Do intensive drive hunts affect wild boar () spatial behaviour in Italy? Some evidences and management implications

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ORIGINAL PAPER

Do intensive drive hunts affect wild boar (*Sus scrofa*) spatial behaviour in Italy? Some evidences and management implications

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Abstract Wild boar have been increasing in numbers all over Western Europe in the last 30 years. The species is a major pest for agriculture, but it has a high value as a game species, and in Italy, as in several other countries, it is traditionally hunted in drive hunts by hunting teams with several dogs. This hunting method can have disruptive effects on the demography and spatial behaviour of wild boar, especially family groups. We conducted a 2-year study (2003 and 2004) to determine the effects of drive hunt disturbance on the spatial behaviour of wild boar family groups in the Northern Apennines (central Italy). Twenty wild boar belonging to ten family groups were ear tagged with a radio device. We located resting sites daily and used intensive tracking sessions during drive hunts. Three seasons were determined: pre-hunting, hunting and post-hunting. A general pattern of increased spatial instability during the hunting season was shown. Resting ranges were larger, and resting sites were more interspersed. Distances between consecutive resting sites were greater during the hunting season and, especially, on hunting days. The displacement of family groups caused by drive hunts was generally short lived except for those groups that were repeatedly hunted and so abandoned their pre-hunt (native) range. During drive hunts, wild boar showed a moderate tolerance to hunting disturbance, and only family groups which were directly chased by dogs escaped or altered their behaviour. The response of wild boar to hunting disturbance seemed to be highly related to the degree of hunting pressure combined with individual variability. The impact on wild boar behaviour should be reduced, above all by avoiding repeated hunts in the same areas within a short period and by employing well-trained hounds.

Keywords Wild boar · Hunting · Human disturbance · Drive hunt

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Introduction

Over the last 50 years, wild boar have increased in number and range throughout western Europe (Saez-Royuela and Telleria 1986) including in Italy (Monaco et al. 2003; Carnevali et al. 2009). Wild boar are a polyginous species which have a very high fertility rate and a shorter generation time compared to similar sized temperate zone ungulates (Servanty et al. 2007), as well as an early age at first reproduction (Gaillard et al. 1993; Franzetti et al. 2002; Servanty 2007). The species has a matrilinear social organisation (Kaminski et al. 2005) centred on adult females and their offspring: kin-related females form family groups with dominance relationships (Teillaud 1986;

Kaminski et al. 2005). The size of family groups varies according to the season and the habitat composition, with the number of individuals within a group being up to 20 boar (Teillaud 1986; Dardaillon 1988). Family groups show high site fidelity (Keuling et al. 2008a), and usually, the direction and the length of displacements are determined by the dominant females (Briedermann 1986; Jezierski 2002). Wild boar are a major agricultural pest because of the crop damage they cause (Calenge et al. 2004; Klein et al. 2004; Monaco et al. 2003; Schley and Roper 2003) as well as being a problem for livestock farmers because of their role as a vector for several infectious diseases (Rossi et al. 2004; Sodeikat and Pohlmeyer 2007) and because they may kill newborn lambs (Pavlov et al. 1981). However, wild boar also have a high economic value as one of the most important game species and are, as a result, subject to an intensive hunting pressure (Monaco et al. 2003; Toïgo et al. 2008; Tsachalidis and Hadjisterkotis 2008). In Italy, the most commonly employed hunting method is the drive hunt (Massei and Toso 1993), which is carried out by a hunting team and involves several tracking dogs, usually in mixed packs of different breeds. The drive hunt is the preferred hunting method in Italy because it is thought to guarantee the highest hunting bag and because it is linked to rural traditions (Monaco et al. 2003). Nonetheless, the use of drive hunts is controversial since it may have a number of negative consequences.

First of all, this hunting method does not always allow to make an assessment and choose which animal to shoot (Martínez et al. 2005), especially in a Mediterranean habitat dominated by maquis and dense woods, which are characterised by poor visibility. When chased, wild boar run very fast away from their resting sites and pass through thick vegetation, and consequently hunters tend to shoot the biggest boar, irrespectively of their age or sex, because they are the most visible (Monaco et al. 2003).

The adoption of drive hunts in this environment therefore has consequences for the demography of the hunted populations (Monaco et al. 2003; Toïgo et al 2008) and can also affect the spatial behaviour of family groups as the loss of a dominant female can lead to increased spatial instability amongst the surviving individuals (Maillard 1996). In addition, wild boar drive hunts usually cover a large area, and in many cases, hunting dogs are not trained to selectively hunt wild boar. This can cause severe disturbance to other species occurring in the same area, such as the brown bear *Ursus arctos* (Boscagli 1987; Ciucci and Boitani 2008), the roe deer *Capreolus capreolus* (Cederlund and Kjellander 1991), the red deer *Cervus elaphus* (Bateson and Bradshaw 1997) and the wolf *Canis lupus* (Ciucci, personal communication).

Many studies highlight how hunting can seriously affect population structure (Ginsberg and Milner-Gulland 1994; Milner et al. 2007), evolutionary traits (Festa-Bianchet 2003; Proaktor et al. 2007) and individual behaviour (Tuytten and McDonald 2000; Sutherland and Gill 2001) in large mammals. In particular, altered spatial behaviour in response to hunting pressure has been reported in several hunted mammalian species. Hunted wild ungulates can display increased movement (Root et al. 1988; Kilpatrick and Lima 1999), an enlarged resting range (Jeppesen 1987; Maillard and Fournier 1995) or changes in habitat selection (Swenson 1982; Kufeld et al. 1988; Kilgo et al. 1998). In some cases, animals remain within the established home range but shift their centre of activity (Vercauteren and Hyngstrom 1998, Kilpatrick and Lima 1999). In several cases, changes in spatial behaviour are transitory: hunted animals move to a refuge area outside of their home range during the hunting season, but in some cases they move back within a few days (Jullien et al. 1991; Jeppesen 1987; Vercauteren and Hyngstrom 1998), while in other cases they move back at the end of the hunting season (Millspaugh et al. 2000).

The effects of hunting pressure on spatial behaviour depend on several factors, including habitat characteristics (Vercauteren and Hyngstrom 1998; Conner et al. 2001; Millspaugh et al. 2000), the hunting method employed (Root et al. 1988; Millspaugh et al. 2000; Vieira et al. 2003) and the level of hunting pressure (Johnson et al. 2004). Social structure is also important for animals which live in a group: the loss of an individual may have different consequences depending on the hierarchical role it played within the group (Tuytten and McDonald 2000).

Few studies have monitored the effects of drive hunts on the choice of resting sites by wild boar family groups, and the results that exist are controversial. Hunted boar may enlarge their resting range, increase their length of movement or move to un-hunted areas outside their resting ranges in response to hunting pressure (Maillard 1996; Brandt et al. 1998; Calenge et al. 2002; Sodeikat and Pohlmeyer 2003), though contrasting results (Jullien et al. 1991; Keuling et al. 2005, 2008b) have shown that boar remain within established resting ranges.

The aim of this study was to investigate the presence of short-lived changes in the spatial behaviour of wild boar family groups during the hunting season by detecting possible variation in the home range size and in its internal spatial structure during the hunting season. A knowledge of the response of wild boar family groups to hunting pressure may help improve management strategies. In fact the displacement of wild boar by drive hunts can reduce the effectiveness of management plans and worsen conflicts with farmers and landholders. For improved management of the species, it is therefore important to minimise the spatial instability induced by hunting.

Study area

The study area (about 20,000 ha) was located in the northern Apennines, Italy (44°16′49.32″ N, 11°28′ 37.49″ E, Fig. 1). Elevation ranges were from 200 m a.s.l. to 1,200 m a.s.l.. The climate was temperate (the mean yearly temperature is 12°C, with variation according to the altitude). Precipitation is concentrated in spring and autumn, mean annual precipitation reaching about 1,000 mm and the mean snow cover length being 25–30 days per year. At lower altitudes (<600 m), the landscape was highly fragmented with fields and orchards (48% of the total area) interspersed with shrubland and woodland. The scrub layer was dominated by Spanish broom (*Spartium junceum*), dog rose (*Rosa canina*) and several bramble species (*Rubus* sp.). Tree species were few and mainly represented by downy oak (*Quercus pubescens*), white poplar (*Populus alba*) and false acacia (*Robinia pseudacacia*). At higher altitudes, woodland was more widespread, and the forest community was composed of downy oak, turkey oak (*Quercus cerris*), hop-hornbeam (*Ostrya carpinifolia*), manna ash (*Fraxinus ornus*), common beech (*Fagus sylvatica*) and European chestnut (*Castanea sativa*).

Forage for wild boar was abundant throughout the year, and supplemental feeding (corn and chestnuts) was provided by hunters, especially during autumn and winter.

There was an occasional wolf presence (*C. lupus*) but no other wild boar predators.

In the study area, wild boar hunting occurred twice a week from the first of November to the 31st of January. Hunting was carried out by several teams which had the exclusive right to hunt in a specific hunting area, with assigned minimum and maximum numbers of wild boar to harvest each year. The hunting teams, which operate mainly for recreational purposes and for the meat, aimed to maximise the number of animals shot in their area but at the same time preserve the reproductive segment of the population in order to have enough animals to hunt the following year. The hunting method used was the drive hunt, in which wild boar were chased by beaters with hounds and forced to run towards the hunters (hereafter called "shooters") posted in strategic points around the hunted area (i.e. mountain ridges). Hunters communicated with each other using radio receivers in order to coordinate their actions, especially in relation to the dogs' movements. The dog breeds employed were: ariege hound, griffon nivernaise, Istrian hound and Italian hound; all of which are typically capable of following the olfactory tracks of the boar (Monaco et al. 2003). If a dog leaves the drive hunt area while following the boar' tracks, beaters use radio receivers to alert other hunters and to try to retrieve it as soon as possible.

Materials and methods

Data collection

Characteristics and effectiveness of drive hunts For each hunting intervention which occurred in the entire hunting

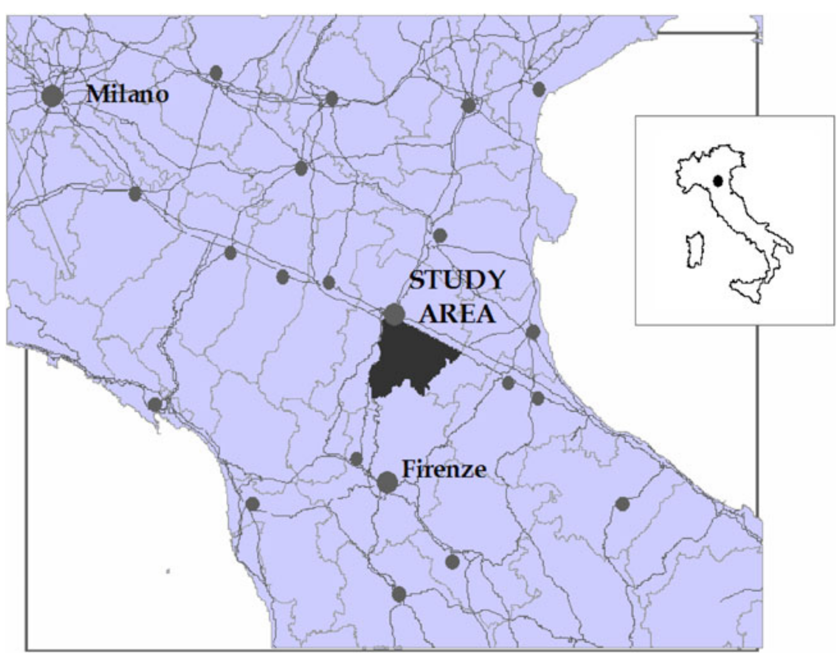

Fig. 1 Map of the study area (in *dark grey*) and its location in Italy

district during 2003–2004, we recorded data regarding the size and shape of the hunt area, the start and end times, the number of hunters and dogs, the composition of the pack, the numbers of shots, the barking of the dogs and the total number of wild boar shot. We also had a long-term data set detailing the characteristics of the wild boar which were shot: records were kept for each animal killed (sex, estimated age, eviscerated weight, females' reproductive status and the identifying numbers stamped on marks ear-tagged boar).

Wild boar capture and monitoring We captured wild boar using corral traps and mobile box traps baited with maize and chestnuts. We weighted, measured, aged by dentition (Monaco et al. 2003) and ear tagged all animals. Wild boar which were heavier than 30 kg were immobilised using a mix of tiletamine, zolazepam (Zoletil 100®) and Xylazine (Rompum ®; Fenati et al. 2008). Sub-adult animals were fitted with an ear tag VHF radio device (Biotrack, UK), while a VHF radio collar (TXH3 Televilt, Sweden) was used for the adults (Monaco and Carnevali 2004). We captured a total of 279 wild boar (57% captured and 43% recaptured) and radio equipped 35 boar. Twenty of the radio-tagged wild boar (15 sows and five young males) belonged to ten family groups, as identified from sightings and capture–recapture data.

We collected data from October 2003 to April 2005, monitoring two hunting seasons. Several studies show how in hunted areas wild boar activity is strictly concentrated in nocturnal hours, while animals remain in resting sites during daylight (Mauget et al. 1984; Boitani et al. 1994; Maillard 1996, Monaco and Scillitani 2006). We therefore located resting sites once a day only for at least 20 days per month and twice a day (repeated localisations: one in the morning and one in the afternoon) on 10 days per month. During drive hunts, we performed intensive monitoring sessions (one localisation every 5 min) of radio-marked wild boar which were resting within (or near) the drive hunt area, in order to detect their reactions and follow their escape movements. Surviving wild boar were located every 15 min until the following day when they went to rest in a new resting site. Hunters were not informed about the position of radio-marked wild boar. During the hunting, we listened in constantly to the hunters with radio receivers so as to better understand how beaters with dogs were moving in the drive hunt area.

We performed triangulation with a portable receiver (R-100 Communication specialist, TRX-2000 Wildlife Materials Inc., USA) and a hand-held yagi antenna (Wildlife Materials Inc., USA); locations were computed using a minimum of three bearings obtained with LOCATE II (Nams, 1990).

Data analyses

Characteristics and effectiveness of drive hunts We investigated the effectiveness of drive hunting during the two hunting seasons. We computed a multiple regression analysis to analyse the number of boar harvested in the all hunting district from 2003–2005 in relation to the number of hunters (beaters and shooters) per square kilometre and the number of dogs per square kilometre. We also performed a linear regression between the number of boars harvested and the number of shots recorded during a hunt. The number of boar harvested was log-transformed to meet a normality assumption.

Wild boar spatial behaviour For each analysis, we used only resting site locations which allowed a good description of the disturbance caused by hunting. As hunting activity took place in daylight while some boar were in their resting sites, and as several studies (Dardaillon 1986; Meriggi and Sacchi 2000; Maillard 1996) point out that wild boar resting sites are located in shrubby or wooden habitat which guarantee shelter from predators, changes in resting site distribution may therefore be related to hunting activities. The use of resting site locations also facilitates a comparison with similar studies (Maillard and Fournier 1995; Calenge et al. 2002; Sodeikat and Pohlmeyer 2007).

The analyses were computed at a monthly and seasonal level. We identified three seasons: pre-hunting (first of July to 31st of October), hunting (first of November to 31st of January) and post-hunting (first of February to 30th of June). Data from the 2-year study were pooled together after checking for differences in climate conditions (ANOVA: minimum temperature: $F_{1,347}$=1.04, p=0.378; maximum temperature: $F_{1,347}$=1.04, p=0.378; precipitation: $F_{1,347}$=1.04, p=0.378) and in hunting intensity (number of drive hunts: Mann–Whitney test, U=121.50, p=0.131; number of dogs used: Mann–Whitney test, U=77989.00, p=0.762).

Resting range We determined the seasonal resting range (the area including resting locations, Maillard and Fournier 1995) size using 100% Minimum Convex Polygon (MCP) and 95% kernel estimators and core areas with 50% kernel estimators. We expected to find an enlarged resting range size during the hunting season as a consequence of hunting disturbance.

Location of resting site Resting range size may provide little information about changes in resting site geographical position. We therefore measured:

– The straight-line distance between consecutive resting sites

- The interspersion of resting sites as an average of distances of resting sites from the arithmetic centre of their distribution
- The capture site fidelity: the distance between each resting site and the capture site location
- Human infrastructure avoidance: the distance between resting sites and human settlements (both single houses and villages) and roads (whether paved or gravel)

During the hunting season, we expected to find a higher variability in resting site location; thus, we predicted increased distances between resting sites and from the capture site, as well as a higher degree of interspersion. Wild boar should choose resting sites far from human infrastructure throughout the year, but during the hunting season we expected to find an increase in the avoidance of human infrastructure and especially of the gravel roads used by hunters.

Avoidance of hunted areas A more detailed analysis was performed to assess, on a small scale, the effect of hunting activity on resting site location. For each drive hunt, we compiled hunting maps which gave a measure of the relative shooting risk for the wild boar. Each map was composed of: (1) a high-risk area, the area involved in the drive hunt; (2) a low-risk area, the boundary area (a buffer zone of 500 m around the drive hunt area) in which wild boar could hear dogs and shots easily; and (3) a no-risk area, the external area not affected by the drive hunt. We superimposed buffered locations of the resting sites (r= 250 m, which corresponds to the measured maximum telemetry error) occupied before and after the drive hunt onto these hunting maps in order to calculate the percentage use of areas with different impacts. Finally, we calculated the distance between the centroid of the high-risk area and the resting sites used by the wild boar on the hunting day and the following day. We expected an avoidance of high-risk areas after a drive hunt by animals initially resting within the high- and low-risk areas.

In each analysis, we tested differences between months or seasons using a Kruskal–Wallis H test (hereafter KWt). For pair comparison between seasons, we used the Mann–Whitney U test (MWt). To test differences between hunting days and days free from hunts, we used the Wilcoxon (Wt) test for paired data. Differences among frequency distributions were tested by means of the chi-squared (χ^2) test.

We used the statistical software SPSS 13® (SPSS Inc.) and SAS 9.1® (SAS 1989) in all analyses. Data handling and spatial analyses were conducted using ArcView GIS 3.2® (ESRI) with Spatial Analyst (Environmental Systems Research Institute 1992) and Animal Movement 2.0 (Hooge and Eichenlaub 2001) extensions.

Results

Characteristics and effectiveness of drive hunts The hunting teams were composed of an average of 23 hunters (range, 7–67) and eight dogs (range, 4–18). The mean duration of a drive hunt was 3 h and 40 min. During the hunts, we recorded an average of 24 shots (range 2–103), in many cases the beaters using shots to increase the rate of disturbance in the area and to try to force wild boar to move towards shooters. The area involved in a drive hunt was from 34.4 to 649.0 ha wide (mean value= 165.3 ha SD=104.7 ha). The same area was hunted from one to eight times during a hunting season (mean value= 2.6 times SD=1.5). The mean number of hunters per square kilometre was 25.31 (SD=19.01), divided into 4.49 beaters per square kilometre (SD=3.81) and 20.85 shooters (19.01 SD) per square kilometre. Although several other species were hunted in the study area between June and March, the largest number of hunters and dogs present in the study area (64.3% of the total number of hunters who hunt in the area) was observed during the wild boar hunting season. A mean number of 2.49 wild boar were shot per square kilometre (SD= 4.50), and an average of 2.74 boar were harvested in a single drive hunt (SD=3.24). We found a significant level of regression ($F_{3,628}$=5.28, p=0.001) between the hunting bag achieved and the variables investigated, but the R^2 obtained was very low (R^2=0.025) indicating that the model used does not consistently explain the variation in the hunting bag size. The estimated regression coefficients are reported in Table 1. Neither the number of dogs per square kilometre nor the number of beaters per square kilometre affected the number of boar killed. The number of shooters per square kilometre was the only factor that was significantly related to the hunting bag achieved (p=0.003); however, the regression coefficient is almost null (b=0.003), indicating a weak linear relationship.

The total number of shots was not related to the hunting bag obtained (F=0.46, p=0.503).

Resting range and movements Resting range size calculated with 100% MCP varied significantly from season to season (KWt, H=6.40, df=2, p=0.041), while no significant variation was found either for 95% kernel size (KWt, H=3.62 df=2, p=0.164) nor for 50% kernel (KWt, H= 5.19, df=2, p =0.074). We observed an enlarged resting range size during the hunting season (Table 2). During the hunting season, three family groups abandoned their pre-hunt resting range and established a new one outside of the familiar territory. In all of these cases, the group had been repeatedly hunted within a short time (two or more times per month) or had lost adult females which were the leading

Table 1 Relationship between the number of wild boar shot in drive hunts and the number of hunters and dogs per Km^2

	DF	Estimated *b*	SE	*t* value	*p*
Intercept	1	1.118	0.04409	25.36	<0.001
Beaters/km^2	1	0.004	0.01211	0.3	0.764
Shooters/km^2	1	0.008	0.00268	3.01	0.003
Dogs/km^2	1	−0.007	0.00565	−1.32	0.188

components of the group. We defined these groups "heavily hunted" in contrast to groups which were chased less often (one drive hunt per month). The mean resting range size for heavily hunted family groups during the hunting season (1,775 ha) was larger than the value observed in groups subjected to a lighter hunting pressure (255 ha; MWt: $U=2.00$, $p=0.083$). Figure 2 reports the case of a family group which was hunted five times during a month and progressively moved away from the area occupied during the pre-hunting season. At the end of the hunting season, the remaining individuals from the group (a sow and a juvenile male) remained in an area 15 km far from the capture site.

The distance between consecutive resting sites followed the same seasonal pattern observed for resting range size: the greatest distances occurred during hunting and post-hunting seasons (KWt: $H=28.38$, $df=2$, $p=0.000$; Table 3). We observed the same pattern on a monthly basis (MWt: November, $U=1119$, $p=0.053$; December, $U=646$, $p=0.03$), except in January (MWt: $U=336$, $p=0.812$). However, this may be due to the reduction in the sample size during the first 2 months of hunting. More in detail, mean distances were greater on hunting days, compared to those for non-hunting days (MWt: $U=5235$, $p=0.001$).

The higher spatial instability during hunting season was confirmed by the analysis of the interspersion of resting sites. During the hunting season, resting sites were more interspersed within the resting range area than during pre-hunting and post-hunting seasons. Observed seasonal values differed significantly (Fig. 3; KWt: $H=138.23$, $df=2$, $p=0.000$) and paired comparison between seasons confirmed this pattern (MWt: pre-hunting vs hunting seasons $U=18013.5$, $p<0.001$; hunting vs post-hunting, $U=68785.5$, $p<0.001$; pre-hunting vs post-hunting, $U=12938.0$, $p<0.001$). The tendency of family groups to occupy different geographic areas for resting was also indicated by the frequency distribution of kilometre classes of distances from the capture site, which differed significantly between seasons (χ^2t, $\chi^2=115.23$, $df=10$, $p<0.001$, Fig. 4). Distances greater than 4 km were observed only during the hunting and post-hunting seasons, and distances above 10 km occurred only in the hunting season; however, once we had isolated data from heavily hunted groups from that for other groups, it was clear that the less hunted animals remained within the 4 km value all year long, while the higher distance values occurred only for the heavily hunted groups. In fact, during the hunting season, we observed a progressive monthly increase in the average distance from the capture site in all heavily hunted groups in contrast to animals which experienced lighter hunting pressure (Fig. 5; MWt: $U=18290.00$, $p=0.000$)

We observed a high significant difference in the avoidance of different kinds of human infrastructure (KWt: $H=102.542$, $df=3$ $p=0.000$): wild boar resting sites were located further from paved roads and villages than from gravel roads and single settlements. We found no seasonal pattern of avoidance for any of the human settlements and roads (KWt: single settlements, $H=5.73$, $df=2$, $p=0.057$; villages, $H=3.46$, $df=2$, $p=0.208$; paved roads, $H=3.46$, $df=2$, $p=0.178$; gravel roads, $H=0.340$, $df=2$, $p=0.844$).

Avoidance of hunted areas Only wild boar resting in high-risk areas avoided hunted areas. A paired comparison of habitats used before and after the hunting day (Fig. 6) showed a significant change in the use of high-risk areas (Wt, $Z=-2.24$, $p=0.025$) and no-risk areas (Wt, $Z=-2.23$, $p=0.026$), while no changes were detected for the use of low-risk areas (Wt, $Z=-0.14$, $p=0.89$). Likewise, the distance between resting sites and the centroid of high-risk area on the day after the hunt only increased significantly (Wt, $Z=-2.66$, $p<0.008$) for family groups which had been resting in high-risk areas (Fig. 7).

These results were confirmed by the data obtained from the intensive radio-tracking sessions performed during

Table 2 Median values, interquartile distances and arithmetic mean with standard error of seasonal resting range size for wild boar family groups, calculated by means of 100% MCP, 95% and 50% kernel

Season	100% MCP				95% kernel				50% kernel			
	Median	Q_3–Q_1	Mean	SE	Median	Q_3–Q_1	Mean	SE	Median	Q_3–Q_1	Mean	SE
Pre-hunting	80	104	88	25	66	156	98	39	4	14	10	3
Hunting	428	1360	825	358	221	696	457	192	23	68	45	16
Post-hunting	195	544	358	151	189	488	284	99	20	88	45	20

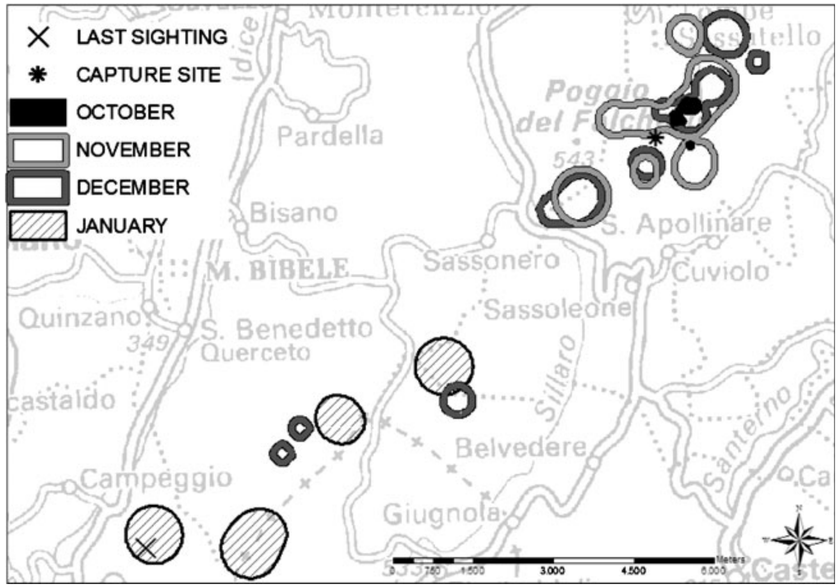

Fig. 2 Monthly changes in resting range size and geographical displacement observed in a family group (composed of three females and at least five piglets) which was subject to intensive hunting pressure. The *asterisk* indicates the capture site. At the end of the hunting season, only one female and one juvenile male survived, in the area indicated by the "*X*"

drive hunts on wild boar family groups resting inside high-risk areas: 76% of family groups moved when the dogs found them and started chasing them, while the remaining 24% of wild boar remained at the resting site for the whole duration of the drive hunt because the dogs did not directly chase them. In contrast, none of the family groups resting in low-risk areas moved for the entire duration of the drive hunt, except in one case in which a dog moved out of the high-risk area into the low-risk area and chased the group.

Discussion

The results of this study suggest that intensive hunting activity may affect the spatial behaviour of wild boar family groups. Most of the studies on wild boar spatial behaviour have focused on factors affecting the home range size. Wild boar home range size is mainly affected by sex, the availability of food and population density (Wood and Brenneman 1980; Singer et al. 1981; Boitani et al. 1994; Maillard 1996; Massei et al. 1997). Few studies have detected a marked seasonal variation due to environmental factors (Singer et al. 1981; Gabor et al. 1999; Lemel et al. 2003; Keuling et al. 2008a), but they do refer to study areas with harsh climatic conditions in which the weather can affect the availability of forage. In this study, we considered only family groups, and we used resting sites which are mainly influenced by the shelter provided rather than by the abundance of food resources or by weather conditions (Dardaillon 1986). In addition, in our study area, the climate was mild all year long, the snow depth was not a limiting factor, hunters provided artificial feeding whenever a shortage of natural forage occurred, and there were no

Table 3 Median values (with relative interquartile distances) and arithmetic mean (with standard error) of seasonal distances between consecutive resting sites

Season	Median (ha)	Q_3-Q_1	Mean (ha)	SE
Pre-hunting	186	381	286	24
Hunting	383	864	891	87
Post-hunting	401	757	733	74

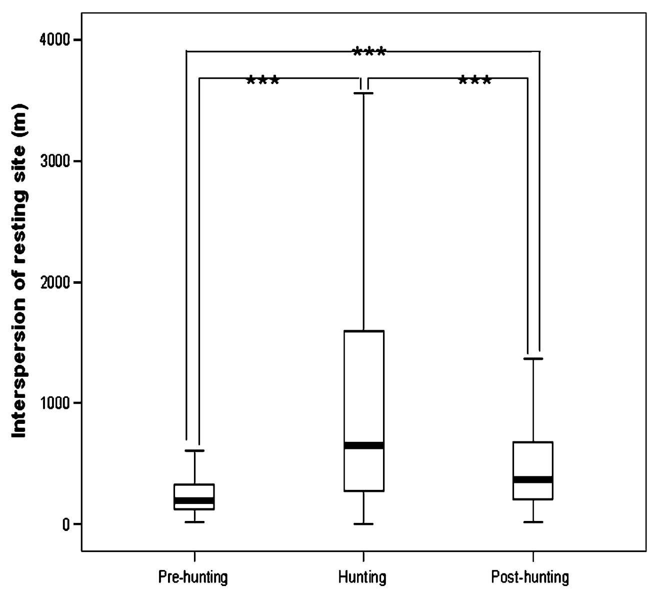

Fig. 3 Box and whisker graph for the seasonal interspersion pattern of wild boar resting sites within the resting range area. ***$p<0.001$

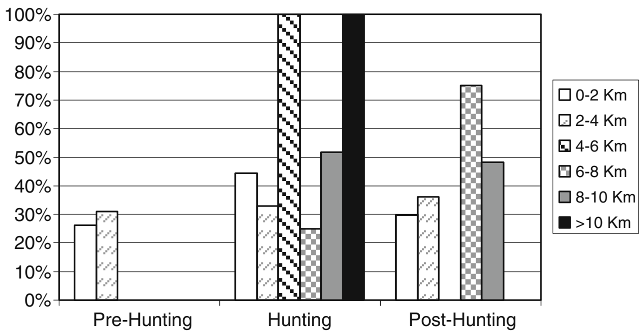

Fig. 4 Frequency distribution of distances between resting sites and capture sites

established populations of predators. Human activity peaked during the 3 months of wild boar hunting, while for the rest of the year human presence and activity was low (Scillitani 2006). Therefore, the modifications in spatial behaviour occurring during the hunting season were most likely due to hunting activity.

In this study, we observed changes in the seasonal distribution of resting sites of wild boar family groups and therefore an altered spatial behaviour. During the hunting season, we observed an enlarged resting range size and a significant raise in spatial instability. Moreover, during the hunting season we observed an increased distance between consecutive resting sites, which were also more interspersed, meaning that wild boar not only chose resting sites further from each other but also tended towards considerably reduced site fidelity. According to some studies (Mauget 1980; Kowalski 1985), wild boar alternate "nomadic phases", in which they change resting site location every day, with "sedentary phases", in which they use always the same place. We did not find such a clear pattern but, in line with other studies (Maillard 1996), we recorded a high individual variability amplified by the occurrence of hunting activity, as indicated by the greater distances between resting sites recorded on days following

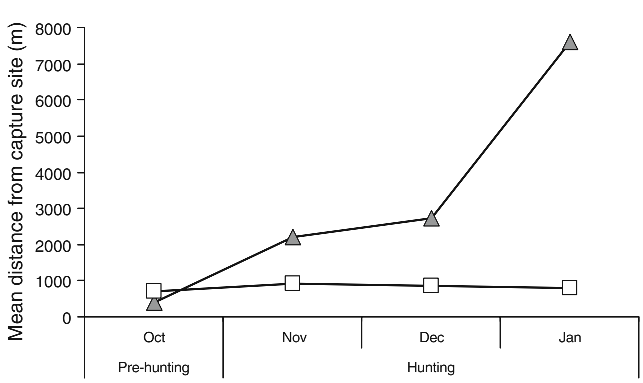

Fig. 5 Mean distances from capture site observed in heavily hunted family groups (*grey triangles*) and in wild boars subjected to a lighter hunting pressure (*white squares*)

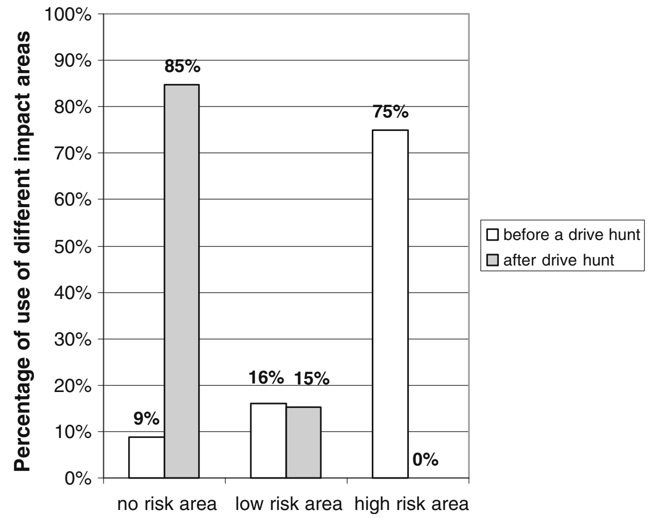

Fig. 6 Percentage of use of no-risk, low-risk and high-risk areas before a drive hunt (*in white*) and after it (*in grey*) by animals involved in a drive hunt

a drive hunt. During the hunting season, we also observed an increased tendency to change resting site in daylight (Scillitani 2006), though this was rare. In fact, in our study area, wild boar were active during the night, and the start of the active phase strongly correlated with the hour of sunset (Monaco and Scillitani 2006), as has also been observed for other populations subject to hunting pressure (Briedermann 1986).

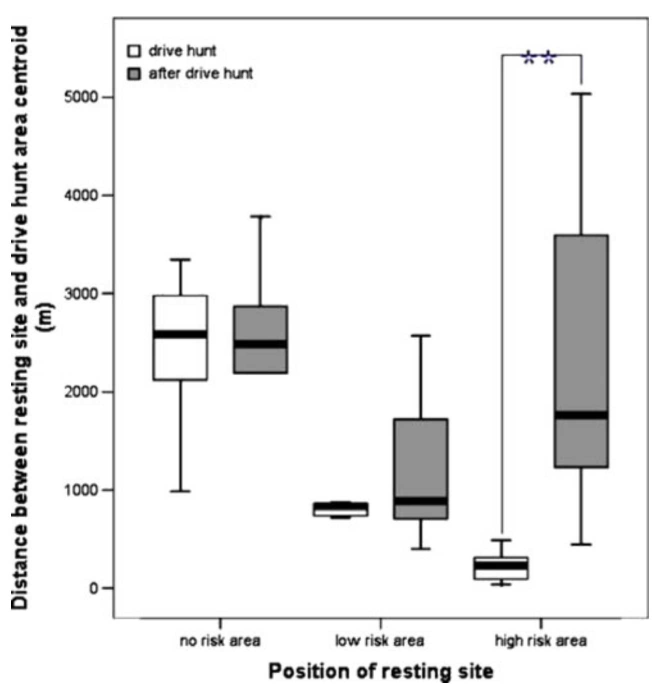

Fig. 7 Box and whisker graphs of the distance of resting sites from the centroid of a drive hunt area, as observed before (in *white*) and after a drive hunt (in *grey*). $^{**}p<0.01$

As a consequence of drive hunts, some family groups left their familiar territory and moved considerable distances away, sometimes over 10 km from the area where they had been captured. According to other studies (Maillard 1996; Brandt et al. 1998; Sodeikat and Pohlmeyer 2003), these displacements of family groups are usually short lived since they return to their familiar areas at the end of hunting season. In contrast, our data, which were obtained from the recovery of ear tags of shot animals and from radio telemetry, seem to indicate that intensively hunted family groups left their familiar areas definitively (Monaco and Scillitani, unpublished data).

Conversely, the response of wild boar to hunting disturbance seemed to be highly related to the degree of hunting pressure combined with individual variability. The groups exposed to intensive hunting disturbance (both in terms of the frequency of drive hunts and the loss of components) were the ones which showed a significantly increased spatial instability and moved away to other areas. On the contrary, groups exposed to lighter hunting disturbance showed a stronger site fidelity and increased their movements within their habitual range or slightly enlarged their resting range area.

A similar behavioural pattern is also reported by other authors (Maillard and Fournier 1995; Brandt et al. 1998; Baubet et al. 1998; Sodeikat and Pohlmeyer 2007), though some found only a slight modification of spatial behaviour and attributed seasonal variability in wild boar movements to factors other than hunting (Keuling et al. 2005, 2008b). However, the frequency of drive hunts in the areas concerned was much lower than that observed in this study: one of our marked family groups was directly involved in a drive hunt on four occasions in the space of a week.

Wild boar are often described as a sedentary species (Vassant et al. 1992). Our results confirm a tendency towards spatial stability in family groups: wild boar showed a high tolerance of human activities other than hunting, and we found no increased avoidance of human infrastructure during the hunting season, though we expected a negative selection of areas near gravel roads used by hunters. Moreover, only wild boar directly involved in drive hunts escaped or altered their activity patterns, while animals resting in low-risk areas, where shots and dog barking were clearly audible, remained in their resting sites and used the hunted area the following day. Even during drive hunts, family groups did not move until the dogs actively harassed them. This hiding behaviour is probably an anti-predator strategy, and it is interesting to notice that in the cases in which wild boar were resting inside the hunted area but were not found by the dogs, no displacement was found. This may indicate that wild boar tolerate hunting disturbance and react only when directly persecuted. Consistent with this hypothesis are the results of a comparison of different hunting methods in Switzerland and France (Tolon et al. 2008), which showed how boar involved in drive hunts moved more than animals stalked by a single hunter. In contrast, a study in Northern Germany (Keuling et al. 2008b) found no significant differences between hunting methods, though it also found that hunting had a slight impact on wild boar spatial behaviour.

In conclusion, family groups reacted to drive hunts if directly chased by dogs and beaters but moved to areas far from their native range only when frequently disturbed. In lightly hunted areas, the behavioural modification exhibited were less pronounced and short lived.

Management implications

The results of this study may have some useful implications for the improvement of the management of wild boar, especially in Italy. As previously stated, wild boar may be considered a pest species, and the major increase in numbers is a great concern for wildlife managers. A management priority is to encourage the culling of wild boar to reduce overall numbers. However, hunters are interested in maintaining a high density of wild boar so as to maintain a constantly high number of animals to hunt.

Our results showed that drive hunts can alter the spatial behaviour of wild boar family groups. Nevertheless, the magnitude of this altered behaviour is highly variable: in most cases, the response of wild boar is moderate, though it increases steadily with hunting pressure and can culminate in the permanent abandonment of the home range area. The displacements exhibited by wild boar family groups are an indication of the hunting disturbance suffered by the animals but are also a major problem for management policies. First, most of the areas frequented by the species are interspersed with cultivated land, and the increased range of wild boar due to hunting activities can result in an increase in crop damage which may exacerbate the conflict between boar and farmers and between hunters and farmers. Furthermore, wild boar can play a role as a reservoir and vector of diseases which affect domestic animals (Aubert et al. 1994; Fritzemeier et al. 2000; Rossi et al. 2004), so increased displacement of family groups should also be avoided in the interests of effective sanitary management.

Finally, most Italian territory is made up of a fine mosaic of different management units (each with their own hunting quota to achieve during the hunting season); even a short range displacement of wild boar can significantly affect the local density of the species and consequently the hunting bags. As previously described, in fact, a family group is often made by up to 20 individuals.

On the basis of our results we propose to reduce hunting pressure in order to minimise the human-induced displacements of wild boar. Since wild boar family groups move away from hunted areas only if heavily disturbed, we strongly recommend the avoidance of repeated hunts in the same area at short time intervals in order to reduce the stress level of family groups and prevent the abandonment of their native areas. Moreover, as this study and similar ones (Maillard 1996) have shown, an important loss of the components of a group increases the spatial instability of the group and should therefore also be avoided.

The reduction of hunting disturbance should also be achieved by decreasing the number of dogs and the number of beaters. In fact, as our analysis of drive hunt effectiveness shows, hunting efficiency is related neither to the number of dogs used nor to the number of beaters, but there is only a weak relationship with the number of shooters per square kilometre. However, since the level of correlation was really low, an increase in the number of shooters would not reliably improve the hunting effectiveness. Therefore, rather than employing a big pack, hunters should rely use of few and well-trained hunting dogs which will selectively search for wild boar only, will actively stalk the animal but will give up the chase in case of a charge and will immediately come back to its owner when called, even if following a track (Monaco et al. 2003). Data on wild boar hunts with a single well-trained dog show that the harvest can be even more successful than using drive hunts. The number of harvested boar per dog and per participant was higher and, as a consequence, the quantity of meat per hunter was greater (Monaco, unpublished data). Adopting this method, the hunt would be more productive, the management of the species would improve, and the impact on the spatial behaviour should be reduced at the same time.

Furthermore, cutting back on the number of beaters and dogs also reduces the disturbance of other species, in particular in areas where species of high conservation concern, such as the brown bear, are present.

In conclusion, we believe that adopting the proposed actions (reducing the size of dogs' pack and avoiding repeated hunting intervention in the same area in a short time) would significantly improve the management of the species. In fact, the negative consequences of human-induced displacements of family groups would be minimised, but at the same time, hunting bag would not decrease.

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