Response of the Biological Components to Climate Change in the Wetland Ecosystem of the Qinghai-Tibet Plateau

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Abstract. Alpine wetlands play a role in water conservation, climate regulation, carbon sequestration, and biodiversity protection. However, due to the unique geological structure and climate characteristics of alpine areas, climate change is highly likely to have an impact on alpine wetlands and their ecosystems, including the abundance and distribution of local species. This paper focuses on analyzing the composition, quantity, and distribution changes of wetland organisms, including producers, consumers, and decomposers. The research findings indicate that, with the intensification of human activities and climate change such as global warming, despite the emergence of some new wetlands, many natural alpine wetlands on Qinghai-Tibet Plateau are facing shrinkage and are gradually retreating towards higher altitudes, latitudes, and wetter areas, which means the extinction of some plants and the shrinkage of wildlife habitats. Changes in wetland environment, such as drying, resulting from increased temperature and decreased precipitation, have led to a decline in biodiversity and degradation of alpine wetland ecosystems. Despite an overall increase in vegetation cover, wetland degradation has caused changes in plant species diversity and community composition. Climate warming have also affected wildlife migration and the activity of microorganisms. The changes in plateau wetlands are primarily shaped by climate conditions, while human activities act as accelerators, causing significant damage to wetland environments, leading to fragmentation and accelerated degradation. This paper proposes strengthening ecological monitoring and risk assessment in these regions, conducting further research, and promptly implementing necessary restoration measures to reduce the ecological risks caused by these changes.

Keywords: Qinghai-tibet plateau, climate change, alpine wetland, ecosystem, risk assessment.

1. Introduction

Wetland ecosystems occupy a unique niche, bridging the gap between terrestrial and aquatic ecosystems and exhibiting characteristics of both, so they play a crucial ecological role, boasting abundant biodiversity and performing significant functions in water retention, conservation, and regulation. The alpine wetlands on the Qinghai-Tibet Plateau (QTP) are often regarded as representing the most prominent wetland distribution areas in China [1]. Recognized as the "Third Pole," this plateau holds tremendous geographical and ecological importance [2]. With vast stretches and core regions surpassing 5000 m in elevation, it stands as a recently formed giant landform unit of significant geological value [2]. Additionally, the QTP serves as a vital ecological barrier, safeguarding not only China but also the broader Asian continent. Its distinctive energy flow and carbon cycling dynamics allow it to contribute to global change responses. Due to its distinctive geographical location and characteristics, the wetlands on the QTP exhibit high sensitivity to climate change. Furthermore, the direct or indirect impacts of global warming on permafrost and vegetation cover significantly affect the vulnerable local ecosystems [3]. There is evidence that global warming may affect the distribution patterns of many species and even be related to species extinction.

Because of limited habitat and geographical barriers, species inhabiting high-altitude ecosystems face greater vulnerability to climate change [4]. There are predictions that climate change will directly or indirectly affect the distribution and distribution of species in high-altitude areas, especially in climate-sensitive areas such as QTP [3]. Currently, common response to climate warming trends is the range shifts of species, which are caused by habitat degradation or loss. For instance, one research conducted in remote Peruvian mountains indicates that climate change will cause upward shifts in elevation and local extinctions of avian species within tropical bird communities [5].

However, the current understanding of the response of wetland organisms on the QTP to climate change is limited due to the scarcity of available data [6]. Given the ecological significance of the plateau wetlands and the potential ramifications of climate change, this paper aims to examine and analyze the adaptive strategies and changes of wetland species and their assemblages in response to the ongoing challenges presented by climate change. This paper analyzes the impact of climate change on the QTP wetland organisms and reveals the changes that occur in wetland ecosystems due to climate change. Ultimately, this research intends to provide potential solutions and recommendations for the preservation of wetlands by enhancing our understanding of their response to climate change.

2. Climate Changes in Qinghai-Tibet Plateau

QTP is a hot spot region for global climate change research. This is one of the most typical regions affected by global climate change [7]. Wetland ecosystems are heavily impacted by climate change, which mainly affects them through changes in temperature and rainfall patterns. Of these factors, temperature is the most important driver of wetland growth and shrinkage [8]. Elevated temperatures can lead to higher soil and water temperatures, causing an increase in evaporation rates and an energy imbalance within the wetland system. In addition to temperature, precipitation can also have a significant impact on wetland ecosystems. Differences in the amount, frequency, and spatial distribution of rainfall can affect wetland vegetation growth, hydrological supply, and ultimately, the size and distribution of wetlands. Changes in precipitation can lead to changes in moisture, vegetation cover and nutrients, all of which can in turn affect diversity of the microbial community, carbon-nitrogen balance, distribution, and organic matter decomposition process. In the past few decades, there are obvious signs of getting wetter and hotter on the QTP. According to the research conducted by Tang et al. (Fig. 1 and Fig. 2), from 1970 to 2015, the annual mean precipitation increased by 10.7 millimeters every 10 years in the study area on the QTP. During the same period, the annual mean temperature of the same study area increased by 0.319°C every 10 years [7].

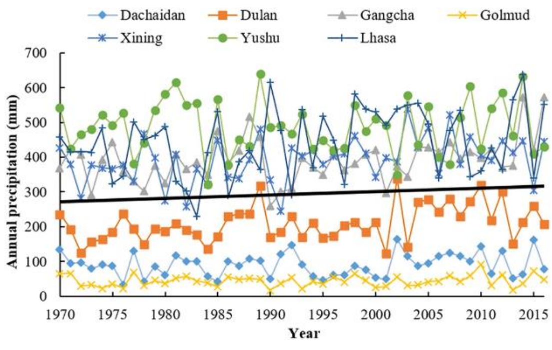

Figure 1. Annual mean precipitation of the seven locations from 1970– 2016. https://doi.org/ 10.1038/s41598-018-25683-3

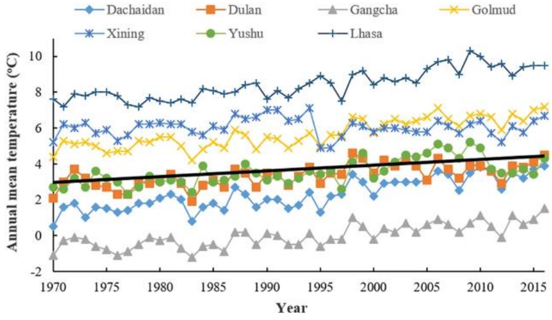

Figure 2. Annual mean temperature of the seven locations from 1970– 2016. https://doi.org/ 10.1038/s41598-018-25683-3

According to the Regional Climate Model version 4 (RegCM4) forecast, with the continuation of climate warming, it is expected that the climate in the region will experience an increase of 0.30°C per decade in temperature and 5.9 mm per decade in precipitation until 2050. Furthermore, the future climate of the region (2051-2100) is expected to remain mainly characterized by warming and increasing precipitation [9]. In addition to changes in common meteorological factors such as changes in precipitation patterns and temperature rise, changes in evaporation levels and snow cover may also have an impact on plateau wetlands and their surrounding ecosystems. Generally, an increase in temperature is beneficial for wetlands, while an increase in precipitation is the opposite, the response of different QTP wetlands is not uniformly consistent, and there is also a certain degree of regional heterogeneity [10].

3. Response of Organisms

Due to rising temperatures, some permafrost layers may dissolve, the water table in these areas will also be disrupted, which can result in the degradation of certain wetlands. Changes in factors such as evaporation, temperature, and precipitation can also lead to the degradation or formation of wetlands. The evolution of high-altitude cold swamp wetlands on the QTP generally manifests as a degradation process from marsh to marshy meadow, typical meadow, and degraded meadow [11]. With climate change and wetland degradation, xerophytes and mesophytes will gradually dominate. Throughout the wetland-marshy meadow-meadow evolution process, vegetation coverage, above ground biomass, and plant height significantly decrease. Changes in vegetation and ecosystems can affect animal and microbial communities living within them, particularly among certain vertebrate species, and may result in a decline in biodiversity. Wetland ecosystems contain various organisms. Based on their ways of obtaining nutrients and energy, and their roles in energy flow and material cycling, they can be divided into three main groups: producers, consumers, and decomposers [12]. The primary driving force behind the following changes is climate change, with human activities acting as secondary contributing factors.

3.1. Producer

Producers refer to autotrophic organisms that can produce organic substances from simple inorganic substances, usually referring to Viridiplantae [13]. These organisms include photosynthetic bacteria, small algae, and large aquatic plants. Large aquatic plants, which include non-vascular plants, lower vascular plants, and higher vascular plants with the exception of small algae, refer to plants that partially or completely submerge in water or float on the water surface for at least several months of the year. These plant groups play an key role in the productivity and biodiversity of wetland ecosystems. The amount of precipitation can influence the net primary productivity of vegetation. Additionally, if plants want to develop and grow normally, they must be within a suitable temperature range for growth. The temperature affects the growth rate of plants by controlling the timing and duration of their reproductive and growth stages, with the potential for advancing, maintaining, or delaying them. For these Autotroph, warming will lead to degradation of vegetation and reduction in hydrophytic plant. In the aspect of limiting seed germination due to lower enzyme activity, the biodiversity is weakened. However, after the degradation, species diversity typically rockets as the plant composition undergoes changes, there is a reduction in grass species, while the dicotyledonous non-grass species become more abundant [14]. With higher level of biomass, species diversity and ecological dominance are higher than original, ultimately leading to the replacement of alpine marshes by alpine meadows [2].

Furthermore, due to the increasing temperature, the Gross Primary Productivity index and Normalized Difference Vegetation Index rise simultaneously, which confirming the trend of vegetation succession.

3.2. Consumer

Consumers refer to various animals that feed on other plants or animals in wetland ecosystems. These organisms include planktonic animals, benthic animals, fish, crustaceans, reptiles, and birds. These consumer groups play important roles in controlling and maintaining ecosystem functions and nutrient cycling in wetland ecosystems. Changes have also occurred in animal communities. For instance, there's an increasing population of rodents who graze on grasses, create burrows, and excavate mounds, leading to significant soil structure and vegetation disruption. As a result, their habitats continue to shrink, populations of rare species are experiencing decline [2]. By 2019, there were 73 bird species, 55 fish species, 14 mammal species, and 9 amphibian species found in the local wetland ecosystem, 21 are listed as rare and endangered, indicating a concerning state of animal biodiversity. According to Zhang et al.'s research on gazelle that more and more species will have suitable geographical distribution areas in higher latitudes in the future [3].

3.3. Decomposer

In wetland ecosystems, decomposers as an essential component, primarily include bacteria, fungi, and detritivores [13]. These organisms break down organic matter into inorganic compounds, making them an essential component of wetland ecosystems. Microorganisms in wetlands serve as the foundation of the entire ecosystem. Microbial community diversity reflects the relationship between microorganisms and the environment, profoundly influencing the composition and balance of local ecosystems. Wetland microorganisms play a significant role in maintaining soil fertility, vegetation productivity, and substance cycling. Specifically, microorganisms in wetland soils play a crucial role in the balance of energy, carbon, and nitrogen. Firstly, as the results of decrease in plant species, there would by changes in soil nematode community diversity and richness. A decrease in algivorous and omnivorous nematodes is occurred, while other groups, herbivores, carnivores and fungi, show relatively minor changes [2]. Secondly, abundance of microbes decreases with changes in soil types and depth, as nitrogen and other nutrition content varies [1]. Also, the meta genomic analysis illustrates that diversity of archaea and fungal communities is significantly lower than bacteria [15]. Thirdly, the activity of microorganisms in wetlands is closely linked to climate, as changes in climate can alter the rates of decomposition of soil organic carbon and surface litter [1]. This relationship is primarily attributed to the warming of temperatures affecting the surface soil moisture, thinning of roots, accelerated nitrogen cycling, and an enhancement of extracellular enzyme activity and microbial activity in soil. But the impact of temperature and precipitation on microbial biomass is not significant.

4. Suggestion

In the near future (present day to 2050) and the long-term future (2051 to 2100), the climate on the QTP is expected to continue warming and becoming wetter [9]. Over the past decades, overall wetland area has shown a decreasing trend, although there are localized areas with increasing trends [16]. The degradation of wetland ecosystems on the QTP is a complex and pressing issue. To address this problem, effective measures are necessary to reverse the current trend of degradation and promote the long-term natural recovery of these ecosystems. An important first step is to establish a robust and comprehensive management mechanism that prioritizes ecological conservation and restoration, with a focus on scientific restoration and protection as the main objectives. This will require a strong commitment to the development of ecological restoration technologies and their integration with engineering projects to enhance the natural recovery capacity of degraded wetlands [2]. In addition to the establishment of a management mechanism, it is also important to construct an evaluation model and indicator system suitable for high-altitude wetlands on the QTP. Such a model and system can help guide the systematic monitoring and evaluation of major engineering projects related to the protection and restoration of wetland ecosystems, ensuring that these efforts are effective and sustainable over the long-term.

To promote sustainable development in the region, policies need to be implemented that encourage environmentally responsible practices at both the public and private level. This can include measures such as smart urban planning, improved transportation systems, and dietary changes to reduce carbon footprints and promote a more sustainable way of life. It is important to recognize that the impact of climate change on alpine wetland has both positive and negative aspects. It is therefore essential to take proactive and effective measures to mitigate the negative effects while enhancing and strengthening the positive effects as an integral part of global environmental change. This will require a continued commitment to scientific research and development, as well as collaboration between governments, industries, and local communities to ensure equitable and sustainable outcomes.

Although global warming can have multiple and complex impacts on wetland ecosystems, the current research hotspots on the impact of global warming on QTP wetland ecosystems mainly focus on some meteorological factors at a brief level on local ecosystems [17]. Further research should focus on exploring the deep-seated mechanisms of wetland ecosystems in response to global warming, as well as conducting in-depth research on the response to multi-level and complex changes, in order to further deepen our understanding of this issue. For example, global warming may affect the composition of local vegetation, leading to changes in other local organisms and exacerbating ecological changes.

5. Conclusion

Due to climate change, the ecological dynamics of the QTP wetlands will undergo significant changes. An important reason for the degradation of alpine wetland ecosystems, decreased biodiversity, or species decline is that sustained high temperatures and changes in precipitation can lead to wetlands becoming arid, altering the original constructive species environment of wetlands. Overall, there has been an increasing trend in vegetation cover, with the trend of conversion from cold grasslands to warm grasslands. However, after wetland degradation, the species diversity of plant communities typically increases, and the species composition within the communities also undergoes changes. The failure of seed germination is also an important reason for changes in plant diversity, which is caused by environmental changes. Climate warming can cause certain wildlife to migrate to higher altitudes or latitudes, thereby shrinking their habitats and living spaces. It will also affect the composition of soil organisms and the activity of microorganisms. The main driving force behind the changes in plateau wetlands is the change in climate conditions, and human activities such as cultivation and grazing also play a role as boosters in the process of wetland changes. Especially unreasonable human activities have caused great damage to the wetland environment, leading to increased fragmentation of wetlands and greatly accelerating the rate of wetland degradation. Further research and data are needed to provide a more comprehensive understanding of these impacts in the context of the Climate Change.

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