

# *Analysis of the Impact of Temperature on Carbon Dioxide (CO<sub>2</sub>) Emissions from the Napahai Plateau Wetland*

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**Keywords:** Northwestern Yunnan Plateau; Wetland Ecosystem; Temperature Increase; Carbon Emissions; Climate Warming

**Abstract:** Napahai, located on the plateau of northwestern Yunnan, is a highly sensitive ecosystem. Based on existing research data, this paper analyzes the potential impact of regional temperature rise on CO<sub>2</sub> emissions from this wetland. By synthesizing key indicators such as temperature change trends, vegetation photosynthetic and respiratory responses, litter decomposition rates, and soil carbon pool dynamics, a comprehensive impact assessment framework was constructed. The results indicate that with rising temperatures, although plant photosynthesis is enhanced, the significant acceleration of litter decomposition rates and the increased volatility of soil carbon stocks may collectively lead to an overall increase in CO<sub>2</sub> emissions from the wetland, posing a risk of weakening its carbon sink function.

## 1. Introduction

Wetlands, hailed as the "kidneys of the Earth," play an indispensable role in the global carbon cycle, climate regulation, and biodiversity conservation. Wetland soils store approximately 20-30% of the world's terrestrial soil carbon, representing a vast carbon reservoir. However, the stability of these reservoirs is under severe challenge from global climate change. Temperature, as one of the most critical environmental factors influencing ecosystem metabolic processes, directly regulates two key carbon flux processes in wetland ecosystems: photosynthesis (CO<sub>2</sub> uptake) and ecosystem respiration (CO<sub>2</sub> emission). A slight imbalance between these two processes can cause a wetland to shift from a "carbon sink" to a "carbon source," releasing large amounts of greenhouse gases into the atmosphere and creating a positive feedback effect on climate change.

Under the background of global warming, the Napahai wetland ecosystem is undergoing profound transformation. Located in the core area of the northwestern Yunnan plateau, Napahai is not only a crucial hub for regional water resource regulation but also a vital component of the plateau ecological barrier. Yet, this unique wetland ecosystem faces significant challenges from climate change. Recent climate monitoring data show an increasing annual average temperature trend in the northwestern Yunnan region, with a notable rise in the frequency of extreme heat events. This trend profoundly impacts the carbon cycling mechanisms of the Napahai wetland, particularly by altering its hydrological seasonality. Specifically, rising temperatures lead to earlier snow and ice melt, causing the high-water period to arrive earlier and last for a shorter duration, while the onset

of the dry season advances, leading to a prolonged dry period. This shift in hydrological seasonality directly influences changes in the water-covered area of the wetland, thereby regulating the spatiotemporal distribution of soil respiration and carbon fluxes.

Simultaneously, as the primary driver of biochemical reaction rates, rising temperatures exert a dual effect on the physiological and ecological responses of the wetland ecosystem. On one hand, dominant plants (e.g., *Schoenoplectus tabernaemontani*, *Zizania latifolia*) exhibit higher photosynthetic efficiency under elevated temperatures, with a significant increase in photosynthetic rates, suggesting the wetland might offset some carbon losses through enhanced biomass production. On the other hand, microbial metabolic activity is also significantly stimulated, leading to faster organic matter decomposition and increased CO<sub>2</sub> emissions. Of particular concern is the extreme sensitivity of litter decomposition processes in the Napahai wetland to temperature, with its Q<sub>10</sub> value as high as 3.48, far exceeding the typical sensitivity of soil respiration. This implies that under warming scenarios, the carbon sink could rapidly transform into a carbon source due to accelerated organic matter mineralization. Furthermore, the degradation of the wetland landscape (e.g., encroachment by swamp meadows or bare land) leads to soil exposure and enhanced oxidative decomposition, which is also a significant factor contributing to increased CO<sub>2</sub> emissions.

Based on this, this paper aims to systematically evaluate the comprehensive impact of temperature rise on CO<sub>2</sub> emissions from the Napahai wetland by integrating data on dominant plant photosynthesis, litter decomposition experiments, and landscape pattern change monitoring. Specific objectives include: quantifying the net effect of temperature on photosynthetic carbon fixation and respiratory consumption, analyzing the temperature sensitivity mechanism of litter decomposition, and assessing the combined effects of landscape degradation and climate warming. Through this research, we can deepen our understanding of carbon cycling dynamics in plateau wetlands and provide a scientific basis for formulating wetland protection and carbon emission reduction strategies in northwestern Yunnan.

## 2. Study Area and Climate Change Context

### 2.1. Natural Geography and Ecological Characteristics of Napahai

Napahai is located in Shangri-La City, northwestern Yunnan Province, with geographical coordinates between 99°37'E to 99°43'E and 27°49'N to 27°55'N. It is a typical plateau tectonic fault-depression basin at an altitude of 3260 meters. This wetland features unique hydrological characteristics, being a seasonal lake. During the summer and autumn rainy season (June-October), water accumulates in the basin to form an extensive lake surface; during the winter and spring dry season (November to May of the following year), lake water drains through underground karst caves, causing the lake surface to recede and expose large areas of swampy meadows. The regional climate is classified as a plateau cold-temperate monsoon climate, characterized by low annual average temperature, large diurnal temperature range, and distinct dry and wet seasons. According to records, the average annual temperature in the Napahai area is approximately 5.4 °C to 6.2 °C. Seasonal temperature variation is significant, with the coldest month (January) averaging around -3.8 °C and the warmest month (July) averaging about 13.2 °C<sup>[1]</sup>. Soil types in the Napahai wetland mainly include bog soil, peat soil, and meadow soil. These soils are rich in organic matter, forming a massive soil carbon pool, which serves as the material basis for carbon cycle research in this ecosystem. Vegetation types show a distinct zonal distribution along the moisture gradient, ranging from aquatic vegetation in the lake center to swamp vegetation and alpine meadow vegetation at the edges. Major plant communities include alpine pine forests, alpine shrubs, and extensive swampy meadows<sup>[2]</sup>. The photosynthesis of this vegetation and the decomposition of its litter are the core processes driving the ecosystem's carbon cycle. Annual precipitation is about 612.8 mm,

concentrated mainly in summer.

## 2.2. Significant Climate Warming Trend in the Napahai Region

Existing research clearly reveals an undeniable climate warming process that the Napahai region and its surroundings have experienced over the past few decades. An analysis based on 50 years (1958-2008) of meteorological observation data from four weather stations around Napahai indicates a significant upward trend in the region's annual average temperature. Over these 50 years, the annual average temperature increased by a total of 1.2 °C, with a linear rate of change of 0.036 °C/year. The study also found an abrupt change in temperature around 1985, shifting from a relatively stable state to an accelerated warming trend. Other studies have reached similar conclusions, confirming a clear warming trend in northwestern Yunnan, including Napahai, in recent decades. This sustained warming, particularly the increase in minimum winter and spring temperatures, will directly affect wetland soil temperature, freeze-thaw cycles, vegetation growing season length, and microbial activity, thereby profoundly impacting the ecosystem's CO<sub>2</sub> emissions.

## 3. Field Measurement Techniques

The establishment and validation of all models rely on high-quality field observation data. Currently, mainstream techniques for measuring wetland CO<sub>2</sub> fluxes include:

**Static Chamber Method:** A widely used portable method that involves placing a sealed chamber over the ground to measure the rate of change in CO<sub>2</sub> concentration inside the chamber over time to calculate the flux. Combined with a gas chromatograph or non-dispersive infrared (NDIR) gas analyzer, high-precision flux data can be obtained. Its advantages include relatively low cost and suitability for multi-point repeated measurements, making it ideal for studying spatial heterogeneity.

**Eddy Covariance (EC) Technique:** A micrometeorological method that involves erecting a tower above the wetland equipped with high-speed sensors (e.g., 3D sonic anemometer and open-/closed-path infrared gas analyzer) to continuously measure turbulent fluctuations in vertical wind speed and CO<sub>2</sub> concentration at high frequency (e.g., 10 Hz), thereby calculating the net ecosystem exchange (NEE) of CO<sub>2</sub> at the ecosystem scale. Its advantages include providing continuous, long-term, large-area flux data, but it is costly and cannot distinguish between gross primary production (GPP) and ecosystem respiration (ER). It typically requires combining nighttime data (assuming GPP is zero at night, so  $NEE = ER$ ) with models for partitioning.

## 4. Results and Analysis

### 4.1. Regional Air Temperature Rise Trend

According to climate monitoring data from Yunnan Province over the past 40 years, the temperature in plateau wetlands in northwestern Yunnan, including Napahai, shows a significant upward trend. Research indicates that against the backdrop of global warming, the frequency of extreme warm events is increasing, and plateau wetlands are particularly sensitive to temperature rise. This provides a direct driving factor for subsequent ecosystem responses.

### 4.2. Vegetation Photosynthetic and Respiratory Response

Experimental results show that with changing climatic conditions (i.e., rising temperatures), the net photosynthetic rate of dominant plants (e.g., *Schoenoplectus tabernaemontani*, *Zizania latifolia*) in the Napahai wetland significantly increases<sup>[3]</sup>. Specifically, the photosynthetic rate of

*Schoenoplectus tabernaemontani* increased by approximately 19.1%-18.4%, while that of *Zizania latifolia* increased by about 43.5%-44.2%. Concurrently, stomatal conductance, transpiration rate, and intercellular CO<sub>2</sub> concentration in these plants also increased, indicating that the enhancement of photosynthesis is primarily driven by rising temperatures.

However, it is noteworthy that although photosynthetic carbon fixation capacity improves, plant autotrophic respiration (Ra) also strengthens with rising temperature, and *Zizania latifolia* exhibits better respiratory adaptation to temperature than *Schoenoplectus tabernaemontani*. This increase in respiration rate partially offsets the carbon sink gain from photosynthesis.

#### 4.3. Litter Decomposition and Temperature Sensitivity (Q10)

The direct contribution of temperature rise to wetland CO<sub>2</sub> emissions is mainly reflected in the accelerated rate of litter decomposition. Studies show that the decomposition rate of litter in the Napahai wetland is fastest in October (average temperature -8.1 °C) and slowest in January (average temperature -1.9 °C). This significant seasonal difference indicates that microbial activity is strongly limited by temperature<sup>[4]</sup>.

More crucially, the litter decomposition process is extremely sensitive to temperature, with its temperature sensitivity (Q10) value as high as 3.48 (mixed litter), far exceeding the typical Q10 value for soil respiration. This means that for every 10 °C increase in temperature, the litter decomposition rate will increase by 3.48 times, releasing a large amount of CO<sub>2</sub>. The Q10 value for *Zizania latifolia* litter is 3.06, also significantly higher than that for *Schoenoplectus tabernaemontani* litter. This high Q10 value predicts a potentially very high growth rate of wetland CO<sub>2</sub> emissions under warming scenarios<sup>[5]</sup>.

#### 4.4. Soil Carbon Pool Fluctuations and Landscape Pattern

Changes in the landscape pattern of the Napahai wetland directly affect the dynamics of the soil carbon pool. Data show that between 1974 and 1994, as the wetland landscape area slightly increased, soil carbon storage increased from 33.46×10<sup>4</sup> t to 36.91×10<sup>4</sup> t, primarily indicating carbon accumulation.

However, entering the 21st century, the replacement of wetland landscapes by non-wetland landscapes (e.g., swamp meadows or bare land) led to significant fluctuations in the soil carbon pool. Between 1994 and 2000, although the wetland area slightly decreased, soil carbon storage dropped to 32.92×10<sup>4</sup> t. During this period, carbon release surged to 5.99×10<sup>4</sup> t, which is 2.28 times that of the previous 20 years. This surge in carbon release is closely related to the combined effects of soil exposure, oxidation, and temperature rise caused by wetland degradation.

#### 4.5. Regulatory Role of Hydrological Seasonality

The Napahai wetland exhibits distinct hydrological seasonality: a lake during the high-water period and meadows during the dry season. Changes in hydrological status have complex regulatory effects on CO<sub>2</sub> emissions. During the high-water period, water cover suppresses soil respiration, leading to relatively low CO<sub>2</sub> emissions; during the dry season, exposed soil and enhanced oxidation result in significantly increased CO<sub>2</sub> emissions.

Temperature rise may cause the high-water period to end earlier and the dry season to start sooner, thereby overall extending the period of high emissions.

## 4.6. Comparison with Other Plateau Wetlands

Napahai exhibits a more intense response to temperature changes due to its unique seasonal lake characteristics. Due to its significant water level fluctuations, Napahai's carbon pool is more susceptible to the effects of alternating wetting and drying of surface soil, leading to greater fluctuations in CO<sub>2</sub> flux, especially during the dry season where the combined effects of litter decomposition and soil respiration are more pronounced<sup>[6]</sup>.

## 5. Discussion

### 5.1. Dual Impact of Temperature Rise on CO<sub>2</sub> Emissions

In summary, temperature rise has a "double-edged sword" effect on CO<sub>2</sub> emissions from the Napahai wetland. On one hand, rising temperatures significantly promote the photosynthetic carbon fixation capacity of dominant plants, particularly strengthening the growth advantage of temperature-tolerant species like *Zizania latifolia*. On the other hand, rising temperatures significantly amplify CO<sub>2</sub> emissions through the following mechanisms:

**Accelerated Litter Decomposition Rate:** The high Q<sub>10</sub> value indicates that microbial activity decomposing organic matter is extremely sensitive to temperature, leading to a substantial increase in the rate at which soil organic carbon is converted to CO<sub>2</sub>.

**Enhanced Soil Respiration:** Although the study does not directly provide the Q<sub>10</sub> value for soil respiration, based on the biological characteristics of plateau wetlands, soil microbial respiration (R<sub>h</sub>) is typically highly sensitive to temperature rise<sup>[7]</sup>.

**Landscape Degradation and Carbon Pool Fluctuations:** As wetlands degrade and landscapes fragment, soil is exposed to the atmosphere, oxidation intensifies, further accelerating CO<sub>2</sub> release.

### 5.2. Risk of Carbon Balance Shift

Despite the enhanced photosynthetic carbon fixation capacity of plants, considering the high sensitivity of litter decomposition and the volatility of the soil carbon pool, the carbon balance of the Napahai wetland tends to shift towards becoming a CO<sub>2</sub> emission (source). Particularly during the dry season, although soil temperature is low, water scarcity leads to oxidative decomposition dominating, further weakening the wetland's carbon sink function.

## 6. Conclusion

Analysis based on existing data indicates that the impact of temperature rise on CO<sub>2</sub> emissions from the Napahai plateau wetland is significant and complex. Although some dominant plants show strong adaptability and enhanced photosynthesis, the high temperature sensitivity of litter decomposition (Q<sub>10</sub> value reaching 3.48) and the instability of the soil carbon pool caused by wetland landscape degradation collectively lead to a potential overall increase in wetland CO<sub>2</sub> emissions. Future wetland conservation and management should focus on landscape restoration and hydrological regulation to mitigate the carbon emission pressure brought by rising temperatures.

## 7. Future Research Outlook

To fill the aforementioned key knowledge gaps and provide a scientific basis for the sustainable management of the Napahai wetland, this report proposes the following future research directions:

- 1) Establish a Long-term Multi-dimensional Integrated Observation Platform: The primary task

is to establish a long-term carbon-water-gas flux integrated observation station at representative sites within the Napahai wetland. Core equipment should include an eddy covariance system to enable long-term, continuous, high-frequency monitoring of ecosystem-scale CO<sub>2</sub> and H<sub>2</sub>O fluxes.

2) Conduct Multi-scale Flux Comparative Observations: Within the footprint of the eddy covariance tower, synchronously use the static chamber method to conduct regular CO<sub>2</sub> flux measurements across different micro-topographies. This will help distinguish between ecosystem respiration and soil respiration and reveal spatial heterogeneity.

3) Quantify Temperature Sensitivity (Q<sub>10</sub>): Utilize long-term observed soil temperature and soil respiration data to fit exponential or Lloyd-Taylor models under different seasons and moisture conditions, precisely calculating the Q<sub>10</sub> value for soil respiration in the Napahai wetland. This will be a key parameter for predicting future changes.

4) Design Multi-factor Controlled Experiments: Conduct in-situ controlled experiments in the field, for example, using open-top chambers to simulate future warming scenarios alongside different water level control treatments. This approach can disentangle the independent effects and interactions of temperature and water level changes on CO<sub>2</sub> emission mechanisms.

5) Develop and Validate Ecosystem Models: Use the acquired long-term observation data and controlled experiment parameters to calibrate and validate ecosystem process models. A locally validated model will become a powerful tool for predicting the carbon budget dynamics of the Napahai wetland under different climate change scenarios.

## Acknowledgements

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

## References

- [1] Guo, X., Tian, K., Xiao, D., et al. (2013). Characteristics of Litter Decomposition in the Lakeside Zones of Napahai Wetland in the Northwestern Plateau of Yunnan. *Acta Ecologica Sinica*, 33(7), 2128–2137.
- [2] Zhang, X., Wei, Y., Li, C., et al. (2013). Litter Decomposition Characteristics of Dominant Lakeside Plants in High-Altitude Wetlands and Their Significance for Carbon Cycling. *Plateau Science*, 22(5), 1056–1062.
- [3] Chen, K., Li, C., Zhang, X., et al. (2013). Effects of Simulated Warming on the Decomposition of Litter from Dominant Plants in Napahai Wetland. *Acta Ecologica Sinica*, 33(9), 2776–2784.
- [4] Wang, Q., Zhang, X., Chen, K., et al. (2013). Temperature Sensitivity (Q<sub>10</sub>) of Litter Decomposition in Northwestern Plateau Wetlands under Different Temperature Conditions. *Acta Ecologica Sinica*, 33(12), 3826–3834.
- [5] Li, H., Chen, K., Zhang, X., et al. (2012). Landscape Pattern Changes in Napahai Wetland and Their Impact on Soil Carbon Stocks. *Dryland Resources and Environment*, 30(5), 23–28.
- [6] Xie, P., Liu, G., Sun, J., et al. (2023). Effects of Simulated Warming on Litter Decomposition and Bacterial Communities in Wetland Ecosystems. *Acta Ecologica Sinica*, 43(7), 2175–2184.
- [7] Wei, Y., Cui, L., Zhang, M., et al. (2020). Effects of Exogenous Carbon Input on Soil Organic Carbon Mineralization and Temperature Sensitivity in Agricultural and Wetland Soils of North China Plain. *Journal of Ecological Agriculture*, 38(3), 369–376.