

Museum specimen data predict crop damage by tropical rodents

Víctor Sánchez-Cordero*[†] and Enrique Martínez-Meyer[‡]

*Departamento de Zoología, Instituto de Biología, Universidad Nacional Autónoma de México, Apartado Postal 70-153, México, D.F. 04510, México; and
[‡]Department of Geography and Kansas Applied Remote Sensing Program, University of Kansas, Lawrence, KS 66045

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Museum collections constitute a massive store of information on biological diversity. We used museum specimen data to generate ecological niche models that provide predictions of geographic distributions of native rodent pest species and agricultural census data that summarize the geographic distribution of nine crops in the state of Veracruz, Mexico, as well as crop losses between planting and harvest. Herein, we show that crop damage is related significantly to the predicted presence of rodent species for seven of nine crops. Museum collections may thus provide important baseline information for designing land-use and agricultural pest-management programs.

Rodents constitute important agricultural pests. High immigration rates from adjacent habitats and increased population recruitment owing to food resource subsidies lead rodents to experience rapid population growth in agricultural fields. Such large populations cause considerable damage to a wide variety of crops worldwide (1–5).

Historically, the economy of the Mexican state of Veracruz has focused on agriculture, which presently occupies 65% of its area (6). Veracruz produces a rich diversity of crops, including corn, beans, oats, wheat, rice, sorghum, introduced grasses for livestock, coffee, and sugarcane (www.inegi.gob.mx). Veracruz has a diverse rodent fauna, of which 17 native species have been reported as pests in crops (7–9). These rodent species share the life-history traits of frequent litters, short gestation periods, postpartum estrous, and aseasonal reproduction (9–11). We hypothesized that regions experiencing high crop damage would coincide with centers of species richness of these rodent pest species.

Materials and Methods

Distributional data for each species were obtained from the mammal collections of the University of Kansas Natural History Museum, Field Museum of Natural History, and the Colección Nacional de Mamíferos, Instituto de Biología, Universidad Nacional Autónoma de México. Species names and taxonomic arrangements followed accepted authorities (9, 12). Locality data were georeferenced to the nearest 10^{-3} degree by direct consultation of maps and were reduced to unique latitude–longitude combinations. The four thematic geographic coverages used (annual mean temperature, annual mean precipitation, elevation, and potential vegetation) consisted of raster grids (7×7 -km pixels) available from the Comisión Nacional para el Uso y Conocimiento de la Biodiversidad (<http://www.conabio.gob/>).

Geographic distributional predictions were developed based on an algorithm designed to identify correlations between known distributional occurrences and environmental characteristics (“ecological niches”). The Biodiversity Species Workshop facility developed by David Stockwell (<http://biodi.sdsc.edu/>) provides an implementation of the Genetic Algorithm for Rule-Set Prediction (GARP; refs. 13 and 14). GARP works in an iterative process of rule selection, evaluation, testing, and incorporation or rejection: first, a method

is chosen from a set of possibilities (logistic regression, bioclimatic envelope, etc.) and then applied to the data; subsequently, a rule is developed. Predictive accuracy is then evaluated based on 1,250 points resampled from the occurrence data set and 1,250 points sampled randomly from the study region as a whole. The change in predictive accuracy from one iteration to the next is used to evaluate whether a particular rule should be incorporated into the model; the algorithm runs 1,000 iterations or until convergence. These component rules are then incorporated into a broader rule set, defining portions of the landscape as within or without the ecological niche. GARP models thus provide a heterogeneous rule set that delimits a polygon or set of polygons within which the species is expected to be able to maintain populations and outside of which it should not. This model of the ecological requirements of a species is the key to the inferential portion of the method (13, 14). GARP has demonstrated the ability to predict the distributions of small mammal species in the neotropics (15).

Rodent species previously identified as crop pests in Veracruz (7–9) can be divided into three categories according to food preferences (refs. 9–11; G, granivore; H, herbivore; O, omnivore) and included one squirrel (*Sciurus aureogaster* O), thirteen rats and mice (*Microtus mexicanus* H, *Oligoryzomys fulvescens* O, *Oryzomys couesi* O, *Oryzomys melanotis* O, *Peromyscus aztecus* G, *Peromyscus leucopus* G, *Peromyscus levipes* G, *Peromyscus maniculatus* G, *Reithrodontomys fulvescens* G, *Reithrodontomys megalotis* G, *Reithrodontomys mexicanus* G, *Reithrodontomys sumichrasti* G, and *Sigmodon hispidus* H), and three pocket gophers (*Orthogeomys hispidus* H, *Pappogeomys merriami* H, and *Thomomys umbrinus* H). Although somewhat arbitrary, these designations were developed independently (indeed before knowledge) of the results of this study.

We included nine main crops, distributed extensively over Veracruz, about which we had reliable data on planted and harvested areas (www.inegi.gob.mx). Areas of crop loss were calculated as the difference between the total planted and total harvested areas for each crop, based on 1991 agriculture census data provided for the 207 municipalities in Veracruz (www.inegi.gob.mx). Such areas of crop loss lead inevitably to bias estimates of actual crop damage inflicted by rodents. Agricultural census data generally lack accurate assessment of factors—climatic (e.g., floodings and droughts), biological (e.g., other animal and plant pests), and economical (e.g., appropriate funding for harvesting)—presumed for crop losses. We assumed that rodent damage was partially related to unharvested crop areas. Stepwise multiple regression was

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Abbreviations: GARP, Genetic Algorithm for Rule-Set Prediction; G, granivore; H, herbivore; O, omnivore.

[†]To whom reprint requests should be addressed. E-mail: victors@ibiologia.unam.mx.

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Table 1. Crop damage related to rodent pests in Veracruz, Mexico

Crop	Total area, ha	Area lost, ha	R^2	$F_{n_2, n_1}(P)$	G	H	O
Grasses (seeds, leaves)	1,322,985	5,315	0.120	$F_{5, 173} (0.001)$	2	1	2
Corn (seeds, stems)	514,213	49,189	0.110	$F_{10, 174} (0.019)$	4	4	2
Sugarcane (stems)	213,221	69,670	0.049	$F_{3, 160} (0.045)$	—	1	2
Coffee (seeds, roots)	175,027	9,417	0.040	$F_{2, 160} (0.037)$	1	1	—
Beans (seeds)	57,988	9,426	0.071	$F_{6, 170} (0.047)$	4	1	1
Rice (seeds)	21,920	1,359	0.650	$F_{8, 29} (0.0001)$	5	1	2
Oats (seeds)	1,981	239	0.500	$F_{6, 20} (0.018)$	4	—	2
Sorghum (seeds, stems)	5,676	555	0.073	$F_{1, 37} (0.094)$	1	—	—
Wheat (seeds)	1,822	378	0.220	$F_{1, 5} (>0.1)$	1	—	—

Total area planted and area lost as well as statistical significance (P) of multiple regression models relating areas with crop damage reported for the municipalities (n_1); rodent species' presence (n_2); and numbers of G, H, and O species included in the stepwise regression models. In parentheses are parts of plant crops damaged by rodents (8). R^2 , coefficient of determination; F , F test; ha, hectare.

implemented with routines in STATISTICA 4.3 by using the forward selection option.

Results and Discussion

We generated ecological niche models for each of the 17 rodent species based on habitat, elevation, and climatic variables (13–15); these models were used as the potential distributional hypotheses for each rodent species. Current land-use maps and agricultural census data (www.inegi.gob.mx) were used to map the distributions of each crop type. Differences between total cultivated area and that harvested (www.inegi.gob.mx) were assumed to represent crop damage potentially resulting, at least in part, from rodents. Percentage of area with crop damage ranged from 0.4% for introduced grasses to 32.7% for sugarcane (Table 1); predicted rodent species diversity ranged from 1 to 13 species (Fig. 1).

Stepwise multiple regression analyses predicted crop damage in each crop in the 207 municipalities for Veracruz (dependent variable) as a function of proportional predicted coverage of that municipality by each of the 17 rodent species (independent variables). Models for seven of nine crops were statistically significant ($P < 0.05$), explaining 4–65% of variation in crop damage (Table 1). Interestingly, rice and oats showed high values of explained variance and were restricted to localized regions in south and central Veracruz, respectively (www.inegi.gob.mx), in contrast with the other, widely distributed crops (Table 1); whether these regions show particularly suitable conditions for rodents to reach disproportionately high densities or *ratadas* (1, 7) remains an intriguing question for further investigation.

Moreover, feeding habits of particular rodent pests included as predictors in the stepwise models matched food items supplied by the particular crop (e.g., granivores with seed crops and herbivores with plant material) more frequently than random expectation (Table 1; sign test, $P < 0.05$). This relationship was not sensitive to assumptions regarding feeding habits of species: e.g., the relationship was actually stronger (sign test, $P < 0.01$) when *Peromyscus* were considered omnivores. This result is consistent with the idea of a causal relationship between rodent pest species richness and crop damage. Factors not taken into account in our approach may

also affect levels of crop damage: the abundances of species, interspecific interactions, the presence of other pests, and unfavorable climatic conditions should be incorporated into future applications.

Considering the scale of cultivated areas in Veracruz, however, our results suggest significant economic impacts of rodent pests on these crops, results that are supported by recent studies documenting effects of *Sigmodon hispidus* and *Oryzomys couesi* on sugarcane and rice in Veracruz (8, 10). Rodents have long been recognized as agricultural pests in Mexico, with farmers frequently complaining of severe economic losses (7). Lacking sound solutions to this problem, desperate farmers use crude methods to control rodent pests, applying enormous quantities of rodenticides. These measures are expensive, because costly rodenticides are applied after the crop has already been damaged (1–3). Thus, rodent pests are harmful to rural economies, the environment, and to wildlife.

A first step toward a large-scale, integrated pest-control program requires precise knowledge of pest species richness across agricultural landscapes (1–5). Our models point to multispecies rodent pest communities matching the complex mosaic of crop distributions and provide a baseline for implementing an integrated pest management program in Veracruz; subsequent research can focus on adjusting patterns of land use to interact optimally with pest species distributions. Our approach provides a low-cost, robust tool with applicability to many other pest taxa and agricultural regions worldwide and demonstrates the power of the enormous store of information in world natural history museums in meeting varied economic challenges.

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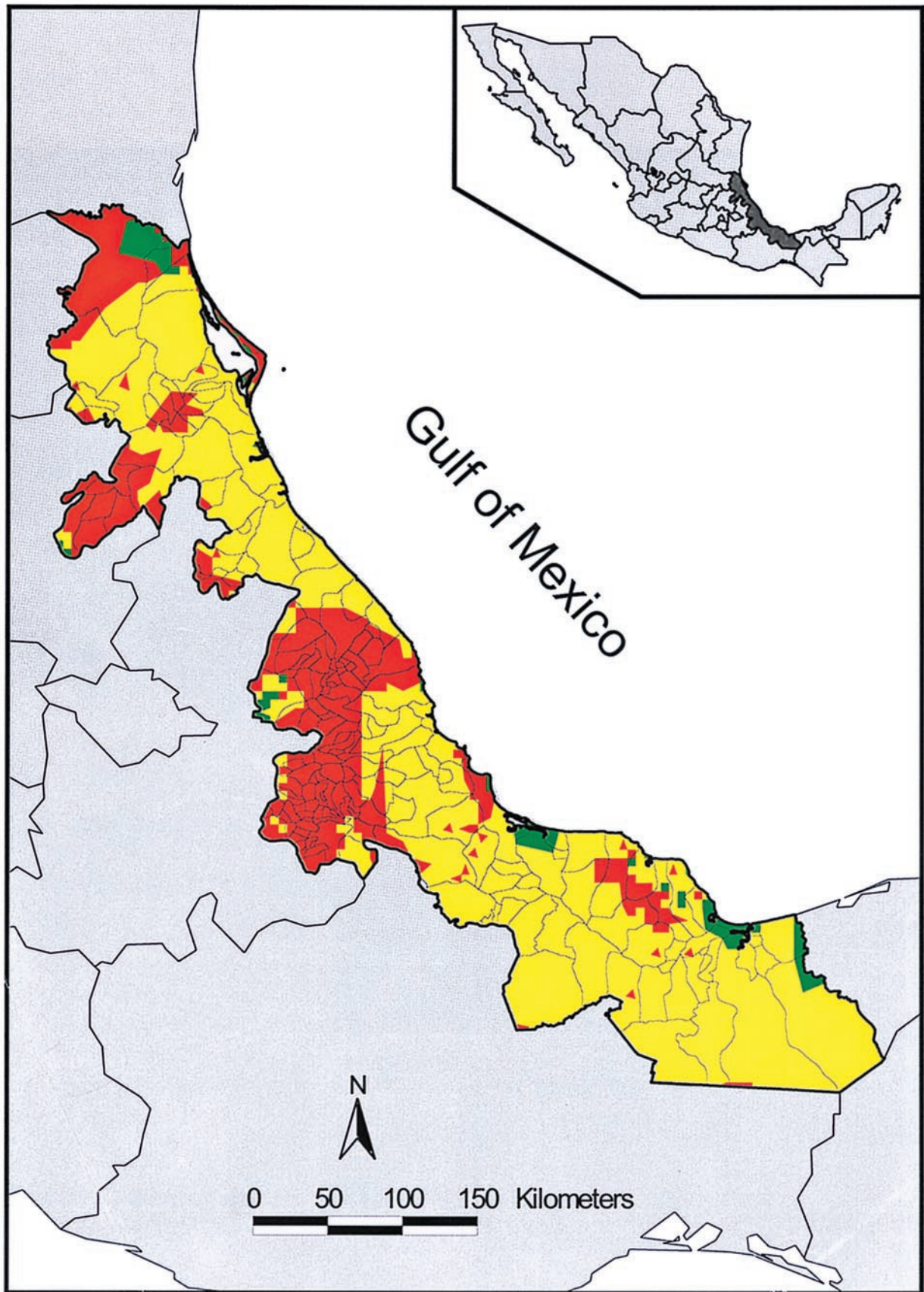


Fig. 1. Map depicting geographic patterns of species richness of 17 native rodent species known to be agricultural pests in Veracruz, Mexico. Colors show rodent pests species richness: green, 1–4 species; yellow, 5–8 species; red, 9–13 species; polygons indicate the 207 municipalities used in the analyses.

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