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The current situation of forest ecological environment in China under the background of climate change

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Abstract:

Against the backdrop of global climate change, terrestrial ecosystems serve as a crucial component of the Earth's ecosystem. Therefore, it is of great significance to explore the responses of forest ecosystems under climate change. This study aims to investigate the impacts of climate change on the distribution pattern, productivity of forest ecosystems, and the frequency of extreme climates. The research indicates that global warming is a double-edged sword for plant productivity: within a reasonable range, it promotes productivity, and rational utilization can bring considerable value. However, due to the frequent occurrence of extreme disasters, species diversity will face significant threats. This study reveals the prominent limitations of current relevant research and provides support for subsequent studies and planning. Moreover, it emphasizes the need for integrating long-term monitoring networks with advanced remote sensing technology to capture fine-scale ecosystem changes. Interdisciplinary approaches that combine ecological modeling, climatology, and socio-economic analysis will be essential to fully understand ecosystem resilience. Ultimately, strengthening international collaboration will play a decisive role in addressing the uncertainties and challenges posed by climate change on forest ecosystems.

Keywords: Climate Change; Forest Ecosystems; Sustainable Development; Forest Productivity.

1. Introduction

In recent years, global climate change has become an indisputable fact, and the IPCC assessment report pointed out that since the industrial revolution, the greenhouse effect caused by human activities has caused a significant trend of global warming, and most of the climate environment in China has been seriously affected, with the temperature rising by 0.4~0.5°C, and the warming in the northwest, north and northeast China is the most significant [1].As the core component of terrestrial ecosystems, forest eco-

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systems have high biodiversity, make great contributions to maintaining local diversity levels, and also provide ecological and economic value functions for human society, such as conserving water sources, maintaining water and soil, purifying air and other ecological functions, which is an important part of human climate change mitigation. However, climate change is affecting the structure and function of China's forest ecosystems through rising temperatures, changes in precipitation patterns, and frequent extreme weather events, and its status and dynamics have become a core topic in ecological research. However, there is still a lack of systematic review and integrated analysis of the role of forest ecosystems in the global carbon cycle and climate regulation and their response mechanisms to climate change.

The response of China's forest ecosystems to climate change presents multidimensional complexity. In terms of spatial distribution, climate warming has led to the migration of mountain forest lines to higher altitudes, such as the northeast red pine forest distribution has shifted northward, while some subtropical forests in southwest China are at risk of drought-tolerant species substitution. Wang Junbang et al. found through model simulation that the actual total primary productivity (GPP) of the forest south of the Yangtze River was higher than the climatic potential due to superior hydrothermal conditions, while the grassland and shrub areas in the west showed the opposite trend due to drought stress, reflecting significant regional heterogeneity [2].In terms of productivity, the increase in CO_2 concentration promotes the growth of some tree species in the short term, but due to the greenhouse effect, the global temperature continues to rise, the nocturnal respiration of trees is enhanced, the summer drought intensifies, and the sensitivity of vegetation to temperature and precipitation is high, which leads to the inhibition of net primary productivity of forests. In addition, climate change has led to an increase in the frequency of extreme weather, exacerbating the vulnerability of forest ecosystems. The frequency and intensity of forest fires in China increased due to climate warming and drying, and the number of fires in Chongqing and other regions increased step by step with the increase of temperature from 2000 to 2011. At the same time, winter warming has led to the intensification of pest and disease problems, and the suitable habitat area of pine wood nematodes and other pests has expanded, posing a serious threat to coniferous forests. For example, the spring phenology of woody plants in North China is advanced, resulting in the disorder of understory plant reproductive cycle, while the delay of phenology in some parts of southwest China affects the competition pattern of resources between species [3].

Although existing studies have revealed the impact of climate change on forest distribution, productivity, and colony building processes, there are still many limitations: insufficient attention to the impact of extreme climate events, most studies regard forest types or species, and do not fully consider the differentiated responses of different species to climate change and niche competition. The main reason for the lack of forest research in India and some countries in Southeast Asia. Therefore, information and assessment of forest degradation caused by climate change in these countries is still very limited [4]. Therefore, it is of great scientific value and practical significance to systematically sort out the current situation of China's forest ecological environment under climate change and analyze its regional differences and driving mechanisms for formulating targeted forest management strategies and improving ecosystem resilience. Moreover, the challenges facing forest ecosystems against the backdrop of climate change manifest not only at the level of the physical environment but also in ecological processes and community stability. Firstly, warming climates alter the species composition and succession patterns of forest communities. Cold-tolerant tree species gradually decline, while heat- and drought-tolerant species gain an advantage in expansion. This species replacement may disrupt the original stable community structure, leading to a decline in biodiversity. Secondly, forest soil systems are also affected. Soil respiration rates increase with rising temperatures, accelerating carbon emissions and partially offsetting forests' role as carbon sinks. Changes in soil moisture conditions further alter microbial community composition, thereby impacting nutrient cycling efficiency and overall forest productivity.

Regarding ecological functions, forests' capacity to regulate climate change exhibits regional variations. Eastern coastal forests significantly modulate regional water cycles and air quality, whereas western arid forests primarily rely on afforestation to maintain ecological equilibrium. In plateau and mountainous regions, forests play a crucial role in water conservation and soil erosion prevention. However, with glacial retreat and reduced snowpack, these water regulation functions face degradation risks. Long-term, this may lead to more uneven spatiotemporal distribution of water resources, exacerbating conflicts between human societies and ecosystems.

Conversely, climate change is driving transformations in forest management approaches. The previous reliance solely on natural forest conservation is increasingly inadequate to address complex environmental trends. Currently, increasing research and practice are exploring models such as 'near-natural management' and 'mixed forest development' to enhance forest adaptability and resilience. Concurrently, dynamic monitoring techniques based on remote sensing and big data are becoming vital tools for assessing forest ecosystem health. Through multi-source data integration, real-time tracking of forest cover changes, pest and disease spread, and fire risks can be achieved, providing scientific foundations for policy formulation and resource allocation.

In the future, forest ecosystems may assume a more multifaceted role in addressing climate change. On the one hand, they will continue serving as carbon sinks to mitigate rising atmospheric greenhouse gas concentrations; on the other, forests could become vital pillars for ecological migration and rural revitalisation strategies. In regions severely impacted by climate change, the judicious utilisation of forest resources to develop ecotourism and understorey economies can not only alleviate climatic pressures but also provide local communities with new livelihood opportunities. Furthermore, forest conservation in the context of climate change necessitates integration with international carbon markets and global governance frameworks, fostering transboundary cooperation to achieve dual sustainability in both ecological and economic spheres.

Overall, China's forest ecosystems are both vulnerable recipients and vital regulators within the climate change landscape. Faced with increasingly severe climate challenges, future research and practice must prioritise interdisciplinary integration. By synthesising perspectives from ecology, climatology, economics, and sociology, we can comprehensively evaluate forests' risks and potential. Only through scientific management and long-term monitoring can we effectively enhance the adaptability and stability of forest ecosystems, enabling them to play a greater role in mitigating climate change and safeguarding the sustainable development of human society.

2. Impacts of Climate Change on Forest Ecosystems in China

2.1 Changes in Forest Distribution Patterns

Climate change profoundly affects the distribution of forest ecosystems through temperature increases, changes in precipitation patterns and extreme weather events. Climate change has led to the migration of mountain forest lines to higher altitudes, and the optimal distribution range of many tree species has changed. Tree species that lag climate change or have difficulty adapting quickly to new climates may be replaced by more adapted species and are at risk of extinction. In addition, extreme meteorological events such as continuous drought can lead to the death of many tree seedlings and adults, further changing the distribution pattern of forests [5].

Climate is an important factor in determining the distribution of forest types, and changes in temperature and precipitation will directly drive the geographical distribution of tree species and forest types. Some scientists use the Holdridge model to predict future changes in vegetation distribution based on GCMs estimates of climate change, and they found that the distribution of forest types will change considerably, such as the conversion of boreal forests to cold temperate forests, cold temperate forests to warm temperate forests, etc., and the area of boreal forests, warm temperate forests and subtropical forests will decrease. Because different species vary greatly in their responses to climate change, as well as their ability to migrate, the transfer of forest types depends largely on the movement of different species through the landscape and the ability of new species to invade existing communities [6].For China, due to the impact of climate change, the distribution of most tree species will be greatly affected, except for the increase in the distribution area of Yunnan pine and red pine (about l2% and 3% respectively), the area of other tree species has decreased, with a decrease of 2%~57%, and the distribution range of grasslands and deserts will expand to western China and high-altitude areas. For climate zonesthe adaptive changes to climate change are not the same, for tropical forests, global warming may extend to subtropical or temperate zones, but some areas may be transformed into savannas due to reduced rainfall; Excessive rainfall or frequent storms in humid tropical regions may reduce the biodiversity of forest ecosystems [6]. while temperate forests will expand to the polar direction, their northern boundary invades the boreal forest zone, the southern boundary may be replaced by subtropical forests, and the inland areas may be transformed into grasslands or deserts due to the intensification of summer drought, and the overall area tends to decrease; Finally, for boreal forests, as the most sensitive forest type to climate change, their area will be greatly reduced due to significant warming in high latitudes. Overall, climate change has led to northward migration, high-altitude migration and area reduction in China's forest distribution, which not only changes the composition and structure of forest communities but may also affect ecosystem functions and service capabilities through species replacement and habitat fragmentation.

2.2 Changes in Forest Productivity

Forest productivity is an important indicator to measure the function and health of ecosystems, and it is also one of the core parameters for assessing the impact of climate change. Forest ecosystems not only play an ornamental or

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economic value role for human society, but also provide great ecological value for human production activities, and their productivity is also the core indicator to measure the function of forest ecosystems.

The results show that the total biomass of forests in China is 4.0~7.1Pg (1Pg = 1015g), and the total biological productivity (excluding economic forests and bamboo forests) is 0.4~0.6Pg/a, after the doubling of CO_2 concentration, China's forest productivity will increase, and the magnitude of the increase will vary from region to region, ranging from 12% to 35%. In addition, based on the model of forest climate productivity in China, the impact of climate change on forestry productivity is explored. The results show that the constructed model basically reflects the geographical distribution pattern of China's forest productivity. The distribution pattern of forest productivity in China mainly depends on the hydrothermal conditions in the climatic environment. Climate change has not changed the geographical distribution pattern of China's primary forest productivity, that is, the trend of decreasing forest productivity from southeast to northwest remains unchanged, but forest productivity has increased to varying degrees in different regions. The geographical distribution pattern of the change rate of forest productivity in China after climate change is opposite to that of the primary forest productivity, showing an increasing trend from southeast to northwest [1].

Interestingly, the effect of rising temperature on productivity is two-sided. Moderate warming can prolong the growing season and increase enzyme activity, especially in cold regions at high latitudes or altitudes, which may promote tree productivity. Studies have shown that forest productivity in some areas of the alpine region of the Tibetan Plateau is increasing due to the trend of warming and humidification [2].

On the contrary, excessive temperature enhances nocturnal respiration, consumes more photosynthetic products, and increases soil water evaporation, leading to drought stress and inhibiting productivity. Liu Guohua mentioned that nighttime warming may cause plants to "consume" more primary productivity, while summer drought will directly limit photosynthesis, and the increase in temperature will increase soil water evaporation, resulting in a decrease in soil moisture, which may cause a "physiological drought" in plants to limit plant photosynthesis and growth rate. In addition, the increase in temperature will also increase the activity of soil microorganisms, accelerate the decomposition rate of organic matter and other material cycles, and change the carbon-to-nitrogen ratio in the soil, so that plant growth is restricted by nitrogen deficiency [6]. Wang and others have shown that NPP is decreasing due to climate warming in the tropical rainforest of the Amazon Basin, and a similar mechanism may appear in the southern forest areas of our country (Fig. 1 and 2) [7, 8].

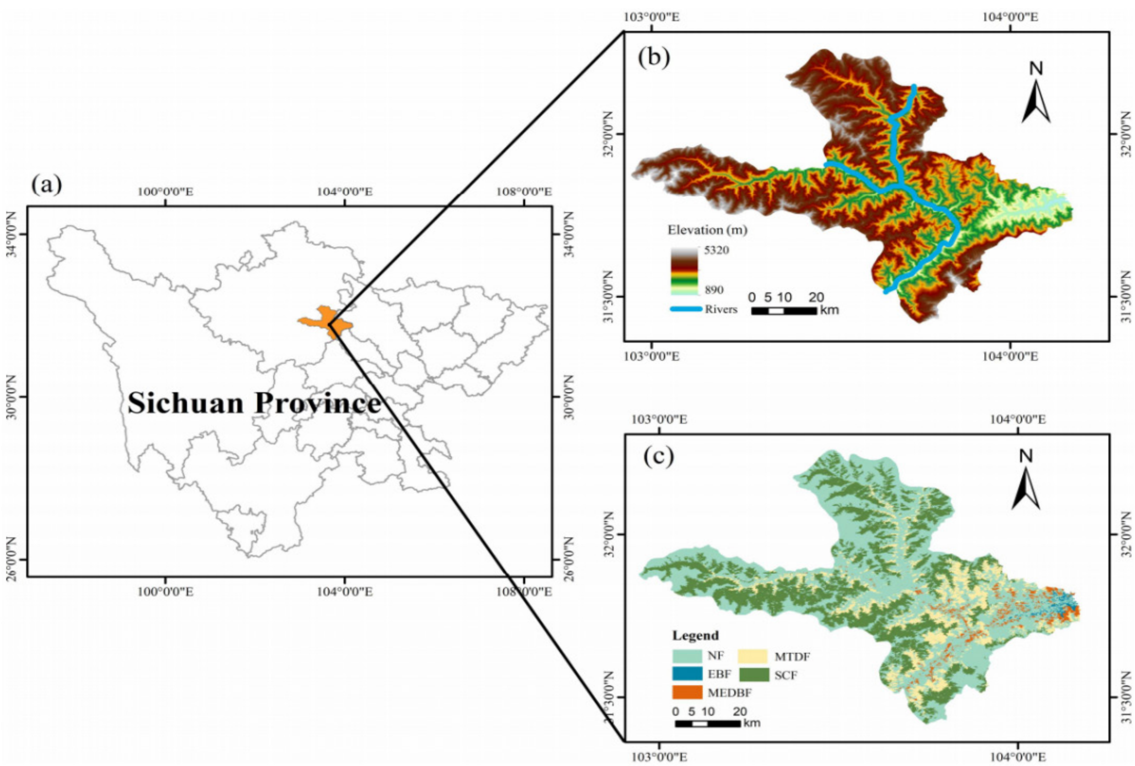

Fig. 1 (a) The position of study region (Mao County), (b) Topographic map of the study region,

(c) Ecotones of the study region [8].

Some studies have taken the area of Majiang County in Aba Tibetan and Qiang Autonomous Prefecture of Sichuan Province, China as the research object to explore the changes of forest ecological resilience under different climate change conditions: Short-term forecast (0~50 years): Climate warming may temporarily increase productivity. For example, simulations of alpine forests in western Sichuan show that short-term climate warming increases ecological resilience (related to productivity), and the productivity change rate of fir and spruce stands is high. Medium- to long-term forecast (over 50 years): Negative impact intensifies. As warming intensifies, the inhibitory effects of temperature and drought exceed the fertilizer efficiency of CO_2, and productivity shows a downward trend. Simulations of alpine forests in western Sichuan show that productivity declines are most significant under the long-term (150~300 years) RCP8.5 scenario [7].

and non-significant difference between RCP2.6 and RCP8.5 within the MEDBF ecotone.

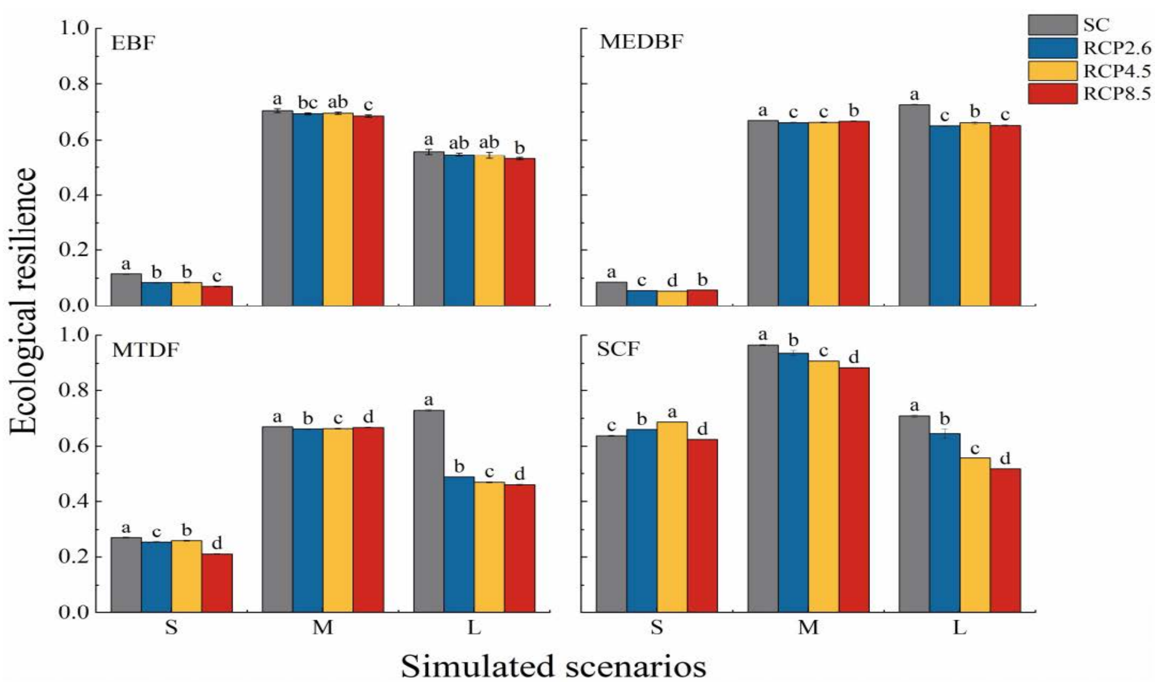

Fig. 2 Impact of Different Climate Scenarios on Forest Ecological Resilience in Ecotones at Different Stages. S: 0–50a; M: 50–150a; L: 150–300a. At the 0.05 level, several small letters showed significant differences among the scenarios [7].

According to existing research, there is a positive association between forest ecosystem service capacity and climate warming in some cases, and this positive effect will continue until 2050 under the RCP4.5 and RCP8.5 scenarios. In this case, the state or relevant departments may formulate short-term to medium-term management measures for forest ecosystem and ecological environmental protection. We can make full use of the positive effects of climate warming, give full play to the production functions of forest ecosystems, and maximize their ecological and economic benefits. At the same time, it is necessary to actively monitor the environmental status of forest ecosystems and pay attention to the imbalance in regional ecological environment development, especially in areas where ecosystem services are weakened. Then, when the negative effects of climate warming are significantly intensified, we should strengthen the climate monitoring and early warning system, strengthen the assessment of forest carrying capacity, pay more attention to forest ecological benefits, and ensure its ability to cope with climate change and human disturbances by improving forest quality [8].

2.3 Impacts of Extreme Climate Events and Ecological Stressors

In the context of severe global climate change, the ability of forest ecosystems, as reserves of biodiversity, is also greatly threatened, and the living environment and productivity of species will be greatly affected, and even may lead to the extinction of some species. For example, Thom et al. used the iLand model to study the biodiversity of forest ecosystems in Kalk National Park in Australia using 36 different disturbances and climatic scenarios, and found that the density of hymenoptera, mollusks, and hoverflies increased. On the contrary, Ma et al. used the Monte Carlo

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simulation coupled forest dynamic disturbance model to study the response of broadleaf forests in the central United States to climate change, and the results showed that by 2100, the dominant tree species in the region changed from oak and hickory to maple, and the species diversity decreased 9. 6% ~ 11. 5% (Fig. 3) [3].

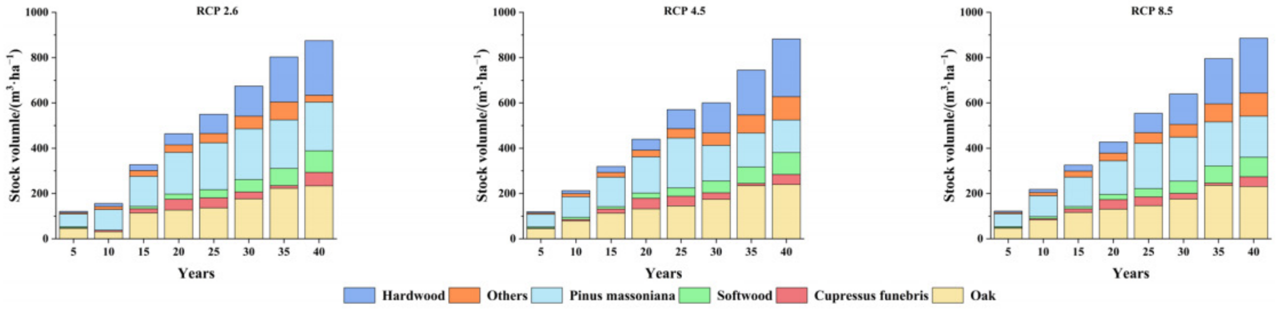

Fig. 3 The change in forest stand volume under different climate scenarios (RCP 2.6, RCP 4.5, RCP 8.5) over the next 40 years [8]

Some studies have shown that the number of trees will increase in the next 15 years under the background of climate change in southern China, and then gradually decrease. The number of hard broad-leaved trees and cypress trees increased significantly, while oak trees increased first and then decreased, while other tree species changed relatively slightly, and the total number of trees was not significantly different under different climate scenarios. The accumulation chart shows that under different climate scenarios, the overall accumulation trend is continuous, with the accumulation of hard broad-leaved trees increasing significantly, and the oak trees stabilizing after the initial 25 years of increase. The accumulation was the largest under the high emission scenario (RCP8.5), indicating that warming may promote stand productivity to a certain extent [9]. Among them, the average annual temperature (MAT) has a promoting effect on the mortality of some tree species, which shows that the high temperature brought by climate change may cause drought and death of trees. In addition, due to the dramatic changes in biological habitats due to climate change, alien species are more susceptible to invasion, and the increase in CO_2 concentration makes C_3 plants more competitive than C_4 plants, making low-nutrient ecosystems more susceptible to invasion. and in the process of competing with native species for resources, it leads to a decline in the biodiversity level of forest ecosystems.

As the habitat of most animals and plants, the changes in the structure, function, distribution and disturbance mechanism of forest ecosystems caused by climate change will have a multi-dimensional impact on wildlife through habitat loss, food resource fluctuations, and imbalance of species interaction. There are differences in the adaptability of different wild animals to forest changes: widely adaptable species (such as golden jackals and Indian foxes) may expand their distribution range due to their ability to take advantage of marginal habitats such as degraded forests and shrubs. Specialized species (such as forest musk deer that relies on fir forests) may be endangered due to the disappearance of forest types due to strict habitat requirements (Fig. 4-6) [10].

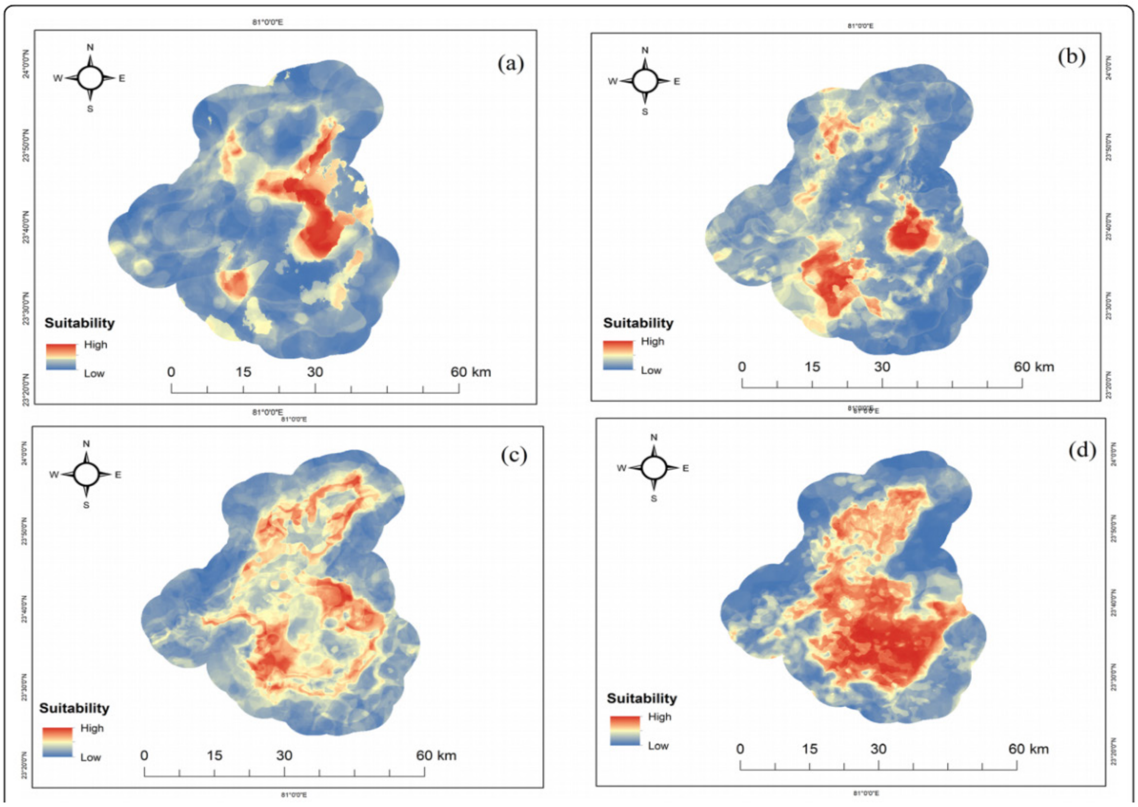

Fig. 4 Predicted habitat suitability of an Indian fox, b golden jackal, c jungle cat, and d Asiatic wildcat using random forest model in Bandhavgarh Tiger Reserve, Madhya Pradesh, India [10]

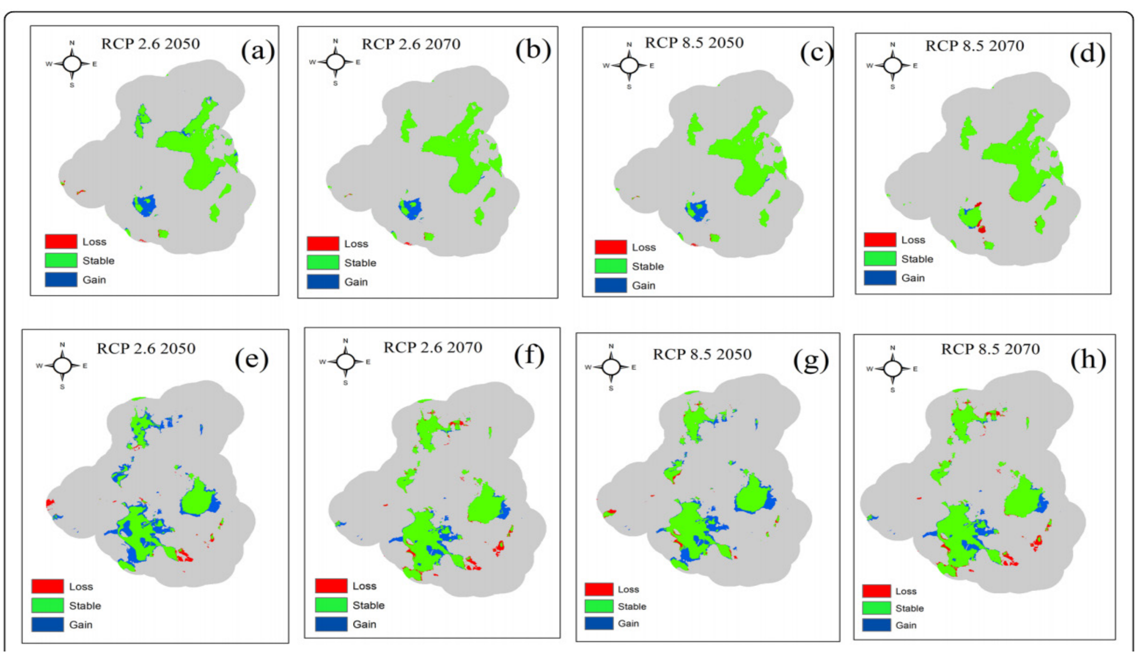

Fig. 5 Predicted change in the distribution of Indian fox and golden jackal under RCP 2.6 and RCP 8.5 scenarios: portions a–d represent the predicted gain and loss for Indian fox, and portions e–h represents the gain and loss in the distribution of golden jackal for the timelines (the 2050s and 2070s) [10]

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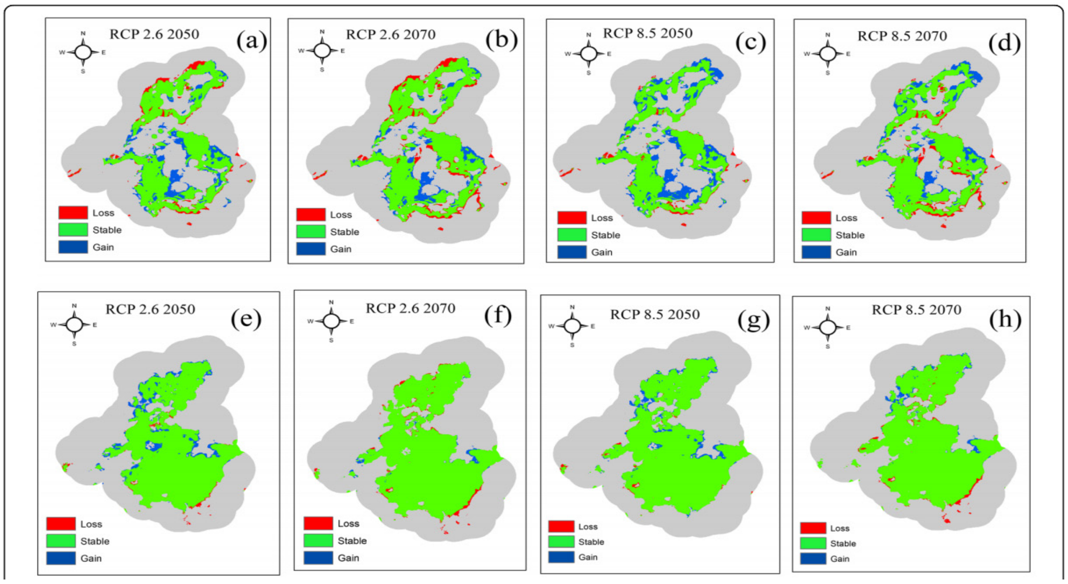

Fig. 6 Predicted change in the distribution of jungle cat and Asiatic wildcat under RCP 2.6 and RCP 8.5 scenarios: portions a–d represent the predicted gain and loss for jungle cat, and portions e–h represents the gain and loss in the distribution of Asiatic wildcat for the timelines (the2050s and 2070s) [10]

In addition, climate change has a great impact on the occurrence of extreme disasters in forest ecosystems, and some studies have taken Yunnan, China as the analysis object, comprehensively analyzed the GRACE data of multiple institutions, analyzed the impact of climate change on the incidence of forest fires from 2003 to 2016, and found that climate change significantly affects the occurrence of forest fires by changing water conditions and extreme climate events. Extreme drought leads to a decrease in precipitation, which directly leads to a dry environment and an increase in fires. The reduction of relative humidity makes surface vegetation more likely to be ignited; The increase of evapotranspiration exacerbates water loss, further deepening the drought situation. Extreme climate events such as El Niño (ENSO) and Indian Ocean Dipole (DMI) indirectly alter regional water balance by affecting precipitation and evapotranspiration, creating a fire-prone environment. Vegetation and soil moisture loss and combustible materials drying out, leading to an increase in the frequency of fires (Fig. 7) [11].

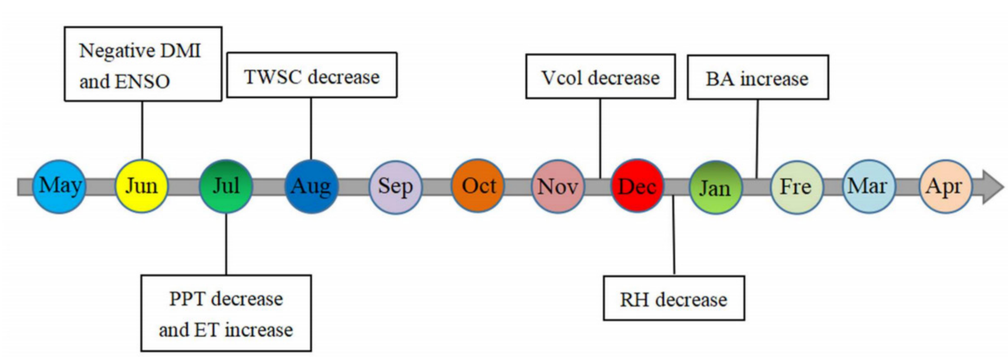

Fig. 7 A series of climatic and hydrological changes before forest fires [11]

3. Conclusion

Through this overview, we can find that the technical shortcomings lead to the limitations of existing research on the complexity and dynamics of forest ecosystems in response to climate change, which need to be further improved through long-term observation, multi-model coupling and mechanism research. The uncertainty of extreme climate events and their interaction with other ecological stresses will pose greater challenges to forest management and protection.

This study also reveals the outstanding limitations of current related research: the short-term impact assessment of extreme climate events (such as persistent drought and strong typhoon) is insufficient, and most studies regard forest types or species, ignoring the differentiated responses of different species and niche competition. The exploration of the "forest-climate" feedback mechanism is relatively weak, and only the impact of climate change on forests is analyzed in one direction, and the reaction of forest carbon sink changes on regional climate is not fully considered. In addition, the research on forest ecosystems in China is still limited by the lack of datasets, and the model parameters are simplified to simplify key factors such as soil fertility and landscape fragmentation, resulting in uncertainty in the prediction of future dynamics, which also points out the direction for subsequent research.

Future research needs to continuously improve theory and technology to provide support for practical operation, provide more accurate support for promoting the sustainable development of China's forests, strengthen ecosystem service functions, and help achieve the "dual carbon" goal, and provide a reference paradigm for regional forest ecological protection and management in the context of global climate change.

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