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Research Article

Managing invasive wild boars in Southern Brazil's protected areas: Challenges and strategies

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Abstract

Invasive species pose significant threats to ecosystems and biodiversity, necessitating effective management strategies to mitigate their impacts. One such invasive species of concern is the wild boar in Brazil, which has the potential to cause widespread environmental changes. A national plan for monitoring and controlling invasive species, including the wild boar, was developed in response to this threat. Despite this initiative, uncertainties persist regarding the presence of wild boars in protected areas (PAs) and the effectiveness of current management actions. This study intends to diagnose the situation of wild boars in protected areas within the southern region of Brazil, specifically focusing on their distribution, management techniques employed, and reasons for the lack of management actions. An online questionnaire was sent to 297 PAs, with 134 responding. The findings revealed that wild boars were present in 36 surveyed PAs, but management efforts were only being carried out in 14 of them. Cages and corrals were identified as the most commonly used techniques, with corn serving as the preferred bait. The study identified two primary reasons for the lack of management actions: the wild boar's low invasion intensity and management capacity limitations. To address these challenges effectively, this study advocates for a centralized organization of management actions and emphasizes the development of materials and resources to support successful management strategies. Implementing these measures is essential to safeguard the conservation of ecosystems and vulnerable species in Brazil's protected areas and ensure the long-term resilience of these valuable ecological assets.

Key words: Conservation efforts, invasive species, management techniques, online questionnaire, *Sus scrofa*

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Introduction

Invasive alien species (IAS) are one of the most important direct drivers of biodiversity loss and ecosystem service change (Pyšek et al. 2020; Jaureguiberry et al. 2022), globally increasing at an unprecedented pace (Butchart et al. 2010). The strong links between invasions and other major drivers of change, such as global warming, pollution, overexploitation of resources, and

habitat loss, are expected to increase the challenges (Simberloff et al. 2013; Spear et al. 2013), as well as the opportunities to manage them (Dudley and Stolton 2010).

Risks associated with biological invasions tend to be greater in Protected Areas (PAs) both because of their importance for biodiversity conservation and because, once created, habitat loss, overexploitation, and pollution tend to be reduced (Klinger et al. 2006; Foxcroft et al. 2017; Liu et al. 2020; Ren et al. 2021). Risks are even greater if the invasive species has the potential to cause various effects on the landscape, such as wild boar (Barrios-Garcia and Ballari 2012; Risch et al. 2021).

The wild boar (*Sus scrofa*), one of the world's most widely distributed invasive exotic mammal species (Long 2005), has a long history of invasion in Brazil's southern region (Hegel et al. 2022; La Sala et al. 2023). Wild pigs' fast expansion in Brazil was documented in the late 1980s – early 1990s, fueled by dispersion from neighboring countries and the introduction of leisure hunting and commercial interests (Deberdt and Scherer 2007; Salvador 2012; Hegel et al. 2022). Wild boar found a favorable breeding ground in the region, with a mosaic of agriculture and native forests supplying resources, and they still occupy these areas today (Hegel et al. 2019).

Managing wild boar populations in PAs is challenged by constraints on techniques, human and monetary resources, and management priorities, despite the recurrent calls for the importance of managing invasive species more efficiently in PAs and the creation of innovative ideas to overcome management obstacles (Laurance et al. 2012; Tu and Robison 2013; Pyšek et al. 2020). Although there is a need to avoid invasive species' effects on conservation targets, assessing such effects is not always easy or possible (de Souza and Alves 2014; Keuling et al. 2016; Castilho et al. 2018). Managing invasive species is still infrequent (Kiringe et al. 2007; Genovesi and Monaco 2013). De Poorter et al. (2007) listed eight main obstacles to the efficient management of Invasive alien species in PAs: (i) the lack of capacity for mainstreaming IAS management into overall PA management, (ii) the limited capacity of staff at the site level, (iii) the low level of awareness, (iv) the gaps in information on IAS available to PA managers, (v) the lack of funding, (vii) legal or institutional impediments, (viii) and the clashes of interests between stakeholders. Despite the wild boar's pervasive presence in protected areas throughout South America and Brazil (Sampaio and Schmidt 2013; La Sala et al. 2023), little is known about control efforts and management barriers in those PA systems. Worldwide, the main techniques used for wild boar control can be divided into two major categories: lethal or non-lethal (West et al. 2009; Gürtler et al. 2018; Rosa et al. 2018; VerCauteren et al. 2019; Jori et al. 2021). Lethal techniques reduce abundance by increasing mortality (e.g., hunting and poisoning), while non-lethal techniques restrict resource access through movement restrictions (e.g., fences) or reduced fertility (Fryxell et al. 2014). In Brazil, it is legally allowed to control wild boars by hunting, either with or without the aid of dogs and live trapping. In this scenario, hunting is the primary technique used for controlling wild pigs in rural properties, while in PAs, trapping is routinely used (Rosa et al. 2018).

Based on documented records and questionnaires sent to managers, we describe the status of wild boar management in Protected Areas of southern Brazil and address the reasons behind the decision to manage or not to

manage wild boards in protected areas. Due to the long history of the introduction and spread of wild boards in South Brazil, we consider that its presence inside the protected areas can be explained by habitat and landscape factors and that the perceived impact, in relation to other management demands, explains management prioritization. We expect that the management actions will differ between the PAs, where despite the techniques potentially being the same, the equipment, routine, and effort will be different. As possible justifications for non-management, we expect to find answers similar to those found by De Poorter et al. (2007).

Methods

Study area

The southern region of Brazil comprises the states of Rio Grande do Sul (RS), Santa Catarina (SC), and Paraná (PR), totaling an area of 576,774 km^2. The region includes two biomes (Dinerstein et al. 2017): Tropical and Subtropical Grasslands, Savannas and Shrublands (Grasslands); and Tropical and Subtropical Moist Broadleaf Forests (Forests). They present approximately 3% and 10.3% of their coverage within protected areas, respectively (MMA 2023).

The Brazilian system of protected areas includes federal, state, municipal, and private PAs, grouped into two major categories: Strictly Protected Areas and Sustainable Use Areas (Rylands and Brandon 2005), equivalent, respectively, to categories I to IV and categories V to VI of the International Union for Conservation of Nature (IUCN data).

Data collection

We compiled the list of protected areas in South Brazil from the National Catalog of Protected Areas (Cadastro Nacional de Unidades de Conservação) maintained by the Chico Mendes Institute of Biodiversity Conservation (https://www.gov.br/mma/pt-br/assuntos/areasprotegidasecoturismo/plataforma-cnuc-1) together with the information found in the state secretariats. We included in the study all areas: Federal, State and Municipal, and private or public. Marine conservation areas were excluded from the work. In all, we compiled 701 protected areas for this region.

We initially contacted the protected areas through e-mails available on the relevant authorities' website. For those without e-mail address information, we tried phone contacts and looked for and tried other e-mails and contacts searched on the web. For all the e-mails found, we sent an online survey addressed to the PA managers. Up to four contact attempts were made to each PA if the e-mail was not returned (October and November 2019 and February and March 2020).

We structured the questionnaire, following the best practices recommended by White et al. (2005), in three sections on the Research Electronic Data Capture (REDCap) platform (Suppl. materials 1, 2). The first section encompassed questions about wild boar occurrence and its effects within the PA. There are also two questions to understand the manager's perception of the effects of the wild boar compared to other generators of negative effects within the

protected area. In these questions, the manager must choose a number from 0% to 100%, where the higher the number, the greater the responsibility of the wild boar in generating the negative effects. The second section was dedicated to obtaining information about control techniques or reasons for not adopting control. Finally, the third section looked at the frequency of control campaigns, the number of animals, and their destination. The questionnaire primarily consists of multiple-choice questions and short texts (Suppl. material 1).

We summarized answers using descriptive statistics. We grouped and named the answers to the open-ended questions a posteriori according to their similarity using the technique for qualitative analysis of Discourse Analysis, where the main ideas are extracted from the text to summarize and group responses into categories (Taylor 2013; Georgakopoulou 2019).

Results

We compiled a list of 701 protected areas from the National Catalog for the south region, of which nine were excluded because they were marine (Table 1). From the final list, an e-mail was found, and the questionnaire was sent to 297 protected areas, of which we got responses from 134 (Table 1). In all cases, the respondents of the surveys were the protected area managers, and only finished questionnaires were considered in the results. Thus, three incomplete questionnaires were removed. Concerning the public sphere, we were able to represent all management spheres of interest and all ecoregions/biogeographical provinces (Suppl. material 3). Due to only two responses for the private sphere (0.6%), these were not considered in this work (Table 1). With the final number being 129 PAs.

Wild boars were reported from 36 of 129 (27.9%) protected areas (Fig. 1 and Table 3), 26 strictly protected, and ten areas of sustainable use. Wild boars were first cited in protected areas in the studied region in 2005 (two reports), and the most recent observation was recorded in 2020 (Table 2). The oldest

Table 1. Summaries of the contact process, questionnaire return, and inclusion of PAs. "Total" represents the number of PAs registered for the administrative sphere, category of use, and biomes. Excluded represents those that were not fetched for contact. Contacted represents those for it was possible to get a contact e-mail. Unanswered and included represents the number of responses to the questionnaire. Inc./Total represents the percentage of returns in relation to the total recorded. Forest = Tropical and Subtropical Moist Broadleaf Forests; Grasslands = Tropical and Subtropical Grasslands, Savannas and Shrublands.

		Total	Excluded	Contacted	No-answer	Included	Inc./Total (%)
Sphere	Federal	40	8	30	1	29	72.5
	State	105	0	60	15	45	42.9
	Municipal	220	1	164	106	58	26.4
	Private	336	0	43	41	2	0.6
Category	Strictly Protected	249	6	181	85	96	38.6
	Sustainable Use	452	3	116	78	38	8.4
Biome	Marine	9	9	–	–	–	–
	Forests	658	0	271	156	115	17.5
	Grasslands	34	0	26	7	19	55.9

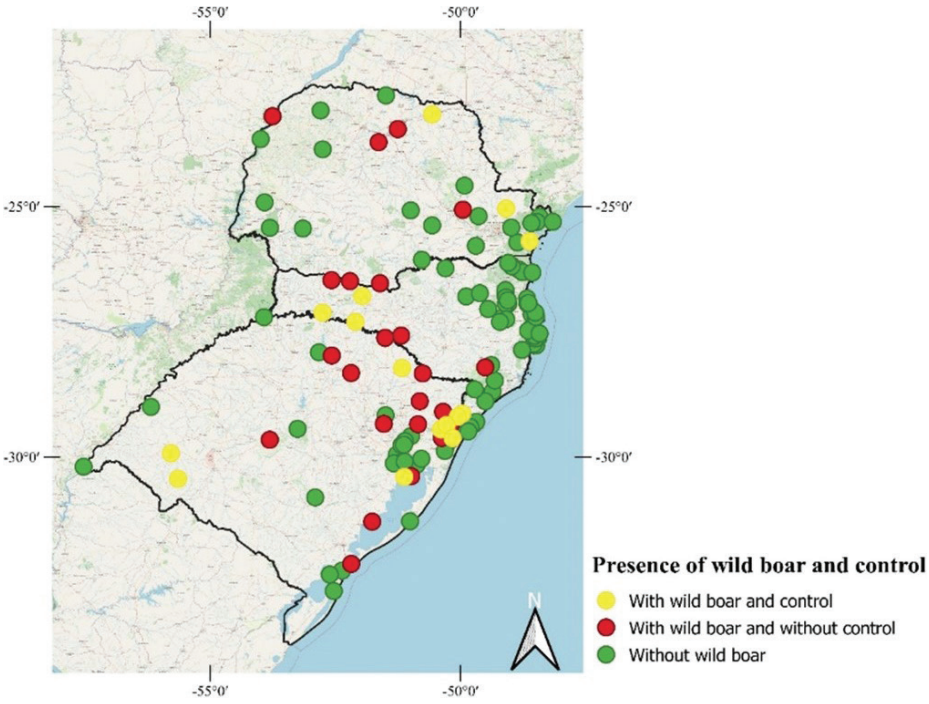

Figure 1. Presence of wild boar and control actions. Presence and absence of wild boar and control campaigns in protected areas in southern Brazil.

three detections (two in 2005 and one in 2006) are in the Forests biome, with 2007 being the first year with records in the Grasslands biome. Regarding the administrative sphere, in RS, after a rapid expansion, detection remained continuous until 2019, with one or two new records in PAs per year, with a gap of two years (2009 and 2010), with a peak in 2015 with four records. For SC, there is a time gap after 2006 being detected in a new PA only in 2014 until 2017, and there are no new detections until 2020. In the case of PR, the first detections are more spread over the years compared to other states.

Wild boars are managed in 13 (36.1%) of the PAs invaded (Fig. 2) – 11 (42.3%) Strictly Protected Areas and two (20%) Sustainable Use Areas; six (37.5%) federals and seven (46.7%) states; or three (50%) in Grasslands and ten (33.3%) in Forests biomes. When asked about the relative importance of wild boar's negative effects against other drivers (in percentage terms), the respondents from the PAs that do not carry out the management of the wild boar were assigned, on average, a value of 28.9% (SD 20.6), while those that practice the management actions has an average of 59.4% (SD 19.3). When asked about the relevance of wild boar among other invasive species, the respondents from PAs without management actions were assigned, on average, a value of 40.7% (SD 23.3), while those that managed wild boar had an average score of 62.6% (SD 21.5).

The answers from respondents of both PA categories (Strictly Protected and Sustainable Use) were similar (Table 3). Sixteen out of the 22 PAs reported not managing wild boars, justifying it with answers related to low Invasion Intensity. We grouped in this category the answers reported as not a priority, few recorded effects, low number of registered individuals, and recently observed. Nine respondents claimed low management capacity. We grouped in this category the answers reporting lack of technical team or/and structure, lack of formal protocols, bureaucratic difficulties to carry out management, conflicts of

Table 2. First record of wild boar in environmental protection areas. The value represents the quantity of PAs. RS (Rio Grande do Sul), SC (Santa Carina), PR (Paraná), F (Federal), S (State), M (Municipal).

	Year	2005	2006	2007	2008	2009–10	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
RS	F	1		5		–	1									
	S			1	1	–			1		2		1	1		
	M					–		1			2			1	1	
SC	F	1	1			–				2		1				
	S					–					1		2			
	M					–										
PR	F				1	–					1	1			1	
	S					–					2					1
	M					–										

Table 3. The table summarizes the answers obtained from the questionnaire. When a PA uses only one action, justification, or method in multiple choice questions, the answer is highlighted in the "Excl." column. SP = Strictly Protected Areas, SU = Sustainable Use Areas. The percentage value is in parentheses. ¹ Textual responses were grouped into categories according to similarity. * Represents the average of the answered values.

First section	SP	SU	Total	
- Presence of wild boar				
Yes	26 (28.0)	10 (27.8)	36 (27.9)	
No	67 (72.0)	26 (72.2)	93 (72.1)	
- Wild boar as a generator of adverse effects among all the factors				
With control actions	60.4*	56.7*	59.4*	
Without control actions	31.1*	25.2*	28.9*	
- Wild boar as a generator of adverse effects among invasive species				
With control actions	59.8*	70*	62.6*	
Without control actions	44.6*	33*	40.7*	
Second section	SP	SU	Total	Excl.
- Performed control actions				
Yes	11 (42.3)	3 (25.0)	14 (36.8)	
No	15 (57.7)	9 (75.0)	24 (63.2)	
- Explain the reason why no wild boar control actions were taken ¹				
Invasion Intensity	10 (71.4)	6 (75.0)	16 (72.7)	11
Not a priority	2 (14.3)	1 (12.5)	3 (13.6)	1
Few recorded effects	1 (7.1)	2 (25.0)	3 (13.6)	
Low number	7 (50)	5 (62.5)	12 (54.5)	9
Recently observed	1 (7.1)	0 (0)	1 (4.5)	1
Management Capacity	6 (42.9)	3 (37.5)	9 (40.9)	4
Lack of technical team	4 (28.6)	3 (37.5)	7 (31.8)	3
Lack of formal protocols	1 (7.1)	1 (12.5)	2 (9.1)	
Bureaucratic difficulty	2 (14.3)	0 (0)	2 (9.1)	
Conflict of interest	1 (7.1)	0 (0)	1 (4.5)	
Management plan being prepared	2 (14.3)	0 (0)	2 (9.1)	1
- Technical support				
Yes	8 (72.7)	2 (66.7)	10 (71.4)	

First section	SP	SU	Total	
No	3 (27.3)	1 (33.3)	4 (28.6)	
- This technical support is provided by:				
University	3	1	4	1
Government agencies	4	0	4	1
NGOs	1	1	2	2
Companies	0	0	0	0
Others	3	1	4	2
- Control technique				
Hunting	5 (45.5)	2 (100)	7 (53.8)	
Hunting with dogs	1 (9.1)	1 (50.0)	2 (15.4)	
Hunting without dogs	4 (36.4)	2 (100)	6 (46.2)	1
Stands	3 (27.3)	2 (100)	5 (38.5)	
Traps	8 (72.7)	2 (100)	10 (76.9)	
Corral	6 (54.6)	1 (50.0)	7 (53.8)	1
Cage	6 (54.6)	2 (100)	8 (61.5)	1
Fencing	1 (9.1)	1 (50.0)	2 (15.4)	
Others	2 (18.2)	0 (0)	2 (15.4)	1
- How many cages were used?	2.2*	5.6*	3.5*	
- How many corrals were used?	2.2*	4.5*	2.9*	
- Bait type				
Unspecified corn	4	1	5	3
Fermented corn	1	2	3	1
Dry corn	2	1	3	2
Corn cob	2	-	2	1
Domestic animal carcasses	-	1	1	
Sweet potato	-	1	1	
Leftover vegetables	-	1	1	
Coarse salt	1	1	2	
Third section	SP	SU	Total	Excl.
- How many individuals were captured?	136.3*	69.2*	91.6*	
- Zoonosis monitoring				
Yes	3 (27.3)	2 (66.7)	5 (35.7)	
No	8 (72.7)	1 (33.3)	9 (64.3)	
- Carcass destination				
Discarded	4	2	6	2
Donated	4	3	7	3
Not Mentioned	5	0	5	

interest with the surrounding community, and management plans still in preparation (Fig. 3 and Table 3). “Low number of recorded individuals” and “Lack of technical team/structure” were the most prevalent answers for not carrying out wild boar management. The first reason was indicated by 12 PAs (54.5% of all respondents and 75% of those from the Invasion Intensity group) and was the sole reason reported by nine of them. The second option was informed seven

times (31.8% of all respondents and 77.8% of those in the Management Capacity group), and three reported this as the sole reason.

All the options available in the questionnaire of techniques for wild boar management were selected in the answers (Table 3). Cage trap was the most common technique used (64.3%), while hunting with dogs was the least reported one (14.3%). The usage pattern is the same when considered between the two types of PAs. On average, 3.5 cages are used in management, showing a difference when separated by type of PA, where Strictly Protected Areas have

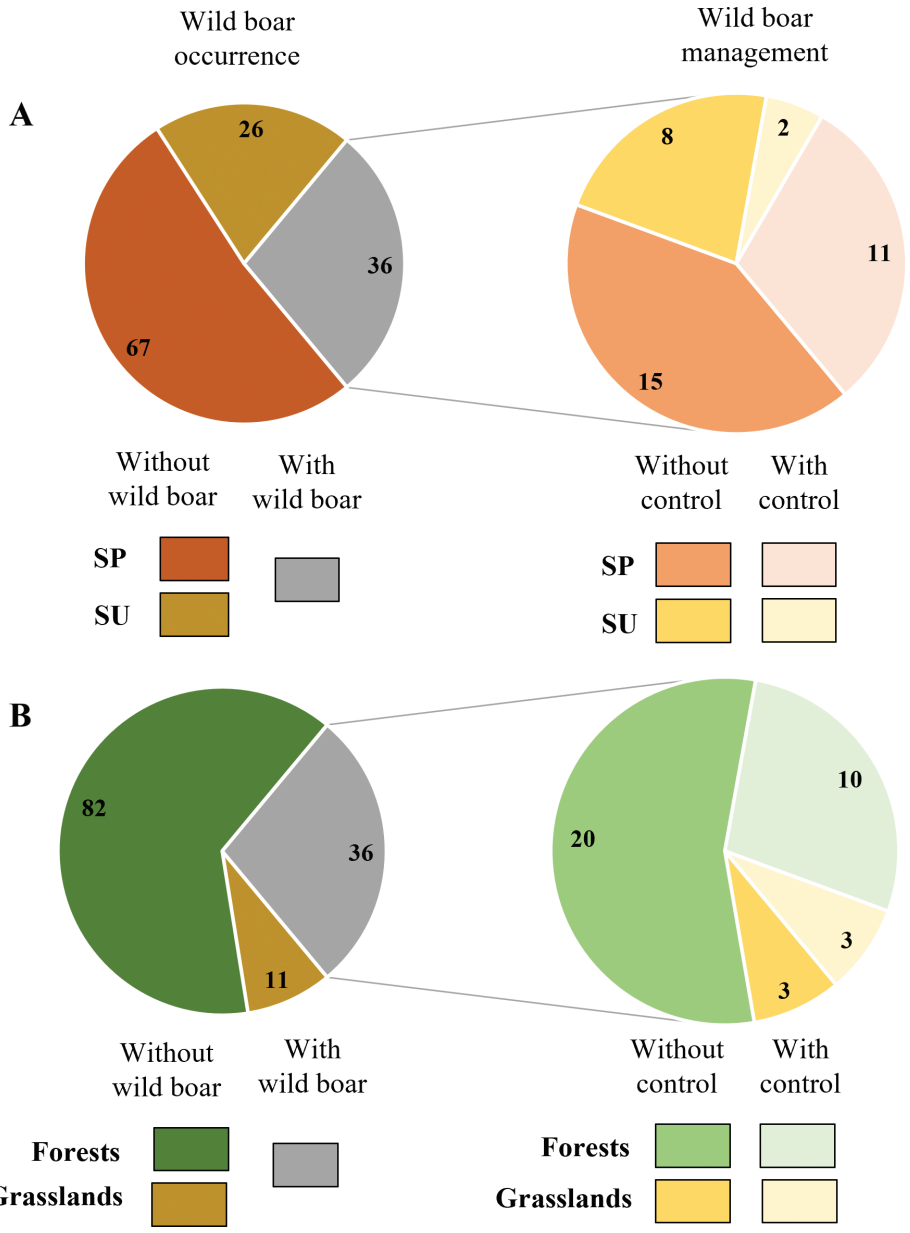

Figure 2. Presence of wild boar in protected areas separated by category of use or Biome. Presence or absence of wild boar in Protected Areas separated by (**A**) category of use or (**B**) by Biome, together with the presence or absence of control actions. In **A** orange colors refer to Strictly Protected Areas (SP), yellow refers to Sustainable Use Areas (SU), and gray groups the two categories. In **B** green colors refer to Tropical and Subtropical Moist Broadleaf Forests (Forests), yellow colors refer to Tropical and Subtropical Grasslands, Savannas and Shrublands (Grasslands), and the gray color groups the two biomes.

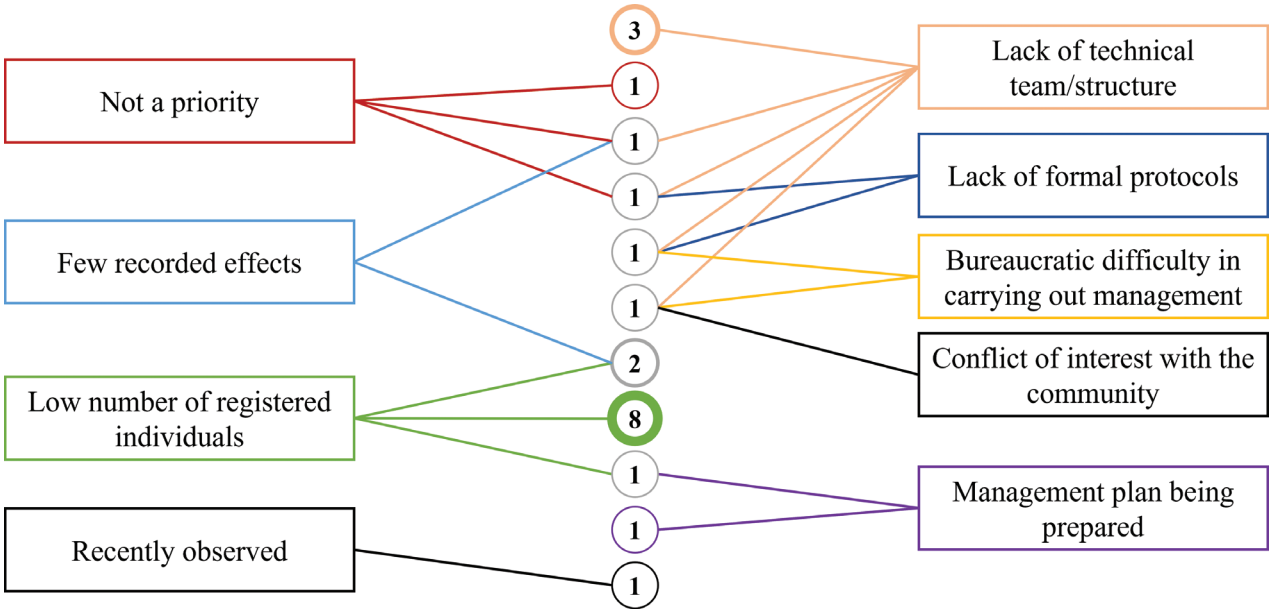

Figure 3. Justifications for not carrying out wild boar management. Grouping of protected areas according to subgroups of justifications for not managing wild boar. On the right are the subgroups related to Management Capacity, and on the left are those related to Invasion Intensity. The number inside and the thickness of the sphere represent the number of PAs that used the justification. The PAs were only grouped if they used the same justifications.

an average of 2.2 while 5.6 for Sustainable Use Areas. The cage sizes reported vary among the PAs, having from two to 32 m^3 with an average of nine cubic meters. Corrals, varying from one to six, were used in seven PAs. Corn was used as bait in all PAs, whether as coarse grain, on the cob, fermented, or salted (Table 3). Bait is usually used at the entrance and center of the trap and either placed one to seven days before the onset of captures or offered continuously. Cages were placed several weeks before the start of baiting or trapping. In most cases (7 out of 11 PAs), the corral or cages were built by PAs' employees or donated by partner institutions. All PAs that manage wild boar employed irregular efforts without precise seasonal distribution (Table 3).

Regarding external support in the elaboration or execution of management actions, ten PAs were reported to have support from external institutions: four from universities, four from other governmental institutions, and two from NGOs (Table 3). Seven of nine PAs donate the carcasses to hunters if interested, and the other two bury the carcasses at licensed sites. Five PAs did not answer this question. Zoonoses monitoring is performed by only five (out of 14) PAs (Table 3).

Discussion

In this study, we show that despite the long presence of wild boar in southern Brazil, managing wild boars in PAs is not a frequent priority, either because its effects are not apparent or because of a lack of resources. We also show that the techniques used follow worldwide standards (trapping and hunting) and using corn as bait (Geisser and Reyer 2004; West et al. 2009; VerCauteren et al. 2019; Keuling et al. 2021). However, there is no regularity in the effort size or spatial and temporal distribution of managing campaigns.

Despite the wild boar being present in the region since the early 1990s (Hegel et al. 2022), our sample's first reported sightings in PAs were in 2005 for Santa Catarina and Rio Grande do Sul and in 2008 for Parana. Reinforcing the history of expansion in RS (Hegel et al. 2022), there was a significant advance in the presence between the years 2005 and 2008. First, wild boar detections were in the federal PAs, later in the state and municipal ones, despite the lower number of federal PAs. The lack of detection in municipal areas may be associated with their location, as most are close to urban or peri-urban areas where wild boar tends to avoid the higher human presence (Amendolia et al. 2019; Morais et al. 2019) or due to their smaller size, by chance are less prone to colonization when compared to federal PAs (Burns 2015; Gallardo et al. 2017). Looking at the use categories, more Sustainable Use PAs reported having wild boar proportionally compared to Strictly Protected Areas. However, more studies are needed to understand if and what may influence this pattern.

Management actions are applied in less than half of the PAs, and it is possible to notice a difference between the categories where more actions are performed in Strictly Protected Areas. This difference may be related to the distribution of resources or the purpose of each type of PA. Nevertheless, when asked about the relevance of wild boar invasion among all factors causing negative effects within the PA, it is not possible to see any difference in the perceived importance of the wild boar effect between the two types of PA. Thus, it is not a matter of perception about the influence of negative effects caused by wild boar. It is only noticeable between those PAs that manage and those that do not manage the species.

Among the reasons for not carrying out the management, the recurrent allegation based on restricted management capacity within individual PAs is compelling evidence for a coordinated management program encompassing the mosaic of federal, state, municipal, and private PAs in a given region. Such an approach mirrors the efforts employed to address other biodiversity threats, as Miranda et al. (2020) and Faria et al. (2022) demonstrated. For successful management, in the case of wild boar, continuous actions are necessary to reduce populations to the point that the effects are within acceptable levels according to the PA conservation objectives (West et al. 2009; VerCauteren et al. 2019; Jori et al. 2021). However, for these campaigns to be efficient, management policies are not sufficient alone, and more resources are required to put them into practice. It is nothing new that the PAs in Brazil are not well-financed, managed, or equipped (Chiaravalloti et al. 2015; de Oliveira and Bernard 2017), and to make matters worse in recent years, environmental policies have been harmed (Bernard et al. 2014; Dobrovolski et al. 2018; Abessa et al. 2019; Golden Kroner et al. 2019), making it even more challenging to face biological invasions. An idea to minimize the losses would be sharing equipment such as corrals and cages between nearby PAs, as animals tend to learn to avoid traps, requiring spatial and temporal rotation (Parkes et al. 2010; Massei et al. 2011; Gaskamp et al. 2021). In addition, exchanging experience between managers, rangers, and the partner community would increase management efficiency by sharing what went right and wrong in each PA (Meyerson and Mooney 2007; Simpson et al. 2009).

Furthermore, downgrading the National Action Plan (BRASIL 2017) to a state scale could promote the plan's effectiveness because many problems may be

at this level as these are at different stages in the wild boar invasion process (Estévez et al. 2015; Early et al. 2016; Courchamp et al. 2017; Shackleton et al. 2019; Hegel et al. 2022). Since the PAs are divided into two large groups and several subgroups that present different possibilities and restrictions, with the lack of protocols and bureaucratic difficulties that were pointed out as justifications for not carrying out the management, leaving it in charge of the national sphere to organize and resolve the doubts of managers regarding legislation and protocols and creating means for exchanging experiences between state environmental agencies can be a good way to stimulate control actions. The state sphere can oversee organizing the exchange of experience between the agents directly involved (managers, rangers, among others), as they are the ones who plan, organize, and execute the actions within the respective PAs. Thus, it may affect the lack of equipment, people, and conflicts by increasing the efficiency of control campaigns.

An interesting point that deserves an awareness campaign is the justification for "no management" based on the low number of recorded animals in the PA. There is accumulating evidence that the first stages of invasion are the best window for effective control or even local eradication (Allendorf and Lundquist 2003; Mooney et al. 2005; Keiter and Beasley 2017; Giakoumi et al. 2019; Reaser et al. 2020; Ziller et al. 2020), where hunting and trapping would be indicated to keep populations at low levels (Gürtler et al. 2018; VerCauteren et al. 2019; Jori et al. 2021). Most of the PAs within this group had the first record of wild boars very recently (after 2015), contrasting with PAs that manage the species where the first record was prior to 2011. This situation could indicate that populations are still expanding in some areas, which could become a problem in the future (Hegel et al. 2022).

Most PAs that manage wild boar use more than one control technique, which is seen as favorable in management effectiveness assessments (Veitch and Clout 2002; Cruz et al. 2005; Mccann and Garcelon 2008; Parkes et al. 2010; Massei et al. 2011). Cages and corrals are highly effective in controlling wild boar populations (Choquenot et al. 1993), and both techniques are used worldwide to control the species within protected areas and rural environments. The use of corrals has been encouraged in Brazil by some initiatives in the Pampa biome, with construction and use guides (Coelho et al. 2018). Unlike the cage, this technique allows the capture of the whole sounder, which is desirable in population control (Choquenot et al. 1993).

Hunting without dogs was the most used active control technique. Unlike the use of corrals, this technique is intended to remove animals that avoid the traps and should be used as a complement to trapping because they have low effectiveness (Hanson et al. 2009; West et al. 2009). In the Brazilian scenario, the most used technique in rural areas is hunting with dogs (Rosa et al. 2018), although only two PAs reported using dogs. The use of hunters within PAs to manage wild boar is a topic that needs more debate between environmental managers and the community. In Brazil, the ban on hunting, especially within protected areas, has generated a culture of conflict where those responsible for PAs actively spend resources to prevent hunters from invading the boundaries of areas to kill protected animals or collect endangered plants (Kauano et al. 2017; Ruas et al. 2017; Bragagnolo et al. 2019; Castilho et al. 2019). However, the situation of the wild boar, the only animal for which hunting is allowed,

requires a change in the history of fighting hunting. The PAs do not have the human resources to handle the control activities alone; however, the loss of confidence in hunters due to the Brazilian history makes the partnership between the two difficult.

Corn was the main bait, according to procedures adopted in other countries since it proved effective (West et al. 2009). However, there are reports that corn may not be attractive depending on the region due to more valuable resources available (West et al. 2009; Hygnstrom et al. 2014). This may happen, for example, in south Brazilian highland forests with abundant *Araucaria angustifolia* seeds, a resource highly consumed by wild boars during winter months (Cervo and Guadagnin 2020). Ideally, bait selection (single species or multispecies) should be locally tested before starting control campaigns (Ballari et al. 2015).

The destination of carcasses varies between PAs, and some prefer to refrain from responding. Due to the lack of human and financial resources, donating the carcass to partner controllers has been a way of dealing with the destination and strengthening the relationship between the agents involved in the management. However, this practice is vetoed by the environmental agency and is only permitted when zoonosis tests are carried out (IBAMA 2020). Additionally, the consumption of game meat is not recommended due to the lack of health control (IBAMA 2020). The problem of carcass disposal must be dealt with in different political spheres to meet the current reality of wild boar management. Beyond that, monitoring diseases could be further encouraged since the wild boar is a species known to be a reservoir of multiple farm animal and human diseases (Maciel et al. 2018; Kmetiuk et al. 2019).

Despite the effort to obtain contact information for all PAs, only 42.3% were accessible, with a return rate of 45.1%. Our sample highly represented federal and state PAs, but less about municipal or private PAs is known. Since this latter comprises the most significant number of PAs, although, in territorial extension, they are smaller and tend to be managed independently, one way to increase their protection or recovery from wild boar invasions may be recognizing them within multijurisdictional PA network action plans.

Conclusions

In general, we see that most PAs did not detect wild boar, possibly due to the actual absence of individuals or the lack of human resources to survey the areas. Since the species is still expanding, we believe that some PAs may not have been detected yet due to the presence of a few individuals. We see that management is carried out at the federal and state levels, using similar techniques but with different materials, which can affect the effectiveness of actions. Another point is management campaigns; some carry out continuous management throughout the year, and others punctually. This is a possible reflection of the lack of an adaptive management plan with well-defined objectives and goals. This does not detract from the merits of the initiatives. However, it is not effective in terms of population control. Thus, an organization of environmental agencies is necessary to assist environmental managers in creating well-defined plans that go in the direction of the national plan.

Additional information

Conflict of interest

The authors have declared that no competing interests exist.

Ethical statement

No ethical statement was reported.

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Data availability

All of the data that support the findings of this study are available in the main text or Supplementary Information.

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Supplementary material 1

Summary of questions asked in the survey

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Supplementary material 2

Online questionnaire

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Supplementary material 3

Summary of PAs characteristics used in this work

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