



# Anthropogenic influences on habitat use by African houbaras *Chlamydotis undulata* on Lanzarote, Canary Islands

Matthew Geary<sup>a,\*</sup>, Joseph R. Cooper<sup>a</sup>, Nigel J. Collar<sup>b</sup>

<sup>a</sup> Conservation Biology Research Group, Department of Biological Sciences, University of Chester, Chester CH1 4BJ, UK

<sup>b</sup> BirdLife International, Cambridge, UK

## ARTICLE INFO

### Keywords:

Bustard  
Display  
Desert  
Farmland  
Distribution  
Abundance  
Disturbance

## ABSTRACT

African Houbara *Chlamydotis undulata* is threatened in North Africa by unsustainable hunting and massive overuse of captive-bred birds to replace wild losses. A small population on the Canary Islands is protected from these threats, but the archipelago is economically dependent on tourism which has led to extensive land-use change, particularly close to the coasts. We investigated the drivers of houbara distribution and abundance in and around the large semi-desert El Jable region of northern Lanzarote in order to identify potential measures to conserve this important population. All houbaras seen during point counts in the centre of 30 tetrads (2 km × 2 km) were recorded, along with their location. We used negative binomial regression to evaluate the effects of land use and human activity on the abundance of birds at tetrad scale. At finer scale we used logistic regression to assess the effect of land use on the distribution of displaying males. We recorded 196 houbara sightings on our surveys, although only 10 males were observed displaying. Houbara abundance had a quadratic relationship with the proportion of *huerta* (agricultural gardens) in a tetrad. The distribution of male displays was positively related to the proportion of long-abandoned farmland within a 100 m radius of their display site. African Houbaras favour the vicinity of small-scale agriculture and abandoned farmland, but avoid areas with higher levels of human land-use. Reduction of extensive land-use change and disturbance in El Jable are key conservation measures.

## 1. Introduction

The African Houbara *Chlamydotis undulata* is a globally threatened bustard (IUCN status Vulnerable) that inhabits semi-desert across North Africa, with an outlying subspecies *fuertaventurae* on the main eastern Canary Islands of Fuerteventura and Lanzarote plus the tiny La Graciosa (BirdLife International 2020). As a large-bodied species, it has traditionally been the quarry of choice of falconers across its North African range, but in the past fifty years it has suffered major declines as increasingly advanced technologies, communication systems, infrastructure and logistics have facilitated access to its habitat by oil-rich hunters (Goriup 1997, BirdLife International 2020, Dolman et al. 2021a). The main conservation response has been the production and release of captive-bred birds to replace wild ones lost to hunting, but this programme is on such a large scale that there are serious concerns, supported by scientific evidence, that the fitness and viability of wild populations may now be significantly compromised (Dolman et al. 2021b, Collar, in press).

The only population of African Houbara to have escaped both the hunting pressure and the risk of impaired fitness is that on the eastern Canary Islands, which therefore now assumes a new importance in the long-term conservation of the species, despite its minor taxonomic differentiation from mainland Africa (Idaghdour et al. 2004; Pitra et al. 2004). Estimates of the size of this population have varied over the years with method and changing environmental conditions, but from the early 1990s evidence emerged that Lanzarote, while only half the size of Fuerteventura (846 vs 1,660 km<sup>2</sup>), might hold significantly higher numbers than was previously believed (Martín et al. 1996). In the mid-2000s the island duly proved to possess considerably more birds than Fuerteventura, such that the highest total estimate for the Canary Islands was 778–1,282 birds with 383–806 on Lanzarote (Lorenzo et al. 2007) or, in a parallel analysis, 383–1,069 with 272–801 on Lanzarote (Carrascal et al. 2006, 2008). More recent estimates have placed the Fuerteventura subpopulation at 84–186 birds in 2011 (Schuster et al. 2012) and the Lanzarote subpopulation at 440–452 birds in 2018 (Alonso et al. 2020) and 460 birds in 2020 (de Colsa et al. 2022). In particular, surveys

\* Corresponding author.

E-mail address: [M.Geary@Chester.ac.uk](mailto:M.Geary@Chester.ac.uk) (M. Geary).

<https://doi.org/10.1016/j.jnc.2022.126231>

Received 25 February 2022; Received in revised form 25 May 2022; Accepted 24 June 2022

Available online 27 June 2022

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of Lanzarote have emphasised the importance of the arid semi-desert region known locally as El Jable, found between Soo and Famara south to the agricultural areas in Zonzamas and containing up to 85% of the island's houbara population (Carrascal et al. 2006, Garcia-del-Rey & Rodriguez-Lorenzo 2011, Alonso et al. 2020).

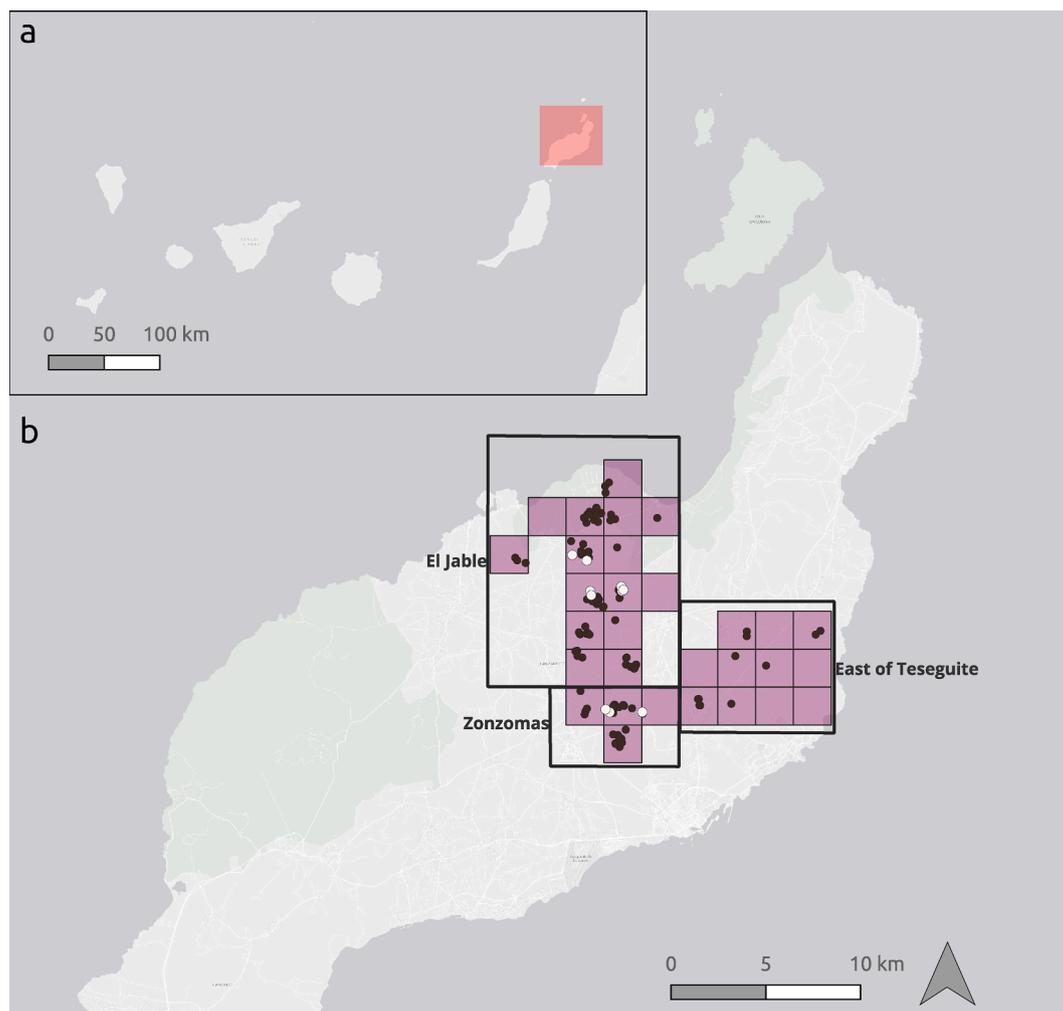
The trajectories of the two subpopulations on Fuerteventura and Lanzarote have not been easy to detect despite commendable work to census the species in the past three decades. Nevertheless, researchers are united that both subpopulations are under pressure from a variety of sources. Powerlines, new to the islands in recent decades, cause alarmingly high mortality levels (Lorenzo et al. 1998, Garcia-del-Rey & Rodriguez-Lorenzo 2011). Loss and disturbance of habitat are pervasive threats, involving tourist complex construction, new roads, access tracks and paths, off-road vehicles, sand extraction, wind farms, military manoeuvres and increased goat grazing (Lorenzo et al. 1998a, Banos-González et al. 2016). Houbara presence declines with increasing density of roads and tracks and increasing proximity of urbanisation (Carrascal et al. 2006, 2008, Schuster et al. 2012), and the conversion of semi-arid grassland and shrubland to agriculture is evidently detrimental (Carrascal et al. 2006, 2008). Nevertheless, there is some confusion whether birds suffer from the abandonment of traditional ('extensive') agriculture (Lorenzo et al. 1998a) or from the reversion of abandoned land to agriculture (Banos-González et al. 2016)—although perhaps both, as they are not mutually exclusive.

These last considerations indicate a need for greater clarity over the influence of anthropogenic factors on the species in the islands, despite the strong evidence base that has accumulated in recent decades. Given the clear importance of El Jable and associated plains, we undertook a preliminary investigation of the drivers of the birds' distribution and abundance there, using a combination of modelling approaches at two different scales, in order to identify potential management actions and options that may help ensure the long-term survival of the species in this key landscape.

## 2. Material and methods

### 2.1. Study area

El Jable is a wide area of approximately 60 km<sup>2</sup> in northern Lanzarote (Fig. 1) characterised by a substrate of white shell-sand (blown inland from the exposed seabed during the Ice Ages) and by xerophilous vegetation, with therophytic forbs and grasses providing variable cover to create a semi-desert habitat (Carrascal et al. 2006, 2008, Garcia-del-Rey & Rodriguez-Lorenzo 2011). We surveyed 15 tetrads (see next section) in El Jable and another 15 in two adjacent areas where birds have been recorded in previous studies (GREFA unpublished data, Martin et al. 2006), namely the area around Zonzamas, south of the LZ-30 road, east of San Bartolomé and west of Nazaret (four tetrads), and



**Fig. 1.** a. Lanzarote's position (pink square) among the Canary Islands; b. Our survey area, consisting of 30 2 km × 2 km tetrads (purple squares), in the northern half of Lanzarote. Observations of houbara flocks are indicated by black dots (many overlaid on each other and involving sites with multiple birds) and those of displaying males by white circles. Black, labelled rectangles indicate the three regions surveyed in our fieldwork; El Jable, Zonzomas and the area east of Teseguite. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

the area east of Teseguite bounded by Tahiche in the south and Gautiza in the north (11 tetrads), all within the municipality of Teguisse (Fig. 1). The substrate in these areas is largely volcanic rather than aeolian; the area around Zonzamas, south of the El Jable plain, largely comprises an agricultural mosaic, whereas the area east of Teseguite mixes agricultural fields with bare stony land. The topography differs somewhat between areas, El Jable and Zonzomas being largely flat with some isolated volcanic features whereas east of Teseguite the terrain is more rugged.

## 2.2. *Houbara* surveys

A grid comprising tetrads  $2 \text{ km} \times 2 \text{ km}$  was overlaid onto the study area and all  $4 \text{ km}^2$  tetrads within this area containing semi-desert habitat were identified for survey. This resulted in 40 potential survey tetrads. Thirty of these (Fig. 1) were surveyed in a randomly assigned order between 7 December 2019 and 15 March 2020, a period chosen to maximise the opportunity to locate displaying male houbaras (Hellmich 2003, Alonso et al. 2020); however, plans to survey the remaining tetrads had to be abandoned owing to the COVID-19 pandemic.

Efforts were made to identify and use an elevated vantage-point near the centre of each tetrad but appropriately remote to minimise disturbance, from which to adopt constant-effort scanning as per the ‘look down’ method (Bibby et al. 1998, Alonso et al. 2020) using  $20 \times 100 \text{ mm}$  tripod-mounted binoculars and an  $18\text{--}55 \times 65$  tripod-mounted telescope. Use of the tripod-mounted binoculars allowed extensive observation and scanning at high magnification. Where a single all-encompassing vantage-point could not be identified, or the terrain hampered visibility, a second vantage-point was located to allow for the remaining landscape to be observed (Bibby et al. 1998). Each tetrad was surveyed once during the morning for five hours (06:30–11:30) and again on the same day in the afternoon to early evening for three hours (15:30–18:30), when males were expected to be displaying (Hellmich 2003).

The distance to each bird’s location was measured using a laser rangefinder and the direction from vantage-point to bird recorded using a compass. The position of birds was also marked on paper maps of the survey square in relation to landscape features. These maps served to support the rangefinder estimates, as we were concerned that the latter may have been difficult to obtain on a relatively featureless plain (but in the event no major discrepancies between the two systems occurred). Where more than one bird was present, the size of the group was noted and each individual was observed in turn for a 10-minute period, so that all birds could be monitored consistently throughout the survey period (Bibby et al. 1998).

When a displaying male was identified we determined the approximate location of the centre of his display site by using a compass and rangefinder, along with reference to nearby landscape features, to establish the distance and bearing of the bird as soon as display feather disposition (before running) was seen, and then marking the place on a map. The extent to which the bird moved around this point was monitored through its displaying behaviours. Later, we visited this location (see next section) and recorded its position using a handheld GPS.

The frequency of anthropogenic disturbance across both survey periods was also recorded, determined by the number of people entering the survey tetrad on foot or by bicycle. A rough measure of grazing intensity within the tetrad was noted by counting the number of goats observed during the surveys. These variables should be considered as coarse estimates of disturbance and grazing due to the limited time available for surveying, as levels of disturbance may, of course, differ from day to day.

## 2.3. Environmental data

Habitat surveys and data collection were carried out once display sites were identified. Each display site was visited during the early afternoon (12:30–15:30) when males were absent or inactive, to avoid

disrupting their breeding display. Habitat variables were recorded from the centre of each display area outwards in two concentric circles, one 10 m in diameter and the other 50 m in diameter. Where no displays were observed, we recorded habitat variables from an equivalent set of circles focusing on the centre of the tetrad. In the 10 m circle, we measured the height of the five tallest shrubs, and in the 50 m circle the number of shrubs  $> 50 \text{ cm}$  tall, in order to represent vegetation height. A measure of rugosity, i.e. small-scale variations in surface height, was taken, recording the elevation above sea level at nine points along the line of the four compass points (N,S,E,W) stopping at 25 m and at 50 m along each bearing using a handheld GPS. The standard deviation of rugosity was calculated prior to analysis. In addition to the 10 m and 50 m circles measured from the centre of each display site, two more concentric circles were established at 250 m from each display site in diametrically opposite directions using compass bearing pairs (N/S, E/W) extending in a straight line. The same measurements were taken in these circles for control comparisons.

## 2.4. GIS data

The Canary Islands government categorises and maps the region’s three main agricultural land-uses as long-abandoned farmland, recently abandoned farmland (as classified by the Canary Islands crop map) and small-scale agriculture (*‘huertas’* in GRAFCAN 2014, Mapa de Cultivos 2014). We calculated the proportions of these land-uses within each tetrad and within a radius of 100 m of our houbara records—the latter to allow for local movement of displaying male houbaras, judged in the Asian Houbara *Chlamydotis macqueenii* to be ‘as great as several hundred metres’ (Launay & Paillat 1990). This information was cross-referenced with current Google satellite images (2020) to ensure accuracy. We also calculated Normalised Difference Vegetation Index (NDVI) from high-resolution image data of Lanzarote from the (02/05/2020) Sentinel-2 sensor (10 m: ESA, 2019a) acquired from the European Space Agency Copernicus data repository (ESA, 2019b), to represent growing vegetation in the area. We used this image as it was cloud-free across the study area, although it was taken outside our survey period. Elevation, slope and topographic ruggedness index (TRI; Riley et al. 1999) measurements were extracted from Shuttle Radar Topography Mission (SRTM) elevation model (<http://srtm.csi.cgiar.org>) images. Of these, only TRI was retained owing to strong correlations between the topographic variables (Pearson’s  $r > 0.7$ ). Distance to the nearest paved road, found to be a driver of houbara distribution by Schuster et al. (2012), was calculated using data derived from OpenStreetMap (map data copyrighted OpenStreetMap contributors and available from <https://www.openstreetmap.org>).

## 2.5. Statistical analysis

Owing to issues with overdispersion in Poisson models we used negative binomial regression to investigate the effects of land-use and human activity on the relative abundance of houbaras (maximum number of birds seen in either survey period) at a tetrad scale (Table 1). We used mean number of large shrubs in our 50 m circles, rugosity measured on the ground, TRI, grazing intensity, proportion of long-abandoned farmland, proportion of *huerta*, NDVI and total number of people observed in the tetrad as predictors of the maximum number of houbaras counted in each tetrad within a single survey period. The count of people in each square was log-transformed before inclusion in the models owing to a strong right-skew. We also included a quadratic term for proportion of *huerta* to reflect the presumed benefit of a small amount of farmland as a good source of food and the presumed danger of a large amount of farmland as a poor source of cover. All predictor variables were measured at the tetrad level. Recently abandoned farmland was not included as a predictor because it has a relatively strong correlation with *huerta* at tetrad scale.

We used logistic regression to investigate the effect of land-use on the

**Table 1**

Summary of analyses performed to investigate the distribution of the African Houbara in El Jable, Zonzomas and east of Teseguete, Lanzarote, indicating response and predictor variables along with the scale on the analysis.

| Research question   | Model type                   | Scale   | Response variable                        | Absences  |  | Candidate predictor variables                                      |        |       |       |
|---|------------------------------|---|--|---|--|--|--------|-------|-------|
|   |                              |   |  |   |  | Mean   | Median | Range |       |
| How is the relative abundance of houbara across the study area influenced by habitat and disturbance?           | Negative binomial regression | Tetrad  | Relative abundance of houbara per tetrad | NA  | Proportion of long-abandoned agriculture within the tetrad     | 0.24   | 0.20   | 0.62  |       |
|   |                              |   |  |   |  | Proportion of 'huerta' within the tetrad                           | 0.04   | 0.01  | 0.26  |
|   |                              |   |  |   |  | NDVI   | 0.06   | 0.06  | 0.06  |
|   |                              |   |  |   |  | Total number of people observed in the tetrad                      | 27.10  | 27    | 89    |
|   |                              |   |  |   |  | Mean number of large shrubs in our 50 m circles                    | 22.01  | 18.00 | 79.33 |
|   |                              |   |  |   |  | Standard deviation of rugosity measured on the ground              | 1.76   | 1.79  | 3.18  |
|   |                              |   |  |   |  | Grazing intensity TRI  | 47.93  | 0     | 504   |
|   |                              |   |  |   |  |  | 2.11   | 1.88  | 2.90  |
| How is the distribution of displaying male houbara across the study area influenced by habitat and disturbance? | Logistic regression          | 100 m radius around points spread across the study area | Male display sites                       | 20 randomly chosen locations per model run from 500 random points where no display was recorded within the surveyed squares | Proportion of long-abandoned agriculture within a 100 m radius | 0.23   | 0.04   | 1     |       |
|   |                              |   |  |   |  | Proportion of recently abandoned agriculture within a 100 m radius | 0.06   | 0.00  | 0.84  |
|   |                              |   |  |   |  | Proportion of 'huerta' within a 100 m radius                       | 0.04   | 0.00  | 1     |
|   |                              |   |  |   |  | NDVI within a 100 m radius   | 0.06   | 0.06  | 0.20  |
|   |                              |   |  |   |  | TRI within a 100 m radius  | 2.05   | 1.71  | 10.67 |
|   |                              |   |  |   |  | Mean height of shrubs within our 50 m circles (m)                  | 0.23   | 0.18  | 0.79  |
| Does the local habitat around male houbara display sites differ from available habitat nearby?                  | Logistic regression          | 50 m radius within 250 m of display sites               | Male display sites                       | Two locations 250 m from recorded display sites   | Number of large shrubs within our 50 m circles                 | 22.05  | 14     | 142   |       |
|   |                              |   |  |   |  | Standard deviation of rugosity measured on the ground              | 1.76   | 1.62  | 4.39  |
|   |                              |   |  |   |  | Distance to nearest paved road (m)                                 | 878.07 | 672   | 2380  |
|   |                              |   |  |   |  |  |        |       |       |
|   |                              |   |  |   |  |  |        |       |       |

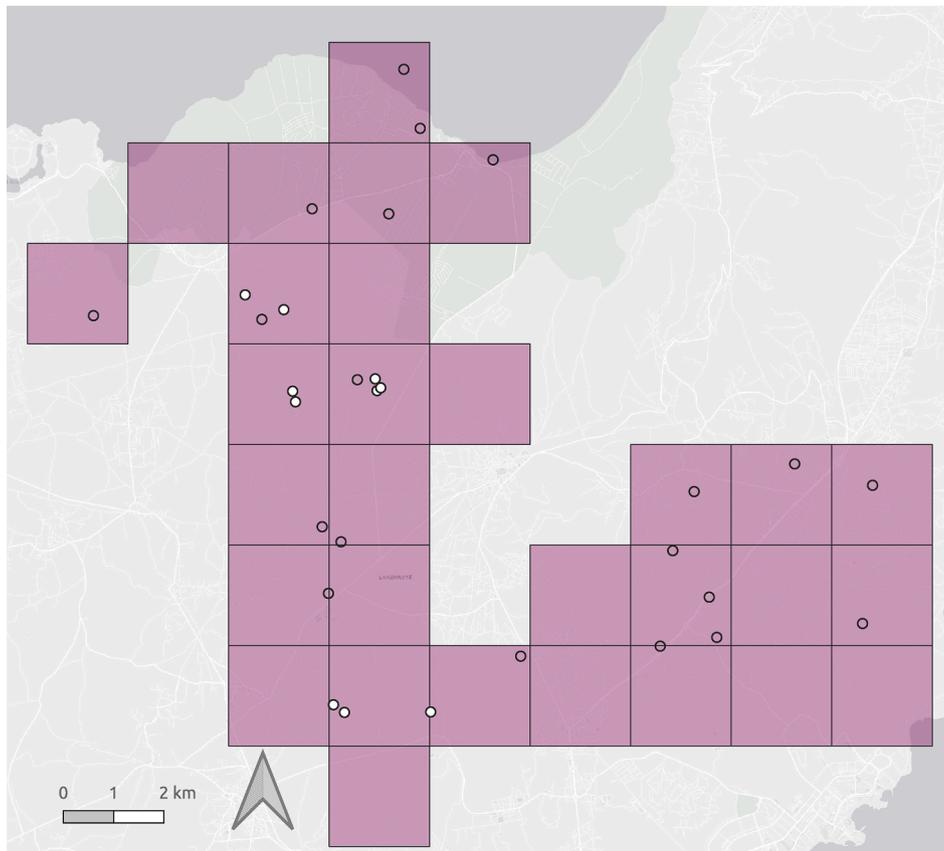
distribution of displaying males based on the specific locations of our sightings and 500 randomly selected pseudo-absences from the rest of the surveyed area (Table 1). Absence points were all within areas which had been surveyed but at least 300 m away from records of displaying males. The choice of 500 potential absences was arbitrary in order to represent as much of the study area as possible. Models were constructed using the proportion of long-abandoned farmland, recently abandoned farmland, *huerta*, NDVI and TRI as predictors of the presence of displaying males. Each of these values was calculated for a 100 m radius around records of displaying males.

We used a random sample of 20 absences (Fig. 2) along with our 10 recorded presences to fit an initial model with all candidate variables, and performed model selection (see below) on this model. Following this we repeated the random sampling of 20 absences 10,000 times and fitted the 'best' model on each occasion. We then tested each of these models for residual spatial autocorrelation and discarded those where this was significant using Moran's I. We used the remaining models ( $n = 2,000$ ) to calculate the mean parameters for each model term along with 95% confidence intervals.

We also used logistic regression to identify habitat differences between display sites and our control non-display sites (those 250 m from

located displaying males; Table 1). As predictors we chose mean height of the five shrubs measured 10 m from the display centre, the standard deviation of the display site's rugosity, the total number of shrubs > 50 cm within 50 m of the display site centre, and the distance to the nearest road from the centre of the display site. Other variables were removed from the analysis due to collinearity between predictors. In each of these cases, the predictor thought to be the most biologically relevant was retained.

In each case, we used all possible combinations of two predictors as well as a null-model with no predictor variables as our candidate model set. We did not consider models with more than two predictors to reduce the chance of overfitting with our relatively small sample size in each case. Models were selected on the basis of the lowest AICc value for negative binomial and logistic models. Where models were within  $\Delta AICc < 4$  of the lowest scoring model, indicating equal support, we found that those with more predictors did not greatly improve the model and therefore preferred the most parsimonious model within this subset. We also calculated an appropriate measure of model performance using the performance package (Lüdecke et al. 2020) for the logistic (Tjur's  $R^2$ ) and negative binomial (Nagelkerke's  $R^2$ ) regression models. All statistical analyses were performed in R v4.0.4 (R Core Team 2021).

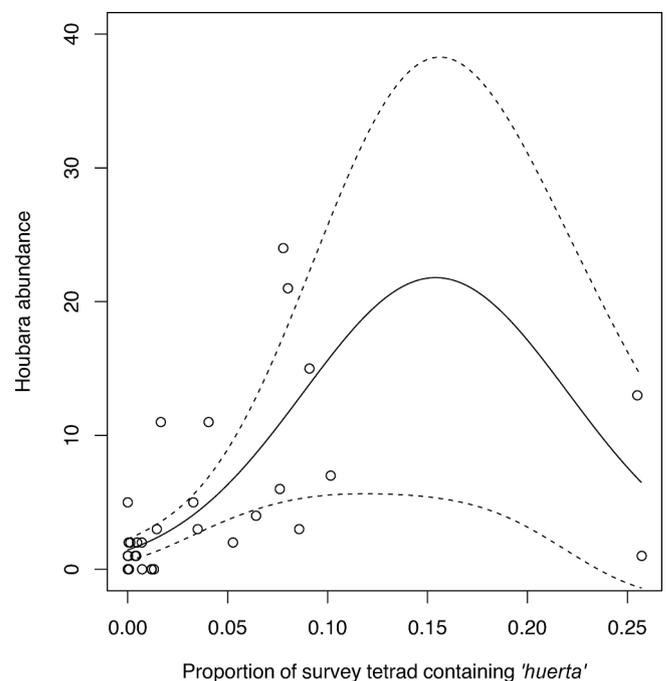


**Fig. 2.** Presence (white circles) and pseudo-absences (from one run using a sample of 20 random absence locations sampled from 500 randomly located absences; unfilled circles) used in our analysis of displaying male African Houbaras; purple squares indicate the surveyed area. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

### 3. Results

We recorded 196 African Houbara sightings on our surveys, although (probably as a result of a very dry winter and spring) only 10 males were observed displaying. Displaying birds were a median distance of 436 m from our observation points. Among all birds observed, the median observation distance was 365 m. Birds were recorded in 22 of the 30 survey squares, with the majority of records in El Jable and the area around Zonzamas (Fig. 1). All 10 displaying males were recorded in these two areas (Fig. 2). Fewer birds were recorded in the squares east of Teseguite and no displaying males were recorded there. The ‘best’ model explaining houbara relative abundance (Nagelkerke’s  $R^2 = 0.65$ ) across the study area used only the proportion of *huerta* ( $\beta = 35.2$ , S.E. = 7.7; Fig. 3) along with its quadratic term ( $\beta = -114.3$ , S.E. = 30.1; Fig. 3), reflecting the largest relative abundance with around 15% of the tetrad covered by *huerta*. All other models had  $\Delta AICc > 4$ , including a simpler model without the quadratic term ( $\Delta AICc = 7.06$ ). Our ‘best’ model showed no significant residual spatial autocorrelation (Moran’s  $I = 0.07$ ,  $p = 0.1856$ ).

The most parsimonious model explaining the distribution of displaying males (Tjur’s  $R^2 = 0.16$  in model produced by model selection process) included only the proportion of long-abandoned farmland within the display area (Table 2). The mean probability of a displaying male being present was positively related to the proportion of long-abandoned farmland within a 100 m radius of his display site (mean  $\beta = 3.1$  [S.E. = 0.004], mean 95% C.I. = 0.77 & 5.95; Fig. 4). However, we found no difference between male display sites and our control measures in the surrounding habitat: the ‘best’ of the candidate models was the null model.

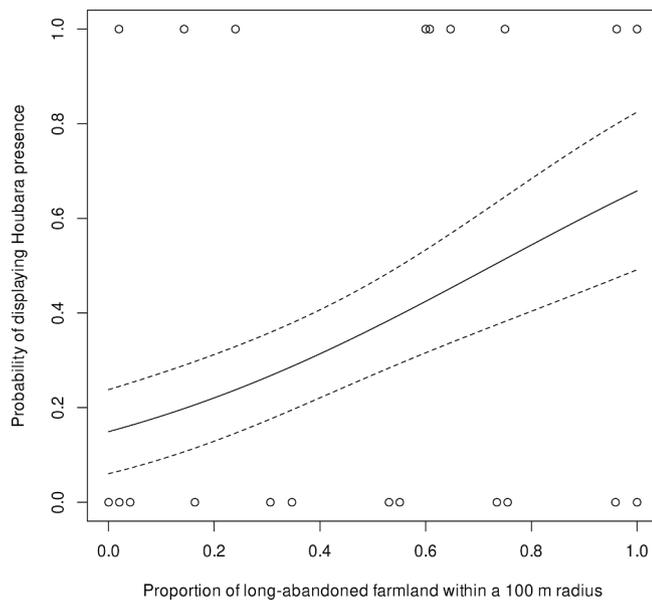


**Fig. 3.** Effect of the proportion of *huerta* and its quadratic term in the survey square on African Houbara abundance, with 95% confidence intervals indicated by dashed lines.

**Table 2**

All models with  $\Delta\text{AICc} < 4$  plus the null model explaining the distribution of male displays. Where variables were used in models their effect on probability of presence is shown; ‘—’ indicates that the variable was not used. LAF = long-abandoned farmland; RAF = recently abandoned farmland. NDVI = Normalised Difference Vegetation Index, TRI = Topographic Ruggedness Index.

| Intercept | Proportion of <i>huerta</i> | NDVI   | Proportion of LAF | Proportion of RAF | TRI   | df | $\Delta\text{AICc}$ | Akaike weight |
|-----------|-----------------------------|--------|-------------------|-------------------|-------|----|---------------------|---------------|
| 1.17      | —                           | −62.21 | 3.47              | —                 | —     | 3  | 0.00                | 0.36          |
| −1.82     | —                           | —      | 4.00              | −21.84            | —     | 3  | 0.74                | 0.25          |
| −2.0      | —                           | —      | 3.47              | —                 | —     | 2  | 1.47                | 0.18          |
| −1.5      | —                           | —      | 3.45              | —                 | −0.25 | 3  | 3.57                | 0.06          |
| −2.0      | −0.08                       | —      | 3.47              | —                 | —     | 3  | 3.94                | 0.05          |
| −0.69     | —                           | —      | —                 | —                 | —     | 1  | 7.88                | 0.01          |



**Fig. 4.** Effect of the proportion of long-abandoned farmland within 100 m radius on the probability of male display (from one run using a sample of 20 random absence locations), with 95% confidence intervals shown as dashed lines.

#### 4. Discussion

Houbara distribution and relative abundance across our study area, an area known to be important for houbaras in Lanzarote, was influenced both positively and negatively by anthropogenic factors. As we focused on this important area, island-wide drivers of houbara distribution may not be reflected in our analyses. The proportion of small-scale agriculture (*huerta*) within the survey squares had positive effects on houbaras up to around 15% of the tetrad, but was negative above this. This was particularly apparent in the areas in the south of El Jable and around Zonzamas. Houbaras are known to feed in such areas (*‘gavias’*) on Fuerteventura (Medina 1999), although they avoid more intensively managed farmland (Carrascal et al. 2008). Asian Houbaras have been recorded making extensive use of farmland in Iran (Aghajani-Zadeh et al. 2010), this being associated with times of low water availability (Yousefi et al. 2017); it is therefore possible that the unusual winter drought of 2019–2020 (C. Portella Ernest pers. comm.) may have influenced the birds’ choice of foraging areas. Agricultural land in this part of Lanzarote often consists of small-scale plots which use traditional agricultural approaches to maximise water availability, and it may be this factor, or that farmers and houbaras are both seeking areas where water is available, that determines their distribution rather than specific food resources in or around fields.

The  $R^3$  values for our models were relatively low, which is not uncommon in ecological studies (Møller & Jennions 2002), suggesting that the true drivers of houbara relative abundance and the distribution of

display sites are likely to be more complex than those highlighted here. The relative predictive power of our models may also have been affected by the relatively low number of sightings, potentially due to environmental conditions, and the available habitat data. Land-use data for this region, especially involving specific agricultural practices, are relatively coarse in both spatial and temporal resolution. In the GRAFCAN (2014) dataset many areas classified as *huerta* were considered to be fallow rather than in production, but separating these two categories did not improve our models. This may reflect the changing distribution of small-scale agricultural production in the El Jable region, as different areas are used in different years. The role of agriculture in the ecology of Canary Islands houbaras would be greatly clarified if we could precisely determine the type and extent of the birds’ use of fields in the El Jable region over the annual cycle, and this information could then form the solid foundation of a conservation strategy for the maintenance of the houbara population in the area.

The distribution of displaying males was also influenced by the distribution of agricultural habitats, but in a different way: they occupied areas in or near long-abandoned farmland (a finding consistent with previous research: Banos-González et al. 2016). Such land is likely to be bare of vegetation or possess more natural, recolonising vegetation. Males of both species of houbara select habitats that increase their visibility when displaying (Le Cuziat et al. 2005b, Koshkin et al. 2016), although our analyses found no differences between display sites and the surrounding landscape in terms of vegetation or rugosity. Unfortunately, however, our sample size for displaying males was small (we suspect the dry conditions of winter 2019–2020 suppressed reproductive activity) and the variation in vegetation height and rugosity within the study area was limited, and as such our models may not have the power to detect some relationships between males and habitat.

The specific locations of our houbara observations were distributed across a number of land-use types. This may support the idea that birds are using a variety of agricultural and wider ‘desert’ habitats for foraging, as previously documented in this species (Carrascal et al. 2008). There was some indication of clustering within our data which may partially reflect our survey method, as there appears to be an effect of distance from observer on detectability. Some birds (31 of 139 observations of birds or groups) were  $>1$  km from our vantage points, so other birds at this distance may have been missed. However, birds were clustered within the  $360^\circ$  distance band of highest detectability, indicating their genuine aggregation. Some of these clusters likely reflected the exploded lek mating system of houbaras (Hingrat et al. 2004, 2008, Chammem et al. 2018, Alonso et al. 2020) and others the natural if weak associative tendency of the species when foraging (Meade-Waldo 1889, Brosset 1961). There was also the potential for birds to move between squares, which would result in them being counted on multiple surveys. However, as we focused on the relative abundance of birds in each tetrad, we believe that our method reflects the use of habitat by houbaras even if it does not allow us to estimate a true population size accurately. Despite these potential issues, the ‘look down’ method offers a useful strategy for understanding habitat use in houbara on Lanzarote.

Using a single survey point and high-powered optics avoids the disturbance caused by a human moving through the study area. This allows the position of birds to be recorded performing natural

behaviours rather than the position of flushed or fleeing birds (Le Cuziat et al. 2005a,b, Alonso et al. 2020). However, detection is unlikely to have been perfect owing to the distances involved and the vegetation and topography of the study area. These effects are likely to have been relatively consistent across our survey squares. In future, our approach could be improved by focusing on repeated surveys in each square, which would allow us to account for imperfect detection more fully.

Houbaras have been shown to avoid human disturbance in both the Canary Islands (Banos-González et al. 2016) and North Africa (Le Cuziat et al. 2005a,b), but in our study disturbance was not strongly related to houbara relative abundance or distribution. Disturbance could have two effects on the species, by causing the avoidance of areas and/or by impacting the detectability of birds during the survey. When disturbed, birds are more likely to remain motionless and undetectable. Nevertheless, we believe that our results genuinely reflect use of the survey squares by houbara, because although our measurements of disturbance occurred in both survey periods, our measure of relative abundance only used the maximum count from one survey period. As such, we would expect birds to be detectable outside of disturbance events in one of the two survey periods. In future, we suggest improving the quantification of disturbance by considering not only the frequency but also the magnitude and duration of disturbance and its effects on abundance and distribution as well as behaviour.

Distance to road did not correlate strongly with houbara abundance in our study, possibly because the distance to roads was generally large, but previous research on Lanzarote found higher houbara abundance along transects further from paved roads (Schuster et al. 2012). On Fuerteventura, too, houbaras are disturbed not only by walkers and cyclists but also by road traffic (Carrascal et al. 2008). This may reflect more than a general avoidance of the sight and sound of traffic, as paved roads provide access into the landscape, disturbing and degrading adjacent habitat (Bennett 2017), and they can cause direct mortality (Tejera et al. 2018). We witnessed disturbance by off-road vehicles, notably quad-bikes, now popular with tourists, and consider this another potential concern if access to El Jable increases. Lanzarote's popularity as a tourist destination (Santana-Jiménez & Hernández 2011, Tejera et al. 2018) certainly raises the potential for human disturbance, especially in areas such as El Jable. Indeed the area in which we observed the fewest birds and the most disturbance is the closest to areas popular with tourists, to the west of Soo in the north, although several areas in the south, close to San Bartolomé and east of Teseguite, were also much disturbed.

Our study was for a single season that was affected by a drought and curtailed by a pandemic. Nevertheless, our findings, combined with those of earlier studies, indicate the potential for various management interventions and further lines of research. Levels of human disturbance and land-use change need to be strongly controlled in order to allow houbaras to range freely over larger areas of otherwise good habitat, and future surveys should aim to repeat sampling across survey squares that will allow analyses which take imperfect detection into account. Intensive mechanised farming is to be discouraged, but traditional small-scale agriculture and long-abandoned fields appear to benefit houbaras to some extent. However, these positive values of human activities need corroboration through further study, as part of a research program which would also embrace the evaluation and mitigation of powerlines, the impact of sand extraction, the influence of livestock-grazing on vegetation and the effects of climate change.

#### Declaration of Competing Interest

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

#### Acknowledgements

We are most grateful to Carmen Portella Ernest and her colleagues in Desert Watch, a charity dedicated to the conservation of El Jable which invited and supported the present research; and to GREFA ([www.grefa.org](http://www.grefa.org)), for access to houbara records in the study area. We also acknowledge the value of information obtained from the Government of the Canary Islands and data copyrighted to OpenStreetMap contributors and available from <https://www.openstreetmap.org>. Robert John Burnside kindly provided important comments on a draft of this paper, and two referees made further very thorough and helpful comments on the submitted text.

#### Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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