BIODIVERSITY RESEARCH

Land use changes affect distributional patterns of desert birds in the Baja California peninsula, Mexico

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ABSTRACT

Reliable plans for desert bird conservation will depend on accurate prediction of habitat change effects on their distribution and abundance patterns. Predictive models can help highlight relationships between human-related and other environmental variables and the presence of desert bird species. Presence/absence of 30 desert bird species of Baja California peninsula was modelled on the basis of explanatory variables taken from the field, maps, and digital imagery. Generalized linear models were fit to each bird species using both variables representing human activity and other environmental factors as predictors that might influence distribution. Probability of species presence was used as a habitat suitability index to evaluate the effect of human activity when the model contained a significant human activity variable. No differences were found in bird species richness between natural sites and those transformed by agriculture or urbanization. Of 59 bird species recorded in surveys, 34% were positively or negatively associated with human-transformed habitats. Fourteen species seem to benefit from transformation of natural vegetation by agriculture or urbanization, while six were negatively affected. Sensitivity analyses of final models indicated all were robust. Results suggest that the occurrence of a large percentage of bird species inhabiting scrub habitats is sensitive to human habitat transformation. This finding has important conservation implications at regional scale as fragmentation and conversion of desert ecosystems into agricultural and urban areas affect the distribution of species that are highly selective for scrub habitat. Land use and anthropogenic activities seem to change ecological patterns at large spatial scales, but other factors could drive species richness distribution too (i.e. individual species response, species–energy relationships). The spatial modelling approach at regional scale used in this study can be useful for designing natural resource management plans in the Sonoran desert scrub.

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INTRODUCTION

Distribution and abundance of animal species are often sensitive to habitat change caused by human activity (Willson *et al.*, 1994; McIntyre, 1995; Vitousek *et al.*, 1997). Birds have been particularly useful to evaluate effects of habitat change because they are easy to watch, and the populations of many have decreased (Stauffer & Best, 1980; Rolstad, 1991; Kattan *et al.*, 1994; Warner, 1994) or increased (Best *et al.*, 1990; Blair, 1996; Bolger *et al.*, 1997; Rodríguez-Estrella *et al.*, 1998) when the landscape has been modified by human activity. There have been attempts to measure

the effects of habitat change over wide areas in the distribution of a particular species or group of species (Andries *et al.*, 1994; Bolger *et al.*, 1997; Berry *et al.*, 1998; O'Connell *et al.*, 2000).

Patterns of abundance and distribution of vertebrates – of birds in particular – are strongly related to environmental factors, which determine their presence and abundance. It is assumed that birds select habitats that fit their requirements for successful reproduction and survival (Cody, 1985; Maurer, 1994). That birds are habitat selective makes it possible to build statistical models of the distribution and abundance of species, using environmental variables as predictors. Models correlating

the presence and abundance of bird species with environmental variables would allow predicting the distribution of adequate habitats for each species within a region (Nicholls, 1989; Guisan & Zimmerman, 2000; Elith *et al.*, 2006), provided the distributions of relevant predictive variables are known.

The Sonoran desert scrub vegetation covers more than 80% of north-western Mexico, including the state of Sonora and the Baja California peninsula. The total area covered by scrub vegetation in north-western Mexico is *c.* 129,144.8 km^2, representing *c.* 41% of total Sonoran desert scrub vegetation. The Sonoran desert vegetation has experienced recent habitat changes caused by human activity, but a great portion of the vegetation remains still undisturbed (SEMARNAT, 2006). The state of Sonora has the highest degree of transformation due to land use changes. Most of the peninsula is covered by desert scrub vegetation (Wiggins, 1980). The Baja California peninsula is an important area for conservation of bird diversity as this is regarded as one of the endemic bird areas of the world (Stattersfield *et al.*, 1998). The habitat changes in the peninsula have occurred on a small scale. However, present growth rate estimates for towns in southern Baja California peninsula is among the highest in Mexico (INEGI, 2000). More changes are expected in the future in the Peninsula (and in all north-west Mexico), as this is considered a strategic economic area for tourism and agriculture and development plans for the region include extensive land use changes. To date, no land management plan has considered the potential effects of human activity on the distribution and abundance of animal species in this region. Local and federal agencies have been involved in the development of rough land management plans for the peninsula, but these usually lack sufficient information for managers to make appropriate conservation decisions. In particular, information on the effects of human activity on distribution and abundance of rare, threatened, endangered, or sensitive endemic species is particularly important for biodiversity management planning (Lawton, 1993). Thus, information on their potential effects on the distribution and abundance of birds is particularly relevant.

With the help of spatial models combining generalized linear models (GLM) and GIS, I examined if (1) human activity is influencing bird species richness in an arid desert of Mexico, where the extent of human transformation of habitats is still small; (It is sometimes assumed that species richness is a good indicator of the degree of conservation of habitats, but human transformation of habitats can facilitate both species extinctions and colonization.) and if (2) individual bird species of the xerophytic scrub vegetation respond differentially to human transformation (agriculture and urbanization) of habitats.

This study is timely because habitat changes have so far affected only a small portion of Baja California peninsula and a small to medium portion of the whole Sonoran desert region. Also, strong land use changes are expected in the scrub vegetation distribution patterns in the Sonoran desert due to extensive land use changes. Thus, predictions of the effects of habitat change on the distribution patterns of bird species will help model the responses of bird distribution under different scenarios of human transformation of habitats.

METHODS

Study area

I conducted the study in the Southern Baja California peninsula, México, between the Sierra de la Giganta and Cabo San Lucas (26°30′ to 23°45′ N; Fig. 1). The area covers approximately 38,900 km^2 and ranges in altitude from sea level to 2000 m. It consists of plains and small hills dissected by occasionally flooded streams (arroyos). Climate is characterized by low rainfall (from 150 to 170 mm) concentrated during the summer months, and an annual mean temperature between 22.1 °C and 23.4 °C (INEGI, 1981).

I limited the study to both the xerophytic scrub vegetation which is the dominant vegetation type in this area, and the tropical deciduous forest present at the base of mountain ranges. Oak forest and oak–pine forests in the mountain ranges (above 700 m a.s.l.) were excluded as also were sampling points having other restricted vegetation communities (i.e. coastal vegetation).

Structurally dominant plant species for scrub habitat are the cacti *Pachycereus* spp., *Stenocereus gummosus*, and *Opuntia cholla*; the trees *Prosopis*, *Cercidium microphyllum*, *Cyrtocarpa edulis*, *Fouqueria diguetii*, and the shrubs *Jatropha* spp. and *Bursera* spp. Tropical deciduous forest is dominated by *Lysiloma* spp., *Euphorbia* spp., and *Pithecellobium mexicanum* (Wiggins, 1980).

Human activity

Baja California Sur has the lowest human density of all of México (INEGI, 2000). Most natural vegetation remains unaltered and covers 91% of the study area (Fig. 1). Small towns and ranches, mainly devoted to livestock, are sparsely distributed throughout the region. Irrigated agricultural lands support crop fields of alfalfa, chili, vegetables, and maize. Agricultural activity is concentrated in some localities (Fig. 1). Urbanized areas are concentrated around the biggest city of La Paz, followed by Cabo San Lucas and José del Cabo, Ciudad Constitución, Todos Santos, Loreto, and several small villages (with fewer than 500 inhabitants each) (Fig. 1).

Urbanization and agriculture are the main human activities causing transformation of habitats in this area. They create great changes in vegetation cover and birds have been shown to be sensitive to these changes in other ecosystems (Ambuel & Temple, 1983; Vickery *et al.*, 1994).

Selection of survey locations

Because human-transformed areas represent only a small proportion of the study area, survey points were randomly distributed in all human-transformed areas, and nearby locations with natural vegetation.

The procedure was as follows: I first delimited towns and agricultural areas on 1 : 50,000 and 1 : 250,000 INEGI maps, and delimited a 3-km buffer around these areas. Three kilometers was chosen because some species such as falconiformes are
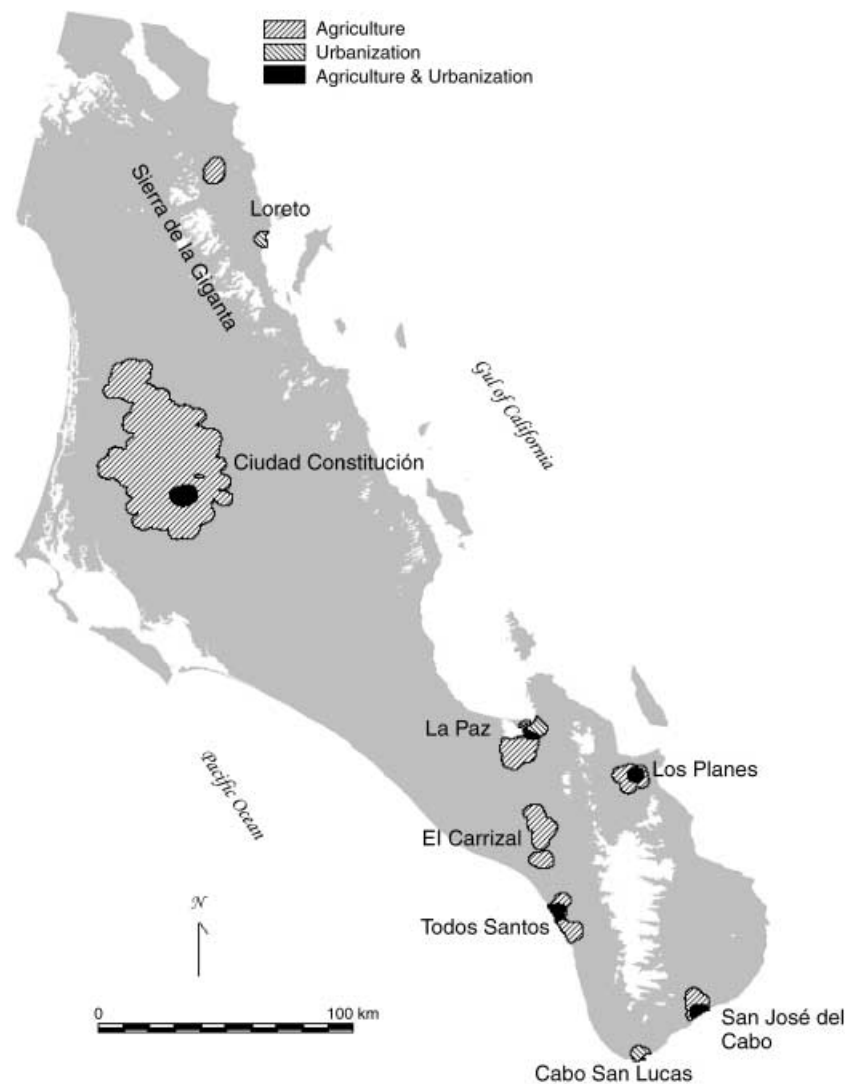
Figure 1 Baja California study area. The map shows contours representing the 3-km buffer around towns and agricultural areas. Note the patchy distribution of towns and agricultural areas.

known to forage over this range, and because of the potential influence of garbage and other waste produced by human settlements (Rodríguez-Estrella *et al.*, 1998). Approximately 0.47% of the study area was affected by both agriculture and urbanization, 0.28% was affected by urbanization only, and 7.9% was affected by agriculture only. Within the 3-km buffers (Fig. 1), I selected as many survey points as possible that were at least 3 km apart, less than 100 m from a crop field, and less than 100 m from an inhabited building. A similar number of points in patches of natural vegetation outside the 3 km buffers were selected. It tried to maximize coverage of the heterogeneity of desert habitats, with different vegetation composition and structure, elevation, topography, and distance to the coast. Locations were surveyed only once to give the data maximum independence (Hurlbert, 1984).

I surveyed 223 points on the basis of the percentage of human transformation: 47 were close to crop fields and considered affected by agriculture, 32 were close to inhabited buildings and considered affected by urbanization, and 144 were in natural vegetation patches at least 3 km from the nearest crop field or

building, as verified from the ground by the observer. All points were positioned by global positioning system (GPS).

Predictive variables

I selected environmental variables that thought had high potential for predicting bird distribution, and that could be measured easily in the field, or derived from available conventional maps, satellite images, or digital maps with a GIS. Names and descriptions of environmental variables are provided in Table 1.

Bird point surveys

One 120-min stationary survey at each of the 223 locations was conducted. Observers recorded the time (to the nearest minute) of first detection, by sight or sound, of each species within unlimited radius from survey points. A 120-min duration and unlimited radius was used to increase detectability of rare and low-density species. Surveys were performed during 1995 and 1996 between May and July, when most species were breeding

Table 1 Environmental variables used for fitting generalized linear models for breeding birds in the desert habitats of Baja California Sur, Mexico. (M, D) indicate average and standard deviation values within a circle of a 20-pixel radius. Plants in boldface were considered as trees, other plants as shrubs.

Variable	Description
Climate	Mean annual temperature in °C, precipitation in mm
Topography (M, D)	Altitude in m a.s.l.; slope; aspect
Latitude	Latitude in minutes and tenths of one minute
Longitude	Longitude in minutes and tenths of one minute
Vegetation index (M, D)	NDVI, SAVI
Bare soil	Percentage of bare soil
Plant cover	Tree cover; shrub cover
Plant richness	Number of plant species
Plant species	***Bursera mycrophylla***, ***Cyrtocarpa edulis***, *Euphorbia xantii*, *Fouquieria diguetii*, *Jatropha* spp., *Larrea tridentata*, *Lophocereus schottii*, ***Lysiloma candida***, ***Mimosa brendegeei***, *Opuntia cholla*, *Prosopis articulata*, *Ruelia californica*, ***Acacia brandegiana***, *Adelia virgata*, *Aeschynomene* spp., *Atamisquea* spp., *Atriplex* spp., *Baccharis* spp., ***Bursera hindsiana***, *Caesalpinea* spp., *Celtis pallidae*, ***Cercidium precox***, ***Colubrina* spp.**, *Condalia globosa*, *Desmanthus* spp., *Haematoxylon* spp., *Lycium* spp., *Machaerocereus gummosus*, *Maytenus* spp., ***Pachycereus* spp.**, ***Pithecellobium* spp.**, *Schaeferia spinosa*
Agriculture	Presence of agriculture areas; distance to agriculture areas
Urbanization	Presence of urban areas; distance to urban areas
Coast	Distance to the coast

and no seasonal fluctuation was detected. No significant effect of inter-year fluctuation was observed in the models when year was included as a factor.

Surveys were conducted between 07.00 and 10.00 hours, and between 15.30 and 18.00 hours. These times and the 120-min duration previously had detected > 95% of terrestrial birds foraging in the sarcocaulescent scrub vegetation of Baja California Sur (R. Rodríguez-Estrella, unpubl. data). Finally, once models were fitted, survey duration was shortened *a posteriori* for abundant species to obtain a more balanced sample of presences–absences, as it has been shown that prevalence, or the ratio of presence to absence, affects model performance (Manel *et al.*, 2001). It was assumed that the time of first detection of a species at a point would be negatively correlated with the species abundance at that point.

Explanatory variables

Plant composition and vegetation structure

It was measured in two 50-m × 5-m quadrats, in which only perennial plants taller than 0.5 m were recorded, and calculated the sampled area by the minimal sample area method (Mueller-Dombois & Ellenberg, 1974). Vegetation variables recorded are indicated in Table 1. A principal component analysis was used to try to reduce the number of vegetation variables considered in the models as explanatory variables; however, the total variance accounted for by the first three principal components was less than 40%. Thus, to reduce the number of explanatory variables, I limited analysis to the 32 plant species (out of 116 recorded) that had at least one point with 10% cover (Table 1).

Urbanized areas and agricultural areas

The observer confirmed during sampling whether the point was located less than 100 m from the nearest crop field (and then recorded this point as in an agricultural area) or from the nearest inhabited building (and recorded this point as in a urbanized area). This was because some small villages and crop fields were not recorded in the available maps, or were too small to be identified clearly on satellite images.

Climatic variables

Average annual rainfall (mm) and average annual temperature (°C) at each survey point were estimated by interpolation from INEGI 1 : 50,000 climatic maps.

Vegetation indices

The normalized difference vegetation index (NDVI, Lillesand & Kiefer, 1994) was calculated for each survey point from LANDSAT MSS images. NDVI correlated well with vegetation cover as measured in the field: a high mean NDVI indicates high vegetation cover, whereas a high NDVI standard deviation indicates high vegetation heterogeneity.

Topography

I estimated the elevation, slope, and aspect from a Digital Elevation Model (DEM). Locations on the coastline were derived from the DEM, and were used to estimate distances from survey points to the coast.

Influence of human activity

Urban and agricultural areas were delimited on LANDSAT images and digitized as polygons. Linear distances from survey points to the nearest urban area were estimated with the GIS. Agricultural areas were identified with basis on the NDVI: active crop fields generally had higher NDVI than natural vegetation areas. Linear distances from survey points to nearest active crop fields where then estimated with the GIS.

The last three variables were derived from Landsat MSS images from the 1990s, georegistered on a 60-m horizontal resolution DEM. All GIS layers and satellite images were raster images with a 60-m pixel resolution. For explanatory variables that can be measured over an area, I calculated the mean and the standard deviation of the variable on a circle of 1200-m (20 pixels) radius around the survey point. This scale of measurement was selected after preliminary testing of bird distribution and variables calculated with 1, 5, 10, 20, and 40 pixels radii around survey points. The 20-pixel radius provided the most significant correlations with bird species distribution.

Statistical analyses

Species richness approach

I tested first for effects of urban areas and crop fields on bird species richness. I wanted to test for any interaction effect between crop fields and towns. Thus, I classified, *a posteriori*, those survey points near both, crop fields and towns, as an additional category. The effects of proximity to towns, proximity to crop fields, and the interaction effect on species richness were tested by means of a two-way ANOVA.

Individual species approach

Analytical procedure for predictive models. A GLM with binomial error and logit link (McCullagh & Nelder, 1983) was used to model the occurrence of individual bird species at survey locations, using environmental variables as predictors that were fitted to observations using the program GLIM (Crawley, 1993). Each variable was tested in turn for significance, including two- and third-degree polynomial terms, and only those variables significant at the 0.05 level were included in the model. Pierce & Ferrier (2000) showed empirically that when fitting logistic regression models for species distribution, the 5% cut-off is a good compromise between the risk of over-fitting if employing a higher significance level and the risk of missing important variables if using a lower significance level. I used a Forward Stepwise Branching Procedure (Donázar *et al.*, 1993) that eventually produced a set of different models, but in most instances they converged into a single model or a set of models from which similar causal relationships could be inferred. Only models in which the relationship between the response and explanatory variables had some plausible ecological explanation were considered.

To test for spatial autocorrelation and to remove its effects, the geographical coordinates of survey points were considered as additional explanatory variables (X and Y). Both variables and their interaction were tested in the models. When no significant spatial autocorrelation was found in a model, I tested also if all environmental variables remained significant when a linear relation with X and Y and their interaction was included. This was equivalent to partialing out the spatial component effect in the models (Legendre, 1993).

I estimated the percentage correct classification for each model, and tested whether this classification was significantly better than random (Fielding & Bell, 1997).

As studies to determine the effects of human activity on species distribution and abundance have traditionally tested for individual effects of environmental variables without simultaneously considering other environmental factors (Berry *et al.*, 1998), I fitted a GLM to each bird species first, using as predictors only variables representing human activity: presence of cultivated areas, presence of towns, distances to cultivated areas, distances to towns, and their interactions. However, species might respond to other environmental factors displaying a similar spatial distribution in the study area. Human transformation of habitats does not occur at random. If observational studies over large regions, where an experimental approach is not possible, do not consider simultaneously other environmental variables that are spatially correlated with human transformation, the estimated influence of human alteration of habitats on species distribution will be wrong. Thus, secondly I tested for effects of human transformation of habitats on individual species, simultaneously considering other environmental factors. When an experimental approach is not possible, there is still the alternative of statistically controlling other environmental variables. I modelled presence/absence data of each species using all environmental variables in Table 1 as predictors. This way, I compared the results between both modelling approaches.

The final models from stepwise branching were explored further with the help of generalized additive models (GAM) (Hastie & Tibshirani, 1990). The variables included in the final model were refitted with smooth splines of 4 d.f. using S-PLUS 200 software (Mathsoft, 2000). The shape of the smooth spline indicated if a parametric model fits reasonably to an environmental variable, and suggested possible transformations in the predictor. In particular, it was checked if second- and third-degree polynomials indicated plausible relationships between the predictor variables and the species distribution. In several instances in which the effect of distance to town or crop field on species distribution was significant only up to a certain distance, it was tested if it was possible to substitute a polynomial for a linear relation over an interval of the environmental predictor. By following this procedure, a parametric final model was obtained that was usually simpler but not significantly different from that obtained by stepwise branching.

In addition, residual analysis was conducted for the best model or set of models. Three measures were used to diagnose the goodness of fit of the model to each observation point: residual lack of fit, potential influence, and coefficient of

sensitivity, an approximate measure of actual influence. Definitions and procedures were outlined by Pregibon (1981). Observations with high residual lack of fit, high potential influence, and high coefficient of sensitivity were checked for incorrect or atypical data. If data were correct, the models were refitted, excluding these observations one at a time, to evaluate their influence on the coefficients and on the conclusions derived from the models.

GAMs and residual analysis of the best model obtained by stepwise branching indicated in some instances that the relationship of the response variable to one or more predictors was not robust, or was ecologically unclear, as in the case of a species showing significant positive affinity for areas close and far from towns, but negative affinity for intermediate distances. In those situations, the variables were excluded one at a time from the GAM model fitting, and residual analysis was undertaken until the relationship of the variable response to all predictors in the model was robust.

I limited models to species that were detected in at least 10% of observation points. Additionally, I tested species present at fewer than 10% of observation points, and those for which no significant model could be fitted, for significant differences as to their presence in transformed vs. natural habitats, and in towns vs. crop fields, with two-tailed Fisher exact tests (Siegel & Castellan, 1988).

RESULTS

Species richness approach

I found no significant differences in bird species richness among sites near both agriculture and urban areas (17.3 ± 5.2 species), sites near urban areas only (18.7 ± 3.9), sites near agriculture areas only (19.7 ± 5.0), and natural sites (18.5 ± 3.5) ($F_{town} = 3.03$, d.f. = 219, $P = 0.08$; $F_{crop} = 0.003$, d.f. = 219, $P = 0.95$; $F_{interac.} = 3.36$, d.f. = 219, $P = 0.067$).

Individual approach

I recorded 59 resident bird species during surveys (see Appendix S1 in Supplementary Material). Of these, 34 species or 58% appeared in more that 10% of surveys and were adequate for statistical modelling; for 28 of these species, significant GLM models could be fitted using only variables indicating human transformation of habitats as predictors (Table 2). There were 16 species negatively associated with human-transformed habitats, nine species positively associated, and three positively associated with agricultural areas, but negatively with urban areas. No species was positively associated with urban areas and negatively with agricultural areas.

For 30 species, significant GLM models could be fitted using all the environmental variables recorded as predictors (Appendix S1). There were 12 species (40%) that had at least one environmental variable indicating influence of human transformation of habitats on distribution (Table 3). The probability of occurrence of crested caracara, common ground dove, greater roadrunner,

and Scott's oriole was higher in agricultural areas, whereas the occurrence of house finch, turkey vulture, common ground dove, and American kestrel was positively influenced by urban areas. Agricultural areas negatively affected black-throated sparrow, northern cardinal, ladder-backed woodpecker, and blue-grey gnatcatcher and urban areas impacted negatively on Costa's hummingbird and blue-grey gnatcatcher (Table 3).

Models fitted to the 30 bird species showed that variables indicating human influence were second in importance to those related to plant cover. The 12 species affected by human activity seemed to respond independently to other environmental variables. There was no group of species affected by human activity that responded similarly to other environmental factor.

Probabilistic models for desert birds affected by human activity in Baja California Sur classified correctly between 61% and 93% of the survey locations, and these classifications were between 23% and 56% better than random (Table 3). Sensitivity analyses of final models indicated that all were robust.

The two-tailed Fisher exact test showed that other seven species were significantly associated with human-transformed habitats: mourning dove, brown-headed cowbird, western meadowlark, European starling, house sparrow, horned lark, and killdeer, whereas only Pyrrhuloxia significantly preferred natural habitats (Table 4).

No correlation was found between body size no the diet of bird species and sensitivity to habitat changes.

DISCUSSION

Effects of human activity

Human transformation of xerophytic scrub habitats affects a relatively small to medium percentage of the Sonoran desert (SEMARNAT, 2006). These changes affect only a small percentage of the Baja California Sur area, but positively or negatively a large percentage of bird species, even though other indicators such as bird species richness, seem to be unaffected. This suggests that human transformation of habitats on bird species richness is usually misleading as an indicator of effects on 'biodiversity' (see O'Connell *et al.*, 2000; Brown *et al.*, 2001), and that more effort should be directed to estimating the effect of human alterations on individual species, especially those that are of conservation concern. Human transformation of habitats is potentially one of the main forces leading to changes in distribution and abundance of terrestrial bird fauna in the area.

Out of the 59 bird species recorded in my surveys, 34% were positively or negatively associated with human-transformed habitats. Of the 30 species for which significant environmental models could be fitted, 40% included explanatory variables related to human activity. This indicates that the proportion of bird species that changed distribution and abundance patterns was significant, notwithstanding the small to medium scale of habitat transformation in the arid desert of Baja California Sur. The results of this study can be applied to the entire Sonoran desert region because most bird species occurring in the study area are widely distributed throughout the region.

Table 2 Results of generalized linear models obtained for each bird species using only variables representing human activity (presence of cultivated area, presence of towns, distance to cultivated areas, distance to towns, and their interactions) as predictors. Negative (−) and positive (+) effects for each bird species are shown for agriculture and urbanization. Significant differences are indicated with *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$.

Species	Effect AGRI	AGRI	DAGRI	Effect URBN	URBN	DURBN	Interaction Factors	Interaction Distance
Verdin	(−)	***					*	
Black-throated sparrow	(−)	***	***	(−)	**	***		
Scrub jay	(−)	***	**	(−)	***			
Red-tailed hawk	(−)	*	*	(−)	*			
California quail								
Costa's hummingbird	(−)	***		(−)	***	***		
Cactus wren	(−)	*						
Crested caracara	(+)	***	***	(+)	*	***		*
Northern cardinal	(−)	*						
Pyrrhuloxia								
House finch								
Turkey vulture				(+)	**	**		
Northern flicker	(−)	***	*	(−)	**			
Common ground dove	(+)	***	***	(+)	***	***	***	
Raven				(+)	*	*		
American kestrel	(+)	***	*	(+)		***		
Greater roadrunner	(+)	**	*	(−)		*		
Xantus' hummingbird	(−)		*					
Hooded oriole	(+)	***	**					
Scott's oriole	(+)	*						
Loggerhead shrike				(+)		*		
Gila woodpecker								
Northern mockingbird	(+)	***	*	(−)	***			
Ash-throated flycatcher	(−)	***	*	(−)	**	*		
Harris hawk								
Phainopepla								
Ladder-backed woodpecker	(−)	*	*	(−)	**	*		
Brown towhee	(−)	***	**	(−)	**			
Blue-grey gnatcatcher	(−)	*		(−)	***			
California gnatcatcher	(−)	*		(−)	*			
Purple martin								
Violet-green swallow	(+)	***	**	(+)	*			
Gray thrasher	(−)		*	(−)	*	*		
White-winged dove	(+)	*	**	(−)	*	*	**	

AGRI, presence of agriculture areas; DAGRI, distance to agriculture areas; URBN, presence of urban areas; DURBN, distance to urban areas.

Changes in species diversity and trends in the percentage of sensitive and benefited bird species seem not to be a pattern when comparing different types of ecosystems. In North American grasslands (considering patches from 0.5 to 650 ha of native prairie, restored prairie and cool-season grass fields at Illinois, and 0.3–404 ha of grassland barren along the Maine coast), near 70% of bird species are sensitive to habitat fragmentation while all other species are insensitive to area but apparently not benefited (Herkert, 1994; Vickery et al., 1994). Contrasting results can be found when comparing shrubsteppe and oak temperate forest bird communities affected by human activity. Knick & Rotenberry (1995) found that 100% of obligated shrubsteppe bird communities were affected by

fragmentation in a well-preserved habitat. Blair (1996) working in an urban–suburban matrix developed since the 1980s found that only 17.5% of bird species were negatively affected by urban development in oak woodland while more than 80% may adapt well to urbanization, mainly to suburban environments. A study of Chilean temperate rainforest (considering patches of 0.5 to more than 100 ha) showed that 79% of bird species have been affected by habitat fragmentation (Willson et al., 1994). Certainly, scale-dependent processes must be considered when this kind of comparisons is made. The avian community can benefit from habitat change at small scale because small openings in continuous habitat create new conditions and do not isolate habitats and populations. This may affect few to sensitive species

Table 3 Predictive models of bird species containing at least one environmental variable related to human activity. Description of variables is given in Table 1 Variables statistically significant at $P < 0.01$ are shown in boldface; the other variables are significant at $P < 0.05$. The percentage of correct classification (cc), Kappa values (indicate whether the percentage of correct classification is better than random), the confidence interval, and the probability are given for each model.

Species	Variables*†	%cc	Kappa	CI	P
Turkey vulture	**–(DURBN – 4000)**	61.4	0.227	0.095–0.357	0.0001
Crested caracara	**–SLPM – RICH – DAGRI**	78.9	0.559	0.438–0.681	0.0001
American kestrel	–SLPD – **DURBN**	67.3	0.344	0.219–0.470	0.0001
Common ground dove	+PPT – **RICH** + **AGRI** + **URBN**	82.4	0.441	0.304–0.578	0.0001
Greater roadrunner	+PPT – **RUEL** + OPUN – OPUN2 + OPUN3 + AGRI	93.4	0.424	0.103–0.745	0.02
Costa's hummingbird	**–DCOAST** + **ALTM** – **ALTM2** – TEMP + **DURBN**	68.2	0.363	0.238–0.488	0.0001
Ladder-backed Woodpecker	–NDVD – SLPD + SLPD2 + **DAGRI**	64.4	0.287	0.158–0.417	0.0001
Blue-grey gnatcatcher	+PPT – URBN + **DAGRI – 500**	67.3	0.345	0.219–0.470	0.0001
Black-throated sparrow	**–NDVM – AGRI**	74.4	0.489	0.372–0.605	0.0001
Northern cardinal	+**NDVM** – **PPT** + DAGRI	65.9	0.318	0.191–0.445	0.0001
Scott's oriole	**–TEMP – LAT** + AGRI	72.1	0.232	0.049–0.414	0.008
House finch	+**(ALTM < 300)** – **(PPT – 250)** + NDVM – NDVM2 **–PBS – (DURBN < 500)**	74.4	0.487	0.363–0.611	0.0001

*The notation used is the one employed by s-plus. The expression (ALTM < 300) indicates hat the slope given is applicable for values of mean altitude below 300 m, while for altitudes above 300 m the effect is constant and is given grouped with the intercept.
†DURBN, distance to urban areas; URBN, presence of urban areas; DAGRI, distance to agriculture areas; AGRI, presence of agriculture areas; DCOAST, distance to the coast; SLPM, slope; SLPD, slope (standard deviation, means variation in slope characteristics, i.e. valleys and mountains); ALT, altitude; NDVM, NDVI (represents vegetation cover); NDVD, NDVI (represents vegetation associations diversity); LAT, latitude; PPT, precipitation; TEMP, temperature; RICH, species richness; PBS, bare soil; RUEL, *Ruelia californica*; OPUN, *Opuntia cholla*.

Table 4 Bird species for which a significant predictive model based on the explanatory variables was not obtained or that were found in less than 10% of the points. Sample size indicates the number of points in each category. Figures for each species indicate the number of points with positive records. Significant differences in the proportion of positive records are tested with two-tailed Fisher exact tests (Siegel & Castellan, 1988). Habitats positively selected by the species are in bold.

Species	Changed		Natural (n = 144)	Natural vs. changed	Crops vs. towns
	Crops (n = 47)	Towns (n = 32)			
Harris hawk	11	3	27	NS	NS
Mourning dove	38	5	14	P < 0.0001	P < 0.0001
Phainopepla	12	4	26	NS	NS
Pyrrhuloxia	3	2	27	P = 0.0154	NS
Brown-headed cowbird	12	6	6	P < 0.0001	NS
Western meadowlark	6	0	1	P = 0.0087	P = 0.0759
European starling	9	2	6	P = 0.0152	NS
House sparrow	11	5	1	P < 0.0001	NS
Horned lark	11	0	1	P < 0.0001	P = 0.0023
Killdeer	17	0	1	P < 0.0001	P < 0.0001

NS, not significant.

and at least maintain species richness and diversity stable (Derleth *et al.*, 1989). On the other hand, when large areas have been disturbed and habitats become extensively fragmented, isolated bird specialists tend to disappear (Lent & Capen, 1995; Ferraz *et al.*, 2007). Even if the association of human-transformed landscapes with human intact landscapes may promote greater species richness (La Sorte, 2006), gains are related to colonization of common species; rare species and specialists may face extinction processes (La Sorte, 2006; Webb *et al.*, 2007). When temporal scales are also considered, results vary in function of the number of years of disturbance and on the practices and land use changes in those areas. On a European scale, the most dramatic declines and range contractions in farmland species have occurred in those countries with most

intensive agriculture in response to changing farming methods (Webb *et al.*, 2007). Clearing forests for agriculture in eastern North America in the last 100 years expanded grassland habitat. Resulting increases in populations of grassland birds were subsequently reversed by changes in agricultural practices (Askins, 1999). In all cases, it was found that common species may change increasing populations while rare species change with a high declining prediction. Although the Baja California is a short-term study, some predictions can be made on the effects of habitat change. It is expected that sensitive Sonoran desert birds will be affected in the long term because the impact on habitat specialists may be more permanent compared with those birds from temperate and tropical forested regions. The regeneration of desert scrub is extremely slow, and recovery via natural plant-successional processes is unlikely but at the very long-term.

Although more studies are needed to evaluate the effects of habitat fragmentation in bird communities, the results of the study in Sonoran scrub desert are consistent with the general pattern of species decline that seems to be stronger for habitat specialists (e.g. shrubsteppe and grassland birds). In the study area, all species negatively affected (i.e. species decreasing their presence or abundance near the edge of agriculture lands or urbanized areas) have a wide distribution in the desert and are still abundant. These species had high indices of habitat selection for arid desert (Rodríguez-Estrella *et al.*, 2005). I predict that if the sizes of human-altered patches increase, and habitat changes continue, populations of even common, widespread species might decline. Costa's hummingbird frequently occurs and breeds in towns of Baja California Sur (R. Rodríguez-Estrella, unpubl. data), but its probability of occurrence is lower in urban than in natural scrub habitat. Similar patterns of distribution have been found for this species Costa's hummingbird in California (Bolger *et al.*, 1997).

Neither the body size nor the diet of bird species was found to be correlated to their sensitivity to habitat change. Although almost all birds that were sensitive to habitat change are insectivorous species notwithstanding the scale of disturbance and fragmentation nor the time since the transformation occurred (100% in grasslands, Herkert, 1994; Vickery *et al.*, 1994; 100% in shrubsteppe, Knick & Rotenberry, 1995; 91% in temperate rainforest, Willson *et al.*, 1994; 71% in oak woodlands, Blair, 1996; 71% in desert, this study), most benefited and non-sensitive birds are insectivorous species as well (67–75% in grasslands; 67% in oak woodlands; 100% in temperate rainforest; 62% in desert, this study). Remarkably, as previously mentioned, most bird species that were negatively affected were habitat specialists. Species having high selectivity for desert scrub habitat, like the black-throated sparrow, blue-grey gnatcatcher, northern cardinal, pyrrhuloxia, ladder-backed woodpecker, and Costa's hummingbird, might be affected by extensive habitat change. Costa's hummingbird and sage sparrow (*Amphispiza belli*), a species similar to the black-throated sparrow having a high preference for scrub habitat, are sensitive to habitat change in suburban areas of California because of 'edge effect' (Bolger *et al.*, 1997). Edges might induce high predation rates, inter-specific competition, and density dependent competition that did not exist before habitat change, which in turn might induce bird population decline in edges (Engels & Sexton, 1994; Murcia, 1995). The edge effect around agricultural and urban areas might be amplified by an increase in cavity nesting non-native bird species such as European starling and house sparrow. These non-native species are aggressive, might compete successfully for nesting sites against native breeding birds, and might change competitive interactions in the community of areas they colonize (Weitzel, 1988; Bennett, 1990; Rodríguez-Estrella *et al.*, 1997). Although American kestrel and house finch apparently have benefited from habitat transformation, caution should be taken to consider potential interaction with European starlings and house sparrows, which might reduce this benefit in the future to the detriment of these species (Weitzel, 1988; Bennett, 1990). Additionally, it is unclear if more extensive habitat transformation might be beneficial for them as suitable natural habitat is removed.

New habitats and new interactions

Agricultural and urban areas are 'new habitats' created by human activity in relatively homogeneous dense vegetation such as scrub. These new open habitats seem to be attractive for some bird species depending on the scale of transformation (see above). Recent studies have shown that these new habitats might offer abundant food, nesting structures, and protection against predators (Banercft *et al.*, 1995; Tella *et al.*, 1996). Some raptors, for example, have become denser around towns and agricultural lands, opportunistically exploiting food as carrion, refuse, or rodents associated with dumping (e.g. crested caracara, turkey vulture, and probably also raven; Rodríguez-Estrella *et al.*, 1998; this study). For instance, the city of La Paz is an important roosting site for turkey vulture. Most raptor species do not seem to be negatively affected by human transformation of the desert, and several have benefited from these changes, at least for foraging activity (Rodríguez-Estrella *et al.*, 1998). Some species, like the white-tailed kite (*Elanus leucurus*), the European starling, and the white-faced ibis (*Plegadis chihi*), have become more widely distributed with the increase in farmed area in Baja California (Rodríguez-Estrella *et al.*, 1995, 1997; Blanco & Rodríguez-Estrella, 1998).

Among species apparently following this pattern, the western meadowlark has ranged farther southward since the 1980s (Wilbur, 1987). During our study, I commonly found this bird breeding in agriculture lands surrounding Ciudad Constitución. The western meadowlark has been reported as a species sensitive to habitat change in California (Bolger *et al.*, 1997) and Illinois, and is declining in most of its northern range due to loss of grassland habitat (Herkert, 1994). This species prefers ungrazed or slightly grazed habitats (Lanyon, 1994). It would be interesting to determine why the western meadowlark has extended its breeding range into transformed agricultural lands of Baja California, where there is intensive use of pesticides such as malathion and persistence of DDT and DDE (Jiménez *et al.*, 2005), while declining in its northern breeding grounds with

apparently less profound habitat change. The horned lark is also breeding in agriculture lands of the Baja California Peninsula. Wilbur (1987) mentioned that the southernmost distribution of this species in Baja California was approximately 30° latitude. Our data indicate that this species has colonized agriculture lands southward to 23° latitude, using small- to medium-size crop fields. This species is also declining in the USA, where it breeds in cleared gaps of forests (Herkert, 1994). Although the opening of attractive gaps of cultivated fields seems to explain its increasing range, it is unclear what the birds are eating in crop fields treated intensively with pesticides. The killdeer seems to benefit from habitat change because I found it throughout the peninsula (Grinnell, 1928; Wilbur, 1987), associated mainly with cultivated areas. Killdeer populations are currently increasing in North America (Herkert, 1994).

Common ground dove, mourning dove, house finch, roadrunner, and Scott's oriole also benefit from towns and crop fields. Except for Scott's oriole, these species are known to be associated with human activity for breeding and feeding.

Finally, the results of this work indicate that anthropogenic activities could be a strong causal factor when considering ecological patterns at large spatial scales. However, other factors may also explain the relations between species richness and changes in distribution patterns. For example, strong positive correlations have been found between species richness and energy availability (Evans et al., 2006). Under the species–energy hypothesis (Wright, 1983), the amount of energy available in ecosystems (i.e. limited by resource availability) may be an important factor determining species diversity. Using the NDVI as a surrogate of primary or plant productivity and mean temperature as surrogates of energy availability (Evans et al., 2006), I found that species richness in the scrub desert of Baja California showed a strong linear correlation with the NDVI values at 1, 10 and 20 pixels scale around each sampling point, but failed to find a correlation with temperature (See Appendix S2 in Supplementary Material; author preliminary data analysis). It means that a positive species–energy relationship was exhibited by breeding desert birds considering plant productivity, but that temperature seems not to impose physiological constraints for birds of desert regions. Additionally, there were 14 species (46%) with significant models that had one environmental variable indicating influence of NDVI on distribution while only four (13%) that had one with temperature (Rodríguez-Estrella, 1997). These results can lead to think in spatial congruence between productive regions and species richness. However, a great portion of species seem to be affected by human land use (Table 2). Thus, caution should be taken when this kind of analysis are performed because human land use can either increase (e.g. irrigated agriculture in semiarid regions) or decrease the plant productivity values (NDVI), but have varying consequences for native species independent of changes in productivity. Landscapes with high NDVI values but without suitable habitat structures or habitat heterogeneity are likely to support fewer species (Luck, 2007). In fact, the most important environmental variables explaining distribution patterns of desert scrub birds were those related to vegetation and habitat structure (Rodríguez-Estrella, 1997).

CONCLUSIONS

There are more species that seem to benefit in their presence from the transformations observed in this study (14 species) than those that seem negatively affected (six species). However, this should be interpreted with caution. First, although the small scale of urbanization and transformation into agriculture has created new opportunities such as new food sources and open foraging habitats that could be interpreted as beneficial for some species, these new habitats still hold natural patches that are used extensively by birds (i.e. for breeding). Second, although adjusted to time of detection, models consider only presence–absence data. An analysis of abundance for each species in each survey point could give other insights. Abundance might diminish strongly in human-transformed habitats although the species could be present with one or a few individuals. Birds benefiting from human transformation could be present in low numbers in all urban and agriculture areas. Species that benefit presently might not do so if transformations become more extensive (Blair, 1996; Campion, 2004). Scale-dependent processes should be considered. Third, agriculture and urbanization have created new habitats that have also favoured the colonization of invasive species to the scrub habitats, like European starling, house sparrow, and bronzed cowbird. Competition with these species for nesting holes might affect native and endemic species of the scrub habitat negatively, especially if transformed habitats increase in size. Fourth, some endemic species of Baja California Sur scrub such as Xantus' hummingbird and grey thrasher do not seem to be clearly affected by human transformation. This also should be taken with caution as although our statistical models suggest that other environmental factors are responsible for their present distribution and abundance, they were negatively associated with human-transformed habitats (Table 2). Fifth, even if few species are affected, the widespread extent of negative effects on Costa's hummingbird, blue-grey gnatcatcher, black-throated sparrow, and ladder-backed woodpecker should be noted. These species are characteristic of the scrub habitat and their global distribution ranges are narrower than those of species benefiting from the transformations like turkey vulture, crested caracara, American kestrel, raven, and mourning dove. Lastly, our data did not allow us to make predictions about effects of transformation on rare species like rock wren, lesser goldfinch, and canyon wren. Rare species are often at a disadvantage when anthropogenic activities alter habitat and/or dispersal opportunities and typically become rarer and, in many cases, face extinction (Davies et al., 2004; La Sorte, 2006).

Although more studies are needed for model building and testing the effects of habitat change by human activity on the distributions of bird species in the Sonoran desert, our models show that the distribution of many birds is strongly affected by agriculture and urbanization in the arid desert scrub. This result has important conservation implications at the regional scale as

the scrub desert is widely distributed in north-western Mexico. For instance, land fragmentation and conversion of the desert ecosystem to agricultural and urban areas impacts on the distribution of species highly selective for scrub habitat. Therefore, human activity could play a key role in the structure and dynamics of the community (Vitousek *et al.*, 1997).

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SUPPLEMENTARY MATERIAL

The following supplementary material is available for this article:

Appendix S1 Number of sites where resident species were recorded at 223 point count stations in Baja California peninsula. Species for which models were derived based on landscape variables (Y) and sensitivity to human activity are shown.

Appendix S2 Plot showing the relationships between species richness of resident desert birds of Baja California and energy availability, measured as the normalizad difference vegetation index (NDVI) at 1, 10, and 20 pixels around sampling points and (b) temperature.

This material is available as part of the online article from: http://www.blackwell-synergy.com/doi/abs/10.1111/j.1472-4642.2007.00387.x
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