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ORIGINAL PAPER

Using camera-trapping to assess grape consumption by vertebrate pests in a World Heritage vineyard region

Lucas Lamelas-López[1] · Ferrante Marco[1]

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Abstract
Vertebrate pests cause significant economic loss in several agricultural crops worldwide; therefore, their populations are often controlled through culling. Correctly identifying the main species responsible for the damage is essential to avoid persecuting the wrong targets, yet it is challenging. During 2016 and 2017, we tested the usefulness of camera-trapping (CT) in Terceira Island, Azores, Portugal to identify vertebrate pests. Vineyard owners in this region cull the Azores woodpigeon (*Columba palumbus azorica*), the common pigeon (*Columba livia*), the house sparrow (*Passer domesticus*), the Azores blackbird (*Turdus merula azorensis*), and the Madeira wall lizard (*Teira dugesii*) to reduce damage to grapes. Using CT photos and videos, we identified nine species damaging the grape, but four of those were only observed occasionally (< 10 consumption events over 2 years). The Madeira lizard (371.09 and 232.47 consumption events$^{100\text{-CT-days}}$ in 2016 and 2017, respectively), the house sparrow (284.01 and 21.73 consumption events$^{100\text{-CT-days}}$ in 2016 and 2017, respectively), and the Azores blackbird (17.35 and 8.23 consumption events$^{100\text{-CT-days}}$ in 2016 and 2017, respectively) had the most frequent consumption events. All three species were most active in the morning (8:00–9:00) and in the afternoon (16:00–17:00 for the Madeira lizard and the house sparrow, and 18:00–19:00 for the Azores blackbird). We demonstrated the advantage of using CT in cultivated habitats to provide valuable information about the identity, behaviour, daily-activity patterns, and relative consumption rates of vineyard pests. We also provided evidence that the endemic Azores woodpigeon and the common pigeon should not be targeted by the farmers in Terceira.

Keywords Azores · Bird pests · Daily-activity pattern · Fruit damage · Reptile pests · Rodent pests

Key message

- Vertebrate pests are generally identified surveying the farmers and by the damage left on the fruit. However, pest identification through such methods is unreliable and can lead to erroneous conclusions.
- We tested the effectiveness and demonstrated the benefits of using camera-traps to assess pest identity, daily-activity patterns, and grape consumption rates in Azorean vineyards.
- Two of the five species culled by farmers, one of which is endemic, cause negligible damage and should not be targeted.

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✉ Lucas Lamelas-López
lucas.l.lopez@uac.pt

Ferrante Marco
marco.ferrante@live.it

[1] Centre for Ecology, Evolution and Environmental Changes (cE3c), Azorean Biodiversity Group, Faculty of Agriculture and Environment, University of the Azores, 9700-042 Angra do Heroísmo, Portugal

Introduction

Although the majority of agricultural pests are invertebrates, vertebrates can cause a substantial economic loss in several agricultural systems (Witmer 2007; Tracey and Saunders 2010). In California, one of the most productive areas worldwide for agriculture, the loss due to vertebrates is valued between $US 168–504 million for 20 crops (Gebhardt et al. 2011). Grapes have great economic importance for many regions around the world (Volpe et al. 2010).

By partially or entirely consuming the fruits, vertebrate pests can cause severe damage in vineyards. For instance, in Australia the economic loss caused solely by birds was estimated at $AUS 120.8 million (Gong et al. 2009).

Birds (Bomford and Sinclair 2002; Anderson et al. 2013) and rodents (Gebhardt et al. 2011) are often the main vertebrate pests in vineyards, whether native (Somers and Morris 2002) or exotic (Kross et al. 2012) to the area. Eliminating those pests through lethal removal is common practice, although programs that aim to reduce the pest population can be undesirable for the conservation of native and endemic species. Reliable information about pest identity and activity is therefore crucial to plan effective pest control strategies and to avoid targeting the wrong species. Vertebrate pest identification in vineyards is done by checking damage left on the partially consumed fruits (Tracey and Saunders 2010) or by surveying farmers (Gebhardt et al. 2011). Yet, farmers rarely have taxonomical training and mostly work during the daytime. Thus, identifying vertebrate pests in vineyards is problematic.

Camera-trapping (CT) is a noninvasive monitoring technique suitable to track the activity of large as well as small-bodied animals such as birds (Krauss et al. 2018) both during the day and at night. CT consists of fixed cameras equipped with passive infrared sensors that are triggered by movements (O'Connell et al. 2011). CT can be done also when traditional sampling is difficult, e.g. extreme weather conditions and at night (O'Connell et al. 2011) and to monitor elusive species (Silveira et al. 2003; O'Connell et al. 2011), and it is often just as effective as traditional sampling methodologies (Silveira et al. 2003; Wearn and Glover-Kapfer 2019). The use of CT is popular in conservation biology (Rowcliffe et al. 2008) and animal behaviour science (Bridges and Noss 2011; Caravaggi et al. 2017), where noninvasive techniques are needed, while it remains less so in agro-environments (but see Honda et al. 2010; Zak and Riley 2017).

In this study, we tested the usefulness of CT in the World Heritage vineyard region of Terceira Island (Azores, Portugal). Since 2016, vineyard owners in Terceira cull four bird species (the Azores woodpigeon, *Columba palumbus azorica*; the common pigeon, *Columba livia*; the house sparrow, *Passer domesticus*; and the Azores blackbird, *Turdus merula azorensis*) and one lizard (the Madeira wall lizard, *Teira dugesii*) that have been suspected to damage the grapes (Table S1).

The aims of this study were: to confirm the identity of the main vertebrate pest species (1) and to determine their consumption rates (2) and daily-activity patterns (3), and to verify if the detection events are a good proxy for feeding events (4). In order to test a technical aspect of CT, we also evaluated whether camera-trap videos give consistent results with camera-trap photos (5).

Materials and methods

Study area

This study was carried out in the World Heritage vineyard region of Biscoitos (Fig.S1), in the northern part of Terceira (38.7º N, 27.2º W), the third largest island of the Azores archipelago. This area comprises 165.40 ha and is categorized as a protected landscape (Regional Legislative Decree Nº 11/2011/A). Vineyards are the most ancient crop in the Azores (Medeiros 1994), having been introduced by the Portuguese during the colonization of the islands in the fifteenth century. Azorean vineyards have been traditionally located on basaltic lava field terroirs, in the lower altitude areas of the islands (Madruga et al. 2015) and are divided in small enclosures delimited by stone walls (Fig. S2), which protect the grapes from the maritime winds (Madruga et al. 2015).

Sampling survey

The study was conducted during the maturation of the fruits (August–September 2016–2017). We moved 15 camera-traps every week to sample a total of 109 enclosures (2016 = 54 and 2017 = 55) ranging in size from 11–36 m^2 (mean = 19.80 m^2, SD = 6.44 m^2) for a total sampling effort of 763 camera-trap days. Eleven enclosures (10%) were excluded from the analysis because of recording failure caused by weather conditions. The minimum distance between two enclosures was 25 m. We placed one camera-trap (*Bushnell Trophy cam HD*) at the edge of each enclosure at 0.5–1 m above the ground, using a wood stick as support to monitor the entire enclosure (Fig. S2). Each camera was programmed to capture high-quality photos (8 MB) or 10-second videos (Meek et al. 2014; Bowler et al. 2017), recording date and time for each detection event (Table S2). After a detection event, a camera stops recording for 30 s to reduce the probability of double-counting the same individual (Rowcliffe et al. 2008).

Species detection and activity pattern

For each species detected in either images or videos we calculated: (1) the relative abundance index (RAI), i.e. the number of detected individuals per 100 camera-trap days (O'Brien et al. 2003), (2) the number of grape consumption events per 100 camera-trap days, (3) the number of enclosures where the species occurred, and (4) the daily-activity pattern.

In order to evaluate if cameras taking photos and videos provided consistent results, we tested if the RAI and the number of consumption events in 2016–2017 were correlated using the Pearson correlation test when recorded by photos or by videos. The sample sizes for these tests were given by the number of cameras taking photos ($n = 65$) and videos ($n = 32$). Rodents were excluded from both tests, as all consumption events were recorded by one camera taking photos in one enclosure in 2017. Rodents and Island blackcaps (*Sylvia atricapilla gularis*) were excluded from both tests, as all detections and consumption events were recorded by one camera taking photos in one vineyards in 2017.

The daily-activity pattern of every detected species was created summing up all records (photos and videos from all cameras) every 2 h intervals. Graphs were created, and all analyses were performed using the statistical software R version 3.3.3 (R Core Team 2019).

Results

Overall, 63,388 detection events (47,783 photos and 15,605 videos) were obtained, of which 52,526 events (82.8%) corresponded to false triggers caused by the vine leaves moved by the wind, invertebrates, and humans. Therefore, our final dataset consisted of 4729 photos and 787 videos taken in 2016, and 3401 photos and 1945 videos taken in 2017. Four species were recorded by the cameras but were never observed consuming the grapes. These were the domestic cat (*Felis catus*), the least weasel (*Mustela nivalis*), the European hedgehog (*Erinaceus europaeus*), and the European rabbit (*Oryctolagus cuniculus*) and were removed from the analysis ($n = 122$ records). An additional four species were removed because they accounted for less than 10 consumption events during the two years of the study. These species were the common quail (*Coturnix coturnix conturbans*), the common pigeon (*Columba livia*), the Azorean woodpigeon (*Columba palumbus azorica*), and the European robin (*Erithacus rubecula*). All rodent species detected (the house mouse, *Mus musculus*; the brown rat, *Rattus norvegicus*; and the black rat *R. rattus*) were combined, as distinguishing between them from the records was not always possible.

Of the 10,740 records obtained, 8449 showed the Madeira wall lizard (3284 and 2932 images; 621 and 1612 videos, in 2016 and 2017, respectively), 2754 birds (1267 and 1196 images; 84 and 207 videos, in 2016 and 2017, respectively), and 537 rodents (93 and 262 images; 72 and 110 videos, in 2016 and 2017, respectively). The Madeira wall lizard was recorded in 85.32% of the enclosures, the house sparrow in 22.01% of the enclosures, the Azorean blackbird in 58.71% of the enclosures, the Azores chaffinch (*Fringilla coelebs moreletti*) in 21.10% of the enclosures, the Atlantic canary (*Serinus canaria*) in 20.18% of the enclosures, the Island blackcap in 14.67% of the enclosures, rodents (the house mouse, the brown rat, and the black rat altogether) in 38.53% of the enclosures. These nine species were the most frequently recorded pests, and all are resident in the island. Madeira wall lizards were observed feeding 2168 times, house sparrows 848 times, Azorean blackbirds 143 times, Atlantic canaries 49 times, Azores chaffinches 29 times, Island blackcaps 17 times. Rodents were never observed feeding in 2016, but were recorded feeding 22 times in 2017 (Table 1). The RAI$^{100\text{-CT-days}}$, and the number of consumption events$^{100\text{-CT-days}}$ from photo CT were highly correlated for all species ($r = 0.46$–0.96, $p < 0.001$, $n = 65$), except for the Atlantic canary ($r = 0.01$, $p = 0.909$, $n = 65$). Similarly, the RAI$^{100\text{-CT-days}}$ and the number of consumption events$^{100\text{-CT-days}}$ from video CT were highly correlated for all species ($r = 0.70$–0.93, $p < 0.001$, $n = 32$), except that for the house sparrow ($r = 0.34$, $p = 0.06$, $n = 32$). For all species, the number of consumption events was proportional to the number of detections.

All bird species and the Madeira wall lizard were continuously active from sunrise until late afternoon (Fig. 1). Rodents were mainly nocturnal, although occasionally appeared throughout the day. The Madeira wall lizard was

Table 1 Relative abundance index (RAI = number of detected individuals over 100 camera-trap days) and number of grape consumption events over 100 camera-trap days for each introduced (*I*) and native (*N*) vertebrate species detected in vineyards of Terceira, Azores, Portugal, between August–September 2016 and 2017

Species	Status	RAI				Consumption events			
		2016		2017		2016		2017	
		Photo	Video	Photo	Video	Photo	Video	Photo	Video
Madeira lizard, *Teira dugesii*	I	1117.01	739.29	1269.26	1046.75	371.09	91.67	232.47	300.65
House sparrow, *Passer domesticus*	I	344.56	7.14	6.93	1.30	284.01	5.95	1.73	2.60
Azorean blackbird, *Turdus merula azorensis*	N	56.46	79.76	50.22	69.48	17.35	48.81	8.23	20.78
Atlantic canary, *Serinus canaria*	N	6.46	7.14	7.79	37.66	1.70	7.14	0	24.68
Azores chaffinch, *Fringilla coelebs moreletti*	N	5.78	4.76	9.52	12.34	1.70	1.19	3.46	6.49
Island blackcap, *Sylvia atricapilla gularis*	N	7.14	0	2.16	3.90	4.42	0	0	2.60
Rodents	I	31.63	85.71	113.42	71.43	0	0	6.93	3.90

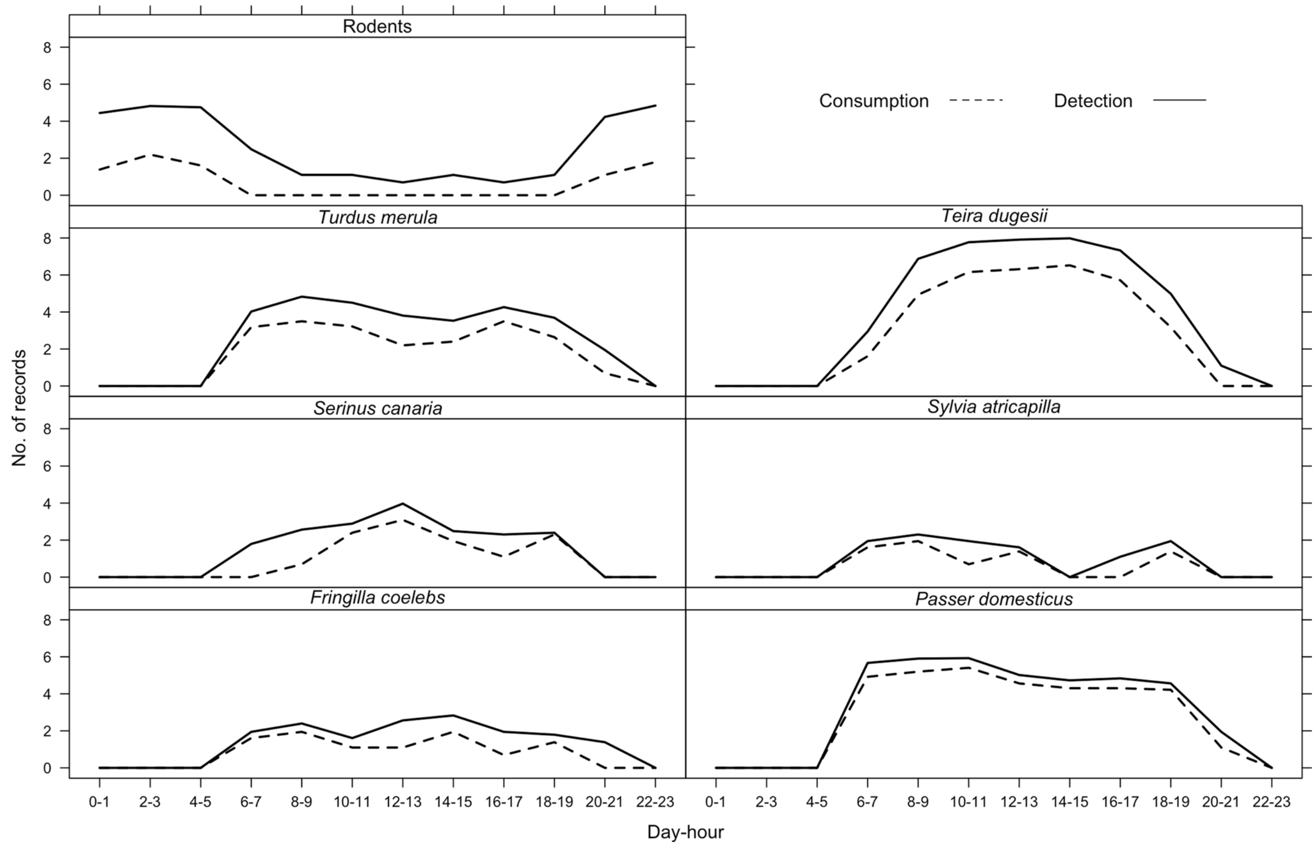

Fig. 1 Daily-activity patterns (log-transformed number of detections and consumptions) at 2 h intervals of vertebrate pests in vineyards in Terceira Island, Azores, Portugal. Solid and dashed lines represent the number of records and consumption events, respectively

mainly active during the warmest time of the day, between 8:00–9:00 and 16:00–17:00 h. Similarly, the house sparrow was detected mostly between 06:00–07:00 h and 16:00–17:00 h. The Island blackcap and the Azorean blackbird showed two activity peaks, the first in the early morning (6:00–8:00 h for both) and the second in the late afternoon (16:00–17:00 and 18:00–19:00 h, respectively). The Atlantic canary showed a single activity peak around midday (12:00–13:00 h), and the Azores chaffinch between 12:00–13:00 and 14:00–15:00 h (Fig. 1).

Discussion

The use of CT is becoming an increasingly popular tool for field ecologists (Rovero et al. 2013), but applications in agro-environments remain rare (Coates et al. 2010), possibly because researchers fear cameras will be stolen or damaged by humans. Although passive infrared sensors of CT can be unreliable when the ambient temperature ranges within the body temperature of most mammals, i.e. 31.5–36.5 °C (Rovero et al. 2013), this was likely not a problem in our study, as the Azores experience mild summers [average temperature 24–25 °C; Atlas climático de los archipiélagos de Canarias, Madeira y Azores (2012)]. In this study, the main limitation of this method was a high record of false detections caused by the wind blowing vine leaves and by non-target species (i.e. insects, cats), which made analysing the records time-consuming, but did not compromise the CT effectiveness.

The higher correlation coefficients between the number of detections and consumptions found for camera-trap videos than for camera-trap photos suggest that camera-trap videos may provide more accurate estimates. Moreover, videos may be adequate to observe pest behaviour. However, videos require more memory space and time to analyse the records (Glen et al. 2013). Camera-traps must be programmed to stop working after a detection event to reduce the chances of recording non-independent events (i.e. avoid recording the same animal multiple times in a short period). For this purpose, we used 30 s activation-delay, which was suitable for most species except the most active ones, such as the Madeira lizard and the house sparrow, for which longer activation-delay (1–1.5 min) could have been more appropriate. However, when the aim is recording several species as in this study, it may be difficult to choose an activation-delay that is optimal for all species at the same time. The methodological trade-off between guaranteeing independent observations and reducing missing observations should be always taken into account when analysing CT photos. Another challenge to the use of CT data is ensuring that the detection probability is constant to obtain reliable data across time, space, and species (O'Connell et al. 2011; Sollmann et al. 2013). Although RAI are widely used in CT-based studies (O'Brien 2011), their use should take into account the interpretability of the data, the sampling costs, and whether suitable alternative or complementary methods exist.

Using CT, we were able to identify vertebrate pests in Terceira's vineyards, except for small rodents, which were, however, recorded much less often than other species and that therefore were not likely to be major pests during our study. We found that two invasive species to the island, the house sparrow and the Madeira wall lizard (Borges et al. 2010), and one endemic species, the Azorean blackbird (Barcelos et al. 2015), were particularly active in vineyards. All species were more frequently recorded feeding on the grapes in 2016, but the difference between recorded consumption events in the 2 years of the study was extremely large only for the house sparrow. Discerning the reasons beyond the number of detections was behind the aim of our study, but it is possible than in 2016 the nesting success of the sparrow population was higher than in 2017. Another possibility is that because of the scarcity of food, sparrows were more active in vineyards and, therefore, were recorded more often. Undoubtedly, the house sparrow, the Madeira wall lizard, and the Azorean blackbird damaged the grapes more often than other vertebrates. Compared to birds, which are often observed feeding on grapes (Stevenson and Virgo 1971), quantification of the lizard damage is rare, probably because reptiles are more difficult to be detected using traditional sampling methods (i.e. visual surveys). Most of the consumption events we observed by the Madeira wall lizard ended with the destruction of small fruits or with partial damage to large fruits. Yet, the damage caused by this invasive lizard is likely to be substantial, as even partial damage can increase the grape susceptibility to other pests and pathogens and reduce the quality of the grape (Tracey et al. 2007).

While two of the three major pests we identified were invasive species, whose presence is often undesirable for both conservation biologists and farmers, the Azorean blackbird creates a situation of conflict. We believe that drastic counter-measures such as culling should not be initiated against endemic species even when they cause economic loss. Alternative solutions such as non-lethal deterrents and/or governmental aids to compensate for the crop loss should be preferred. Another benefit of the use of CT is that it provides data on daily-activity patterns; information that can be useful to enhance the effectiveness of pest deterrents used in our study area, such as scare cannons. Additionally, it is necessary to consider that introduced birds protect the crops against insect pests, too, and that the ecosystem services provided may exceed the ecosystem disservices (Zhang et al. 2007).

Although CT data cannot be directly translated to the economic loss, they provide reliable information about the identity, behaviour, and daily-activity pattern of vineyard pests, and about their relative consumption rates. The case of Terceira is emblematic of situations where pest control strategies are implemented without the assurance of correct identification of the pests. CT proved to be a valuable technique to confirm if the species that growers perceive as pests are indeed a problem for the crop. Our results clearly demonstrated that culling common pigeons and Azores woodpigeons is unjustified. The latter, particularly, is not only not responsible for any remarkable damage on the grape, but is also a priority species for conservation in Europe (Barcelos et al. 2015).

Author contributions

LLL conceived, designed, and performed the research. MF performed the statistical analysis. Both authors contributed to the writing of the manuscript.

References

Anderson A, Lindell CA, Moxcey KM et al (2013) Bird damage to select fruit crops: the cost of damage and the benefits of control in five states. Crop Prot 52:103–109. https://doi.org/10.1016/j.cropro.2013.05.019

Atlas climático de los archipiélagos de Canarias, Madeira y Azores (2012) Agencia Estatal de Meteorología, Ministerio de Agricultura, Alimentación y Medio Ambiente

Barcelos L, Rodrigues P, Bried J et al (2015) Birds from the Azores: an updated list with some comments on species distribution. Biodivers Data J 3:e6604. https://doi.org/10.3897/BDJ.3.e6604

Bomford M, Sinclair R (2002) Australian research on bird pests: impact, management and future directions. Emu 102:29–45. https://doi.org/10.1071/MU01028

Borges PAV, Costa A, Cunha R et al (eds) (2010) A list of the terrestrial and marine biota from the Azores. Princípia, Cascais

Bowler MT, Tobler MW, Endress BA et al (2017) Estimating mammalian species richness and occupancy in tropical forest canopies with arboreal camera traps. Remote Sens Ecol Conserv 3:146–157

Bridges AS, Noss AJ (2011) Behavior and activity patterns. In: O'Connell AF, Nichols JD, Karanth KU (eds) Camera traps in animal ecology: methods and analyses. Springer, Tokyo, pp 57–69

Caravaggi A, Banks PB, Burton AC et al (2017) A review of camera trapping for conservation behaviour research. Remote Sens Ecol Conserv 3:109–122. https://doi.org/10.1002/rse2.48

Coates RW, Delwiche MJ, Gorenzel WP, Salmon TP (2010) Evaluation of damage by vertebrate pests in California vineyards and control of wild turkeys by bioacoustics. Hum Wildl Interact 4:130–144

Gebhardt K, Anderson AM, Kirkpatrick KN, Shwiff SA (2011) A review and synthesis of bird and rodent damage estimates to select California crops. Crop Prot 30:1109–1116. https://doi.org/10.1016/j.cropro.2011.05.015

Glen AS, Cockburn S, Nichols M et al (2013) Optimising camera traps for monitoring small mammals. PLoS ONE 8:e67940. https://doi.org/10.1371/journal.pone.0067940

Gong W, Sinden J, Braysher ML et al (2009) The economic impacts of vertebrate pests in Australia. Invasive Animals Cooperative Research Centre, Canberra

Honda T, Miyagawa Y, Suzuki Y, Yamasaki S (2010) Possibility of agronomical techniques for reducing crop damage by sika deer. Mamm Study 35:119–124. https://doi.org/10.3106/041.035.0202

Krauss SL, Roberts DG, Phillips RD, Edwards C (2018) Effectiveness of camera traps for quantifying daytime and nighttime visitation by vertebrate pollinators. Ecol Evol 8:9304–9314. https://doi.org/10.1002/ece3.4438

Kross SM, Tylianakis JM, Nelson XJ (2012) Effects of introducing threatened falcons into vineyards on abundance of passeriformes and bird damage to grapes. Conserv Biol 26:142–149. https://doi.org/10.1111/j.1523-1739.2011.01756.x

Madruga J, Azevedo EB, Sampaio JF et al (2015) Analysis and definition of potential new areas for viticulture in the Azores (Portugal). SOIL 1:515–526. https://doi.org/10.5194/soil-1-515-2015

Medeiros CA (1994) Contribuição para o estudo da vinha e do vinho dos Açores. Finisterra 29:199–229. https://doi.org/10.18055/Finis1832

Meek PD, Ballard G, Claridge A et al (2014) Recommended guiding principles for reporting on camera trapping research. Biodivers Conserv 23:2321–2343. https://doi.org/10.1007/s10531-014-0712-8

O'Brien TG (2011) Abundance, density and relative abundance: a conceptual framework. In: O'Connell AF, Nichols JD, Karanth KU (eds) Camera traps in animal ecology: methods and analyses. Springer, New York, pp 71–96

O'Brien TG, Kinnaird MF, Wibisono HT (2003) Crouching tigers, hidden prey: Sumatran tiger and prey populations in a tropical forest landscape. Anim Conserv 6:131–139. https://doi.org/10.1017/S1367943003003172

O'Connell AF, Nichols JD, Karanth KU (eds) (2011) Camera traps in animal ecology: methods and analyses. Springer, New York

R Core Team (2019) A language and environment for statistical computing. Version 3.3.3. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org

Regional Legislative Decree Nº 11/2011/A (2011) About the creation and re-classification of Protected Areas of the Azores. Diário da República, Região Autónoma dos Açores

Rovero F, Zimmermann F, Berzi D, Meek P (2013) Which camera trap type and how many do I need? A review of camera features and study designs for a range of wildlife research applications. Hystrix 24:148–156. https://doi.org/10.4404/hystrix-24.2-8789

Rowcliffe JM, Field J, Turvey ST, Carbone C (2008) Estimating animal density using camera traps without the need for individual recognition. J Appl Ecol 45:1228–1236. https://doi.org/10.1111/j.1365-2664.2008.01473.x

Silveira L, Jácomo ATA, Diniz-Filho JAF (2003) Camera trap, line transect census and track surveys: a comparative evaluation. Biol Conserv 114:351–355. https://doi.org/10.1016/S0006-3207(03)00063-6

Sollmann R, Mohamed A, Samejima H, Wilting A (2013) Risky business or simple solution–Relative abundance indices from camera-trapping. Biol Conserv 159:405–412. https://doi.org/10.1016/j.biocon.2012.12.025

Somers CM, Morris RD (2002) Birds and wine grapes: foraging activity causes small-scale damage patterns in single vineyards. J Appl Ecol 39:511–523. https://doi.org/10.1046/j.1365-2664.2002.00725.x

Stevenson AB, Virgo BB (1971) Damage by robins and starlings to grapes in Ontario. Can J Plant Sci 51:201–210

Tracey JP, Saunders GR (2010) A technique to estimate bird damage in wine grapes. Crop Prot 29:435–439. https://doi.org/10.1016/j.cropro.2009.10.008

Tracey JB, Bornford M, Hart Q et al (2007) Managing bird damage to fruit and other horticultural crops. Bureau of Rural Sciences, Canberra

Volpe R, Green R, Heien D, Howitt R (2010) Estimating the supply elasticity of California wine grapes using regional systems of equations*. J Wine Econ 5:219–235. https://doi.org/10.1017/S1931436100000924

Wearn OR, Glover-Kapfer P (2019) Snap happy: camera traps are an effective sampling tool when compared with alternative methods. R Soc Open Sci 6:181748. https://doi.org/10.1098/rsos.181748

Witmer G (2007) The ecology of vertebrate pests and integrated pest management (IPM). In: Kogan M, Jepson P (eds) Perspectives in ecological theory and integrated pest management. Cambridge University Press, Cambridge, pp 393–410

Zak AA, Riley EP (2017) Comparing the use of camera traps and farmer reports to study crop feeding behavior of moor macaques (*Macaca maura*). Int J Primatol 38:224–242. https://doi.org/10.1007/s10764-016-9945-6

Zhang W, Ricketts TH, Kremen C et al (2007) Ecosystem services and dis-services to agriculture. Ecol Econ 64:253–260. https://doi.org/10.1016/j.ecolecon.2007.02.024