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Evaluating hunting and capture methods for urban wild boar population management

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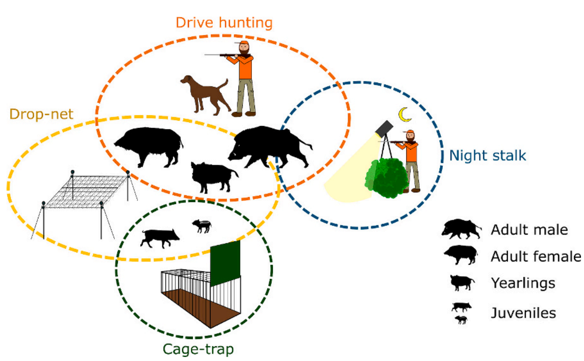
HIGHLIGHTS

- Increasing synurbic wild boar populations generate conflict requiring management.
- Selective age and sex wild boar removal improves population management efficiency.
- Hunting and capture methods differ in age and sex bias, performing better in summer.
- Differences in applicability, sex and age bias, and cost allow synergic method use.
- Such features must be considered for cost-efficient resource allocation management.

GRAPHICAL ABSTRACT



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ABSTRACT

Wild ungulates are expanding in range and number worldwide leading to an urgent need to manage their populations to minimize conflicts and promote coexistence with humans. In the metropolitan area of Barcelona (MAB), wild boar is the main wildlife species causing a nuisance, from traffic accidents to health risks. Selective harvesting of specific sex and age classes and reducing anthropogenic food resources would be the most efficient approach to dealing with overpopulation. Nonetheless, there is a gap in knowledge regarding the age and sex selectivity of the capture methods currently applied in the MAB for wild boar population control.

Thus, this study aimed to evaluate the performance and age and sex bias of different hunting and capture methods and the seasonal patterns in their performance (number of captured individuals per event). From

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February 2014 to August 2022, 1454 wild boars were captured in the MAB using drop net, teleanaesthesia, cage traps, night stalks, and drive hunting. We applied generalized linear models (GLM) to compare the performance of these methods for the total number of wild boars, the wild boars belonging to each age category (i.e., adult, yearling, and juvenile), and for each season.

The studied capture methods showed age-class bias and sex bias in adults (>2 years). Drive hunting and drop net removed mainly adult females and yearlings (1–2 years), with drive hunting having the highest performance for adult males. Instead, cage traps and drop net were the best methods to capture juveniles (<1 year). Overall, global performance was higher in summer, decreasingly followed by autumn and spring, winter being the worst performing season. Wildlife managers and researchers should consider the different performance and sex and age bias of each hunting and capture method, as well as the associated public cost, to improve efficiency and achieve the best results in wild boar population management.

1. Introduction

Urbanization causes habitat loss and fragmentation, and while it threatens biodiversity, it also offers new ecological niches for adaptable wildlife species (Luniak, 2004; McIntyre, 2014). This phenomenon has inevitably led to increased human-wildlife interactions (Grimm et al., 2008; Kowarik, 2011; McCleery et al., 2014), especially with overabundant or expanding wildlife populations (Massei et al., 2012). These interactions often result in human-wildlife conflicts (HWC), negatively affecting both parties (Soulsbury and White, 2015; Hill, 2021; Pascual-Rico et al., 2021; González-Crespo et al., 2023a).

Among the principal taxa involved in HWC are wild ungulates, whose populations have increased since the mid-20th century recolonising large areas worldwide (Valente et al., 2020; Carpio et al., 2021). Wild boar (*Sus scrofa*), an extremely adaptable ungulate with the highest reproductive rate among its taxon is a representative example (Fonseca et al., 2011; Massei et al., 2015). In Europe, wild boar populations have been increasing steadily since the beginning of the 1980s (Massei et al., 2015) and they are currently present in cities such as Barcelona, Berlin, Budapest, Rome and Vilnius (Massei et al., 2015; Náhlik et al., 2017; Stillfried et al., 2017). This has led to a habituation process in which wild boars are losing their fear of humans, intensifying conflicts such as vehicle collisions, enhanced risk of zoonosis transmission, damage to crops and green areas, and direct attacks on humans and/or companion animals (Wang et al., 2019; Gibb et al., 2020; Carpio et al., 2021; Castillo-Contreras et al., 2021a, 2021b; González-Crespo et al., 2023b; McKee et al., 2024). In Catalonia (northeastern Spain), wild boars have tripled their population in the last two decades (DARP, 2020). Specifically, in Collserola Natural Park (CNP), within the metropolitan area of Barcelona (MAB), the wild boar population has risen ten-fold during this same period (Cahill et al., 2012; González-Crespo et al., 2018; Minuartia, 2023). Furthermore, under the current scenario, their populations are predicted to keep increasing (González-Crespo et al., 2018), probably intensifying these conflicts (Massei et al., 2015; Vajas et al., 2020; González-Crespo et al., 2023a).

Despite the challenges posed by the human component (McCleery et al., 2014), managing urban wildlife populations has become imperative. Strategies include lethal and non-lethal management (Nyhus, 2016). Hunting, professional culling, poisoning, and trapping are the most implemented methods for lethal control and are more cost-effective than non-lethal practices (Adams, 2018), although infrequently applied in cities due to legal and safety restrictions (BOE, 1970; Treves, 2009; Peebles et al., 2013; Drake, 2014; Apollonio et al., 2017). Conversely, nonlethal approaches, such as reducing habitat carrying capacity (Van Vuren and Smallwood, 1996; González-Crespo et al., 2018) enjoy greater public acceptance, reflecting growing concerns for animal welfare (Sijtsma et al., 2012; Hunold and Mazuchowski, 2020; Martínez-Jauregui et al., 2020).

In the specific case of wild boar population control, the management has traditionally relied on hunting as a lethal measure (Gortázar and Fernández-de-Simón, 2022). However, although suspending hunting activity results in the rise of wild boar numbers (Quirós-Fernández et al., 2017), populations keep increasing even under recreational hunting pressures by over 50 % (Toïgo et al., 2008; Massei et al., 2015). Therefore, to effectively halt the increasing population trends, reducing anthropogenic food resources and the selective harvest of targeted age and sex classes have been suggested as the best approaches (Toïgo et al., 2008; González-Crespo et al., 2018). Different hunting methodologies result in different performance and targeting of age and sex classes (Bergqvist, 2022; Vajas et al., 2023), determining the differential capabilities of each method for controlling wild boar populations (González-Crespo et al., 2018). Nevertheless, hunting in urban areas cannot be applied because of legal and public safety reasons (BOE, 1970), and there is an increasing negative attitude towards hunting (Gortázar et al., 2016), with non-hunting lethal methods gaining better public acceptance than hunting to control synurbic wild boar populations (Conejero et al., 2019; Conejero et al., 2024). Hence, live-capture methods, such as teleanaesthesia, cage traps, and drop net would play a significant role in controlling the wild boar population and reducing HWC in urban and peri-urban environments (Torres-Blas et al., 2020), while maintaining humane trapping standards (Conejero et al., 2022).

To determine the capability and efficiency of each method to manage wild boar populations according to the specific circumstances of each region and conflict, the features determining performance must be characterized (Torres-Blas et al., 2020; Vajas et al., 2020), as well as the sex and age classes captured (González-Crespo et al., 2018). Furthermore, since live-capture methods are normally enforced by the administration, they incur public expenses. Thus, evaluating the specific impact of each hunting and capture method on wild boar population dynamics is essential to inform optimal resource allocation decisions (Pepin et al., 2017). Hence, the purpose of this study is to address the differences in performance, the age and sex classes targeted, and the seasonal patterns of two hunting and three live-capture methods currently employed as wild boar population control measures in urban and peri-urban areas (namely drive hunting, night stalking, drop net, cage trap, and teleanaesthesia). The results should allow informed decision-making to manage and control wild boar populations in urban and peri-urban areas and will be useful for wildlife researchers and managers.

2. Material and methods

2.1. Study area

The study area includes the urban and peri-urban areas of Barcelona City, the CNP, and the campus of the Universitat Autònoma de Barcelona (UAB), all within the MAB in Catalonia, NE Spain (Fig. 1). The urban area of Barcelona spreads southeast from the edge of CNP, with an extension of 101.35 km^2. Although it is mostly urbanized, 13 % of its surface is covered by green areas, composed mostly of small, isolated parks (Ajuntament de Barcelona, 2020). The Collserola massif covers approximately 111 km^2, including the 82.95 km^2 of the CNP (Departament d'Agricultura Ramaderia Pesca i Alimentació, 2020). It is surrounded by human infrastructure, receiving an increasing trend of human visitors yearly; from three million in 2019 to more than five million in 2022 (Parc de Collserola, 2023). Location, natural heritage, proximity to cities, and human disturbance define CNP as a peri-urban habitat, hosting a partially synurbic wild boar population genetically distinct from the surrounding rural populations (Hagemann et al., 2022). In CNP, hunting is allowed in 30.21 km^2 (36.4 % of the CNP surface), but due to local political and regulatory constraints, it is carried out only in 17.38 km^2 (21.0 % of the CNP surface) (Parc de Collserola, 2023). Finally, the UAB campus is located 1.3 km north of CNP, connected to it through several streams and roads. The UAB campus includes approximately 2.60 km^2, and it is an urbanized environment with approximately 60 % green areas (UAB, 2023a). In the three locations, the vegetation and the climate are typically Mediterranean. CNP and the UAB are primarily characterized by Mediterranean forests, including Aleppo pine (*Pinus halepensis*) and holm oak (*Quercus ilex*), as well as scrubland (Parc de Collserola, 2022; UAB, 2023b). For further details regarding the study area, see Castillo-Contreras et al. (2018, 2021a).

2.2. Capture methods and wild boar handling

Between February 2014 and August 2022, 1454 wild boars were either hunted through drive hunt, and night stalks, or captured with drop net, teleanaesthesia, and cage traps (Table 1, Fig. 1). The mean number of captured wild boars both overall and for each age and sex class per event was evaluated for each capture method. For consistency, a capture event was defined as a capture, activation or hunting occurring on a specific day in a specific location. When multiple drive hunts, night stalks, cage traps or teleanaesthesia protocols took place on the same day, each was considered a separate capture event.

For descriptive statistics, the total number of events conducted during the study period was considered for hunting methods (N = 99 for drive hunts and N = 1195 for night stalks, Table 1). However, to fit the models only a subset of successful events where age and sex could be accurately determined (N = 67 for drive hunts and N = 116 for night stalks, Table 1) was utilized.

Drive hunts (99 altogether, 91 successful, 67 of which included in the model, Table 1) were conducted in the hunting grounds of CNP during the regular hunting season, spanning from October to March, between 2015 and 2021. (Table 1, Fig. 1). During these hunts, beaters and dogs were used to flush out wild boars from their resting places and drive them towards the waiting hunters stationed at fixed posts (Vajas et al.,

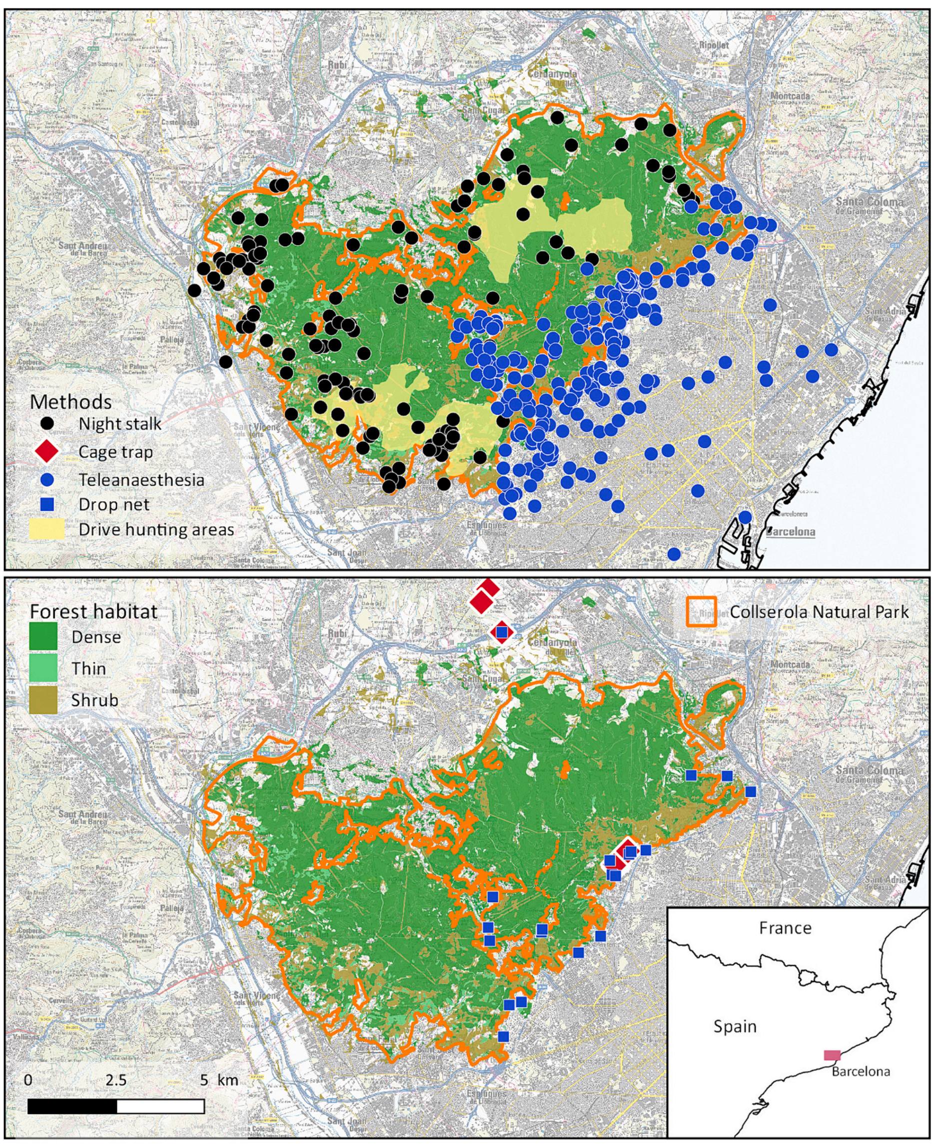

Fig. 1. Study area. (A) Locations of drive hunting areas, night stalk, and teleanaesthesia capture events in Collserola Natural Park (CNP) and Barcelona, respectively. (B) Locations of cage traps and drop nets at Universitat Autònoma de Barcelona (UAB) (upper red and blue squares) and in the interface between CNP and the urban area of Barcelona. The forest type is indicated in both (A) and (B).

Table 1
Number of captures, efficacy and efficiency rates, number of wild boars (WB), participants and cost of wild boar population control in the metropolitan area of Barcelona (MAB).

	Capture method				
	Drive hunting	Night stalk	Cage trap	Drop net	Teleanaesthesia
Complete database for descriptive statistics					
Years	2015–2021	2015–2021	2014–2021	2016–2022	2014–2021
Events (successful/total)	91/99	421/1195	101/472	49/55	240/259
Efficacy (%)	91.9	41.1	21.4	89.1	92.7
WB captured	420	519	227	317	464
WB captured/observed	420/1024 (41.0 %)	519/1442 (36.0 %)	–	–	–
$WB/event_{Total}$	4.25 ± 3.60^{A}	0.41 ± 0.50^{B}	0.48 ± 0.05^{B}	5.76 ± 0.58^{C}	1.83 ± 0.12^{D}
$WB/event_{Successful}$	4.57 ± 0.53^{A}	1.21 ± 0.24^{B}	2.25 ± 0.14^{C}	6.47 ± 0.57^{D}	1.93 ± 0.12^{E}
Subaset database for modelling including only successful events with complete wild boar data used					
Events	67	116	101	49	240
Autumn	41 (61.2 %)	14 (12.1 %)	13 (12.9 %)	17 (34.7 %)	44 (18.3 %)
Winter	26 (38.8 %)	22 (19.0 %)	14 (13.9 %)	2 (4.1 %)	32 (13.3 %)
Spring	–	60 (51.7 %)	24 (23.8 %)	7 (14.3 %)	96 (40.0 %)
Summer	–	20 (17.2 %)	50 (49.5 %)	23 (46.9 %)	68 (28.3 %)
WB captured	300	146	227	317	464
Adult females	76 (25.3 %)	23 (15.8 %)	9 (4.0 %)	70 (22.1 %)	59 (12.7 %)
Adult males	76 (25.3 %)	65 (44.5 %)	7 (3.1 %)	15 (4.7 %)	20 (4.3 %)
Yearling females	44 (14.7 %)	11 (7.5 %)	26 (11.5 %)	37 (11.7 %)	45 (9.7 %)
Yearling males	50 (16.7 %)	33 (22.6 %)	15 (6.6 %)	22 (6.9 %)	73 (15.7 %)
Juvenile females	32 (10.7 %)	10 (6.9 %)	83 (36.6 %)	84 (26.5 %)	121 (26.1 %)
Juvenile males	22 (7.3 %)	4 (2.7 %)	87 (38.3 %)	89 (28.1 %)	146 (31.5 %)
Effort and cost					
Participants/event	38.6 ± 15.3 (17–105)	1 (1)	2–4 (2)	3–6 (5)	3–12 (5)
$Efficiency_{total}$ (WB/people-day)	0.12^{A}	0.48^{B}	0.24^{C}	1.15^{D}	0.37^{B}
$Efficiency_{successful}$ (WB/people-day)	0.12^{A}	1.21^{B}	1.12^{C}	1.29^{B}	0.39^{C}
Cost/WB captured (€)	1325*	377*	746**	840**	904**

The efficacy was the ratio between the number of successful captures (at least one wild boar) and the total number of captures. The efficacy was additionally calculated as the ratios between the captured and observed individuals for the two hunting methods. The number of participants per capture included the minimum, the maximum and the mean number of people involved in each capture event. The efficiency was the mean number of wild boars per participant for each event. Mean performance per event ($WB/event_{Total}$) and per successful event ($WB/event_{success}$) were also estimated; the values sharing a letter in the same row did not differ statistically.

* Private funding calculated from Ferrón (2019).

** Public funding estimated from own data by the authors.

2020).

Night stalks (1195 altogether, 421 successful, 116 of which included in the model, Table 1) were carried out in the Collserola massif from 2015 to 2021 (Table 1, Fig. 1). This hunting method was employed all year round, with a single hunter using a spotlight and waiting for wild boars in specific points baited with corn (Braga et al., 2010), determined by the local Government and the hunters as a response to crop damages.

Fifty-five drop net capture events (all 49 successful events included in the model, Table 1) were conducted all year round from 2016 to 2022 in the interface between CNP and the urban area of Barcelona (Table 1, Fig. 1). The capture spots were selected according to the hotspots for human–wild boar conflicts detected through the incidences reported by citizens to the Local Police of Barcelona the year before (Castillo-Contreras et al., 2018; González-Crespo et al., 2023a), and considering the physical suitability for drop net assembly in discrete sites. They were baited with corn for 1–2 weeks to attract individuals and monitored through camera traps to confirm wild boar presence before the trapping day (Peris et al., 2019; Torres-Blas et al., 2020; Conejero et al., 2022). In the same capture day (considered as an event), the trap was activated as many times as required (range 0–3) by the presence of wild boars.

Cage trapping events (472 altogether, all 101 successful events included in the model, Table 1) were conducted from 2014 to 2021 in the UAB campus (n = 73, three cages deployed) and in two urban green areas in Barcelona City (n = 28, three cages deployed in each area; Barasona et al., 2013; Torres-Blas et al., 2020). At the UAB campus, the wild boars visiting the cages were continuously monitored by camera traps, and the cages were activated only when wild boar presence was detected. When damage to surrounding crops or gardens was observed, or when wild boar detection by camera traps increased, the cages were first baited with the door of the trap secured in an open position for one week. Then, once wild boars were detected inside the cages by bait consumption or by the cameras, the cage door was unlocked during the afternoon to activate the trap.

Teleanaesthesia capture events (259 altogether, all 240 successful events included in the model, Table 1) were reactively performed from 2014 to 2021 to solve emergency problematic situations in the urban area of Barcelona. This capture method involved the Barcelona Local Police and a wildlife veterinarian, who anaesthetized the wild boars using a blowpipe and a combination of tiletamine (3 mg/kg) and zolazepam (3 mg/kg) (Zoletil 100, Virbac Animal Health, Spain) with xylazine (3 mg/kg) (Xilagesic 20 %, Calier Laboratories, Spain) (Barasona et al., 2013; Casas-Díaz et al., 2015). For more technical details about the live-capture methods, see Torres-Blas et al. (2020) and Conejero et al. (2022).

Wild boar sex was determined by visual inspection of the external genitalia. Ageing was conducted using tooth eruption, replacement and wear patterns (Matschke, 1967; Iff, 1978; Borgo and Dotta, 2011). Subsequently, the wild boars were assigned to three age categories (Servanty et al., 2009), namely juveniles (<12 months), yearlings (12 to 24 months), and adults (over 24 months). Table 1 summarises the information regarding the five hunting and capture methodologies.

2.3. Data analysis

The database was constructed considering all the age-sex categories (adult male, adult female, yearling male, yearling female, juvenile male, and juvenile female), the hunting or capture method, the date, and the season. A first complete database including all the events (i.e., 99 drive hunts, 1195 night stalks, 472 cage trapping, 55 drop netting, and 259 teleanaesthesias) was used to calculate descriptive statistics, i.e., the number of captures, efficacy, efficiency, and mean performance summarised in Table 1. The efficacy was defined as the ratio between successful capture events (with at least one captured wild boar) and the total number of events. For the hunting methods, the efficacy was additionally defined as the ratio between the number of actually hunter-harvested wild boars and the number of wild boars observed in each event. For capture method efficiency, assessed as person-days per wild boar hunted, the mean number of captured individuals per event was divided by the mean number of participants (i.e., the human resources required to carry out the hunting or capture operation). Efficiency was calculated for both the total and the successful events (Table 1). The differences in efficacy between the methods were assessed using Fisher's exact test. In contrast, differences in efficiency were analyzed with a Kruskal-Wallis test followed by Dunn's test for pairwise comparisons. A subset database encompassing only the successful events where complete information of the wild bar age and sex was available, not considering neither the unsuccessful events nor the successful events where the sex and age of the wild boars was not ascertained, was used to calculate the mean number of captured wild boars by sex, age class, and period (autumn-winter and spring-summer) for each hunting and capture method. This second database included 67 successful drive hunts, 116 successful night stalks, 101 successful cage trapping, 49 successful drop netting, and 240 successful teleanaesthesias (Table 1). The resulting values are summarised in Table 2.

A generalized linear model (GLM) with a Poisson error distribution and log link function was used to compare the capture and hunting methods. The number of wild boars per event (performance hereafter) was the response variable, whereas age class, method of capture, sex,

Table 2
Descriptive statistics for the number of wild boars (mean ± standard error, minimum-maximum, and n = number of capture events) captured by age class and period of the year (P: "AW" Autumn-Winter and "SS" Spring-Summer), showing separately the results for female, male, and total number of wild boars ("T") for each category.

Age class	P	Sex	Capture methods				
			Drive hunting	Night stalk	Cage trap	Drop net	Teleanaesthesia
All age classes together	AW	♀	2.27 ± 0.21^{A} (0–9, n = 67)	0.42 ± 0.09^{B} (0–2, n = 36)	1.04 ± 0.20^{B} (0–4, n = 27)	3.05 ± 0.46^{A} (1–8, n = 19)	0.75 ± 0.11^{B} (0–5, n = 76)
		♂	2.21 ± 0.20^{A} (0–6, n = 67)	0.44 ± 0.09^{B} (0–2, n = 36)	1.04 ± 0.24^{BC} (0–4, n = 27)	1.95 ± 0.30^{AC} (0–5, n = 19)	0.83 ± 0.10^{B} (0–4, n = 76)
		T	4.48 ± 0.32^{A} (1–15, n = 67)	1.17 ± 0.06^{B} (1–2, n = 36)	2.07 ± 0.29^{C} (1–6, n = 27)	5.00 ± 0.63^{A} (2–11, n = 19)	1.58 ± 0.15^{C} (1–7, n = 76)
	SS	♀	–	0.36 ± 0.06^{A} (0–2, n = 80)	1.22 ± 0.11^{B} (0–3, n = 74)	4.43 ± 0.50^{C} (0–13, n = 30)	1.02 ± 0.12^{D} (0–9, n = 164)
		♂	–	0.94 ± 0.07^{A} (0–2, n = 80)	1.09 ± 0.12^{A} (0–5, n = 74)	2.97 ± 0.44^{B} (0–9, n = 30)	1.07 ± 0.08^{A} (0–5, n = 164)
		T	–	1.30 ± 0.07^{A} (1–4, n = 80)	2.31 ± 0.16^{B} (1–7, n = 74)	7.40 ± 0.80^{C} (1–21, n = 30)	2.10 ± 0.17^{D} (1–14, n = 164)
Adults	AW	♀	1.12 ± 0.15^{A} (0–5, n = 67)	0.25 ± 0.08^{B} (0–2, n = 36)	0.11 ± 0.08^{B} (0–2, n = 27)	1.21 ± 0.25^{A} (0–4, n = 19)	0.21 ± 0.05^{B} (0–2, n = 76)
		♂	1.12 ± 0.14^{A} (0–5, n = 67)	0.44 ± 0.09^{B} (0–2, n = 36)	0.04 ± 0.04^{C} (0–1, n = 27)	0.26 ± 0.10^{BC} (0–1, n = 19)	0.09 ± 0.04^{C} (0–2, n = 76)
		T	2.27 ± 0.09^{A} (0–8, n = 67)	0.69 ± 0.10^{B} (0–2, n = 36)	0.15 ± 0.09^{C} (0–2, n = 27)	1.47 ± 0.31^{A} (0–4, n = 19)	0.30 ± 0.06^{D} (0–2, n = 76)
	SS	♀	–	0.18 ± 0.04^{AB} (0–1, n = 80)	0.08 ± 0.03^{A} (0–1, n = 74)	1.57 ± 0.23^{C} (0–5, n = 30)	0.26 ± 0.04^{B} (0–3, n = 164)
		♂	–	0.61 ± 0.07^{A} (0–2, n = 80)	0.08 ± 0.03^{B} (0–1, n = 74)	0.33 ± 0.11^{A} (0–2, n = 30)	0.08 ± 0.02^{B} (0–2, n = 164)
		T	–	0.79 ± 0.07^{A} (0–3, n = 80)	0.16 ± 0.04^{B} (0–1, n = 74)	1.90 ± 0.26^{C} (0–6, n = 30)	0.34 ± 0.05^{D} (0–5, n = 164)
Yearlings	AW	♀	0.65 ± 0.1^{A} (0–3, n = 67)	0.03 ± 0.03^{B} (0–1, n = 36)	0.22 ± 0.08^{AB} (0–1, n = 27)	0.53 ± 0.18^{AC} (0–2, n = 19)	0.20 ± 0.05^{BC} (0–2, n = 76)
		♂	0.75 ± 0.11^{A} (0–4, n = 67)	0.25 ± 0.09^{B} (0–2, n = 36)	0.15 ± 0.07^{BC} (0–1, n = 27)	0.42 ± 0.22^{ABC} (0–3, n = 19)	0.32 ± 0.06^{B} (0–2, n = 76)
		T	1.40 ± 0.16^{A} (0–5, n = 67)	0.28 ± 0.09^{B} (0–2, n = 36)	0.37 ± 0.09^{BC} (0–1, n = 27)	0.95 ± 0.35^{ABC} (0–5, n = 19)	0.51 ± 0.07^{B} (0–2, n = 76)
	SS	♀	–	0.13 ± 0.04^{A} (0–1, n = 80)	0.27 ± 0.06^{A} (0–2, n = 74)	0.90 ± 0.19^{B} (0–3, n = 30)	0.18 ± 0.04^{A} (0–3, n = 164)
		♂	–	0.30 ± 0.06^{A} (0–2, n = 80)	0.39 ± 0.06^{A} (0–2, n = 74)	0.47 ± 0.16^{A} (0–3, n = 30)	0.30 ± 0.04^{A} (0–3, n = 164)
		T	–	0.43 ± 0.06^{A} (0–2, n = 80)	0.42 ± 0.07^{A} (0–2, n = 74)	1.37 ± 0.30^{B} (0–5, n = 30)	0.48 ± 0.06^{A} (0–5, n = 164)
Juveniles	AW	♀	0.47 ± 0.08^{A} (0–3, n = 67)	0.14 ± 0.06^{B} (0–1, n = 36)	0.70 ± 0.20^{AC} (0–4, n = 27)	1.32 ± 0.29^{C} (0–4, n = 19)	0.34 ± 0.08^{AB} (0–4, n = 76)
		♂	0.32 ± 0.07^{AC} (0–2, n = 67)	0.06 ± 0.04^{C} (0–1, n = 36)	0.85 ± 0.25^{AB} (0–5, n = 27)	1.26 ± 0.21^{B} (0–3, n = 19)	0.42 ± 0.10^{AC} (0–4, n = 76)
		T	0.81 ± 0.12^{A} (0–4, n = 67)	0.19 ± 0.07^{B} (0–1, n = 36)	1.76 ± 0.34^{AC} (0–6, n = 27)	2.58 ± 0.41^{C} (0–4, n = 19)	0.76 ± 0.15^{AB} (0–6, n = 76)
	SS	♀	–	0.06 ± 0.03^{A} (0–1, n = 80)	0.86 ± 0.11^{B} (0–3, n = 74)	1.97 ± 0.28^{C} (0–6, n = 30)	0.58 ± 0.08^{D} (0–5, n = 164)
		♂	–	0.03 ± 0.02^{A} (0–1, n = 80)	0.86 ± 0.13^{B} (0–5, n = 74)	2.17 ± 0.35^{C} (0–7, n = 30)	0.7 ± 0.08^{B} (0–5, n = 164)
		T	–	0.09 ± 0.0^{A} (0–1, n = 80)	1.72 ± 0.19^{B} (0–7, n = 74)	4.13 ± 0.51^{C} (0–12, n = 30)	1.27 ± 0.13^{D} (0–10, n = 164)

Methods sharing a letter do not differ significantly in the mean number of captured individuals for each category.

and their interactions were set as explanatory factors. The best-fit model incorporated a three-way interaction between the capture method, sex, and age class (Table S1), resulting in a high-order interaction model with 30 degrees of freedom. Given the complexity of interpreting the results of this model, specific GLMs were developed for each age class to facilitate more interpretable analysis. In this second set of models, the number of wild boars per event for each age category was the response variable, whereas the method of capture, sex, and their two-way interactions were set as explanatory factors, yielding results much easier to interpret, communicate, and understand. Since drive hunting is limited to autumn and winter, the analysis was performed on a limited data subset comprising the capture and hunting events for all methods from these seasons for each age class.

On the contrary, drive hunting was excluded from the second model, since it attempted to detect seasonal patterns in the performance of the different methods. In this second GLM, the response variable was also the number of wild boars per capture event (both total and for each age category). In contrast, the explanatory factors were the capture method, the season of the year (spring, summer, autumn, and winter), and their two-way interaction.

Model selection was performed according to the Akaike Information Criterion (Burnham and Anderson, 2002). The Akaike weight (ωi) for each competing model was also calculated. Once the models were ranked according to their AIC value, overdispersion was checked (residual deviance higher than the degrees of freedom and the dispersion statistic) and negative binomial distribution was used when necessary (Zuur et al., 2013). For post hoc comparisons, the Kruskal-Wallis tests with a Bonferroni correction in the library "emmeans" 1.7.2 version were used (Lenth, 2022). To determine statistical differences in performance for the total number of wild boars and for each specific age category between pairs of capture methods, pairwise Wilcoxon sum rank tests were also conducted. Significance was established at $p < 0.05$. The relative probability of capturing a wild boar of a specific age and sex class using the method or methods with the highest performance versus the alternative methods was also assessed. This evaluation involved calculating the ratio of the mean number of captured individuals per event for the two methods, as well as determining the range. All the statistical analyses were performed in the R Statistical Software 4.1.2 version (R Core Team, 2022).

2.4. Cost and effort estimation

The cost and human effort required by the hunting methods were estimated from a previous study (Ferrón, 2019). For drop nets, the cost of each wild boar capture was obtained by dividing the budget charged to Barcelona municipality by the pest control enterprises by the total number of wild boars captured. Finally, the costs and efforts for wild boar cage trapping and teleanaesthesia were calculated from own data. Table 3 summarises the maincosts and efforts to be considered in wild boar hunting and capture, grouped under three different concepts: (1) required equipment and budget; (2) deployment costs, both as material and human effort; and (3) required people involved in the hunting or capture event. While the first concept has a constant annual value, the two latter vary according to the number of hunting or capture events carried out. Finally, all the values were added up and divided by the total number of wild boars hunted or captured with each method, to obtain an estimation of the hunting or capture cost per wild boar (Table 1).

Table 3
Human efforts, implementation and deployment costs for the hunting and capture methods.

	Equipment and budget	Deployment costs	People and effort required
Drive hunting (Ferrón, 2019)	- Firearms - Permits and insurance - Dogs - Radio transceivers - Facilities for carcass dressing	- Travel expenses - Subsistence allowance - Bullets - Analyses (*Trichinella* spp.) - Offal management	- Hunters and drivers (12–105) - Dogs (7–83) - Access control to hunting area (7–12)
1325 €/wild boar	**608 €/wild boar**	**717 €/wild boar**	
Night stalk (adapted from Ferrón, 2019)	- Firearms - Permits and insurance - Facilities for carcass dressing	- Travel expenses - Bait - Bullets - Analyses (*Trichinella* spp.) - Offal management	- Baiting (2–7 days) - Stalking - Hunter (1)
377 €/wild boar	**302 €/wild boar**	**75 €/wild boar**	
Cage trap (calculated from own data)	- Cage trap - Camera trap for surveillance - Teleanaesthesia equipment - Euthanasia equipment	- Travel expenses - Subsistence allowance - Bait - Euthanasic drugs - Carcass management	- Cage trap deployment - Baiting (1–2 weeks) - Camera trap image processing - Cage trap activation - Trapper (1) - Veterinarian intervention (1)
746 €/wild boar	**28 €/wild boar**	**718 €/wild boar**	
Drop net (calculated for control pest enterprise budget)	- Drop net - Camera trap for surveillance - Euthanasia equipment	- Travel expenses - Subsistence allowance - Bait - Euthanasic drugs/ Captive bolt - Carcass management	- Baiting and camera trapping (1 week) - Camera trap image processing - Drop net deployment - Trappers (3–4) - ± Veterinarian intervention (1)
840 €/wild boar			
Teleanaesthesia (calculated from own data)	- Teleanaesthesia equipment - Euthanasia equipment	- Travel expenses - Anaesthetic drugs - Carcass management	- Wild boar location, control and surveillance (2–6 rangers/ police authorities) - Veterinarian intervention (1)
904 €/wild boar	**24 €/wild boar**	**880 €/wild boar**	

3. Results

Table 1 summarises the number of boars captured by method and season as well as the mean efficacy, efficiency, participants, and the economic cost of each capture event. Table 2 includes descriptive statistics (mean, standard error; "SE", min-max) for the number of wild boars captured by sex and age class (juveniles, yearlings, and adults) each period of the year (summer-spring and autumn-winter). In general terms, teleanaesthesia, drive hunting and drop net had the highest efficacy (number of successful capture events/total capture events), with the highest performance (number of wild boars captured/capture event) for drive hunting and drop net (Table 1).

The best model to explain the observed variability in the number of adult wild boars captured included the interaction between sex and method (AIC = 746.06, ωi = 0.98, Table 4). This model explained 33.04 % of the observed variability.

For adult females, there were statistically significant differences among capture methods ($H(4) = 61.27$, $p < 0.001$). The drop net and

Table 4
Model selection for the number of wild boars captured in the metropolitan area of Barcelona, northeast Spain.

Biological models	K	AIC	AICc	Δi	ωi
Adults					
Method * Sex	10	746.06	746.56	0.00	0.98
Method	7	754.85	755.10	8.79	0.01
Method + Sex	5	754.88	755.02	8.82	0.01
M_0	1	914.80	914.81	168.74	0.00
Yearlings					
Method * Sex	10	687.73	688.23	0.00	0.38
Method + Sex	6	688.08	688.27	0.35	0.32
Method	5	688.19	688.33	0.47	0.30
M_0	1	738.24	738.25	50.51	0.00
Juveniles					
Method	6	779.14	779.33	0.00	0.70
Method + Sex	7	781.05	781.30	1.91	0.27
Method * Sex	11	785.52	786.13	6.38	0.03
M_0	2	829.46	829.49	50.32	0.00

K = number of parameters, AIC = Akaike Information Criterion, AICc = Akaike Information Criterion corrected for small sample sizes, Δi = difference of AIC concerning the best model, ωi = Akaike weight. In bold, the models with substantial support, M0 = null model including the intercept and error terms. The models were developed from 225 hunting and capture events: 67 drive hunts (41 in autumn and 26 in winter); 36 night stalks (14 in autumn and 22 in winter); 27 cage trapping (13 in autumn and 14 in winter); 19 drop-nets (17 in autumn and 2 in winter); and 76 teleanaesthesia (44 in autumn and 32 in winter), accounting for 450 observations (male and female captures for each event).

drive hunting performed better than the other three methods (all Wilcoxon sum rank tests with $p < 0.001$, Table 2).

In the case of adult males, the Kruskal-Wallis test ($H(4) = 71.66$, $p < 0.01$) also found statistically significant differences among methods, with a higher performance (adult males captured per event) for drive hunting, followed by night stalks and drop net, with teleanaesthesia and cage trapping as the methods capturing less adult males (Table 2, Fig. 2B).

Concerning yearlings, three models had an ΔAIC < 2. The simplest model (AIC = 687.73, ωi = 0.30, Table 4) included the single effect of the capture method, explaining 12.84 % of the observed variability. The models including also sex, with and without interaction with the capture method, explained 15.17 % and 13.31 % of the observed variability, respectively (Table 4). Statistically significant differences in performance were detected among methods ($H(4) = 39.836$, $p < 0.001$). Drive hunting significantly captured more yearlings than any other method except the drop net, which in turn, did not significantly differ from night stalks, cage traps, and teleanaesthesia (Table 2, Fig. 2C).

With regards to juveniles, two models had an ΔAIC < 2. The simplest model (AIC = 779.14, ωi = 0.70, Table 4) included the single effect of the capture method, explaining 14.94 % of the observed variability. The model including the method and the additive effect of sex (AIC = 781.05, ωi = 0.27, Table 4) explained 14.97 % of the observed variability. Statistically significant differences in performance among methods ($H(4) = 144.48$, $p < 0.001$) were also observed, with drop net and cage trap having the highest performance (Fig. 2D). However, while drop net performance was significantly higher than that of the other three methods (drive hunting, night stalk, and teleanaesthesia), cage trap only differed significantly from night stalks (Table 2).

A seasonal trend was observed in the total number of hunted or captured wild boars and in the number of juveniles, with the highest performance in summer (Fig. 3). For adults and yearlings, however, the capture methods performed similarly across seasons (Table 5). The models including method and season explained 41.51 % of the variability in the total number of captured wild boars (AIC = 4860.21, ωi = 0.99, Table 5), and 31.05 % of the variability in the number of captured juveniles (AIC = 1384.20, ωi = 0.76, Table 5).

Finally, the number of participants required, efficiency (in terms of wild boar per people-day), and cost of each wild boar hunted or captured with each method are also shown in Table 1. Drive hunt required the highest number of participants, followed by drop net and teleanesthesia, with night stalks and cage trap as the methods that can be handled by fewer operators. Drop net had the highest efficiency, followed by similar values of night stalks and teleanaesthesia, and cage traps and drive hunts in decreasing order. The cost of each wild boar was similar in the two hunting methods, in both cases funded by the hunters, and higher than the public cost of each wild boar captured using teleanaesthesia, drop net, and cage trap, in this order.

4. Discussion

In this study, we investigated the performance and the potential sex and age class bias associated with two hunting and three live-capture methods for controlling wild boar populations in urban and peri-urban areas. The models detected sex bias for adult and yearling wild boars, but not for juveniles (Table 4). In general terms, drop net is a collective operator-activated physical capture method, which allows for capturing whole wild boar breeding groups (Torres-Blas et al., 2020; Gaskamp et al., 2021; Conejero et al., 2022), and drive hunting involves a large number of participants (including dogs; Vajas et al., 2020, 2023). These factors could explain the higher performance of these two methods as compared to the other three.

While drive hunting had the highest performance for capturing adult and yearling individuals of both sexes, these two age classes have a lower demographic impact than juveniles on wild boar population dynamics (Festa-Bianchet, 2017; González-Crespo et al., 2018). This bias observed in drive hunting may be linked to hunters' preferences, with an emphasis on pursuing larger males for coveted trophies (García-Jiménez et al., 2013; Kamieniarz et al., 2020). This raises questions about hunters' perceptions of responsibility in population management, even in the face of acknowledged overabundance issues (Keuling et al., 2016). Nevertheless, age class and sex bias in hunting can be influenced by different factors, like animal behaviour and abundance, population structure, and habitat openness (Mysterud, 2011). Therefore, it is also likely that larger-sized animals are inherently more accessible for pursuit and shooting in densely vegetated environments such as Collserola, where the presence of bushes complicates the discernment of wild boar sexes. (González-Crespo et al., 2018). The main value of drive hunting is the high number of captured wild boars with no associated public cost. Besides, for population control, hunting efficiency could be improved by a higher hunting effort (Vajas et al., 2020; Simon et al., 2023). The main disadvantages include the necessity for a large number of participants, its unfeasibility in urbanized areas, and environmental constraints that can hinder the capability of the hunters to select the age and sex classes required by the management goals. Furthermore, the global hunter population is declining, experiencing an annual decrease in membership and an increase in average age (Massei et al., 2015; Cerri et al., 2018; Lovelock et al., 2021). This demographic trend underscores the need for alternative or supplementary approaches to ensure effective wildlife management strategies in the future.

The low performance and effectiveness of night stalks corresponded to the low personnel requirement of this method and were comparable to previous publications on bow hunting for wild boar population control (Delibes de Castro et al., 2022). However, the efficiency, evaluated as person-days per wild boar hunted, was higher for night stalks, mainly due to the lower participant requirement compared to other methods. Furthermore, the performance and efficiency may be improved by the use of supporting tools such as silencers or night vision (Sauter-Louis et al., 2021), where allowed. Night stalks preferably hunted adult males, according to previous reports (Braga et al., 2010). This method allows hunters to watch and choose the target, and therefore harvest criteria for management can be acknowledged more easily than in driving hunts

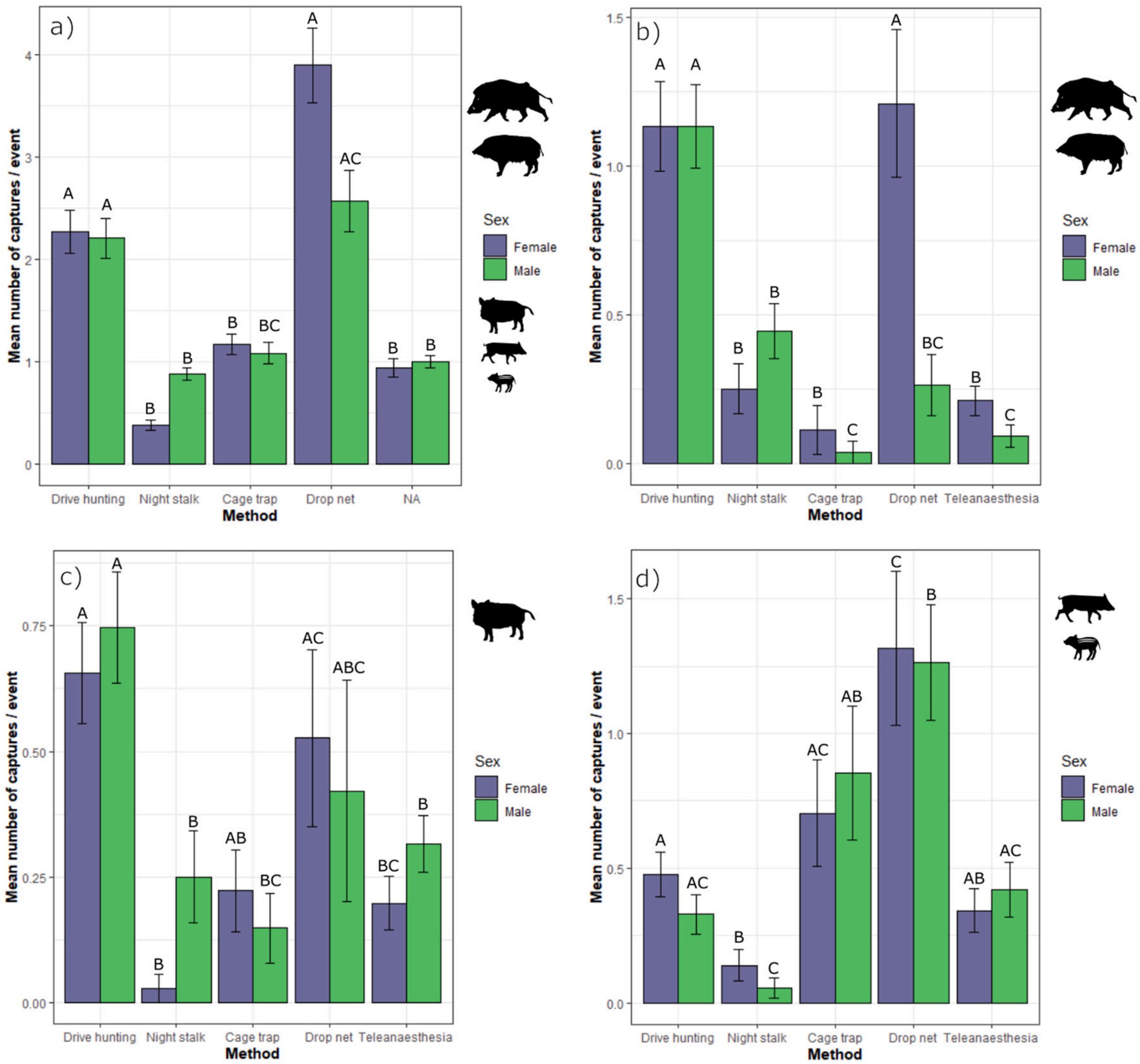

Fig. 2. Mean number of hunted and captured wild boars of any age class (a), adult (b), yearling (c) and juvenile (d) wild boars per event during autumn and winter. Whiskers represent the standard error. A, B, C = Mean number of wild boars captured by each method with different superscripts are significantly ($p < 0.05$) different within each sex.

(Braga et al., 2010). Nevertheless, rising awareness among hunters carrying out night stalks to target the age and sex class required for population control is crucial to achieving the management goal.

Cage trap was the method with the highest performance for capturing juveniles, probably due to the stronger exploratory, risk-taking, and playing behaviour that young wild boars may exhibit (Mitchell, 2011; Marks et al., 2017). This cost-effective approach requires a low number of participants, and it is useful as a long-term method that requires a medium-intensity effort (Torres-Blas et al., 2020). Despite not being entirely species-specific, the selectivity of cage traps for wild boar can exceed 95 % (Barasona et al., 2013). Nevertheless, if captured individuals are not promptly anesthetised by a wildlife veterinarian, they can suffer stress and injure themselves (Barasona et al., 2013). This method had lower efficacy than the other live-capture methods, likely attributed to its passive nature. Its use is also limited to discrete sites and requires continuous monitoring to prevent cage sabotage in urban and peri-urban environments.

Drop-net is one of the most versatile, effective, and efficient methods, capturing all sex and age categories but adult males. Yet, its performance can be influenced by the specific composition of the group. Breeding groups typically comprise overlapping generations of philopatric reproductive females, typically adults and/or yearlings, along with offspring (Iacolina et al., 2009; Kaminski et al., 2005; Maselli et al., 2014). However, when dispersal among yearlings occurs (Truvé and Lemel, 2003), the drop-net efficacy diminishes for this age class. In urban and peri-urban environments, the utility of drop nets is constrained to conflict hotspots characterized by specific environmental features, (discrete sites, clear vegetation, flat soil). Besides, the presence of a wildlife veterinarian could be required for chemical euthanasia by the legislation, as is the case in Spain (BOE, 2023) (BOE-A-2023-7936). While drop-net ensures animal welfare (Conejero et al., 2022), it also incurs the highest associated public cost, as outlined in Table 1.

Teleanaesthesia was the third best-performing method with the highest efficacy rate (Table 1). Due to its reactive nature, the age class and sex-related bias of this method depend on the intrinsic characteristics of the individuals causing a disturbance, typically breeding females with their offspring or dispersing individuals that venture into the city seeking resources in late spring, summer, and early autumn (Castillo-Contreras et al., 2018; Torres-Blas et al., 2020). This is the less stressful method for capturing wild boar and it is necessary as a reactive intervention in urban environments, where other methods are not feasible to remove problematic individuals (Torres-Blas et al., 2020). The public cost associated with a single wild boar capture with this approach was slightly higher than cage trapping, but a higher number of participants is required to ensure success.

The higher performance of the hunting and capture methods in

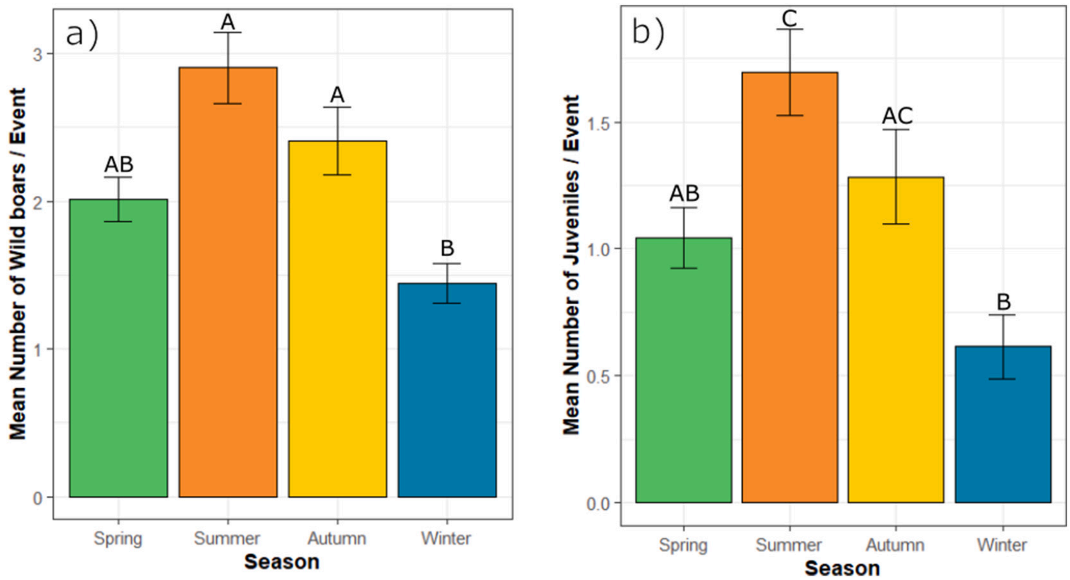

Fig. 3. Mean number of hunted and captured wild boars of any age class (a), and juvenile wild boars (b) per event each season of the year. Whiskers represent the standard error. A, B, C = Mean number of wild boars captured with different superscripts are significantly ($p < 0.05$) different between seasons. Drive hunting events were excluded since they were only carried out during the regular hunting season (autumn and winter).

summer, autumn, and spring, suggests that the observed seasonality is not an intrinsic methodological feature but rather a reflection of seasonal variation in wild boar population abundance and density. Mediterranean wild boar populations follow an annual seasonal trend, with higher numbers in spring, summer, and autumn mainly due to the birth of piglets (Maselli et al., 2014; González-Crespo et al., 2018). Additionally, the number of incidences and conflicts involving wild boars in urban environments significantly increases during spring and summer, also due to the birth of piglets and the consequent higher nutrient requirements for piglet lactation, but also to environmental seasonal drought conditions and natural food resource scarcity in the Mediterranean environment, with higher availability of resources in urban environments (Cahill et al., 2012; Castillo-Contreras et al., 2018; González-Crespo et al., 2018; Castillo-Contreras et al., 2021a, 2021b). Higher seasonal performance of live-capture methods related to higher seasonal juvenile abundance and wild boar population density has been previously reported for live-capture methods, including cage traps (Yokoyama et al., 2020), and also agrees with higher performance of drive hunts at the beginning (autumn) as compared to the end of the hunting season (winter; Vajas et al., 2020). This implies that a higher number of planned or reactive hunting or capture events in the seasons with higher wild boar population abundance and presence in urban and peri-urban areas (i.e., summer, autumn, and spring) would increase the performance, and therefore the efficacy and efficiency to control wild boar population. As for drive hunts, this would mean extending this activity beyond the traditionally restricted seasons (autumn and winter) to include spring and summer (Table 3), which would probably also increase the mean performance of the method. Moreover, such increased hunting and capture activity in the seasons with higher wild boar abundance would also increase the removal of juveniles (Yokoyama et al., 2020), the age class with a higher demographic effect on wild boar population dynamics (González-Crespo et al., 2018), thus enhancing the efficacy and effectiveness of the evaluated hunting and capture methods not only quantitatively but also qualitatively.

There is a need for knowledge to improve wild boar population control measures to mitigate HWC (Massei et al., 2015; Vetter et al., 2020). For efficient control of overabundant species, it is necessary to identify the life stages with a key contribution to population growth (González-Crespo et al., 2018). For wild boar, it has been suggested that limiting supplementary food and the selective harvesting of piglet and juvenile (Bieber and Ruf, 2005; González-Crespo et al., 2018), yearling (Servanty et al., 2011; González-Crespo et al., 2018; Vetter et al., 2020), and adult (Servanty et al., 2011) females would contribute to reducing population growth. Currently, there is a continuing debate over the principal classes to harvest (Keuling et al., 2010; Vetter et al., 2020) and over the demographic and evolutionary effects of selective harvesting itself (Bischof et al., 2008; Festa-Bianchet, 2017), and thus, more empirical research is needed (Milner et al., 2007; Servanty et al., 2011).

Recreational hunting is considered significant but insufficient to control wild boar population growth (Keuling et al., 2013; Quirós-Fernández et al., 2017; Bengsen et al., 2020) in the current overabundance context, where >60 % of the population would need to be harvested for control (Sanguinetti and Pastore, 2016). Nevertheless, one advantage against live-capture methods is that they can provide a valuable and sustainable alimentary resource (i.e., wild game meat) cost-effectively (Macháčková et al., 2021). Table 6 shows the applications, usefulness, strengths, weaknesses, opportunities and threats (SWOT analysis) of the hunting and capture methods evaluated in this study. Considering the age and sex class bias, the strengths and weaknesses, as well as the contexts in which each hunting and capture method can be applied, they could all potentially synergize for effective wild boar population control (Hanson et al., 2009). Drive hunt and drop net had the higher efficiency (Table 1) and are therefore probably the two methods with the higher quantitative demographic effect for population control. However, drop net could have a higher qualitative impact on the long-term wild boar population dynamics thanks to its capture bias towards the most population-sensitive age classes (i.e., juveniles, Bieber and Ruf, 2005; González-Crespo et al., 2018), particularly in peri-urban environments. Drive hunt qualitative performance could nevertheless be improved by extending the hunting period to spring and summer and raising awareness of the management responsibility role among hunters (Table 6). Cage traps and night stalks can complement the demographic pressure of drive hunt and drop net in non-urban and peri-urban environments. As for drive hunts, raising awareness on the management responsibility role among hunters would be required to increase qualitatively the demographic impact of night stalks on wild boar population dynamics (Table 6). Night stalks also accomplish a human-wild boar conflict-solving function in non-urban and peri-urban environments, comparable to that of teleanaesthesia in urban environments (Table 6). On the other hand, teleanaesthesia is

Table 5
Model selection to explore the seasonal variation in the number of captured wild boar in the metropolitan area of Barcelona, northeast Spain.

Biological models	K	AIC	AICc	Δi	ωi
Total wild boar					
Method + Season	7	4860.21	4860.25	0.00	0.99
Method * Season	16	4870.59	4870.77	10.52	0.01
Method	4	4873.22	4873.23	12.99	0.00
Season	4	5143.58	5143.60	283.35	0.00
M_0	1	5194.72	5194.72	334.47	0.00
Female adults					
Method	4	634.52	634.60	0.00	0.86
Method + Season	7	638.03	638.25	3.65	0.14
Method * Season	16	648.00	649.11	14.51	0.00
Season	4	754.01	754.09	119.48	0.00
M_0	1	763.67	763.68	129.07	0.00
Male adults					
Method	4	486.21	486.29	0.00	0.90
Method + Season	7	490.49	490.71	4.42	0.10
Method * Season	16	503.44	504.56	18.27	0.00
M_0	1	565.13	565.14	78.85	0.00
Season	4	565.27	565.35	79.06	0.00
Yearlings					
Method	5	951.28	951.40	0.00	0.89
Method + Season	8	955.27	955.56	4.16	0.11
Method * Season	17	961.61	962.86	11.46	0.00
M_0	2	979.01	979.03	27.63	0.00
Season	5	979.69	979.81	28.41	0.00
Juveniles					
Method + Season	8	1384.20	1384.49	0.00	0.76
Method	5	1386.95	1387.07	2.57	0.21
Method * Season	17	1389.56	1390.81	6.32	0.03
Season	5	1531.74	1531.86	147.37	0.00
M_0	2	1547.29	1547.31	162.82	0.00

K = number of parameters, AIC = Akaike Information Criterion, AICc = Akaike Information Criterion corrected for small sample sizes, Δi = difference of AIC concerning the best model, ωi = Akaike weight. In bold, the models with substantial support, M_0 = null model including the intercept and error terms. The models were developed from 506 hunting and capture events: 116 night stalks (14 in autumn, 22 in winter, 60 in spring, and 20 in summer); 101 cage trapping (13 in autumn, 14 in winter, 24 in spring, and 50 in summer); 49 drop-nets (17 in autumn, 2 in winter, 7 in spring, and 23 in summer); and 240 teleanaesthesia (44 in autumn, 32 in winter, 96 in spring, and 68 in summer). Drive-hunting was performed only in autumn and winter and thus was not included in this analysis.

limited to urban environments since the fleeing distance of rural wild boars is longer than both the fleeing distance of urban wild boars (Stillfried et al., 2017) and the effective teleanaesthetic range. However, relying on such hunting and capture methods as the last-chance solution for human-wild boar conflict is a reactive measure that does not prevent problems (Castillo-Contreras et al., 2018; Conejero et al., 2019; Conejero et al., 2024). Conversely, proactive informed management of synurbic wild boar populations, combining hunting and capture with other measures such as reducing anthropogenic food availability and the attractiveness of the urban environment (Castillo-Contreras et al., 2018; González-Crespo et al., 2018; Castillo-Contreras et al., 2021a, 2021b; González-Crespo et al., 2023a) would probably be a better management strategy. This would also reduce the public cost associated with the management of synurbic wild boar populations since reactive measures are more costly than proactive ones and do not prevent the costs associated with human-wild boar conflicts. Furthermore, the sex and age class bias of the capture method should also be taken into account when describing demographic parameters of wild boar populations based on the animals harvested using a single capture method (i.e., the use of hunting statistics), since this approach may not accurately reflect wild boar demography (Herrero et al., 2008; ENETWILD-consortium et al., 2022).

The cost associated to each hunting and capture method estimated in this study (Tables 1 and 3) is orientative and conditioned to the specific circumstances of the population, environment, management and socio-political context. Thus, the conclusions extracted from these values must be interpreted with caution. Nevertheless, the main difference between the two hunting methods and the three capture methods in our study area was that the cost and effort was assumed by hunters and by the public administration, respectively (Table 6). For all methods but for night stalks, deployment costs were higher than equipment redemption (Table 3), demonstrating that the sustained effort to control wild boar populations is more costly than equipment acquisiton. This further stresses the relevance of carefully planning and assessing the demographic effects of management and control actions to optimise the usually limited public budgets (González-Crespo et al., 2018). A more thorough study on the costs associated with each hunting and capture method in relation with the demographic impact achieved on the wild boar population should be performed in order to allow a better estimation of the cost-benefit ratio for each method.

One limitation of this study was that the hunting and capture methods were not homogeneously distributed throughout the study area, since their use was restricted or limited to specific spots (e.g., hunting methods are prohibited in urban areas for security reasons). This could have affected both the number, sex and age class of the wild boars hunted or captured by each method. However, the wild boars in the study area are a rather genetically homogeneous population different from the surrounding rural ones (Hagemann et al., 2022). Admittedly, despite being genetically homogeneous, different wild boars of different sexes and age classes or social groups could make different use of the peri-urban and urban environments within the study area (Keuling et al., 2008). Nevertheless, the environment and location of each hunting or capture method are intrinsic features of the methods that cannot be disentangled, thus also contributing to the performance, sex, and age class bias of the method. Further studies on the differential use of peri-urban and urban habitats of synurbic wild boars, overall and for each sex and age class, are required to contribute to shed light on this issue.

5. Conclusions

This study shows that hunting and live-capture methods applied for wild boar population control have differential performances and biases towards age and, in the case of adults, sex classes. This is probably related to the intrinsic features of each method, wild boar space use, social behaviour, and urban habituation degree, as well as hunter preferences, social awareness of wild boar overpopulation and the need to control it. Moreover, the methods also differed in their cost, required effort, seasonality, and applicability. Despite the higher number of wild boars visiting the urban areas during spring and summer, live-capture methods had a similar performance throughout the year. Therefore, increasing hunting and/or capture events during or around the conflict season peak to target juveniles, reportedly the age class with the higher demographic impact on wild boar population dynamics, should increase the efficacy and efficiency of these methods to reduce human-wild boar conflict. All the hunting and capture methods included in this study can contribute to managing synurbic wild boar populations in urban and peri-urban areas since they are applied in different environments, contexts and conditions, and they differently target age and sex classes. Combining all these methods, taking advantage of the specific features of each of them, with a reduction of anthropogenic food sources and social awareness campaigns would probably be the best strategy to reduce human wild boar conflict in urban and peri-urban environments. The results of this study may be helpful for wildlife managers, researchers, and administrations to consider the age and sex class bias, the required effort, and the associated costs of each approach, depending on the management goals and the economic budget. This bias needs to be

Table 6
Applications, usefulness, and SWOT (strengths, weaknesses, opportunities, and threats) analysis of the hunting and captured methods evaluated.

	Applications and usefulness	Strengths	Weaknesses	Opportunities	Threats
Drive hunting	Non-urban Autumn and winter Traditional population control	High performance Cost assumed by hunters Socially implemented Sustainable meat source	Hunts mainly adults Requires high number of participants High cost Low efficiency Seasonal Non-urban	Extension to all seasons Hunter training to select age class	Decreasing number of hunters Ageing hunters Depending on hunter willingness Antihunting social perception
Night stalk	Non-urban/Peri-urban Response to damage All year round	Requires low number of participants Cost assumed by hunters Response to damages in rural environments Sustainable meat source	Low performance High cost Medium efficiency Bias to adult male	Hunter training to select age class Technology (silencers, night vision, …)	Decreasing number of hunters Ageing hunters Depending on hunter willingness Antihunting social perception
Cage trap	Non-urban / Peri-urban Constant population control All year round	Captures juveniles Low effort and cost Can be sustained in time	Public cost Low performance Low efficiency Accident hazard in human-populated areas Carcass destruction	Technology for remote activation Spread use to other environments	Social awareness Trap destruction
Drop net	All environents All year round	Capturs juveniles High performance High effectiveness High efficiency Medium requirement of people Versatility Captures whole synurbic family groups	Public cost Nos discrete, requiring specific locations Carcass destruction	Raising social awareness Implementing trap networks	Increasing public cost Social acceptance
Teleanaesthesia	Urban Emergency response All year round	Solves urban conflict Specialized High efficacy Only reactive solution in urban environments	Public cost Low performance Medium efficiency Solves but does not prevent conflict Carcass destruction	Standardizing operational services Combined awareness campaigns to reduce wild boar feeding	Relying on it as last-chance solution Increasing social conflict Increasing accident hazard

accounted for also when describing wild boar population structure based on a single hunting or capture method.

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CRediT authorship contribution statement

María Escobar-González: Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation. **Josep-Maria López-Martín:** Writing – review & editing, Data curation. **Gregorio Mentaberre:** Writing – review & editing, Data curation. **Marta Valldeperes:** Writing – review & editing, Data curation. **Josep Estruch:** Writing – review & editing, Data curation. **Stefania Tampach:** Writing – review & editing, Data curation. **Raquel Castillo-Contreras:** Writing – review & editing, Data curation. **Carles Conejero:** Writing – review & editing, Data curation. **Joan Roldán:** Writing – review & editing, Data curation. **Santiago Lavín:** Writing – review & editing, Data curation. **Emmanuel Serrano:** Writing – review & editing, Supervision, Methodology. **Jorge Ramón López-Olvera:** Writing – review & editing, Supervision, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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References

Adams, C.E., 2018. Urban Wildlife Management. CRC Press, Boca Raton, FL, USA. https://doi.org/10.1201/9781315371863.

Ajuntament de Barcelona, 2020. Urban statistics. Surface (m2) of the territory. https://ajuntament.barcelona.cat/estadistica/angles/Estadistiques_per_temes/Medi_urba/Territori/Superficie/a2020/index.htm. (Accessed 13 August 2023).

Apollonio, M., Belkin, V.V., Borkowski, J., Borodin, O.I., Borowik, T., Cagnacci, F., Danilkin, A.A., Danilov, P.I., Faybich, A., Ferretti, F., Gaillard, J.M., Hayward, M., Heshtaut, P., Heurich, M., Hurynovich, A., Kashtalyan, A., Kerley, G.I.H., Kjellander, P., Kowalczyk, R., Kozorez, A., Matveytchuk, S., Milner, J.M., Mysterud, A., Ozoliņš, J., Panchenko, D.V., Peters, W., Podgórski, T., Pokorny, B., Rolandsen, C.M., Ruusila, V., Schmidt, K., Sipko, T.P., Veeroja, R., Velihurau, P., Yanuta, G., 2017. Challenges and science-based implications for modern management and conservation of European ungulate populations. Mammal Res. 62 (3), 209–217. https://doi.org/10.1007/s13364-017-0321-5.

Barasona, J.A., López-Olvera, J.R., Beltrán-Beck, B., Gortázar, C., Vicente, J., 2013. Trap-effectiveness and response to tiletamine-zolazepam and medetomidine anaesthesia in Eurasian wild boar captured with cage and corral traps. BMC Vet. Res. 9, 107. https://doi.org/10.1186/1746-6148-9-107.

Bengsen, A.J., Forsyth, D.M., Harris, S., Latham, A.D.M., McLeod, S.R., Pople, A., 2020. A systematic review of ground-based shooting to control overabundant mammal populations. Wildl. Res. 47 (3), 197–207. https://doi.org/10.1071/WR19129.

Bergqvist, G., 2022. Harvest bag composition differs among hunting methods for wild boar in Sweden. Eur. J. Wildl. Res. 68 (3), 2–4. https://doi.org/10.1007/s10344-022-01576-9.

Bieber, C., Ruf, T., 2005. Population dynamics in wild boar *Sus scrofa*: ecology, elasticity of growth rate and implications for the management of pulsed resource consumers. J. Appl. Ecol. 42 (6), 1203–1213. https://doi.org/10.1111/j.1365-2664.2005.01094.x.

Bischof, R., Mysterud, A., Swenson, J.E., 2008. Should hunting mortality mimic the patterns of natural mortality? Biol. Lett. 4 (3), 307–310. https://doi.org/10.1098/rsbl.2008.0027.

BOE núm. 75, de 29 de marzo de 2023, páginas 45618 a 45671. Ley 7/2023, de 28 de marzo, de protección de los derechos y el bienestar de los animales.

BOE núm. 82, de 06/04/1970. Ley 1/1970, de 4 de abril, de caza. Ley que regula la protección, conservación y fomento de la riqueza cinegética nacional y su ordenado aprovechamiento en armonía con los distintos intereses afectados.

Borgo, C., Dotta, R., 2011. Cinghiale (*Sus scrofa*). Determinazione dell'età dall'analisis della dentizione. IBIS s.n.c. Consulenze faunistiche.

Braga, C., Alexandre, N., Fernández-Llario, P., Santos, P., 2010. Wild boar (*Sus scrofa*) harvesting using the espera hunting method: side effects and management implications. Eur. J. Wildl. Res. 56 (3), 465–469. https://doi.org/10.1007/s10344-010-0373-1.

Burnham, K.P., Anderson, D.R., 2002. Model Selection and Multimodel Inference: A Practical Information-theoretic Approach, 2nd ed. Springer.

Cahill, S., Llimona, F., Cabañeros, L., Calomardo, F., 2012. Characteristics of wild boar (Sus scrofa) habituation to urban areas in the Collserola Natural Park (Barcelona) and comparison with other locations. Anim. Biodivers. Conserv. 35, 221–233.

Carpio, A.J., Apollonio, M., Acevedo, P., 2021. Wild ungulate overabundance in Europe: contexts, causes, monitoring and management recommendations. Mammal Rev. 51 (1), 95–108. https://doi.org/10.1111/mam.12221.

Casas-Díaz, E., Closa-Sebastià, F., Marco, I., Lavín, S., Bach-Raich, E., Cuenca, R., 2015. Hematologic and biochemical reference intervals for wild boar (*Sus scrofa*) captured by cage trap. Vet. Clin. Pathol. 44 (2), 215–222. https://doi.org/10.1111/vcp.12250.

Castillo-Contreras, R., Carvalho, J., Serrano, E., Mentaberre, G., Fernández-Aguilar, X., Colom, A., González-Crespo, C., Lavín, S., López-Olvera, J.R., 2018. Urban wild boars prefer fragmented areas with food resources near natural corridors. Sci. Total Environ. 615, 282–288. https://doi.org/10.1016/j.scitotenv.2017.09.277.

Castillo-Contreras, R., Magen, L., Birtles, R., Varela-Castro, L., Hall, J.L., Conejero, C., Aguilar, X.F., Colom-Cadena, A., Lavín, S., Mentaberre, G., López-Olvera, J.R., 2021a. Ticks on wild boar in the metropolitan area of Barcelona (Spain) are infected with spotted fever group rickettsiae. Transbound. Emerg. Dis. e82–e95. https://doi.org/10.1111/tbed.14268 (December 2020).

Castillo-Contreras, R., Mentaberre, G., Fernandez Aguilar, X., Conejero, C., Colom-Cadena, A., Ráez-Bravo, A., González-Crespo, C., Espunyes, J., Lavín, S., López-Olvera, J.R., 2021b. Wild boar in the city: phenotypic responses to urbanisation. Sci. Total Environ. 773, 145593 https://doi.org/10.1016/j.scitotenv.2021.145593.

Cerri, J., Ferretti, M., Coli, L., 2018. Where the wild things are: urbanization and income affect hunting participation in Tuscany, at the landscape scale. Eur. J. Wildl. Res. 64 (3), 23. https://doi.org/10.1007/s10344-018-1183-0.

Conejero, C., Castillo-Contreras, R., González-Crespo, C., Serrano, E., Mentaberre, G., Lavín, S., López-Olvera, J.R., 2019. Past experiences drive citizen perception of wild boar in urban areas. Mamm. Biol. 96, 68–72. https://doi.org/10.1016/j.mambio.2019.04.002.

Conejero, C., López-Olvera, J.R., González-Crespo, C., Ráez-Bravo, A., Castillo-Contreras, R., Tampach, S., Velarde, R., Mentaberre, G., 2022. Assessing mammal trapping standards in wild boar drop net capture. Sci. Rep. 12 (1), 1–12. https://doi.org/10.1038/s41598-022-17407-5.

Conejero, C., González-Crespo, C., Fatjó, J., Castillo-Contreras, R., Serrano, E., Lavín, S., Mentaberre, G., López-Olvera, J.R., 2024. Between conflict and reciprocal habituation: human-wild boar coexistence in urban areas. Sci. Total Environ. Under Review.

DARP, 2020. Programa de seguiment de les poblacions de senglar a Catalunya. Temporada 2019-2020. Departament d'Agricultura, Ramaderia, Pesca i Alimentació. Realitzat per Minuartia Informe inèdit, 82 pp + annexos.

Delibes de Castro, J., Ría-Marín, R., González-Jiménez, A., Martín-Romero, S., Sintes-Pelaz, J., Sobrini, I., 2022. Urban wild boar bow hunting control in Madrid [Abstract]. In: Abstracts of the 13th International Symposium on Wild Boar and other Suids, p. 83 (Seva, Barcelona, Spain, September 6–9).

Departament d'Agricultura Ramaderia Pesca i Alimentació, 2020. Generalitat de Catalunya. Pla tècnic de Gestió Cinegètica. Zona de Caça Controlada de Collserola. Temporada 2019/2020.

Drake, D., 2014. Wildlife damage management in the urban landscape. In: McCleery, R. A., Moorman, C.E., Peterson, M.N. (Eds.), Urban Wildlife Conservation, 1st ed. Springer, pp. 389–401. https://doi.org/10.1007/978-1-4899-7500-3_17.

ENETWILD-consortium, Pascual-Rico, R., Acevedo, P., Apollonio, M., Blanco-Aguiar, J. A., Body, G., del Rio, L., Ferroglio, E., Gomez, A., Keuling, O., Plis, K., Podgórski, T., Preite, L., Ruiz-Rodriguez, C., Scandura, M., Sebastian, M., Soriguer, R., Smith, G.C., Vada, R., Zanet, S., Vicente, J., Carpio, A., 2022. Wild boar ecology: a review of wild boar ecological and demographic parameters by bioregion all over Europe. EFSA Supporting publication, 2022.

Ferrón, S., 2019. Despesa econòmica de la caça del senglar en la modalitat de batuda. In: Jornada Tècnica "Perspectives de futur en la gestió del porc senglar". Palau-Solità i Plegamans, Barcelona, Spain (11 d'octubre de 2019).

Festa-Bianchet, M., 2017. When does selective hunting select, how can we tell, and what should we do about it? Mammal Rev. 47 (1), 76–81. https://doi.org/10.1111/mam.12078.

Fonseca, C., da Silva, A.A., Alves, J., Vingada, J., Soares, A.M.V.M., 2011. Reproductive performance of wild boar females in Portugal. Eur. J. Wildl. Res. 57 (2), 363–371. https://doi.org/10.1007/s10344-010-0441-6.

García-Jiménez, W.L., Fernández-Llario, P., Benítez-Medina, J.M., Cerrato, R., Cuesta, J., García-Sánchez, A., Gonçalves, P., Martínez, R., Risco, D., Salguero, F.J., Serrano, E., Gómez, L., Hermoso-de-Mendoza, J., 2013. Reducing Eurasian wild boar (*Sus scrofa*) population density as a measure for bovine tuberculosis control: effects in wild boar and a sympatric fallow deer *(Dama dama*) population in Central Spain. Prev. Vet. Med. 110 (3–4), 435–446. https://doi.org/10.1016/j.prevetmed.2013.02.017.

Gaskamp, J.A., Gee, K.L., Campbell, T.A., Silvy, N.J., Webb, S.L., 2021. Effectiveness and efficiency of corral traps, drop nets and suspended traps for capturing wild pigs (Sus scrofa). Animals 11, 1565.

Gibb, R., Redding, D.W., Chin, K.Q., Donnelly, C.A., Blackburn, T.M., Newbold, T., Jones, K.E., 2020. Zoonotic host diversity increases in human-dominated ecosystems. Nature 584 (7821), 398–402. https://doi.org/10.1038/s41586-020-2562-8.

González-Crespo, C., Serrano, E., Cahill, S., Castillo-Contreras, R., Cabañeros, L., López-Martín, J.M., Roldán, J., Lavín, S., López-Olvera, J.R., 2018. Stochastic assessment of management strategies for a Mediterranean peri-urban wild boar population. PLoS One 13 (8), 1–19. https://doi.org/10.1371/journal.pone.0202289.

González-Crespo, C., Martínez-López, B., Conejero, C., Castillo-Contreras, R., Serrano, E., López-Martín, J.M., Lavín, S., López-Olvera, J.R., 2023a. Predicting human-wildlife interaction in urban environments through Agent-Based Models. Landsc. Urban Plan. 240, 104878 https://doi.org/10.1016/j.landurbplan.2023.104878.

González-Crespo, C., Martínez-López, B., Conejero, C., Castillo-Contreras, R., Serrano, E., López-Martín, J.M., Serra-Cobo, J., Lavín, S., López-Olvera, J.R., 2023b. Assessing the epidemiological risk at the human-wild boar interface through a One Health approach using an Agent-Based Model in Barcelona, Spain. One Health 17, 100598. https://doi.org/10.1016/j.onehlt.2023.100598.

Gortázar, C., Fernández-de-Simón, J., 2022. One tool in the box: the role of hunters in mitigating the damages associated to abundant wildlife. Eur. J. Wildl. Res. 68 (3), 1–14. https://doi.org/10.1007/s10344-022-01578-7.

Gortázar, C., Ruiz-Fons, J.F., Höfle, U., 2016. Infections shared with wildlife: an updated perspective. Eur. J. Wildl. Res. 62 (5), 511–525. https://doi.org/10.1007/s10344-016-1033-x.

Grimm, N.B., Faeth, S.H., Golubiewski, N.E., Redman, C.L., Wu, J., Bai, X., Briggs, J.M., 2008. Global change and the ecology of cities. Science 319 (5864), 756–760. https://doi.org/10.1126/science.1150195.

Hagemann, J., Conejero, C., Stillfried, M., Mentaberre, G., Castillo-Contreras, R., Fickel, J., López-Olvera, J.R., 2022. Genetic population structure defines wild boar as an urban exploiter species in Barcelona, Spain. Sci. Total Environ. 833 (March), 155126 https://doi.org/10.1016/j.scitotenv.2022.155126.

Hanson, L.B., Mitchell, M.S., Grand, J.B., Jolley, D.B., Sparklin, B.D., Ditchkoff, S.S., 2009. Effect of experimental manipulation on survival and recruitment of feral pigs. Wildl. Res. 36 (3), 185–191. https://doi.org/10.1071/WR08077.

Herrero, J., García-Serrano, A., García-González, R., 2008. Reproductive and demographic parameters in two Iberian wild boar Sus scrofa populations. Acta Theriol. 53 (4), 355–364.

Hill, C.M., 2021. Conflict is integral to human-wildlife coexistence. Front. Conserv. Sci. 2, 1–4. https://doi.org/10.3389/fcosc.2021.734314.

Hunold, C., Mazuchowski, M., 2020. Human-wildlife coexistence in urban wildlife management: insights from nonlethal predator management and rodenticide bans. Animals 10 (11), 1–15. https://doi.org/10.3390/ani10111983.

Iacolina, L., Scandura, M., Bongi, P., Apollonio, M., 2009. Nonkin associations in wild boar social units. J. Mammal. 90 (3), 666–674. https://doi.org/10.1644/08-MAMM-A-074R1.1.

Iff, U., 1978. Détermination de l'âge chez le Sanglier. Diana 95 (10), 377–381.

Kamieniarz, R., Mass, B., Sus, B., Jankowiak, Ł., Fratczak, M., Panek, M., 2020. The relationship between hunting methods and the sex, age and body mass of wild boar. Animals 10, 1–10.

Kaminski, G., Brandt, S., Baubet, E., Baudoin, C., 2005. Life-history patterns in female wild boars (*Sus scrofa*): mother-daughter postweaning associations. Can. J. Zool. 83 (3), 474–480. https://doi.org/10.1139/z05-019.

Keuling, O., Stier, N., Roth, M., 2008. Annual and seasonal space use of different age classes of female wild boar *Sus scrofa* L. Eur. J. Wildl. Res. 54 (3), 403–412. https://doi.org/10.1007/s10344-007-0157-4.

Keuling, O., Lauterbach, K., Stier, N., Roth, M., 2010. Hunter feedback of individually marked wild boar *Sus scrofa* L.: dispersal and efficiency of hunting in northeastern Germany. Eur. J. Wildl. Res. 56 (2), 159–167. https://doi.org/10.1007/s10344-009-0296-x.

Keuling, O., Baubet, E., Duscher, A., Ebert, C., Fischer, C., Monaco, A., Podgórski, T., Prevot, C., Ronnenberg, K., Sodeikat, G., Stier, N., Thurfjell, H., 2013. Mortality rates of wild boar *Sus scrofa* L. in central Europe. Eur. J. Wildl. Res. 59 (6), 805–814. https://doi.org/10.1007/s10344-013-0733-8.

Keuling, O., Strauß, E., Siebert, U., 2016. Regulating wild boar populations is "somebody else's problem"! - human dimension in wild boar management. Sci. Total Environ. 554–555, 311–319. https://doi.org/10.1016/j.scitotenv.2016.02.159.

Kowarik, I., 2011. Novel urban ecosystems, biodiversity, and conservation. Environ. Pollut. 159 (8–9), 1974–1983. https://doi.org/10.1016/j.envpol.2011.02.022.

Lenth, R.V., 2022. emmeans: estimated marginal means, aka least-squares means. R package version 1.7.2. Retrieved from. https://CRAN.R-project.org/package=emmeans.

Lovelock, B., Yanata, K., Seto, Y., Yamaguchi, M., 2021. Societal factors influencing hunting participation decline in Japan: an exploratory study of two prefectures. Soc. Nat. Resour. 35 (2), 149–166. https://doi.org/10.1080/08941920.2021.2006843.

Luniak, M., 2004. Synurbization: adaptation of animal wildlife to urban development. In: Proceedings 4th International Urban Wildlife Symposium, pp. 50–55.

Macháčková, K., Zelený, J., Lang, D., Vinš, Z., 2021. Wild boar meat as a sustainable substitute for pork: a mixed methods approach. Sustainability (Switzerland) 13 (5), 1–21. https://doi.org/10.3390/su13052490.

Marks, K.A., Vizconde, D.L., Gibson, E.S., Rodriguez, J.R., Nunes, S., 2017. Play behavior and responses to novel situations in juvenile ground squirrels. J. Mammal. 98 (4), 1202–1210. https://doi.org/10.1093/jmammal/gyx049.

Martínez-Jauregui, M., Delibes-Mateos, M., Arroyo, B., Soliño, M., 2020. Addressing social attitudes toward lethal control of wildlife in national parks. Conserv. Biol. 34 (4), 868–878. https://doi.org/10.1111/cobi.13468.

Maselli, V., Rippa, D., Russo, G., Ligrone, R., Soppelsa, O., D'Aniello, B., Raia, P., Fulgione, D., 2014. Wild boars' social structure in the Mediterranean habitat. Ital. J. Zool. 81 (4), 610–617. https://doi.org/10.1080/11250003.2014.953220.

Massei, G., Cowan, D.P., Coats, J., Bellamy, F., Quy, R., Pietravalle, S., Brash, M., Miller, L.A., 2012. Long-term effects of immunocontraception on wild boar fertility, physiology and behaviour. Wildl. Res. 39 (5), 378–385. https://doi.org/10.1071/WR11196.

Massei, G., Kindberg, J., Licoppe, A., Gačić, D., Šprem, N., Kamler, J., Baubet, E., Hohmann, U., Monaco, A., Ozoliņš, J., Cellina, S., Podgórski, T., Fonseca, C., Markov, N., Pokorny, B., Rosell, C., Náhlik, A., 2015. Wild boar populations up, numbers of hunters down? A review of trends and implications for Europe. Pest Manag. Sci. 71 (4), 492–500. https://doi.org/10.1002/ps.3965.

Matschke, G.H., 1967. Aging European wild hogs by dentition. J. Wildl. Manag. 31 (1), 109–113. https://doi.org/10.2307/3798365.

McCleery, R.A., Moorman, C.E., Peterson, M.N., 2014. Urban Wildlife Conservation Theory and Practice. Springer. https://doi.org/10.1007/978-1-4899-7500-3.

McIntyre, N.E., 2014. Wildlife responses to urbanization: patterns of diversity and community structure in built environments. In: McCleery, R.A., Moorman, C.E., Peterson, M.N. (Eds.), Urban Wildlife Conservation. Springer, pp. 103–104. https://doi.org/10.1007/978-1-4899-7500-3_7.

McKee, S.C., Psiropoulos, J.L., Mayer, J.J., 2024. Frequency and vehicle damage costs of wild pig-vehicle collisions in the United States, 2015–2022. Eur. J. Wildl. Res. 70, 44. https://doi.org/10.1007/s10344-024-01792-5.

Milner, J.M., Nilsen, E.B., Andreassen, H.P., 2007. Demographic side effects of selective hunting in ungulates and carnivores: review. Conserv. Biol. 21 (1), 36–47. https://doi.org/10.1111/j.1523-1739.2006.00591.x.

Minuartia, 2023. Programa de seguiment de les poblacions de senglar a Catalunya. https://senglar.cat/programa-de-seguiment/. (Accessed 17 April 2024).

Mitchell, J., 2011. Trapping of Feral Pigs. NQ Dry Tropics, Townsville.

Mysterud, A., 2011. Selective harvesting of large mammals: how often does it result in directional selection? J. Appl. Ecol. 48 (4), 827–834. https://doi.org/10.1111/j.1365-2664.2011.02006.x.

Náhlik, A., Cahill, S., Cellina, S., Gál, J., Jánoska, F., Rosell, C., Rossi, S., Massei, G., 2017. Wild boar management in Europe: knowledge and practice. In: Ecology, Conservation and Management of Wild Pigs and Peccaries. https://doi.org/10.1017/9781316941232.033.

Nyhus, P.J., 2016. Human-wildlife conflict and coexistence. In: Annual Review of Environment and Resources, vol. 41. https://doi.org/10.1146/annurev-environ-110615-085634.

Parc de Collserola, 2022. Clima y meteorología. Retrieved June 07, 2022, from. https://parcnaturalcollserola.cat/clima-i-meteorologia/.

Parc de Collserola, 2023. Uso público, divulgación y educación ambiental. Retrieved December, 2023, from. https://www.parcnaturalcollserola.cat/es/uso-publico-divulgacion-y-educacion-ambiental/.

Pascual-Rico, R., Morales-Reyes, Z., Aguilera-Alcalá, N., Olszańska, A., Sebastián-González, E., Naidoo, R., Moleón, M., Lozano, J., Botella, F., von Wehrden, H., Martín-López, B., Sánchez-Zapata, J.A., 2021. Usually hated, sometimes loved: a review of wild ungulates' contributions to people. Sci. Total Environ. 801, 149652 https://doi.org/10.1016/j.scitotenv.2021.149652.

Peebles, K.A., Wielgus, R.B., Maletzke, B.T., Swanson, M.E., 2013. Effects of remedial sport hunting on cougar complaints and livestock depredations. PLoS One 8 (11), 1–8. https://doi.org/10.1371/journal.pone.0079713.

Pepin, K.M., Davis, A.J., Cunningham, F.L., VerCauteren, K.C., Eckery, D.C., 2017. Potential effects of incorporating fertility control into typical culling regimes in wild pig populations. PLoS One 12 (8), 1–23. https://doi.org/10.1371/journal.pone.0183441.

Peris, A., Closa-Sebastià, F., Marco, I., Serrano, E., Casas-Díaz, E., 2019. Baiting improves wild boar population size estimates by camera trapping. Mamm. Biol. 98, 28–35. https://doi.org/10.1016/j.mambio.2019.07.005.

Quirós-Fernández, F., Marcos, J., Acevedo, P., Gortázar, C., 2017. Hunters serving the ecosystem: the contribution of recreational hunting to wild boar population control. Eur. J. Wildl. Res. 63 (3), 4–9. https://doi.org/10.1007/s10344-017-1107-4.

R Core Team, 2022. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. URL. https://www.R-project.org/.

Sanguinetti, J., Pastore, H., 2016. Abundancia poblacional y manejo del jabalí (*Sus scrofa*): Una revisión global para abordar su gestión en la Argentina. Mastozool. Neotrop. 23 (2), 305–323.

Sauter-Louis, C., Conraths, F.J., Probst, C., Blohm, U., Schulz, K., Sehl, J., Fischer, M., Forth, J.H., Zani, L., Depner, K., Mettenleiter, T.C., Beer, M., Blome, S., 2021. African swine fever in wild boar in Europe—a review. Viruses 13 (9). https://doi.org/10.3390/v13091717.

Servanty, S., Gaillard, J.-M., Toïgo, C., Brandt, S., Baubet, E., 2009. Pulsed resources and climate-induced variation in the reproductive traits of wild boar under high hunting pressure. J. Anim. Ecol. 78, 1278–1290. https://doi.org/10.1111/j.1365-2656.2009.01579.x (PMID: 19549145).

Servanty, S., Gaillard, J.M., Ronchi, F., Focardi, S., Baubet, É., Gimenez, O., 2011. Influence of harvesting pressure on demographic tactics: implications for wildlife management. J. Appl. Ecol. 48 (4), 835–843. https://doi.org/10.1111/j.1365-2664.2011.02017.x.

Sijtsma, M.T.J., Vaske, J.J., Jacobs, M.H., 2012. Acceptability of lethal control of wildlife that damage agriculture in the Netherlands. Soc. Nat. Resour. 25 (12), 1308–1323. https://doi.org/10.1080/08941920.2012.684850.

Simon, J.F., Ferreres, J., Gortázar, C., 2023. The number of hunters and wild boar group size drive wild boar control efficacy in driven hunts. Eur. J. Wildl. Res. https://doi.org/10.1007/s10344-023-01661-7.

Soulsbury, C.D., White, P.C.L., 2015. Human-wildlife interactions in urban areas: a review of conflicts, benefits and opportunities. Wildl. Res. 42 (7), 541–553. https://doi.org/10.1071/WR14229.

Stillfried, M., Fickel, J., Börner, K., Wittstatt, U., Heddergott, M., Ortmann, S., Kramer-Schadt, S., Frantzl, A.C., 2017. Do cities represent sources, sinks or isolated islands for urban wild boar population structure? J. Appl. Ecol. 54, 272–281. https://doi.org/10.1111/1365-2664.12756.

Toïgo, C., Servanty, S., Gaillard, J.M., Brandt, S., Baubet, E., 2008. Disentangling natural from hunting mortality in an intensively hunted wild boar population. J. Wildl. Manag. 72 (7), 1532–1539. https://doi.org/10.2193/2007-378.

Torres-Blas, I., Mentaberre, G., Castillo-Contreras, R., Fernández-Aguilar, X., Conejero, C., Valldeperes, M., González-Crespo, C., Colom-Cadena, A., Lavín, S., López-Olvera, J.R., 2020. Assessing methods to live-capture wild boars (*Sus scrofa*) in urban and peri-urban environments. Vet. Rec. 187 (10), e85 https://doi.org/10.1136/vr.105766.

Treves, A., 2009. Hunting for large carnivore conservation. J. Appl. Ecol. 46 (6), 1350–1356. https://doi.org/10.1111/j.1365-2664.2009.01729.x.

Truvé, J., Lemel, J., 2003. Timing and distance of natal dispersal for wild boar *Sus scrofa* in Sweden. Wildl. Biol. 9 (Suppl. 1), 51–57. https://doi.org/10.2981/wlb.2003.056.

UAB, 2023a. Landscape gardens. Retrieved April, 2023, from. https://www.uab.cat/web/natural-heritage/description-1345676863978.html.

UAB, 2023b. Wooded areas. Retrieved April, 2023, from. https://www.uab.cat/web/nature-and-biodiversity/wooded-areas-1345676863802.html.

Vajas, P., Calenge, C., Richard, E., Fattebert, J., Rousset, C., Saïd, S., Baubet, E., 2020. Many, large and early: hunting pressure on wild boar relates to simple metrics of hunting effort. Sci. Total Environ. 698, 134251 https://doi.org/10.1016/j.scitotenv.2019.134251.

Vajas, P., Von Essen, E., Tickle, L., et al., 2023. Correction: meeting the challenges of wild boar hunting in a modern society: the case of France. Ambio 52, 2056. https://doi.org/10.1007/s13280-023-01932-2.

Valente, A.M., Acevedo, P., Figueiredo, A.M., Fonseca, C., Torres, R.T., 2020. Overabundant wild ungulate populations in Europe: management with consideration of socio-ecological consequences. Mammal Rev. 50 (4), 353–366. https://doi.org/10.1111/mam.12202.

Van Vuren, D., Smallwood, K.S., 1996. Ecological management of vertebrate pests in agricultural systems. Biol. Agric. Hortic. 13 (1), 39–62. https://doi.org/10.1080/01448765.1996.9754765.

Vetter, S.G., Puskas, Z., Bieber, C., Ruf, T., 2020. How climate change and wildlife management affect population structure in wild boars. Sci. Rep. 10 (1), 1–11. https://doi.org/10.1038/s41598-020-64216-9.

Wang, H., Castillo-Contreras, R., Saguti, F., López-Olvera, J.R., Karlsson, M., Mentaberre, G., Lindh, M., Serra-Cobo, J., Nörder, H., 2019. Genetically similar hepatitis E virus strains infect both humans and wild boars in the Barcelona area, Spain, and Sweden. Transbound. Emerg. Dis. 66 (2), 978–985. https://doi.org/10.1111/tbed.13115.

Yokoyama, Y., Nakashima, Y., Yajima, G., Miyashita, T., 2020. Simultaneous estimation of seasonal population density, habitat preference and catchability of wild boars based on camera data and harvest records. R. Soc. Open Sci. 7, 200579 https://doi.org/10.1098/rsos.200579.

Zuur, A.F., Hilbe, J.M., Leno, E.N., 2013. A Beginner's Guide to GLM and GLMM With R: A Frequentist and Bayesian Perspective for Ecologists. Highland Statistics Ltd.