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Estimating feral cat density on Corvo Island, Azores, to assess the feasibility of feral cat eradication

Estimativa de densidades de gatos assilvestrados na Ilha do Corvo, Açores, para avaliar a viabilidade de erradicar a população de gatos assilvestrados

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ABSTRACT - Feral cats have had negative effects on native biodiversity on many islands worldwide. Eradicating feral cats from islands is often feasible, and can yield great benefits to native biodiversity, especially for seabirds. Corvo Island (Azores) is an important island where feral cats limit the distribution and abundance of breeding seabirds. To assess whether the eradication of feral cats on Corvo would be feasible we used camera traps to estimate the density of feral cats. We deployed 24 camera traps at 253 locations around the island for 14 months, and identified cats detected by camera traps individually based on the coat colour. We then used spatially explicit capture-recapture models to estimate cat density for Corvo. Cat density in the uninhabited upland part of Corvo, which is dominated by cow pastures, was 0.036 (95% CI 0.025 – 0.054) cats/ha. The lowland part of Corvo, which is inhabited by humans and contains domestic cats, had an estimated cat density of 0.734 (0.581 – 0.927) cats/ha. Overall, we estimated that the cat population on Corvo during our study period included 163 (123 - 228) individuals. The estimated cat densities are within the range of cat densities from other islands where cats have been successfully eradicated, and we conclude that feral cat eradication on Corvo would be technically feasible. However, the co-existence of feral and domestic cats would create operational challenges, and the current lack of a legal framework to ensure that all domestic cats are sterilised would increase the risk of a feral cat population becoming re-established after eradication.

RESUMO - Foram registados impactos negativos causados por gatos assilvestrados na biodiversidade nativa de várias ilhas do mundo. A erradicação destes de ilhas é muitas vezes viável, e pode trazer muitos benefícios para a biodiversidade nativa, especialmente aves marinhas. Na Ilha do Corvo (Açores) os gatos assilvestrados limitam a distribuição e abundância de aves marinhas nidificantes. Para determinar a sua densidade e a viabilidade de uma erradicação foram utilizadas câmaras-armadilha. Assim, foram colocadas 24 câmaras em 253 locais diferentes da ilha durante 14 meses. Os gatos detetados foram identificados individualmente pela cor do pelo. Através de modelos espaciais específicos de captura-recaptura foi estimada a densidade de gatos no Corvo. Na área de maior altitude, que é desabitada e dominada por pastagens com gado bovino, a densidade de gatos assilvestrados estimada foi de 0,036 (95% IC 0,025 – 0,054) gatos/ha. Na área de baixa altitude, que é habitada e contém gatos domésticos, a densidade de gatos assilvestrados foi de 0,734 (0,581 – 0,927) gatos/ha.

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No total, durante o período de estudo a população de gatos no Corvo foi estimada em 163 (123 - 228) indivíduos. A estimativa de gatos para o Corvo está dentro dos valores estimados para outras ilhas onde os gatos assilvestrados foram erradicados com sucesso, pelo que concluímos que a erradicação de gatos assilvestrados no Corvo é tecnicamente viável. No entanto, a co-existência de gatos domésticos e assilvestrados poderá ser um problema na logística operacional, além da falta de enquadramento legal para garantir a esterilização de todos os gatos domésticos, o que aumentará o risco de restabelecimento dos gatos assilvestrados após uma erradicação.

Feral cats (*Felis catus*) are a widespread introduced predator on many islands, and are known to have negatively affected many populations of native vertebrates (Bonnaud et al. 2010a, Medina et al. 2011). Because many vertebrates that are native to oceanic islands evolved in the absence of mammalian predators such as cats, they are extremely vulnerable to cat predation and many cannot co-exist with feral cats. Seabirds in particular have suffered greatly from cat predation (Keitt et al. 2002, Bonnaud et al. 2009), and the removal of feral cats from islands is often the most efficient way to preserve populations of vulnerable seabirds (Keitt & Tershy 2003, Bonnaud et al. 2010b, Ratcliffe et al. 2010).

Minimising or eliminating the negative effects of feral cats on native taxa on oceanic islands requires knowledge about the biology of feral cats in order to target control or capture techniques effectively (Nogales et al. 2004, Campbell et al. 2010). One important aspect of cat biology that aids in designing effective control or removal programmes is the ranging behaviour and the density of feral cats, as this will determine the efficient placement of traps or poison bait stations to ensure every single cat has access to such a control device (Moseby et al. 2009, Bengsen et al. 2012b). However, estimating the density of a solitary and far-ranging carnivore like feral cats is logistically challenging (Obbard et al. 2010, Can et al. 2011, Sollmann et al. 2011).

Corvo Island (39°42'N 31°6'W; 1760 ha) is the smallest island in the Azores, and is home to a large population of seabirds (Monteiro et al. 1996, Groz et al. 2005). Feral cats were introduced to Corvo before 1717, and are continuously supplanted by offspring from an un-neutered domestic cat population. Feral cats are currently the main predators of the most abundant seabird on Corvo, the Cory's Shearwater (*Calonectris diomedea*; Hervías et al. 2013), and are presumably the main reason why other species of smaller seabirds are restricted to cliffs that are inaccessible to feral cats (Groz et al. 2005). The eradication of feral cats from Corvo Island may therefore benefit the local seabird community.

In this study, we estimated the density of feral cats on the island of Corvo in order to assess whether a feral cat eradication would be technically feasible. We used camera traps for 14 months to record cats at various points across the island, and identified individual cats based on coat colour pattern. These spatially referenced photograph data were then used to estimate cat density with spatially explicit capture-recapture models. Our study provides a first estimate of the number of feral cats on Corvo, and describes the challenges associated with cat density estimation that may be useful for similar assessments elsewhere.

METHODS

» Study area

Corvo is geographically dominated by the dormant volcano that originally created the island (França 2006). The most dominant habitat is grassland grazed by cows, followed by small agricultural plots and cliffs vegetated by native small shrub or invasive vegetation such as Giant Reed Grass (*Arundo donax*). There are no forests on Corvo, and only small (<1 ha) woodlands along riparian areas. Corvo ranges in elevation from sea level to 718 m, and the only village (437 inhabitants) and most agricultural areas are situated in the lower part of the island (<150,

Fig. 1). Because the populated and more intensively farmed area of Corvo has habitat characteristics that are distinctly different from the remainder of the island, we separated the island into a lowland (below 150 m) and an upland part (above 150 m), and estimated cat density for these two parts separately (Fig. 1).

» Measuring cat activity using trail cameras

We used passive infra-red motion sensor cameras (Bushnell Trophy Cam) triggered by temperature alterations and movements to detect feral cats. We set the delay between each trigger to ten seconds and recorded three images per trigger event to maximise identification of cats and to reduce excess images from slow-moving animals. Cameras were placed 50 cm above ground and attached to fixed objects (rocks, fence-posts, trees), and no attractants were used to lure cats in front of cameras. To achieve greater spatial coverage, cameras were moved to a new position every 2 weeks.

From May through October 2010, cameras were deployed at six shearwater colonies to assess predator activity (Hervías et al. 2013). However, to estimate cat density across the entire island we also deployed cameras at random locations around the island outside the breeding season (November 2010 – April 2011). Spatial deployment of cameras during the breeding season was based on a 15 x 15 m grid that was created for each shearwater colony. For every 2-week period, each camera was assigned to a randomly chosen grid cell, with 2-4 cameras operating simultaneously in a given colony. Within the randomly chosen grid cell, cameras were placed along paths or boundaries to maximise the likelihood that a lateral view of a passing cat could be obtained. Outside the breeding season, cameras were placed at randomly generated locations around the entire island (Fig. 1).

The images downloaded from cameras were processed manually to filter out images that contained cats (<1% of all images), and each cat was individually identified by its unique coat markings (Mendoza et al. 2011). To match new images with previously identified individuals we manually compared each new image with all others in an existing archive of cat images. Animals that could not be matched to an existing individual in the archive were given a new identification number. Some cat detections involved cats that were not uniquely identifiable, due to uniform coat colour that did not exhibit distinguishable characteristics. These detections received a unique identification number indicating the observation of an unidentifiable cat, and were excluded from the analysis of cat density. To account for the number of unidentifiable cats in the population, we calculated the proportion of cat detections that involved indistinguishable cats. The final estimates of cat density were then divided by the proportion of unidentifiable individuals in our sampled population, assuming that the total feral cat population would harbour the same proportion of unidentifiable cats as the sampled population (Wilson et al. 1999, Gormley et al. 2005).

» Cat density estimation using spatially explicit capture-recapture models

Spatially explicit capture-recapture (SECR) models use the individual identification of animals at different locations within the study area to estimate the approximate location of each individual's home range centre (Efford et al. 2009, Royle et al. 2009, Borchers 2012). These methods utilise additional spatial information compared to standard capture-recapture analyses to estimate abundance, and require no *a priori* definition of the effective sampling area (Borchers 2012).

We deployed cameras at 125 locations in the upland part and at 128 locations in the lowland part. Cameras were deployed for at least 14 nights at each location, and we reduced continuously acquired camera images into encounter occasions spanning 7 days, yielding 57 discrete encounter occasions between March 2010 and April 2011. The length of these encounter occasions was chosen to maximise the number of detections per encounter occasion, while minimising the loss of information from cats being repeatedly recorded during a single occasion (Bengsen et al. 2012a). The long study duration (> 1 year) was required to obtain sufficient recaptures of previously identified animals for the estimation of density.

One of the major assumptions of SECR models is that the population is closed during the study period. Although Corvo is an island and emigration and immigration of feral cats is highly unlikely, the

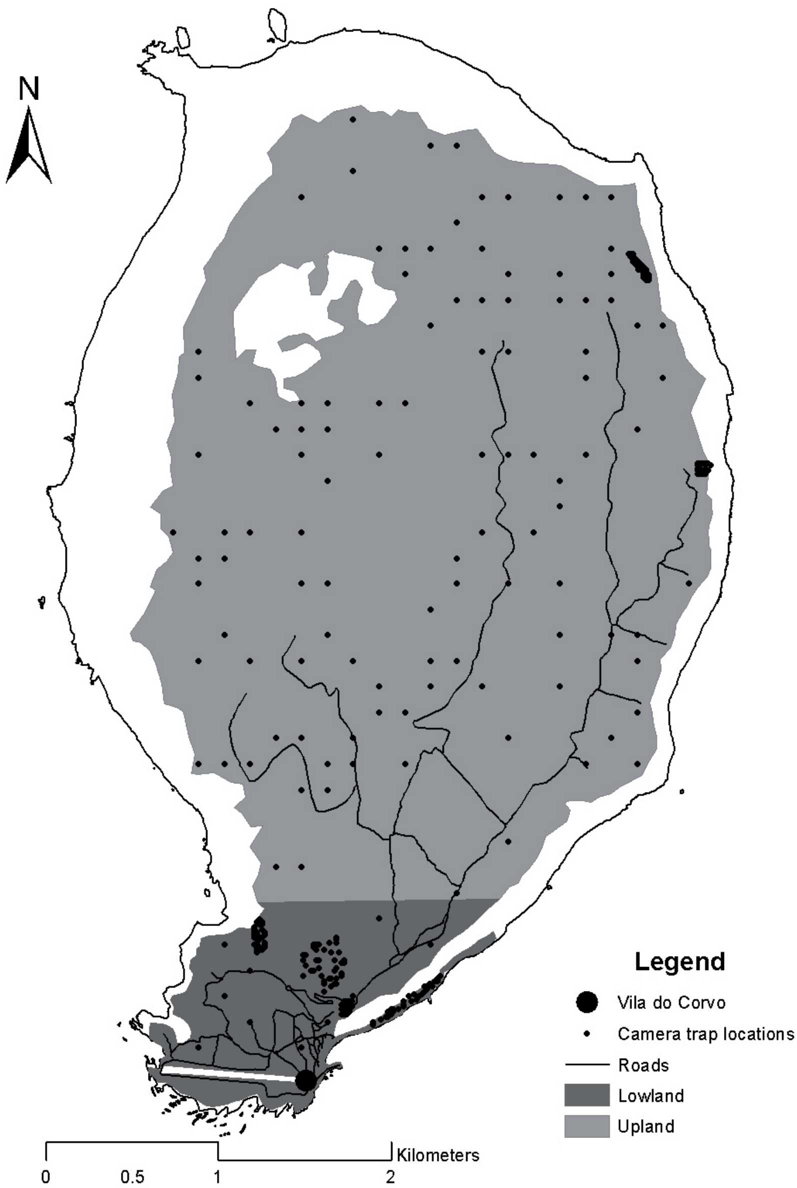

Figure 1. Map of Corvo showing the location of the village, the roads, and all camera trap locations used during this project. The area in dark grey represents the lowland habitat, and the area in light grey the upland habitat for which cat density was estimated. White areas were excluded from cat density estimation because they were inaccessible to humans or cats (e.g. vertical cliffs, the crater lake, and the airport). Dense aggregation of camera traps occurred in study colonies of Cory's Shearwaters.

Figura 1. *Mapa do Corvo com a localização da vila, as estradas e os locais de colocação das câmaras. A densidade de gatos foi estimada no habitat de baixa altitude, área representada em cinzento escuro, e a área em cinzento claro representa o habitat de alta altitude. As áreas em branco foram excluídas do estudo por serem inacessíveis a humanos e gatos (p.e. falésias, o Caldeirão e o aeroporto). As áreas com uma maior densidade de câmaras correspondem às colónias de cagarra.*

long study duration rendered it likely that the feral cat population was not demographically closed, i.e. that births and deaths occurred during the study period. We used a closure test to evaluate whether our data met the assumption of population closure (Stanley & Burnham 1999). If the closure assumption was violated, we adopted the reduced version of SECR model that collapses all occasions into one and simply uses the spatial encounter history of individuals (Borchers & Efford 2008).

We evaluated two different spatial detection functions (half-normal and exponential), and two different functions for the distribution of home range centres, a Poisson point process (Borchers & Efford 2008) and a binomial point process (Royle et al. 2009). We thus fit four different candidate models combining each combination of detection function and distribution process. For numerical integration, the likelihood function was evaluated at points spaced 50 m apart and distributed evenly throughout the accessible parts of Corvo. We created a habitat mask that excluded areas from integration that are inaccessible to cats (open water in the crater lake, vertical cliffs, Fig. 1). All SECR models were fit in R 2.13.0 (R Development Core Team 2010) using the library 'secr' (Efford 2011).

For each part of the island we ranked models using AIC_c and estimated density by model-averaging across all candidate models using the Akaike weight of each model as a weighing factor (Burnham & Anderson 2002). For each part we estimated the number of cats by multiplying the estimated density by the area (1140 ha for the upland part, 139 ha for the lowland part), and correcting for the proportion of unidentifiable cats as described above. We present cat density and abundance estimates as model-averaged mean with 95% confidence intervals.

RESULTS

In the upland part of Corvo, we identified 30 individual cats in 83 detection events at 58 camera locations. An additional 21 detections involved unidentifiable individuals, yielding a proportion of 20.2% of all detections (n = 104) being not identifiable. In the lowland part of Corvo, we identified 74 individual cats in 352 detection events at 92 camera locations. An additional 43 detections involved unidentifiable individuals, yielding a proportion of 10.8% of all detections (n = 395) being not identifiable. The closure test indicated that the population in each part was not closed over the study period (upland: z = -3.20, lowland: z = -1.17, both $p < 0.001$), hence we reduced the encounter history of all detectors to a single occasion.

For each part of the island, the model that assumed a negative exponential detection function and a Poisson point process received the most support from the data (upland: ωAIC_c = 0.75, lowland: ωAIC_c = 1.0). The model-averaged density of feral cats was 0.036 (95% CI 0.025 – 0.054) cats/ha in upland Corvo, and 0.734 (0.581 – 0.927) cats/ha in the lowland part. Accounting for unidentifiable individuals we estimated that the feral cat population in the upland part contained 52 (35 – 77) individuals, while the lowland part contained 111 (88 – 141) individuals. Thus, the cat population on Corvo during our study period was 163 (123 – 228) individuals. This figure includes an unknown proportion of semi-domestic cats that venture out from the village and were included in our density calculation because they were detected on cameras. However, the figure does not include the truly domestic cats that remain in and around the houses of their owners and were never detected on cameras.

DISCUSSION

Our study provides the first estimate of the number of feral cats on Corvo. We estimated that 123 – 228 cats existed on Corvo during the study period, with a marked difference in density between the lowland and the upland part of the island. The lowland part had a cat density ~20 times higher than the upland part, which is unsurprising given the presence of the village and a large number of available food sources (rubbish dump, agricultural fields and livestock pens that sustain high numbers of rats and mice) and places that provide cats with shelter from inclement weather. While the estimate of density in the upland part of the island probably reflects only feral cats, the lowland part is inhabited by both feral and domestic cats. The human population in the village of Corvo sustains a domestic (pet) and semi-domestic (regularly fed) cat population that together encompass 100 – 120 individuals (113 pet cats were officially registered between February and August 2010). Some of these cats roam around parts of the island, and were detected at camera locations in our study. Hence, our abundance estimate for the lowland part surrounding the village includes some of the owned cats on Corvo, which are not truly feral but fed by humans.

The cat densities that we estimated fall within the range of other islands where cats have been eradicated successfully (Nogales et al. 2004, Campbell et al. 2010). Particularly in the upland area, cat density appeared to be lower than on some sub-Antarctic islands where cats have been successfully eradicated (e.g. Macquarie Island: 0.2 cats/ha, (Copson & Whinam 2001); Marion Island: 0.1 cats/ha, (Van Aarde 1979), Kerguelen: 0.002 – 0.2 cats/ha (Say et al. 2002)). Although the cat density in the lowland part of the island was substantially higher, the estimated density is still much lower than densities of domestic cats estimated in urban areas (1.3 – 15.8 cats/ha; Sims et al. 2008). Thus, we believe that the eradication of feral cats from the island of Corvo would be technically feasible with currently available technology.

However, when considering the eradication of feral cats from an island, the presence of domestic and semi-domestic cats can create substantial operational obstacles. In addition, many of the cat owners on Corvo may oppose the eradication of feral cats, or it may not be practical to ensure that domestic cats will not re-establish a feral population (Oppel et al. 2011). Although the distinction between domestic and truly feral cats could be misleading from a conservation perspective, because domestic cats also prey heavily on local wildlife (Woods et al. 2003, van Heezik et al. 2010, Horn et al. 2011), the control and minimisation of cat predation on native fauna by feral and domestic cats requires different political and practical approaches (Calver et al. 2011).

The largest inhabited island on which feral cat eradication has been accomplished to date is Ascension Island (9700 ha, 859 m elev.), a U.K. overseas territory in the Atlantic Ocean with ~1100 human inhabitants (Bell & Boyle 2004, Ratcliffe et al. 2010). Although Corvo has only 437 human inhabitants, the problems experienced with domestic cats during the feral cat eradication campaign on Ascension are directly transferrable to the situation on Corvo. In particular, the use of poison bait to kill feral cats would be inacceptable due to the substantial risk of accidentally poisoning domestic cats (Ratcliffe et al. 2010). Hence, a feral cat eradication campaign on Corvo would have to rely on live trapping, which is generally more expensive and less efficient (Nogales et al. 2004, Campbell et al. 2010, Ratcliffe et al. 2010). Despite the inadvertent side-effects of the feral cat eradication, the Ascension Island operation may offer a viable and instructive example for Corvo with respect to domestic cats. On Ascension, all domestic cats are legally required to be registered, micro chipped and neutered, thus eliminating the risk of unwanted kittens being released into the wild and re-establishing a feral cat population (Ratcliffe et al. 2010). A similar effort to provide free sterilisation and micro-chipping of domestic cats on Corvo during 2010 received broad acceptance by most cat-owners on the island (51% of 113 domestic cats were sterilised), but found no support by the regional government. Hence, there is currently no legal framework and no available opportunity to sterilise the domestic cat population, which would render an eradication of the feral cat population an almost futile exercise with only temporary benefits for native wildlife.

» Methodological challenges in estimating cat density

Our approach to estimate cat density using spatially explicit capture-recapture models yielded realistic and moderately precise estimates of the number of cats on the island of Corvo. Such assessments are vital to allocate resources appropriately during control or eradication efforts (Moseby et al. 2009, Bengsen et al. 2012b). We encountered several challenges during the camera trapping, which may be instructive for similar projects elsewhere. The cost of camera traps (~US$200 per unit) restricted the number of cameras that could be employed in this project to 24, thus limiting the spatial coverage that could be achieved. We rotated cameras around locations to overcome that limitation, which led to the problem that at many locations no cats were detected because the camera was only present for 2 weeks. An alternative approach to maximise the detection probability of cats at camera traps would be to bait camera traps and entice cats to be detected (Bengsen et al. 2012a). However, baiting camera traps violates a core assumption of spatially explicit capture-recapture models (Efford et al. 2009, Foster & Harmsen 2012) and of other procedures to estimate density (Rowcliffe et al. 2008). These methods both model the natural movement process of cats, and thus require that recorded cat movements are unbiased and not distorted by a cat being attracted to a baited recording station. We therefore chose to deploy unbaited camera traps.

Ideally, mark-recapture studies are conducted over a time frame during which the population under study is closed. Possibly as a result of unbaited camera traps, the encounter rates of cats at cameras were too low to estimate density within a short time frame, and we therefore accumulated data over more than one year. Although it would have been possible to estimate density with a subset of our data, these estimates were generally too low because the number of individual cats identified during the entire study period was larger than the number estimated had we used only a subset of data.

Further challenges in our approach included a large number of images that did not contain any cats and required substantial effort to be filtered out. Excessive images resulting from cows or moving vegetation occasionally led to overload of available memory (2 GB), resulting in a truncation of the effective operation time because no more images could be stored. While some of these excessive images could be reduced by altering camera sensor settings, passing sheep or cows will always trigger cameras designed to detect small mammals. We received help from a large group of volunteers to screen thousands of images for the presence of cats, and caution practitioners interested in using this approach to not underestimate the amount of effort that is required to manually filter images. Besides detecting cats on images, the individual identification of cats presented another challenge. Although novel techniques continue to be developed to enhance the reliability of individual identification (Mendoza et al. 2011, Morrison et al. 2011, Goswami et al. 2012), we found that automated identification algorithms are difficult to apply to images of cats, because the angle, lighting, distance, and posture of cats differed between images, requiring a human to positively match individuals among different images.

Despite these challenges we believe that the resulting density estimates provide extremely useful information to advance the planning of cat control or eradication actions for the benefit of seabirds on the island of Corvo.

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