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NEW DATA ON THE POPULATION, DISTRIBUTION AND HABITAT PREFERENCES OF THE CANARY ISLANDS STONECHAT *SAXICOLA DACOTIAE*

NUEVOS DATOS SOBRE EL TAMAÑO POBLACIONAL, LA DISTRIBUCIÓN Y LAS PREFERENCIAS DE HÁBITAT DE LA TARABILLA CANARIA *SAXICOLA DACOTIAE*

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SUMMARY.—*New data on the population, distribution and habitat preferences of the Canary Islands stonechat* Saxicola dacotiae.

This paper updates estimates of population size, distribution and habitat preferences of the endemic Canary Islands stonechat *Saxicola dacotiae* on the basis of data gathered across their whole distribution range, the island of Fuerteventura. We surveyed 1,462 0.5-km line transects during the reproductive seasons in 2005 and 2006, distributed across the whole island. Results were used to estimate population size using two methods: stratified estimates of mean densities and sum of estimated abundances across strata, and sum of estimations of abundance in 1 km x 1 km UTM squares based on statistical models built by boosted regression trees (BRT). In both methods we accounted for the effects of bird detectability in transects. Overall, 490 mature individuals were recorded. The Canary Islands stonechat preferred high, steep terrain (particularly above 20% slope and 200 m a.s.l.) and selected negatively the lower and flatter areas comprising most of the island. These habitats were occupied, however, albeit at low density. The highest average densities sampled per habitat (up to 43 birds/km^2) were registered on steep areas (> 11%) with scrub, although the statistical models predicted densities of 66 birds/km^2 in the optimum

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sites (slopes higher than 22.5% with rocky ground). The population size of Canary Islands stonechat estimated with the stratified design was 20,504 individuals (CI 95%: 16,217-25,973), and the model-based estimate (which we consider more reliable) was 14,436 (CI 95%: 13,376-15,492). These estimates are much higher than previous ones. We argue it is difficult to compare with Bibby and Hill's (1987) results due to the different methodologies involved and areas covered by the monitoring programs, although we can not exclude an increase in population size during the last three decades. Discrepancies with García del Rey's (2009) estimate appears to be due to an underestimate of the population size because of the lack of sampling in extensive areas and habitats of low bird density on the island.

Key words: boosted regression trees, distance sampling, Fuerteventura, habitat preferences, population size, *Saxicola dacotiae.*

RESUMEN.—*Nuevos datos sobre el tamaño poblacional, la distribución y las preferencias de hábitat de la tarabilla canaria* Saxicola dacotiae.

Este trabajo actualiza las estimas del tamaño poblacional, distribución y preferencias de hábitat de la endémica tarabilla canaria *Saxicola dacotiae*, basándose en datos recogidos en toda su área de distribución en la isla de Fuerteventura. Muestreamos 1.462 transectos lineales de 0,5 km distribuidos por toda la isla durante los periodos reproductores de 2005 y 2006. Los resultados se usaron para estimar el tamaño poblacional mediante dos métodos: estimas estratificadas de la densidad media por hábitat y suma de las abundancias de los estratos, y la suma de las predicciones de abundancia en cuadrículas UTM de 1 km x 1 km dadas por modelos construidos con árboles de regresión y técnicas de remuestreo ('boosted regression trees'). En ambos casos se tuvieron en cuenta los efectos de la detectabilidad en los transectos. En total, se detectaron 490 individuos adultos. La tarabilla canaria prefirió terrenos altos y empinados (particularmente por encima de los 200 m s.n.m. y con pendientes mayores del 20%) y seleccionó negativamente las áreas más bajas y llanas que comprenden la mayor parte de la isla. No obstante, estos últimos hábitats estuvieron ocupados, aunque en menor densidad. Las densidades promedio más altas que se muestrearon (hasta 43 aves/km^2) se registraron en áreas de gran pendiente (> 11%) con matorral, aunque los modelos estadísticos predijeron densidades de 66 aves/km^2 en los lugares óptimos (pendientes superiores a 22,5% con terreno pedregoso). El tamaño poblacional de la tarabilla canaria estimado con el diseño estratificado fue de 20.504 individuos (CI 95%: 16.217-25.973), y el estimado con los modelos estadísticos (que consideramos más fiable) fue de 14.436 (CI 95%: 13.376-15.492). Estas estimas son mucho mayores que las dadas anteriormente. Argumentamos que es difícil comparar los resultados con los de Bibby y Hill (1987) debido a las diferencias en la metodología y en el área de prospección, aunque no podemos excluir un incremento en el tamaño poblacional durante los últimos 25 años. Las discrepancias con la estima más reciente (García del Rey, 2009) parecen deberse a una infravaloración por su parte del tamaño poblacional debido a la ausencia de muestras en zonas y hábitats subóptimos pero de gran extensión superficial.

Palabras clave: árboles de regresión, muestreo de distancias, Fuerteventura, preferencias de hábitat, tamaño poblacional, *Saxicola dacotiae*.

INTRODUCTION

The Canary Islands stonechat (*Saxicola dacotiae* Meade-Waldo, 1889) is a small passerine endemic to the island of Fuerteventura, which is located in the easternmost and driest part of the Canary archipelago. It has been listed as endangered by the IUCN (IUCN, 2010), based on its restricted distribution and small population size (estimated by Bibby and Hill, 1987). It figures prominently on both the local red list and the regional threatened species catalogue (Illera, 2004a). Individuals of this species, whose adults are resident and extremely territorial (although nothing is known on juvenile dispersal and some long-distance dispersal has been reported), can be found on steep, rocky hillsides (slope > 15%) and in gullies dominated by medium/large-sized scrubland (height > 0.25 m; Illera, 2001; Martín and Lorenzo, 2001; Illera and Díaz, 2008). These environments not only favour its ground-nesting behaviour but also supply an abundance of invertebrates, which constitute its basic food resource (Illera and Díaz, 2006; Nicolai and Grimm, 2009; Illera *et al.*, 2010). The species is mainly threatened by alterations to or destruction of its habitat due to the rapid urban expansion taking place on the island (Illera, 2004a), and by the presence of introduced predators such as cats and rats (Illera, 2003).

Despite its rarity and worrying conservation status, the species has not been the focus of a large survey since the pioneering work of Bibby and Hill (1987), who sampled 210 km^2. These authors estimated a population size of between 1,300 and 1,700 individuals (750 ± 100 pairs) and identified the hilly and rough terrain landscapes as the best areas for the species. More recently, a less intensive survey (accumulating 60 km of linear transects) focusing on just the best areas for the species has been undertaken (García del Rey, 2009) with an estimate of 832-1,287 individuals.

The general objectives of this study are to provide an up-to-date estimate of the abundance and distribution of the Canary Islands stonechat, as well as a description of the habitat preferences in the whole island. We estimate population size using two methods: stratified estimates of mean densities and sum of estimated abundances across strata, and sum of estimations of abundance in 1 km x 1 km UTM squares based on statistical models built by boosted regression trees. In both methods we accounted for the effects of bird detectability in transects. In surveys, a fraction of the individuals occupying an area inevitably go undetected, which leads to underestimates of real population sizes. This fraction can be estimated by recording the distance to sampled birds and by modelling the distribution of these distances (Thomas *et al.*, 2010). Finally, we validate our estimates of population size to assess their robustness. We undertake the description of the habitat preferences because there is no previous study based on the whole range of the species and to aid in the interpretation of the abundance estimates. Additionally, we provide comparisons with the previous censuses (Bibby and Hill, 1987; García del Rey, 2009).

MATERIAL AND METHODS

Study area

Fuerteventura (28º 46’ N, 14º 31’ W) is the second largest of the Canary Islands (1,655 km^2) and the nearest to continental Africa (< 100 km). The topography of the island is mainly low and flat, with a maximum elevation of 807 m above sea level. The island’s climatic conditions (arid and semi-arid) reflect the shortage of water. Average rainfall is 132 mm/year, concentrated during the autumn and winter months (Illera and Díaz, 2006), whilst the monthly temperature ranges from 17º in January to 24º in August (Illera, 2004b). The vegetation is xerophytic, dominated by sparse pasture and scrubland (Rodríguez *et al.*, 2000).

Census method

Fieldwork was carried out during the reproductive seasons in 2005 (from 20/02 to 09/04) and 2006 (from 05/03 to 14/03), using 0.5-km linear transects. Line transects were performed across the whole island, including all of the main habitats: scarcely vegetated lava fields (locally called *malpaís*), shrubby steppe-like plains, stony/sandy desert areas, traditional cultivations, hilly/mountain slopes, gullies and urban environments (fig. 1). Due to limitations of sampling effort we left unsurveyed some areas that, nevertheless, we consider include equivalent habitats to the surveyed ones. Transects were covered cross-country on foot at a velocity of 2-3 km/h. Five (in 2005) and three (in 2006) observers recorded all contacts heard or seen (most frequently both), as well as the number of individuals per contact and the perpendicular distance from the transect line. We made an effort to improve accuracy and to reduce inter-observer variability in distance estimates by training continuously with a laser range-finder. Families were recorded as two individuals (a pair) and the few juveniles detected were excluded from the analysis, because the aim of the survey was to quantify the reproductive population of the species. We also attempted to avoid double-counting by proceeding at a constant speed and disregarding birds that approached from behind the observer, and by paying attention to the actual locations of birds (particularly when the transects proceeded in a curve line). It should be noted that this species has small territories and shows strong year-round site fidelity, which make double-counting unlikely (Illera and Díaz, 2008).

Fieldwork was designed as a broad-scale sampling for landbirds (focusing on steppe areas in 2005, n = 1,058 transects, and adding other habitats in 2006, n = 404) and thus transects were performed across the whole island in an attempt to sample the total range of vegetation formations, land-use types and degrees of slope. Each transect traversed just one main type of landscape. The approximate number of transects on each strata (see below) were roughly determined in proportion to the percentage of each type of main landscape present. The starting point of the first transect was randomly determined and then the rest of transects were performed one after the other. We feel confident in assuming that these transects provide a representative sample of abundance within strata. This is so, first, because we roughly defined the limits of the strata to be sampled, according to predominant habitat characteristics (e.g., flat or uneven terrain, sandy or rocky soils) and geographical features (e.g., mountain ridges), and let the observers to choose their paths, knowing that they had to sample some broad habitat classes typical of the stratum (e.g., densely vegetated sand plains, bushy hilly slopes, sparsely vegetated rocky surfaces, etc.). Transects were never proceeded with on the grounds of the perceived value of the neighbouring habitat for the species. This non-random design allowed us to sample the common habitats in approximate proportion to their surface and also to sample most particular vegetation remnants in remote valleys. However, most of transects in the impracticable volcanic terrain (young and broken lava fields) had to be done along dirt roads. Our assumption relies also on the fact that most strata were so intensively sampled that there is little room for any geographical bias and on the resampling procedure to estimate abundances that takes as sampling units groups of several transects (see below).

Data analyses

Abundance estimates were calculated with counts of the Canary Islands stonechat corrected for detectability. Detectability models for the global dataset were constructed using Distance 5.0 software (Thomas *et al.*, 2005) and abundance estimates were predicted for each habitat. We used the same detectability model for all data, irrespective of habitat and observer, because previous trials incorporating factors accounting for vegetation or observer did not improve the models. This is probably due to the fact that stonechats generally appeared in places with similar vegetation structure. Also, these models yield unbiased estimates of overall abundance when the distance data is registered under variable conditions such as different observers, weather and habitat (Buckland *et al.*, 2001; 2004). Detectability models were constructed after discarding 5% of the longest recorded distances in order to improve the modelization (following Buckland *et al.*, 2001). The final estimates used to calculate abundances (detection probability and effective strip width) were weighted averages of the best fitted models (ΔAICc < 2), with weights $w = \exp[-0.5\,(\Delta \text{AICc}) / \Sigma(\Delta \text{AICc})]$ (Burnham and Anderson, 2002). Confidence intervals were calculated using nonparametric bootstrap methods (N = 999 replicates within habitat).

To extrapolate the results of bird counts from the sample transects to the entire area of study a post-stratification scheme was used, based on the different habitats present and the species' preferences (habitats were not known in advance, thus preventing an alternative *a priori* stratification). The stratification was achieved by developing a habitat map of the island, taking into account vegetation structure and slope. These were chosen as the two key variables determining the species' presence during the reproductive season (Illera, 2001). The vegetation structure categories were assigned based on an existing map of plant communities in the Canary Islands (Del Arco *et al.*, 2003), aerial photographs and our personal knowledge of the island. The following nine broad classes were identified: scrubland (low, medium and high), arboreal habitats, pasture, rural environment, aquatic vegetation, no vegetation (*malpaís* but also urban/industrial areas) and others. Three slope categories (< 6%, 6-11%, > 11%) were chosen, based on reported restrictive thresholds for other cursorial species (11% for the cream-coloured courser *Cursorius cursor*, and 5% for Dupont's lark *Chersophilus duponti*; Seoane *et al.*, 2006; Palomino *et al.*, 2008). Slope and vegetation classes were overlaid to form the habitat map. Some combinations of classes were grouped together to keep the number of transects per habitat category above ten. The final map identified 19 different habitats (appendix 1). We obtained a final estimate of population size by multiplying population densities in the 19 habitats by the area covered by each habitat in the island, and adding up the numbers. Confidence intervals (95%) were calculated through bootstrapping, (resampling transects 999 times within the habitat strata).

In addition, a stonechat distribution map in Fuerteventura was elaborated by first calculating the density of birds per habitat (see appendix 1), and then superimposing a 1 × 1-km Universal Transverse Mercator grid layer on the island, in order to assign the estimated number of birds to each cell based in the area occupied by each habitat category. An internal validation of the resulting distribution map was performed. A density map was constructed using each bootstrap replicate to obtain 1,000 predicted density values for each cell. These predicted densities were compared to the densities observed in transects within surveyed cells (the recorded abundances in transects were extrapolated to a 1 km^2 area, taking into account the detection probability). Comparisons were made using Pearson correlations, residuals (observed – predicted densities) and calibration plots.

Habitat preferences were explored with regression trees (De' Ath and Fabricius, 2000). We analysed the effect of seven variables of geographical location and habitat description on the number of stonechats observed in transects of 0.5 km, namely: latitude, longitude, altitude, slope, soil type, vegetation index (NDVI) and urban surface cover. The latitude, longitude and altitude were obtained through a GPS in the centre of each transect. The terrain slope in the centre of each transect (in percentage) was obtained from a digital model of the terrain (module SLOPE of Idrisi Kilimanjaro, Eastman, 2003). The soil type was codified in five categories from the information available in Del Arco *et al.* (2003): 0-rock; 1-pyroclastic debris; 2-non-rocky compact; 3-sandy; 4-very loose sand (locally called '*jable*'). Finally, we also used a normalized difference vegetation index (NDVI, range 0-255) as a radiometric index of photosynthetic activity (high NDVI values indicate high values of green vegetation). Raw data were ten-day synthesis at 1 km^2 spatial resolution obtained from the sensor VEGETATION onboard the SPOT satellite (available freely at http://free.vgt.vito.be/). We built monthly maximum composite of NDVI images, averaging from 1999 to 2004 (discarding cloudy pixels).

With the aim of further assessing the distribution and abundance of Canary Islands stonechat in the whole island, BRT models were employed using the seven predictive variables used in the regression trees, and the number of stonechats per 0.5 km transect as

FIG. 1.—Study area with the approximate locations of the places mentioned in the text. Dots show the centre of each 0.5-km line transect (grey: 2005, black: 2006).

[Área de estudio, donde se señalan las localizaciones aproximadas de los lugares que se mencionan en el texto. Los puntos muestran el centre de cada transecto lineal de 0,5 km (en gris: 2005, en negro: 2006)].

response variable. BRT algorithm builds a number of regression trees (typically hundreds) in a stagewise fashion on randomly selected subsets of data and combine them to improve predictive performance (see for details: De' Ath, 2007; Elith *et al.*, 2008). 20 BRT models were built and each was used to predict the relative abundance of the Canary Islands stonechat in all of the 1x1 UTM squares of Fuerteventura. These estimates were averaged and converted to absolute densities (birds per km^2) applying the averaged effective strip width estimated by the detectability models. We aggregated these values to get an estimation for the population size of the Canary Islands stonechat (in the case of the coastal squares we considered that their surface was lower than 1 km^2). The confidence interval was obtained through bootstrapping.

RESULTS

Study area coverage and coarse-grained habitat preferences

During the study period, 1,462 0.5-km linear transects were surveyed in 292 hours and 490 mature individuals were detected (fig. 1). A total of 661 1-km^2 cells were surveyed and 212 cells were traversed by at least three transects. The area surveyed was 183.9 km^2 or 11% of the island (calculated using a strip width of 125 m on each side of transects, which was the longest recording distance in our data set). A first crude estimate of the detection rate and density may be therefore calculated as 1.68 individuals/h and 2.7 individuals/km^2, respectively (not taking yet into account the detection probability).

The distribution of sampling effort in relation to the NDVI, altitude and slope reached high percentages of similarity with the variability observed on the island (respectively, the similarity index was 90.7, 93.0 and 95.8; Renkonen, 1938). Therefore, the sampling was unbiased with respect to these environmental descriptors.

Taking into account the terrain slope, the distribution of transects with presence of Canary Islands stonechat (implying resource use) differs very significantly from the distribution of all the transects carried out (those implying resource availability; $\chi^2_5 = 264.1$, $P << 0.001$). Slopes greater than 10% are clearly selected positively (i.e. greater use than that with which it would correspond considering their availability), especially those greater than 20%. Nonetheless, despite the fact that the areas with a slope of less than 10% were negatively selected (lower use than availability), there existed an important fraction of the population that inhabited the areas of the island with lower slopes (15.7% of transects with presence of Canary Islands stonechat, and 10.6% of stonechats detected). Something similar happened when altitude was taken into account ($\chi^2_4 = 66.5$, $P << 0.001$). The altitude band from 100 to 200 m was used proportionately to its availability, while the band located below 100 m was not favoured. Almost half (49.8%) of all of the birds detected were observed below 200 m. The altitudes comprised between 200 and 500 m were selected very positively (use greater than availability). The distribution pattern of the species did not differ taking into account the vegetation index (NDVI; $\chi^2_5 = 4.8$, $P = 0.436$).

Detectability analysis

Four similarly plausible detectability models (ΔAICc < 2) were obtained using data truncated at 80 m and 468 birds (half-normal with polynomial adjustments [weight = 0.39, detection probability = 0.51], negative exponential with cosine adjustments [w = 0.23, d = 0.47], uniform with cosine adjustments [w = 0.19, d = 0.54] and negative exponential with polynomial adjustments [w = 0.19, d = 0.43]). The weighted average of the effective strip width was 39.4 m (35.5-43.8), and probability of detection within belts of 80 m at both side of the observer was 0.49.

Density variability among habitats and population size

The density calculated in each of 19 mayor types of habitat found in Fuerteventura is shown in appendix 1. The best habitats were those of high, medium, and low scrub with high slopes (> 11%), although medium-scrub habitat with intermediate slopes (6-11%) was moderately good. The arboreal habitats, which include tamarisk *Tamarix* spp. stands, palm *Phoenix* spp. and Canary pine *Pinus canariensis* plantations often with a layer of medium-high scrubs, were estimated to have a moderate density with a large confidence interval. Nonetheless, the surface that woody habitats occupy on the island is very small and their effect on the stonechat population size estimation was very low.

The resulting global abundance of the Canary Islands stonechat was calculated as 20,504 individuals (CI 95%: 16,217-25,973), considering the detection probability of the species, its population density in the 19 habitats and the area covered by these habitats in Fuerteventura.

Model of habitat preferences

The regression tree describing habitat preferences of Canary Islands stonechat is

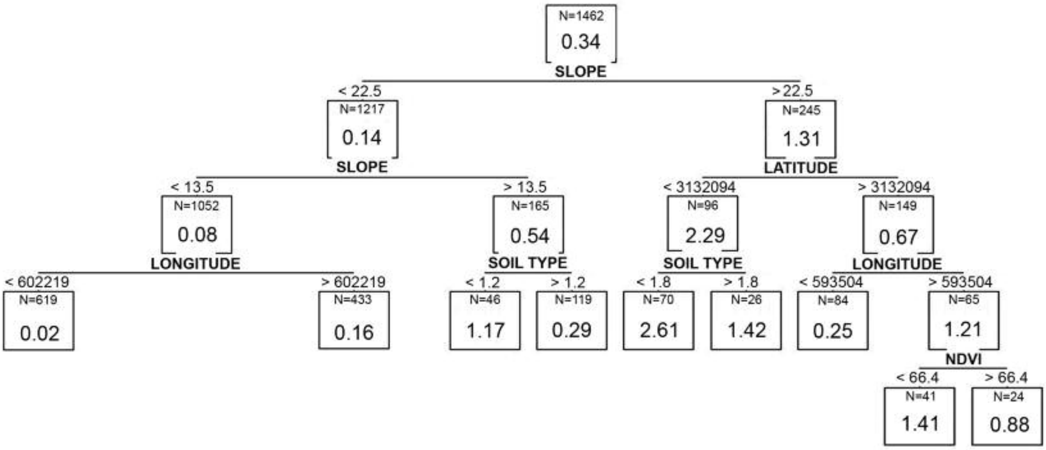

FIG. 2.—Regression tree describing habitat preferences of the Canary Islands stonechat. The response variable is the number of stonechats registered in 1,462 0.5-km line transects. The explanatory variables are latitude, longitude and altitude, slope (in percentage) and soil type (from rocks, coded as 0, to loose sand areas, coded as 4). In each box it is given the average of the number of birds per transect and the number of transects (N) from which this figure is calculated.

[Árbol de regresión que describe las preferencias de hábitat de la tarabilla canaria. La variable respuesta es el número de aves detectado en 1.462 transectos lineares de 0,5 km. Las variables explicativas son la latitud, longitud, altitud, pendiente (en porcentaje) y el tipo de suelo (desde rocoso, codificado como 0, hasta arenas sueltas, codificado como 4). En cada caja se da el número medio de aves por transecto y el número de transectos con los que se hizo ese cálculo.]

shown in figure 2 ($R^2 = 0.469$, $P << 0.001$). The terrain slope had a positive effect on the abundance of the species (very abundant in areas with a slope greater than 22%). Geographic position had a complex influence (see below). Soil type was also a relevant determinant of stonechat abundance: the stonechat was abundant only in sites with rocky or stony soil. Finally, the Canary Islands stonechat was very scarce in areas with an NDVI higher than 66 (the average NDVI for the entire island was 60.1). The geographic and environmental characteristics that maximise the local abundance of this species were the following: terrain slope greater than 22.5% in areas to the south of latitude 3,132,094 (approximately south of Tuineje), and with a predominance of rocky soil (soil index less than 1.8). In these circumstances, the average number of stonechats per transect was 2.61 (sd = 2.07, N = 70 transects), which corresponds to an average density of 66.2 stonechats/km^2 (i.e., 2.61 birds in the area surveyed by a transect, which is 500 m * 2 * ESW [= 39.4 m], expressed in km^2).

The relative importance of the explanatory variables used to build boosted regression tree models, describing habitat preferences of Canary Islands stonechat, is shown in figure 3 (based on 20 processes of modelization using different combinations of transects sampled). Among the predictive variables, terrain slope had maximum influence. Next in importance was geographic location measured in latitude and longitude (averages of 0.7-0.8), although at a greater distance, the NDVI, the type of soil, and the altitude (average values of 0.50-0.55) were also im-

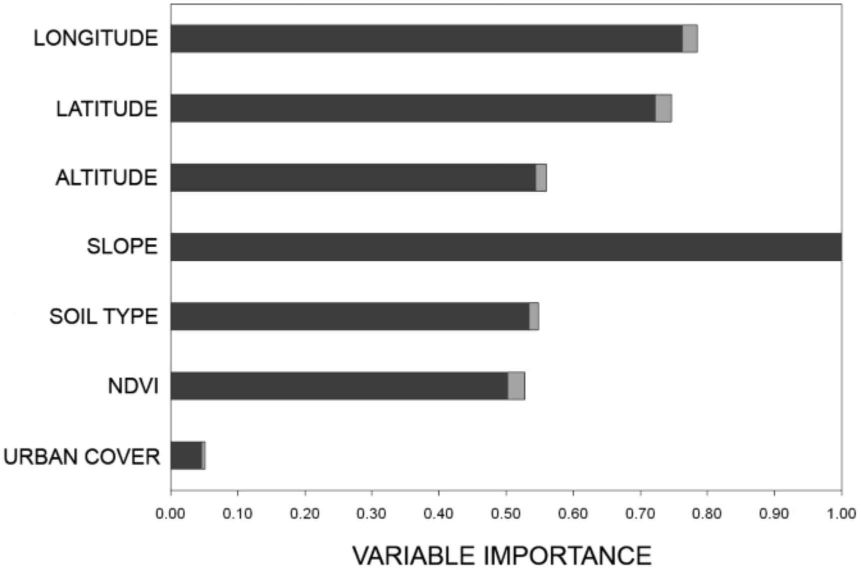

FIG. 3.—Relative importance of the explanatory variables used to build the regression tree models describing habitat preferences of the Canary Islands stonechat. It is given the average (black bars) and standard error (grey bars) of the estimate, based on 20 processes of modelization.

[Importancia relativa de las variables explicativas usadas para construir los modelos de árboles de regresión que describen las preferencias de hábitat de la tarabilla canaria. Se da la media y el error estándar de la estima (respectivamente, barras negras y grises), basados en 20 procesos de modelización.]

portant. Lastly, the cover of urban habitats around transects had little influence on the abundance of the Canary Islands stonechat.

Distribution of population density in Fuerteventura

Figure 4 shows the map of predicted distribution of the Canary Islands stonechat using the cartographic method. The median value of the 1,000 Pearson's correlations between the bootstrapped predicted density values in 1×1-km UTM squares and the observed ones was $r = 0.51$ ($P < 0.001$). Calibration plots (not shown) of predicted vs. observed densities showed a fair agreement between them, except for cells having transects with higher counts, whose densities were underestimated. Negative residuals (i.e., overestimation of density) were more frequent than positive ones (83% of cells overestimated) but were lower in magnitude (mean number of individuals per km^2 overestimated was –7.4 ± 0.28 sd, vs. 34.6 ± 3.22 sd underestimated). Consequently, the residuals balanced out (the

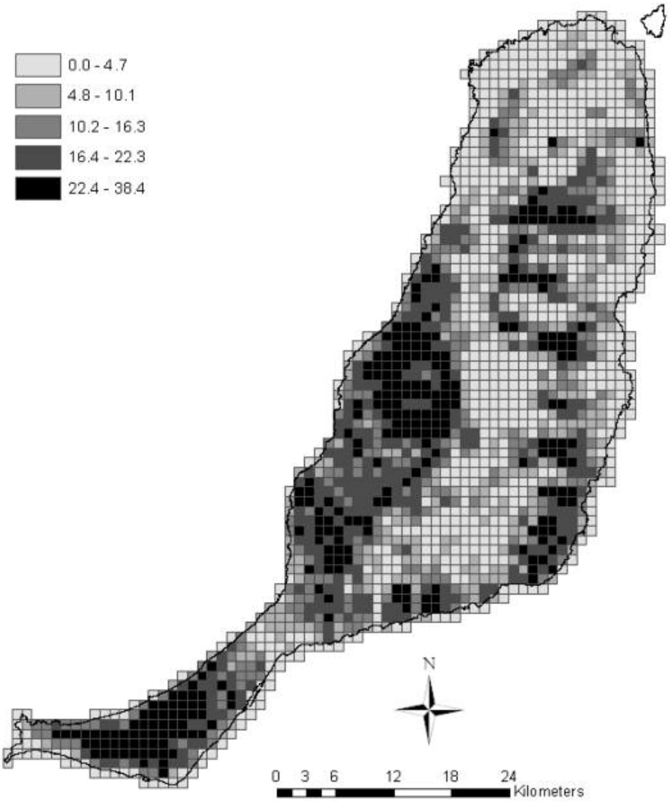

FIG. 4.—Map of predicted distribution of the Canary Islands stonechat using the cartographic method (based on density estimates per habitat). Density is given as individuals per km^2 (cells are 1x1 km UTM squares). *[Mapa de distribución de la tarabilla canaria predicha usando el método cartográfico (basado en estimas de densidad estratificadas por hábitat). La densidad se da en individuos por km^2 (la malla es de cuadrículas UTM de 1 x 1 km).]*

sum was –142.6). Cells with larger negative residuals (overestimations) were generally scattered, except for a cluster in Betancuria (centre-west of the island). Cells with larger positive residuals were also scattered, except for a cluster in Jandía mountains (south-west).

The density predicted by the BRT models also agreed with observed densities (average $r = 0.56$, $sd = 5.6$, $P < 0.0001$ in 20 different random extractions of 70%-analysis and 30%-test proportions of all transects) and was unbiased (the regression between observed and predicted values had intercept 0.023 [sd = 0.036] and slope 0.93 [sd = 0.162], which did not differ significantly from 0 and 1, respectively). The distribution map built by averaging the predictions from BRT models was very similar to the map derived from the cartographic method except for the centre west (area of Betancuria, compare figures 4 and 5). The population size for the Canary Islands stonechat, estimated by adding up the predictions of all of the 1x1-km UTM squares, was 14,436 individuals (95% confidence interval 13,376-15,492, estimated via randomization of the 20 predicted densities per square).

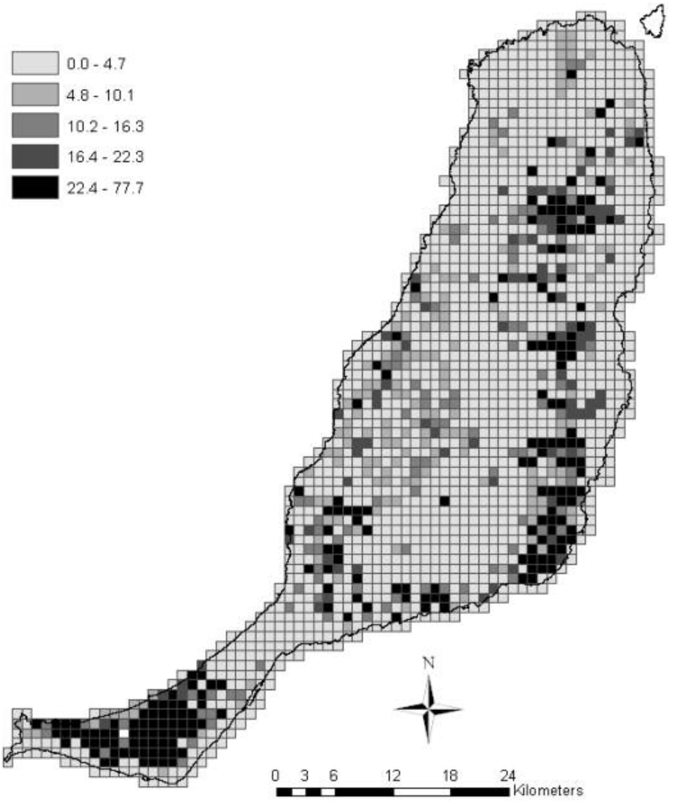

FIG. 5.—Map of predicted distribution of the Canary Islands stonechat using Boosted Regression Trees. Density is given as individuals per km^2 (cells are 1x1 km UTM squares).
[Mapa de distribución de la tarabilla canaria predicha usando los modelos de árboles de regresión con remuestreo ('Boosted Regression Trees'). La densidad se da como individuos por km^2 (la malla es de cuadrículas UTM de 1 x 1 km).]

DISCUSSION

Habitat preferences and density

In agreement with previous studies, we have found that the Canary Islands stonechat prefers high, steep areas (particularly with more than 20% slope and 200 m a.s.l.), where it reaches the highest densities (see also Bibby and Hill, 1987; Illera, 2001; García del Rey, 2009). However, flatter and lower areas, despite being relatively avoided, accumulate a great number of birds simply because they occupy a large area of Fuerteventura. When additional potentially explanatory variables were included in more complex analysis of habitat preferences based on models, we also found a spatial effect (meaning that there are gradients in density) and subtle effects of the ground type (the stonechat was more numerous in rocky areas) and NDVI (avoidance of some particular areas with high productivity). The BRT models built to describe the habitat preferences of the Canary Islands stonechat were unbiased, explanatory and robust, and identified the slope as the main determinant of the abundance of the species in the island. Geographical position, altitude, ground type and NDVI were, in this order, other important variables explaining the distribution of the species. Accordingly, the highest densities were sampled in the habitat categories high-, medium- and low-scrub with steeper slopes (> 11%), where the species reached roughly 30-40 birds per km^2.

Population distribution

The spatial realizations of the models (fig. 5) show that there were large unfavourable areas in the Jandía stretch and at the centre and north of the island. High abundance areas were largely in the mountains of the Jandía peninsula and the east part of Fuerteventura, though some smaller nuclei occurred in the centre-north of the island and to the north of the Jandía area. Therefore, most of the population was concentrated in the eastern and south-western mountains of Fuerteventura.

The distribution map built based on the cartographic method (fig. 4) coincided by pinpointing the east and south-west mountains as the best places for the Canary Islands stonechat, though this map also suggested that the Betancuria massif, in the centre-west of the island, was also highly suitable for the species. However, we consider that this result is partly artefactual because Betancuria is predominantly occupied by steep slopes but it is largely poorly vegetated, in spite of which our cartography databases identifies it as having shrub cover. Therefore, our estimate based on the cartography of habitats attributes to the unvegetated Betancuria the density found in other more vegetated and favourable areas for the species. Interestingly, this last map coincides greatly with the ones provided by Bibby and Hill (1987) and Illera *et al.* (2010), who discussed that the Betancuria mountains were not likely to be as favourable as their maps suggested.

Population size

In this paper we offer two estimations of the population size of Canary Islands stonechat. The approach based on the average abundance per habitat estimated to be 16,000 to 26,000 individuals, and the other using regression-type statistical models estimated to be 13,000 to 15,000.

The estimation based on a cartographic model is made defining “habitats” as a combination of the two main variables that affect the distribution of Canary Islands stonechats: slope and type of vegetation. Then, the average results of density of the sampling of each habitat were extrapolated to the surface they covered in Fuerteventura. This logical scheme assumes, however, that the average density in a given plot with a given habitat is the same, regardless of where the plot is located (that is to say, according to its geographic location), its area, or its location with respect to other neighbouring plots (i.e., according to its connectivity-isolation between habitat patches). Nevertheless, it seems that this cannot be completely generalised, given the great variability of the density of stonechats in some habitats. For example, the confidence interval for the scrub environments with a slope of 6-11% has an average of 11.9 stonechats/km^2, but its range varies from 0 to 32. Similarly, the medium scrubs with a slope greater than 11% have an average of 43.2 birds/km^2 and a range between 22.8 y 70.7. Also, those three aspects for which the cartographic model makes no provision are elements that often contribute in determining if an area will be occupied by any organism (Hanski, 1998). For example, the location of a plot may determine differences in its suitability (Santos *et al.*, 2002), as a consequence of differences in environmental characteristics (e.g., being in sites that are more or less sunny or humid, high or low, near to or distant from the coast), or of population characteristics (such as proximity to a dense population nucleus from which individuals can migrate). In fact, the statistical models identify the geographic position as an important determinant of the distribution of the Canary Islands stonechat. Also, these are built with a more numerous set of predictors, which allows them to explain the most complex patterns of the distribution of the species. Therefore, we consider that the statistical models provide the most exact estimation of population size, while the most valuable contribution of the cartographic model is the estimation of density per habitat.

Comparisons with previous estimates

The first assessment of the species distribution and population size of the Canary Islands stonechat was carried out by Bibby and Hill (1987), who estimated a population size of between 1,300 and 1,700 individuals (750 ± 100 pairs). Recently, a new study estimated the population size to be 1,035 individuals (832-1,287) (García del Rey, 2009). The estimates in this study are considerably higher than the previous ones. These differences deserve a detailed account.

The discrepancy with Bibby and Hill's (1987) estimate could be attributed either to an increase in the population over the last 25 years, despite the observed habitat loss and emergent threats (Illera, 2004a; Carrete *et al.*, 2009), or to differences between methodologies used or both. Bibby and Hill (1987) carried out a census in what they considered to be a random sample of areas, and extrapolated their findings to the whole island based on the relationship between slope and bird counts. However, they counted birds without accounting for the detectability of the species. Notwithstanding these differences, the field effort and the proportion of individuals observed per square kilometre (relative abundances) can be crudely compared. Bibby and Hill (1987) visited a total area of 209.8 km^2 at an intensity of about 2-3 man-hours per square kilometre (a sampling intensity of about 2.5 hours per km^2). During the census, 75 pairs and 24 male individuals were detected, making a total of 174 individuals, i.e., 0.33 individuals per sampling hour, and an average of 0.83 individuals/km^2. In comparison, 183.9 km^2 were covered in the present study, with a sampling intensity of 1.61 hours per km^2 to record 1.65 individuals per sampling hour, and an average of 2.7 individuals/km^2 (without including detection probabilities). Therefore, Bibby and Hill (1987) detected fewer individuals, although the intensity of their survey was higher. Based on this comparison, it seems likely that the population has increased during the last 25 years, although local extinctions have probably also occurred due to urban expansion in some parts of the island.

Some of the discrepancies between Bibby and Hill's (1987) population size estimate and that derived in this study could be because they did not consider the detection probability of the species in the analyses. Bibby and Hill (1987) conceded that they might have overlooked a maximum of 10% of pairs in their final population estimate. This would amount to a detection probability of 0.9, which is much higher than the one reported here (d = 0.49). However, even if we optimistically assume that our survey was 90% efficient (d = 0.9), then the 490 individuals found in this study would extrapolate to 4,410-4,851, which is still much higher than Bibby and Hill's estimate (1987). It seems likely that Bibby and Hill (1987) may have underestimated the population size of the Canary Islands stonechat in the 1980s by assuming an overly high detection probability, but it is also plausible to think that the Canary Islands stonechats have become more numerous.

García del Rey's (2009) work used the same distance sampling method employed in the present study to estimate abundance. However, the sampling effort was considerably lower (60 km against 736 km) and he does not extrapolate correctly the results from the survey to the whole island. This is because of an underestimation of the potential suitable areas in the island, and the assumption that the Canary Islands stonechat inhabits only a narrower set of ecological conditions that it really does. First, García del Rey's (2009) study extrapolates the results by assuming an extremely low potential distribution for the species (just 19.53 km^2, see fig. 6). This author predicts a new potential distributional range of the species based on three publications (i.e. Bibby and Hill, 1987; Snow and Perrins, 1998; Illera, 2001) and his personal field experience. This range (the sampling universe) would afterwards be sampled and then the results from the survey (the sample) are extrapolated to the whole range. However, García del Rey's (2009) study did not consider as potential sites several locations where individuals were previously found according to the literature (not only in Bibby and Hill, 1987, but also in Martín and Lorenzo, 2001, pp. 532-534; Illera and Díaz, 2006; figure 1; Illera, 2007, see all the 5x5 km UTM squares having confirmed breeding; Illera and Díaz, 2008, figure 1). For example, a visual comparison between figure 1 in Bibby and Hill (1987) with figure 1a in García del Rey (2009) shows that several areas in the southeast (e.g. the Vigán mountains) had stonechat records in the former but were disregarded in the latter. Indeed, the present study not only found stonechats there, but also recorded a high abundance of individuals (fig. 6). The same discrepancy may be found in other parts of the island such as some in the north of the island (near Lajares) or in the east (e.g., whereabouts of Guisguey, Ampuyenta and Las Salinas), where both Bibby and Hill's (1987) and the present study recorded stonechats but García del Rey's (2009) work did not consider within the potential distributional range for the species. The more important consequence of this is that García del Rey's (2009) study extrapolates the results of the survey to an unrealistically small potential range, and hence underestimates the total population size.

Second, the present study recorded 490 mature individuals. Simply considering this raw number makes implausible the previous estimates of population size below two thousand birds (of which 490 would be a great proportion). Such a high number of records might be suspicious of having included fledglings and juveniles or double-counting adults, thus inflating the abundance estimate. However, during the fieldwork we disregard fledglings, which are easy to spot, or juveniles, which are harder to tell apart from adults but are detected within family groups that we recorded as pairs. Lastly, we struggle to avoid double-counting by following the same standard fieldwork practices that we assume were followed by the previous studies (Bibby and Hill, 1987; García del Rey, 2009).

Finally, García del Rey's (2009) study further cut the already underestimated potential range by including within the sampling universe just the steepest hills and gullies (average slope 45%) above 200 m a.s.l., and excluding crests and areas of low shrub cover. The study argues that these conditions represent the best habitat available for the stonechats in Fuerteventura and with which we agree. The study also states that these conditions represent probably the only habitat available and we have to profoundly disagree. Approximately a third of the stonechats found in the present study were recorded in slopes below 20%, which cover a large area of the island, and most of the records (95%) took place on slopes below 50%. That is, García del Rey (2009) assumed the areas with gentle slopes were totally unsuitable for the species and did not visit them, while in contrast the present study explored these areas and found birds within them. We believe that gentler slopes provide suboptimal conditions for the species, but these habitats accumulate an

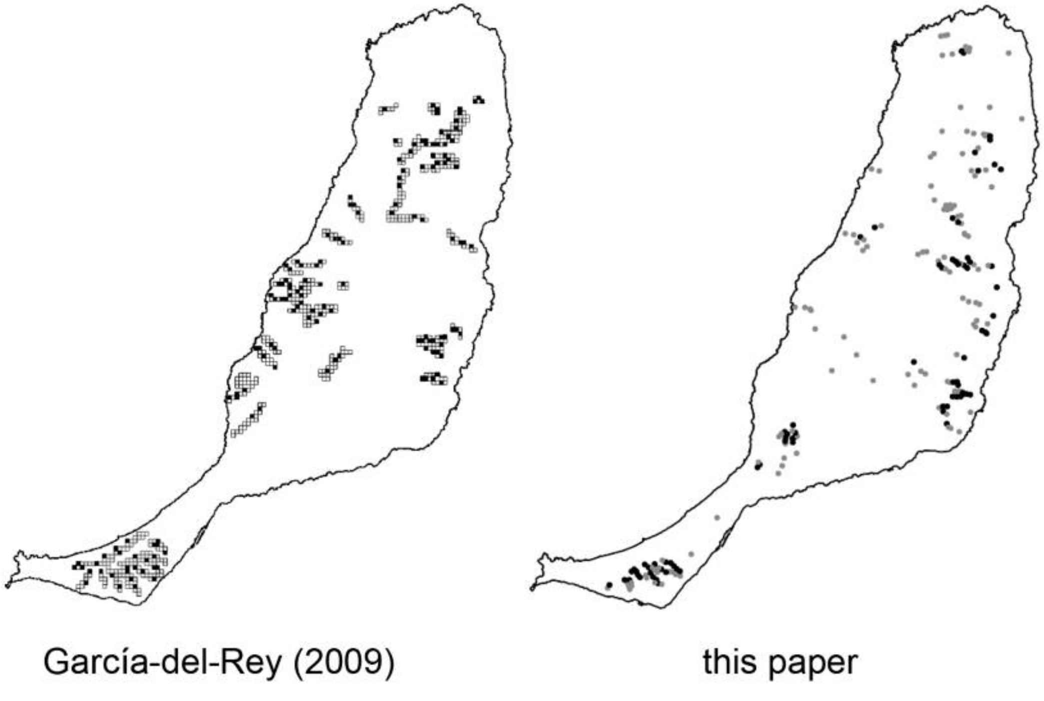

FIG. 6.—Distribution of the Canary Islands stonechat according to García del Rey (2009), where black squares show the sampled locations (cells are 500 x 500 m squares). Right: line transects where the present study registered stonechats (grey dots: one or two individuals detected; black dots: three or more individuals detected).

[Izquierda: distribución de la tarabilla canaria de acuerdo a García del Rey (2009), donde las cuadrículas negras muestran las localizaciones muestreadas (los cuadrados miden 500 x 500 m). Derecha: transectos lineares donde en el presente estudio se registraron tarabillas (puntos grises: uno o dos individuos detectados; puntos negros: tres o más individuos).]

appreciable number of birds by their sheer area. García del Rey's (2009) study focused on the most favourable areas for the Canary Islands Stonechat. Consequently, the average densities given for the habitats studied there are higher than, or comparable to, the average densities in the best habitats found in the present study (respectively: 71 birds/km^2 in hillsides and 36 birds/km^2 in gullies against 66 birds/km^2 in hill slopes greater than 22.5%, 43 birds/km^2 in medium shrubs with slopes above 11% or 31 birds/km^2 in high shrubs with slopes above 11%). In our opinion, these estimates are valuable as they represent maximum ecological densities – the highest densities the species may attain. The main effect of these issues is that García del Rey's (2009) study further underestimates the population size by extrapolating the results of the survey to a much reduced range, even if his density estimates are biased to the biggest attainable.

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APPENDIX 1 *[APÉNDICE 1]*

Average density and 95% confidence intervals (birds per km^2) of the Canary Islands stonechat in the habitats defined according to combinations of vegetation and slope. For each habitat, we give the number of birds detected (Nb, excluding long-distance recordings further than 80 m), the number of line transects surveyed (Nt), and the area covered (Area, in km^2). Rural environment includes cottages, farms and vegetable garden. Arboreal habitats include riparian, palm groves and non-native young forest stands. *[Densidad media e intervalos de confianza al 95% para la abundancia (en aves por km^2) de la tarabilla canaria en los hábitats definidos de acuerdo a clases de vegetación y pendiente. En cada hábitat se da el número de aves observado (Nb, excluyéndose los avistamientos lejanos, más allá de 80 m), el número de transectos lineares muestreados (Nt), y el área prospectada (área, en km^2). La clase 'ambiente rural' ('rural environment') incluye cortijos, granjas y huertas. Los hábitats arbóreos incluyen manchas forestales riparias, cultivos de palmera y plantaciones jóvenes de especies alóctonas.]*

Habitat	**Density (birds/km^2)**	**Nb**	**Nt**	**Area (km^2)**
Grassland, slope ≤ 5% *Pastizal, pendiente ≤ 5%*	1.3 (0-4.5)	2	39	51.2
Grassland, slope > 5% *Pastizal, pendiente > 5%*	3.6 (0-8.5)	3	21	36.9
Low scrub, slope ≤ 5% *Matorral bajo, pendiente ≤ 5%*	2.3 (1-2.7)	39	588	435.1
Low scrub, slope 6-11% *Matorral bajo, pendiente 6-11%*	5.2 (3.6-7.7)	79	381	346.2
Low scrub, slope > 11% *Matorral bajo, pendiente > 11%*	25.1 (19.5-34.1)	253	257	587.2
Medium scrub, slope ≤ 5% *Matorral medio, pendiente ≤ 5%*	6.4 (0-14.9)	4	16	8.9
Medium scrub, slope 6-11% *Matorral medio, pendiente 6-11%*	11.9 (0-32)	7	15	6.3
Medium scrub, slope > 11% *Matorral medio, pendiente > 11%*	43.2 (22.8-70.8)	22	13	12.1
High scrub, slope ≤ 5% *Matorral alto, pendiente ≤ 5%*	0 (0-0)	0	24	25.9
High scrub, slope 6-11% *Matorral alto, pendiente 6-11%*	0 (0-0)	0	10	7.6
High scrub, slope > 11% *Matorral alto, pendiente > 11%*	31.2 (16.8-53.4)	44	36	53.0

APPENDIX 1 *[APÉNDICE 1]* (cont.)

Habitat	**Density (birds/km^2)**	**Nb**	**Nt**	**Area (km^2)**
Arboreal, slope ≤ 5% *Arbóreo, pendiente ≤ 5%*	11.9 (0-29.3)	7	15	6.3
Arboreal, slope 6-11% *Arbóreo, pendiente 6-11%*	18.6 (0-43)	4	5	1.6
Arboreal, slope > 11% *Arbóreo, pendiente > 11%*	14.6 (0-48.6)	4	7	1.9
Rural environment *Medios rurales*	0 (0-0)	0	14	36.5
Aquatic vegetation *Vegetación acuática*	0 (0-0)	0	0	0.008
Unvegetated, slope ≤ 5% *Sin vegetación, pendiente ≤ 5%*	0 (0-0)	0	19	19.4
Unvegetated, slope > 5% *Sin vegetación, pendiente > 5%*	0 (0-0)	0	11	13.0
Others *Otros*	0 (0-0)	0	0	4.3