1.1%), indirect signs of presence (1.1%), photos from camera traps (0.3%), and damage to properties (0.3%), both from the central and the peripheral portions of the range (Tab. 1). In particular, verified locations data referred to reproducing female bears were 22828 that covered 103 grid cells (927 km^2), essentially comprising telemetry relocations (98%) followed by direct observations (1.4%) and genetically verified hair samples (0.5%; Tab. 2). For both datasets, the Stable model fit the empirical semivariogram best (bear distribution: nugget=0, sill=3.5, range=19.6 km; distribution of reproducing females: nugget=0, sill=1.25, range=18.0 km). According to the kriging surface produced with all bear location data, we estimated a range of 5422 km^2 across the central Apennines (Fig. 1). This is disjunct in a major, southern portion (4923 km^2, 90.8% of the estimated distribution), largely overlapping with the historical stronghold of the species over the last decades (main distribution), and a smaller one (499 km^2; 9.2% of the estimated distribution), at about 55 km north, exclusively frequented by an adult male from 2006–2010. Reproducing female bears occupy an area of 1460 km^2 that is entirely nested within the main bear distribution (Fig. 2). Both the main distribution and the distribution of reproducing females encompass 3 regions, 5 including the disjunct northern portion. Protected areas, limited to National and Regional Parks, cover 38.8% of the main distribution and 34.7% of that of reproductive female bears. The Natura 2000 network covers 57.1% of the main distribution (Tab. 3, Fig. S1) and, even though the Natura 2000 considerably overlaps to the other protected areas (i.e., National and Regional parks), it contributes with additional 953.5 km^2 otherwise not covered by any protected area, thus increasing to 58.3% the proportion of the bear distribution theoretically secured. Similarly, the Natura 2000 network covers 55.6% of the reproductive female bears' distribution (Tab. 3, Fig. S1), contributing with additional 350 km^2 and increasing to 58.7% the proportion of protected female bears' range.

Discussion

Our analysis depicts for the first time the distribution of brown bear in the Apennines using a large dataset of verified location data from 2005–2014. Our distribution map provides immediate and practical indications both for planning and evaluating conservation management, especially if contrasted with the habitat suitability and connectivity projected at a landscape scale (Posillico et al., 2004; Falcucci et al., 2009; Maiorano et al., 2015, 2017).

Theoretically, a species' range should be described as the area where populations show positive growth rates (i.e., $\lambda \geqslant 1$; Krebs, 2001). However, for the scope of our analysis, we referred to an area of stable bear presence irrespective of population performance (see below). Nevertheless, the sampling strategies we adopted to collect bear location data are far from being ideal. Whereas in the core portion of the range we adopted intensive and systematic sampling schemes, in the peripheral areas location data were collected opportunistically and only when indirect evidence of bear presence justified the adoption of more intensive sampling. Accordingly, raw presence-only data in these areas may suffer from relevant spatial and temporal variability in sampling effort (Burgman and Fox, 2003). However, by transforming raw location

Figure 2 – Distribution of female bears producing cubs in the central Apennines, Italy, 2005–2014, estimated using zonal analysis of 22828 verified location data from multiple sources and ordinary kriging. Location data refer to sightings of bear family groups (2005–2014), telemetry, and non invasive genetic relocations of 7 marked females known to have produce cubs from 2005–2010. Four additional sightings of females with cubs have been reported outside the estimated range, including one from the Majella National Park (November 2014; star symbol), and three from the Sirente Velino Regional Park (2007 and 2013, asterisks), that was not possible to fully validate due to lack of additional information.

data using the zonal analysis we mitigated the marked heterogeneity in the amount of data originating from different sampling methods and effort, so that individual bears and zones across the study area contributed comparably to the final dataset. In addition, even though we did not formally account for imperfect detection (MacKenzie et al., 2006), we reduced the chance of false negatives in our sample by combining complementary sampling methods over a long time frame, hence increasing the probability of detection of resident bears and enhancing the sampling coverage. Moreover, by pooling data across a 10-year period we unlikely missed areas of stable occupancy within the main bear distribution, that otherwise would have been overlooked had we partitioned the study period in shorter time intervals. Given the relatively high human density in the central Apennines we also believe that bear presence would unlikely go unnoticed in the long term, especially if all reported indications of bear occurrence are promptly verified. Nevertheless, we recognize that the distribution we estimated, especially with regard to the stable area of occupancy of reproducing female bears, should be interpreted as a minimum area of occupancy rather than an extent of occurrence (Bjornlie et al., 2014).

Table 2 – Verified locations (n=22828) of reproductive female bears and family groups collected in the core distribution of the Apennine brown bear, central Italy, 2005–2014.

Type of location data	Sampling period		Sample size
	From	to	
VHF-locations[1]	2 April 2005	22 Dec 2005	121
GPS-locations[2]	25 May 2006	16 Nov 2010	22268
Hair samples[3]	17 July 2005	23 July 2011	116
Sightings (FWC)	26 Apr 2006	26 Sept 2014	323

[1] 1 adult female bear.
[2] 7 adult female bears.
[3] DNA-identified hair samples belonging to 7 female bears known to have reproduced at least once during 2005–2010.

Table 1 – Verified bear locations (n=48331), distinguished by type, sampling period and portion of the range, used to estimate the distribution of the bear population in the Apennines, central Italy, 2005–2014.

Agency	Sampling period	Portion of the range	Hair tufts/scats	Other signs of presence	Sightings	Damages to property	Clips/photos	VHF locations	GPS locations	Total locations
University of Rome/PNALM[1]	2005–2014	core	4087	-	323	-	-	1014[2]	40532[3]	45956
PNALM[1]	2006–2011	core	890	360	-	-	-	-	-	1250[4]
Monte Genzana-Alto Gizio Nature Reserve	2010–2014	core	71	10	96	58	43	-	-	278
Gole Sagittario Nature Reserve	2010–2013	core	1	2	17	-	12	-	-	32
Majella National Park	2006–2014	core/peripheral	107	49	51	66	58	7	-	338
National Forestry Service	2005–2014	core/peripheral	14	3	12	12	-	-	-	41
Bear monitoring network (Lazio Region)	2005–2014	peripheral	166	34	9	1	-	-	-	210
Sirente-Velino Regional Park	2005–2014	peripheral	10	8	8	4	-	-	-	30
Gran Sasso-Laga National Park	2005–2014	peripheral	-	1	-	-	-	-	-	1
Sibillini National Park	2006–2010	peripheral	99	65	-	17	14	-	-	195
Total	2005–2014		5445	532	516	158	127	1021	40532	48331

[1] Abruzzo Lazio and Molise National Park.
[2] 26 bears (12 adult females, 9 adult males, 1 subadult male, 4 cubs).
[3] 18 adult bears (11 females, 7 males).
[4] excluding sightings and foraging signs.

Table 3 – Extent, by jurisdiction, of the brown bear main distribution and the area of stable occupancy by reproductive females (central Apennines, Italy, 2005–2014). The distribution has been estimated by grid-based ordinary kriging using bear location data obtained by complementary sampling strategies.

Jurisdiction	Main bear distribution		Reproductive female bears' stable area of occupancy	
	Area (km^2)	%	Area (km^2)	%
Abruzzo Region	3331	67.7	953	65.3
Lazio Region	1170	23.8	367	25.1
Molise	422	8.6	140	9.6
Umbria	-	-	-	-
Marche	-	-	-	-
National Parks	1163	23.7	507	34.9
Regional Parks	745	15.1	-	-
Other protected areas[1]	85	1.7	28	1.9
Natura 2000	2810	57.1	813	55.7

[1] including national and regional nature reserves.

By pooling data across a 10-year period, our analysis lacked the temporal resolution to detect year-to-year variations in the distribution. Unless systematic sampling accounting for imperfect detectability is used over shorter time frames (i.e., each year of every two years), short-term dynamics in occupancy patterns would be confounded by sampling variability (MacKenzie et al., 2006). Nevertheless, ad hoc intensive local monitoring allowed us to detect the temporary nature of range extensions, even though these were included in the kriging prediction surface. For instance, intensive monitoring allowed us to confirm that the northern section of the distribution (Fig. 1), continuously occupied by a single male bear (G70) from 2006–2010 (Forconi et al., 2014), has most likely never been occupied by bears afterwards. Although bears are typically elusive and difficult to detect at very low density, intensive monitoring conducted locally after G70's leaving, coupled with isolated but widespread human settlements, make any unnoticed bear presence in the area a very unlikely event.

Monitoring bear presence through a network allowed us to confirm that G70 permanently moved about 80 km south, where he was sampled in 2010 and 2012 and eventually died suspectedly from Aujeszki's disease (Forconi et al., 2014; L. Gentile personal communication 2014). Although currently not included in the main bear distribution, the temporarily used northern portion of the range confirms the occurrence of habitat suitability and landscape connectivity outside the main bear distribution. This and similar areas, identified through projections of habitat suitability (e.g., Falcucci et al., 2009), are the first that we would expect to be steadily re-colonized by Apennine bears should a few females be able to disperse, survive, and successfully reproduce locally.

The main bear distribution we depicted (Fig. 1) does not appear significantly larger compared to the informal representations of the species' extent of occurrence of previous decades (Febbo and Pellegrini, 1990; Boscagli et al., 1995; Ciucci and Boitani, 2008). Although the lack of a formal estimation approach in the past precludes any meaningful comparison, this tends to suggest that the area of occupancy of Apennine brown bears has been relatively stable in the past decades. While this is clearly related to the overall bear population dynamics, we suspect this is mostly due to the lack of consistent reproduction outside the stable area of occupancy of adult, reproducing female bears. Based on intensive GPS-tracking and noninvasive sampling of reproducing females, coupled with annual counts of bear family groups extended to public participation (Tosoni et al., in press), the distribution of reproducing female bears that we depicted represents the only area, within the main bear distribution, where most reproducing females occur and reproduce annually, approximating what has been previously referred to as the core bear distribution (Ciucci and Boitani, 2008). Although small, this area features a rather high population density (Ciucci et al., 2015b), and might act as a source from where young bears disperse into the peripheral areas of the main distribution. Due to their marked philopatry, dispersion in female bears is much less pronounced than in males (Swenson et al., 1998; Støen et al., 2005), and even though few female genotypes have been noninvasively sampled outside the core female range, most of the bear records in these areas are from males, most probably young, dispersing bears (Carotenuto et al., 2014). Remarkably, 1–4 anecdotal reports of females with cubs do exist outside the reproductive females' distribution map (Fig. 2): one verified as recently as November 2014 in the Majella National Park (A. Antonucci personal communication 2014), the other three recorded in 2007 and 2013 in the Sirente-Velino Regional Park, even though these could not be verified according to the criteria we used to combine location data (P. Morini personal communication 2015). Nevertheless, taken together, these reports indicate that female bears are able to disperse from their core distribution, though the rate of this process and the survival of dispersing female bears ad their cubs needs additional investigation. Although no information is available on the survivorship and reproductive performance of bears dispersing from the core distribution, we suspect these are quite low. In addition to a few anecdotal cases (e.g., Forconi et al., 2014), the apparent lack of range expansion, the widespread occurrence of ecological traps (Falcucci et al., 2009), and the recorded levels of human-caused mortality (L. Gentile personal communication 2014) are all consistent with a rather high mortality of bears dispersing outside the core distribution.

Once again our results underline the precarious status of Apennine bears, with an isolated population of small size and a particularly restricted distribution of reproducing females. Despite the female bears' limited distribution, current productivity in the core population seems compatible with population growth (Tosoni et al., in press), and habitat suitability and connectivity do not seem limiting at the landscape scale (Posillico et al., 2004; Falcucci et al., 2009). Under intensive management and effective protection, other small and isolated brown bear populations have proven capable of expanding their range over the long term (e.g., Cantabrian bears in Spain: Gonzalez et al., 2016). The protected bear population in the Yellowstone ecosystem has expanded its range at an exponential rate since 1940, doubling the extent of occurrence roughly every 20 years (Pyare et al., 2004). Although a formal investigation of factors limiting population growth has not been conducted, we suspect that lack of range expansion in Apennine bears is largely due to the human-induced mortality, both in the core and the peripheral distribution (Falcucci et al., 2009), coupled with the tendency of phylopatric females to remain close to their mothers' home range. In a densely populated country such as Italy, human-bear conflicts can be substantial and yet difficult to mitigate due to cultural and social resistance, especially outside the historical strongholds of the species where attitudes are generally positive and tolerance toward bears is notably high (Glickmann et al., 2012). Monitoring the fate of bears dispersing outside the core distribution, and understanding conditions and causes of their mortality, are necessary to plan and adapt conflict management to local conditions. In particular, more monitoring and conservation efforts should be ensured to dispersing bears, especially in the case of females or family groups detected outside the core range (Gibeau et al., 2002).

Our distribution map, especially through comparison with habitat suitability projections (Falcucci et al., 2009), facilitates managers and administrations to pre-emptively implement conflict management in the peripheral areas of the bear distribution, as well as where the species is not present yet but may likely expand in the near future. The relevant share of protected areas within and outside the main bear distribution across the central Apennines (Fig. 1) facilitates protection of this bear population, an opportunity further enhanced by the widespread occurrence of Natura 2000 sites (Fig. S1). At least in these areas, bear conservation has to be definitively ensured priority over multiple-use by humans, and habitat interventions and forestry practices planned in view of the long-term availability of high-quality, natural foods for bears (Ciucci et al., 2014).

Our approach based on multiple data sources, zonal analysis, and ordinary kriging seems particularly suited to update the bear distribution more frequently (i.e., every 2–3 years), and this is instrumental to monitor and evaluate the success of management and conservation actions toward the goal of population expansion. To this aim we recommend that existing networks and initiatives to monitor bear presence be

consolidated, and that more formal sampling strategies be adopted to model presence and absence of the species throughout the range. In particular, the long-term monitoring of this bear population would benefit from the estimation of occupancy dynamics, including modelling the effect of environmental and sampling covariates on the probability of occupancy accounting for imperfect detectability (MacKenzie and Royle, 2005).

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Supplemental information

Additional Supplemental Information may be found in the online version of this article:

Figure S1 Main brown bear distribution in the Central Apennines, Italy, overlaid to the Natura 2000 network.