First wild boar density data from Araucaria forest in Patagonian Andes

Oscar Skewes[1,*], Annaluisa Kambas[2,*], Paula Gädicke[1] and Oliver Keuling[2]

[1] Facultad Ciencias Veterinarias, Universidad de Concepción, Chillán, Chile
[2] Institute for Terrestrial and Aquatic Wildlife Research, University of Veterinary Medicine Hannover, Hannover, Germany
[*] These authors contributed equally to this work.

ABSTRACT

As *Sus scrofa* is an invasive species in South America, it may have a significant impact on biodiversity. Evaluating this threat requires reliable data, and population density can serve as a critical measure. However, such data is currently lacking for the southern Andes region. To address this gap, we monitored wild boar density in the Villarrica National Park, located in the Andes of south-central Chile. This study area is notable not only for its challenging climatic conditions but also for its endangered *Araucaria araucana* forest, which provides abundant food resources during autumn seed fall. The density calculated for the entire study period was 1.4 individuals/km^2, with no significant variation between cold and warm seasons. The encounter rate showed strongly monthly variations. Given that this represents the first density estimate for wild boar in this region, our findings emphasize the need for continued monitoring, particularly due to the potential threat to the ecosystem and the already endangered Araucaria forest.

Subjects Conservation Biology, Ecology, Zoology, Population Biology
Keywords *Sus scrofa*, Chile, Camera trapping, Invasive species, Endangered species, National Park management, Density, Wild boar, *Araucaria araucana*, Patagonian Andes

Submitted 18 March 2024
Accepted 16 January 2025
Published 17 February 2025

Corresponding author
Oliver Keuling, oliver.keuling@tiho-hannover.de

Academic editor
Alan Hastings

Additional Information and Declarations can be found on page 9

DOI **10.7717/peerj.18951**

INTRODUCTION

The wild boar (*Sus scrofa*) is an invasive species in South America and was first introduced there in 1904 in Argentina with animals from Europe. They were soon relocated to different parts of the country including the southern Andes. A contingent also arrived directly in Chile many years later, and the first population of wild boars in Chile likely existed around 1950 and is attributed to the direct import of some animals from Germany (*Skewes & Jaksic, 2015*). The main reason for the release of these animals was for hunting, but some individuals also escaped from farms by accident. The Argentinian and Chilean populations intermixed and formed the basis of the present wild boar population of the southern cone of America (*Cuevas et al., 2021*).

Wild boars can have detrimental effects on biodiversity, agriculture, and livestock (*Barrios-Garcia & Ballari, 2012*). These effects are often density-dependent, meaning that higher population densities lead to more severe impacts on biodiversity, greater agricultural damage, and higher disease risks (*Fulgione & Buglione, 2022*). They are described as ecosystem engineers, as they can significantly impact habitats. This occurs in their native habitats (*Croft et al., 2020*) as well in non-native environments (*Risch et al., 2010*). Given that the severity of their impact correlates strongly with population density, assessing the density of wild boar populations is crucial for understanding and mitigating these effects. Density assessments can be achieved through methods such as the Random Encounter Model (REM), which estimates population density based on the frequency of animal encounters (*Rowcliffe et al., 2008*); distance sampling, which involves measuring the distances of observed animals from a line or point to estimate density (*Thomas et al., 2010*); and capture-recapture techniques, where animals are captured, marked, and released to determine population size based on subsequent recapture rates (*Otis et al., 1978*). These approaches provide essential data to inform management strategies aimed at reducing the negative impacts of wild boar on ecosystems and agricultural areas.

In 2014, the first outbreaks of African Swine Fever, affecting wild boar in the European Union, increased public concern (*Jori et al., 2021*). Following, experts of the EU under the ENETWILD Consortium selected a method to estimate wild boar density (*Enetwild-Consortium et al., 2018*). As a result, they adopt the procedure based on images captured by camera traps and processed with the REM (*Rowcliffe et al., 2008*; *Palencia et al., 2022*). Thus, wild boar density values in Europe ranged from 0.35 individuals/km^2 to 15.25 individuals/km^2 (*Enetwild-Consortium et al., 2022*). But it is exactly this varying range of density in Europe that shows the impact of different environments on the species.

Therefore, it is necessary to have data about the density of this species, to evaluate and possibly take further management actions. However, there is no information on the density of wild boar in Chile, even though it extends to important habitat for many threatened and endangered species and is also considered one of the 36 Biodiversity Hotspots in the world (*Myers et al., 2000*). Consequently, we studied the population density of wild boar in an Araucaria (*Araucaria araucana)* forest.

Notably, *A. araucana* is a Gondwana long-lived coniferous and endangered species with a small range (*Premoli, Quiroga & Gardner, 2017*). It is not only important for conservation value, but also because the seeds are collected by the indigenous groups of Chile and Argentina and also serve as food for native birds and rodents (*Sanguinetti et al., 2023*). The species was classified as endangered by the IUCN in 2013, which was mainly caused by fires, years of logging and invasive species. Although wild boar has been present in these forests for decades (*Skewes & Jaksic, 2015*), the impact of wild boar as depredator of seed may shift from individual trees to stand scale, threatening Araucaria forest regeneration (*Sanguinetti & Kitzberger, 2010*).

Considering the multiple impacts of an enlarged wild boar population, investigating the population density is important for estimating this danger for humans and nature, especially for the endangered Araucaria. This study aims to provide, for the first time, an estimate of wild boar density in Araucaria forests. Based on these results, conservation actions for this endangered forest species and wild boar management measures can be proposed in the future.

MATERIALS AND METHODS

Study area

The study site named "Puesco" is in the Andes of south-central Chile (39°35′S, 71°31′W) at elevations of 1,200 to 1,400 m asl and covers 15 km^2. It is located on the north side of the Lanín volcano in the Villarrica National Park (permission no. 03/2015 CONAF) in the Araucanía Region, Chile (Fig. 1).

There is no hunting, visitors circulate along trails and in autumn the neighboring indigenous communities collect Araucaria seeds. According to the climatic station "Ea. Mamuil-Malal" (39°64′739″S, 71°26′955″W) at 900 m asl and circa 20 km east, the mean annual precipitation is 1,081 mm and the mean annual temperature is 9.3 °C. The coldest month is July with a mean of 1.3 °C and the warmest is February with 15.5 °C (http://www.aic.gov.ar/sitio/estaciones). In the site snow falls from June to September, the snow cover stays for approximately 45 days with a maximum height of up to 0.9 m (Author observation).

The site is dominated by forests of the long-lived monkey puzzle tree *A. araucana* mixed with lenga beech *Nothofagus pumilio*. The understory is composed of poaces *Festuca gracillima*, *Alstroemeria aurea*, and patches of dense bamboo *Chusquea* spp. thickets, *Gaultheria* sp. and *Nothofagus antarctica* shrubs (<5 m height). The Araucaria seed fall starts in March and ends in June, but seeds are also available in spring after the thick snow cover melts. As there are no other fruit bearing trees in the study area and the other occurring plants are not as remotely comparable nutritious, the food availability changes drastically over the year.

Data capture

We conducted a camera trap (CT) study from May 2020 to April 2022. It was carried out by the deployment of 10 Ltl Acorn® 6210 CTs, that have a trigger speed of 0.8 s. The location of the CTs were set randomly on the Google Earth® platform with a 1,000 to 1,400 m distance between each CT on the map. At each site, an area with 10 m of clear vision in front of the camera lens was selected. CTs were attached to a tree (diameter > 20 cm) at 1 m above ground, facing north or south, to prevent the sun flare from the sunrise or sunset that results in overexposed photos where animals become challenging to identify (*Apps & McNutt, 2018*). Even though *Palencia et al. (2021)* suggested that the height level should be at shoulder height, which would be 80 cm in case of the wild boar, we had to attach the cameras at 1 m height, as there can be up to 0.9 m snow in winter (author observation, compare Fig. 2).

Despite two CTs being moved from the initial place, maintaining the restrictions already described. CTs were programmed to capture three consecutive images, with no delay and with normal PIR sensitivity. We did not use bait or attractors at the site. The CTs were maintained every 3 to 5 months, depending on the weather conditions.

This CT study was authorized by the national forestry corporation CONAF in Chile. Field permit to conduct the study in the National Park of Villarrica was given by Ministerio de Agricultura (Chile), Depto. Areas Silvestres Protegidas Region de la Araucaria. The Bioethics commission of the University of Concepcion approved the study. The pictures of

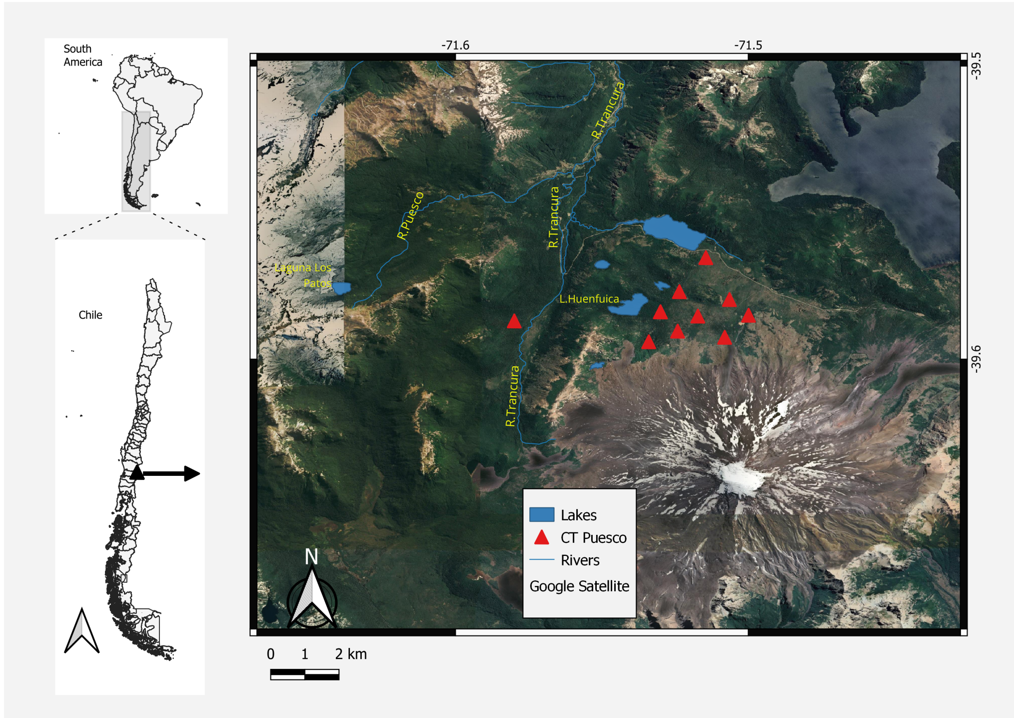

Figure 1 Map of the study area. Map created with Free and Open Source QGIS (http://qgis.org), under a CC BY-SA license.

Full-size DOI: 10.7717/peerj.18951/fig-1

people were handled following the guidelines of *Sharma et al. (2020)*, which means that the privacy of individuals inadvertently photographed by camera traps was strictly protected. Photos of unknown people were securely stored and not disclosed. Suspected researchers in photos were consulted on whether to destroy or receive the images. Wildlife images were shared with and credited to the relevant agencies overseeing the National Park, ensuring proper use and acknowledgment.

Data processing

All photographs were screened by the authors to identify those that contained wild boar (compare Fig. 2). The REM (Random Encounter Model) by *Palencia et al. (2021)* estimates animal densities using CT data. It models random encounters between animals and cameras, factoring in animal movement and detection probability. For the REM, we used all wild boar images, irrespective of the time between pictures. Density is calculated using the following formula:

$$D = \frac{y}{t} \times \frac{\pi}{v \times r \times (2 + \theta)} \quad (1)$$

where $\frac{y}{t}$ denotes the trapping rate, the number of captures per unit time, v is the average speed of the animals, r is the effective detection range of the camera, and θ is the camera's detection angle.

Figure 2 **Pictures of wild boars captured by CTs in the study area.**
Full-size DOI: 10.7717/peerj.18951/fig-2

We divided the study period into cold and warm seasons. The cold season spanned from May to October, while the warm season covered the months from November to April.

Activity level was estimated after *Rowcliffe et al. (2014)* using the R package 'activity' (*Rowcliffe, 2023*). The REM density was calculated for all CTs and then averaged for season. The activity level between seasons was tested with 1,000 bootstrap replications. To establish the angle and radius of detection, we carried out thorough walk tests at our CTs (*Cusack et al., 2015*).

Day range, which is the average daily distance traveled by an individual was calculated based on speed and activity level (*Palencia et al., 2019*). The speed of the wild boars was obtained from information from CTs and processed as described by *Rowcliffe et al. (2016)*. In this method, we divided the distance traveled by the duration of the sequence (the difference in time between the timestamps on the first and last picture). To the end of the study, we recorded the location of every captured wild boar in one single image for each CT. Then, in the field, with the diagram in hand, we measured the corresponding locations with tape. Subsequently, the CT images were reviewed, and the distance traveled, as well as time were noted for each animal sequence. Those sequences in which animals reacted to the CT or in which there was only one image of wild boar were considered for encounter rate but not for speed (*Rowcliffe et al., 2016*). The encounter rate is the number of (n°) contacts divided by the product of n° CTs and n° days. For the monthly encounter rate, we considered independent images as a 30 min interval of the same CT. To analyze differences in monthly encounter rates, the Chi-square test for independence was carried out with 95% confidence level. Also, the Kruskal-Wallis's test was carried out.

All the statistical analyses were performed on Infostat software (*Di Renzo et al., 2020*).

RESULTS

The total effort for this study involved 4,703 24h-periods, with 2,516 in the cold season and 2,187 in the warm season. We had a total number of wild boar encounters of 370, of which 320 were independent. Our CT had a detection angle of 0.741 radians and a detection radius of 8.0 m. From analyzing 280 image sequences, we estimated the speed of movements to be 0.43, 0.49, and 0.42 m/s for the two years, cold and warm seasons, respectively. We found significant differences in speed between the seasons (p value = 0.0334, Kruskal-Wallis's test).

In terms of encounter rates, there are significant differences among months. March and April had significantly the highest rates at 0.24 and 0.25, respectively (Chi square, $df = 11$, $p < 0.05$). The lowest encounter rates were in September with no pictures at all during the study and in August with only 0.005 (two pictures) ($p < 0.05$) (Fig. 3).

The activity index was determined by analyzing 370 pictures. The overall activity index was calculated to be 0.48 (SE $\pm$ 0.05). During the cold season, the activity index was 0.45 (SE $\pm$ 0.06), while during the warm season it was 0.43 (SE $\pm$ 0.03) (Table 1). The overall group size was 2.1 (SE $\pm$ 0.1), with a group size of 2.3 (SE $\pm$ 0.4) in the cold season and 2.0 (SE $\pm$ 0.2) in the warm season (Table 2). There was no significant difference in the activity between seasons ($p > 0.05$).

Using the activity index and estimated animal speed, we were able to determine that the animals had a day range of 11.4 km over two years. Accordingly, throughout the entire study period, the estimated population density was 1.4 individuals/km^2 (Table 2). In the cold season, the density was 1.0 individuals/km^2, while in the warm season it was 2.6 individuals/km^2.

DISCUSSION

While interpreting our results, it is crucial to acknowledge certain limitations. Firstly, the relatively small number of CTs used was due to budget constraints. Surveys range from 1 to 1,000 CTs (*Burton et al., 2015*). Typically, 20 to 30 CTs are recommended for monitoring populations of medium to large mammals, such as wild boars, to ensure sufficient detection and data collection across a given study area (*Kays et al., 2020*). Our small sample size likely caused wide confidence intervals for density. The variability in CT captures may be due to random placement or the small number of CTs.

Massei et al. (2018) suggested a minimum of nine cameras per km^2 for evaluating wild boar density, while our study had a much lower density (0.7 cameras per km^2). According to *Guerrasio et al. (2022)*, higher camera density would reduce error related to the contact rate. Thus, our data should be interpreted cautiously due to high confidence intervals. The nested CI analysis showed that adding more CTs decreases CI width without stabilization,

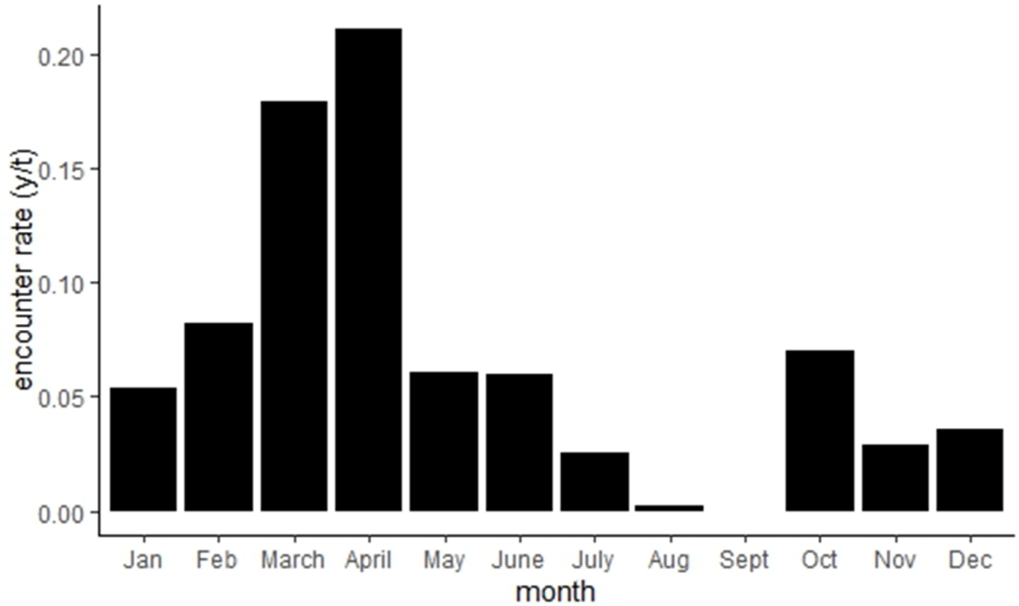

Figure 3 **Monthly encounter rate (encounter (y)/ time (t)) of wild boar in Villarrica NP 177 (Chile) from May 2020 until April 2022 ($n = 370$).**

Full-size DOI: 10.7717/peerj.18951/fig-3

Table 1 **Estimated activity index for SE wild boar in study area.**

	Entire period	Cold season	Warm season
act	0.48	0.45	0.43
Se	0.05	0.06	0.03
lcl 2.5%	0.43	0.31	0.33
ucl 97.5%	0.56	0.49	0.44

Notes.
act, activity index Activity package Rowcliffe 2023; lcl 2.5%, lower confidence limit; ucl 97.5%, upper confidence limit.

indicating the need for more CTs for accurate results. Overestimating precision could undermine management practices (*Guerrasio et al., 2022*).

Second, the trigger speed of our cameras was slower than the 0.5 s recommended by *Palencia et al. (2021)*, operating at 0.8 s, which may have impacted detection probability. Additionally, our CTs were positioned 20 cm higher than *Palencia et al.*'s *(2021)* recommendation due to significant snow accumulation in winter, a factor that could have also influenced detection probability. However, the CTs used to have detection probabilities near 1 for wild boar similar to other models, such as Bushnell, (*Palencia et al., 2021*), when employed in the same way. Our CTs, still almost covered by snow, continued to capture images, for example, of *Lepus europaeus* during the harsh winter.

To evaluate the meaning of our results, it is essential to compare our findings with previous studies. Our study's unique contribution is the quantification of population density, which has not been investigated in prior research in this geographical area. Most previous studies have focused on estimating population abundance, but our research

Table 2 Estimated random encounter model (REM) parameter values for each period. Where y/t is the encounter rate (nº contacts/nº camera traps*days); v, the average distance travelled by an individual during a day (day range); r, the radius of detection. We present standard errors (SE), 95% confidence intervals and coefficient of variation (CV, %) for density.

Season	Entire period	Cold season	Warm season
y/t (ind/CT day)	0.07 (370/4,703)	0.035 (88/2,516)	0.128 (282/2,181)
v (km/day)	11.4	11.6	10.0
r (km)	0.008	0.008	0.008
Group size (±SE)	2.1 (0.1)	2.3 (0.4)	2.0 (0.2)
Density (indiv/km^2) (±SE)	1.4 (0.6)	1.0 (0.5)	2.6 (1.0)
low IC 95% (indiv/km^2)	0.36	0.1	0.6
Upper IC 95% (indiv/km^2)	2.6	1.9	4.6
CV (%)	128.6	145.0	124.1

provides an added dimension by considering the seasonal variation in movement speed, activity index and therefore density, thereby enriching the understanding of animal behavior in different climatic conditions.

The estimated density of 1.4 individuals/km^2 is the first ever calculated density for wild boar in South American temperate forests. However, our density is still difficult to evaluate. Compared to the European average density of 7.8 individuals/km^2 (*Guerrasio et al., 2022*), our density may seem rather low. This is also considering that there is no hunting in the area and the availability of the nutritious seeds of the Araucaria, although the presence of puma can have some effect on the daily movement, as they hunt the wild boar as well (*Skewes et al., 2012*).

This low density can presumably not be explained by the later introduction of the species in South America, as the species is highly adaptable and reproductive. The first introduction in this area was 70 years ago (*Skewes & Jaksic, 2015*), the population could be at a higher level just by reproductive rate. The different environmental factors are surely causing this disruption.

When comparing the European data to ours, it must be taken into account that most of the studies have not been conducted in extreme ecosystems, but in ones that are native to the wild boar and in areas of known wild boar abundances. This difference includes the low food availability at the study site, which is caused by the rough environmental conditions at 1,400 m altitude. We suggest that the reason for April being the month with the highest encounter rate is on the one hand, that it is the rutting time of wild boar in Chile (*Skewes, 1990*), which causes a higher mobility of animals (*Morelle et al., 2015*). On the other hand, because in March it is the Araucaria seed fall, which leads to higher food availability (*Sanguinetti & Kitzberger, 2008*). The Araucaria seeds are not only consumed by animals like wild boars and rodents, but also by the indigenous people that collect the seeds. The main component of the 3–4 g weight Araucaria seeds is starch (about 88.0 g/100 g solids) (*Henríquez et al., 2008*) followed by protein (about 7.0 g/100 g solids). The protein of this seed has a high nutritional quality, like that of soy protein

(*Conforti & Lupano, 2011*). Also, the Araucaria seeds as a food item for wild boar has been described (*Pelliza-Sbriller & Borrelli, 2008*).

The fluctuation between the cold and warm seasons should be considered. To further evaluate them, the climatic conditions need to be analyzed. Snow is present from June to September, including July being overall the coldest month with an average of 1.3 °C (http://www.aic.gov.ar/sitio/estaciones). The changes in temperature in the cold season not only generate a drastic decrease in edible flora, but also impede movement through up to 90 cm of snow. Even though wild boars decrease their activity in winter, the high snow layer hinders them from any longer movement in these months. These conditions, combined with the significantly lower encounter rate, suggest that the population could be moving between areas seasonally. This would be consistent with findings from research conducted in Poland, as well as in mountainous regions in Italy and Spain (*Andrzejewski & Jezierski, 1978*; *D'Andrea et al., 1995*; *Sarasa & Sarasa, 2013*). In consequence, it could be hypothesized that wild boars migrate to the Araucaria forest due to the increased food availability. This would pose a risk to the endangered Araucaria trees, as the boars' chewing could hinder seed germination. In Europe (*Jezek et al., 2021*), the damaging of seedlings through wild boars has been described, which could be possible with the Araucaria seedlings as well. This would imply an even higher damage to the already endangered species.

Considering the limitations to our study, we propose a continuing survey of the wild boar population with more CTs and possibly even management actions, if further population growth is observed.

CONCLUSIONS

In conclusion, our study provides new insights into animal movement speed, activity index, and population density. However, the results should be interpreted with caution due to the limitations associated with the number of the CTs and the estimation methods used. Further research with more advanced tracking technologies and larger sample sizes would be beneficial to validate and expand upon our findings.

ACKNOWLEDGEMENTS

We would like to thank Paula Aravena, Edmundo Schuster and Mario Talbotu for their help within our research.

ADDITIONAL INFORMATION AND DECLARATIONS

Funding

The authors received no funding for this work. The publication of this study was financially supported by the Open Access Publication Fund of the University of Veterinary Medicine Hannover, Foundation. The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Grant Disclosures

The following grant information was disclosed by the authors:

Open Access Publication Fund of the University of Veterinary Medicine Hannover, Foundation.

Competing Interests

The authors declare there are no competing interests.

Author Contributions

- Oscar Skewes conceived and designed the experiments, performed the experiments, analyzed the data, prepared figures and/or tables, authored or reviewed drafts of the article, and approved the final draft.
- Annaluisa Kambas analyzed the data, prepared figures and/or tables, authored or reviewed drafts of the article, and approved the final draft.
- Paula Gädicke analyzed the data, prepared figures and/or tables, and approved the final draft.
- Oliver Keuling conceived and designed the experiments, authored or reviewed drafts of the article, and approved the final draft.

Field Study Permissions

The following information was supplied relating to field study approvals (i.e., approving body and any reference numbers):

Field permit to conduct the study in the National Park of Villarrica was given by Ministerio de Agricultura (Chile), Depto. Areas Silvestres Protegidas Region de la Araucaria.

This camera trap study was authorized by the national forestry corporation CONAF in Chile. The Bioethics commission of the University of Concepcion approved the study and the pictures of people were handled following the guidelines of *Sharma et al. (2020)*.

Data Availability

The following information was supplied regarding data availability:

The raw data are available in the Supplementary Files.

Supplemental Information

Supplemental information for this article can be found online at http://dx.doi.org/10.7717/peerj.18951#supplemental-information.

REFERENCES

Andrzejewski R, Jezierski W. 1978. Management of a wild boar population and its effect on commercial land. *Acta Theriologica* **23(09)**:309–339 DOI 10.4098/AT.arch.78-23.

Apps PJ, McNutt JW. 2018. How camera traps work and how to work them. *African Journal of Ecology* **56**:702–709 DOI 10.1111/aje.12563.

Barrios-Garcia MN, Ballari SA. 2012. Impact of wild boar (*Sus scrofa*) in its introduced and native range: a review. *Biological Invasions* **14(11)**:2283–2300 DOI 10.1007/s10530-012-0229-6.

Burton AC, Neilson E, Moreira D, Ladle A, Steenweg R, Fisher JT, Bayne E, Boutin S. 2015. REVIEW: wildlife camera trapping: a review and recommendations for linking surveys to ecological processes. *Journal of Applied Ecology* **52**:675–685 DOI 10.1111/1365-2664.12432.

Conforti PA, Lupano CE. 2011. Selected properties of *Araucaria Angustifolia* and *Araucaria Araucana* seed protein. *International Journal of Food Properties* **14(1)**:84–91 DOI 10.1080/10942910903131431.

Croft S, Franzetti B, Gill R, Massei G. 2020. Too many wild boar? Modelling fertility control and culling to reduce wild boar numbers in isolated populations. *PLOS ONE* **15(9)**:e0238429 DOI 10.1371/journal.pone.0238429.

Cuevas MF, Ballari SA, Ojeda RA, Skewes O. 2021. Wild boar invasion in Argentina and Chile: ecology, impacts, and distribution. In: Jaksic FM, Castro SA, eds. *Biological invasions in the South American anthropocene: global causes and local impacts*. Cham: Springer International Publishing, 203–229 DOI 10.1007/978-3-030-56379-0_10.

Cusack JJ, Swanson A, Coulson T, Packer C, Carbone C, Dickman AJ, Kosmala M, Lintott C, Rowcliffe JM. 2015. Applying a random encounter model to estimate lion density from camera traps in Serengeti National Park, Tanzania. *Journal of Wildlife Management* **79(6)**:1014–1021 DOI 10.1002/jwmg.902.

D'Andrea L, Durio P, Perrone A, Pirone S. 1995. Preliminary data of the wild boar (*Sus scrofa*) space use in mountain environment. *IBEX Journal of Mountain Ecology* **3**:117–121.

Di Renzo JAC, Balzarini MG, González I, Tablada M, Robledo CV. 2020. InfoStat. Universidad Nacional De Córdoba. *Available at http://www.infostat.com.ar*.

Enetwild-Consortium, Acevedo P, Aleksovski V, Apollonio M, Berdión O, Blanco-Aguiar JA, del Rio L, Ertürk A, Fajdiga L, Escribano F, Ferroglio E, Gruychev G, Gutiérrez I, Häberlein V, Hoxha B, Kavčić K, Keuling O, Martínez-Carrasco C, Palencia P, Pereira P, Plhal R, Plis K, Podgórski T, Ruiz C, Scandura M, Santos J, Sereno J, Sergeyev A, Shakun V, Soriguer R, Soyumert A, Sprem N, Stoyanov S, Smith GC, Trajçe A, Urbani N, Zanet S, Vicente J. 2022. Wild boar density data generated by camera trapping in nineteen European areas. *EFSA Supporting Publications* **19(3)**:7214E DOI 10.2903/sp.efsa.2022.EN-7214.

Enetwild-Consortium, Vicente J, Plhal R, Blanco-Aguiar JA, Sange M, Podgórski T, Petrovic K, Scandura M, Nabeiro AC, Body G, Keuling O, Apollonio M, Ferroglio E, Zanet S, Brivio F, Smith GC, Croft S, Acevedo P, Soriguer R. 2018. Analysis of hunting statistics collection frameworks for wild boar across Europe and proposals for improving the harmonisation of data collection. *EFSA Supporting Publication* **15(12)**:EN-1523 DOI 10.2903/sp.efsa.2018.EN-1523.

Fulgione D, Buglione M. 2022. The Boar War: five hot factors unleashing boar expansion and related emergency. *Land* **11(6)**:887 DOI 10.3390/land11060887.

Guerrasio T, Brogi R, Marcon A, Apollonio M. 2022. Assessing the precision of wild boar density estimations. *Wildlife Society Bulletin* **46**:e1335 DOI 10.1002/wsb.1335.

Henríquez C, Escobar B, Figuerola F, Chiffelle I, Speisky H, Estévez AM. 2008. Characterization of piñon seed (*Araucaria araucana* (Mol) K. Koch) and the isolated starch from the seed. *Food Chemistry* **107(2)**:592–601 DOI 10.1016/j.foodchem.2007.08.040.

Jezek S, Jonak M, Burget R, Dvorak P, Skotak M. 2021. Deep learning-based defect detection of metal parts: evaluating current methods in complex conditions. In: *13th International congress on ultra modern telecommunications and control systems and workshops (ICUMT), Brno, Czech Republic, 2021*. 66–71 DOI 10.1109/ICUMT54235.2021.9631567.

Jori F, Massei G, Licoppe A, Ruiz-Fons F, Linden A, Václavek P, Chenais E, Rosell C (eds.) 2021. Chapter 8. Management of wild boar populations in the European Union before and during the ASF crisis. In: *Understanding and combatting African Swine Fever—A European perspective*. Wageningen: Wageningen Academic Publishers DOI 10.3920/978-90-8686-910-7_8.

Kays R, Arbogast BS, Baker-Whatton M, Beirne C, Boone HM, Bowler M, Burneo SF, Cove MV, Ding P, Espinosa S, Gonçalves ALS, Hansen CP, Jansen PA, Kolowski JM, Knowles TW, Lima MGM, Millspaugh J, McShea WJ, Pacifici K, Parsons AW, Pease BS, Rovero F, Santos F, Schuttler SG, Sheil D, Si X, Snider M, Spironello WR. 2020. An empirical evaluation of camera trap study design: how many, how long and when? *Methods in Ecology and Evolution* **11**:700–713 DOI 10.1111/2041-210X.13370.

Massei G, Coats J, Lambert MS, Pietravalle S, Gill R, Cowan D. 2018. Camera traps and activity signs to estimate wild boar density and derive abundance indices. *Pest Management Science* **74**:853–860 DOI 10.1002/ps.4763.

Morelle K, Podgórski T, Prévot C, Keuling O, Lehaire F, Lejeune P. 2015. Towards understanding wild boar (*Sus scrofa*) movement: a synthetic movement ecology approach. *Mammal Review* **45(1)**:15–29 DOI 10.1111/mam.12028.

Myers N, Mittermeier RA, Mittermeier C, daFonseca GA, Kent J. 2000. Biodiversity hotspots for conservation priorities. *Nature* **403**:853–858 DOI 10.1038/35002501.

Otis DL, Burnham KP, White GC, Anderson DR. 1978. Statistical inference from capture data on closed animal populations. In: *Wildlife monographs*. 3–135.

Palencia P, Barroso P, Vicente J, Hofmeester TR, Ferreres J, Acevedo P. 2022. Random encounter model is a reliable method for estimating population density of multiple species using camera traps. *Remote Sensing in Ecology and Conservation* **8**:670–682 DOI 10.1002/rse2.269.

Palencia P, Vicente J, Barroso P, Barasona JÁ, Soriguer RC, Acevedo P. 2019. Estimating day range from camera-trap data: the animals' behaviour as a key parameter. *Journal of Zoology* **309(3)**:182–190 DOI 10.1111/jzo.12710.

Palencia P, Vicente J, Soriguer RC, Acevedo P. 2021. Towards a best-practices guide for camera trapping: assessing differences among camera trap models and settings under field conditions. *Journal of Zoology* **316(3)**:197–208 DOI 10.1111/jzo.12945.

Pelliza-Sbriller A, Borrelli L. 2008. Observaciones sobre dieta jabali en Neuquén. *Presencia* **52**:28–30.

Premoli A, Quiroga P, Gardner M. 2017. *Araucaria araucana*, Monkey Puzzle. IUCN. Retrieved 28/08/2023 DOI 10.2305/IUCN.UK.2013-1.RLTS.T31355A2805113.en.

Risch AC, Wirthner S, Busse MD, Page-Dumroese DS, Schutz M. 2010. Grubbing by wild boars (*Sus scrofa*) and its impact on hardwood forest soil carbon dioxide emissions in Switzerland. *Oecologia* **164(3)**:773–784 DOI 10.1007/s00442-010-1665-6.

Rowcliffe M. 2023. activity: Animal Activity Statistics. R package version 1.3.4. *Available at https://CRAN.R-project.org/package=activity*.

Rowcliffe JM, Field J, Turvey ST, Carbone C. 2008. Estimating animal density using camera traps without the need for individual recognition. *Journal of Applied Ecology* **45(4)**:1228–1236 DOI 10.1111/j.1365-2664.2008.01473.x.

Rowcliffe JM, Jansen PA, Kays R, Kranstauber B, Carbone C, Pettorelli N. 2016. Wildlife speed cameras: measuring animal travel speed and day range using camera traps. *Remote Sensing in Ecology and Conservation* **2(2)**:84–94 DOI 10.1002/rse2.17.

Rowcliffe JM, Kays R, Kranstauber B, Carbone C, Jansen PA, Fisher D. 2014. Quantifying levels of animal activity using camera trap data. *Methods in Ecology and Evolution* **5(11)**:1170–1179 DOI 10.1111/2041-210x.12278.

Sanguinetti J, Ditgen RS, Donoso-Calderón SR, Hadad MA, Gallo L, González ME, Ibarra JT, Ladio A, Lambertucci SA, Marchelli P, Mundo IA, Nuñez MA, Pauchard A, Puchi P, Relva MA, Skewes O, Shepherd JD, Speziale K, Vélez ML, Salgado-Salomón ME, Zamorano-Elgueta C. 2023. Información científica clave para la gestión y conservación del ecosistema biocultural del Pewén en Chile y Argentina. *Bosque* **44(1)**:179–190 DOI 10.4067/s0717-92002023000100179.

Sanguinetti J, Kitzberger T. 2008. Patterns and mechanisms of masting in the large-seeded southern hemisphere conifer *Araucaria araucana*. *Austral Ecology* **33(1)**:78–87 DOI 10.1111/j.1442-9993.2007.01792.x.

Sanguinetti J, Kitzberger T. 2010. Factors controlling seed predation by rodents and non-native *Sus scrofa* in Araucaria araucana forests: potential effects on seedling establishment. *Biological Invasions* **12(3)**:689–706 DOI 10.1007/s10530-009-9474-8.

Sarasa M, Sarasa JA. 2013. Intensive monitoring suggests population oscillations and migration in wild boar *Sus scrofa* in the Pyrenees. *Animal Biodiversity and Conservation* **36(1)**:79–88 DOI 10.32800/abc.2013.36.0079.

Sharma K, Fiechter M, George T, Young J, Alexander JS, Bijoor A, Suryawanshi K, Mishra C. 2020. Conservation and people: towards an ethical code of conduct for the use of camera traps in wildlife research. *Ecological Solutions and Evidence* **1(2)**:e12033 DOI 10.1002/2688-8319.12033.

Skewes O. 1990. Status des Wildschweines, *Sus scrofa* L. in Chile. *Dokumentation einer Fremdansiedlung von eiropäischem Wild*. Göttingen: Georg-August Universität zu Göttingen, Germany.

Skewes O, Jaksic FM. 2015. History of the introduction and present distribution of the European wild boar (*Sus scrofa*) in Chile. *Mastozoología Neotropical* **22(1)**:113–124.

Skewes O, Moraga C, Arriagada P, Rau J. 2012. El jabalí europeo (*Sus scrofa*): Un invasor biológico como presa reciente del puma (*Puma concolor*) en el sur De Chile. *Revista Chilena De Historia Natural* **85**:227–232 DOI 10.4067/S0716-078X2012000200009.

Thomas L, Buckland ST, Rexstad EA, Laake JL, Strindberg S, Hedley SL, Bishop JRB, Marques TA, Burnham KP. 2010. Distance software: design and analysis of distance sampling surveys for estimating population size. *Journal of Applied Ecology* **47**:5–14 DOI 10.1111/j.1365-2664.2009.01737.x.