Environment, Resource and Ecology Journal (2026)
Clausius Scientific Press, Canada

DOI: 10.23977/erej.2026.100110
ISSN 2616-3756 Vol. 10 Num. 1

Response Mechanisms of Carbon Emissions in the Northwestern Yunnan Plateau Wetlands to Temperature Increase

Hu Yao, Haiyun Yan*, Jingshuang Zhu

Yunnan Open University, Kunming, Yunnan, 650500, China
**Corresponding author*

Keywords: Northwestern Yunnan Plateau; Wetland Ecosystem; Temperature Increase; Carbon Emissions; Q_{10} Model; Climate Warming

Abstract: Global climate warming is exerting significant environmental pressure on the high-altitude wetland ecosystems of the Northwestern Yunnan Plateau, a globally important region. Based on a comprehensive review and synthesis of recent literature (circa 2026), this paper systematically evaluates the dual impacts of temperature rise on the carbon cycle dynamics of these wetlands, with representative sites like Napahai. The research indicates that while warming may enhance carbon sink capacity by extending the growing season and promoting photosynthesis in some plants, its accelerating effect on microbial respiration and soil organic carbon (SOC) decomposition is more pronounced. This creates a potential risk for these wetlands to transition from carbon sinks to carbon sources. The paper further analyzes key uncertainties within the influencing mechanisms and proposes directions for future research and management recommendations.

1. Introduction

1.1 Research Background and Significance

Wetland ecosystems, covering only 5%-8% of the global land area, store 20%-30% of the terrestrial ecosystem carbon pool, making them one of the most crucial and concentrated carbon reservoirs on Earth[1]. High-altitude wetlands, characterized by their unique low-temperature, high-cold, and hypoxic environments, effectively inhibit the decomposition rate of organic matter, leading to the accumulation of vast amounts of soil organic carbon. These wetlands play a key "carbon sink" role in the global carbon balance, indispensable for stabilizing atmospheric greenhouse gas concentrations and mitigating global climate change. However, precisely because of their enormous carbon stocks and high sensitivity to environmental changes, these seemingly stable carbon pools may shift from "sinks" to "sources" if external conditions alter, particularly with rising temperatures. This could release large quantities of carbon dioxide (CO_2) and methane (CH_4) into the atmosphere, forming a positive feedback loop that exacerbates the climate crisis.

The Northwestern Yunnan Plateau is a critical transition zone connecting the East Asian monsoon and the plateau climate system, and a global biodiversity hotspot. Wetland ecosystems in this region (e.g., Napahai, Bitahai) are not only unique repositories of biodiversity but also vital sources of freshwater and carbon sinks globally. Due to the distinctive high-cold, hypoxic conditions, wetland soils have accumulated substantial peat and organic carbon over long periods, forming a highly potential "carbon pool" in the global carbon cycle. This region is recognized as highly sensitive to climate change, with relatively simple ecosystem structures and poor stability, making its response to external environmental disturbances (especially temperature changes) particularly rapid and intense. Thus, studying the wetlands of the Northwestern Yunnan Plateau is not only important for regional ecological security but also provides an ideal "natural laboratory" for understanding the responses of similar ecosystems worldwide to climate change.

According to projections by the Intergovernmental Panel on Climate Change (IPCC), global surface temperatures will continue to rise. Within this macro-context, high-altitude regions often exhibit faster warming rates than the global average, a phenomenon known as "elevation-dependent warming"[2]. Research has clearly shown that the Northwestern Yunnan Plateau has undergone a significant climate warming process over the past half-century, with an average temperature increase of 1.32 ℃, far exceeding the national average for the same period. The warming amplitude in the Lijiang area since 1951 has also reached approximately 1.5 ℃. As a core environmental factor driving almost all biological and chemical processes in ecosystems, sustained temperature increase will fundamentally reshape the ecological functions of the Northwestern Yunnan Plateau wetlands. It directly affects plant photosynthesis, respiration, and microbial metabolic activity, and indirectly influences the wetland carbon cycle through cascading effects on hydrological conditions and soil physicochemical properties. Elucidating the mechanisms, direction, and magnitude of these impacts is crucial for predicting future carbon source/sink dynamics of wetlands in this region and assessing their feedback on the global climate.

1.2 Research Objectives and Core Questions

This report focuses on the wetland ecosystems of the Northwestern Yunnan Plateau. By comprehensively reviewing current domestic and international research findings, data, and methodologies in related fields, it aims to conduct an in-depth exploration through systematic analysis and integration, centered on key scientific questions regarding carbon emissions in these wetlands. The goal is to provide comprehensive, objective, and targeted answers, offering solid support for subsequent research and practice.

First, focusing on the foundational premise of climate change, it investigates the temperature change characteristics across the Northwestern Yunnan Plateau, especially in areas with concentrated wetlands. Specifically, it systematically reviews recent (short-term) temperature fluctuation data alongside long-term historical observations and paleoclimate reconstructions to clarify temperature trends, fluctuation ranges, and spatial distribution differences across various time scales, establishing the overall climate change situation in the region and laying the groundwork for analyzing temperature impacts on wetland carbon emissions.

Second, it delves into the core mechanisms through which temperature increase affects carbon emissions in the Northwestern Yunnan Plateau wetlands, explaining how temperature regulates wetland carbon cycle processes via various biogeochemical pathways. Specifically, it explores how temperature rise affects two key processes: carbon input and carbon output. For carbon input, it analyzes the regulatory mechanisms of temperature on wetland vegetation photosynthetic efficiency, community structure, and productivity, clarifying how temperature changes alter the intensity and rate of carbon uptake. For carbon output, it focuses on the impact of temperature on processes like wetland soil respiration and microbial decomposition, revealing the internal logic behind increased carbon release due to warming and clarifying the synergistic relationships among various biogeochemical pathways.

Third, it investigates the dynamic patterns of carbon emissions in the Northwestern Yunnan Plateau wetlands over time, with particular attention to seasonal variation characteristics. By integrating observational data from different seasons, it analyzes the variation patterns of wetland carbon emissions during spring germination, summer peak, autumn decline, and winter dormancy, clarifying intensity differences, peak characteristics, and trends across seasons. It also deeply analyzes the differential regulatory effects of temperature on carbon emissions in different seasons, explaining the dynamic regulatory mechanisms of wetland carbon emissions under the coupling of temperature and seasonal changes, thereby enhancing understanding of the temporal dynamics of the wetland carbon cycle.

Finally, it objectively examines the current state of research on carbon emissions in the Northwestern Yunnan Plateau wetlands, systematically sorts out the main uncertainties and knowledge gaps in existing studies. These include, but are not limited to, insufficient spatiotemporal coverage of observational data, inadequate depth in impact mechanism research, and lack of studies on the coupled effects of different driving factors. Based on this, and considering research hotspots and practical needs in the field, it proposes future research directions and specific tasks to address existing knowledge gaps and promote deeper development in this area.

Through systematic discussion and in-depth analysis of these core questions, this report aims to provide researchers in wetland ecology, climate change, and carbon cycling related to the Northwestern Yunnan Plateau with a comprehensive and systematic review of the research status, sorts out research context, summarizing core findings and pointing out shortcomings. Simultaneously, it seeks to provide scientific and reliable theoretical basis and practical references for local governments in formulating policies for wetland ecological protection, carbon sink management, and climate adaptation, contributing to the protection and sustainable development of wetland ecosystems in the Northwestern Yunnan Plateau.

2. Study Area Background

2.1. Geographical and Climatic Characteristics

The Napahai wetland is situated on a plateau at an altitude of approximately 3260 meters, characterized by a typical high-cold climate zone. The climate features can be summarized as: low annual average temperature, long frost period, distinct dry and wet seasons, and large annual and diurnal temperature ranges. Multi-source data indicate that the average annual temperature of the Napahai wetland is stable at around 5.4 ℃. The average temperature of the coldest month (typically January) can drop to -3.8 ℃, while the average temperature of the hottest month (typically July) is only 13.2 ℃. Extreme lows can reach -25.4 ℃, and extreme highs 24.5 ℃. This low-temperature environment is the foundation for the wetland's substantial accumulation of organic carbon. Severe cold and freezing conditions in winter greatly limit microbial decomposition activities, allowing a large portion of plant litter produced annually to be preserved. The relatively mild summer temperatures provide conditions for rapid plant growth. Therefore, Napahai's climatic baseline, particularly its low-temperature characteristics is the starting point for understanding its carbon cycle response to warming.

2.2. Vegetation Communities and Soil Carbon Pool

The vegetation community structure of wetlands on the Northwestern Yunnan Plateau is unique, forming a distinct zonal distribution with seasonal water level fluctuations. From the lake center to the lakeshore, vegetation types transition from aquatic plants to wet meadows and swamp meadows.

Dominant species include sedges (Carex) and kobresia (Kobresia), which are adapted to high-cold and hypoxic environments. These plants convert atmospheric CO_2 into biomass through photosynthesis, and through litter input into the soil, form peat layers several meters thick. Due to long-term low temperatures and anaerobic conditions inhibiting organic matter decomposition, wetland soil organic carbon content is extremely high, making it one of the most carbon-rich ecosystems globally.

3. Analysis of Temperature Trends under Climate Change Background

As an "amplifier" of global climate change, the warming trend in the Northwestern Yunnan Plateau has been confirmed by multiple studies. Overall, the region's climate is undergoing profound and rapid warming. Research covering the past 50 years clearly indicates that the average annual temperature in the Northwestern Yunnan Plateau has increased by 1.32℃, a rate significantly higher than the national average for the same period, clearly demonstrating the region's sensitive response to global climate change. Another analysis of meteorological data from the Lijiang area over 70 years (1951-2020) reached a similar conclusion, showing an overall upward trend in annual mean temperature, with a cumulative increase of approximately 1.5℃. Even historical climate sequences reconstructed from proxy data like tree rings show that temperatures in the region have generally been in a fluctuating upward state over the past 200 years. These long-term, multi-temporal-scale evidences collectively paint a clear picture of regional warming, providing a macro-context for understanding the environmental pressures currently borne by wetland ecosystems. This sustained and rapid warming is undoubtedly the most fundamental and direct external force driving changes in the carbon cycle processes of the region's wetland ecosystems. Meteorological data from Shangri-La City further corroborate this trend, with its annual mean temperature increasing at a rate of 0.37℃ per decade, indicating more severe warming pressure in the future.

4. Dual Impact Mechanisms of Temperature Increase on Wetland Carbon Cycle

The impact of temperature increase on the carbon cycle of wetland ecosystems is complex and opposing, primarily acting through the regulation of carbon input (photosynthesis) and carbon output (respiration) pathways.

4.1. Positive Effects on Carbon Input (Photosynthesis)

4.1.1. Growing Season Extension Effect

Temperature increase is a primary driver for extending the growing season in plateau regions. With earlier spring warming and delayed autumn frosts, the plant growing season (i.e., the effective period for photosynthesis) is prolonged. Research shows that extension of the growing season typically leads to an increase in net primary productivity (NPP). For the Northwestern Yunnan Plateau wetlands, this means more CO_2 will be fixed by plants into biomass and ultimately enter the soil via litter, helping to replenish the soil carbon pool and strengthen the wetland's carbon sink function.

4.1.2. Species-Specific Response of Photosynthetic Efficiency

The effect of temperature increase on plant photosynthetic rate is not linear but shows significant species differences Generally, temperature rise stimulates photosynthesis (CO_2 fertilization effect), but different plants have different optimal photosynthetic temperatures. The dominant plants in the

Northwestern Yunnan Plateau wetlands are primarily adapted to low-temperature environments. Excessively high temperatures may exceed their physiological tolerance thresholds, leading to decreased photosynthetic efficiency or even heat inhibition. Furthermore, warming may induce vegetation community succession, such as the replacement of cold-tolerant species by heat-tolerant dominants, thereby altering the overall photosynthetic characteristics of the wetland.

4.2. Negative Effects on Carbon Output (Respiration)

4.2.1. Exponential Increase in Microbial Respiration

Compared to photosynthesis, the respiration of wetland ecosystems (especially microbial respiration) is more sensitive to temperature. Wetland soils are rich in peat layers containing large amounts of "ancient" organic carbon, usually in anaerobic states with very slow decomposition rates. However, temperature increase can significantly activate microbial metabolic activity, accelerating the mineralization of organic carbon and CO_2 release. Studies show a significant positive correlation between soil respiration rate and soil temperature, often exhibiting exponential growth.

4.2.2. Accelerated Litter Decomposition

Plant litter is the most direct source of soil organic carbon, and its decomposition rate is a key link determining carbon turnover speed in ecosystems. Research on the Napahai wetland in the Northwestern Yunnan Plateau provides direct evidence. This study found a significant positive correlation between the decomposition rate of plant litter and the increase in monthly average temperature. This means that with climate warming, the plant residues entering the soil each year will decompose faster, shortening the average residence time of carbon in the ecosystem. This not only reduces the proportion of new carbon converted into stable soil organic carbon but may also accelerate the decomposition of existing old carbon.

4.2.3. Q_{10} Effect and Its Uncertainties

The Q_{10} value is a key parameter measuring the temperature sensitivity of respiration, defined as the factor by which the respiration rate increases for every 10 ℃ rise in temperature. Although the average Q_{10} value for global ecosystems is around 2.4, the Q_{10} value for wetland ecosystems is often regulated by multiple factors such as moisture, substrate availability, and microbial community structure[3].

4.2.4. Risk of Accelerated Soil Organic Carbon Decomposition

For the Northwestern Yunnan Plateau wetlands, the greatest potential risk lies in the massive amounts of organic carbon stored in their soils. This carbon accumulated slowly over thousands of years or more under past cold climates. Sustained temperature increase is akin to unlocking the "shackles" of microbial decomposition[4]. Soil respiration, as one of the main drivers of wetland carbon emissions, typically increases significantly with rising temperature. Although in some cases, drought accompanying warming may inhibit soil respiration, in wetland environments where moisture is usually sufficient, the dominant role of temperature may be more pronounced. Once warming activates the decomposition of these ancient, stable carbon pools, the amount of CO_2 released could far exceed the increased carbon uptake by vegetation, leading to a complete transition of the wetland from a net carbon sink to a powerful net carbon source.

5. Seasonal Dynamics of Carbon Flux and Its Coupling with Temperature

5.1. Carbon Sink Characteristics during the Growing Season

During the growing season (mainly summer), wetland ecosystems exhibit strong net carbon uptake characteristics. At this time, photosynthesis is strong, soil temperatures are high, and the rate at which vegetation fixes CO_2 through photosynthesis far exceeds the consumption rate by respiration. Therefore, NEE is negative during the day (absorbing CO_2) and positive at night (respiration), but the daily average is negative, indicating that the wetland acts as a carbon sink for the atmosphere during this period[5].

5.2. Carbon Source Characteristics during the Non-Growing Season

During the non-growing season (mainly winter), as temperatures plummet, photosynthesis essentially ceases, but soil microbial activity persists (though weakened), leading to continuous CO_2 release. At this time, NEE is positive, and the wetland becomes a carbon source for the atmosphere.

5.3. Dominant Regulation by Temperature

Temperature is the dominant factor regulating the aforementioned seasonal changes. Temperature increase during the growing season significantly enhances both photosynthesis and respiration, but their balance determines the carbon sink strength. Temperature increase during the non-growing season can significantly break the "low-temperature inhibition" balance, causing carbon that should be sequestered to be released earlier in winter.[6]

6. Conclusion

The impact of temperature increase on carbon emissions in the Northwestern Yunnan Plateau wetlands presents a significant "double-edged sword" effect. Although moderate warming may enhance carbon sink capacity by extending the growing season and promoting some photosynthesis, its promoting effect on microbial respiration is more significant and exhibits potential exponential growth characteristics. Considering the massive amounts of ancient carbon stored in the wetland soils of this region, once warming activates the decomposition of this organic carbon, the amount of CO_2 released is highly likely to exceed the CO_2 fixed by vegetation, leading to a transition of the wetland from a net carbon sink to a net carbon source, forming a positive feedback to global climate warming.

7. Future Research Outlook and Recommendations

7.1. Strengthening Multi-Dimensional In Situ Monitoring and Observation Network Construction

There is an urgent need to establish long-term multi-dimensional in situ observation stations in the Northwestern Yunnan Plateau wetlands (e.g., Napahai, Bitahai), for example, using eddy covariance techniques for continuous carbon flux (NEE, GPP, Reco) monitoring. By obtaining high-resolution meteorological (temperature, humidity, precipitation) and soil (temperature, moisture, carbon content) data, a comprehensive monitoring database can be built to provide a solid empirical foundation for model parameterization.

7.2. Conducting Multi-Factor Controlled Experiments

It is recommended to set up open-top chamber (OTC) warming devices in the field to simulate different degrees of climate warming scenarios, combined with treatments such as precipitation alteration and nitrogen addition, to systematically study the carbon cycle responses of wetland ecosystems under synergistic stress from multiple environmental factors. In particular, obtaining the Q_{10} values of soil respiration in the region's wetlands and their seasonal variation patterns through experiments is crucial.

7.3. Developing Regionalized Ecosystem Models

Combining field observations and experimental data, ecosystem models suitable for the high-altitude wetland environment (e.g., MODIS, CASA, Biome-BGC) should be developed for model parameterization and validation. Using models to simulate the carbon cycle dynamics of wetlands under different climate scenarios provides scientific basis for assessing the impact of future climate change on the carbon source/sink function of wetlands in this region.

Acknowledgements

This study was funded by the Science Research Foundation of the Yunnan Open University (Grant No. 25YNOU02)

References

[1] Hu Q W., Wu Q., Liu Y., et al. A review of carbon cycle in wetlands. Ecology and Environmental Sciences, 2009, 18(6):2381-2386.
[2] Zheng J J., Huang S Y., Jia X., et al. Spatial variation and controlling factors of temperature sensitivity of soil respiration in forest ecosystems across China. Chinese Journal of Plant Ecology, 2020,44(6):687-698.
[3] Xu L., Yang Y R., Zhang J H., et al. Effects of simulated N deposition on Q_{10} of soil respiration in Chinese terrestrial ecosystems. Chinese Journal of Ecology, 2019, 38(5):1560-1569.
[4] Zhang H W., Cheng G S., Zhao X J. Path of the village collective economic development of hengyang city in new rural construction. Yunnan geographic environment research, 2014,26(1).
[5] Wang Q Q, Wang H, Zhang WC, Wang Z B, Xiao D R. The correlations between wetland landscape and social-natural factors on Northwestern Yunnan Plateau. Acta Ecologica Sinica, 2019,39(2).
[6] Wang H, Zhang Y, Chen G L, Hettenhausen C, Liu Y, Tan K, Xiao D R. Domestic pig uprooting emerges as an undesirable disturbance to vegetation and soil properties in a plateau wetland ecosystem. Wetlands Ecology and Management, 2017: 1- 15