6-2021

EVALUATING GLOBAL ENVIRONMENTAL CHANGES FROM 1979 TO 2019, TO IDENTIFY PRIORITY CONSERVATION AREAS FOR BIRDS

Qihui Wang
qihwang@clarku.edu

EVALUATING GLOBAL ENVIRONMENTAL CHANGES FROM 1979 TO 2019, TO IDENTIFY PRIORITY CONSERVATION AREAS FOR BIRDS

QIHUI WANG

MAY 2021

A MASTER'S PAPER

Submitted to the faculty of Clark University,

Worcester, Massachusetts,

in partial fulfillment of

the requirements for

the degree of Master of Arts

in the departments of International Development, Community, and Environment

And accepted on the recommendation of

Florencia Sangermano, Chief Instructor

ABSTRACT

EVALUATING GLOBAL ENVIRONMENTAL CHANGES FROM 1979 TO 2019, TO IDENTIFY PRIORITY CONSERVATION AREAS FOR BIRDS

QIHUI WANG

Nowadays, global warming is unignorable. In response, climate changes have caused impacts on natural and human systems on all continents and across the oceans, which means that global species' distributions, populations, and other activities are highly affected by climate change (AR5 Synthesis Report, n.d.). Therefore, studying environmental changes to identify priority protected areas is of significance to species protection.

In this study, 19 global bioclimatic variables from 1979 to 2019 were developed and used to evaluate temporal trends. The variables include annual averages, seasonality, and climatic extremes. As these variables are known to limit species physiological performance, changes in these variables can be related to the distributional effects of biological organisms. The species distribution data from the IUCN Red List of Threatened Species™ (IUCN 2020) was used to calculate birds' diversity. Finally, global Priority Conservation Areas for birds were identified by combining the temporal change in 19 bioclimatic variables with birds' diversity.

Florencia Sangermano, Ph.D.
Chief Instructor

ACKNOWLEDGEMENTS

I am grateful to my advisor Professor Florencia Sangermano, for her patience and continuous encouragement and guidance in developing this thesis, which significantly improved my understanding of academic writing and taught me many specific research skills. Without her constant support and enlightening guidance, I would not have finished this paper. I also need to thank my parents for their support and understanding during my master’s study.

Table of Contents

Introduction

Climate is the main factor restricting the distribution, growth, and reproduction of organisms. Organisms can be sensitive to temperature and climate fluctuations because of adaptations to specific ranges of climate conditions. Others are indirectly affected by changes in the interactions with other species. Nowadays, global climate change is unignorable and has affected ecosystems(*AR5 Synthesis Report*, n.d.; Remya et al., 2015; Rinawati et al., 2013; Sintayehu, 2018; Tilman et al., 2006; Watson et al., 2006; Wormworth & Mallon, 2010). As AR5 Synthesis Report: Climate Change 2014 showed that the global average surface temperature increased 0.85 ^{O}C from 1880 to 2012 and will keep increasing due to continued emission of greenhouse gases (*AR5 Synthesis Report*, n.d.). Changes in climate have caused impacts on natural and human systems on all continents and across the oceans.

Global species' distributions, populations, diversity, and other activities are highly affected by climate change (*AR5 Synthesis Report*, n.d.). Several studies have shown evidence of the relationship between temperature increase, changes in precipitation patterns, and other extreme climatic events on widespread impacts on biodiversity (Parmesan & Yohe, 2003; Root et al., 2003; Watson et al., 2006). Even slight changes in climate conditions can drive species to extinction, such as the golden toad and Monteverde harlequin frog (McCarthy et al., 2001), or the edge of extinction, such as the Polar bear and North Atlantic whale (Sintayehu, 2018). Climate changes can lead to phenological changes, which have been widely observed globally (Both et al., 2004; Cooke et al., 2004; Crick & Sparks, 1999; Fitter & Fitter, 2002; Menzel, 2000; Murphy-Klassen et al., 2005, p.; Roy & Sparks, 2000; Wormworth & Mallon, 2010). This would result in a biological mismatch, affecting species' reproduction (Both et al., 2006, Sanderson et al., 2006). The variation in temperature and precipitation patterns can result in more frequent droughts and floods, making the plants more vulnerable to pests and disease (Tibbetts, 2007). And the temperature increases may also lead to forest movement much faster than the rate of natural forest movement (Gates 1990).

Biodiversity increases the resilience of ecosystems to climate changes (Campbell et al., 2011; Jiang & Pu, 2009; Loreau & Mazancourt, 2013; Tilman et al., 2006), it enhances the efficiency of ecological communities in capturing resources, biomass production, and nutrient recycling (Cardinale et al., 2012). Thus, the loss of local and global species may threaten the stability of ecosystem services on which humans depend (McCann, 2000). According to the insurance hypothesis (Yachi & Loreau, 1999), ecosystems with high biodiversity are more likely to contain species with characteristics that enable them to adapt to changing environments, providing an ecological buffer that may prevent further ecosystem changes and biodiversity loss.

Climate stability is important for biodiversity, and ecosystem stability may respond to climate change in a complex and multi-dimensional manner(Donohue et al., 2016). For example, changing climatic conditions will affect the stabilization of plant diversity(Hautier et al., 2015; Ma et al., 2017; Shi et al., 2016). Cowling et al. (2004) also found a strong positive relationship between long-term climate stability and regional-scale plant diversity in the four Mediterranean-type ecosystems (Cowling et al., 2004).

Conservation prioritization is necessary to protect the stability of ecosystems. Identifying conservation priorities is an essential step in conservation planning (Ferrier & Wintle, 2009), as it can provide information about when, where, and how we can efficiently achieve conservation goals (Kremen et al., 2008; Wilson et al., 2009).

The objective of this study was to identify global priority conservation areas for birds based on the assessment of 40 years of global trends in bioclimatic variables. Combined with global bird species distribution from IUCN/ Birdlife, priority conservation areas for birds were identified based on species richness and climate stability.

Method

This study aims to identify global conservation priority areas for birds based on richness and environmental stability. The study was divided into two parts: Time series analysis of Bioclimate variables and Identifying Priority Conservation Areas. The workflow is shown in the figure 1.

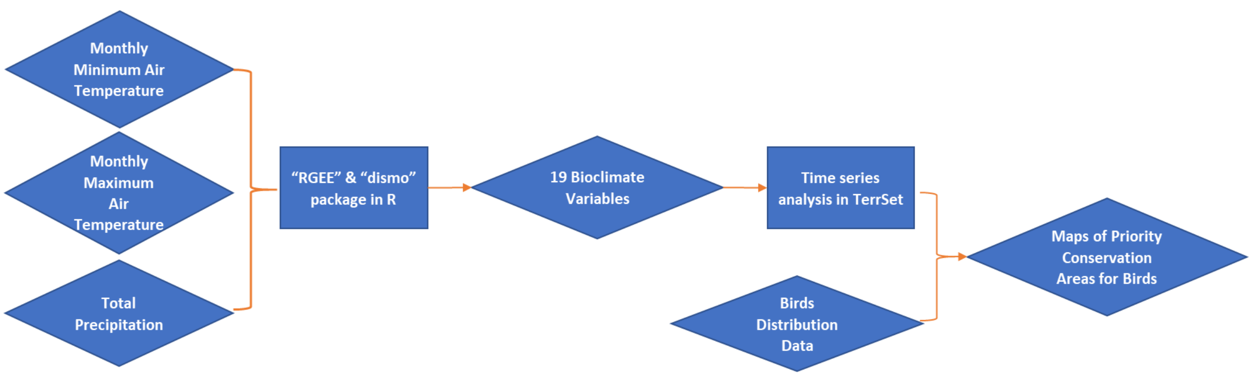


Fig 1. Workflow

Bioclimate variables and Time series analysis

The climate data I used is ERA5, which is the fifth-generation ECMWF atmospheric reanalysis of the global climate. ERA5 combines modeled data with global observations into a globally complete and consistent dataset. In this research, I used ERA5 monthly minimum air temperature at 2m height, maximum air temperature at 2m height, and total precipitation data with 0.25 degrees resolution from 1979 to 2019 (Copernicus Climate Change Service (C3S) (2017)).

To better capture climate conditions related to species physiology, the U.S. Geological Survey proposed a set of 19 bioclimatic predictors (USGS Data Series 691: Bioclimatic Predictors for

Supporting Ecological Applications in the Conterminous United States, n.d.). I used "RGEE" package (C Aybar et al.) and "dismo" package (Robert J. Hijmans et al.) in R to calculate these global bioclimate variables as shown in table 1 from 1979 to 2019. The process resulted in 19 time series - one for each bioclimatic variable.

Bioclimatic trends over the 40 years were analyzed through a linear trend analysis. The analysis results were the slope coefficient of an ordinary least squares regression between the values of each pixel over time and a perfectly linear series, which showed the expressions of the rate of change per time step (in this case: per year).

Tab 1. 19 Bioclimate variables with descriptions

Variables	Description
BIO1	Annual Mean Temperature (◦C)
BIO2	Mean Diurnal Range (Mean of monthly (max temp − min temp))
BIO3	Isothermality (BIO2/BIO7) (* 100)
BIO4	Temperature Seasonality (standard deviation *100)
BIO5	Max Temperature of Warmest Month (◦C)
BIO6	Min Temperature of Coldest Month (◦C)
BIO7	Temperature Annual Range (BIO5-BIO6)
BIO8	Mean Temperature of Wettest Quarter (◦C)
BIO9	Mean Temperature of Driest Quarter (◦C)
BIO10	Mean Temperature of Warmest Quarter (◦C)
BIO11	Mean Temperature of Coldest Quarter (◦C)
BIO12	Annual Precipitation (mm)
BIO13	Precipitation of Wettest Month (mm)
BIO14	Precipitation of Driest Month (mm)
BIO15	Precipitation Seasonality (Coefficient of Variation)
BIO16	Precipitation of Wettest Quarter (mm)
BIO17	Precipitation of Driest Quarter (mm)
BIO18	Precipitation of Warmest Quarter (mm)
BIO19	Precipitation of Coldest Quarter (mm)

Identify Priority Conservation Areas

Species distribution data used in this study were obtained from the IUCN Red List of Threatened Species™ (IUCN 2020). In this study, I used the avian distribution range dataset to calculate bird diversity on each pixel. Species richness was then categorized it into 3 classes (Low Diversity: [0,5); Median Diversity: [5,16); High Diversity: [16,68]) by using Natural Breaks partitioning.

I calculated the mean values and standard deviation values of linear trends for all 19 bioclimate variables and also reclassified each linear trend into three classes (Low Change: between 1 std from mean; Median Change: between 2 std to 1 std from mean; High Change: above 2 std from mean).

Tab 2. Criterions for reclassification

Classes	Diversity Value Range	Classes	Linear Trend Value Range
Low Diversity	[0,5)	Low Change	between 1 std from mean
Median Diversity	[5,16)	Median Change	between 2 std to 1 std from mean
High Diversity	[16,68]	High Change	above 2 std from mean

Combing the reclassified temporal change for every 19 bioclimatic variables with reclassified birds' diversity resulted in 3 priority classes. As Figure 2 shown, high variables temporal change and high birds' diversity richness were classified as High Priority; High Change and Median Richness, Median Change and High Richness, and Median Change and Median Richness were classified as Median Priority; and other combinations were classified as Low Priority. Finally, the 19 conservation priority maps were combined by counting the frequency of each pixel that identified as High, Median, or low Conservation Priority for birds.

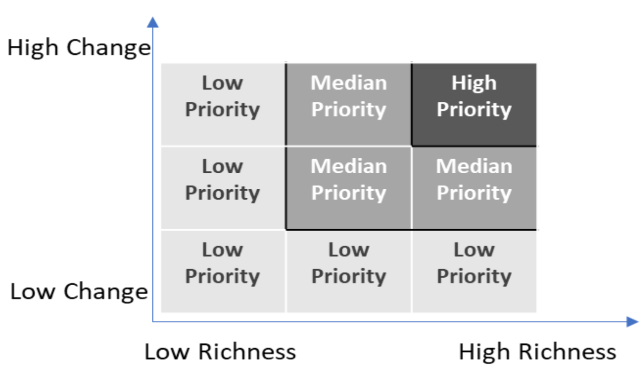


Fig 2. Illustration of defining conservation priority

Results

Trend of bioclimate variables

From the result of ordinary least squares regression (OLS), only a few areas showed an increasing trend of Annual Mean Temperature (Bio 1). For Mean Diurnal Range (Bio 2), Isothermality (Bio 3), Temperature Seasonality (Bio 4), and Temperature Annual Range (Bio 7), there are more decrease trends near the northern pole and south pole. For Max Temperature of Warmest Month (Bio 5), Min Temperature of Coldest Month (Bio 6), Mean Temperature of Warmest Quarter (Bio 10), and Mean Temperature of Coldest Quarter (Bio 11) the majority part showed increased trends, while the decrease trends of Bio 5 appeared near two poles, and the decrease trends of Bio 6, Bio 10, and Bio 11, which are similar, are generally shown in the southern hemisphere. The results of ordinary least squares regression of Mean Temperature of Wettest Quarter (Bio 8) and Mean Temperature of Driest Quarter (Bio 9) have similar spatial patterns; Results of Annual Precipitation (Bio 12), Precipitation of Wettest Month (Bio 13), Precipitation of Driest Month (Bio 14), Precipitation Seasonality (Bio 15), Precipitation of Wettest Quarter (Bio 16), and Precipitation of Coldest Quarter (Bio 19) have similar patterns that northern hemisphere and southern hemisphere are in a degree symmetrical with the equator as the axis of symmetry. All the other maps of OLS results of other Bioclimate variables are in the Appendix 1.

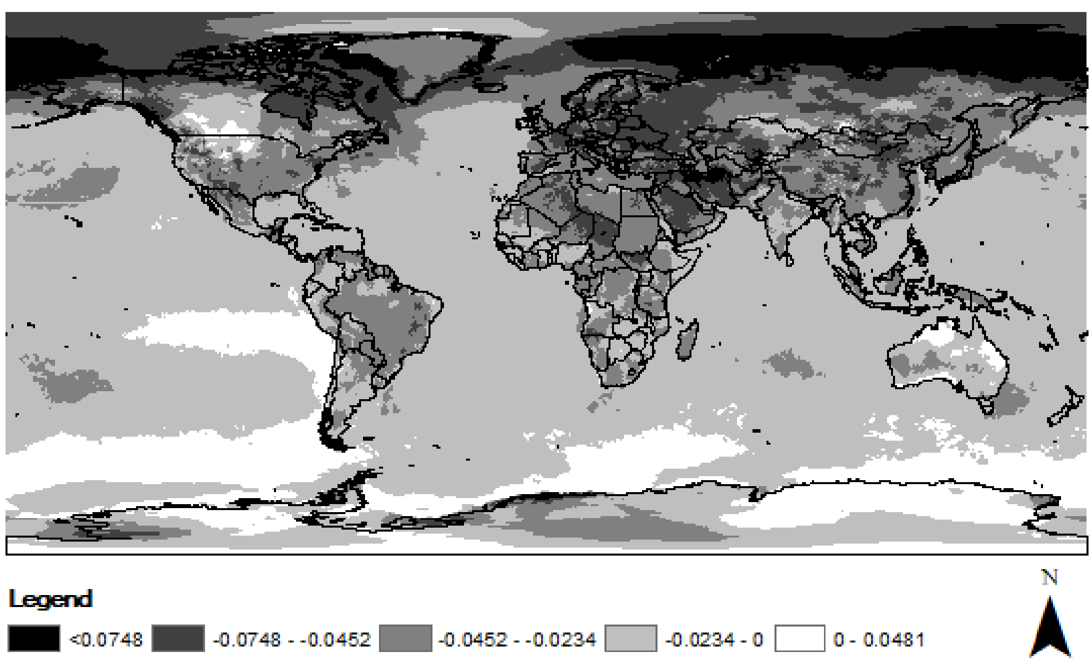
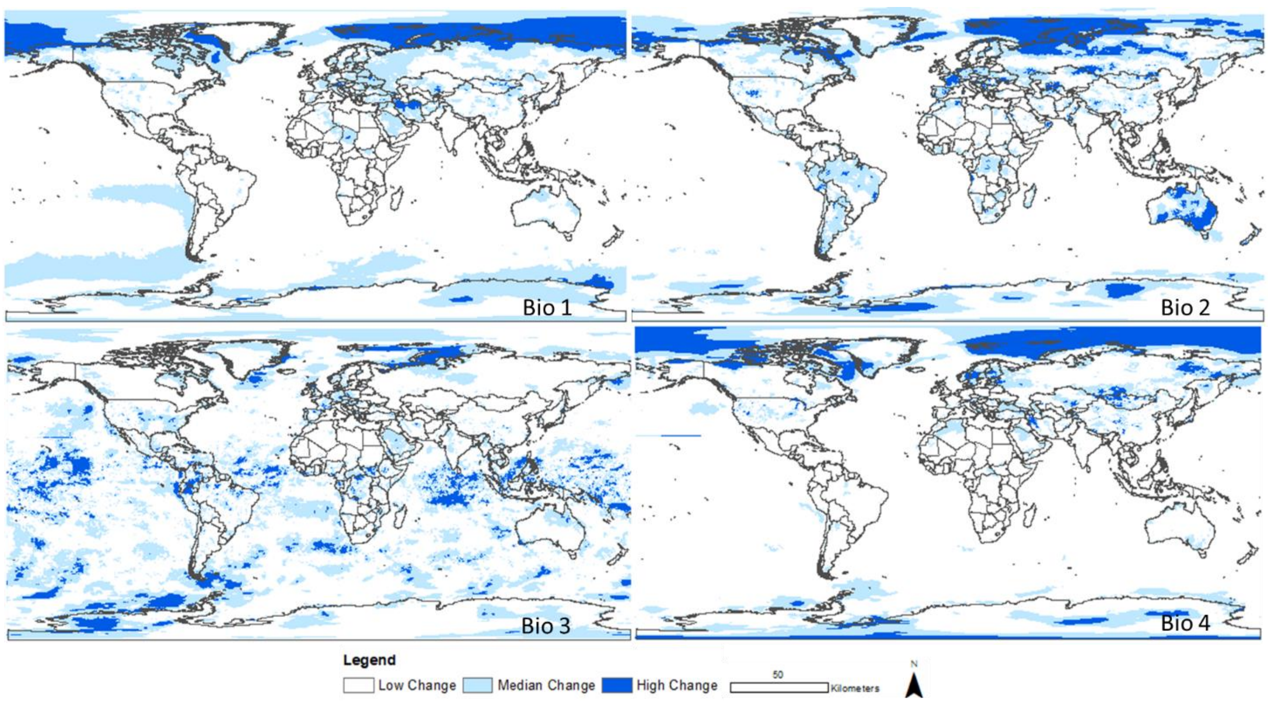
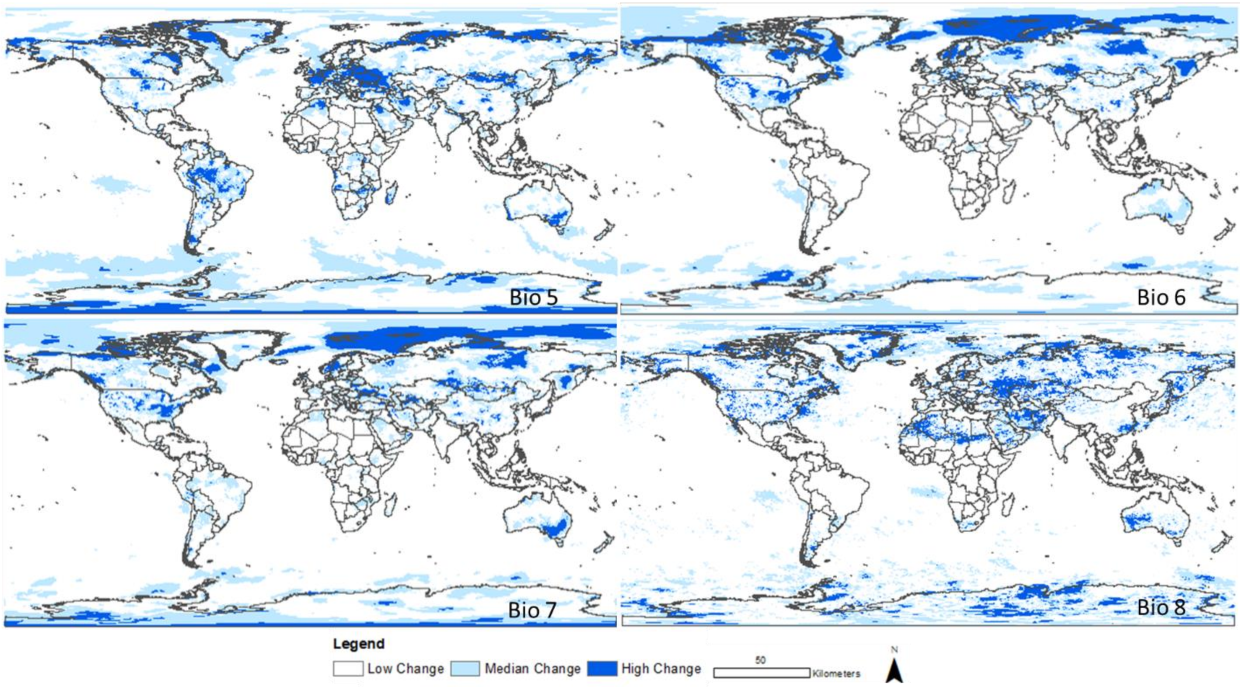


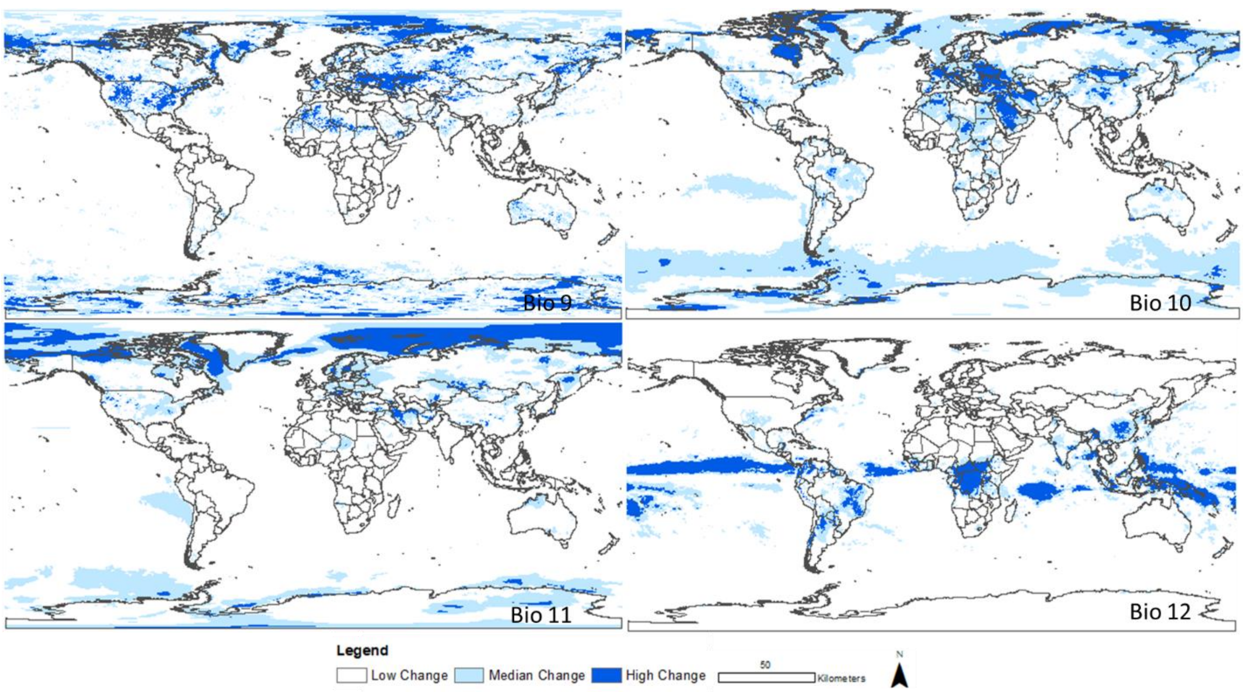
Fig 3. OLS slope of Bio 1

Figure 4 shows the low change, median change and high change areas of slope of ordinary least squares regression (OLS). We can see the highest changes of mean annual temperature (Bio 1) mostly presented in ocean areas, particularly in the arctic ocean. The linear trends for Mean

Diurnal Range (Bio 2), Temperature Seasonality (Bio 4), Min Temperature of Coldest Month (Bio 6), Temperature Annual Range (Bio 7), and Mean Temperature of Coldest Quarter (Bio 11) presented similar spatial patterns of OLS slope as Bio 1, which were mostly located near the northern pole, south pole, the Asian continent, and Australia. Trends in Annual Precipitation (Bio 12), Precipitation of Wettest Month (Bio 13), Precipitation of Driest Month (Bio 14), Precipitation Seasonality (Bio 15), Precipitation of Wettest Quarter (Bio 16), Precipitation of Driest Quarter(Bio 17), Precipitation of Warmest Quarter(Bio 18) and Precipitation of Coldest Quarter (Bio 19) had similar spatial patterns that high change areas mostly locating along equator and high and median change areas were in a degree symmetrical with the equator as the axis of symmetry. For Max Temperature of Warmest Month (Bio 5), Mean Temperature of Wettest Quarter (Bio 8), Mean Temperature of Driest Quarter (Bio 9), and Mean Temperature of Driest Quarter (Bio 10), the high change areas were mostly appeared in northern hemisphere, like north America, Neighboring areas between Africa and Asia, and northern part of Asian. The spatial pattern of high changes in Isothermality (Bio 3) was different than others, which scattered mostly in oceans, especially along the equator, northern pole and south pole.




Bio 5
Bio 6
Bio 7
Bio 8
Legend
Low Change
Median Change
High Change
50
Kilometers
N


Bio 9
Bio 10
Bio 11
Bio 12
Legend
Low Change
Median Change
High Change
50
Kilometers
N

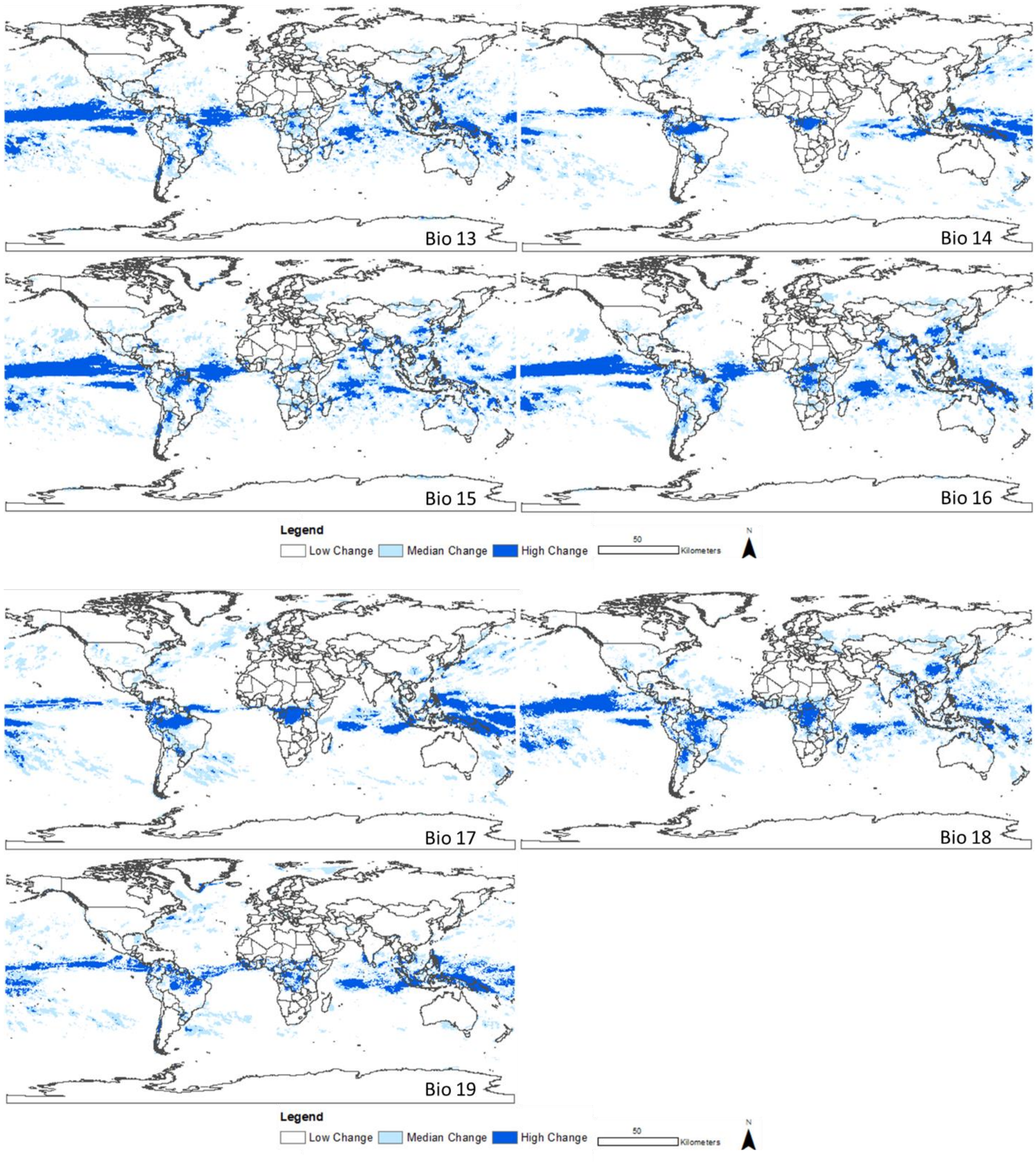


Fig 4. Reclassified OLS slope for 19 Bioclimate variables

Identify Priority Conservation Areas

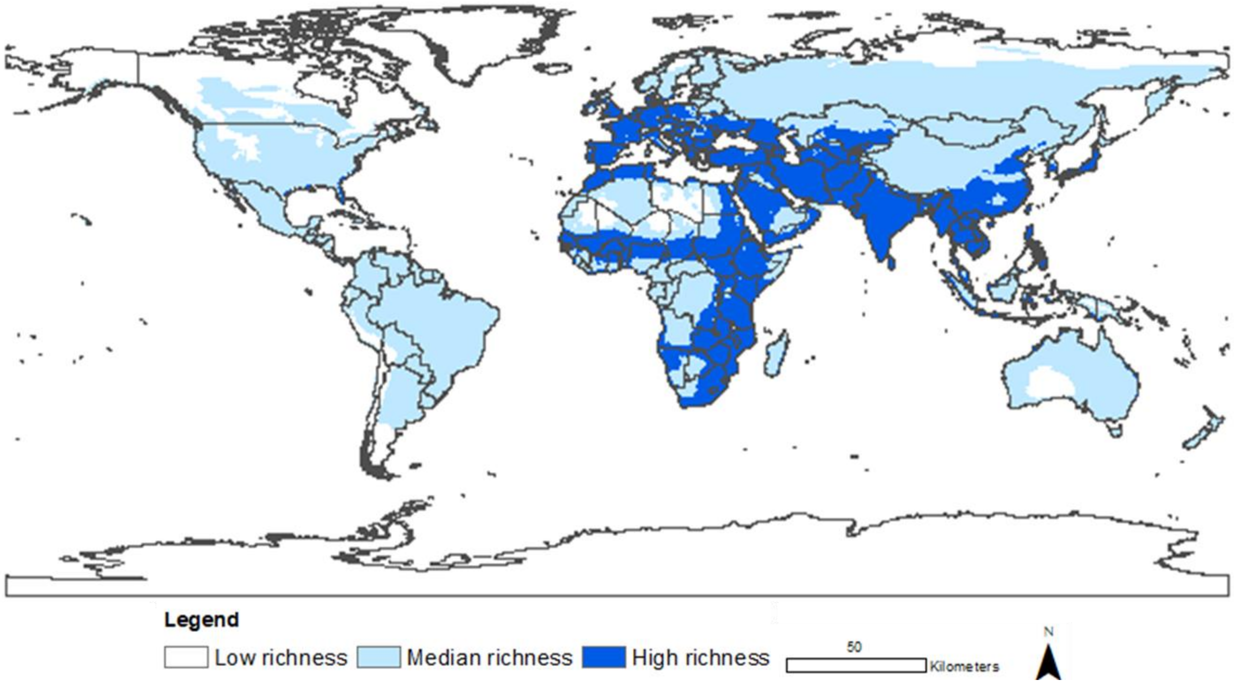


Fig 5. Global bird richness in 2019

Figure 5 shows the global distribution of bird species reclassified into low, medium, high. This figure shows that, except for Greenland and Antarctica, generally, bird richness on lands were higher than that on oceans. In southern Asia, southwestern and central Africa, eastern coastal and northwestern coastal areas, those areas had high bird richness.

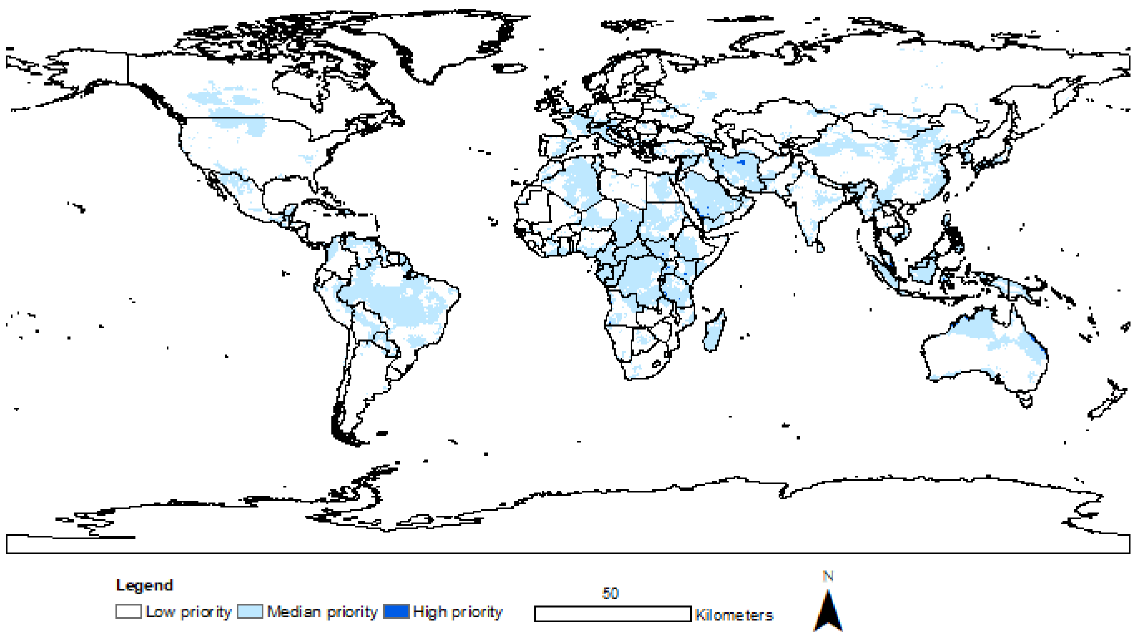


Fig 6. Priority Conservation Area for Bio 1

From the figure 6, we can see that the High Priority Conservation Areas for Bio 1 was in the central of Iran. And all the other maps of Priority Conservation Areas are in the Appendix 2. To better explore the spatial patterns between all the bioclimate variables, the frequency of each pixel that identified as High, Median, or low Conservation Priority for birds in all 19 maps is shown in the figure 7, 8 and 9.

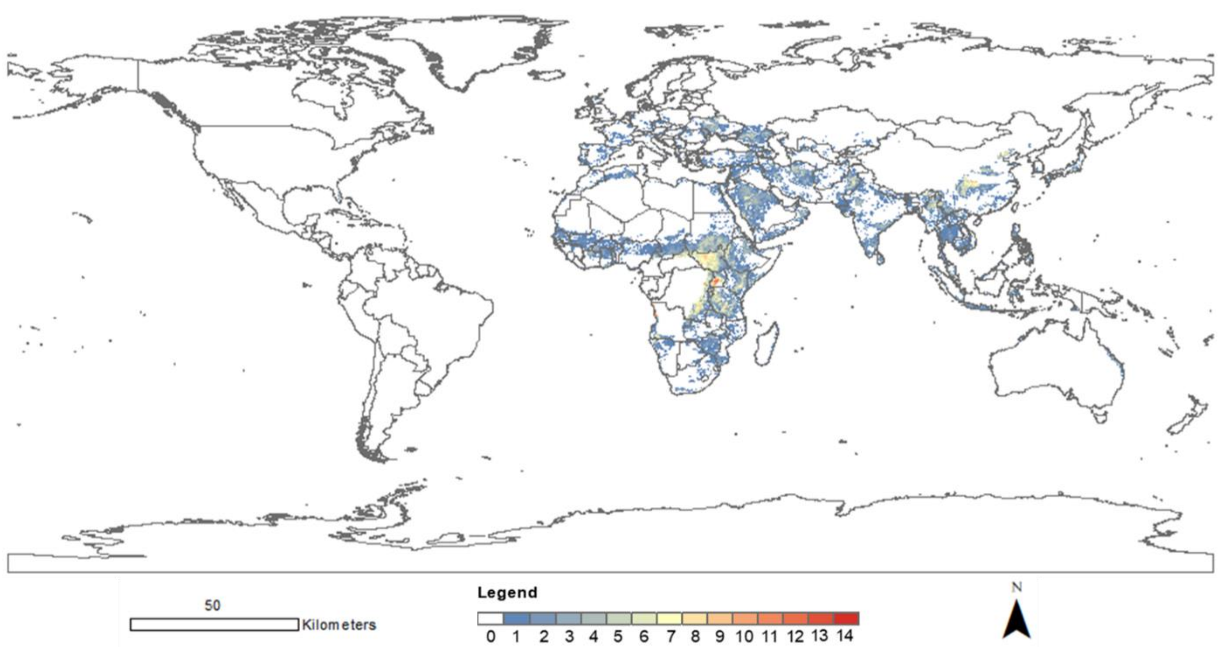


Fig 7. The frequency for each pixel that identified as High Priority Conservation Areas for birds in 19 maps

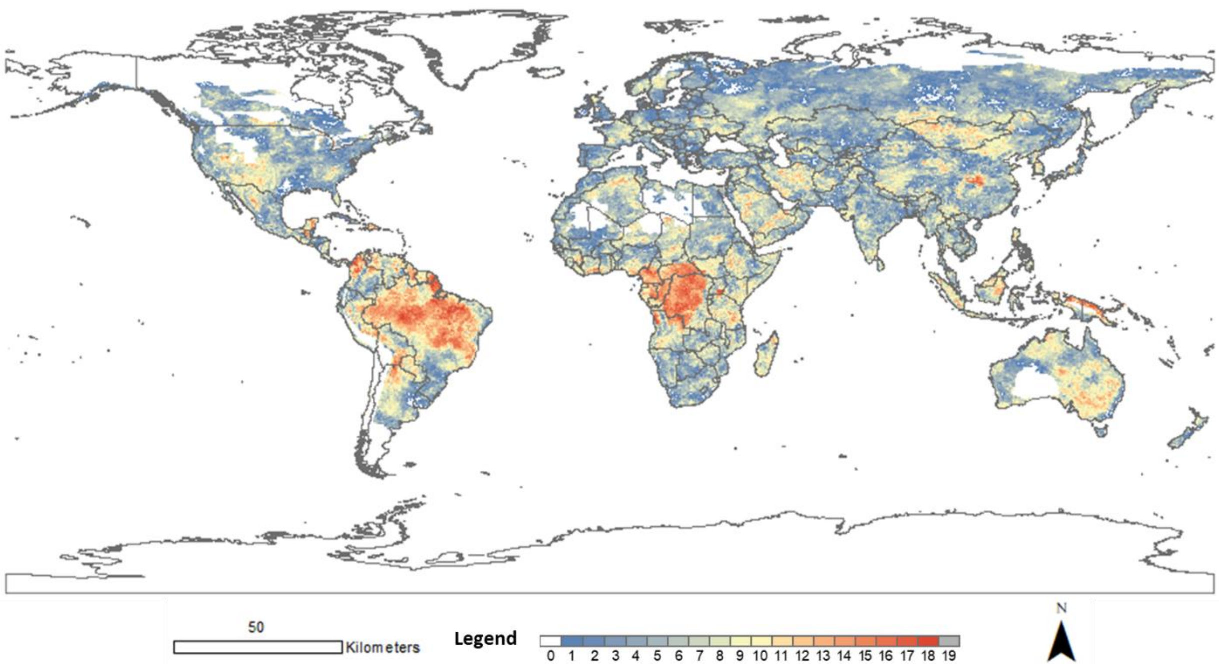


Fig 8. The frequency for each pixel that identified as Median Priority Conservation Areas for birds in 19 maps

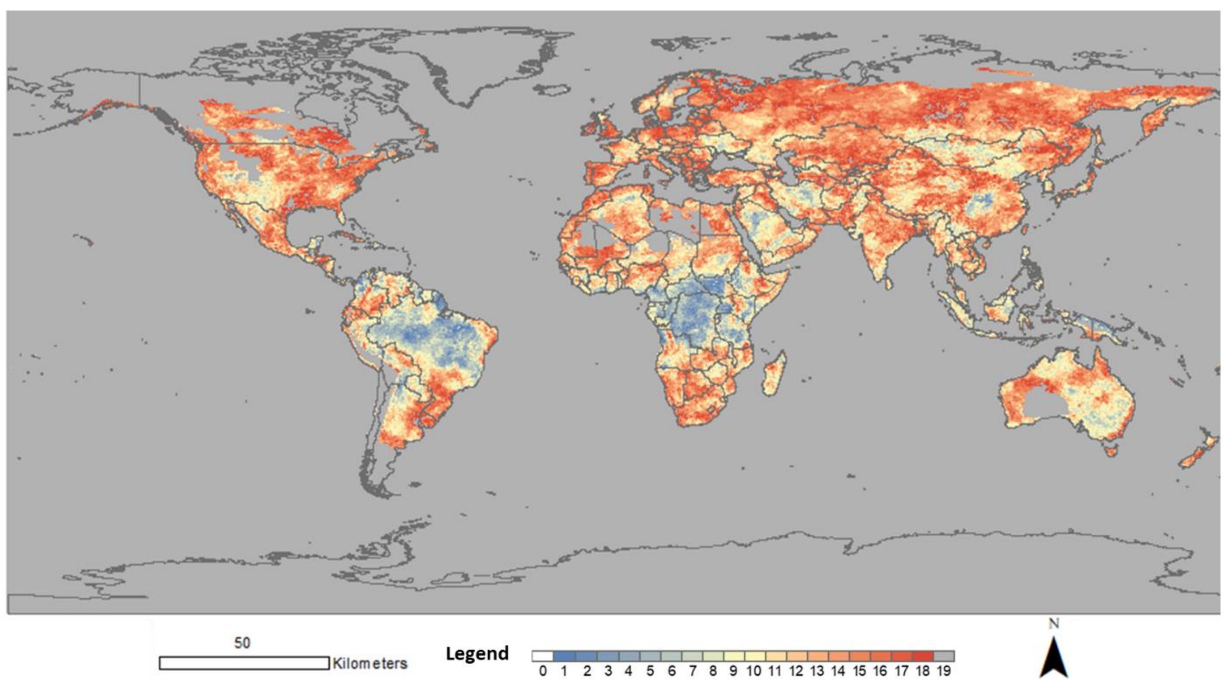


Fig 9. The frequency for each pixel that identified as Low Priority Conservation Areas for birds in 19 maps

From Figure 7, there are some similar spatial patterns of High Priority Conservation Areas that are identified as High Conservation Priority in more than 9 out of 19 Priority Conservation Areas maps. Those High Priority Conservation Areas were located in the central part of Africa, such as the Middle of South Sudan, Uganda, the western Democratic Republic of the Congo, northwestern coastal of Angola, and appeared on central part of China (near the Sichuan Basin).

Table 4 and table 5 shows the areas of High and Median Conservation Priority for each bioclimate variables. We can see the for both Bio 9 and Bio 18 the High and Median Conservation Priority areas were relatively high (ranked in the top 3).

Tab 4. Total area (in square kilometers) identified as High Conservation Priority

	Sq kilometers	Proportion		Sq kilometers	Proportion
BIO 1	310561.5	0.0411%	BIO 11	1585733.4	0.2019%
BIO 2	1819210.7	0.2484%	BIO 12	4564284.4	0.6156%
BIO 3	2183277.4	0.3151%	BIO 13	2740431.6	0.3764%
BIO 4	909818.4	0.1234%	BIO 14	1918622.0	0.2578%
BIO 5	1053913.5	0.1487%	BIO 15	2935827.0	0.3989%
BIO 6	986229.0	0.1307%	BIO 16	3747861.8	0.5179%
BIO 7	1002076.5	0.1356%	BIO 17	2357185.2	0.3172%
BIO 8	3208856.9	0.4194%	BIO 18	5160082.8	0.7101%
BIO 9	4034295.4	0.5447%	BIO 19	2680717.2	0.3593%
BIO 10	1602220.7	0.2188%			

Tab 5. Total area (in square kilometers) identified as Median Conservation Priority

	Sq kilometers	Proportion		Sq kilometers	Proportion
BIO 1	39844527.4	5.5625%	BIO 11	36470230.3	5.3218%
BIO 2	42967121.8	6.5646%	BIO 12	43945616.4	6.6306%
BIO 3	35152132.0	5.5285%	BIO 13	42249922.8	6.4684%
BIO 4	29299105.8	4.4443%	BIO 14	36988844.5	5.5503%
BIO 5	37168126.3	5.3684%	BIO 15	41896223.9	6.4057%
BIO 6	30681535.5	4.7095%	BIO 16	44361938.4	6.8000%
BIO 7	35243911.1	5.3764%	BIO 17	42508464.5	6.2451%
BIO 8	38984706.2	5.6332%	BIO 18	44441040.1	6.7656%
BIO 9	44052638.5	6.6430%	BIO 19	36225995.2	5.4847%
BIO 10	41338595.4	5.8771%			

Discussion

Just mentioned in results, for linear trends, most areas showed increasing trends for most of the bioclimate variables, and the decreasing trends existed in all bioclimate variables and many of which were appeared similar spatial patterns; also, the most spatial patterns of highest changes of all 19 bioclimatic variables were similar. Those similar spatial patterns may be caused by that variable may be highly correlated or represent similar environmental characteristics.

The High Priority Conservation Areas appeared most in the central part of Africa, such as South Sudan, Uganda, and the Democratic Republic of the Congo, which are typical countries in Africa that are some of the least developed countries globally, and the environments and economic conditions of these countries are similar (Huntley et al., 2019; Orindi & Eriksen, 2005). They all have an abundance of natural resources like water, oil, and mineral wealth, and also have expansive grasslands, swamps, and tropical rain forest. These countries are very vulnerable to climate changes. For example, in South Sudan, the increasing deforestation due to the increased demands for charcoal and fuelwood as well as land for agricultural and residential purposes leads to increased soil erosion. And within the last two decades, it also suffered from reduced water quantity and quality(*South Sudan Launched the National Adaptation Programme of Actions (NAPA) for Climate Change*, 2017). Similar situations also happened in the other two countries, which increased their vulnerability to climate changes.

China's land use pattern has undergone profound changes during the 20 years from 1990 to 2010, with the further development of the national economy and overall social progress: the urban and rural construction land continued to expand, with the east as the center of gravity, spreading to the central and western regions; Cultivated land decreased in the south and increased in the north, and the center of cultivated land reclamation in the north moved from the northeast to Xinjiang; affected by the implementation of the six major national forestry projects, forest land decreased and then increased; grassland continued to decrease(Both et al., 2006).

For all those areas human activities caused much Land use/land cover changes (LUCC). Land use/land cover change (LUCC) caused by human activities is the most direct signal that characterizes the impact of human activities on the earth's land surface natural ecosystems. It is the main process leading to the fragmentation and loss of species' habitats and ecosystems, and it is the primary threat to diversity(Kuemmerle et al., 2013).

In this study, only the climate changes were considered, while changes of LUCC were not included. Careful consideration of the impact of LUCC factors on biodiversity, such as the change in the area distribution of each type of ecosystem caused by the conversion of land use, the fragmentation of the biological habitat landscape, and the change in land management methods(Böhning-Gaese & Lemoine, 2004; Thomas & Lennon, 1999), needs to be included for a comprehensive assessment of conservation priorities.

Due to the limitation of 0.25-degree resolution of bioclimate variables, those bird species with small species ranges were excluded from this research. Thus, this prioritization does not include range-restricted species and only applies to wide-ranging ones. The ranges of birds' distribution may include species omissions, range errors and inaccuracy. Sullivan et al. (2017) introduced an open access datasets called eBird, where individuals can submit bird distribution and abundance data (Sullivan et al., 2017). Combining open-access datasets in the identification of species richness can improve future prioritizations.

CONCLUSION

This work defined areas that can be considered the High/Median/Low Priority for the global conservation of wide-ranging birds. For both High and Median Priority, these areas are located primarily in Asia and Africa.

References

AR5 Synthesis Report: Climate Change 2014 — IPCC. (n.d.). Retrieved November 30, 2020, from https://www.ipcc.ch/report/ar5/syr/

Böhning-Gaese, K., & Lemoine, N. (2004). Importance of Climate Change for the Ranges, Communities and Conservation of Birds. *Advances in Ecological Research - ADVAN ECOL RES*, *35*, 211–236. https://doi.org/10.1016/S0065-2504(04)35010-5

Both, C., Artemyev, A. V., Blaauw, B., Cowie, R. J., Dekhuijzen, A. J., Eeva, T., Enemar, A., Gustafsson, L., Ivankina, E. V., Järvinen, A., Metcalfe, N. B., Nyholm, N. E. I., Potti, J., Ravussin, P.-A., Sanz, J. J., Silverin, B., Slater, F. M., Sokolov, L. V., Török, J., … Visser, M. E. (2004). Large–scale geographical variation confirms that climate change causes birds to lay earlier. *Proceedings of the Royal Society of London. Series B: Biological Sciences*, *271*(1549), 1657–1662. https://doi.org/10.1098/rspb.2004.2770

Both, C., Bouwhuis, S., Lessells, C. M., & Visser, M. E. (2006). Climate change and population declines in a long-distance migratory bird. *Nature*, *441*(7089), 81–83. https://doi.org/10.1038/nature04539

Campbell, V., Murphy, G., & Romanuk, T. (2011). Experimental design and the outcome and interpretation of diversity–stability relations. *Oikos*, *120*, 399–408. https://doi.org/10.1111/j.1600-0706.2010.18768.x

Cardinale, B. J., Duffy, J. E., Gonzalez, A., Hooper, D. U., Perrings, C., Venail, P., Narwani, A., Mace, G. M., Tilman, D., Wardle, D. A., Kinzig, A. P., Daily, G. C., Loreau, M., Grace, J. B., Larigauderie, A., Srivastava, D. S., & Naeem, S. (2012). Biodiversity loss and its impact on humanity. *Nature*, *486*(7401), 59–67. https://doi.org/10.1038/nature11148

C Aybar, Q Wu, L Bautista, R Yali and A Barja (2020) rgee: An R package for interacting with Google Earth Engine Journal of Open-Source Software. URL https://github.com/r-spatial/rgee/.

Cooke, S. J., Hinch, S. G., Farrell, A. P., Lapointe, M. F., Jones, S. R. M., Macdonald, J. S., Patterson, D. A., Healey, M. C., & Kraak, G. V. D. (2004). Abnormal Migration Timing and High en route Mortality of Sockeye Salmon in the Fraser River, British Columbia. *Fisheries*, *29*(2), 22–33. https://doi.org/10.1577/1548-8446(2004)29[22:AMTAHE]2.0.CO;2

Cowling, R. M., Ojeda, F., & Rundel, P. W. (2004). Climate stability in mediterranean-type ecosystems: Implications for the evolution and conservation of biodiversity. *Proceedings of the 10th MEDECOS — International Conference on Ecology, Conservation and Management of Mediterranean Climate Ecosystems, Rhodes Island, Greece, 25 April–1 May 2004*.

Crick, H. Q., & Sparks, T. (1999). Climate change related to egg-laying trends. *Nature*. https://doi.org/10.1038/20839

Donohue, I., Hillebrand, H., Montoya, J. M., Petchey, O. L., Pimm, S. L., Fowler, M. S., Healy, K., Jackson, A. L., Lurgi, M., McClean, D., O'Connor, N. E., O'Gorman, E. J., & Yang, Q. (2016). Navigating the complexity of ecological stability. *Ecology Letters*, *19*(9), 1172–1185. https://doi.org/10.1111/ele.12648

Ferrier, S., & Wintle, B. (2009). *Quantitative approaches to spatial conservation prioritization: Matching the solution to the need*. /scholarlywork/319983-quantitative-approaches-to-spatial-conservation-prioritization--matching-the-solution-to-the-need

Fitter, A., & Fitter, R. (2002). Rapid Changes in Flowering Time in British Plants. *Science (New York, N.Y.)*, *296*, 1689–1691. https://doi.org/10.1126/science.1071617

Hautier, Y., Tilman, D., Isbell, F., Seabloom, E. W., Borer, E. T., & Reich, P. B. (2015). Anthropogenic environmental changes affect ecosystem stability via biodiversity. *Science*, *348*(6232), 336–340. https://doi.org/10.1126/science.aaa1788

Hijmans, R. J., Phillips, S., & Elith, J. L. and J. (2020). dismo: Species Distribution Modeling (1.3-3) [Computer software]. https://CRAN.R-project.org/package=dismo

Huntley, B., Russo, V., Fernanda, L., & Ferrand, N. (2019). Biodiversity of Angola Science & Conservation: A Modern Synthesis: Science & Conservation: A Modern Synthesis. In *Biodiversity of Angola: Science and Conservation: A Modern Synthesis*. https://doi.org/10.1007/978-3-030-03083-4

IUCN 2020. The IUCN Red List of Threatened Species. Version 2020-2. https://www.iucnredlist.org. Downloaded on 09 July 2020.

Jiang, L., & Pu, Z. (2009, August 5). *Different effects of species diversity on temporal stability in single-trophic and multi-trophic communities*.

Kremen, C., Cameron, A., Moilanen, A., Phillips, S. J., Thomas, C. D., Beentje, H., Dransfield, J., Fisher, B. L., Glaw, F., Good, T. C., Harper, G. J., Hijmans, R. J., Lees, D. C., Louis, E., Nussbaum, R. A., Raxworthy, C. J., Razafimpahanana, A., Schatz, G. E., Vences, M., … Zjhra, M. L. (2008). Aligning Conservation Priorities Across Taxa in Madagascar with High-Resolution Planning Tools. *Science*, *320*(5873), 222–226. https://doi.org/10.1126/science.1155193

Kuemmerle, T., Erb, K., Meyfroidt, P., Müller, D., Verburg, P. H., Estel, S., Haberl, H., Hostert, P., Jepsen, M. R., Kastner, T., Levers, C., Lindner, M., Plutzar, C., Verkerk, P. J., van der Zanden, E. H., & Reenberg, A. (2013). Challenges and opportunities in mapping land use intensity globally. *Current Opinion in Environmental Sustainability*, *5*(5), 484–493. https://doi.org/10.1016/j.cosust.2013.06.002

Loreau, M., & Mazancourt, C. de. (2013). Biodiversity and ecosystem stability: A synthesis of underlying mechanisms. *Ecology Letters*, *16*(s1), 106–115. https://doi.org/10.1111/ele.12073

Ma, Z., Liu, H., Mi, Z., Zhang, Z., Wang, Y., Xu, W., Jiang, L., & He, J.-S. (2017). Climate warming reduces the temporal stability of plant community biomass production. *Nature Communications*, *8*(1), 15378. https://doi.org/10.1038/ncomms15378

McCann, K. S. (2000). The diversity–stability debate. *Nature*, *405*(6783), 228–233. https://doi.org/10.1038/35012234

Menzel, A. (2000). Trends in phenological phases in Europe between 1951 and 1996. *International Journal of Biometeorology*, *44*(2), 76–81. https://doi.org/10.1007/s004840000054

Murphy-Klassen, H. M., Underwood, T. J., Sealy, S. G., & Czyrnyj, A. A. (2005). Long-Term Trends in Spring Arrival Dates of Migrant Birds at Delta Marsh, Manitoba, in Relation to Climate Change. *The Auk*, *122*(4), 1130–1148. https://doi.org/10.1093/auk/122.4.1130

Orindi, V. A., & Eriksen, S. (2005, January 1). *Mainstreaming Adaptation to Climate Change in the Development Process in Uganda*. Africa Portal; African Centre for Technology Studies (ACTS). https://www.africaportal.org/publications/mainstreaming-adaptation-to-climate-change-in-the-development-process-in-uganda/

Parmesan, C., & Yohe, G. (2003). A globally coherent fingerprint of climate change impacts across natural systems. *Nature*, *421*(6918), 37–42. https://doi.org/10.1038/nature01286

Remya, K., Ramachandran, A., & Jayakumar, S. (2015). Predicting the current and future suitable habitat distribution of Myristica dactyloides Gaertn. Using MaxEnt model in the Eastern Ghats, India. *Ecological Engineering*, *82*, 184–188. https://doi.org/10.1016/j.ecoleng.2015.04.053

Rinawati, F., Stein, K., & Lindner, A. (2013). Climate Change Impacts on Biodiversity—The Setting of a Lingering Global Crisis. *Diversity*, *5*(1), 114–123. https://doi.org/10.3390/d5010114

Root, T. L., Price, J. T., Hall, K. R., Schneider, S. H., Rosenzweig, C., & Pounds, J. A. (2003). Fingerprints of global warming on wild animals and plants. *Nature*, *421*(6918), 57–60. https://doi.org/10.1038/nature01333

Roy, D. B., & Sparks, T. (2000). Phenology of British butterflies and climate change. *Global Change Biology*, *6*, 407–416. https://doi.org/10.1046/j.1365-2486.2000.00322.x

Shi, Z., Xu, X., Souza, L., Wilcox, K., Jiang, L., Liang, J., Xia, J., García-Palacios, P., & Luo, Y. (2016). Dual mechanisms regulate ecosystem stability under decade-long warming and hay harvest. *Nature Communications*, *7*(1), 11973. https://doi.org/10.1038/ncomms11973

Sintayehu, D. W. (2018). Impact of climate change on biodiversity and associated key ecosystem services in Africa: A systematic review. *Ecosystem Health and Sustainability*, *4*(9), 225–239. https://doi.org/10.1080/20964129.2018.1530054

South Sudan Launched the National Adaptation Programme of Actions (NAPA) for Climate Change. (2017, August 7). UNEP. http://www.unep.org/news-and-stories/story/south-sudan-launched-national-adaptation-programme-actions-napa-climate

Sullivan, B. L., Phillips, T., Dayer, A. A., Wood, C. L., Farnsworth, A., Iliff, M. J., Davies, I. J., Wiggins, A., Fink, D., Hochachka, W. M., Rodewald, A. D., Rosenberg, K. V., Bonney, R., & Kelling, S. (2017). Using open access observational data for conservation action: A case study for birds. *Biological Conservation*, *208*, 5–14. https://doi.org/10.1016/j.biocon.2016.04.031

Thomas, C. D., & Lennon, J. J. (1999). Birds extend their ranges northwards. *Nature*, *399*(6733), 213–213. https://doi.org/10.1038/20335

Tilman, D., Reich, P., & Knops, J. (2006). Biodiversity and Ecosystem Stability in a Decade-Long Grassland Experiment. *Nature*, *441*, 629–632.

USGS Data Series 691: Bioclimatic Predictors for Supporting Ecological Applications in the Conterminous United States. (n.d.). Retrieved November 30, 2020, from https://pubs.usgs.gov/ds/691/

Watson, R., Gitay, H., Suarez, A., Dokken, D. J., & Leemans, R. (2006). Climate Change and Biodiversity. *[S.l.] : [S.n.], 2002. - ISBN 92-9169-104-7*.

Wilson, K. A., Carwardine, J., & Possingham, H. P. (2009). Setting Conservation Priorities. *Annals of the New York Academy of Sciences*, *1162*(1), 237–264. https://doi.org/10.1111/j.1749-6632.2009.04149.x

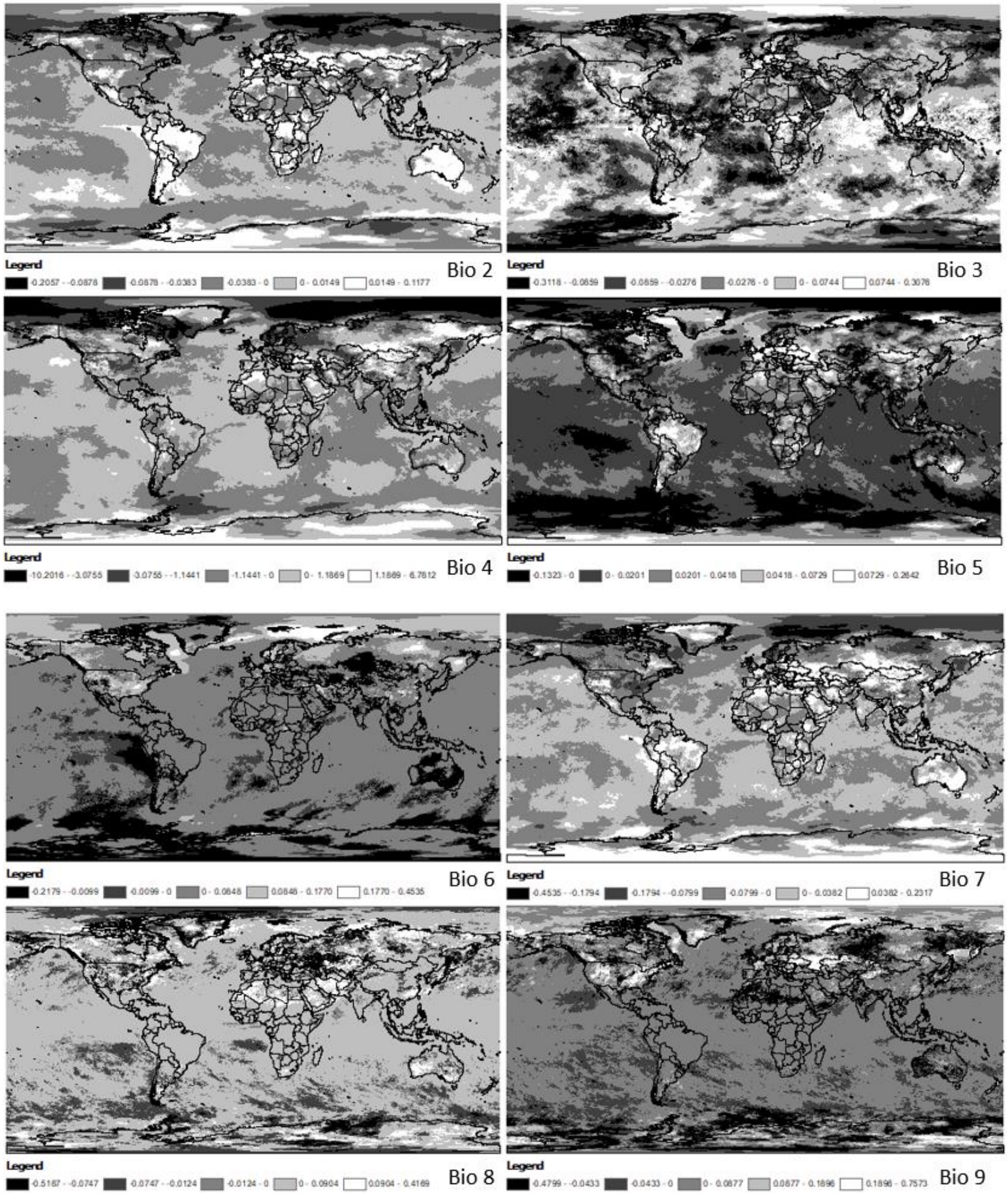
Wormworth, J., & Mallon, K. (2010). Bird Species and Climate Change: The Global Status Report: A synthesis of current scientific understanding of anthropogenic climate change impacts on global bird species now, and projected future effects. *Undefined*. /paper/Bird-Species-and-Climate-

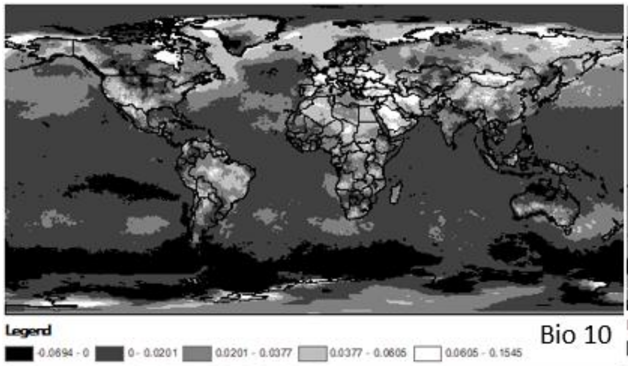
Change%3A-The-Global-Status-Wormworth-Mallon/8bd796a72d515daa048d5c3e928def72edb181f1

Yachi, S., & Loreau, M. (1999). Biodiversity and ecosystem productivity in a fluctuating environment: The insurance hypothesis. *Proceedings of the National Academy of Sciences of the United States of America*, *96*(4), 1463–1468. https://doi.org/10.1073/pnas.96.4.1463

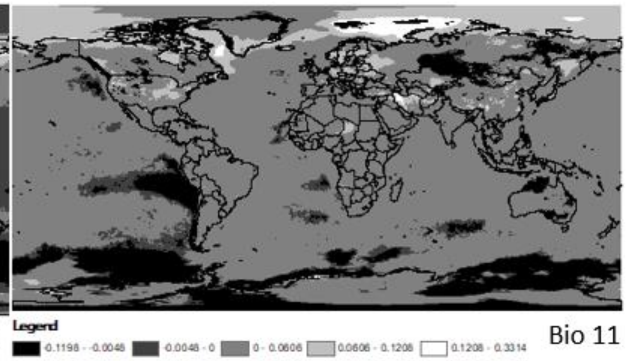
Appendix

Appendix 1- Slope of ordinary least squares regression

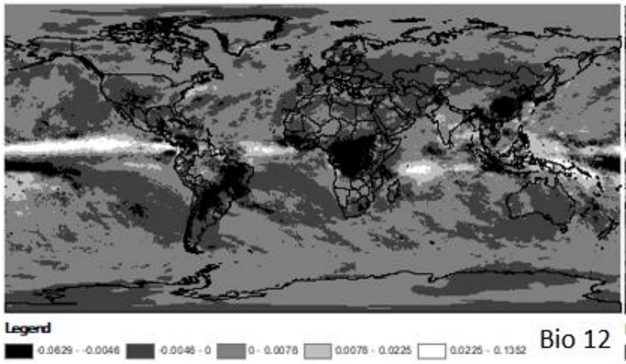




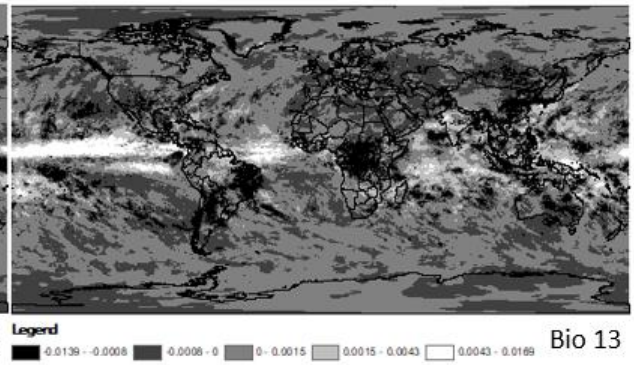
Bio 10



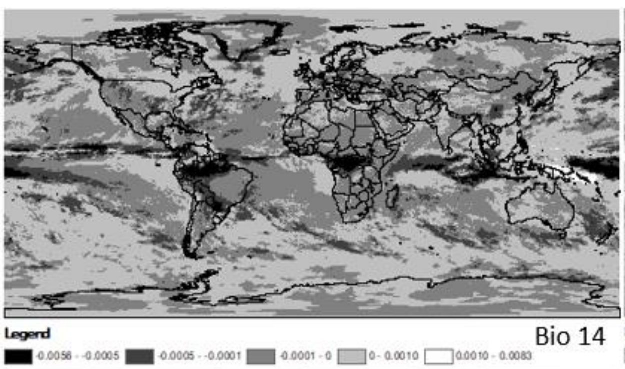
Bio 11



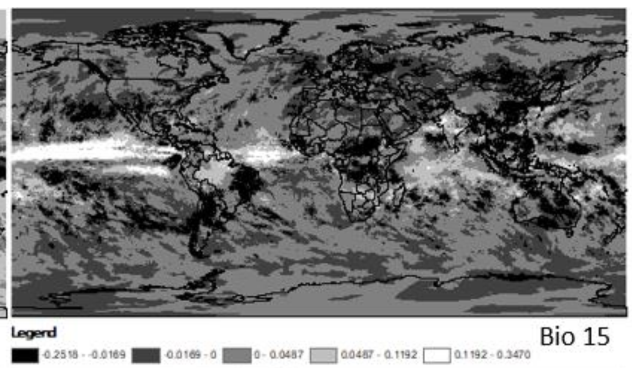
Bio 12



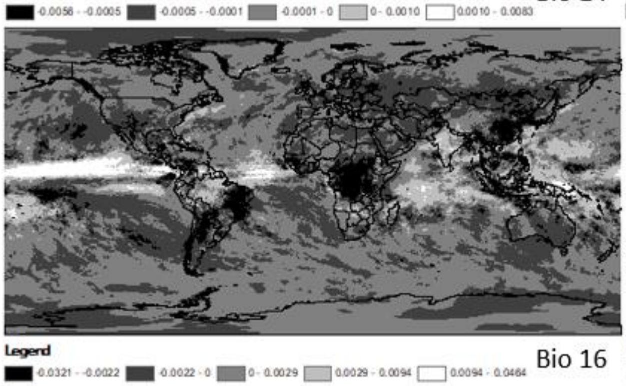
Bio 13



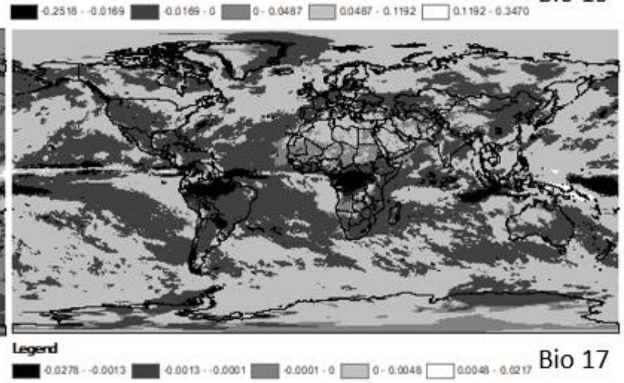
Bio 14



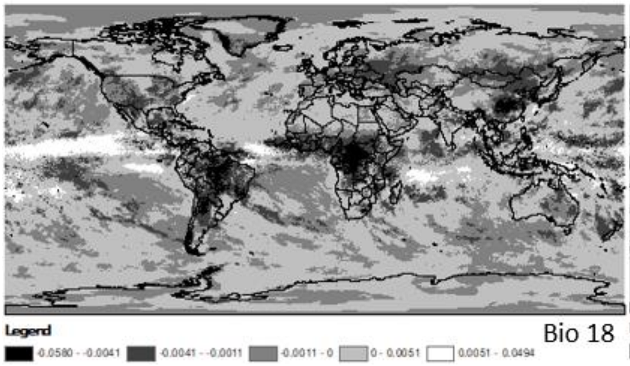
Bio 15

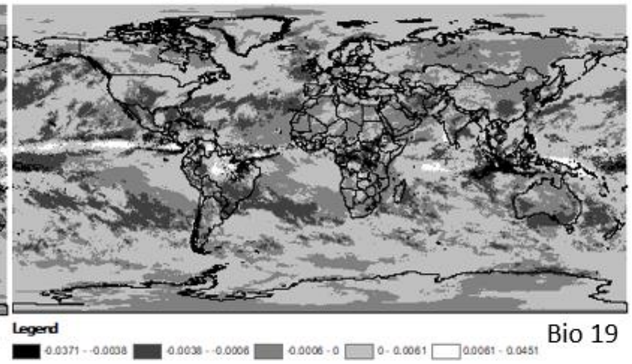


Bio 16

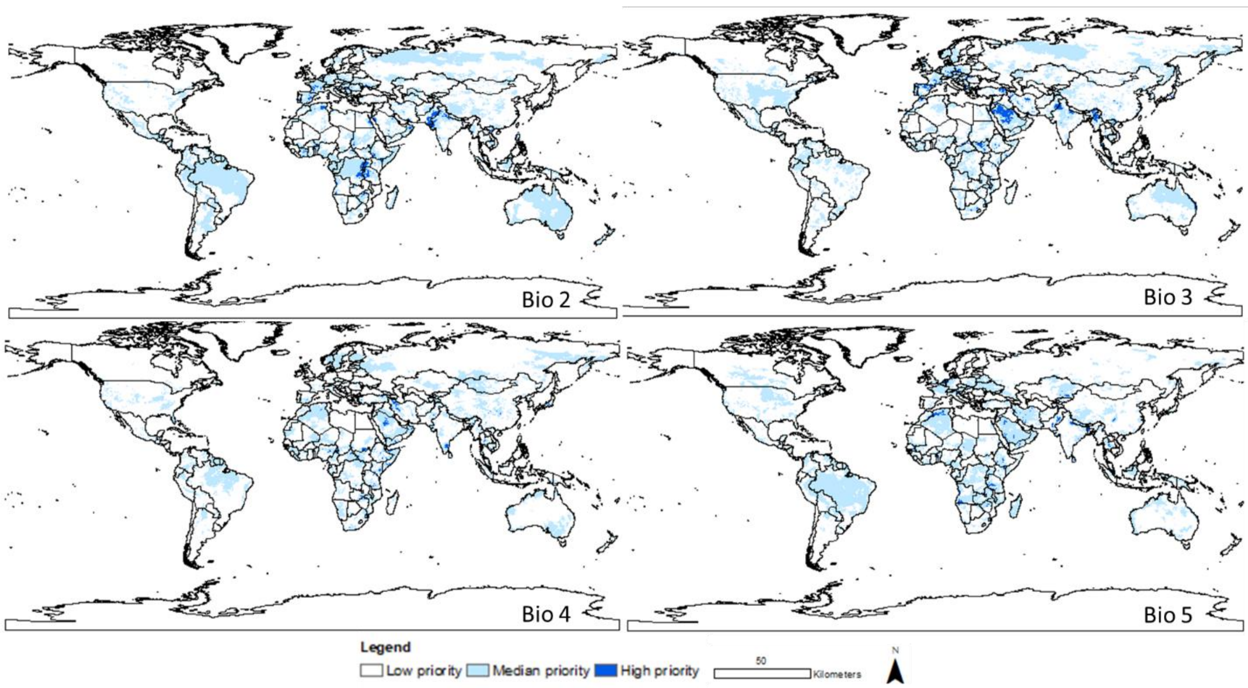


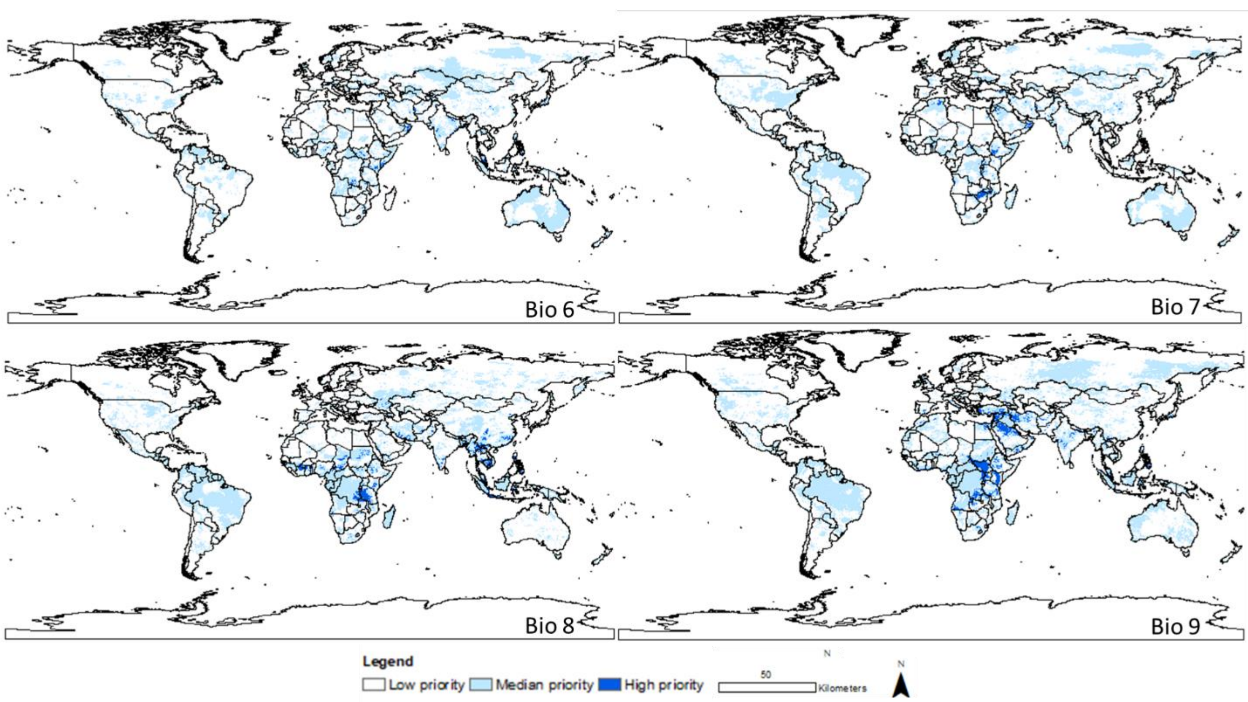
Bio 17

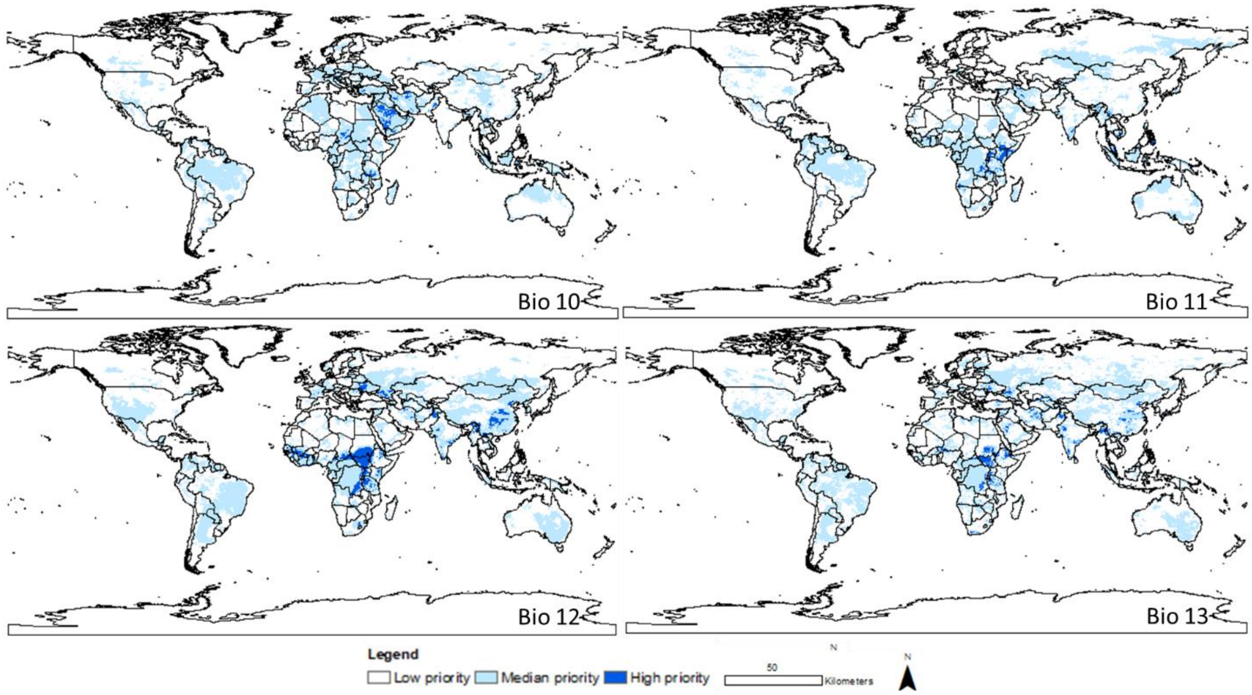

Legend
-0.0580 - -0.0041
-0.0041 - -0.0011
-0.0011 - 0
0 - 0.0051
0.0051 - 0.0494
Bio 18

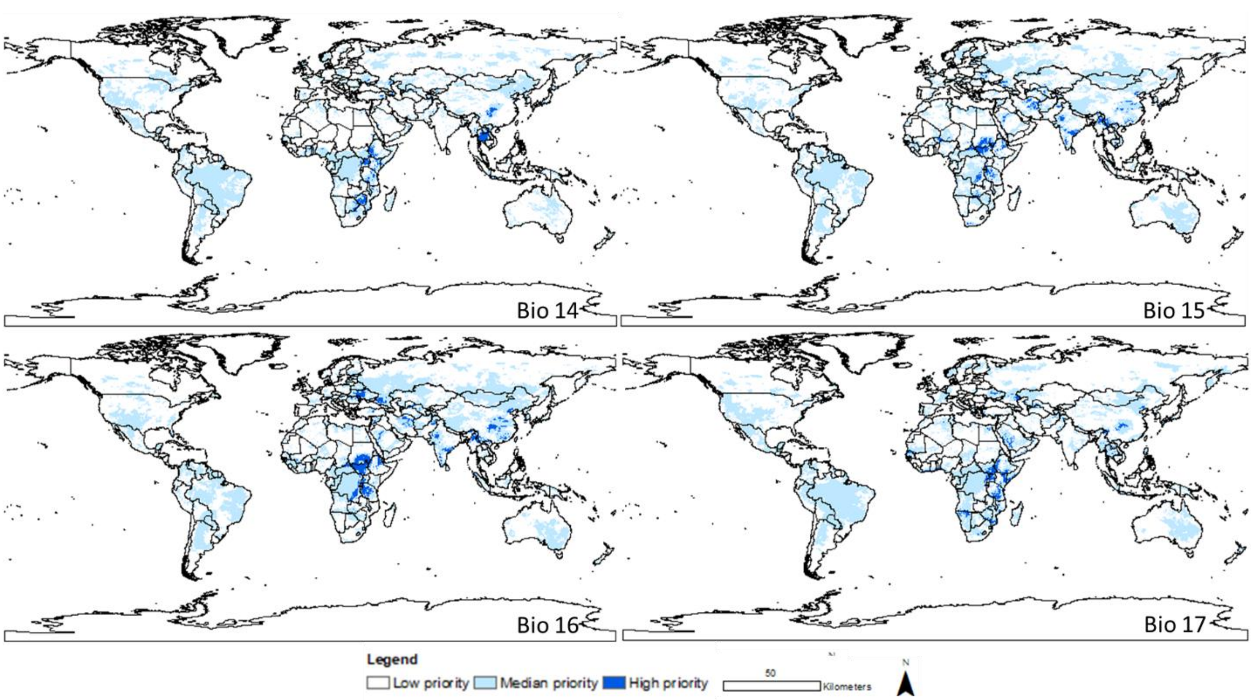

Legend
-0.0371 - -0.0038
-0.0038 - -0.0006
-0.0006 - 0
0 - 0.0061
0.0061 - 0.0451
Bio 19

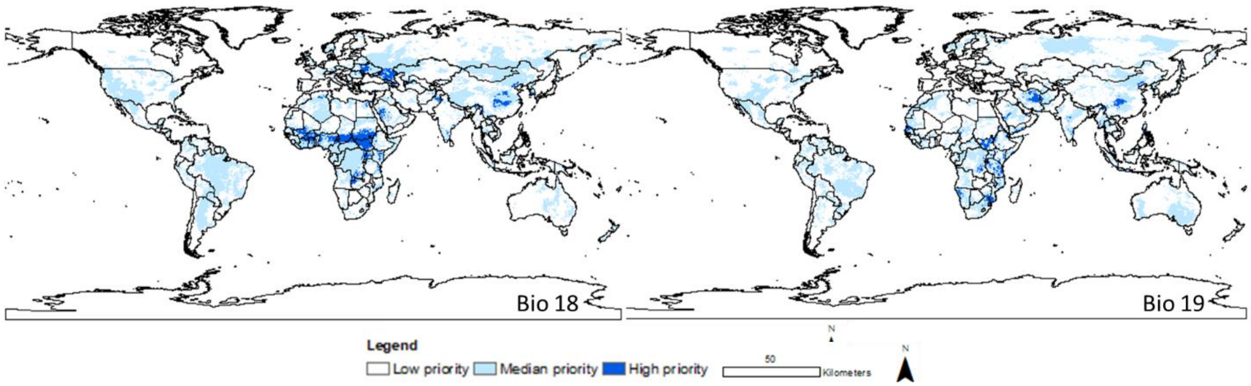
Appendix 2- Priority Conservation Area for each Bioclimate variable






Bio 10
Bio 11
Bio 12
Bio 13
Legend
Low priority
Median priority
High priority
50
Kilometers
N


Bio 14
Bio 15
Bio 16
Bio 17
Legend
Low priority
Median priority
High priority
50
Kilometers
N


Bio 18
Bio 19
Legend
Low priority
Median priority
High priority
50
Kilometers
N