Modeling the Spatial Impact of Climate Change on Grevy's Zebra (Equus grevyi) niche in Kenya

Charles Kigen
Moi University

Okoth Patrick
Masinde Muliro University of Science and Technology

William Shivoga
Masinde Muliro University of Science and Technology

Dennis M.W. Ochieno
Masinde Muliro University of Science and Technology

Available online at www.elixirpublishers.com (Elixir International Journal)

Remote sensing

Elixir Remote sensing 62 (2013) 17608-17611

ISSN: 2229-712X

Modeling the Spatial Impact of Climate Change on Grevy's Zebra (*Equus grevyi*) niche in Kenya

Kigen C.[1*], P. Okoth[1], M. Konje[1], W. Shivoga[1], D. Ochieno[1], S. Wanjala[1], H. Agevi[1], Z. Onyando[1], B. Soy[2], P. Kisoyan[3] and S. Makindi[3]

[1]Department of Biological Science, Masinde Muliro University of Science and Technology.

[2]Department of Natural Resources, Chuka University.

[3]Department of Environmental Science, Egerton University.

ARTICLE INFO

Article history:

Received: 18 July 2013;

Received in revised form: 20 August 2013;

Accepted: 2 September 2013;

Keywords

Equus grevyi,

Climate change,

Species distribution model,

Niche,

Conservation.

ABSTRACT

Although Grevy's zebra (*Equus grevyi*) is listed as endangered species and is an important attraction in Kenya's tourism industry, there have been no attempts to model the implications of climate change on their niche. This study modeled the potential current and future (the year 2080) distribution in Kenya. The *E. grevyi* location data were sourced from published literature and climate data was downloaded from world climate database website and analysis done using MaxEnt and DIVA-GIS. The model generated an excellent AUC of 0.984 and the future niche is shown to expand. The main five variables contributing more than 2% of change in niche expansion are isothermality, precipitation of coldest quarter, annual mean temperature, annual precipitation, min temperature of coldest period and precipitation of wettest quarter. The generated information will assist conservation policy makers to make informed decisions.

Introduction

Climate change is of global concern affecting all biomes ranging from grasslands, forests to aquatic ecosystems. These biomes are natural habitats of many organisms whose niches are also affected in the same magnitude and direction (Millennium Ecosystem Assessment, 2005). The changes in temperature and rainfall patterns have had direct impacts on the land use land cover (LULC) (Stephenson, 1990) and other organisms. Ecologically, particular biomes have distinct characteristics including the animals they support. An ecosystem like tropical savannah grasslands support directly and indirectly a huge number of animals including the endangered *E. grevyi* (IUCN 2013; KWS 2008) and is a legally protected animal in Kenya (KWS 2008). The Intergovernmental Panel on Climate Change (2000) findings indicated that developing countries such as Kenya will be hit most by climatic variations due to various reasons. Climate change is therefore a concern for Kenya as it plans to promote sustainable utilization of its natural resources and promotion of sustainable development in the tourism sector.

The natural ecological niche of *E. grevyi* in Kenya is confined in the arid and semi-arid lands where water availability is permanent Williams (2002). *Equus grevyi* are primarily grazers but brows up to 30% of their diet during drought Williams (2002). Climate variability, poaching activities disease outbreaks and human activities are cited as the critical factors controlling *E. grevyi* population (Muoria *et al.* 2005a). Climate variables especially precipitation and temperature controls the distribution of *E. grevyi* pastures and water availability. The *Equus grevyi* pasture is controlled by the climatic variables such as rainfall and temperature requirements. These weather elements have been documented to have changed and also projected to change in the future (WMO 1996; Hijmans *et al.* 2005).

Equus grevyi have undergone one of the most substantial reductions of range of any African mammal species (KWS 2008) and was listed as Endangered A1a, 2c by the IUCN/SSC Equid Specialist Group (IUCN, 2003). Its population estimates have been on decline from 13,718 in 1977 (Dirschl and Wetmore, 1978) to between 1,838 and 2,319 (Mwasi and Mwangi, 2007). They are of economic importance in Kenya's tourism industry and modeling their distribution will provide a fundamental approach in understanding and effectively managing their current and future potential distribution.

A number of studies have been done on spatial species distribution modeling using one method or comparison of different methods. Pearson and Dawson (2003) in their studies recommended the use of CEM in species distribution studies. Climate Envelope Modeling (CEM) and spatial analysis tools will be used in estimating the current and future niche of *E. grevyi*. The modeling system combines several information namely geo-referenced species locality and climate data containing nineteen variables (Philips *et al.* 2006). Other researchers like Skidmore *et al.* (2000), Christensen *et al.* (2004), Lunetta *et al.* (2006) and Zonneveld *et al.* (2009) have used GIS in their studies and have recommended its application in similar studies as they are easy to use, integrate a lot of information and do complex analysis. The output is a map showing current range of niche and the changes in the niche with climate variability. The future distribution output map comprises areas of high impact, areas of low impact and potential new areas of niche expansion (Philips *et al.* 2006). Such information is important in the sense that the conservation of these endangered species should be prioritized in areas with suitable niche.

In view of these climatic variations, this paper sought to model *E. grevyi* potential distribution in current and the year 2080 climatic times. Regardless of its dependence on climate

Tele:

E-mail addresses: charleskigen@gmail.com

variables, the future distribution of *E. grevyi* has not been modeled, where useful policy and planning information can be generated.

Methods

Data sources

The *Equus grevyi* location data were sourced from Kenya Wildlife Service information in their website (*www.kws.org*), a conservation and management strategy for *E. grevyi* in Kenya 2007-2011 report, World Resources Institute (*www.wri.org*) with Kenya's spatial data of protected areas, publication descriptions from Williams (2002), Mwasi, S. and Mwangi, E. (2007), Muoria *et al.* (2005a), Muoria, *et al.* (2005b) and the International Union for the Conservation of Nature red list (*www.iucnredlist.org*). From this data, sixty geo-referenced *E. grevyi* occurrence points were generated proportionately giving preference to areas with high natural populations. The current and future (2080) climate data with a resolution of 5 km were downloaded from Global Climate Data website (*www.worldclim.org*). The future climate data is under CCM3 A2 carbon dioxide emission scenario and contains nineteen variables coded as BIO1 = Annual mean temperature, BIO2 = Mean diurnal range (max temp – min temp) (monthly average), BIO3 = Isothermality (BIO1/BIO7) * 100, BIO4 = Temperature Seasonality (Coefficient of Variation), BIO5 = Max Temperature of Warmest Period, BIO6 = Min Temperature of Coldest Period, BIO7 = Temperature Annual Range (BIO5-BIO6), BIO8 = Mean Temperature of Wettest Quarter, BIO9 = Mean Temperature of Driest Quarter, BIO10 = Mean Temperature of Warmest Quarter, BIO11 = Mean Temperature of Coldest Quarter, BIO12 = Annual Precipitation, BIO13 = Precipitation of Wettest Period, BIO14 = Precipitation of Driest Period, BIO15 = Precipitation Seasonality (Coefficient of Variation), BIO16 = Precipitation of Wettest Quarter, BIO17 = Precipitation of Driest Quarter, BIO18 = Precipitation of Warmest Quarter and BIO19 = Precipitation of Coldest Quarter.

***Equus grevyi* Potential Distribution Modeling**

The DIVA-GIS program was used to extract the 19 climate variables data of Kenya while Maxent described the present *E. grevyi* distribution using the location data as presence training points. The climate envelopes were then mapped and changes in the distribution range analyzed for present and future climates. The climate variables in the same grid as presence points were extracted, averaged and the difference sought from current to 2080. The robustness of the model developed was validated using cross tabulation one of the methods available in the Maxent software.

Results and Discussion

All the 19 climatic variables were used in the model, 57 of the location data were used for training and 10049 points used to determine the Maxent distribution (background points and presence points). Figure 1 is the omission rate and predicted area as a function of the cumulative threshold which is calculated on the training presence records, on the test records. The closer the Omission on training samples line is to the Predicted omission, the more accurate the generated model. In work done by Zonneveld, *et. al* (2009) they location data used for *Pinus kesiya* and *P. merkusii* were 46 and 50 respectively.

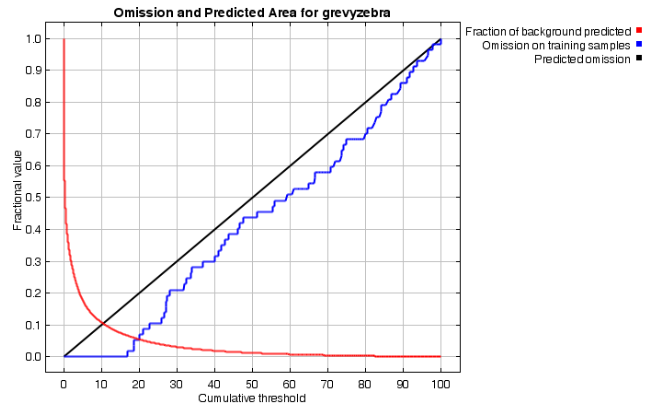

Figure 1: The omission rate and predicted area as a function of the cumulative threshold for *E. grevyi*

Area Under Curve (AUC) of the Receiver Operating Characteristic (ROC) curve figure 2, is a parameter used to evaluate the predictive ability of the generated model. It measures the likelihood that a randomly selected presence point is located in a raster cell with a higher probability value for species occurrence than a randomly selected absence point. The generated model's AUC for training data was 0.984 with a random prediction AUC of 0.5. This is an excellent model as the AUC is more than 0.90 as recommended by Araújo *et al.* (2005).

Philips *et al.* (2005) compared Maxent and Genetic Algorithm for Rule-Set Prediction methods in species geographic distribution work. Their results showed that both models were significantly better than random when tested for omission and ROC analysis. They further concluded that Maxent showed better discrimination of suitable and unsuitable areas of the species in the analysis of AUC.

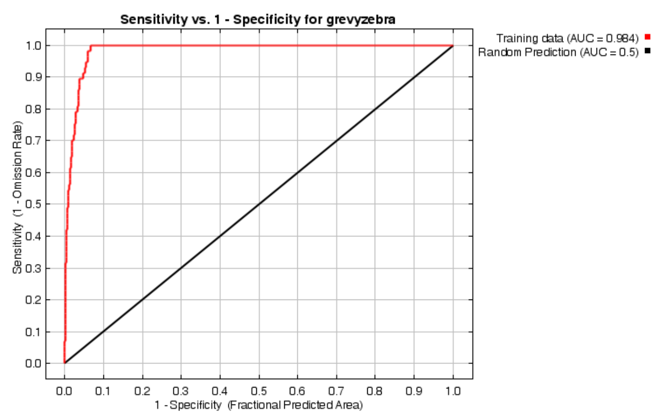

Figure 2: The receiver operating characteristic (ROC) curve for *E. grevyi*

The key environmental variables that contributed to more than two percent of the Grevy 's zebra distribution and variations between the two time periods (table 1) are Isothermality (49.3%), Precipitation of Coldest Quarter (34.4%), Annual mean temperature (2.7%), Annual Precipitation (2.5%), Min Temperature of Coldest Period (2.3%) and Precipitation of Wettest Quarter (2.3%). These parameters were extracted from the presence points and averaged for all the points. Apart from isothermality that is projected to decrease, all the other variables increase as indicated in table1.

Table 1: ***Change in the key environmental variables contributing more than 2% in E. grevyi distribution***

Environmental Variable	Percent contribution	Present Value	2080 Value	Change Value
Isothermality	49.3	83.52	84.31	-0.79
Precipitation of Coldest Quarter	34.4	27.25	12.32	14.93
Annual mean temperature	2.7	14.30	15.22	-0.92
Annual Precipitation	2.5	579.93	448.73	131.20
Min Temperature of Coldest Period	2.3	17.69	16.20	1.49
Precipitation of Wettest Quarter	2.3	278.80	221.88	56.92

Present and Future Potential Distribution of *Equus grevyi*

Current distribution

The developed current potential distribution map figure 3 areas with over 10% chance of it being *E. grevyi* niche. It shows that apart from, the recorded presence points in game reserves, game parks and conservancies, the *E. grevyi* niche occur in several other locations within the arid lands of Kenya. Its continuous current niche covers Laikipia, Marsabit, Samburu, Isiolo, Meru North, Tharaka and Mwingi districts. Other districts covered by the *E. grevyi* isolated niches are, Tana River, Garissa, Mbeere, Machakos and Turkana. The areas where the *E. grevyi* was introduced Southern part of Tsavo East National Park (KWS, 2008) was not captured as the current niche by the model output. The modeled current niche covers largely the same area as the published IUCN (2003) map available in their website. It is also in consistent with the KWS (2008) map and descriptions from Muoria *et al.* (2005a), Muoria *et al.* (2005b) and Williams (2002).

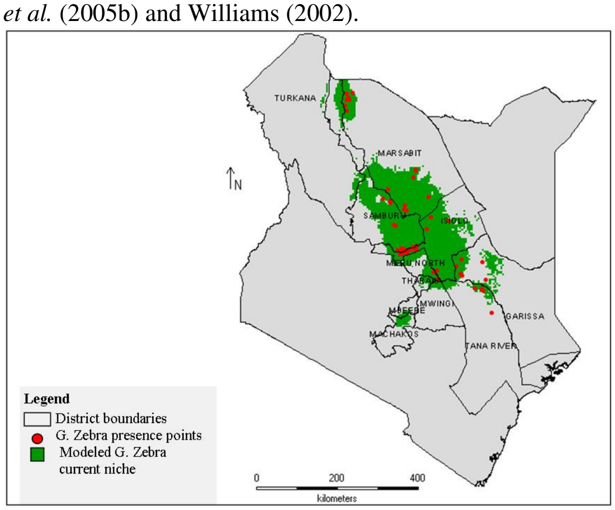

Figure 3: current modeled *E. grevyi* niche

The current modeled niche covers large areas than the currently documented *E. grevyi* areas of existence. The populations of *E. grevyi* are under pressure from livestock activities, poaching and are also controlled by climatic conditions.

The potential *E. grevyi* niche in the year 2080 climate figure 4 shows evidence of changes in the niche categorized as high impact, low impact and potential new areas. The high impact area (most negatively affected) are isolated and covers Tharaka, Meru North, Isiolo and Samburu districts. The low impact region is one continuous niche extending through Isiolo, Samburu, Marsabit, Garissa, Tana River, Turkana, Mbeere and Machakos. Also generated in the model are potential areas of niche expansion coveringTurkana, Marsabit, Mandera, Moyale, Wajir, Garissa, Tana River, Mwingi and isolated pockets in Machakos and Kajiado districts.

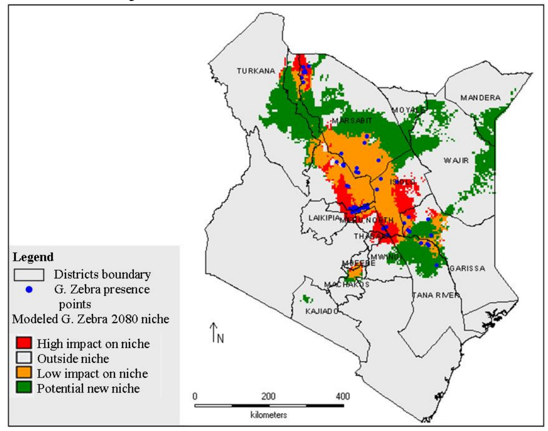

Figure 4: Modeled 2080 *E. grevyi* niche

These results are consistent with what other researchers concluded. A study in South East Asia on the impacts of climate on pine distribution used Maxent and DIVA GIS software concluded that the spatial distribution of pine will change with climate by the year 2050. The pine populations especially in China, Cambodia and Thailand are under threat Zonneveld *et al.* (2009). They further discovered that areas with potential new pine niche cover Malay Archipelago. The key environmental variables in the output model were annual temperature, maximum temperature, temperature seasonality, annual precipitation and precipitation in the driest quarter. Ward (2007) used DOMAIN, MAXENT and BIOCLIM to model the potential geographic distribution of six invasive ant species in New Zealand. The research concluded that unlike DIMAIN and MAXENT, BIOCLIM performed poorly with low AUC and higher omission errors.

Conclusion and recommendations

The *E. grevyi* conservation is critical for Kenya's economy and ecology. With the changing climate, modeling can provide the potential changes in their niche. The model performance was good and the output generated important information for decision making process. It predicted the potential extent and nature of climate impacts on *E. grevyi* niche enabling authorities to anticipate the impacts and identify new opportunities. In general, climate change is predicted to support the expansion of *E. grevyi* niche where land could be set aside in advance for their future conservation. Other important variables that should be considered in the model are human activities such are farming, livestock and ranching.

Reference

Araújo MB, Pearson RG, Thuiller W, Erhard M. Validation of species–climate impact models under climate change. Global Change Biology. 2005; 11: 1504–1513.

Cullen BR, Johnson IR, Eckard RJ, Lodge GM, Walker RG, Rawnsley RP, McCaskill MR. Climate change effects on pasture systems in south-eastern Australia Crop and Pasture Science, 2009; vol. 60, 933–942

FAO (1996). Agro-ecological Zoning Guidelines. FAO Soils Bulletin 73. Rom.

Food and Agricultural Organization. Agro-ecological Zoning Guidelines. FAO Soils Bulletin. 1996; 73. Rom.

Hernandez PA, Graham CH, Master LL, Albert DL. The effect of sample size and species characteristics on performance of different species distribution modeling methods. Ecography. 2006; 29: 773-785.

Hijmans RJ, Susan EC, Juan LP, Jones PG, Jarvis A. Very High Resolution Interpolated Climate Surfaces for Global Land Areas. Int. J. Climatol. 2005; 25: 1965–1978

Intergovernmental Panel on Climate Change. 'Emissions scenarios. Special Report of the Intergovernmental Panel on Climate change.' (Eds Nakicenovic N, Swart R). 2000; (Cambridge University Press: Cambridge, UK).

Intergovernmental Panel on Climate Change. Climate Change 2001: Synthesis Report - A contribution of Working Groups I, II and III to the Third Assessment Report of the Intergovernmental Panel on Climate Change (Watson RT, Core Writing Team (Eds)). 2001; Cambridge University Press, UK, 398 pp.

International Union for the Conservation of Nature. IUCN Red List of Threatened Species. 2003; (cited May 2013). Available from http://www.iucnredlist.org. Vol. 2003. IUCN/SSC, Cambridge.

Kenya Wildlife Service. Conservation and Management Strategy for Grevy's Zebra (*Equus grevy*) in Kenya 2007-2011 Report. 2008; Nairobi Kenya pp 9, 35.

Liu C, Berry PM, Dawson TP, Pearson RG. Selecting thresholds of occurrence in the prediction of species distributions. Ecography. 2005; 28: 385 -393.

Millennium Ecosystem Assessment. Ecosystems and human well –being: Synthesis. 2005; Island Press, Washington DC, pp 68.

Muoria PK, Rubenstein D, Oguge N. Conservation of Grevy's zebras (*Equus grevyi*) in Samburu, Kenya. In Samburu Conservation Research Initiative Annual Report 2005a. 2005; 19-25

Muoria, PK, Muruthi P, Rubenstein D, Oguge NO, Munene E. Cross-Sectional survey of gastro-intestinal parasites of Grevy's zebras in southern Samburu, Kenya. Afr. J. Ecol. 2005b; 43, 392–395

Mwasi S, Mwangi E. Proceedings of the National Grevy's Zebra Conservation Strategy Workshop 11 -14 April 2007. 2007; KWS Training Institute, Naivasha, Kenya.

Pearson RG, Dawson TP. Predicting the impacts of climate change on the distribution of species: are bioclimate envelope models useful? Global Ecology and Biogeography. 2003; 12: 361–371.

Phillips, SJ, Anderson RP, Schapire RE. Maximum entropy modeling of species geographic distributions.Ecological Modeling. 2006; 190: 231–259.

Stephenson, NL,. Climatic control of vegetation distribution: The role of the water balance. American Naturalist. 1990; 135: 649–670.

Ward DF. Modelling the potential geographic distribution of invasive ant species in New Zealand. Biol Invasions. 2007; 9:723–735 DOI 10.1007/s10530-006-9072-y

Williams SD. Status and Action Plan for Grevy's zebra (*Equus grevyi*). In: Moehlman, P.D. (ed.) Equids: Zebras, Asses, and Horses: Status Survey and Conservation Action Plan. IUCN/SCC Equid Specialist Group. 2002; IUCN (The World Conservation Union), Gland Switzerland and Cambridge.

World Meteorological Organization. Climatological Normals (CLINO) for the period 1961–1990. 1996; World Meteorological Organization: Geneva, Switzerland.

Zonneveld MV, Koskela J, Vinceti B, Jarvis A. Impact of climate change on the distribution of tropical pines in Southeast Asia. Unasylva 2009; Vol. 60231/232.