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Erythrocyte micronucleus cytome assay in *Passer domesticus* and environmental remote sensing for inferring the quality of wild, rural, and urban areas

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Abstract The study of biomarkers in free-living birds can help to indicate the degree of contamination in distinct environments. In addition, these environments can be characterized through the information provided by satellite images. The objectives of the present study were to analyze the types and quantity of cytogenetic biomarkers in *Passer domesticus* (House sparrow) from three different environments, wild, rural, and urban, and to analyze them in the context of land use and anthropogenic actions. Five thousand erythrocytes per bird were analyzed for the following nuclear alterations (NA): micronuclei (MN), nuclear buds, notched nuclei, binucleated cells, nucleoplasmic bridges, nuclear tails, peripheral nuclei, and anucleated cells. In the study, wild birds exhibited five types of NA, seven types were found in rural birds, and all types were encountered in urban birds. The only NA that exceeded a frequency of 2 NA/1000 erythrocytes were peripheral nuclei in birds from the rural and urban sites, the latter environment characterized by 87% urban soil and air pollution. The highest frequencies of MN, peripheral nuclei, and anucleated erythrocytes were recorded in sparrows from the rural site ($p \leq 0.05$). This area had been sprayed with chlorpyrifos 48%, the most widely used organophosphate in the region. Sparrows from the wild site, made up of 100% native forest, had higher frequencies of notched nuclei ($p \leq 0.05$). A precedent is set for the use of environmental remote sensing in a complementary manner with cytogenetic biomarker studies in birds for a joint analysis in environmental assessment.

Keywords House sparrow · Environmental health · Micronucleus · Geographic information system

Introduction

The characterization of land use and land cover is an essential aspect in the analysis of the quality of environments, as it enables to assess the state of the environment and analyze the subsequent impacts on it (Posada & Salvatierra, 2016; Avilés-Ramírez et al., 2017; Sepúlveda-Varas et al., 2019). Remote sensing provides images with information for a large number of applications such as land use mapping, urban planning, environmental monitoring, and crop management (Cardozo & Da Silva, 2013). Satellite images are digitally generated through an electromagnetic interaction that occurs between the satellite and objects on the Earth's surface (Chuvieco, 2015). The Landsat 8 satellite has a sun-synchronous, near-polar orbit system with an altitude

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of 705 km, which ensures full coverage of the Earth's surface and the same solar illumination conditions for all of the areas observed (USGS, 2021a, b). The objects present in a satellite image are characterized through various picto-morphological criteria (Cardozo & Da Silva, 2013). Remote sensing and Geographic Information Systems (GIS) are used in environmental studies as a tool for monitoring animals, detecting changes in vegetation cover, and creating land use maps, among other such studies. This is a technology that works together with remote sensors to provide detailed information and knowledge of the environmental conditions in the areas under study and also allows the analysis of the different factors that influence them, providing a detailed and integrated study of the territory (Perpiña et al., 2013).

The quality of environments can be assessed by using animals that behave as bioindicators. Birds are good candidates because they occupy a wide range in trophic levels, are widely distributed, have a long life span, and are sensitive to atmospheric changes (Tietze, 2018). Performing cytological and physiological studies in birds from different environments is useful for performing comparisons; organisms can be affected by urban pollutants of anthropogenic origin and by active ingredients used in production animals, fruit trees, and vegetables, particularly those applied to combat insect pests, fungi, and weeds, commonly known as pesticides (Ferré et al., 2018a).

Passer domesticus (house sparrow) is a cosmopolitan species, belonging to the order *Passeriformes*, known as the songbirds (BirdLife, 2021). Sparrows are adaptable to diverse environmental conditions, with a relatively high abundance in ecosystems (categorization of least concern established by the IUCN), they are easy to handle, possess sexual dimorphism, and there is extensive knowledge of their biology, life history, and ecology (IUCN, 2021). One of the biological characteristics of great interest for the development of this study is that a sparrow has peridomestic and residential habits (Summers-Smith, 2003). It exhibits opportunistic foraging strategies adapting to neophobia; as a consequence, it is commonly found in both urban and agricultural areas (Anderson, 2006; MacGregor-Fors et al., 2017). The fact that sparrows live in close association with humans means that they share potential environmental risks, as well as live close to other species that are common in habitats altered by anthropogenic actions. Several research studies have attempted to use sparrows as bioindicators of potential hazards posed by environmental contaminants as metals (Gragnaniello et al., 2001; Pan et al., 2008) and neonicotinoid pesticides (Humann-Guilleminot et al., 2019).

Biomarkers are molecules, cellular structures, and behaviors, which can reflect changes occurring in a biological system. Cytogenetic biomarkers reflect alterations due to spontaneous causes or induced effects resulting from the exposure of an organism, ideally a bioindicator, to a xenobiotic agent (Garte & Bonassi, 2005; Quero et al., 2016, 2019). Micronuclei (MN) are well recognized biomarkers of genetic damage that are produced by genotoxic agents acting at the subcellular level. It is postulated that they may be related to the generation of mutagenic and carcinogenic processes in animals and humans (Fenech et al., 2011; Ferré et al., 2018b; Aiassa et al. 2019). The Micronucleus-Cytome (MN-Cyt) assay can potentially be performed in any tissue, with simplicity and rapid results it allows simultaneous detection of multiple events indicating chromosomal instability (Fenech, 2020). Using this assay, field biomonitoring can be performed in animal and human populations at risk of genetic damage (Ferré et al., 2018b) and also in experimental groups in a laboratory. Nucleated erythrocytes from birds are useful in the MN-Cyt assay to evaluate and monitor ecosystems that have been altered by genotoxic agents (Jones, 2015; Quero et al., 2019).

The objectives of the present study were to analyze the type and quantity of cytogenetic biomarkers in house sparrows from three environments, wild, urban, and rural, all belonging to the same phytogeographic region, and to analyze them in the context of land use, characterized by using visual and digital analysis of satellite images.

Materials and methods

Characteristics of the sampling sites

The sites under study belong to the Monte phytogeographic region which is one of the most extensive in Argentina. Initially, visual field surveys and interviews were carried out with farm owners at site R, park rangers at site W, and citizens surrounding the sampling site U. Information was obtained about the types of crops, their management, the components of anthropogenic activities, and/or the environmental conservation degree. In this visual analysis, the 3 different land uses W, R, and U were determined.

A Wild site (W) that preserves its soil unaltered and also its native flora due to the absence of anthropic actions, Ñacuñán Biosphere Reserve (Fig. 1), is located in the eastern plain of Mendoza province (34°02′00″ S, 67°55′00″ W), with an average altitude of 583 m.a.s.l. The protected reserve covers an area of 12,880 ha and is recognized as an Important Bird Area (IBA) by BirdLife (2021), for the identification, documentation, and conservation of critical sites for the world's birds (Di Giacomo et al., 2007). The second site is a Rural site (R) where the soil is used for agricultural activities, and its native flora has suffered modifications due to the introduction of grazing systems for domestic livestock and agricultural crops: a fruit production farm in the eastern part of Mendoza province (36°37′13″ S, 64°17′26″ W) (Fig. 1), 177 m.a.s.l. At this site, 8 days prior to the bird captures, spraying with the insecticide chlorpyrifos 48% (Lorsban 48®), organophosphate, class II moderately hazardous according to WHO, had been carried out, and finally, an Urban one (U) with commercial and industrial activities, residential zone, where its native flora structure has been replaced by others associated with human habits. The U site was the headquarters of the Juan A. Maza University (Fig. 1) located in the central region of the province of Mendoza (32° 53′ 57.5″ S, 68° 48′ 3.3″ W), 720 m.a.s.l. It belongs to the metropolitan area, where multiple economic activities are carried out and where air pollutants of anthropogenic origin have been evidenced (Allende et al., 2016).

An imaginary circle with a radius of 2.5 km, corresponding to the flight radius of *P. domesticus* (Summers-Smith, 2003), was drawn around the geographic coordinates of each sampling point. Satellite images were obtained within this circle. The hectares (ha) covered by each circle were calculated by spatial analysis (Cisneros et al., 2017) using Google Earth Pro® and the ha corresponding to each land use and land cover through visual interpretation on screen with the polygon creation technique (Avilés-Ramírez et al., 2017). Picto-morphological criteria were applied for the visual identification of each land use and land cover. All images correspond to the spring–summer season in the southern hemisphere, a time of the phenological cycle in which the vegetation is vigorous (Chuvieco, 2015). Images with less than 10% cloud

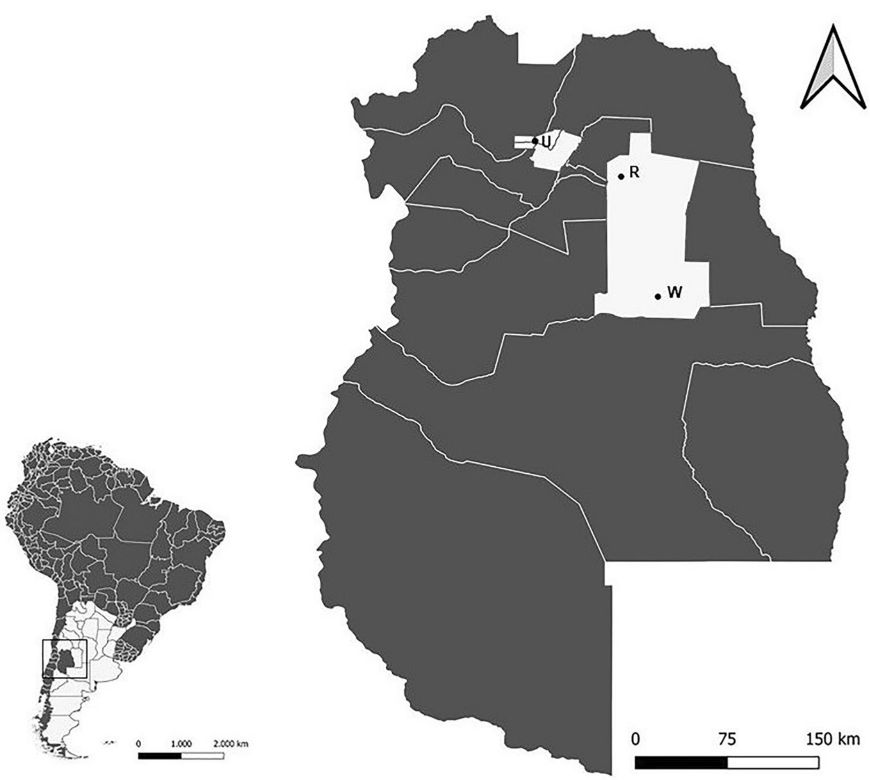

Fig. 1 Geographic map where the three environments under study are indicated (Province of Mendoza, Argentina). U: Urban (32°53′55″S 68°48′42″W, 720 m above sea level [masl]), R: Rural (33°09′39.5″S 68°10′42.0″W, 175–179 masl), W: Wild (34°2′0″S 67°55′0″W, 583 masl)

cover were selected. The combination of bands belonging to the infrared-false color (RGB: NIR-R-G) was performed to highlight vegetation and to be able to characterize land uses and land covers at each site. The RGB (Red, Green, Black) system made it possible to define the areas of native Woodland in green, bare ground in beige, urban ground in white, and agricultural crops in red. The percentage of every area in each site was obtained.

Captures of birds and cytogenotoxicity analysis

The captures of the sparrows were carried out in the spring, by installing ECOTONE® mist nets for 3 days at each site. The nets were opened half an hour before dawn and checked every 20 min. Every caught bird was removed from the nets, prioritizing animal welfare (Ralph et al., 1996). All the birds sampled were adults, with healthy appearance, without signs of illness. Body weight, tarsus length, and sex were registered. A heparinized capillary of blood was extracted from the brachial vein and stored at 4 °C until processing. Finally, absorbent cotton was placed on the vein, and only after hemostasis was completed could the bird then be released. One blood smear per bird was taken, fixed in methanol for 1 min, and then stained with Romanowsky type stain. A total of 5000 mature erythrocytes/bird were analyzed under an optical microscope (1000×) to search for various nuclear alterations (NA); for its identification, we have used the criteria adapted and described for birds (Clark & Raidal, 2013; Quero et al., 2016) and for reptiles (López-González et al., 2019).

The required authorization was obtained from the Directorate of Renewable Natural Resources (Resolution No. 1170), and the use of protocol No. 119 was evaluated and approved by the Interdisciplinary Commission for the Care and Use of Laboratory, Experimental and Teaching Animals (CICUALE) of UMaza.

Statistical analysis

The arithmetic mean and the respective standard errors were calculated for each NA in the animals of each study site. The Kolmorogov-Smirnov test was implemented to determine the distribution pattern of the data. For each NA, the Kruskal–Wallis test with pairwise multiple comparison was applied to detect whether the frequencies of the biomarkers analyzed in each group of animals presented any statistical difference between sites ($p \leq 0.05$). In the principal component analysis, for the elaboration of the covariance matrices, only 2 components were generated that integrated 100% of the data obtained in the microscopic analysis. The frequencies of each NA obtained in the birds of the sites studied were included, in order to determine whether there were a particular association between any of these NA with each of the 3 environments studied. Cophenetic relationship index was 0.97. Statistical analyses were performed in Infostat® (version 2016 software).

Results

Cover characterization of sampling sites W, R, and U (Fig. 2) comprised on average 1915 ha per site. W site comprised 100% of native forest. The R area comprised 95% of native forest surrounding a 5% of agricultural crop covers where the sampling point was centered. The characterized as U area comprised 0% of native forest, being the major proportion of the area (87%) used as urban land and 13% of public squares with trees.

In the W site, the natural forest presented a red color with light tones representing photosynthetic vegetation, which can be seen on the right side of the image (Fig. 2), whereas sectors with darker tones indicate areas where the shrub vegetation has a high absorption of sunlight due to the pigments of the leaves, which are visible on the left side of the image. The high percentage of natural bush characterizes the site as an ecosystem that could be considered pristine.

In the U site, the light white-beige tones indicate urban soil with a high reflectivity due to the sands found in the concrete composition. In this site, the vegetation refers to public trees. In the R site, the agricultural vegetation presented different colors and tones due to the different types of crops. The fruit trees presented a red color with a light tone and fine texture; the vineyards being predominant in the site presented a dark red to brown color which represents the shrub vegetation. The forest plantations corresponding to Eucalyptus were red with a light tone, which represents high reflectivity. In the areas where the forest is dense, the tone was darker, and in the areas where the forest is sparse, a lighter tone

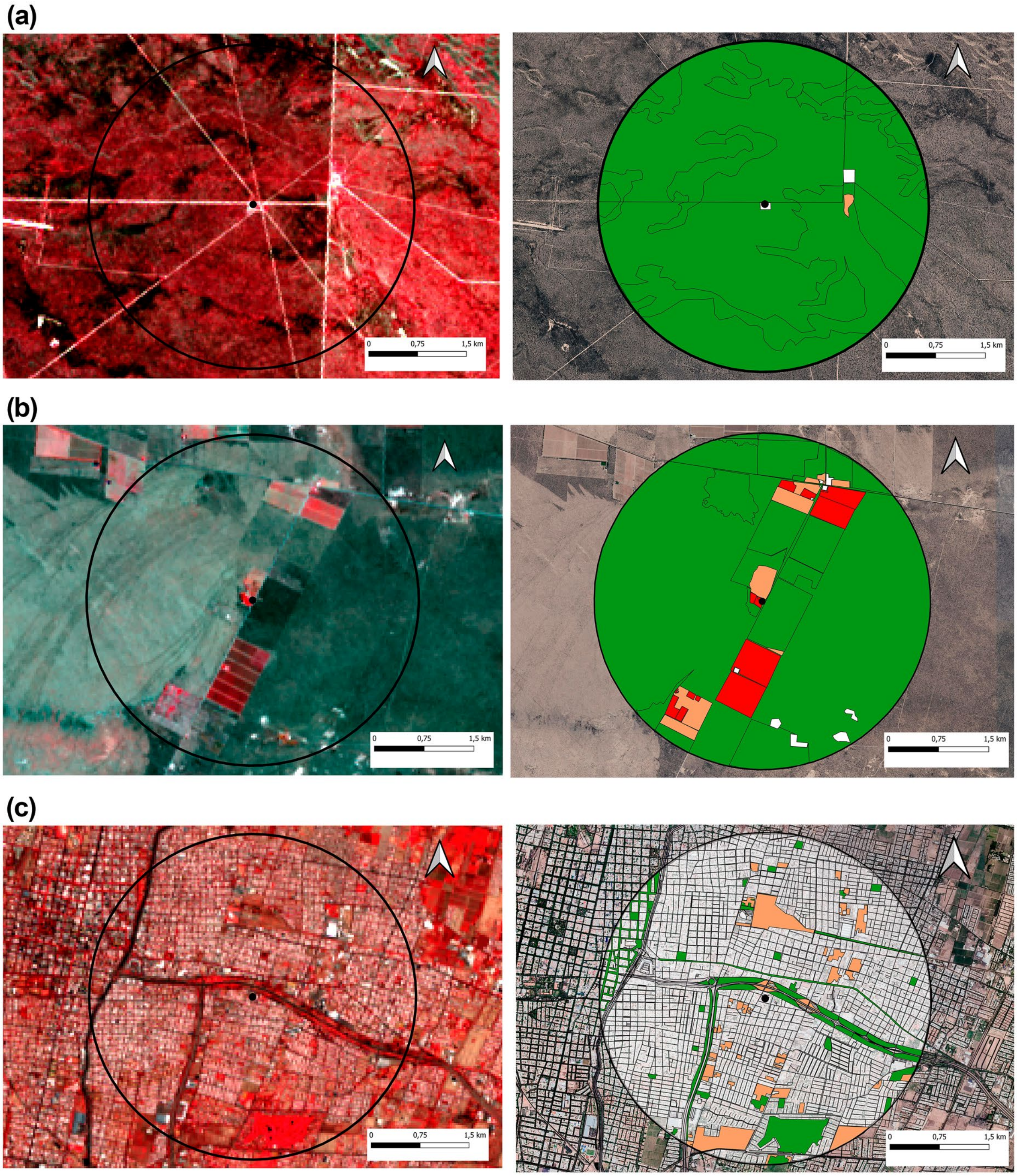

Fig. 2 Sampling sites in Mendoza province and circles that delimit the home range of *P. domesticus* (5 km diameter). (**a**) Wild site (34°2′0″S, 67°55′0″W), (**b**) Rural site (33°09′39.5″S, 68°10′42.0″W), (**c**) Urban site (32°53′55″S, 68°48′42″W). *Left:* Landsat 8 satellite image OLI/TIRS, 05/12/17. Combination of bands 5, 4, 3 (NIR, R, G) Infrared color–false color. *Right:* Polygons of land use and land cover. Satellite image obtained from Google Earth Pro, 05/12/17. Composition 4, 3, 2 (RGB) natural color, *green:* native woodland, *beige:* bare ground, *white:* urban ground, *red:* agricultural crops

was presented, since it represents a higher reflectivity similar to bare soil.

The following sparrows were captured: W site $n = 7$ (2 males, 5 females), U site $n = 11$ (8 males, 3 females), and R site $n = 15$ (10 males, 5 females). Body weight in W, R, and U site were = 23.86 g ± 3.19, 28.56 g ± 0.87, and 28.56 g ± 1.59, differences $p = 0.013$. Tarsal length sparrows in W, R, and U sites were 19.05 mm ± 0.33, 19.20 mm ± 0.51, and 19.38 mm ± 0.68, differences $p = 0.711$. In each site, 5 nets were deployed for 10 h per day, 3 consecutive days representing a trapping effort of 150 h net.

The study of cytogenotoxicity in the sparrows sampled in the three sites showed the NA presented in Table 1, micronucleus (MN), nuclear bud (Bud), binucleated cell (Bin), notched nucleus (Notch), peripheral nucleus (Periph), anucleated cell (Anuc), bridge (Bridge), and nuclear tail (Tail). In the sum of the 3 sites, 33 birds were analyzed, totaling 165,000 erythrocytes. We detected a total of 8 types of NA. All of them were represented in the Passers from site U; 7 of them in the Passers from site R; and 5 different types of NA in the Passers from site W. All birds had some type of NA. NA frequencies ranged from 0 to 3.27. Frequencies higher than 1 were reached by the buds and periph of the Passer from the 3 sites and by the Notch of the Passer from the W and U sites. Statistically, differences were observed between micronucleated cells, more frequent in birds from site R, and notched nuclei, more abundant in animals from site W ($p \leq 0.05$). The most frequent alteration at all 3 sites was peripheral nuclei.

The analysis of these results was confirmed by multivariate principal component analysis, which indicates that Buds would be more related to the U site Passers, notch to the W site Passers, and periph, Bin, Mn, and Anuc to the R site Passers (Fig. 3).

Discussion

The selected and digitally transformed satellite images allowed us to characterize the biotic and abiotic components of the sampling sites, and at the same time to contemplate the home range of the house sparrow. There are multiple band combinations, of which one of the most outstanding is the infrared color composition, used in the present study, from which it was possible to differentiate the different land uses and land covers. GIS are already used to assess avian population dynamics and their relationship with anthropogenic modifications in the environment (Le Louarn et al., 2018; Zhang & Huang, 2020). The high percentage of urban soil of the site represented the anthropogenic activities and their possible impact on the birds of this site.

The sampling procedure and efforts were kept constant in the 3 sites, but fewer sparrows were caught in the wild site, about half of the other sites. The difference is possibly due to their abundance in the urban and rural sites, with greater availability of food and water than the wild site. Birds at sites R and U had statistically higher body weights than those at the other sites, possibly due to the greater availability of food at these sites with human activities and the peridomestic habits of this species. The increase in population density of the sparrow seems to be equivalent to the increase in the degree of urbanization. In the

Table 1 Frequencies of nuclear alterations in *P. domesticus* captured in three different environments (province of Mendoza)

Passer domesticus	Type of nuclear alterations/1000 erythrocytes Mean ± SE							
	MN	Bud	Bin	Notch	Periph	Enuc	Bridge	Tail
Wild $n = 7$	0.00 ± 0.00^{b}	1.71 ± 0.28	0.11 ± 0.07	1.54 ± 0.28^{a}	1.17 ± 0.37^{b}	0.00 ± 0.00^{b}	0.03 ± 0.03	0.00 ± 0.00
Urban $n = 11$	0.05 ± 0.03^{b}	1.87 ± 0.46	0.42 ± 0.13	0.93 ± 0.34^{b}	2.60 ± 0.42^{b}	0.04 ± 0.02^{b}	0.02 ± 0.02	0.04 ± 0.02
Rural $n = 15$	0.13 ± 0.05^{a}	0.89 ± 0.36	0.59 ± 0.31	0.52 ± 0.27^{b}	2.79 ± 0.48^{a}	0.20 ± 0.07^{a}	0.00 ± 0.00	0.09 ± 0.04

Different letters in the same column mean significant differences $p \leq 0.05$

SE standard error, *MN* micronuclei, *Bud* nuclear buds, *Bin* binucleated cells, *Notch* notched nuclei, *Periph* peripheral nucleus, *Enuc* anucleated cells, *Bridge* nucleoplasmic bridges, *Tail* nuclear tails

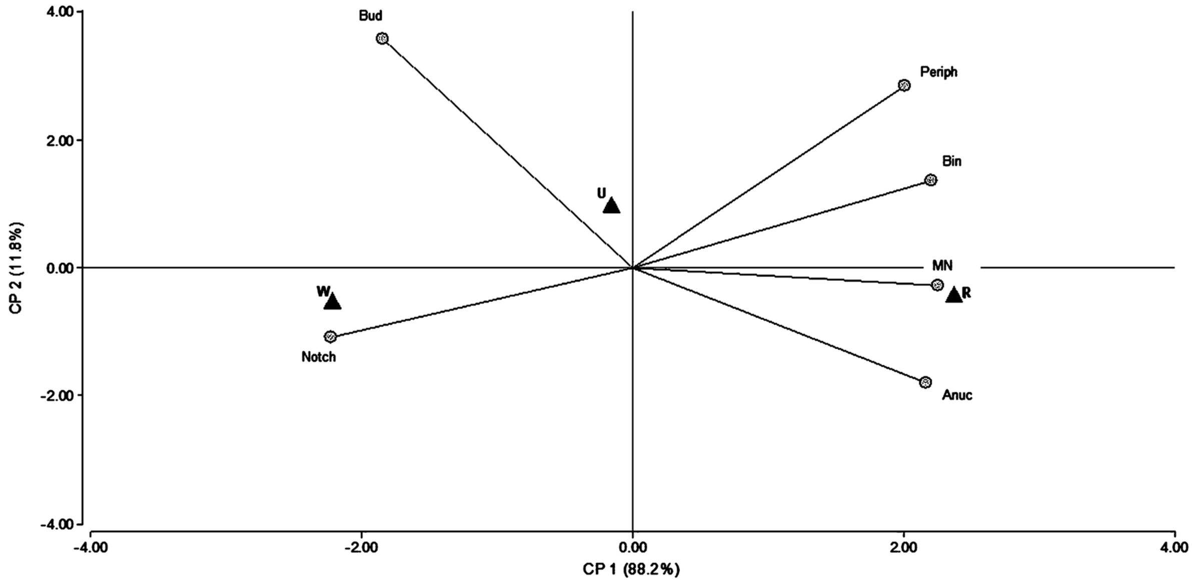

Fig. 3 Diagram of the principal component analysis for the variables nuclear alterations in the *P. domesticus* groups of three environments under study. W: wild, U: urban, R: rural. CP1: principal component 1, CP2: principal component 2, Anuc (anucleated cells), Bin (binucleated cells), Notch (notched nuclei), Bud (nuclear buds), MN (micronuclei), Periph (peripheral nucleus)

agricultural farm in area R, and the site represented in area U, the number of specimens captured seems to reflect a higher population density of the sparrow, due to its peridomestic habits, which is why it has been considered as a potential bioindicator of pollution generated by anthropogenic sources (Anderson, 2006; Cid et al., 2018). It is a resident species with a low displacement range, and it is likely that in zone R it lives a large part of its life with the pesticides used in that environment, as well as having peridomestic habits that reinforce its proximity to humans (Summers-Smith, 2003).

Evidence of increased genotoxicity biomarkers in avian populations near anthropized regions (Queiroz-Baese et al., 2019; Fonseca-Gonçalves et al., 2020) reinforces the need to combine bioassays with GIS tools to help achieve a more accurate typification of ecosystems. This technology has been used to contribute to biodiversity monitoring of plant (Rocchini et al., 2015) and animal species in sites with a high degree of conservation such as Ramsar sites (Palma-Leotta et al., 2019) and in distribution monitoring studies and detection of areas of high bird richness (Su et al., 2018), among other uses.

Among the NA, some has a well-known genotoxicity basis such as MNs and Buds (Fenech et al., 2011), others less frequent with important chromosomal breakage such as bridges that reveal a previous chromosomal translocation, and others with less known significance, but that reveals an error in nuclear functioning such as bin and anuc and finally a chromosomal alteration described mainly in genotoxicity studies in fish, the notch. Quantitatively, the most informative are those that reach values of 1 to 3 per 1000 erythrocytes. This value is met by the buds of Passer from the W and U sites, the buds and periph of Passer from the W site, and the periph nuclei of individuals from the U and R sites. Statistically, differences were seen between micronucleated cells, more frequent in birds from the R site, and notch cells, more abundant in animals from the Wild site. The most frequent alteration in the 3 sites were the peripheral nuclei, NA that is beginning to be reported by authors (López-Gonzalez et al., 2019).

MN are a type of NA that represent damage to genetic material and may be related to the presence of air pollution contaminants generated by anthropization and extreme levels of vehicle circulation (Queiroz-Baesse et al., 2019). Recently, in a study with pigeons with the DBD-FISH (DNA Breakage Detection Fluorescence In Situ Hybridization) technique, the presence of substantial damage in both MNs and buds due to the effect of physical and chemical genotoxic agents has been proven (Cortés-Gutiérrez et al., 2019).

The sparrows from the W site have higher frequencies of notched nuclei compared to the animals from the other 2 sites. This observation confirms the results we have previously obtained in this same reserve (Quero et al., 2016). The notched nuclei appear as a well-defined cleft of uniform size extending to an appreciable depth in the cell nucleus. The causes and mechanisms of their formation are not yet known. The presence of lobed, blebbed, notched nuclei, and binucleate cells is a biomarker of cytogenotoxicity observed mainly in fish (Anbumani & Mohankumar, 2012; Handa & Jindal, 2020). Some of these authors hypothesize and discuss its possible origin without reaching a definite conclusion. Nucleated red blood cells of birds, fish, and amphibians are proposed as important models to study cellular abnormalities, classifying them into 2 main categories: nuclear abnormalities including binucleates, lobed nuclei, nuclear bud, vacuolated nuclei, and also cytoplasmatic abnormalities (Farag & Alagawany, 2018) which we are not concerned with in this study. But we strongly suggest that any increase of knowledge and understanding should be directed to standardize the use of the names given to NA and, more importantly, the criteria for analysis and what they mean.

A peripheral nuclei is observed when the nucleus does not occupy a normal central position, but peripheral, also called eccentric nuclei are reported in *Caiman latirostris* exposed to mixtures of pesticides (López-González et al., 2019). Birds from the R site presented the highest frequencies of this alteration.

Erythrocytes pass immaturely into the circulation, mature in 3 days, and their half-life is between 28 and 45 days (Jones, 2015). Sampling was performed 8 days after spraying, so the erythrocytes analyzed may have been affected by the insecticide. We found no data on chlorpyrifos clastogenicity in wildlife birds, although genotoxic effect of this active principle has been observed in rat liver cells, brain cells, and erythrocytes (Mehta et al., 2008; Okonko et al., 2016). This organophosphate is of interest in the study area because it is one of the most widely used insecticides in regional agricultural activity (Ferré et al., 2018a), in addition to its high persistence in the environment and easy dispersion in air, water, and soil. The percent of area occupied by crops in the R site is included within the sparrow's home range, thus representing a probable food supply for the species. It is hypothesized that the sparrows captured and analyzed at this site may have had contact with this pesticide or other substances derived from agricultural activity in the R site.

Erythroplasts are erythrocytes without nucleus and the mechanisms that modulate their formation in birds have not been determined (Clark & Raidal, 2013), although several hypotheses have been put forward such as: a controlled enucleation as occurs in mammals; artefacts, which do not seem to be the case in our study given the adequate quality and coloration of the cells, and by the effect of genotoxic agents that result in the ejection of the nucleus. Birds from R and U sites presented anucleated erythrocytes. It has been observed that avian populations residing in areas closer to urbanized areas and with lower air quality present an increase in the frequencies of this biomarker compared to those populations that are farther away and with lower levels of air pollution (Fonseca-Gonçalves et al., 2020). Erythrocyte enucleation and apoptotic vesicle formation induced by hydrogen peroxide and high ambient temperatures have also been observed in pigeons (Devyatkin et al., 2006), or by orally administered lead in chickens and pigeons (Hiraga et al., 2008; Cortés-Gutierrez et al., 2019).

In the area characterized as U, the house sparrows sampled showed nuclear buds with the highest frequencies. According to Fenech et al. (2011), buds represent a process of amplified DNA elimination, complex DNA repair processes, and possibly excess chromosomes from aneuploid cells. A nuclear bud is virtually the same as a micronucleus, except for its connection to the nucleus, and buds also contain interstitial or terminal fragments without centromeric or telomeric regions (Dutra et al., 2010). Nuclear buds are associated with MN and other nuclear anomalies such as nucleoplasmic bridges, which are rarely present in our study. In this area, stationary sources constitute 30% of the air pollution, and mobile sources of vehicular origin constitute the remaining 70%. The identification of sulfur compounds, nitrogen oxides, particulate matter, ozone, hydrocarbons, carbon monoxide, polychlorinated biphenyls, polybrominated diphenyl ethers, dichlorodiphenyltrichloroethane, dioxins, and furans has been reported (Allende et al., 2016). Perhaps, there may be a relationship between both factors, urban air pollutants and the types and frequencies of NA, observed there. This hypothesis promotes studies with a larger number of animals in concomitance with the analytical measurement of the compounds.

Regarding the selection of the house sparrow as a bioindicator of environments, it can be stated that given their peridomestic habits they represent suitable organisms when it is intended to evaluate the genotoxic effects of atmospheric pollutants affecting human populations (Cortés-Gutiérrez et al., 2019). The bioaccumulation of heavy metals in sparrow tissues suggested considering the house sparrow as an indicator of environmental pollution (Millaku et al., 2015). Other species have been postulated as possible biomonitors due to their close relationship of habits with anthropized environments, such as *Columba livia*, to evaluate genotoxicity of urban air in Italy (Sicolo et al., 2010) and quantification of erythroplastids in *Antilophia galeata* in Brazil (Fonseca-Gonçalves et al., 2020). With a *n* similar to this study, *Volatinia jacarina* was indicated as a good candidate for sensitive biomonitor species (Souto et al., 2018) and *Myiothlypis flaveola* as a clear reflection of the quality of an area (Baesse et al., 2015). It is a fact that the presence of environmental chemical contaminants with the capacity to damage the structure and/or functioning of genetic material is a threat to animal and human populations, as well as to ecosystem health, and we must be able to assess this situation.

Conclusion

The complementary use of satellite images to characterize urbanized and non-urbanized areas, together with the quantification of genotoxicity biomarkers in erythrocytes of birds living there, was used to evaluate the quality and health of the environments. The house sparrow, as a cosmopolitan bird with life habits closely related to humans, was used as a candidate species for these evaluations.

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Availability of data and material The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval The required authorization was obtained from the Directorate of Renewable Natural Resources, Mendoza, Argentina (Resolution No. 1170), and the use of protocol No. 119 was evaluated and approved by the Interdisciplinary Commission for the Care and Use of Laboratory, Experimental and Teaching Animals (CICUALE) of Juan Agustín Maza University.

Consent to participate All authors accepted to participate in the manuscript.

Consent for publication All authors are aware of and accept the publication of the manuscript.

Conflict of interest The authors declare no competing interests.

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