Impact of Climate Change on Freshwater Biodiversity in Tropical River Ecosystems

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Abstract: Climate change (CC) arises from the augmentation of greenhouse gas (GHG) environmental emissions due to diverse human activities. The decomposition of CO2, which constitutes the predominant proportion of GHG contributing to global warming, jeopardizes the continuity of life on the planet. The changing climate is critically significant due to its substantial effects on water supplies and the agricultural sector. CC impacts impose intricate pressures on aquatic life and ecological aquatic ecosystems. Alterations in the water's temperature modify aquatic creatures' metabolic processes and physiology, influencing the growth, reproductive capacity, feeding habits, shipping, immigration, and population density of fish and other marine creatures.

Keywords: Climate Change; Freshwater; Biodiversity; River.

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I. Introduction

Forecasting the impacts of warming temperatures on the geographic distribution of species and, therefore, on their biodiversity (BD) Islam, K. N., Rana, L. R. S., & Islam, K. (2021) is a complicated and significant endeavor, but it is essential. A prevalent but straightforward method to accomplish this objective has been the development of Species Distribution Models (SDMs) Adde et al. (2023). SDMs associate a collection of species distributions with the physical characteristics of the corresponding locations to provide forecasts for several climatic scenarios.

SDMs can also be employed to estimate several forms of worldwide change, including land use and population density. Hence, they are not confined to climate change (CC) Benveniste, H., Oppenheimer, M., & Fleurbaey, M. (2022) alone. SDMs can be regarded as predictive models, where the accuracy of predictions is significantly influenced by the quality of the information used and the robustness of the correlation between global change and the spread of species. When the outcomes of these correlated algorithms are assessed using occurrence information from an alternate timeframe, whether for hindcasting or projections, the outcomes are often inadequate.

Freshwater fish are particularly susceptible to climatic alterations and face a significant danger of extinction due to anticipated shifts in hydrological patterns and rising temperatures Nimma et al. (2025). Aquarium fish have seen significant modifications in their ranges due to recent CCs, which have profoundly impacted riverine aquatic assemblage structure. SDMs are frequently employed to assess the impact of warming temperatures on freshwater fish populations. The preponderance of research has been concentrated on species inhabiting cold-water environments. So far, no research has sought to assess the possible impacts of upcoming climate shifts on aquatic creatures globally. This method adopts a fundamentally comprehensive viewpoint on the worldwide study of multiple organisms to enhance the understanding of the potential impacts of CC, as opposed to the predominant focus on single species investigated in freshwater surveys.

II. CCs and Aquatic Ecosystems

The aquatic environment has a limited capacity to respond to warming temperatures. Minimizing the probability of substantial effects on these ecosystems will rely on human actions that mitigate other ecological stressors and bolster the capacity for adaptation Kasperson, J. X., Kasperson, R. E., Turner, B. L., et al. (2022). Species have adapted to thrive within specific climate ranges and can endure fluctuations in weather conditions. CC drives certain organisms to the brink of extinction, whereas others thrive. The increase in temperature disrupts the circadian rhythms of several animal species. Global temperature levels will rise by 1.4 to 5.6°C by 2200. CC affects both marine and freshwater habitats.

1. Marine Ecosystems Venegas, R. M., Acevedo, J., & Treml, E. A. (2023): CC affects the marine environment via the increase in ocean temperatures, which enhances thermal stratification and diminishes rising waters, as well as via rising sea levels, raised wave intensity and frequency, loss of ocean ice, heightened risk of illness in marine organisms, and reductions in pH and carbonate ion concentrations in surface the seas. Nutrient diversification is theoretically affected by the anticipated decreased pH levels in the coming century. Reductions in rising and deep-water development and heightened upper ocean stratification would diminish the influx of vital nutrients into illuminated oceanic zones, hence decreasing production.
2. Aquatic Freshwater Ecosystems Ceschin, S., Bellini, A., & Scalici, M. (2021): The effect of CC on inland aquatic environments will encompass both immediate consequences resulting from rising temperatures and CO2 levels and indirect effects stemming from hydrological alterations due to shifts in neighborhood or global rainfall patterns and the disappearance of glaciers and ice covers.

The interplay of rapid land use transformation, habitat modification, contamination, enrichment of nutrients, hydrological alterations, proliferation of introduced species, escalating UV radiation, and CC is seen as a significant threat to aquatic environments. An elevated climate will lead to increased evaporation from water surfaces and enhanced absorption by vegetation, hence intensifying the water cycle. Subsequent CC will immediately affect ecosystems in lakes due to elevated temperatures and alterations in the water cycle.

Accelerated CC has several detrimental effects on the BD of waterways. CC leads to extinction across several taxonomic groups. At the organism threshold, creatures with limited geographic distribution are susceptible to global extinction Pigot, A. L., Merow, C., Wilson, A., et al. (2023). This applies to aquatic organisms where regional variations in the proportionate prevalence of species render them susceptible to worldwide extinction.

III. CC and Aquatic BD

BD refers to the range of living species within a particular region, including the range of life forms, their genetic composition, and the natural environments they constitute. Microbes in a community exhibit a range of sizes and shapes, from the smallest unicellular prokaryotes to the more sophisticated multicellular eukaryotes. Every creature serves a crucial function and helps maintain the stability of the environment. CC significantly affects BD and agricultural practices. CC influences on:

1. Deep-sea (DS) BD: The DS is a significant marine life repository. The deep seafloor is thought to harbor greater diversity than all other aquatic ecosystems. Marine BD and ecosystems are imperiled by pollution, transport, military operations, and CC, but fishing poses the most significant danger now. Bottom fishing poses the most critical threat to DS BD. DS fishing is more detrimental to seamounts and the cold-water reefs they support. These areas provide a habitat for several commercially valuable benthic fish species.
2. Coastal fish variety: Coastal fisheries are essential resources for hundreds of millions of individuals. Numerous experts now identify the significant abuse of fishing and the decrease in fish populations as the primary cause of alterations in marine ecosystems over the last two centuries. Recent data indicate that oceanic and climatic variability have significantly influenced fish populations. The correlation between CC and the variety of fish and population is likely intricate. In some instances, nuanced alterations influence circumstances and significant transformations in the life cycle of different kinds of fish; the most prevalent impacts of climate manifest on both primary and

secondary productivity within aquatic environments. The rise of carbon dioxide in the atmosphere affects the pH level of saltwater.

3. Crustaceans: The elevation of CO2 levels in water leads to a reduction in saltwater pH, resulting in the acidity of saltwater. This adversely impacts crustaceans. The exoskeletons of crustaceans are composed of aragonite, a prevalent form of magnesium carbonate, which is soluble in acidic saltwater. The proliferation of these little crustaceans at the base of the food chain alters the whole marine ecology. Oceanography experts indicate that tiny crustaceans known as krill, which consume phytoplankton, have declined by 80% over the previous 30 years.
4. Coral Reef: Tropical littoral and subtidal zones are inhabited mainly by ecosystems defined by corals. This environment sustains many fish, birds, sea turtles, and marine mammal species. Reefs are environments where many substantial organisms congregate for reproduction. Fish heavily harvested by people either spawn at these reefs or employ the resources they generate. A reduction in light entry, temperatures, and limestone alkalinity of saltwater disrupts the establishment of limestone reefs. However, owing to global warming and other stressors, corals have seen significant alterations over the last two decades, and these modifications have been unequivocally associated with intervals of elevated sea temperatures.

IV. Diversity Indices and Statistical Evaluation

Indexes of diversity were assessed for each river region, both in current assessments and future forecasts for 2050 and 2070, based on findings from the RCP 4.0 and RCP 6.0 scenarios. The indicator operates from the R store. EcolndR facilitates the computation of 32 distinct indices for every river basin, categorized into five groups: uncommonness (two indicators), variation (14 indicators), uniformity (seven indicators), taxonomic diversity (two indicators), and functional variety (six indicators). Due to the absence of a universally applicable index for all biological groupings, the algorithm was used to choose the indicators of diversity that most effectively demonstrated the variations across river basins. Just one from each group was selected among all the calculated indices.

Every statistical analysis was conducted using the RWizard program StatR. Gradually, multiple regression analyses were performed using the R statistical software. A backward-forward methodology was employed using the Akaike Information Criteria (AIC) to identify the least parsimonious design. The relative impact of every factor in the declines was assessed using the approach (the mean r contribution across different sequences of regression coefficients) using the R relaimpo tool. Using the statistic, the dwtest tool from the Imtest library was used to assess oscillation.

V. Outcomes

The correlation slope between the basin's diversity of species, derived from accumulating curves, and observable species richness from recordings is considerably less than one ($P < 0.001$), with an average of 0.82. This indicates that the BD richness of the basins is overestimated when using the accessible unprocessed information, with the underestimation being more pronounced in basins with high species diversity. This is probably attributable to the inadequate quality of current inventories in several nations, particularly tropical regions with greater diversity of organisms.

Among the various methods employed to delineate the accessible space in the modeling processes (such as convex hull, alpha form with varying alpha values, and Kernel minimum density utilizing various smoothing parameters), the model that exhibited the optimal fit about species richness derived from buildup curves was produced employing a Kernel density estimation with a flattening value of one. The starting point of this association was not substantially distinct from zero ($P = 0.271$), and the slope was barely different from one ($P = 0.601$), with a value of 0.98. The abundance of species information estimated by the kernel distribution estimate was chosen for input into the periodic transfer modeling technique since it closely mirrored the amount of species derived from accumulating curves.

The reduction in diversity of species was comparable across forecasts RCP 4.0 and RCP 6.0. The models in question forecasted the total eradication of the distributional ranges of fifty percent of all aquatic fish species (ranging from 44.5% to 47.8%, irrespective of the year or environmental condition). The decrease was more significant in tropical rivers.

VI. Conclusion

Alterations in climatic variables significantly affect the BD of an area. Factors such as elevated temperatures and increasing sea levels have significantly affected ecosystems on both continents, resulting in the loss of many species, with many classified as endangered or on the brink of extinction. Deforestation, extensive growth, building activities such as reservoirs, and the conversion of forest area for farming and non-agricultural use have profoundly affected BD. The preservation of BD is essential in contemporary times. Understanding the implications of CC on BD is crucial, and mitigation methods must be implemented to alleviate the harm inflicted by the adverse impacts of climate change on BD. The preservation of BD involves strategic preparation and oversight of natural assets to ensure their extensive use and sustained availability, while preserving their quality, worth, and variety.

It is imperative to avoid expansion via effective planning and administration. An urgent need exists to intensify efforts to alleviate the decline in BD and establish enduring solutions to conserve this valuable resource. The research must consider future expenditures, namely, whether to invest in advancing humanity or distributing it. BD protection cannot be achieved just via the execution of laws. These data imply that CC poses a substantial danger to the diversity and functionality of aquatic environments. As CC modifies the productivity of ecosystems and diversity of species, several unexpected changes in the environment are anticipated that might jeopardize the goods and services these structures provide to humanity. BD protection is essential since it protects nature against calamities.

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