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Landscape Features Associated with Damage to Maize (*Zea mays*) Fields in Central México: A Comparison of Wind and Wildlife Damage

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Abstract: Damage to maize (*Zea mays*) fields leads to negative attitudes towards wildlife that can affect conservation. In a Biosphere Reserve in central Mexico, local inhabitants perceive that wildlife causes major damage to maize fields. Therefore, we quantified maize damaged by wildlife species and by wind, and we explored whether this was related to the proportion of land-use categories in the landscape surrounding maize fields and the distance from maize fields to the nearest human settlements, water sources and forest patches. We quantified damaged maize plants and cobs in 180 samples from six 100 m^2 quadrats in each of 30 maize fields. On average, damage in maize fields was less than 2% and 6.5% of the total maize cobs and plants, respectively. The white-nosed coati (*Nasua narica*) and the white-tailed deer (*Odocoileus virginianus*) were responsible for most of the total damage to maize cobs, while wind was responsible for most of the damage to plants. Classification and regression tree analyses (CARTs) revealed that the highest levels of maize cob damage occurred in maize fields with less agricultural land cover in the surrounding landscape units and with longer distances to the nearest villages. Measured levels of maize damage were lower than the amount of damage perceived by local inhabitants. This human–wildlife conflict should be further addressed in the study area to avoid negative consequences for wildlife conservation.

Keywords: human–wildlife conflicts; negative interactions; biosphere reserve; crop raiding; wildlife conservation

1. Introduction

The arrangement, composition and configuration of the patches that make up a landscape, including unmodified lands and modified environments like agricultural lands, can shape the presence, behavior and population dynamics of species [1–5]. The spatiotemporal availability of food and other resources within vegetation patches often drives the presence, abundance, distribution and dynamics of the wildlife species that rely on them [6–10]. The context created by patches rich in food resources can affect the time spent by foraging individuals on feeding sites, the probability of encounter with conspecific individuals or the use of corridors to access such resources [2,11–13].

Agriculturally productive landscapes in many countries, and particularly in Mexico, can be highly heterogeneous, with crop lands, cattle pastures, human settlements and natural habitats (some of which are protected) all interspersed. The complexity of such widespread human-dominated systems leads to interactions between humans and wildlife species [14–17] that can be positive (e.g., pollination), but also negative that arise when the wildlife compete with humans for valuable resources or when the regular activities of wildlife species near crops or settlements are perceived as negative by humans, for example, because of (real or perceived) damage to crops or danger to domestic animals or people [17,18].

Human–wildlife conflicts (HWC) are defined as the result of negative interactions, either real or perceived, that most often lead to harmful effects on the involved wildlife individuals or populations [17–23]. It is notable that human reactions towards wildlife species involved in HWC do not consider species' conservation status, which can lead to negative scenarios for the conservation of wildlife species, particularly if lethal control measures are used.

One of the major factors that have been related to the emergence of HWC is habitat transformation, which results in spatiotemporal modifications of the availability and quality of food resources for many wildlife species [17,19,24–28]. Habitat transformations, often including their replacement, are driven by direct land-use for agricultural and urban expansions, as well as by indirect factors such as floods and fires [15,29].

It has been noted that the frequency and intensity of damage to crop fields are related to the individual responses of wildlife species to the landscape features surrounding the crop [3,8,30–34]. Damage to maize (*Zea mays*) fields caused by wildlife has been reported worldwide for several species such as elephants (*Loxodonta africana, Elephas maximus*), zebras (*Equus quagga, E. zebra, E. grevyi*), wild pigs (*Sus scrofa*), several wild deer species, white-lipped peccary (*Tayassu pecari*) and white-nosed coati (*Nasua narica*), to mention some of the most common conflictive species [35–37].

In Mexico, biosphere reserves (BR) are natural protected areas (NPA) that do not exclude human settlements and that consider sustainable use of natural resources necessary to achieve biological conservation. Most of the land protected under the BR framework belongs to rural communities, and therefore BR zoning is needed to separate areas exclusively devoted to conservation from those where human subsistence activities, such as agriculture, can be performed [38]. In the Sierra de Huautla Biosphere Reserve (REBIOSH, for its acronym in Spanish), rainfed agriculture (mainly of maize) is the main economic activity [39], making maize production highly relevant for the people inhabiting the area. Notably, the majority of local farmers perceive that wildlife species are responsible for major losses to their maize production [40], and although wildlife damage to maize fields caused by the white-tailed deer (*Odocoileus virginianus*) and by the white-nosed coati (*Nasua narica*) have been previously reported for the studied area [40–42], such phenomenon has never been quantified in the region. Generating such information would allow a better understanding of the level of negative human–wildlife interactions, which is especially important because damage (or even the perception of damage) by these species can cause local inhabitants to have negative attitudes towards them and make them more likely to use lethal control measures. The challenge is how to avoid this situation by implementing alternative, non-lethal strategies to manage and mitigate negative interactions be they real or perceived [43,44], to reduce risks to wildlife conservation in this and other NPAs [45].

Studies evaluating damage caused by wildlife to maize are scarce. Few of them separate between damage found on maize cobs or other parts of the respective plant or explore the role that abiotic factors, such as wind, can play in such interactions, e.g., [35,46]. Therefore, in this study, we assessed factors that cause damage to maize in 30 maize fields distributed across three ejidos (a peculiar communal land tenure system on which individuals belonging to the community farm designated parcels and collectively keeps communal holdings [47]) within the REBIOSH. We also quantified separately the overall damage to maize plants and to maize cobs by different factors.

Furthermore, we explored whether wildlife damage to maize cobs was related to the surrounding landscape features or not. In particular, we considered that the number of maize cobs damaged by wildlife species should be smaller in maize fields near towns or in landscapes dominated by agriculture and greater in maize fields near patches of natural vegetation types or in landscapes with a small percentage of agriculture. Exploring these relationships is an important step toward improving our understanding of the factors that affect the intensity of wildlife damage to crops, which in turn is relevant for the development of effective management strategies.

2. Materials and Methods

2.1. Study Area

The REBIOSH was designated as a BR in 1999 and is located in the southern region of the State of Morelos, in central Mexico, with extreme geographical coordinates of 18°19′59.78″–18°34′15.34″ N and 98°51′13.29″–99°24′16.86″ W (Figure 1). It is a 59,030 ha federally protected area, of which 41.4% is considered to be mature, nearly unperturbed, forested habitat [39]. It is one of the most important NPAs in the country for the conservation of tropical dry forest, the dominant type of vegetation, which has a marked seasonality with most trees losing their leaves during the 5–7 months dry season [48]. It presents an elevational range of 700–2200 m asl [39].

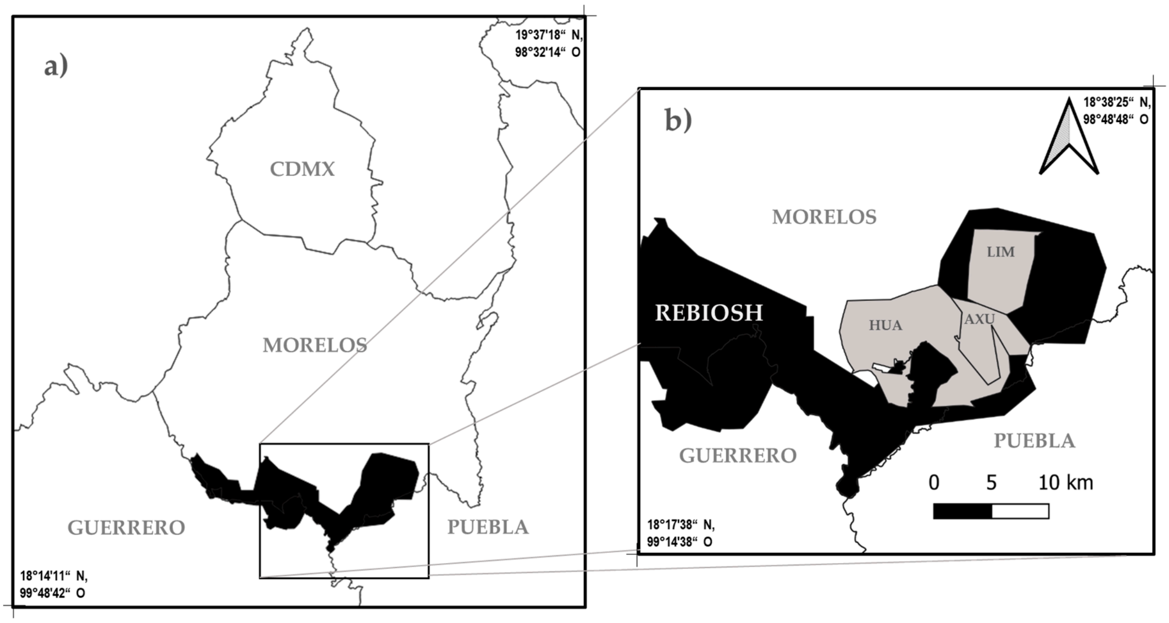

Figure 1. Location of: (**a**) Morelos state in central Mexico and the Sierra de Huautla Biosphere Reserve (REBIOSH) in Morelos (black polygon); (**b**) location of the three ejidos where the study was done (dark gray polygons; AXU = Ajuchitlán; HUA = Huautla; and LIM = El Limón de Cuauchichinola) within the REBIOSH, in southern Morelos.

The REBIOSH represents an area of high biodiversity with several species of animals and plants considered endemic (for instance, among vertebrates 71 species at this NPA are endemic) and/or vulnerable (nationally or internationally). This includes plants, tempisque *Sideroxylon capiri* and venenillo *Sapium macrocarpum*, and animals, the firefly *Cratomorphus huautlense*, Balsas catfish *Ictalurus balsanus*, sparkling-tailed hummingbird *Tilmatura dupontii*, military macaw *Ara militaris*, grayish mouse opossum *Tlacuatzin canescens*, Mexican long-tongued bat *Choeronycteris mexicana* and margay *Leopardus wiedii*, among others [39,49,50]). The REBIOSH has been considered relevant for the conservation of biodiversity at the national and international levels [51–55].

There are 31 human settlements whose lands are partially or completely within the REBIOSH, whose total human population is 20,682 inhabitants (4032 of which live inside the boundaries of the protected area). Rainfed agriculture is the main economic activity, followed by extensive animal husbandry, in the region where the REBIOSH is located. Both activities are mainly carried out in flat and low areas that represent 10.62% of the protected area, although some agricultural lands are on hillsides [39]. Another common human activity is hunting animals for food or for medicinal and commercial purposes. The white-tailed deer, eastern cottontail (*Sylvilagus floridanus*) and nine banded armadillo (*Dasypus novemcinctus*) are among the most commonly targeted species (none of them are threatened [42,56,57]).

We studied human–wildlife conflicts in three ejidos, located within the REBIOSH: El Limón de Cuauchichinola (Tepalcingo municipality), Ajuchitlán and Huautla (Tlaquiltenango; municipality; see [39] for further details on site description; Figure 1). In these areas, inhabitant's perceptions of conservation and sustainable harvesting have been previously studied, showing awareness that wildlife populations are increasing in the area due to the conservation policies [40]. They consider this increase is negatively affecting them, since wildlife is perceived to damage their maize production [40,57,58], a situation that can lead to wildlife hunting to prevent damage to maize fields [42]. Roughly half of the local campesinos (hereafter, farmers) previously interviewed perceived that wildlife cause "great" or "major" damage to maize fields during any given year (based on their experience) the other half, considered damage was "little" or "minor" [40,59].

2.2. Maize Damage

We surveyed local farmers to determine their perception of wildlife damage on maize fields (see [40]). We chose maize fields for study based on their land-use context [30], by considering the percentage of agricultural land within a circular buffer of 100 m radius from the center of the pre-selected maize crop. This buffer allowed us to explore land cover effects at a fine spatial scale near the edges of maize, similar methods using the same buffer size have been used by other studies [60]. The land cover in the buffer area was estimated from a land-use and vegetation map previously generated for the REBIOSH ([61] and V. Sorani, pers. comm.). We considered four categories of agricultural cover within a 100 m radius circular buffer around each maize field: <25%, between 26 and 50%, between 51 and 75% and >76% of the buffer area covered by agricultural land. This was considered the land-use context in the immediate vicinity of a particular maize field.

We were granted permission from local farmers to survey maize damage in 30 fields where maize was grown in monoculture although on four fields, squash (*Cucurbita pepo*) plants were present in small sections of the fields. The total area of the 30 sampled maize fields was 39.05 ha (average maize field area was 1.30 ha ± SD 0.71); each maize field sampled was at least 300 m from any other on the sampled field in each ejido and all sampled maize fields were in a narrow range of altitude (less than 150 m). While we tried to sample a balanced number of maize fields on each of the four ranges of agricultural cover on each ejido, we had to sample a different number of maize fields per ejido and each of the four agricultural cover ranges. We sampled 12, 9 and 9 maize fields in Ajuchitlan, Huautla and El Limon de Cuauchichinola, respectively.

To quantify wildlife damage to maize fields, we established six 100 m^2 sampling quadrats distributed randomly in each maize field (similar to [46,62]), and hence the potential border effect on damage was not controlled. We did not have any assumptions about quadrats distribution nor did we expect autocorrelation between them. A total of 180 sampling quadrats were established, representing 1.8 ha and 4.60% of the total area of the selected fields. Sampling quadrats is a common method to estimate wildlife damage to maize, since adequate-sized quadrats yield unbiased estimates of damage and are of practical use [63,64]. Data were collected in 2016, 2017 and 2018, sampling one ejido per year. Each maize field was visited three times during the period of maize cob formation. On the first visit (at the onset of maize cob maturation) we recorded the total number of plants and maize cobs per quadrat. In the following two visits, 20–30 days apart each (to capture the middle and final part of the cob maturation before harvest, which interviewees reported as the period of peak damage we recorded all damaged plants and all damaged maize cobs.

We considered a plant to be damaged when it was bent or broken at ground level and cobs to be damaged when they had evident signs of damage found either on the ground or still attached to the plant. The recorded damage was attributed to each species or damage factor (i.e., white-tailed deer, white-nosed coati, several bird species and wind) based on local farmers' knowledge considering identifiable signs of damage by different animals such as beak, claw or teeth marks, tracks, feces, hairs or by the particular part of a plant or cob that was damaged.

2.3. Landscape Features

Since landscape features and configuration are known to influence home range and movements of wildlife species [31,65], we measured some landscape features within a 600 m radius buffer around each maize field (113 ha; considered here a landscape unit) to explore their influence on maize crop damage. We choose this area because it is of similar size to home ranges reported for white-tailed deer (113 ha) and white-nosed coati (78.3 ha) in similar ecosystems and seasons [3,66].

We quantified the proportion of each land-use category within each landscape unit using high-quality satellite images (DigitalGlobe satellite images from 2016) using ArcMap 10.3. We considered six land-use categories (classified based on physical characteristics, the dominant vegetation—e.g., trees, shrubs, herbs—and the density in the vegetation layer): (1) Well-preserved tropical dry forest (i.e., areas with dense tree cover), (2) disturbed tropical dry forest (i.e., areas where tree cover was still dominant but less dense, with the soil surface easily visible between trees), (3) secondary vegetation (i.e., areas where vegetation cover is dominated by shrubs, with sparse trees and a relatively high proportion of land surface composed of an herbaceous layer or bare soil) (4) water bodies, rivers and riparian vegetation (i.e., all areas with water availability and strips of vegetation dominated by trees along temporal streams and streamlets between hillsides), (5) human settlements and (6) agricultural cover (e.g., all areas with very sparse or no tree or shrub coverage and with evident signs of agriculture). We used this classification because we sought to identify resource areas that are important for wildlife like foraging and cover sites [30]. Finally, we measured the closest linear distance between the centroid of each maize field to the nearest edge of the nearest polygon (patch) of each of these categories.

2.4. Statistical Analysis

We performed a correlation matrix to assess correlation among independent variables, identifying those that were moderate-to-highly correlated ($r > 0.5$, $p < 0.05$ [67]). We considered those with highest statistical variance in further analyses. Since we were particularly interested in damage caused by wildlife to maize cobs, we analyzed the proportion of total maize cobs affected by all damage factors in general and by white-tailed deer and white-nosed coati independently (since these two species were the most commonly reported by the farmers as causing damage to maize). Preliminary analysis confirmed that damage to maize cobs related non-linearly to landscape features.

Given the evident non-linearity of the relationships we used classification and regression trees (CARTs), to explore the relationships between crop damage and the measured independent variables (i.e., distance to nearest patch of well-preserved forest, disturbed forest or to nearest human settlement). CART has been extensively used in the fields of agriculture, forestry, natural resources management and landscape ecology, among other disciplines [68–73]. Given its simplicity and versatility it is a robust analytical tool. Briefly, it seeks for hierarchical relationships between a dependent variable and a group of independent variables that are assumed to be relevant in explaining the changes in the variation of the dependent variable. The graphical outcome of CARTs is a tree constructed using a binary recursive partitioning algorithm to identify the independent variables that best explain variations of the dependent variable [74,75]. The use of CART in ecological research has a number of advantageous features that make it preferable over many of the traditionally used parametric procedures. CART is characterized by its flexibility, since as a non-parametric procedure, it does not require a specific data distribution, allowing for non-linear relationships to occur between the set of independent variables and the dependent one. This feature is particularly useful when the shape of the relationship between a dependent variable and multiple independent variables is not known a priori [76].

Additionally, due to the recursive partitioning nature of the algorithm, each single split in a CART is determined by the rank order of only one numeric independent variable. Thus, this approach is well suited for dealing with data sets that have a high number of independent variables, a mix of continuous and categorical variables, missing data points and a high degree of co-linearity and/or interaction among its independent variables [77,78]. Moreover, the graphical representation of CARTs is highly intuitive and show a clear picture of the structure of complex data sets, as well as the interactions between variables, many of which may be masked by multiple regression techniques [75].

We ran the CARTs using the "rpart" package for R [79,80], which performs ANOVA sequences to split the entire dataset into two mutually exclusive subsets at the terminal node of the tree based on a threshold value of the independent variable. At the end of each terminal node, the mean value of the dependent variable is displayed (here, proportion of the total damaged maize cobs). Based on the identified related independent variables and their threshold values, CARTs provide scenarios under which the dependent variable changes in a dichotomous and hierarchical manner as a result of different sets of combinations of the related independent variables [75], providing easily comprehensible decision strategies that easily could help managers of natural protected areas and farmers to understand the variables involved in wildlife damage to maize fields and to take proactive measures to decrease the conflict [68,72].

3. Results

On the 180 sampling quadrats we recorded a total of 70,624 maize plants and 47,158 maize cobs. Overall, we found damage evidence to 3.3% of the plants and 2.7% of the maize cobs. Among the total damaged maize cobs (n = 1286), most had signs of being damaged by wildlife species, the majority (76%) of which was attributed to white-tailed deer and white-nosed coati. Only a small proportion was damaged by wind. This differed from the total damaged maize plants (n = 2422), of which 64% was attributed to wind and 36% to wildlife.

The average damage per maize field was only 1.65% (± 2.3% SD; n = 30) of the total maize cobs recorded and only 6.44% (± 10.2% SD) of the total plants recorded. The contribution of each damage factors to this low impact level varied for maize cobs and for maize plants. Of the total number of damaged maize cobs damaged from each maize field, the white-nosed coati was responsible, on average, for 27.3% (30.3% ± SD), the white-tailed deer for 34.3% (35.5% ± SD), different bird species for 27.8% (34.8% ± SD) and wind for 10.6% (24.4% ± SD). Damage to plants was mainly from wind (73.2% on average ± 31.4% SD), followed by the white-nosed coati, the white-tailed deer and different bird species causing 17.9% (± 29.5% SD), 7.4% (± 16.4% SD) and 1.5% (± 4.1% SD) of the total damage to plants, respectively.

We recorded some damage to maize cobs from each of the sources in most of the sampled fields (between 60% and 77% of them depending on the factor involved), although the total number of maize cobs damaged per maize field varied greatly (0 to 471). Damage to plants was recorded in fewer of the sampled maize fields (between 20% and 47% of the total depending on the causing factor).

However, sampling at the quadrat level (six per field) revealed that damage was generally localized to a small area. Of the 180 sampled quadrats, more presented maize cob damage (26–36% of the sampling quadrats) than plant damage (3–19%) caused by different species of wildlife. The inverse pattern is observed in the damage caused by wind, since maize cob damage by this factor was present in a smaller percentage of the total sampling quadrats (11%) than maize plant damaged by wind (in 63% of the total sampling quadrats).

At the scale of the immediate vicinity of the maize field, higher percentages of damaged plants and maize cobs by white-nosed coati and white-tailed deer were found in maize fields with less agricultural cover within the 100 m buffer around the maize field. Wind damage was present in almost all the studied fields and tended to be higher with the increase in the agricultural cover within the 100 m buffer (Tables 1 and 2).

Table 1. Total maize plants, total damaged maize plants and percentage of damaged maize plants by different factor (WTD = white-tailed deer; WNC = white-nosed coati; B&O = birds and others; W = wind), on all maize fields within each of the four ranges of percentage of agricultural land use (%ALU) within a 100 m buffer around each field.

			% of Total Damaged Maize Plants by Each Damaging Factor			
% ALU	**Total Maize Plants**	**Total Damaged Maize Plants**	**WTD**	**WNC**	**B&O**	**W**
<25	15,422	1021	38.0%	21.1%	1.9%	39.1%
26–50	17,544	197	15.7%	22.8%	0.0%	61.4%
51–75	15,674	632	7.3%	10.4%	7.8%	74.5%
>76	21,984	572	2.3%	1.9%	2.8%	93.0%

Table 2. Total maize cobs, total damaged maize cobs and percentage of damaged maize cobs by different factor (WTD = white-tailed deer; WNC = white-nosed coati; B&O= birds and others; W = wind), on all maize fields within each of the four ranges of percentage of agricultural land use (%ALU) within a 100 m buffer around each field.

			% of Total Damaged Maize Cobs by Each Damaging Factor			
% ALU	**Total Maize Cobs**	**Total Damaged Maize Cobs**	**WTD**	**WNC**	**B&O**	**W**
<25	10,294	597	71.0%	20.4%	1.0%	7.5%
26–50	8108	143	23.8%	53.8%	16.8%	5.6%
51–75	11,225	306	32.7%	25.5%	0.0%	41.8%
>76	17,531	160	23.1%	26.9%	3.8%	46.3%

The majority of the plant damage was caused by wind, while most of the damage to maize cobs was caused by white-nosed coati (which damage the entire plant to access the cobs) and white-tailed deer. Considering that, we further explored, only how landscape features was related to the total damage on maize cobs by all factors and by white-nosed coati and white-tailed deer separately (Figure 2).

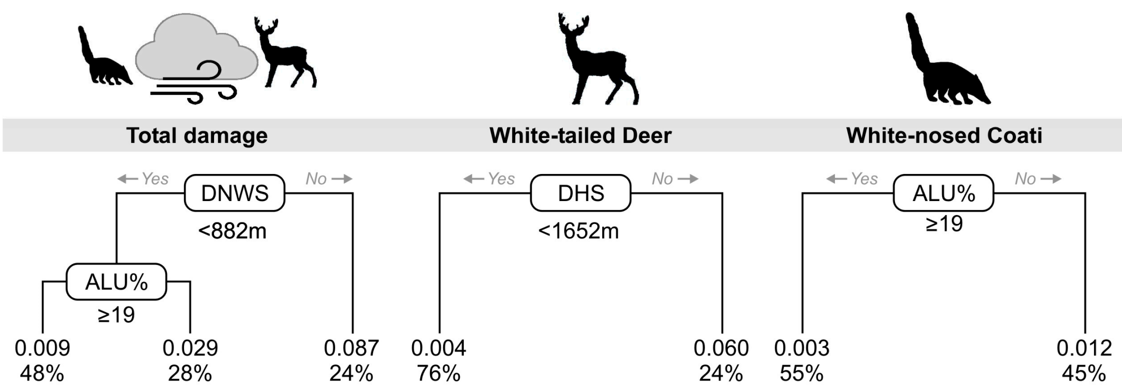

Figure 2. CARTs (classification and regression trees) representing the variation in damage to maize cobs by all factors and only by white-tailed deer or white-nosed coati, separately. in the REBIOSH in relation to landscape features considered. DNWS = distance to nearest water source; %ALU = % of agricultural land use in the surrounding 113 ha landscape unit; DHS= distance to nearest human settlement.

According to the CARTs, the average proportion of the total damaged maize cobs was higher (0.087) in maize fields located further from the water sources and riparian vegetation (24% of the 30 maize fields studied) than in the rest of the fields that were closer to water sources and riparian vegetation, which had a smaller proportion of the total damaged maize cobs (0.009–0.029) particularly those surrounded by landscape units with a higher proportion of agriculture land use (48% of the 30 maize fields studied; Figure 2).

In the case of maize cobs damaged by white-tailed deer, the average proportion of damage, although low, was much higher (0.060 of the total maize cobs) in fields that were the furthest away from human settlements (24% of maize fields) than on those closer to settlements (76% of maize fields), where the average proportion of damage was 0.004 of total maize cobs damaged (Figure 2).

Finally, in the case of maize cobs damaged by white-nosed coati, the average proportion of damage, though also low overall, was considerably higher in fields where the surrounding landscape unit had lower agriculture coverage (45% of fields) than on those with higher agricultural land cover (0.012 versus 0.003 of the total maize cobs; Figure 2).

4. Discussion

Of the total maize cobs and maize plants sampled (nearly 47,000 and 71,000, respectively) less than 2% and 7%, respectively, were damaged. Of this small amount of damage wildlife, particularly white-nosed coati (*Nasua narica*) and white-tailed deer (*Odocoileus virginianus*) cause most of the damage to cobs, but wind, causes more than 70% of the damage to maize plants.

Our numbers of total damaged maize plants and cobs are relatively low, even smaller than data reported by studies previously carried out in similar tropical regions in Mexico that reported losses due to wildlife damage of ~9–11% of the maize cobs, representing relatively high production losses (>107 kg of maize per hectare [46,62,81]. While we do not take into account the differences between years, the different conditions are sampled in the three ejidos/years. So even if there were differences between years in total damage that would not affect the relationships between damage and landscape features.

It is relevant to point out that in the REBIOSH, the perception of maize damage by wildlife has been reported to be high [40,59]. These perceptions are based on the experience of local farmers over multiple crop cycles. While we are aware that damage can also vary within a season, we measured cumulative damage to maize fields during one crop season in each ejido.

The wildlife species we recorded causing most of the damage to maize cobs are the same as those most frequently reported or perceived as causing damage to maize fields in other studies in the REBIOSH and other sites [40,42,46,57,62]. Our observations are also consistent with those reported by Can-Hernández et al. [81] and Chávez [82] which showed that white-nosed coatis caused more damage than white-tailed deer, since they usually gather in groups and damage large areas [46,62,83]. This was also the perception of inhabitants at REBIOSH [40].

Damage attributed to white-tailed deer in our study was low, even considering that deer are found in high densities in the REBIOSH (21.3 to 28 ind/km^2 [58,84]) in contrast to other areas with similar vegetation types (1.7–6.7 ind/km^2 [85–87]).

While we were mainly interested in evaluating of damage to maize fields by wildlife, another important finding of our study was that, when considering damage to different parts of the plants, maize cobs are damaged mostly by wildlife but wind caused significantly more damage to maize plants than wildlife, which is consistent with observations by other authors [62,81] for two different localities in Tabasco, Mexico. Our results suggest that local farmers should not only use strategies to mitigate damage to maize fields by wildlife but also to diminish maize damage by wind, since it is causing most of the damage to maize plants and can be a relevant factor in causing loss in maize production. For instance, wind it has been reported to cause an estimated 5% loss annually in maize production in the United States [88], although it is necessary to consider that average maize field size in the US can be much larger than in Mexico.

Strategies for mitigating wind damage to crops are focused mainly on the selection of crop variety [88]), since resistance to wind damage varies extensively among varieties. For instance, in the Central Depression region of Chiapas, the percentage of maize fields presenting high degrees of damage from wind varied from 0% to 20%, depending on the maize variety planted by local farmers [89]. In our study, we have not explored differences among maize varieties. The local farmers we interviewed used hybrid maize varieties including VS-535, H-404, H-443 and H-516, which were selected primarily based on yield. Future studies should consider if commonly used maize varieties in this area differ in resistance to wind damage.

Another strategy that can be used to mitigate wind damage in tropical dry forests can be to promote the re-location of maize fields on agricultural areas with less vulnerability to wind (but also less vulnerability to wildlife) as well as promoting ecological restoration in areas between remnant forest patches [90–92].

In our study, maize cob damage by wildlife was highest in maize fields located further away from human settlements or with the lowest agricultural land cover. In the REBIOSH this implies areas closer to native vegetation, which is in agreement with findings of Hinton et al. [93] and Naughton-Treves [94] for study sites in eastern Mississippi, USA and in Kibale National Park, Uganda, respectively.

In the REBIOSH, due to the spatial distribution of the agricultural areas and the distribution of natural vegetation communities, maize fields are often located near natural vegetation that can act as a natural fence [92], preventing cattle from entering the maize fields, but not impede wildlife or humans.

Additionally, forest borders and ecotones often have higher plant diversity and abundance. At our study sites these are more commonly located in areas with higher slopes. In such transitional ecotones wildlife using early successional vegetation stages [95,96] can find a higher availability of food and dense protection cover at forest patches [58].

Maize fields with differing resting periods and the perturbed areas in their vicinity create a mosaic of habitat and feeding grounds that can be used by wildlife species of hunting interest, such as the white-tailed deer [97]. However, on agricultural land the probability of human–wildlife interactions is high and wildlife are more likely to be hunted there. Therefore, the white-tailed deer could exploit more food resources by entering isolated farming areas or those more distant from human settlements, with a lower probability of interactions with humans [98].

Our results show that this seems to be the case in the REBIOSH, since maize cobs in fields that are farther away from human settlements were more often damaged by white-tailed deer compared to those closer to settlements, which is consistent with the results of [61]. Maize fields that are farther away from settlements are frequently surrounded by dense and abundant vegetation, which provide hiding places for white-tailed deer [62]. In the case of white-nosed coatis, we found that fields with a lower proportion of agricultural areas in the surrounding landscape had more damage. This is consistent with results of Romero-Balderas et al. [46], who found that fields with more damage had the highest percentage of adjacent forest in a study site in the Lacandon Forest, Chiapas, Mexico.

While we did not directly evaluate human–wildlife interactions here, data from the literature provide some support for this idea, since it has been reported that the proximity to human settlements and roads has a negative effect on white-tailed deer presence and that higher densities of white-tailed deer are reported for areas located further away from settlements and for areas of forest disturbed infrequently by timber harvests due to dense vegetation and rugged terrain [3,84,87,94,99,100]. Further, it has been reported that human-wild boar conflicts in a study site in Iran, are more frequent "when agricultural fields are located within landscapes where human densities are low and opportunities to escape at nearby forest edges are high" [101].

5. Conclusions

The results of our research are consistent with other studies, where damage caused by wildlife to maize fields was low in relation to their productivity and less than perceived by local farmers. However, the negative perceptions of the inhabitants are not only derived by the amount of damage inflicted, but also because crop damage has negative impacts on local livelihoods by decreasing their food reserves [102,103]. In this context, it is important to highlight that by separating maize cob and maize plant damage, we found that wildlife was more relevant for maize cob damage, but wind caused far more damage to maize plants than wildlife. Thus, wind, in addition to shifting rainy periods, are likely a much more serious concern than wildlife in terms of maize production in the area.

In the REBIOSH, the wildlife species that caused most of the damage to maize fields were white-nosed coati and white-tailed deer. Damage events were more intense in fields located further from human settlements or with a lower proportion of agriculture coverage in the surrounding area, which we consider to be related to a response of animals to reduce the risk of being hunted. This is relevant since it links the perception of an increase in wildlife populations due to the establishment of conservation policies in the area, with the negative perceptions of maize crop damage by these species. This scenario creates a propensity for hunting these species in response for damage. Indeed, one of the motivations for hunting among local farmers in the REBIOSH was the removal of crop-damaging animals [42].

It is necessary to design an effective strategy to inform the local farmers about the quantified levels of damage found in their maize fields and how damage is related to different landscape features. Alternatives need to be explored along with the local farmers to mitigate damage to both maize plants and cobs by wildlife and by wind and to avoid negative consequences for wildlife species of perceived or real damage to maize fields.

While we did not study HWC directly, the wildlife damage to maize that we recorded, and in particular, that is perceived in the area, can create such conflicts. We consider that wildlife damage to maize fields and the potential HWC that it can trigger should be studied in depth, including the social and historical context of the interaction in the study area and elsewhere. We recommend that systematic strategies be proposed and implemented to verify, quantify, mitigate and compensate for the damage caused to maize crops by wildlife and by wind. We recommend that systematic strategies be proposed and implemented to verify, quantify, mitigate and compensate for the damage caused to maize crops by wildlife and by wind.

In such strategies, local authorities, managers of the protected area, local farmers and academics, should come together to discuss this HWC based on scientific evidence in order to seek agreements aimed at changing the negative local perceptions, increase farmers' tolerance of conflictive wildlife species and eventually implement effective mitigation strategies. We think that it is best to move away from a perspective of conflict and lethal control of wildlife species to a perspective of coexistence with wildlife or at least of non-lethal control methods. Studies analyzing patterns of HWC and levels of human tolerance to wildlife are also needed in order to develop appropriate conservation education initiatives.

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