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ORIGINAL ARTICLE

Spatial and temporal dynamics of wild boars *Sus scrofa* hunted in Alpine environment

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Abstract

This study evaluated the trend and spatial distribution of wild boar population harvested in the Alpine hunting district C.A. CN1 (Piedmont, Italy) from 1996 to 2018, and its relation with hunting effort. Protected areas were found to shape the distribution of the harvested wild boars, which decreased in number as the distance from those zones increased. The hunting bag data presented large yearly fluctuation, with a trend in line with the hunting effort until 2007 when the maximum capacity of the population to cope with the hunting pressure was reached. The variation of reproductive parameters (percentage of piglets in the hunted population and piglets to sexually matured female ratio) showed a decreasing trend in both time series. Conversely, hunting effort increased over the years, with significant trend changes in 2000 and 2015, probably associated with the increased preference for hunting activity on wild boars, and the parallel reduction of the extension of hunting areas. Predation, hunting activity, and environment could have modulated the wild boar population dynamics in the study area. Decrease in chestnut *Castanea sativa* production, due to the gall wasp *Dryocosmus kuriphilus* Yasumatsu, were reported during the period of study. This might be the main factor determining the downtrend of piglets in 2003. In addition, predation by wolves *Canis lupus*, whose population has sharply increased in the southwestern Alps in the last decades, might have contributed to the decline since 2010. This work outlines the importance of a proper management of protected areas, which influence the density and distribution of wild boars. In this context, hunting bags analysis is of pivotal importance to monitor population dynamics and develop proper wildlife policies.

Keywords *Sus scrofa* · Hunting bags · Population structure · Spatial analysis · Temporal analysis · Italian Alps

Introduction

Wild boar *Sus scrofa* occupies one of the widest geographic ranges among mammals (Massei and Genov 2004). Since 1980, wild boar population has notably increased in Europe causing numerous economic, environmental, and social problems (Tack 2018). The specialization and intensification of agricultural activities led to the abandonment of marginal areas, allowing the expansion of the species (Amici et al. 2018). Other factors affecting wild boar abundance were climatic changes and a decrease of hunting practices. In particular, higher winter and spring temperatures improved food availability and reduced piglets mortality rate (Geisser and Reyer 2005).

In rural areas, wild boars have a high socio-economic importance. Hunting practices can provide supplementary income and, in some countries, make a significant contribution to the game-meat industry (Bodnár and Bodnár 2014).

Hunting or car accidents are the main cause of wild boar mortality (Keuling et al. 2013; Toïgo et al. 2008; Gamelon et al. 2011; Šprem et al. 2013; Morelle et al. 2013; Prevot and Licoppe 2013). However, the species showed to be able to adapt to hunting pressure by increasing the proportion of juveniles that reproduce early (Gamelon et al. 2011). Other causes of mortality include diseases, starvation, and predation (Okarma et al. 1995; J drzejewski et al. 1992; Nores et al. 2009; Rossi et al. 2011; Prevot and Licoppe 2013).

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The recent uptrend of wild boar population raised public health concerns due to the increased chances of exposure to domestic animals and humans. In fact, wild boars serve as reservoirs for many important infectious diseases in domestic animals and humans (Meng et al. 2009). Moreover, the increase of wild boar population was associated with enormous crop damages (Herrero et al. 2006). In Italy, it was estimated that wild boar is responsible alone for 90% of losses caused by ungulates to agriculture (Apollonio et al. 2010).

In the Western Alps at the end of the nineteenth century, wild boar was absent (Apollonio et al. 1988). In 1919, the species recolonized Piedmont coming from France (De Beaux and Festa 1927). Since that date, wild boar was also illegally reintroduced in the whole country for hunting practices (Apollonio 2004).

In the Alpine hunting district C.A. CN1 (Cuneo province, Piedmont, Italy), wild boar is the main big game species and it is exposed to an intensive hunting pressure during the whole hunting season (from September to December). It is is mainly hunted with drive hunts method, carried out by hunting teams with several dogs. This does not always allow to make an assessment and choose which animal to shoot (Scillitani et al. 2010).

Considering that protected areas, where hunting is not allowed, have shown to play an important role in the overabundance of wild boar (Santilli and Varuzza 2013), one of the objectives of the present study is to investigate how the number and distribution of the harvested wild boars is related to the presence of suitable protected areas. Moreover, as wild boar might undergo large, rapid population fluctuations (Bieber and Ruf 2005), possible sources of temporal variation were investigated.

To our knowledge, this is also the first study evaluating the temporal and spatial patterns of hunted wild boars in the Italian Alps. Specifically, we used data collected from 1996 to 2018 in the hunting district C.A. CN1 to evaluate (1) the relationship between the number of harvested animals and the distance from the ZRC, (2) changes in the hunted population structure considering the age and the piglet to sexually matured female ratio (as a proxy of reproductive index), and (3) whether the hunting effort has changed through the years. The results of this study must be interpreted in terms of management implications.

Materials and methods

Study area

The study was carried out in the Alpine hunting district C.A. CN1 (44°40′48.4″N 7°15′33.6″E), which is located in the Po Valley in Cuneo province (Piedmont, Italy) (Fig. 1). This area covers a total of 383.07 km^2. The climate varies from cool-temperate to cold. The average annual rainfall is between 1000 and 2000 mm. Due to the absence of constant winds, the humidity is always high also during summer. The valley is characterized by a prevalence of broad-leaved forests, with chestnut *Castanea sativa* as predominant species, whereas coniferous forests are marginally represented, including larch trees *Larix decidua* and Arolla pines *Pinus cembra*. The open areas are essentially grasslands, pastures, and rocks. There are also annual crops, mainly located in the floor of the valley (Comprensorio alpino CN1—Valle Po 2014).

By law, hunting is not allowed in some areas. These include the Natural Park of Monviso and protected areas, used to re-introduce and restock wildlife populations (called "ZRC"). The ZRC might be subjected to changes according to 5-year wildlife management plans. In this district, the big game species are the wild boar (mainly hunted with dogs), chamois *Rupicapra rupicapra*, roe deer *Capreolus capreolus*, and red deer *Cervus elaphus*, which are hunted only by stalking with rifles. Contrary to other Alpine hunting districts where the most common game species are chamois, roe deer, and red deer, wild boar is the most abundant hunted species in the C.A. CN1 (e.g., hunting bags for ungulates in 2018 are structured as follows—276 wild boars, 10 chamois, 40 roe deer, and 31 red deer). The hunting season lasts 3 months for wild boars (October to December) and 2 months (60 days) for all other ungulates. According to the regional law (D.G.R. N° 94-3804 2012), there are official prescriptions related to the proportion of heads, sex, and age structure of wild ungulates hunted. However, this is not applied to wild boars whose shooting plans do not include any hunting quota, as well as no assignment of specific hunting areas. In other words, this means that the hunting pressure of wild boar is homogenously distributed in the district.

Data collection

Records of 6582 harvested wild boars were retrieved from the hunting district database. Data were gathered for hunting seasons from 1996 to 2018. Information about sex, age (estimated by the wildlife technician according to chronology of teeth eruption; Osservatorio regionale sulla fauna selvatica 2007) and geographical coordinates (WGS 84/UTM zone 32 N) of hunted wild boars were used. Records on yearly number of hunted wild boars, hunters, huntable area (km^2), and hunting days per year (number of days for which hunting activity was reported) were retrieved as well.

Spatial dataset on protected areas was used. The spatial analysis took into consideration only the ZRC, as they are characterized by a woody and suitable habitat for wild boar populations. The other protected area (Natural Park of Monviso) was not considered, as its main land use type is

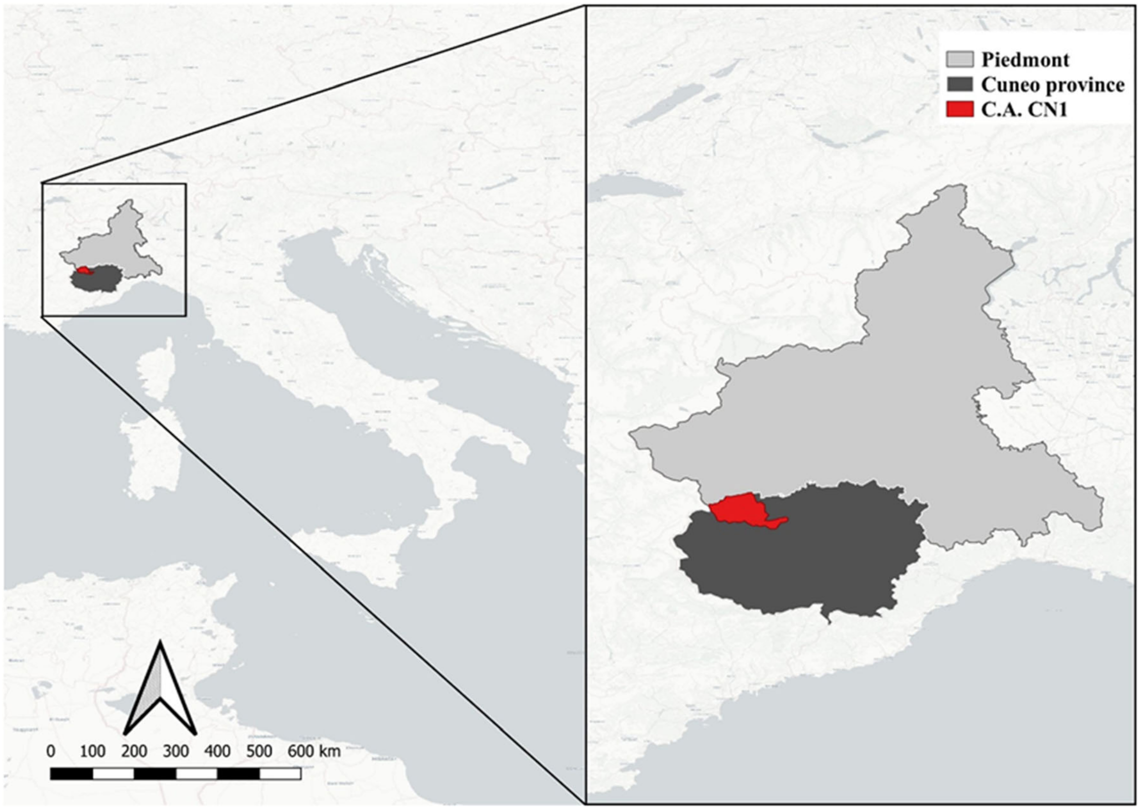

Fig. 1 Map showing the study area: the hunting district C.A. CN1, located in Cuneo province in Piedmont region (North-Western Italy). The hunting district C.A. CN1 coincides with the Po Valley

constituted of rocky area and open meadows, not suitable for the stable presence of wild boar.

Methods

Spatial distribution of hunted wild boars in presence of protected areas

Georeferenced data on the wild boars harvested and the shapefiles of the ZRC were introduced in QGIS 3.6.0 (QGIS Development Team 2017). To facilitate a semi-quantitative visualization of the information, two heatmaps were built. In doing that, changes of the ZRC according to the wildlife monitoring plan were considered.

Distance from the protected areas was computed using the geoprocessing tool "Distance to nearest hub." A Kernel density of the hunted animals over the computed distances was estimated and plotted. Afterwards, a linear regression was used to model the relationship between the number of hunted wild boars and the distance from the ZRC.

The same analysis was repeated with only the points falling in wood areas due to their influence on the distribution of the species. This was done to normalize the distance analysis with points sharing the same habitat condition and to remove the potential bias related to distribution of area suitable for wild boar. To do that, land cover use shapefile produced by Piedmont Region was used (http://www.geoportale.piemonte.it/cms/).

Hunting data dynamics

Animals were grouped in three classes: piglets—under 8 months old; subadult—between 8 and 14 months old; adults—older than 14 months. To assess the age–sex structure of the hunted population, the population pyramids was built.

The dynamics of hunted wild boars were investigated using several statistical analyses. First, hunting bag data were plotted along with its trend. Then, we carried out time-series of (1) the percentage of piglets in the hunted population (as an index of age structure), (2) the ratio of piglets to sexually matured females (as a proxy of reproductive index), and (3) the hunting effort. The hunting effort was defined as the yearly number of hunters per square kilometer multiplied by the number of hunting days (Vajas et al. 2020, modified).

Each time series was formatted into a time-series object using the ts () function in R software 3.5.2 (R Core Team 2018). Sen's method was used to determine whether there was a positive or negative trend in the data with statistical significance. Breaks in time series were estimated implementing breakpoints () function in the strucchange package (Bai and Perron 2003; Zeileis et al. 2003).

Results

Spatial distribution of hunted wild boars in relation to the ZRC

Figure 2 shows the density of the harvested wild boars in relation to the ZRC distribution for the period 1996–2015 and 2016–2018. Higher densities are represented with darker colors. Major density is consistently located very close to the protected areas, indicating their role as reservoir for wild boar population.

Figure 3 shows the Kernel density plot of the wild boars harvested over the distance from the ZRC. The shape of the distribution is skewed to the left. The maximum distance at which wild boar was shot was 16 km. Thirty-eight percent of wild boars were harvested at a distance lower than 3.5 km.

The linear model shows a strong negative relationship between the distance from the ZRC and the number of hunted wild boars ($\beta = -0.03$, $p = 0.0003$, adjusted $R^2 = 0.33$). The same trend is confirmed in the analysis of wild boars harvested only in the woody areas ($\beta = -0.03$, p value = 0.01, adjusted $R^2 = 0.16$). Thus, this result is not influenced by the type of coverage, highlighting that protected areas positively affect wild boar hunting density.

Dynamics of the hunted wild boars

Yearly hunting bag data are presented in Fig. 4a while the age–sex structure of the hunted population is presented in Fig. 5. Sex ratio computed from shooting harvest is lightly skewed toward females. In total, 51.5% of the shot animals are adults, 11.5% subadults, and 36.9% piglets. The time series analysis using Sen's method shows a significant decrease in trend in the percentage of piglets in the hunted population and piglets to sexually matured females time-series are characterized by significant downtrends (Fig. 4b, d) whereas the hunting effort significantly increases (Fig. 4c). Table 1 shows the results of Sen's slope estimator and corresponding 95% CI for each time series.

Structural breaks from data are detected in (1) 2010 for percentage of piglets in the hunted population, (2) 2003 for the piglets to sexually matured females, and (3) 2000 and 2015 for the hunting effort.

Discussion

As it appears evident also in other studies, combining the evaluation of spatial and temporal dynamics allows a better insight of the information derived from a database, which can stay otherwise undetected, if treated with a more traditional approach (Iacopelli et al. 2020; Fanelli et al. 2020a, b, c). In the present study, we found that protected areas influenced the distribution of hunted wild boars. The number of harvested wild boars decreased with the increase of the distance from the ZRC. This relationship is well explained by a linear regression.

It is worth noting that the high rate of wild boars hunted close to the ZRC remained significant when normalized for the habitat suitability (Boitani et al. 1994; Hebeisen et al. 2008). This means that the distribution of the hunted animals is not biased by the habitat characteristics. In addition, as highlighted in the "Material and methods" section, hunting pressure was homogenously distributed across the hunting district; therefore, it does not bias this outcome as well.

Our work provides strong evidence that ZRC acts as reservoir for wild boars, offering refuge to the species. This is in line with Santilli and Varuzza (2013) who found that protected areas positively affected wild boar hunting density. The same authors stated that in early autumn, many wild boars might spread outside toward hunting areas because of the raised density. Similarly, our study demonstrates that there is a high chance for hunters to shoot a larger number of wild boars in proximity to ZRC.

It is interesting to note that the changes from 1996–2015 to 2016–2018 in the size and location of ZRC led to a spatial variation of the hunting activity. Specifically, the creation of a main larger ZRC, connecting the two previously isolated ones, caused a concentration of the hunting bags around this area.

This finding highlights the effect of more interconnected protected areas on wildlife population dynamics. In other words, larger areas seem to better sustain higher population density. In fact, the fragmentation of protected areas may cause reduction of the amount of viable "core" habitat area, increasing also the edge effects. Larger protected areas allow species having a larger amount of suitable habitat (Ewers and Didham 2007). This is of particular interest considering that wild boar might severely alter the structure and composition of grasslands (Welander 2002; Bueno et al. 2009).

Another problem related to the high wild boar density concerns a great risk of car accidents. Several studies showed that vehicle accidents involving wild boars are increasing worldwide (Sáenz-de-Santa-María and Tellería 2015; Gren et al. 2016). In particular, in Cuneo province, most of the ungulate–vehicle collisions were caused by wild boar over the last years (Putzu et al. 2014).

From 1996 to 2018, the hunting bag data showed a large fluctuation in the yearly number of harvested wild boars. This

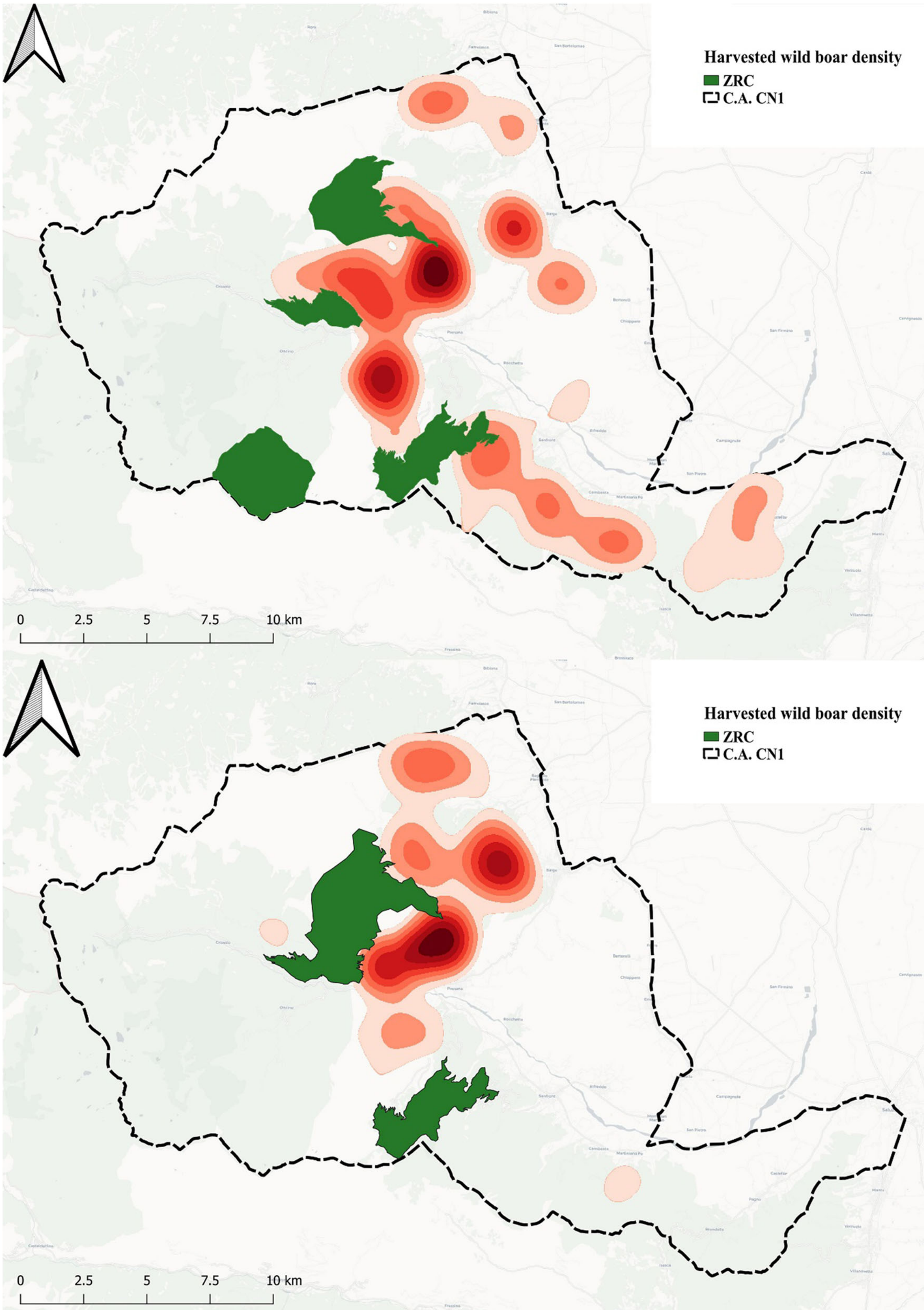

Fig. 2 Heatmaps of the harvested wild boars in relation to the ZRC (in green): from 1996 to 2015 (on top), from 2016 to 2018 (at the bottom). Higher densities are represented with darker colors

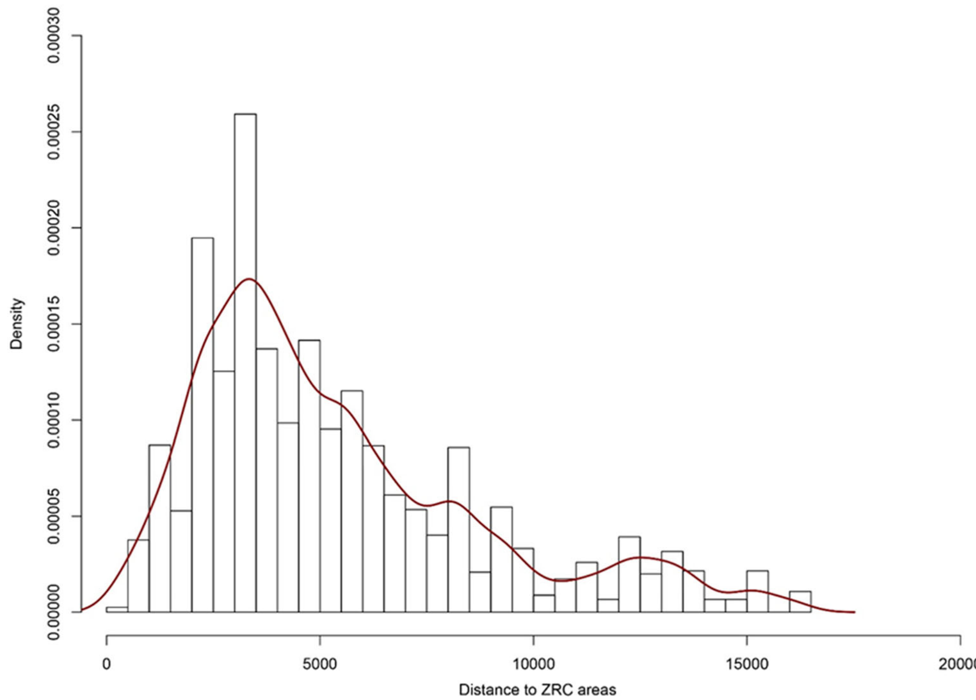

Fig. 3 Kernel density plot of the harvested wild boars over the distance from the ZRC (no huntable areas). Kernel density estimation is a technique that uses distances to known samples in order to assign probabilities

trend seems to be related to the hunting effort in the first period of the study. In fact, hunting bags responded linearly to the increase of the hunting effort until 2007, when the maximum capacity of the population to cope with the hunting pressure is reached. After this year, despite the hunting effort increased, the population lost this ability, and a decrease in the number of harvested animals was reported. Interestingly, the increase of the hunting efforts in Po Valley contrasts with the general European situation. Indeed, the number of hunters has remained relatively stable or declined in Europe in the last decades. At the same time, an increase of wild boar densities has been observed (Massei et al. 2015).

In the Po Valley, the progressive decrease in piglets to sexually matured females might be an additional factor at the base of the dynamics detected. Generally, the increase of piglets' productivity is associated with an uptrend of the hunting pressure. In our study area, this was observed only in the first part of the study (until 2003), whereas piglets' abundance progressively decreased in the remaining years. This pattern is quite different from wild boar populations in other study areas (Gürtler et al. 2017).

The structural breaks analysis of the hunting effort highlights 2000 and 2015 as years after which trend changes. The break in 2000 might be explained by the combined effects of the decrease of European hare *Lepus europaeus* density and the parallel increase of wild boar population. Indeed, local hunters started to find wild boars to be an important hunting asset at the end of the nineties, while in the previous years, the European hare was the most important game species in the valley. Since the sixties, hare population has dramatically declined as a consequence of changes in rural landscape throughout Europe. This reduction was observed later in the Alps (Smith et al. 2005; Tizzani and Dematteis 2009), when wild boar hunting began to receive special attention by locals. As regards 2015, the abrupt change (increase of hunting effort) might depend on the reduction of the hunting areas (around 40 km^2) due to the enlargement of the Natural Park of Monviso (Regione Piemonte 2016).

Despite the limitation of the hunting data, a valuable information concerning mortality regards the age of animals killed. The evaluation of the trend in the piglets to sexually matured females indicated a downtrend across the years. This is quite surprising and in contrast with the evidences provided by other authors who claimed that wild boar compensates hunting pressure (Gamelon et al. 2011). Even if not analyzed in this manuscript, there are several possible drivers responsible for

Table 1 Trends of time series from 1996 to 2018 in the hunting district C.A. CN1: hunting effort, percentage of piglets in the hunted population, piglets/sexually matured females

Time series (1996–2018)	Sen's slope	95% CI	*p* value
Hunting effort	0.57	[0.32; 0.85]	0.0006
Percentage of piglets in the hunted population	−0.009	[−0.01; −0.004]	0.002
Piglets/sexually matured females	−0.036	[−0.05; −0.01]	0.003

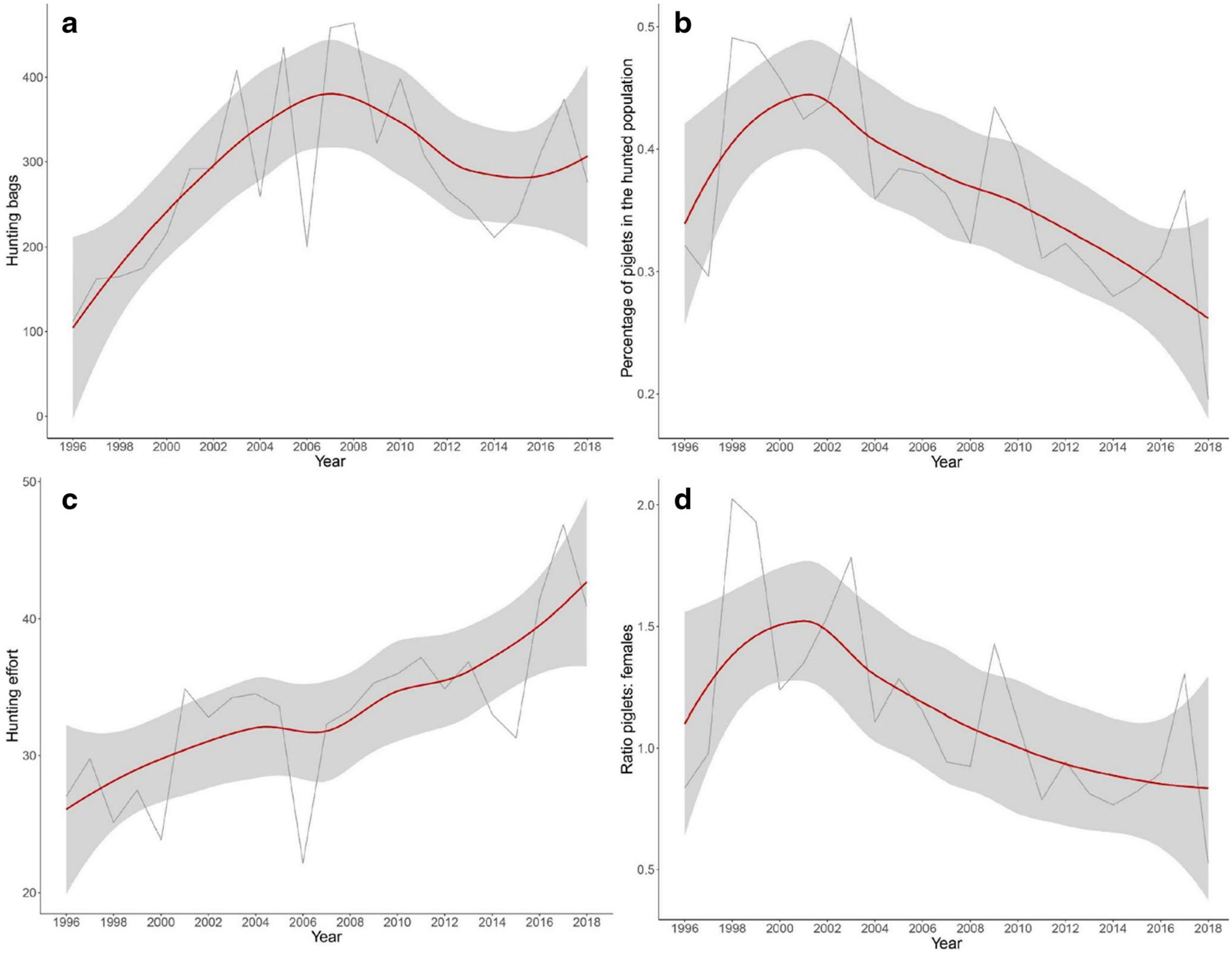

Fig. 4 Yearly hunting bag data from 1996 to 2018 in the hunting district C.A. CN1 (**a**), percentage of piglets in the hunted population per year from 1996 to 2018 in the hunting district C.A. CN1 (**b**), yearly hunting effort from 1996 to 2018 in the hunting district C.A. CN1 (hunting effort is defined as the yearly number of hunters/km^2 multiplied by the number of hunting days) (**c**), ratio of piglets to sexually matured females per year from 1996 to 2018 in the hunting district C.A. CN1 (**d**)

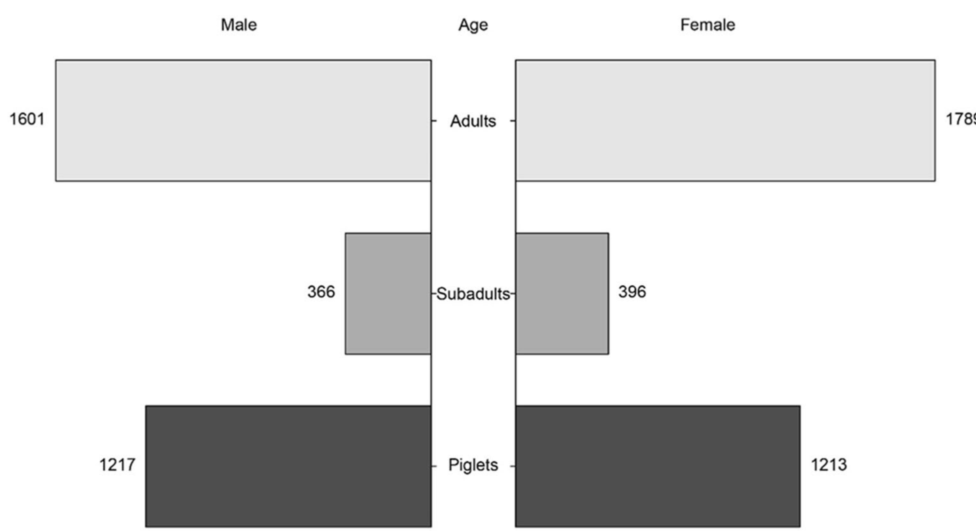

Fig. 5 Population pyramid of the hunted wild boars from 1996 to 2018 in the hunting district C.A. CN1

this outcome. Indeed, it is worth noting that the break point was detected in 2003, after the arrival (2002) of the oriental chestnut gall wasp *Dryocosmus kuriphilus* Yasumatsu which caused serious damage to chestnut orchards in Cuneo province (Brussino et al. 2002). Although there is no general agreement (Herrero et al. 2008), some authors pointed out that tree masting is a dominating factor in wild boar population dynamics (Briedermann 1990; J drzejewska et al. 1997; Bieber and Ruf 2005). Therefore, the downtrend in chestnut fruit production could have impacted on wild boar population. The reduction of the reproductive index may reflect the adaptation of wild boar to food resource. This is consistent to the finding of Bucci and Casanova on the important role played by chestnut fructification in wild boar reproduction (Bucci and Casanova 2006). However, after the implementation of the biological control program started in 2005, the gall wasp infestation levels have drastically declined over the years in Piedmont (Ferracini et al. 2019), with chestnut production substantially increasing after the initial collapse caused by the parasite infestation (personal communication). Therefore, other factors were responsible to keep the decreasing trend of piglets afterwards.

Predation by wolves might explain the downtrend of the percentage of piglets. Wild boar is in fact particularly susceptible to wolf predation because of its social behavior (Meriggi et al. 1996). Indeed, an increase of wolf *Canis lupus* predation on wild ungulates has been documented in Northern Italy in the last years, being wild boar one of the most consumed species (Meriggi et al. 2015; Torretta et al. 2017).

Hunters and predators affect different wild boar age classes: predators are known to remove primarily young wild boar, while hunters remove relatively more adults (J drzejewski et al. 1992, 2002; Keuling et al. 2013). Several studies highlighted the higher vulnerability of young wild boars to predation: up to 94% of the wild boars killed by wolves in Poland (J drzejewski et al. 1992), and more than 77% in the northern Apennines (Italy) (Mattioli et al. 1995).

In the hunting district C.A. CN1, the percentage of piglets in the hunted population has significantly reduced through out the study period, with a break point in 2010. This result ties well with the sharp increase in wolf population observed in Piedmont Alps over the last years (estimated population size in 2018 = 33 wolf packs, including minimum 195 individuals).

Indeed, since the nineties, wolves have been naturally recolonizing the southwestern Alps (Lucchini et al. 2002). Even if signs of wolf presence in the Po Valley have been described since the early 2000s (personal communication), a breeding pair of wolves have been officially reported in 2010. This was followed by a rapid population growth (LIFE WOLFALPS 2018), with potentially a major influence on ungulate dynamics in our study area.

Conclusions

This work describes the spatial and temporal patterns of a wild boar hunted population in the Alpine hunting district C.A. CN1.

First, it highlights that large protected areas may sustain higher wild boar population density, acting as reservoir of the species. Therefore, the authors advocate that a strict monitoring of the areas where hunting is not allowed should be implemented to control wild boar population.

Second, it depicts a particular local context in which the increase in hunting effort was causing large fluctuations of the harvested animals over the years. This is of particular interest as it is in contrast with the general trend described in Europe where hunting activity is declining and is currently insufficient to halt wild boar population growth.

In this work, the age structure of the harvested population was also evaluated, discussing possible factors (hunting pressure, masting productivity, and wolf predation) which could have influenced the reproductive parameters and consequently the population dynamics. However, it is important to highlight that the discussion on the effect of masting productivity and wolf predation is based on qualitative literature rather than on detailed figures relative to the study area. Therefore, the authors suggest performing dedicated studies to better quantify and confirm the effect of these factors on wild boar population dynamics.

Author contributions E.F. and A.P. conceived of the presented work. A.F. analyzed and interpreted the data, developed tables and figures, and wrote the manuscript draft. E.F., A.P., and A.F. critically reviewed the manuscript and approved it.

Declarations

Conflict of interest The authors declare no competing interests.

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