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The Genetic Diversity Changes in Alpine Plant Species under the Background of Global Warming

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Abstract This study aimed to review the genetic diversity changes in alpine plant species in the context of global warming. With rising global temperatures, global warming has had a profound impact on the genetic diversity of alpine plant species. This paper introduces the context of global warming and the impact on alpine ecosystems, focusing on the challenges of climate change, snowfall and glacier melting to the adaptability of alpine plants. In terms of the concept and importance of genetic diversity, how to measure and protect genetic diversity is crucial. This study explores the mechanisms of global warming on fitness of alpine plant species, including the effects of temperature on gene flow, genetic drift and natural selection, and the relationship between genetic diversity and fitness, emphasizing the importance of protecting and managing genetic diversity in alpine plants. This study aims to provide a comprehensive perspective into the genetic diversity changes in alpine plants in the context of global warming and to provide a scientific basis for future research and conservation.

Keywords Global warming; Alpine plants; Genetic diversity; Species adaptability; Conservation and management

Global warming is one of the most serious environmental issues today, with widespread and far-reaching impacts on the global ecosystem (Fang et al., 2018). Global warming refers to the phenomenon of the Earth's surface temperature continuously rising, mainly due to the increasing emissions of greenhouse gases (such as carbon dioxide, methane, and nitrogen oxides) in the atmosphere, leading to the strengthening of the greenhouse effect in the atmosphere. This phenomenon has had a wide and profound impact on the Earth's ecosystem and biodiversity (Choi et al., 2020). Rising temperatures, increasing extreme weather events, rising sea levels, and changes in ecosystems are all clear signs of global warming.

Alpine plants are key members of the ecosystem and are crucial for maintaining ecological balance in alpine areas. They have unique survival strategies and adapt to extreme growth conditions such as low temperatures, strong winds, and high radiation (Cai and Xue, 2018). Alpine plants play a crucial role in hydrological cycling, soil erosion control, and other ecosystem functions. However, due to their unique habitats, alpine plants are often very sensitive to climate change and have relatively poor adaptability. Therefore, global warming poses a threat to the vulnerability of alpine plants, which may lead to species reduction and ecosystem collapse (Inouye, 2020).

The main purpose of this study is to deeply explore the impact of global warming on the genetic diversity of alpine plants and provide a comprehensive perspective on this important topic. The article will explore the relationship between the adaptability, genetic diversity, and ecological risks of alpine plants, in order to better understand the impact of global warming on alpine plant populations. In addition, this study aims to emphasize the urgency of protecting and managing the genetic diversity of alpine plants, as well as the key role of interdisciplinary cooperation in this regard. By conducting in-depth research on this topic, this study can provide scientific basis for developing strategies for protecting alpine ecosystems in response to global warming, ensuring the survival of alpine plants and the sustained stability of ecosystems.

1 Global Warming and Alpine Plants

1.1 Impact of temperature rise on alpine ecosystems

Temperature rise is one of the most significant features of global warming, which has a widespread impact on alpine ecosystems (Grabherr et al., 2010). As the temperature increases, the climate pattern in high mountain areas has undergone significant changes. This temperature rise has led to changes in the growth season of alpine plants, thereby affecting their life cycle and reproductive patterns. Higher temperatures may also lead to vertical migration of plant communities, affecting the structure and function of alpine ecosystems. For example, some alpine plant species have already advanced their flowering and seed maturation periods to adapt to the earlier arrival of the warm season. This phenomenon may lead to changes in the relationship with plant pollinators (such as bees or butterflies), as their activity time may not be able to keep up with this change, thereby affecting the success rate of plant reproduction. In addition, rising temperatures can increase the risk of fires in high mountain areas, negatively affecting the adaptability and population stability of plants.

1.2 Impact of snowfall and glacier melting

Snow and glaciers are important water resources for alpine ecosystems, and global warming has led to reduced snowfall and accelerated glacier melting (Grabherr et al., 2010). This has a direct impact on the survival and growth of alpine plants. The reduced snowfall may lead to scarcity of water resources, affecting the water use of plants and the hydrological cycle of ecosystems. Melting glaciers can alter the water flow patterns in alpine areas, potentially leading to an increase in floods and drought events, further threatening the survival conditions of alpine plants. Some alpine plants rely on snowmelt water for nourishment, and this change in dependency may affect their growth and survival.

1.3 Mountain climate change and adaptability of alpine plants

The adaptability of alpine plants depends on their ability to respond to mountain climate change (Grabherr et al., 2010). Global warming has triggered changes in climate factors such as temperature, rainfall, and humidity in high-altitude areas. Alpine plants must adapt to these rapidly changing climatic conditions to maintain their population stability. For example, some alpine plant species have begun to migrate to higher altitudes to adapt to rising temperatures. This migration may lead to increased species competition in lower altitude areas, while plants in higher altitude areas may face new competition and predation pressures. However, due to the adaptation of alpine plants to specific ecological conditions during their evolution, their adaptability may be limited and difficult to cope with rapid climate change. Therefore, understanding the relationship between mountain climate change and the adaptability of alpine plants is crucial for predicting their future survival status.

2 The Concept and Importance of Genetic Diversity

Genetic diversity is an important component of biodiversity, involving genetic variations and diversity within species, and is one of the key factors for alpine plant survival and adaptation to global climate change (Ellegren and Galtier, 2016).

2.1 Definition and measurement methods of genetic diversity

Genetic diversity can be defined as the genomic differences and genetic variations between different individuals or subpopulations within a biological population. This diversity includes genotype, gene frequency, number of alleles, and the combination of alleles. The measurement of genetic diversity can use various molecular biology techniques and genetic marker analysis methods, including DNA sequencing, microsatellite markers, AFLP (Amplified fragment length polymorphism), etc. These methods allow scientists to understand the genetic differences between different individuals and help researchers reveal the degree of genetic diversity within species.

In the context of global warming, the measurement of genetic diversity is of great significance. By tracking the genetic diversity of alpine plant populations, this study can understand their response and adaptability to climate change. The increase in genetic diversity usually means that species have greater adaptability potential when facing environmental changes, as they have more genetic resources to cope with new pressures and selection

pressures. Therefore, the measurement of genetic diversity can help us predict the survival and reproduction ability of alpine plants under global warming conditions.

2.2 Relationship between genetic diversity and species adaptability

There is a close correlation between genetic diversity and species adaptability (Reed and Frankham, 2003). Species with high genetic diversity typically exhibit stronger adaptability. This is because within a population, there are more genotypes and genetic variations, which may include adaptive characteristics to different environmental conditions. When the environment changes, species can rely on these adaptive characteristics for survival and reproduction. Therefore, maintaining and increasing the genetic diversity of alpine plants is crucial to ensure their better survival and reproduction ability in the context of climate change.

Ranunculus glacialis is a plant that grows in high mountain areas, commonly found in the Alps and Karakoram Mountains of Europe. This plant grows in extreme mountain environments and faces challenges such as low temperatures, short growing seasons, and strong ultraviolet radiation. In the context of global warming, the population of alpine sheep teeth is facing the threat of rising temperatures and climate change. However, due to the high genetic diversity of alpine sheep teeth, there are different genotypes and genetic variations among different individuals. Some individuals may already have adaptive characteristics to temperature rise and increased ultraviolet radiation, such as more effective leaf protection mechanisms or faster growth rates. In the context of climate change, individuals with adaptive characteristics are more likely to survive, reproduce, and pass on adaptive characteristics to their offspring (Figure 1).

Figure 1 Living and reproduction of alpine sheep teeth

2.3 Protection and management of genetic diversity

In order to protect the natural habitat of alpine plants, it is necessary to establish and maintain protected areas and adopt appropriate habitat management strategies. These measures can include limiting human interference, controlling the number of tourists, and protecting critical breeding sites.

Establish a genetic resource bank to collect and preserve seeds, samples, or genetic data of alpine plants for future breeding and conservation work. These resource banks can be used to restore endangered species, increase genetic diversity, and protect lost genetic diversity.

By introducing appropriate gene flow and avoiding inbreeding, we aim to increase genetic diversity within the population. This can be achieved by relocating seeds or individual plants to ensure gene exchange between different subpopulations.

Protecting the genetic diversity of alpine plants requires interdisciplinary collaboration, including the joint efforts of ecologists, geneticists, conservation biologists, and policy makers. This helps to develop comprehensive conservation plans and management strategies to ensure the survival and reproduction of alpine plants in the context of global climate change.

3 The Mechanism of Genetic Diversity Changes in Three Alpine Plants

The mechanism of genetic diversity changes in alpine plants is key to understanding how they adapt to global warming (Stöcklin et al., 2009). The genetic diversity of alpine plants is influenced by various complex mechanisms, including the impact of temperature on gene flow, genetic drift and natural selection, as well as genetic diversity and genetic relationships.

3.1 The impact of temperature on gene flow

The rise in temperature has a direct impact on the genetic diversity of alpine plants, and one key mechanism is the impact of temperature on gene flow. Gene flow refers to the process of gene exchange between different subpopulations or populations. In alpine ecosystems, cooling temperatures typically limit gene flow because ecological barriers between species are difficult to cross. However, as temperatures rise, vegetation zones and ecosystem boundaries in high mountain areas may change, thereby promoting gene flow.

Specifically, as temperatures rise, the distribution range of alpine plants may migrate upwards, leading to gene exchange between populations at different heights. This can increase genetic diversity as genetic material from different subpopulations mixes with each other. However, this gene flow may also bring some challenges, such as increasing the risk of gene pollution, where foreign genes flowing into purebred populations may disrupt local adaptive characteristics.

3.2 Genetic drift and natural selection

Genetic drift and natural selection are two other important mechanisms that affect the genetic diversity of alpine plants. Genetic drift refers to the change in gene frequency caused by random events, especially in small populations. In small populations of alpine plants, genetic drift may cause certain genotypes to become more common, while others may be lost. This process may reduce genetic diversity, especially in small populations.

Natural selection refers to the process of environmental selection for different genotypes. In the context of global warming, alpine plants may face new climate challenges, such as higher temperatures, more frequent droughts or fires. Natural selection will tend to select individuals with adaptive characteristics, making them more likely to survive and reproduce. This helps to maintain and increase genotypes with adaptive characteristics, thereby enhancing genetic diversity.

3.3 Genetic diversity and genetic relationships

The genetic diversity and genetic relationships of alpine plants are closely related. Kinship refers to the degree of kinship between different individuals, usually determined through genomic analysis. The distribution and genetic relationships of genetic diversity help us understand the relationships between genotypes within species and the maintenance mechanisms of genetic diversity.

In alpine plants, genetic relationships may affect the distribution of genetic diversity. Individuals with closer relatives may be more genetically similar, while individuals with farther relatives may be more genetically different. This difference may reflect different adaptive strategies and niches. In the context of global warming, gene exchange between individuals with closer relatives may be more frequent, while communication between individuals with farther relatives may be less, thereby affecting the distribution pattern of genetic diversity.

In addition, understanding genetic relationships can also help protect the genetic diversity of alpine plants. By identifying genetic relationships, targeted population selection can be carried out for protection and management to ensure the preservation of genetic diversity among different genetic populations. This helps improve the adaptability and survival ability of plants to cope with climate change and environmental challenges.

4 The Impact of Global Warming on the Adaptability of Alpine Plant Species

Global warming has had a complex and profound impact on the adaptability of alpine plant species (Jay et al., 2012). Understanding the relationship between genetic diversity and adaptability, changes in intra and inter species adaptability, and potential ecological and genetic risks is crucial for developing protection and management measures to ensure the survival of alpine plants. These species play an important role in alpine

ecosystems, and their survival is crucial for maintaining the balance of alpine ecosystems and the stability of global ecosystems.

4.1 Relationship between genetic diversity and adaptability

There is a close relationship between the adaptability of alpine plants and their genetic diversity. Genetic diversity provides genetic resources for alpine plants to adapt to new environmental conditions. In the context of global warming, temperature rise, changes in precipitation patterns, and other climate change factors have posed challenges to alpine ecosystems. A population with rich genetic diversity is more likely to adapt to these changes.

The adaptability of alpine plants can be reflected in multiple aspects, including growth rate, flowering time, tolerance, stress resistance, etc. Species with diverse genotypes are more likely to maintain successful reproduction under new climate conditions, as some individuals may already possess adaptive characteristics. Genetic diversity can also provide species flexibility, making it easier to adapt to constantly changing environmental conditions.

Rhododendron nivale is a plant that grows in high mountain areas such as the the Himalayas. Research has found that as global temperatures rise and snow lines rise, the habitat of alpine rhododendrons is squeezed. However, due to the high genetic diversity of alpine rhododendrons, some individuals exhibit adaptive characteristics to higher temperatures and reduced snowfall, such as earlier flowering times and shorter growth forms. These individuals are more likely to survive and reproduce under new climate conditions, while those lacking adaptive characteristics may face survival challenges.

4.2 Changes in intraspecific and interspecific adaptability

Global warming has triggered changes in intra species and inter species adaptability of alpine plants. Intraspecific adaptive change refers to the adaptive differences between different individuals or subpopulations within the same species. In environments with elevated temperatures, intra species adaptability differences may lead to some individuals being more adaptable to new climate conditions, while others may not be able to adapt, which will affect the maintenance of genetic diversity.

Interspecific adaptive change refers to the adaptive differences between different alpine plant species. Global warming may lead to changes in the distribution range of alpine plants, and different species may begin to share habitats or compete for the same resources. This may trigger new ecological interactions and competition, posing challenges to the adaptability of species. Some species may be threatened due to a lack of adaptive features, while others may benefit from adaptive features.

Taking the European Alps as an example, Salix retusa is a typical alpine herbaceous plant that typically grows in high-altitude areas of the European Alps. It adapts to extreme mountain environments and grows in cold, high-altitude, and snowy areas. Alpine spruce (Pinus cembra) is a type of subalpine tree commonly found in lower altitude areas of the Alps, but its distribution range may expand upwards as temperatures rise (Figure 2). This means that Alpine spruce may begin to enter the habitat of Alpine weeping willows. Alpine weeping willows may face competitive pressure from Alpine spruces as they grow faster, form a wider canopy, block sunlight, and reduce soil moisture. This may lead to suppression of the survival and reproduction of Alpine weeping willows. On the other hand, this change may also trigger new complementary relationships. Alpine weeping willows may benefit from the shade provided by trees, especially in cases of rising temperatures, where their canopies can provide shade and alleviate heat stress. In addition, the canopy of trees can capture precipitation and provide water for the surrounding vegetation. The changes in inter species adaptability will determine which species can adapt in new competitive relationships.

4.3 Potential ecological and genetic risks

Global warming also brings potential ecological and genetic risks, which pose a threat to the adaptability of alpine plant species. One of the risks is a change in ecological niche. As temperatures rise, the distribution range of alpine plants may migrate upwards, leading to niche recombination in alpine ecosystems (Walther et al., 2005).

This may affect the interactions between alpine animals and plants, such as food chains and pollination relationships, thereby affecting the survival and reproduction of alpine plants.

Figure 2 Ecological competition in Alpine spruce

Lilium nepalense is a kind of alpine plant, which grows in high altitude areas such as the the Himalayas. As the global temperature rises, the snow line in the the Himalayas rises, resulting in the habitat of alpine lily being compressed. This may cause the distribution range of alpine lilies to shift upwards. This movement may lead to alpine lilies sharing similar habitats with other plant species, such as alpine rhododendrons and alpine bidentates. The potential ecological risk is that this habitat sharing may lead to more intense competitive pressure on alpine lilies. Alpine plants typically adapt to specific survival strategies in extreme alpine environments, but competition with other species may disrupt these strategies. The survival and reproduction of alpine lilies may be squeezed, especially when competing with species that are more adapted to new environments. This competition may increase the survival risk of alpine lilies, especially in the face of more intense competition pressure and limited living space.

Another potential risk is the loss of genetic resources. Under the pressure of global warming, certain alpine plant species may be threatened or even endangered. This may lead to a decrease in genetic diversity, as the population of species decreases or disappears, leading to a reduction in the gene pool of genetic diversity. This may weaken the adaptability and survival ability of the surviving population.

High mountain Icelandic sedge (*Carex atrata*) is a herbaceous plant that grows in high mountain areas of Europe. With global warming, the living environment of alpine Icelandic sedge is threatened as it typically grows in cold alpine wetlands, and rising temperatures may cause these wetlands to disappear. This situation may lead to a decrease in the population and distribution range of alpine Icelandic sedge. The potential genetic risk is that the population of alpine Icelandic sedge may become smaller and more isolated, and the gene pool of genetic diversity may also shrink. This will make alpine Icelandic sedge more susceptible to random genetic drift, which may lead to the accumulation of harmful genotypes or the loss of adaptive characteristics. If the alpine Icelandic sedge is challenged in adapting to new environmental conditions, its survival and reproductive ability may be affected, which poses a risk to the long-term survival of the species.

5 Protection and Management of Genetic Diversity of Alpine Plants

In the context of global warming, the genetic diversity of alpine plants is facing threats. In order to protect the genetic diversity of alpine plants, a series of comprehensive measures need to be taken, including establishing protected areas, habitat management, establishing gene resource banks, protecting germplasm resources, and interdisciplinary and international cooperation.

5.1 Conservation area and habitat management strategy

In order to protect the natural habitat of alpine plants, it is necessary to establish protected areas to limit human interference. These protected areas should cover the distribution range of alpine plant species, ensuring that their

living space is not threatened. At the same time, law enforcement measures should be strengthened to prevent illegal collection and destruction.

The survival of alpine plants depends on their specific habitat conditions. Therefore, habitat management strategies should focus on maintaining and restoring these habitats. This includes controlling the impact of human activities such as mountaineering, tourism, and animal husbandry to reduce soil erosion and habitat destruction. At the same time, it is necessary to regularly monitor changes in habitats and the health status of alpine plant populations.

5.2 The importance of gene resource banks and germplasm resources

It is crucial to establish a gene resource pool in order to preserve the genetic diversity of alpine plants. These resource libraries will contain seeds, tissue samples, and genetic data of alpine plants to ensure the preservation of species' genetic diversity. In the face of population loss and threats, genetic resource banks can be used to restore and reintroduce species.

Germplasm resources refer to the diversity of germplasm among different genetic groups, which is crucial for the protection of alpine plants. These different genetic groups may have different adaptive characteristics that can help species adapt to different environmental conditions. Protecting the germplasm resources of different genetic groups helps to maintain the genetic diversity of alpine plants and improve their survival ability.

5.3 The necessity of interdisciplinary cooperation

In order to better protect the genetic diversity of alpine plants, close cooperation between experts from different fields is needed. Ecologists can provide advice on habitat management, geneticists can study changes in genetic diversity, and conservation biologists can implement conservation plans. Cross disciplinary cooperation will provide stronger support for comprehensive protection of alpine plants.

Due to the fact that the distribution of alpine plants typically spans multiple countries, international cooperation is also crucial. International organizations, scientists, and governments should work together to share information and resources, and jointly develop and implement conservation plans. Only by taking coordinated measures at the international level can the genetic diversity of alpine plants be more effectively protected.

6 Conclusion and Outlook

Global warming has had a profound impact on alpine plants, mainly manifested in rising temperatures, reduced snowfall, and glacier melting. These climate change factors pose challenges to the living environment of alpine plants, threatening their adaptability and genetic diversity. Elevated temperatures may lead to species migration up the mountain, leading to changes in competition and complementarity between different species. The protection of genetic diversity is crucial for the adaptability and survival of alpine plants.

Genetic diversity is the foundation for the survival and adaptability of alpine plants. Species with high genetic diversity are usually better able to cope with climate change and new environmental conditions. Protecting the genetic diversity of alpine plants not only helps maintain ecosystem stability, but also contributes to human food supply and drug development. By establishing protected areas, managing habitats, establishing gene resource banks, and promoting interdisciplinary cooperation, we can better protect the genetic diversity of alpine plants. Public participation and education are also key factors in protection, and it is necessary to enhance people's awareness of protection and sense of responsibility.

Future research should continue to focus on the changes in genetic diversity and adaptive mechanisms of alpine plants. Further carry out genetic diversity monitoring to understand the genetic structure and dynamic changes of alpine plant populations, as well as their relationship with environmental changes. Conduct in-depth research on the adaptive mechanisms of alpine plants, including their adaptive characteristics to temperature, precipitation, and habitat changes, to help predict the future adaptability of species. Explore more effective conservation strategies, including ecological habitat restoration, establishment of protected area networks, and international cooperation, to address the threat of global warming to alpine plants. Study the impact of human activities on

alpine plants, such as tourism, mountaineering, and harvesting, in order to develop sustainable management and protection measures. Using climate change models to predict changes in the distribution range of alpine plants and help develop future conservation plans.

In summary, the study of genetic diversity changes in alpine plants is a complex and important field that requires interdisciplinary cooperation and global attention. By continuing in-depth research and adopting effective protection measures, this study can help alpine plants adapt to the challenges of global warming, ensure their survival and reproduction in the future, and maintain the stability of alpine ecosystems. This will also provide sustainable ecological services and biodiversity protection for human society.

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