



From town to town: Predicting the taxonomic, functional and phylogenetic diversity of birds using NDVI

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ARTICLE INFO

Keywords:

Birds
Diversity facets
Extrapolation
Mapping
MODIS

ABSTRACT

Biodiversity mapping in urban areas is imperative for their conservation. Remote sensors produce environmental information, such as the Normalized Difference Vegetation Index (NDVI), an indicator of vegetation cover in urban areas. NDVI can be used to predict the taxonomic, functional and phylogenetic bird diversity in urban areas. Moreover, a predictive model constructed in one city can be used to predict the bird diversity in other cities. The objectives of this study were: 1) to construct and evaluate predictive models between NDVI and taxonomic, functional and phylogenetic diversity of birds in Mar del Plata city, Argentina; and 2) to extrapolate these models to two other cities in the region: Balcarce and Miramar. Generalized additive models were applied to relate bird diversity variations to NDVI. In Mar del Plata, the taxonomic and functional diversity increased with increasing NDVI values, and the predictive models explained 64–81% of the taxonomic and functional diversity variation. The models correctly predicted taxonomic and functional diversity values in additional transects not included in the models, although they had a low predictive power of phylogenetic diversity. The models constructed in Mar del Plata adequately predicted the spatial variation of species diversity (Shannon index) in Balcarce and Miramar, the spatial variation of species richness in Balcarce, and the variation of functional diversity in Miramar. Our analysis revealed that a predictive model of bird diversity based on NDVI patterns created in one city can also depict the expected species diversity in other cities, being a time-saving and cost-effective method to create a tool for urban biodiversity conservation.

1. Introduction

Urbanization is one of the most abrupt forms of landscape change because it rarely returns to an initial natural or seminatural state, but persists over time. In general, urban growth occurs through two processes: 1) urban expansion over natural or rural areas, known as “geophagy” in Latin America (Morello et al., 2000), and “urban sprawl” in the Northern Hemisphere (EEA, 2006); and 2) urban densification, i.e. the increase of urbanization in a limited area, causing vegetation loss and fragmentation (Dallimer et al., 2011; Vergnes et al., 2014).

Vegetation loss due to urban densification is the main cause of biodiversity loss in cities (Beninde et al., 2015). Taking into account the possible relationship between human well-being and biodiversity (Fuller et al., 2007; Hedblom et al., 2014; Aerts et al., 2018; Cox and Gaston, 2018), the loss of green areas and biodiversity could have negative consequences on human health. Moreover, the existence of green

areas in cities is essential to diminish the “extinction of experience” of citizens (Miller, 2005; Dearborn and Kark, 2010).

Biodiversity loss entails different facets, such as the taxonomic, functional and phylogenetic diversity (Devictor et al., 2010; Morelli et al., 2017; Liu et al., 2019; Leveau and Leveau, 2020). First, taxonomic diversity has been a predominant facet used for protecting particular species with conservation value or areas with a large number of species (Cadotte and Tucker, 2018). Second, functional diversity typically focuses on the range and variety of resources that species obtain (Díaz and Cabido, 2001), and is generally related to the variety of ecosystem properties (Hooper et al., 2005). Third, phylogenetic diversity is related to uniquely divergent genomes and functions (Jetz et al., 2014). Given that an area can have high taxonomic diversity but low functional diversity (Devictor et al., 2010; Bae et al., 2018; Chapman et al., 2018), or high functional diversity but low phylogenetic diversity (Mazel et al., 2018), it is necessary to adopt an

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integrative conservation strategy for biodiversity conservation. In urban areas, birds are one of the most frequently studied taxa, since they rapidly respond to anthropogenic changes, are easy to survey, and can function as surrogates of diversity for other taxa (Lepczyk et al., 2017).

Although spatial biodiversity information of extensive areas such as cities is scarce, the use of environmental information provided by remote sensors and the elaboration of statistical models can help to construct predictive maps of biodiversity, which are essential for conservation (Travaini et al., 2007; Skidmore et al., 2015; Bae et al., 2019). NDVI is an indicator of vegetation cover and primary productivity (Pettorelli et al., 2005; Haedo et al., 2017; Gillespie et al., 2017). NDVI indicates resource availability for birds; according to the species-energy relationships, more resources promote increases in diversity (Wright, 1983; Hurlbert, 2004; Seto et al., 2004; Coops et al., 2019; Radeloff et al., 2019). On the other hand, most urban studies reported a positive relationship between vegetation cover and bird diversity (Beninde et al., 2015). Since NDVI is an indicator of vegetation cover, several studies showed positive relationships between NDVI and both bird taxonomic and functional diversity (Lee et al., 2004; Bino et al., 2008; Coetzee and Chown, 2016; Haedo et al., 2017; Leveau et al., 2018). However, the use of NDVI to predict the joint variation of bird taxonomic, functional and phylogenetic diversity in urban areas has been scarcely analyzed (Liu et al., 2019).

Given that bird species richness responds similarly to vegetation cover in cities of distant areas (Filloy et al., 2019), it is possible to extrapolate a predictive model between taxonomic, functional, and phylogenetic diversity, and NDVI constructed for one city to other cities in a region. To our knowledge, no other studies have extrapolated predictive models to different cities. The objectives of our study were: 1) to construct and evaluate predictive models between NDVI and taxonomic, functional and phylogenetic diversity of birds in Mar del Plata city; and 2) to extrapolate these models to two other cities of the region, Balcarce and Miramar. We expected positive relationships between different facets of bird diversity and NDVI, and to observe an adequate extrapolation between cities.

2. Methods

2.1. Study area

Bird surveys were conducted in three cities of Argentina: Mar del Plata (618 989 inhabitants, 2010 National Census) (38° 00' S; 57° 33' W), Balcarce (38 823 inhabitants, 37° 50' S; 58° 15' W), and Miramar (29 629 inhabitants, 38° 16' S; 57° 50' W). Mar del Plata and Miramar are coastal and tourist cities, whereas Balcarce is located 59 km in the hinterland (Fig. 1a, b). All cities are surrounded by crop fields, pastures, and a few small fragments of native grasslands, whereas Mar del Plata is also surrounded by small fragments of native woodlots. Phytogeographically, Mar del Plata is located in the ecotone between the Espinal and the Pampas provinces (Cabrera, 1976), Balcarce and Miramar are located in the Pampas province. Annual mean temperature in the region is 14 °C and mean annual rainfall is 924 mm.

2.2. Study design

To study the relationship between NDVI and bird diversity, sampling areas along urbanization gradients were considered in each city, which spanned from the urban center dominated by impervious surfaces (buildings and paved roads) to periurban areas composed of single-family houses surrounded by yards and unpaved streets on the boundary of the city (mean building cover of 25%). Sampling units consisted of strip transects (100 × 50 m) established at a minimum of 100-m intervals (Fig. 1c). In Mar del Plata, a total of 82 transects were surveyed, of which 43 were selected (located at least 300 m apart) to model the relationship between NDVI and bird diversity. Transects

were grouped in six sectors; the first transect of each sector was systematically selected, leaving out the next one, and selecting the following one, located at 300 m from the first one. The remaining 39 transects were used to assess the performance of the predictive models in Mar del Plata. To evaluate the model extrapolation from Mar del Plata to Balcarce and Miramar, 20 transects established at a minimum of 200-m intervals were located in each city along urbanization gradients (Fig. 1d, e). Coordinates of transects were obtained using a GPS Trimble Navigation Ensign XL. In those transects with poor signal, the coordinate data were positioned by Google Earth.

2.3. Bird surveys

Surveys in the three cities were conducted along transects during four hours after sunrise from December 2012 to February 2013 (austral spring-summer), coinciding with the bird breeding season. Transects were visited three times, and birds were surveyed by an observer who walked along each transect (100 m) and recorded individuals on both sides of the transect (25 m each) during three to five minutes. On each visit, birds were identified by sight or sound on days with favorable meteorological conditions, without strong wind or rain. Surveys were performed by the same observer. Both resident and migrant birds were counted.

2.4. NDVI estimation

The product MOD13Q1 from the MODerate resolution Imaging Spectroradiometer (MODIS sensor; Terra satellite) was used to obtain NDVI values at 16-day intervals with a spatial resolution of 250 m (Huete et al., 2002). Six images covering the sampling period were used to calculate an average value for each transect. Images were referenced using the MODIS reprojection Tool software, using the UTM projection. Then, the images were reprojected again to the Argentina Gauss-Krüger projection. Mean NDVI values and ranges were similar in all cities (Mar del Plata, mean = 0.43, range = 0.12–0.72; Miramar, mean = 0.43, range = 0.27–0.58; Balcarce, mean = 0.42, range = 0.23–0.65).

2.5. Taxonomic, functional and phylogenetic diversity of bird communities

We used two indices to estimate taxonomic diversity: bird species richness, which quantifies the number of species in each transect, and the Shannon index (H'), which quantifies bird species diversity in each transect taking into account both the number of species and their numerical proportions (Magurran, 2004). Bird species richness was estimated using the COMDYN software, available at <http://www.mbrpwr.usgs.gov/comdyn.html>. This software estimates species richness of a site and the associated variance by taking into account differences in detectability among species and sites (Hines et al., 1999).

To explore differences in functional diversity among bird communities, we constructed a matrix of bird traits as columns and bird species as rows (see Supplementary Material, Table S1). Traits were related to the type and variety of acquired resources, which are related to ecosystem processes such as predation, frugivory and pollination (Díaz and Cabido, 2001; Sekercioglu, 2006). Therefore, we considered diet, feeding substrate, resident or migrant status, and body weight. Diet and feeding substrate were ranked from 0 to 3, indicating different degrees of use (Schütz and Schulze, 2015): 0, not used; 1, rarely used; 2, moderately used; 3, often used. For example, the Glittering-bellied Emerald (*Chlorostilbon lucidus*) has a degree 3 of nectar feeding, whereas the Greyish Baywing (*Agelaioides badius*) has a degree 1, because it occasionally visits flowers (Leveau and Leveau, 2011). Since trait values were discrete, continuous and ordinal data, Gower dissimilarity was calculated among species (Casanoves et al., 2011), using the function `gowdis` of the package `FD` (Laliberté et al., 2014). We used the `FD` index (Petchey and Gaston, 2002) and the functional dispersion index (FDIs, Laliberté and Legendre, 2010). On the one hand, `FD`

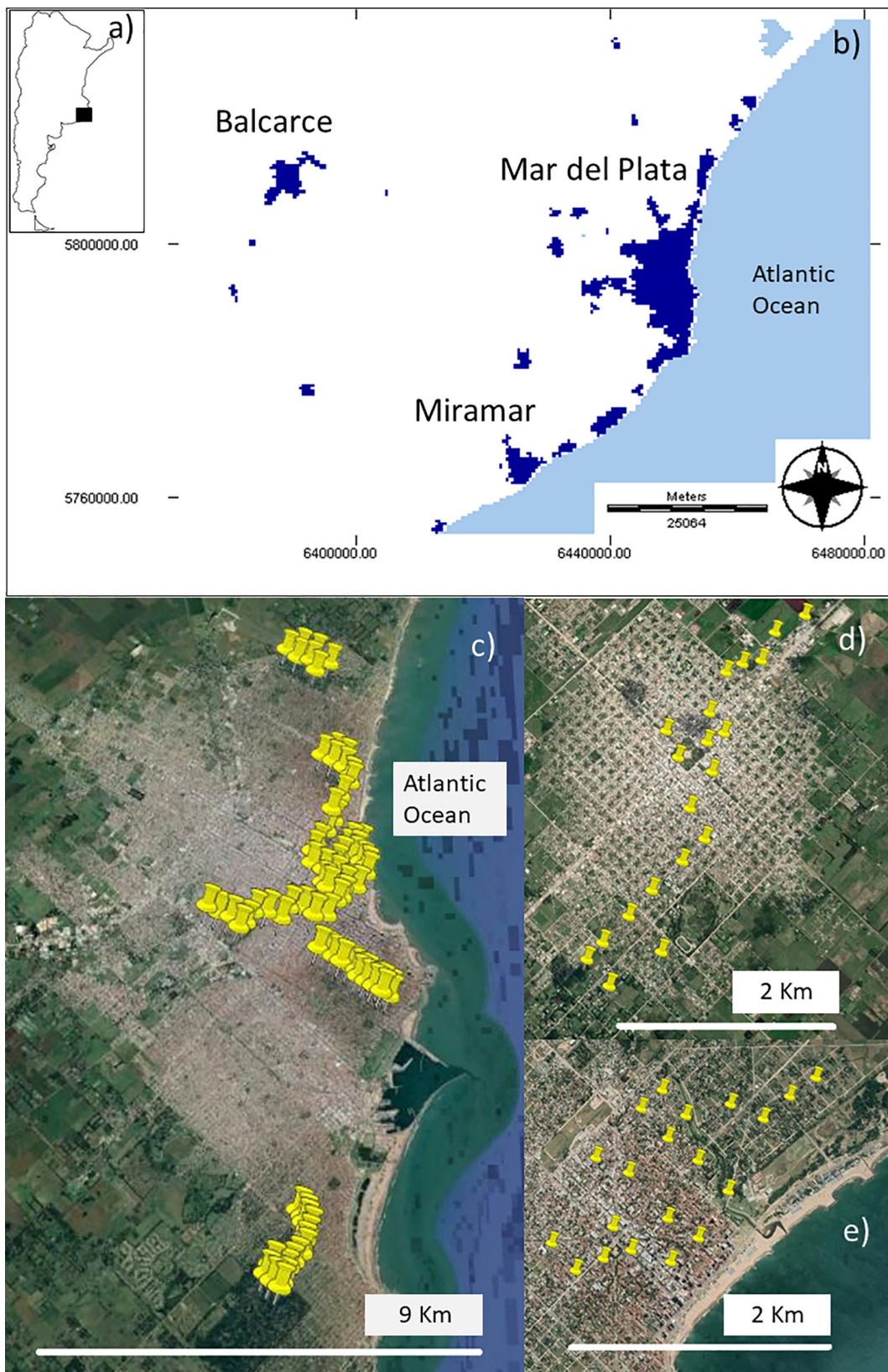


Fig. 1. Location of the three cities in Argentina (a), detail of the three cities (b) and location of transects in Mar del Plata (c), in Balcarce (d), and in Miramar (e).

(Petchey and Gaston, 2002) is based on a dendrogram of bird species trait characteristics, and measures the total branch length of species present in a given sampling unit. Therefore, a dendrogram was constructed for all species using the function `hclust` for hierarchical

clustering of the package `stats` in R (R Development Core Team, 2017). The function `treedive` of package `vegan` (Oksanen et al., 2017) was used to calculate FD for each plot. On the other hand, `FDis` is the mean distance of individual species to the centroid of all species in the

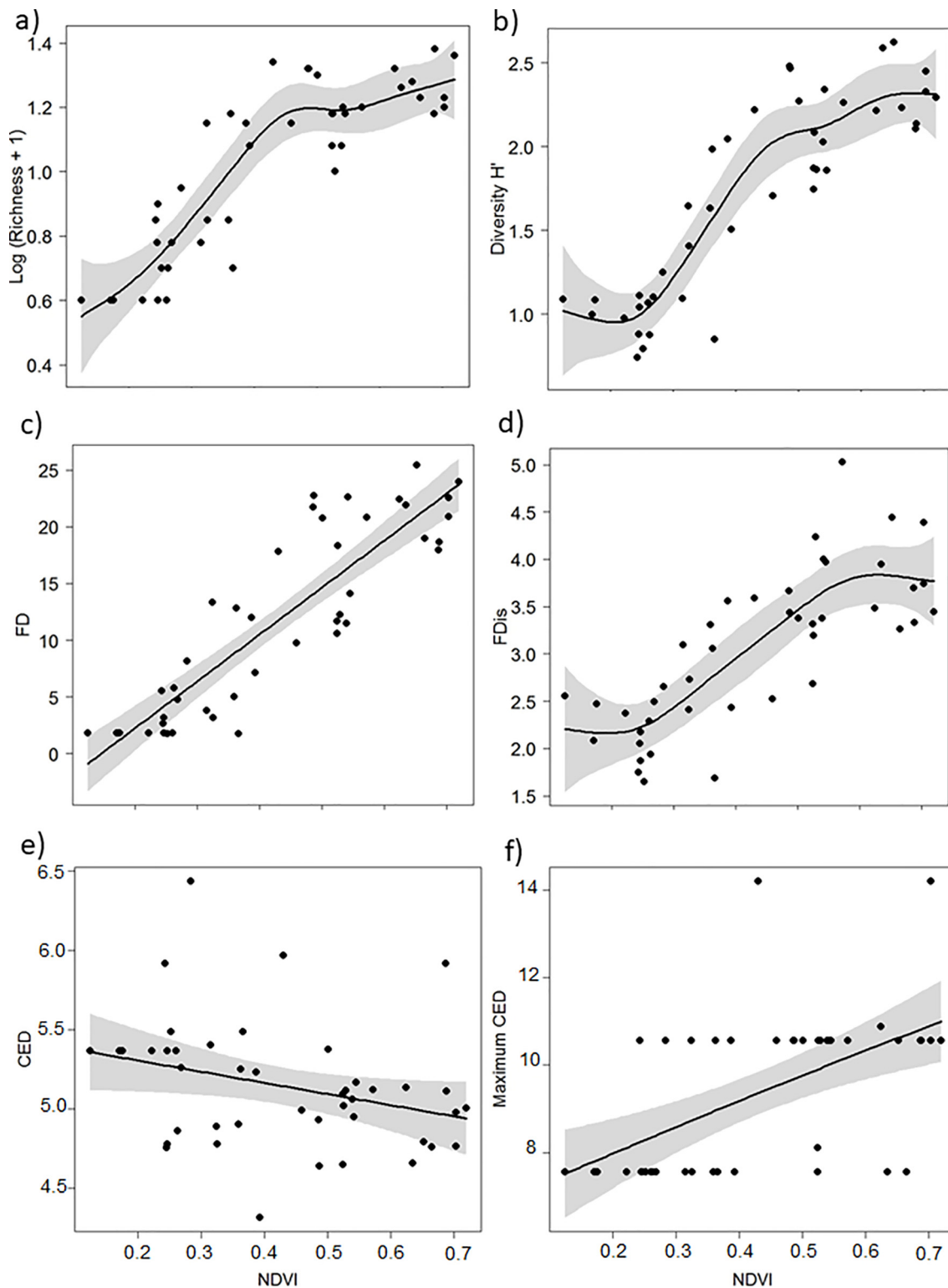


Fig. 2. Relationship between a) bird species richness (number of species per transect, y axis), b) bird species diversity (H'), c) functional diversity (FD), d) functional dispersion (FDis), e) community evolutionary distinctiveness (CED), f) maximum community evolutionary distinctiveness (maxCED) and mean NDVI along the urban gradient of Mar del Plata city. Graphs show the smoothed curves estimated by the Generalized Additive Models. The black line represents the fitted curve and the grey areas are the confidence intervals at 95%.

multidimensional trait space (Laliberté and Legendre, 2010). The multidimensional space is obtained through a principal coordinate analysis from the Gower dissimilarity matrix. FDis, unlike FD, can account for relative abundances of species, and the position of the centroid in the multidimensional space will shift toward the most abundant

species.

Phylogenetic diversity was calculated using the evolutionary distinctiveness (ED) of each species, which is a measure of the species uniqueness and is expected to capture uniquely divergent genomes and functions (Jetz et al., 2014). The median ED score for each species was

Table 1

Generalized additive models between bird diversity variables and NDVI along the urban gradient of Mar del Plata city. Estimated degrees of freedom (edf), ANOVA tests (F), P values, and percentage of variation explained by the models (r^2).

	Response variable	edf	F	P	r^2
Taxonomic diversity	Bird species richness (log)	4.40	29.45	< 0.001	0.79
	Bird species diversity (H')	4.65	32.66	< 0.001	0.81
Functional diversity	Functional diversity (FD)	1.00	137.90	< 0.001	0.77
	Functional dispersion (FDis)	3.49	17.23	< 0.001	0.64
Phylogenetic diversity	Community evolutionary distinctiveness (CED)	1.00	4.05	0.051	0.07
	Maximum community evolutionary distinctiveness (maxCED)	1.07	15.91	< 0.001	0.28

obtained from the database available in Jetz et al. (2014). Then, the community evolutionary distinctiveness (CED) of each transect was calculated as the mean ED for all species present in the transect (Morelli et al., 2016). Moreover, the maximum value of ED recorded in each transect (maxED) was also calculated (Ibáñez-Álamo et al., 2017).

2.6. Statistical analysis

Relationships between species diversity variables and NDVI were analyzed with Generalized Additive Models (GAMs), using the mgcv package in R (R Development Core Team, 2017). Bird richness was $\log(x + 1)$ transformed to improve homoscedasticity. Therefore, all dependent variables were continuous, assuming a Gaussian distribution of errors. Plots of the regression models were constructed with the visreg package (Breheny and Burchett, 2013).

To assess the adequacy of models to predict the bird diversity variables in the 39 additional transects of Mar del Plata and the 20 transects in Balcarce and Miramar, the observed values of bird diversity in these transects were compared with predicted values using the NDVI values. Only models that explained 50% or more of diversity variation in Mar del Plata were extrapolated to the additional transects in that city and to Balcarce and Miramar transects. Spatial auto-correlation of residuals was analyzed with the Moran index using the SAM software (Rangel et al., 2010), and no significant autocorrelation was found ($P < 0.05$). Model performance was assessed by analyzing the precision and accuracy of predicted values. Precision was measured by calculating the Pearson coefficient between the model-predicted and the observed values (Zar, 1999). Precision refers to the closeness of the predicted values to each other. Pearson coefficients equal to or higher than 0.5 were considered adequate (Hinkle et al., 2003). Accuracy was measured using a paired t -test of the difference between observed and model-predicted values that removes the covariance between values (Tedeschi, 2006). Accuracy measures the proximity between observed and predicted values (Tedeschi, 2006). The acceptance of the null hypothesis ($P > 0.05$) indicates that the difference between predicted and observed values is not significant. Predictive maps were produced for models of bird diversity with adequate precision and accuracy using the raster package in R (Hijmans & van Etten, 2014).

3. Results

A total of 40 species and 5469 individuals were analyzed, of which the House Sparrow (*Passer domesticus*), the Eared Dove (*Zenaida auriculata*), and the Rock Dove (*Columba livia*) were the most abundant species in the three cities. A total of 21 species were recorded in the three cities, accounting for 95% of the observed individuals (see Supplementary Material, Table S2).

The relationship between NDVI and taxonomic diversity was strong and non-linear (species richness, $r^2 = 0.79$; H' , $r^2 = 0.81$; Fig. 2a, b, Table 1). Taxonomic diversity increased at NDVI values of 0.3; this increase was higher in the case of H' , showing more abrupt spatial changes than species richness in the expected distributional maps (Fig. 3a, b). Functional diversity also had a strong relationship with NDVI (FD, $r^2 = 0.77$; FDis, $r^2 = 0.64$; Fig. 2c, d). FD increased linearly

with NDVI and FDis had a non-linear relationship with NDVI, increasing abruptly to NDVI values of 0.3 and showing stronger spatial changes in the expected distributional maps (Fig. 3c, d). Phylogenetic diversity had a low relationship with NDVI (CED, $r^2 = 0.07$; maxCED, $r^2 = 0.28$; Table 1). CED had a nearly significant negative relationship with NDVI, whereas maxCED increased with NDVI (Fig. 2e, f). The relationship between observed and expected values of taxonomic and functional diversity in the additional transects showed adequate precision and accuracy of the models (Table 2, Fig. 4).

The extrapolation of NDVI-bird diversity models developed for Mar del Plata to Balcarce and Miramar showed that only H' was adequately predicted in these two cities (Figs. 5c, d, 6a, b, Table 3). Species richness was adequately extrapolated only to Balcarce (Fig. 5a, 6c), whereas precision was low in Miramar and the expected species richness was significantly higher than the observed one (Fig. 5b). The expected spatial patterns of H' in Balcarce had stronger changes than the spatial changes of species richness (Fig. 6a, c), a similar pattern as that found in Mar del Plata city (Fig. 3a, b). FD was successfully extrapolated to Miramar (Fig. 5f, 6d), whereas precision was low in Balcarce (Fig. 5e). FDis was not adequately extrapolated to Balcarce because the observed values were higher than expected by the Mar del Plata model; precision was low in Miramar (Table 3).

4. Discussion

Our results showed that, in a given city, NDVI was a good predictor for the taxonomic and functional diversity of bird assemblages. However, phylogenetic diversity was poorly explained by NDVI variation. The predictive power of the NDVI for the studied nearby cities was lower, but still allowed for the adequate extrapolation of H' and, to some extent, the extrapolation of species richness and functional diversity.

Several studies have shown the importance of NDVI for explaining the spatial variation of species richness and diversity in urban areas (Koh et al., 2006; Bino et al., 2008; Haedo et al., 2017; Leveau et al., 2018; Leveau, 2019). Our results highlighted the importance of analyzing non-linear relationships between variables (see also Coops et al., 2019), since most of the models showed a sigmoid-like relationship between NDVI and bird taxonomic and functional diversity. Bird taxonomic and functional diversity increased at intermediate values of NDVI and then remained relatively constant. NDVI in urban areas is a proxy of vegetation cover and net primary productivity (Pettorelli et al., 2005; Haedo et al., 2017; Gillespie et al., 2017), which are potential resources for birds. According to the species-energy relationships, more resources can support more species (Evans et al., 2005), and more bird traits (Coetzee and Chown, 2016; Barnagaud et al., 2017). The most densely urbanized areas of our cities, which had low NDVI values, were dominated by a few species, such as the Rock Dove (*Columba livia*), the Eared Dove (*Zenaida auriculata*) and the House Sparrow (*Passer domesticus*). These species have very similar functional traits, such as a gregarious and omnivorous diet, and a resident status; these traits coincide with traits of other highly urbanized bird assemblages (Jokimäki et al., 2016; Leveau, 2013; La Sorte et al., 2018; Palacio et al., 2018; Hensley et al., 2019).

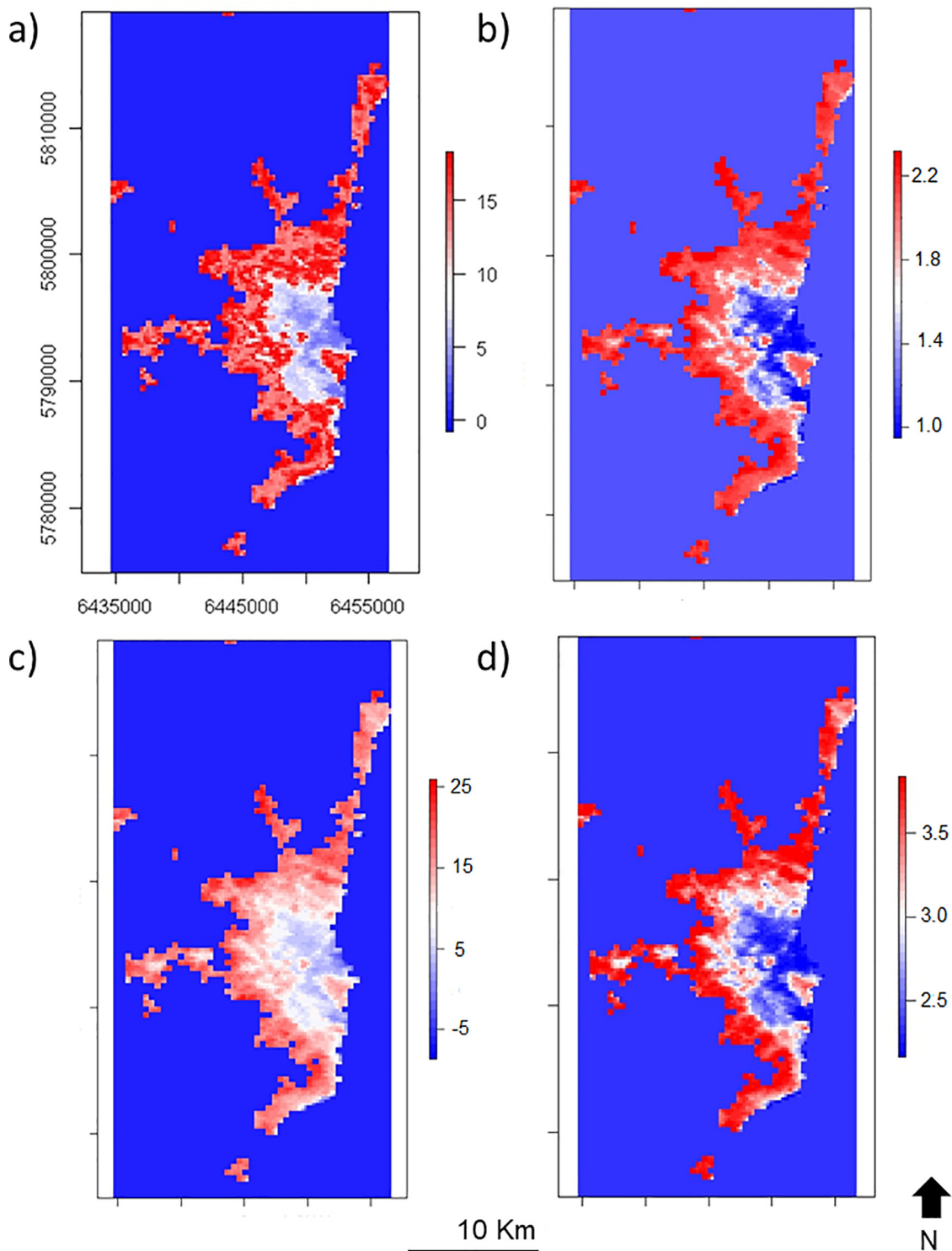


Fig. 3. Maps depicting a) expected bird species richness (number of species per transect), b) expected bird species diversity (H'), c) expected functional diversity (FD), and d) expected functional dispersion (FDi) along the urban gradient of Mar del Plata city.

Our analysis suggests threshold responses of bird diversity to vegetation cover in urban areas, in which taxonomic and functional diversity decrease drastically below NDVI values of 0.5. Thus, NDVI values lower than 0.5 suggest dramatic changes in green cover, which induce the extirpation of several bird species (Zuckerberg and Porter, 2010). This pattern agrees with findings reported by Batáry et al. (2018), who showed strong increases of bird richness from urban to suburban habitats and similar bird richness values between suburban

and rural areas. Additionally, Palomino and Carrascal (2006) found that a building cover $> 70\%$ reduced bird richness significantly. Moreover, this type of relationship was more marked for diversity indices that took into account bird abundance, such as H' and FDi. Maps depicting expected changes of H' and FDi showed stronger changes along the urban gradient than maps depicting expected changes of species richness or FD. These patterns suggest that sites covered mostly by impervious surfaces are dominated by only a few species sharing

Table 2

Adequacy of predictive models on additional transects regarding precision (Pearson coefficient, r) and accuracy (t -test). All t -test are non-significant ($P > 0.05$).

	Response variable	r	t -test
Taxonomic diversity	Bird species richness (log)	0.84	0.69
	Bird diversity (H')	0.89	0.22
Functional diversity	Functional diversity (FD)	0.85	0.68
	Functional dispersion (FDIs)	0.84	1.29

similar suites of traits, indicating a low functional dispersion, and that an increase of green cover promotes a steep rise in the variety and frequency of functional traits.

Threshold responses of biotic communities to urbanization have been extensively analyzed in relation to city size (Jokimäki and Suhonen, 1993; Jokimäki and Kaisanlahti-Jokimäki, 2003; Garaffa et al., 2009), urban green areas (Natuhara and Imai, 1999; Mörtberg and Wallentinus, 2000; Hashimoto et al., 2005; Ferenc et al., 2014), and stream habitats (Roy et al., 2003; King et al., 2011). However, threshold responses of urban bird communities varying among sites with different impervious cover have been scarcely explored (Suarez-Rubio et al., 2013; Silva et al., 2015). The existence of threshold responses is very informative for conservation planning because they indicate the minimum amount of habitat necessary for persistence of wildlife populations in urban areas (Zuckerberg and Porter, 2010; Batáry et al., 2018). Therefore, it is necessary to explore non-linear responses of bird diversity along urban gradients to determine the occurrence of threshold responses.

Our findings highlight the importance of considering different diversity facets. Bird taxonomic and functional diversity increased with NDVI, indicating that more vegetation retained more bird species and

traits. These findings are similar to those reported by Morelli et al. (2017), Palacio et al. (2018), Zhang et al. (2018), and Leveau and Leveau (2020). However, the response of phylogenetic diversity to NDVI varied, being negative in the case of CED and positive in the case of maxCED. On the one hand, CED tended to increase in more urbanized areas because of the common presence of species with relatively high ED, such as the Eared Dove and the Rock Dove. Therefore, urban areas tended to hold species with high evolutionary uniqueness. Similarly, Palacio et al. (2018) found a positive relationship between terminal phylogenetic diversity and building cover. Moreover, Ibáñez-Álamo et al. (2016) showed a lower impact of urbanization on CED in South America than in the Northern Hemisphere. On the other hand, maxCED increased with NDVI, showing a positive response to vegetation cover. Urban areas could be extirpating lineages with extremely high ED values, which would be associated with those species with very particular requirements/adaptations (i.e., particular food or inability to fly, Ibáñez-Álamo et al. 2016). For example, the Picazuro Pigeon (*Patagioenas picazuro*), the Monk Parakeet (*Myiopsitta monachus*), and the Guira Cuckoo (*Guira guira*) had the highest ED values and were observed in suburban and periurban areas with high vegetation cover (Leveau and Leveau, 2012). Moreover, the response of maxCED to NDVI was less clear than that of taxonomic and functional diversity, indicating that urban areas can hold species with high evolutionary distinctiveness (Sol et al., 2017); this finding agrees with those of Ibáñez-Álamo et al. (2016).

Our study revealed that a model of bird diversity based on NDVI patterns developed for a city can be extrapolated to other cities. This finding supports the idea that bird taxonomic diversity has similar responses to vegetation cover in different cities. While extrapolation was possible with H' , results obtained for species richness and functional diversity were dissimilar. Other variables not related to NDVI, such as vegetation type and human disturbance, may be influencing the spatial

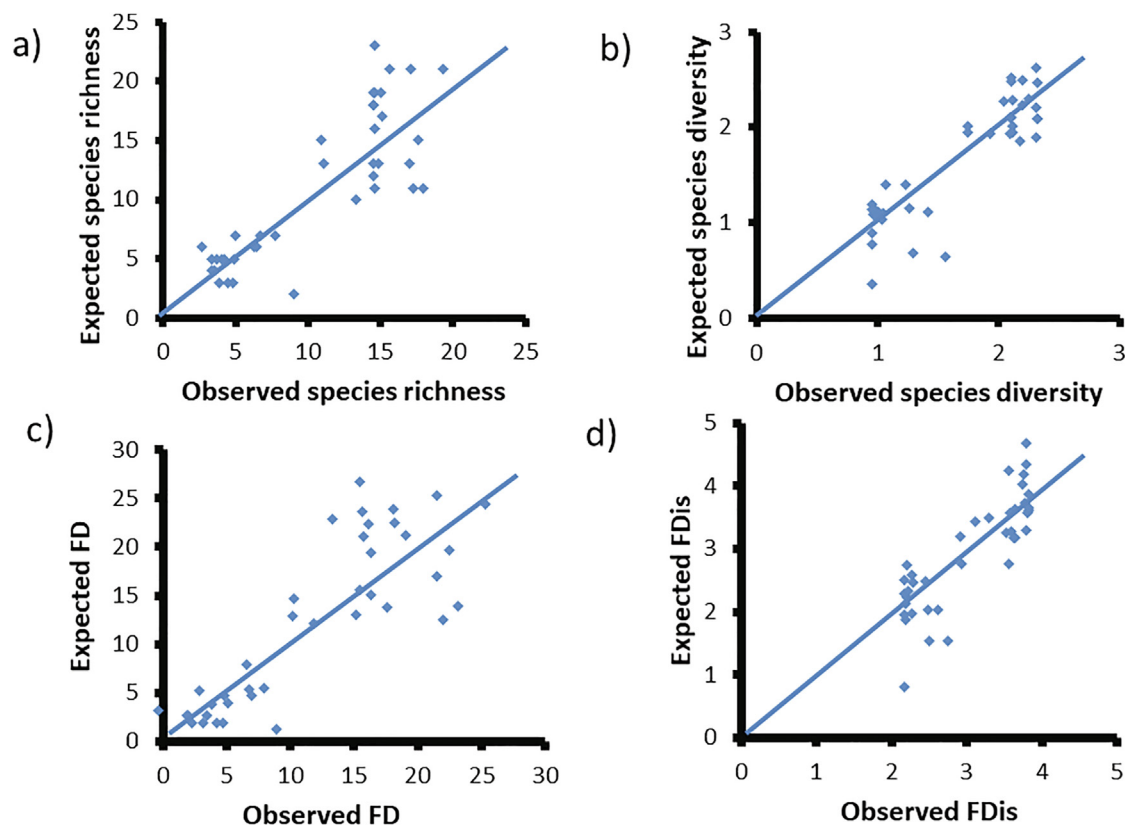


Fig. 4. Relationship between expected and observed values in additional transects not included in the predictive models for a) bird species richness (number of species per transect, y axis), b) bird species diversity (H'), c) functional diversity (FD), d) functional dispersion (FDIs). The line indicates a 1:1 relationship between the two values. A high dispersion of points indicates low precision, whereas point deviations from the line indicate low accuracy.

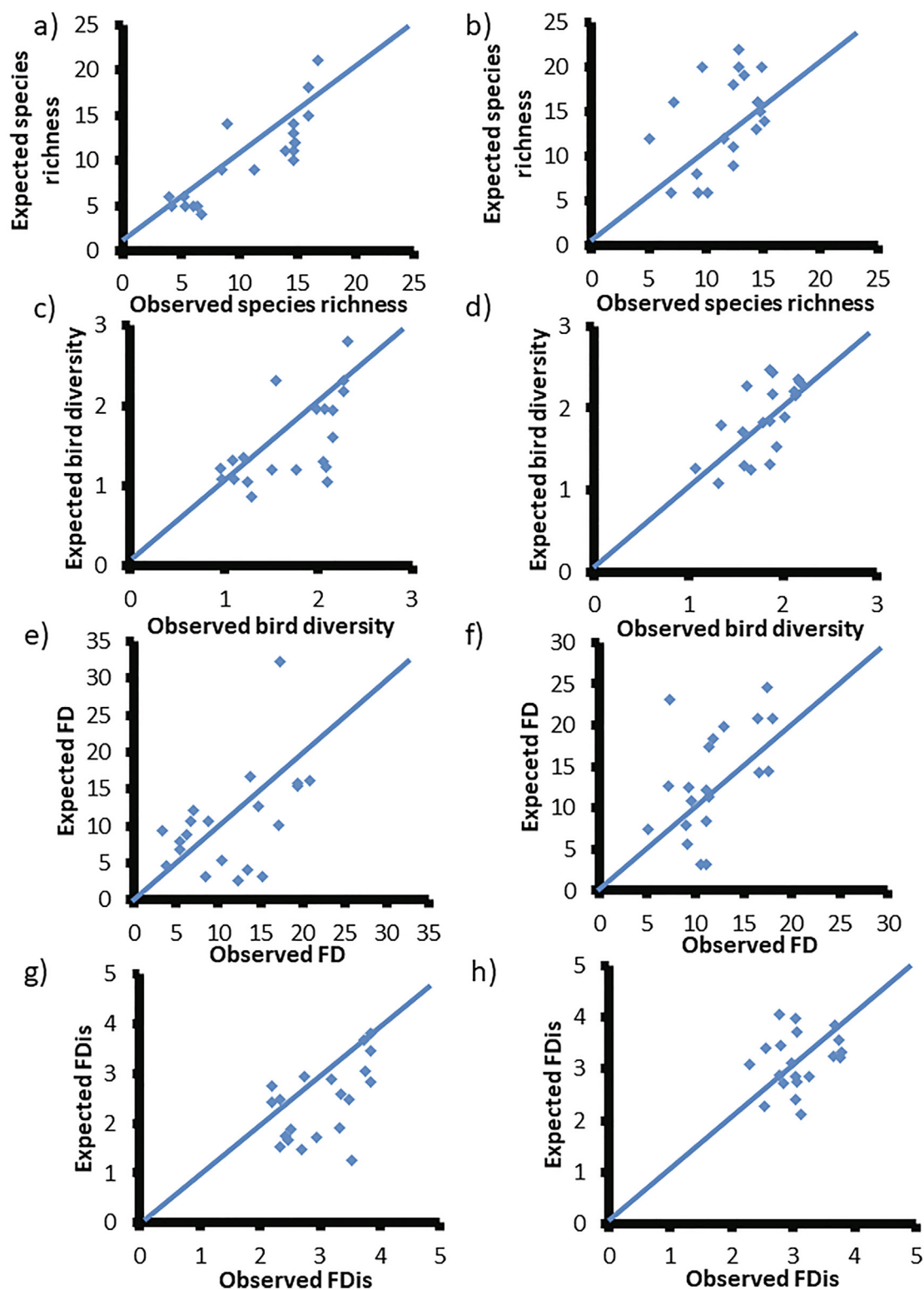


Fig. 5. Relationship between expected values from the Mar del Plata model and observed values obtained in Balcarce (left column) and Miramar (right column) for a and b) bird species richness (number of species per transect, y axis); c and d) bird species diversity (H'); e and f) functional diversity (FD); and g and h) functional dispersion (FDIs). The line indicates a 1:1 relationship between the two values. A high dispersion of points indicates low precision, whereas point deviations from the line indicate low accuracy.

variation of species richness and functional diversity. For example, Morelli et al. (2017) found that shrub cover influenced functional richness in urban parks of Beijing (China). On the other hand, differences in car and pedestrian traffic between cities can influence the spatial variation of species richness (Fernández-Juricic, 2000; Leveau

and Leveau, 2006; de Castro Pena et al., 2017). Although the three cities were dominated by the same bird species, changes in species composition between cities may also affect the extrapolation of models. For example, the Barn Swallow (*Hirundo rustica*) represented 4% of the individuals observed in Balcarce, whereas it was rare or absent in

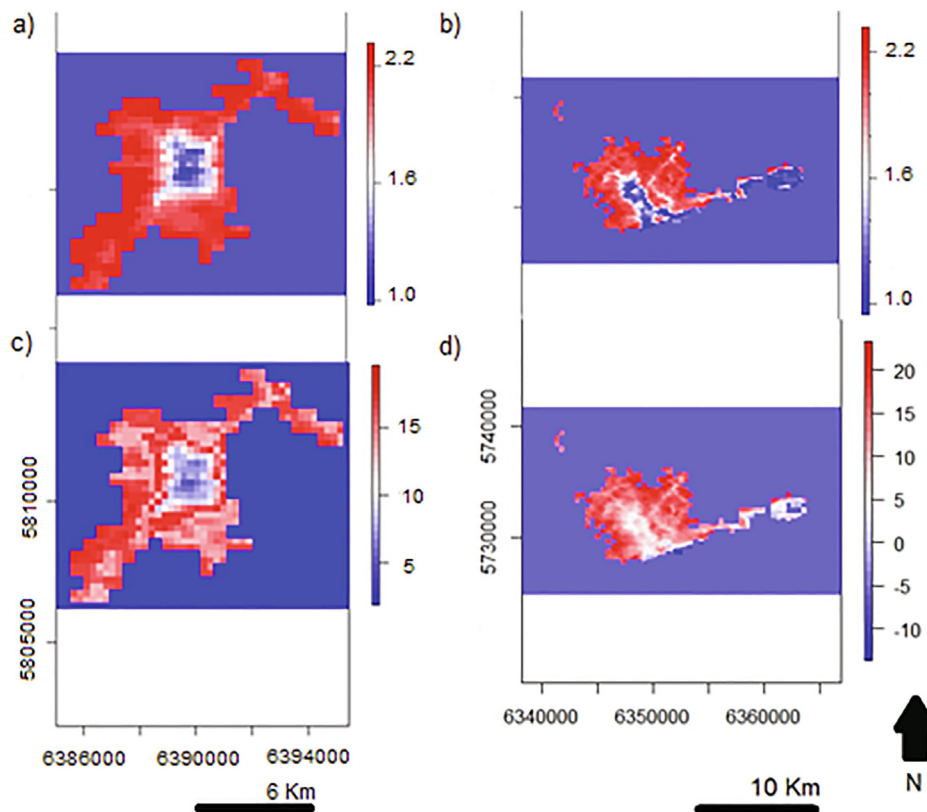


Fig. 6. Maps depicting a) the expected bird species diversity (H' per transect) in Balcarce, b) the expected bird species diversity in Miramar, c) the expected bird species richness in Balcarce, and d) the expected functional diversity (FD) in Miramar.

Table 3

Mar del Plata model adequacy for predicting taxonomic and functional diversity on transects along the urban gradients in Balcarce and Miramar regarding precision (Pearson coefficient, r) and accuracy (t -test). Asterisks indicate adequate precision ($r \geq 0.50$) or accuracy (t -test, $P > 0.05$).

Response variable	Balcarce		Miramar		
	r	t -test	r	t -test	
Taxonomic diversity	Bird species richness (log)	0.85*	1.08*	0.45	2.21
	Bird diversity (H')	0.62*	1.56*	0.66*	0.92*
Functional diversity	Functional diversity (FD)	0.48	0.74*	0.50*	1.37*
	Functional dispersion (FD _{is})	0.53*	4.04	0.22	0.36*

Miramar and Mar del Plata, respectively.

The creation of expected bird taxonomic diversity maps in urban areas is fundamental to planners, scientists and the general public for conserving bird diversity (Gillespie et al., 2017; Jalkanen et al., 2020). Our analysis revealed that a predictive model created in one city can also depict the expected species diversity in other cities, being a time-saving and cost-effective method to create a tool for urban biodiversity conservation. A similar approach was performed by Gillespie et al. (2017), who extrapolated a predictive model of tree species richness based on NDVI developed for Los Angeles to European cities, although they did not evaluate the adequacy of the model in those cities.

5. Conclusions

The results obtained showed that NDVI was an adequate predictor of taxonomic and functional bird diversity facets in a medium-sized city, although phylogenetic diversity did not show strong responses to NDVI. Overall, phylogenetic diversity metrics may be less

responsiveness to urbanization than functional and taxonomic diversity. The type of response of bird diversity to NDVI changed when bird abundance was taken into account. Functional diversity responses to NDVI changed from linear, when only species richness was considered, to non-linear responses when bird abundance was considered. Therefore, abrupt changes of bird functional diversity are expected when bird abundance is considered, showing threshold responses of bird diversity to vegetation in urban areas.

Bird diversity extrapolation to other cities using NDVI was adequate in the case of taxonomic diversity, suggesting that factors other than NDVI influence the spatial variation of functional diversity. Further research is needed to elucidate which factors allow the adequate extrapolation of bird diversity based on NDVI among cities.

CRediT authorship contribution statement

Lucas M. Leveau: Conceptualization, Methodology, Software, Data curation, Formal analysis, Writing - original draft, Visualization, Investigation. **Federico I. Isla:** Conceptualization, Supervision, Software, Writing - review & editing. **M. Isabel Bellocq:** Supervision, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

We thank Luis Cortizo and Marcelo Kittlein for assistance with MODIS image processing and the raster package. Three anonymous reviewers greatly improved a first draft of the manuscript. Jorgelina

Brasca revised the English writing.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.ecolind.2020.106703>.

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