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Sensitivity, Exposure, and Vulnerability to Climate Change of the Long-legged Buzzard (Buteo rufinus) in Europe

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Abstract

Species response to climate change can be viewed in three main directions: range changes, phenological changes, and genetic selection of different traits to ensure adaptation to new conditions. Climate-niche factor analysis (CNFA) is a tool developed in order to assess species vulnerability to climate change. In order to test the usefulness of CNFA method, we have chosen the long-legged buzzard (Buteo rufinus) as a case study. This species breeds in south-east Europe, from the southern Balkans to north-western Mongolia and China, preferring open areas, arid steppes and semi-desert or mountains. According to CNFA model, long-legged-buzzard habitat receives less precipitation during the warmest period (PWQ), relative to European area, and exhibits less temperature variations during the year (TS). On the other hand, the presence of the long-legged-buzzard is associated with high values for mean diurnal range (MDR) and precipitation variations (PS). The greatest sensitivity of this species came from amount of precipitation during the warmest period (PWQ) and temperature and precipitation variations during the seasons (TS and PS). Long-legged-buzzard shows the most vulnerability in relation to precipitation of warmest period (PWQ), temperature seasonality (TS) and annual mean temperature (AMT).

Keywords: *sensitivity, exposure, vulnerability, CNFA, long-legged buzzard, climate change*

Rezumat. Sensibilitatea, expunerea şi vulnerabilitatea la schimbările climatice ale şorecarului mare în Europa

Răspunsul speciilor la schimbările climatice pot fi analizate din 3 perspective principale: schimbările ale ariei de distribuţie, schimbările fenologice şi secţia genetică a diferitelor caracteristici pentru a se putea adapta la noile condiţii. Analiza factorilor climatici de nişă (CNFA) este un instrument dezvoltat pentru a ajuta la evaluarea vulnerabilităţii speciilor la schimbările climatice. Pentru a testa utilitatea metodei CNFA, am ales ca studiu de caz şorecarul mare (Buteo rufinus). Această specie se regăşeşte în Europa de Sud-Est, din sudul Balcanilor până în nord-vestul Mongoliei şi China, preferând zonele deschise, stepele aride şi semi-deşerturile sau zonele muntoase. Conform modelului CNFA, habitatul şorecarului mare primeşte o cantitate mai mica de precipitaţii în sezonul cald (PWQ) comparative cu regiunea europeană, şi înregistrează mai puţine variaţii de temperature în timpul anului (TS). Pe de altă parte, prezenţa şorecarului mare este asociată cu valori mari ale variaţiei diurne medii (MDR) şi variaţii ale precipitaţiilor (PS). Cea mai mare sensibilitate a speciei provine de la cantitatea de precipitaţii din sezonul cald (PWQ) şi de la variaţiile de temperatură şi umiditate din toate anotimpurile (TS şi PS). Cea mai mare vulnerabilitate pentru şorecarul mare este cauzată de precipitaţiile din cea mai caldă perioadă (PWQ), sezonalitatea temperaturilor (TS) şi temperatura medie anuală (ATM).

Cuvinte-cheie: *Sensibilitate, expunere, vulnerabilitate, CNFA; şorecarul mare, schimbări climatice*

Introduction

According to Intergovernmental Panel on Climate Change (IPCC- https://www.ipcc.ch), warming induced by human activities reached approximately 1°C above pre-industrial levels in 2017, increasing on average by 0.2°C per decade. The extinction rates of vertebrate, which are higher today than ever, are mainly due to the effect of habitat loss, over-exploitation, invasive species (Foden et. al, 2013) and pollution (Lovejoy & Hannah, 2019). Overall, the principal threat to the survival of biodiversity is climate change, as the most important dimension of pollution impact (Lovejoy & Hannah, 2019). So, climate change is a real threat for living organisms. Species response to climate change can be viewed in three main directions: range changes, phenological changes, and genetic selection of different traits to ensure adaptation to new condition. Species can adapt to climatic changes, move to new and more suitable habitats, or do both (Frankham et. al., 2017).

Birds distribution is affected (directly and indirectly) by how the global climate varied over time (Fjeldsa et. al., 2020). Most avian groups have evolved within a restricted geographical area, despite the fact that birds can fly and theoretically could move around in response to changing conditions (Fjeldsa et. al., 2020). Substantial range expansions in the last 200 years could be revealed for some bird species, expansions attributed to climate changes, because climate has changed in this period of time (Newton, 2003). Population pressure in the area already occupied and the presence of suitable conditions in the area invaded are the two conditions on which any natural species expansion is based on (Newton,

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2003). In the northern hemisphere, the annual average temperature increase by up to a few degrees centigrade in many places, and the May-June isotherms moved up to several hundred kilometers northwards (Newton, 2003).

In order to identify the species most vulnerable to extinction, a framework was developed (Williams et. al., 2008; Foden et. al, 2013; Rinnan & Lawler, 2019), which guide users to measure three dimensions of climate change vulnerability: sensitivity, the degree to which the persistence of a species is determined by intrinsic factors; exposure, the extent to which the species will experience climate change in its habitat, and adaptive capacity, including evolutionary changes and plastic ecological responses.

Rinnan and Lawler (2019) have developed a technique, namely climate-niche factor analysis (CNFA) in order to assess species vulnerability to climate change. This technique is based on a method to quantify the environmental niche of a spe¬cies using presence-only data named ecological-niche factor analysis (ENFA), first introduced by Hirzel et. al. (2002).

In order to test the usefulness of CNFA method, we chose the long-legged buzzard (Buteo rufinus) as a case study, for two reasons: on the one hand, birds of prey are indicators of the diversity of communities and directly participate in regulating their stability, and on the other hand this species is expanding its range in Europe, taking advantage of global warming. The long-legged buzzard breeds in south-east Europe, from the southern Balkans (where we find the largest European breeding population) to north-western Mongolia and China (Huntley et. al., 2007; Danko, 2012; Ferguson-Lees & Christie, 2001; BirdLlife, 2020), preferring open areas, arid steppes and semi-desert or mountains (Svensson, 2009).

Methods

In ecological-niche factor analysis (ENFA), the distribution of a species in niche space is compared to the distribution of available habitat conditions (Rinnan & Lawler 2019). Because these distributions may differ with respect to their mean and their variances, the species' niche is described by two metrics, marginality and specialization. First metric expresses the position of the species conditions mean relative to global mean, and the second reflects the size of the species' niche relative to the size of the total niche space, global distribution (Hirzel et. al., 2002; Rinnan & Lawler, 2019). Marginality values close to zero indicates that the species prefer average conditions throughout the study area, whereas higher values indicate a species tendency to live in a very particular habitat. Specialization on the other hand ranges from 1 to infinity and measures the narrowness of the niche (Hirzel et. al., 2002; Basille et. al., 2008). Regarding the restriction of the species' occurrence on some bioclimatic variables, which mean a narrowness of the its ecological niche, the specialization could be interpreted as the sensitivity of species to variation around its optimum, in order to discover the limiting factors (Basille et. al., 2008).

For our study, we quantify sensitivity, exposure and vulnerability to climate change:

Sensitivity

If a species tolerates a narrow range of climatic conditions, we will expect the sensitivity to climatic factors to rise. The overall sensitivity S reflects the average specialization in each variable (Rinnan & Lawler, 2019). With CENFA tool we can create a map which could help us identify the places where we expect the species to be most sensitive to climate changes.

Exposure

Exposure to climate change can be evaluated by a dissimilarity d measure (departure factor) between current climatic data and future predictions of climate. The higher the d values, the greater the departure from current climate (Rinnan & Lawler, 2019). For each climatic variable, the departure factor identifies the average amount of change that is expected across the study area. The exposure map identifies the zones where we expect species to be most exposed to climate change.

Vulnerability

Species vulnerability to climate change can be appreciated based on interaction between sensitivity and exposure, larges values for sensitivity and departure indicating higher vulnerability in a climatic factor (Rinnan & Lawler, 2019). A specific function of CENFA R package can create a vulnerability map that identifies where we expect the species to be most vulnerable to climate change.

To quantify sensitivity, exposure and vulnerability for a species based on CENFA we need information about species presence and values of environmental factors covering the study area. The long-legged buzzard digital range map was obtained from the IUCN's Red List of threatened species GIS database (IUCN, 2019). To analyse the climate we downloaded from the WordClim (https://www.worldclim.org) database 19 bioclimatic variables, at 2.5 minutes resolution. The variation inflation factor (VIF) was used to minimize the impact of multicollinearity and over-fitting of the model, removing variables with a VIF that exceeded a threshold value of 10 (Keith, 2015), with usdm R library. Climate projections from HadGEM2 (Hadley Centre Global Environment Model version 2) climate model, for 2050 (average for 2041-

2060) and for two different representative concentration pathways (RCP4.5 and RCP8.5) was used to simulate future climate. The HadGEM2 model has been built and evaluated with all the earth system components. These components are found to perform very well, compared to observations and other models, and are certainly sufficient to replicate the desired climate feedbacks.

All analyses were conducted in R (R Core Team), version 3.6.2, mainly with the help of CENFA library (Rinnan, 2018).

Results

Given the issues related to multicollinearity, only 7 bioclimatic variables of 19 have been selected for further analysis: Annual Mean Temperature (AMT), Mean Diurnal Range (MDR), Temperature Seasonality (TS), Mean Temperature of Wettest Quarter (MTWQ), Precipitation Seasonality (PS), Precipitation of Warmest Quarter (PWQ) and Precipitation of Coldest Quarter (PCQ).

Table 1: The first three CNFA factors for long-legged buzzard (*Buteo rufinus*), sensitivity factors, departure factors and vulnerability factors calculated for 2050 HadGEM2 climate projections for two RCPs (4.5 and 8.5)

Bioclimatic variable	Marg. (6.91%)	Spec. 1 (44.35%)	Spec. 2 (17.42%)	Sens.	Dep. (RCP4.5)	Dep. (RCP8.5)	Vuln. (RCP4.5)	Vuln. (RCP8.5)
AMT*	**1.08**	0.2	0.25	1.56	**0.63**	**0.80**	**1.60****	**1.68**
PS	**1.66**	0.26	-0.66	**1.69**	**0.35**	**0.41**	1.51	**1.54**
PWQ	**-1.71**	0.7	-0.29	**2.86**	0.19	0.26	**1.85**	**1.90**
PCQ	0.75	-0.21	0.59	**1.66**	0.11	0.16	1.36	1.39
MDR	**1.73**	0.16	0.06	1.16	**0.35**	**0.41**	1.25	1.28
TS	-0.24	-0.49	0.18	**2.14**	0.32	0.38	**1.68**	**1.72**
MTWQ	-1.07	-0.28	0.16	1.33	**0.46**	**0.61**	1.39	1.46

* see text for variable name

** bold values indicate the four coefficients with the largest magnitude for each parameter

Long-legged-buzzard habitat receives less precipitation during the warmest period (PWQ), relative to the European area, and exhibits less temperature variations during the year (TS). On the other hand, the presence of the long-legged-buzzard is associated with high values for mean diurnal range (MDR) and precipitation variations (PS) (Table 1). Ecological-niche factor analysis (ENFA) and climate-niche factor analysis (CNFA) revealed that long-legged-buzzard habitat is substantially different from mean climatic conditions of Europe (overall marginality M = 3.408), but the range of long-legged-buzzard tolerable climatic conditions are not so restricted in general (overall sensitivity S = 1.331), so no narrow climatic niche for this species. The greatest sensitivity of this species came from the amount of precipitation during the warmest period (PWQ) and temperature and precipitation variations during the seasons (TS and PS) (Table 1).

Despite the fact that this raptor species appears sensitive to the amount of precipitation which falls during the coldest period of the year (PCQ), the PCQ departure and vulnerability were quite small, for both representative concentration pathways (RCP4.5 and RCP8.5). Contrary, although long-legged-buzzard showed less sensitivity to annual mean temperature (ANM), overall ANM departure and vulnerability were high (Table 1).

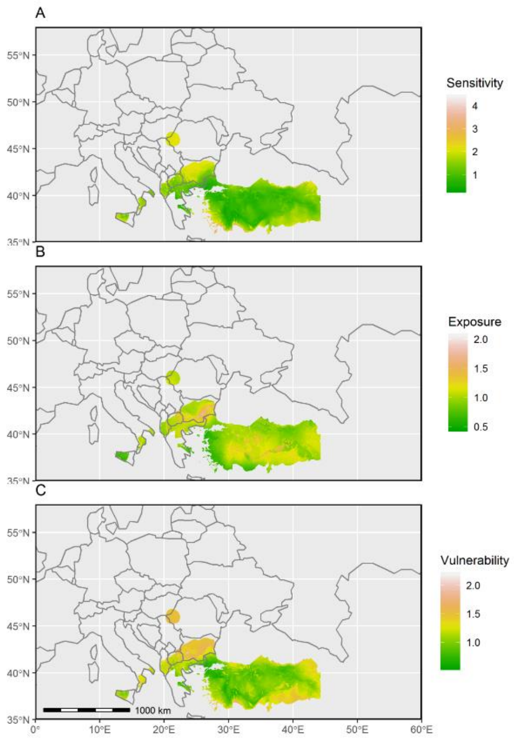

Fig. 1: Predicted sensitivity (A), exposure (B) and vulnerability (C) of long-legged buzzard (Buteo rufinus rufinus) across its european range for the HadGEM2 RCP4.5 climate scenario

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The long-legged-buzzard shows the most vulnerability in relation to precipitation of warmest period (PWQ), temperature seasonality (TS) and annual mean temperature (AMT) (Table 1). Along the long-legged-buzzard European range, the most vulnerable habitat zones are located in the northern part, throughout Bulgaria and Macedonia, and small areas in Albania, southern Italy, Serbia, Greece and the north-western part of Romania (Fig. 1 and Fig. 2).

As expected, the RCP8.5 scenario has greater departure and vulnerability than RCP4.5 scenario for all environmental variables, due to the influences of concentration of greenhouse gas emissions on the climate change magnitude (Table 1).

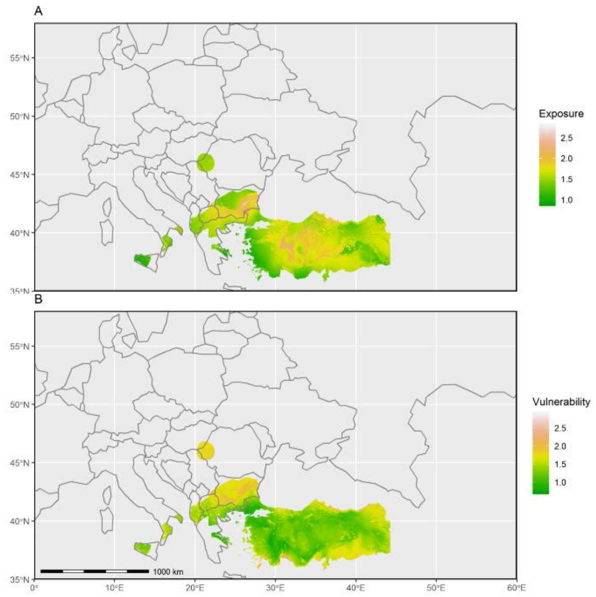

Fig. 2: Predicted exposure (A) and vulnerability (B) of long-legged buzzard (Buteo rufinus rufinus) across its european range for the HadGEM2 RCP8.5 climate scenario

Discussion

The long-legged buzzard is a raptors species which is expanding his range to the north, according to field observations (Danko, 2012) and from computer simulated future potential distribution (Huntley et. al., 2007). In the 19th century the species was present as a breeding species in Europe, but only in southern and central Greece. It was bred in Macedonia only beginning with the 1950s and in Bulgaria from 1960s (Danko, 2012). The long-legged buzzard is present in Romania too as a breeding species, since 1996 (Schmitz, 1999). Today, confirmed nesting places of the species in Romania are in Dobrogea and Arad regions (Daróczi & Zeitz, 2008, Danko, 2012), and also in Moldova (Baltag, 2010). The long-legged buzzard is also present in Slovakia, Czech Republic, Austria, Poland and Hungary in increasing numbers, with very little evidence of nesting (Danko, 2012).

Bird distributions can be affected by climate directly, on the birds themselves, or indirectly, by influencing their habitats, foods, natural enemies etc (Newton, 2003). In a study regarding the influence of the environmental factors in the establishment of the African long-legged buzzard (Buteo rufinus cirtensis) in western Europe, climatic variables (variation coefficient of precipitation, mean annual precipitation and annual temperature range) had the strongest predictive power in the model at the coarser scale (Chamorro et. al., 2017).

According to Climatic Atlas of European Breeding Birds, the long-legged buzzard breeding range is associated with dry regions, where Actual Evapotranspiration (AET) / Potential Evapotranspiration (PET) ≤0.7 (Huntley et. al., 2007). The results of this paper support this idea, the habitat of this species being characterized by less precipitation in summer (PWQ) comparing with the entire European region. More than that, the greatest sensitivity of the long-legged buzzard came from this bioclimatic variable (Table 1), which leads to the highest values of vulnerability, for both representative concentration pathways (RCP4.5 and RCP8.5).

From a spatial point of view, the most vulnerable areas of this species are located in the northern part of its range, and not by chance (Fig. 1 and Fig. 2). Beside precipitation, temperature factors, such as temperature seasonality (TS) and annual mean temperature (AMT) increase the species vulnerability. The metabolic and physiological adaptations of birds are suitable for the climate regimes in which birds live. Each species has an thermoneutral zone, which is the range of outside temperatures for which the basal metabolic rate of a bird does not change at rest (Newton, 2003). The metabolic rate increase progressively as extern temperatures falls outside the thermoneutral zone. In a study regarding North American winter bird distributions, the temperature have directly influenced the northern limit of certain species, the lenght of northern boundary beign associated with January isotherm (Newton, 2003).

Conclusions

Climate change is accelerating the extinction rates of vertebrate, being the principal threat to address of biodiversity. Species can adapt to climatic changes, move to new and more suitable habitats, or do both. In order to identify the species most vulnerable to extinction we need to measure three dimensions of climate change vulnerability: sensitivity, exposure, and adaptive capacity, especially by using a new method, namely climate-niche factor analysis (CNFA).

The greatest sensitivity of the long-legged buzzard to climate change, according to CNFA method, came from the amount of precipitation duing the warmest period (PWQ) and temperature and precipitation variations during the seasons (TS and PS). Long-legged-buzzard shows the most vulnerability in relation to precipitation of warmest period (PWQ), temperature seasonality (TS) and annual mean temperature (AMT). Vulnerability score for each species could be added to the criteria of the IUCN Red List, for adequately accounting for threats from climate changes.

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