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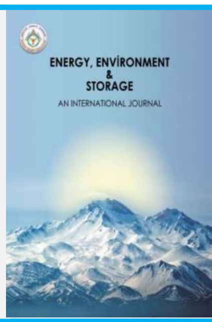

Climate Change and Animal Movement Integration in the Environmental Niche Model

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ABSTRACT. Changing precipitation and temperature patterns due to climate change, shift ecological niches which pose a challenge for species. Furthermore, it is still unclear that if climate change faster than the speed of the species to move to more suitable environments. Climate Envelope models (GEMs) are used extensively in this matter to predict species geographical distribution. In this study, climate data and animal movement strategies integrated into the environmental niche model to analyze the successes of the species that have different movement strategies under the changing climate conditions. Four different movement strategies are formulized; lazy knowledge strategy (LKS), lazy no knowledge strategy (LNKS), proactive knowledge (PKS) and proactive no knowledge strategy (PNKS). In this study, mean annual temperature and annual precipitation data gathered for the RCP8.5 scenario from the HadGEM2-ES GCM model at a 10-minute resolution. Results show that the PKS has the highest survival rates which makes it the most successful strategy. Furthermore, the species with knowledge had performed higher survival rates than the species without knowledge due to their skill to find the most suitable cells around them. One-Way Anova test confirmed that there are significant differences between the strategies. Moreover, the analysis suggests that the species with knowledge of their environment have the most successful strategies for facing the climate change.

Keywords: Environmental Niche, Climate Change, Animal Movement, Climate Envelope Models

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1. INTRODUCTION

Climate Envelope Models (CEMs) have been commonly used to predict species geographical distribution depending on their environmental necessities (Hijmans and Graham, 2006). Distribution of species is being affected by climate change, however changes in dispersion can vary substantially by species (Prevey et al., 2020;Smithers et al.,2018). The expected climatic changes will represent a demanding challenge for species to find a suitable environment, resulting in possible distributions shifts. In fact, in numerous studies, it is suggested that global climate change will cause species to move to more suitable locations (Chen at al., 2011; Ehrlén & Morris, 2015; Kelly & Goulden, 2008; Lenoir at al., 2008; Parmesan & Yohe, 2003). Miller and Holloway (2015) have highlighted the importance of including real data in species movement patterns, especially for future distributions projections ruled by climate change. Additionally, species movement may also be influenced by their biology and by interaction with the environment and other species. Different studies such as Stanton et al. (2015) affirm that species will have to traverse extensive landscapes to cope with climate change which could result in species extinction. Also, in recent years a many studies investigated how climate change effect species by using climate projections (Adde et al., 2020; Baisero et al., 2020; Hosni et al., 2020) Furthermore, climate change may be faster than the ability of species to move to more suitable environments (IPCC, 2014), and may be a driver of species extinction. The success of these distribution projections are still unclear (Hijmans &Graham, 2006), several important variables (species movement) need to be included to obtain more advance future scenarios. The purpose of this research is to understand how different species movement patterns in combination with environmental suitability may affect species distribution projections. Based on the purpose of the study, this research aims to acknowledge how will 4 different movement strategies in combination with environmental suitability (mean annual temperature and annual precipitation) affect species distribution projections for the RCP 8.5 scenario.

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2. MATERIALS AND METHODS

In this research, the Matlab modelling tool was used to combine the Environmental Niche model and the Cellular Automata model to implement more realistic species movement based on the climatic suitability. The climatic suitability is dependent on the change of 2 climatic variables; annual mean temperature and annual precipitation. The implementation of movement into the Niche model will enable the visualization of the change of species distribution over time based on initial distribution rather than probability.

2.1 Bioclimatic variables and time steps

The data on the Annual Mean Temperature and the Annual Precipitation was gathered from WorldClim for the period ~1950-2000 (current conditions) and the year 2050 (average 2041-2060) and the year 2070 (average for 2061-2080) (WorldClim, 2016.). For the current condition, the middle value of the years (~1950-2000) was selected (1975) to be the starting year for our model run. The values for the bioclimatic variables; Mean Annual Temperature and Annual Precipitation were gathered for the RCP8.5 scenario from the HadGEM2-ES GCM model at a 10-minute resolution. The reason for selecting the RCP8.5 scenario is that the changes in precipitation and temperature will be large and hence will lead to a larger effect on the movement and distribution of the species. The modelled time period is 1975-2050 and 2050-2070. Since movement is dynamic through time, annual values for the bioclimatic variables were required rather than snapshot values at 1975, 2050 and 2070. Therefore, a linear relationship was used to interpolate the values of the two climatic variables for the years from 1976 to 2049 and from 2050 to 2069. This resulted in values for the climate variables for each time step for the period of 1975-2070. By using these values, it becomes possible to apply movement to the distribution, hence show the changes in distribution over time due to climate change.

2.2 The species and its initial distribution

The species used for this research are fictive species and is therefore not based on real data. The reason for choosing a fictive species is that this research focuses on the influence of different movement patterns on the distribution of a species under changing climate conditions; it is irrelevant what the exact species is. The initial distribution of species is located around the equator since the cell size varies little in comparison to cells closer to the poles. The gauss function was used to establish the combined suitability of every cell for the species for the two climatic variables. For temperature, the optimum (mu) was set to 25 degrees Celsius with a sigma value of 5 to model a species sensitive to temperature which lives in the tropical forest around the equator. For precipitation, a mu of 1800mm and a sigma of 100 was used to place the species in the wet climate of the tropics. To establish the initial (equilibrium) distribution the suitability was used; every cell where the suitability in 1975 was higher than 0.8 one individual was placed. This resulted in an initial distribution of 4966 individuals around the equator, mainly in Brazil, Africa and Indonesia. For this research, the focus was on the distribution in the tropics in Central Africa since the density was adequate for visualization.

2.3 Movement

The species is assumed to move only one cell each time step to one of the 8 neighboring cells. Four different movement strategies were created to simulate how the way a species moves affects its survival and distribution under changing climate conditions. The movement strategies are based on two different scalars; no knowledge / knowledge and lazy / proactive. Knowledge means the species has knowledge about the suitability of the neighboring cells and the species will therefore only move to cells suitable than the one it is currently located in. No Knowledge means the species has no knowledge about the suitability of the neighboring cells. Lazy means the species prefers to stay in its current cell as long as it is suitable, because of attachment to its current environment. Proactive means the species prefers to roam around annually. Below the four different are described.

2.3.1 The Lazy Knowledge strategy (LKS)

Species with the LKS strategy have the characteristic of moving only to cells that have better suitability than the one they are currently located, because they have knowledge of the suitability values from their neighboring cells (Figure 1). There are two types of rules that drive this strategy. If the local suitability is high, the species has a low probability to move, and vice versa. If the species does decide to move, it will evaluate the environmental suitability of the neighboring cells. If there are no neighboring cells with a higher suitability, the species will stay in its current cell. If there are neighbors with higher suitability values, the species will move with a probability condition; if the probability condition is met, the species choose randomly to which cell to move. If the probability condition is not met, the species remains in its current cell. The species that uses this strategy have a high inclination of saying in their cell if it is suitable.

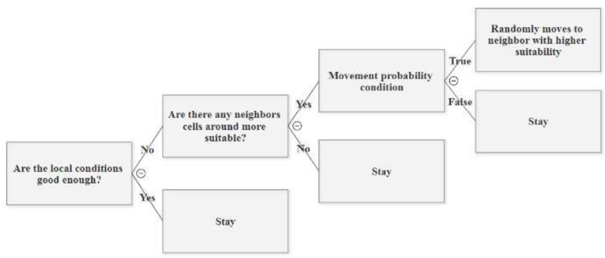

Fig. 1. The decision tree for the movement strategy Lazy Knowledge Strategy (LKS)

2.3.2 The Lazy No Knowledge strategy (LNKS)

The LNKS is similar to the LKS. The main difference is that this strategy does not have knowledge of the suitability of the surrounding cells. If the suitability of the local cell is low, the species has a high probability to move randomly to a neighboring cell, and vice versa, without taking into account the suitability of the cell it moves to (Figure 2).

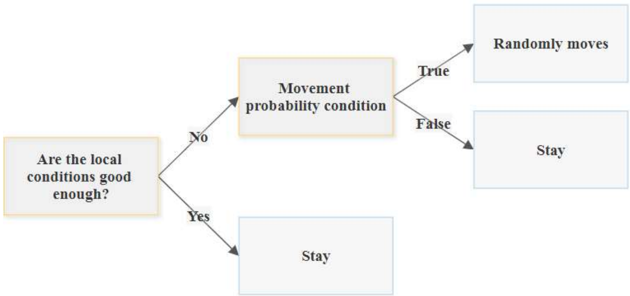

Fig. 2. The decision tree for the movement strategy Lazy No-Knowledge Strategy (LNKS)

2.3.3 The Proactive knowledge Strategy (PKS)

The PKS knows the suitability of their neighboring cells, just like the LKS. If the suitability of the neighboring cells is lower than the suitability of the current cell, the species will remain in the current cell. If the suitability values of the neighboring cells are higher, the species has a probability to move to every neighboring cell. If the probability condition is met, the species will randomly move to any neighbor with a higher suitability (Figure 3). This movement strategy has a higher chance of movement than the LKS, hence it is proactive.

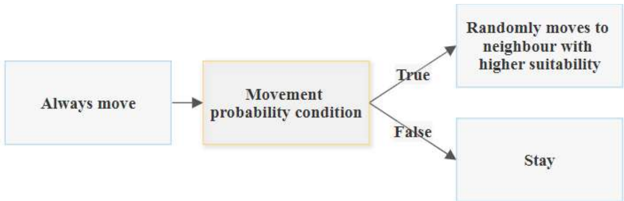

Fig. 3. The decision tree for the movement strategy Proactive Knowledge Strategy (PKS)

2.3.4 The Proactive No Knowledge Strategy (PNKS)

The PNKS is the simplest strategy; the species will randomly move to a neighbor every year. The species has no knowledge about the suitability of the neighboring cells; the movement is driven by randomness and is therefore similar to dispersal (Figure 4).

Fig. 4. The decision tree for the movement strategy proactive no knowledge (PNKS)

2.4 Movement Rules

Extinction due to climate conditions was added to the model to make sure that individuals living under unsuitable conditions would not survive since this would give unrealistic distributions. However, even at high suitability extinction due to climate conditions can happen due to local conditions, albeit at a low rate. There a mathematical function was introduced that will have a high probability of extinction at low suitability values and a low probability of extinction at high suitability values (Figure 5): the Probability to go extinct = 1*exp (-10.*Suitability of the Cell). By making the function an exponential decline function, the extinction probability is low for a suitability of >0.5. Below 0.5 the chance to go extinct increases exponentially to a probability of 1 at a suitability of 0. This extinction probability is included for all movement strategies.

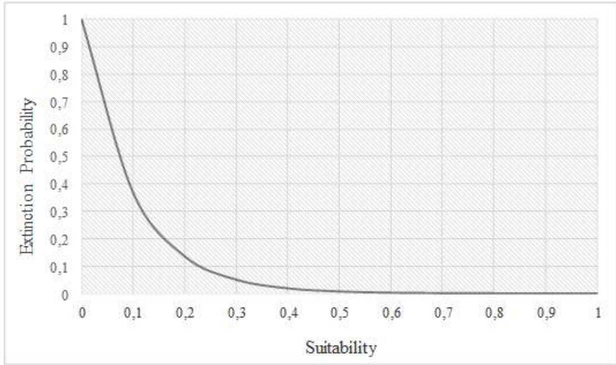

Fig. 5. The visualization of the extinction formula, probability to go extinct = 1*exp(-10*Suitability)

2.5 Statistical analysis

A One-way Anova test was performed to determine if there were any statistical differences between movement strategies in relation with number of individuals and cells occupied. A Shapiro Wilk test was performed to identify if variables were normally distributed. Additionally, a Levene's test was used to check for homoscedasticity.

3. RESULTS

The spatial distribution of the species for the four different movement strategies is shown in figure 6. It is obvious that the PNKS strategy is least successful, both in individual numbers and the extent of its distribution. However, for the strategies, the differences are less clear. The results of the statistical tests are discussed below to distinguish between the success of the various movement strategies.

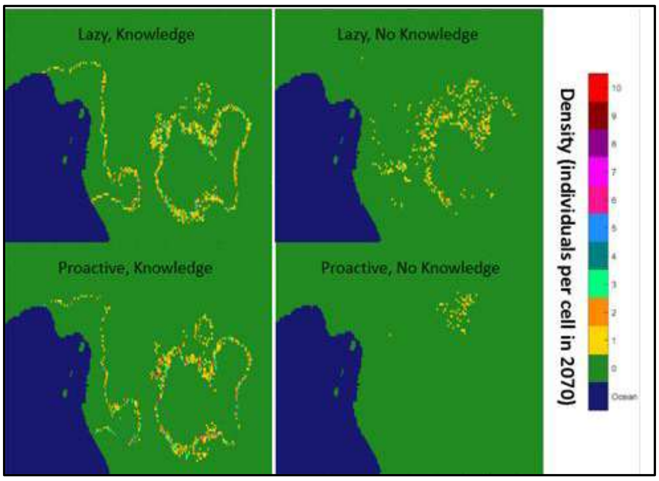

Fig. 6. The distribution maps in 2070 for the four different movement strategies in Central Africa

The results of the model indicate that the PKS is the best strategy for species to survive under the RCP 8.5 scenario. The species with knowledge had a better survival performance than the species without knowledge (Figure 7). For each strategy, different distributions were observed (Figure 6); the species with knowledge tend to congregate together in highly suitable cells while the species who do not have knowledge disperse and experience higher extinction rates. There is a considerable decrease in populations by 2070 for LNKS and PNKS by 78.7% and 98.6% respectively. On the other hand, the LKS and PKS performed better by 35.6% and 40% decrease in population respectively. The One Way Anova test confirmed that there are strong significant differences between all groups (p=0.00).

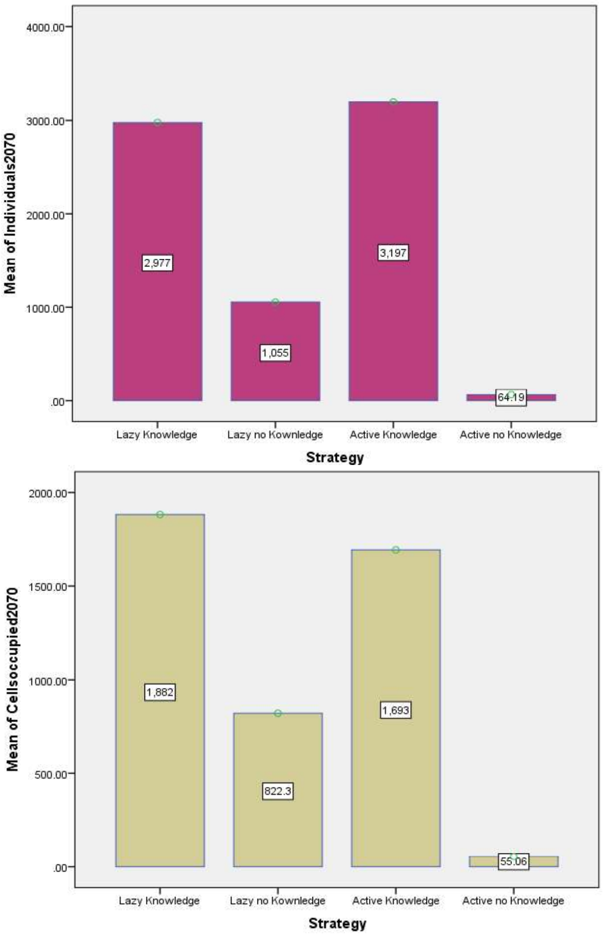

Fig. 7. The mean amount of individuals that survived in 2070 (top) and the mean amount of cells occupied (n=33 runs) in 2070 for the four different movement strategies (bottom).

Regarding occupied cells, the Anova tests also confirmed significant differences between strategies (p=0.00). The PKS is the strategy with most cells occupied in 2070, followed by LKS, LNKS and PNKS (figure 7). The occupied cells results are consistent with the number of individual alive in 2070, showing the strategies with more individuals alive are also the ones with more occupied cells due to high number of individuals.

4. CONCLUSIONS

The study suggests species with knowledge of their environment have the most suitable strategy for facing climate change. On the other hand, even if strategies are significantly different (p=0.00), the LKS strategy leads to a high number of surviving individuals in 2070 compared to the no knowledge strategies. The clustering of the PKS may seem to be a good strategy to face climate change. However, the model does not take into account the interaction between individuals (competition) or any sort of carrying capacity. Therefore high densities of individuals in one cell are unlikely to occur in reality, although this is also partially dependent on the characteristics of the species. This assumption, and the lack of adaptation, stem from the original Niche model.

Different assumptions might have influenced strategies movement. The model assumed species could only move one cell per year in eight directions. In reality, the step size is dependent on the characteristics of the species and therefore could potentially be smaller or larger than one cell. The model used a fictive species with an equilibrium distribution located around the equator, since the cell sizes in this region are similar. The rule of moving one cell per year is more valid than for areas closer to the poles where the differences in cell size are larger. The movement strategies fit within a simple version of the Lagrangian approach applied to the Niche model (Smouse et al., 2010).

Another assumption is based on the climatic parameters and data. The model only used two climatic parameters (annual mean temperature and annual precipitation), whereas other climatic factors may also have influenced species movement projections. The available data was limited to only three averages in time and linear changes in mean annual temperature and annual precipitation around the globe was assumed to be able to model annual distribution changes. Natural movement barriers such as lakes and rivers, and anthropogenic structures such as city, roads and towns were also not taken into account.

This model included different strategies that species may use to compensate with climate change projections. However, further research may include real data and species behavior to have a better understanding of how climate change will relate to species movement and extinction.

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