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The Threat of Climate Change on Alpine Birds and Their Habitats.

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Abstract

Alpine birds are high-elevation specialists with unique adaptations such as delayed and reduced breeding and the physiological ability to withstand hypoxic, arid, and windy conditions—unfortunately, their populations are expected to decline due to anthropogenic climate change. These birds are short-migrating species, usually only migrating vertically up to the highest peaks for the breeding season. With the changing landscape and climate, scientists have been trying to understand the risk alpine birds face and whether they will change their distribution or decline. Abiotic changes such as drastic retreating of glaciers, reduced snowpack, increased temperatures, and increased precipitation as rain are shrinking the available breeding and foraging habitat of alpine birds. Indirectly, these abiotic changes are triggering biotic changes; for example, forest and shrub vegetation are invading alpine tundra, and snowpack decline is reducing snowbed habitat available for foraging. Additionally, the environmental cues triggered at lower elevations are becoming increasingly mismatched with higher elevation conditions, causing birds to migrate earlier to regions that are still completely covered in snow. Studies focused on understanding alpine bird responses to climate change have found heterogeneity in the birds' responses. Unfortunately, this complicates conservation efforts because it limits our ability to apply one species' response to another. Going forward, conservation efforts should focus on understanding specific bird ecology and on restoring and protecting alpine habitats.

Introduction

Mountain and alpine regions cover about 25% of the Earth's terrestrial surface, and they provide resources for a quarter of its biodiversity (Scridel et al. 2018). More specifically, alpine habitats make up 3% of the terrestrial surface, which is about four million km^2 (Martin 2001). These complex ecosystems not only accommodate diverse flora and fauna, but their glacial and snowpack content provide humans with a large fraction of the water they consume. The alpine life zone is the region above the natural tree-line and tends to be composed of snowfields, rocky terrain, and tundra vegetation. Although elevation may be a determinant of where an alpine ecosystem begins, the best determinant is actually climate; high winds, low effective moisture, low temperatures, and short growing seasons typically characterize alpine habitats (Martin 2001). In addition, alpine habitats decrease in elevation from smaller latitudes to larger latitudes and from inland to the coast (Martin 2001). Due to these characteristics, many alpine fauna and flora have adapted to sustain themselves in highly variable and extreme environmental conditions. Alpine birds have developed specialized physiological, morphological, and behavioral characteristics to survive such conditions. Birds in alpine ecosystems have developed adaptations for the hypoxic (reduced oxygen concentration) and arid conditions of high elevation environments, such as increased energy expenditure and delayed breeding schedules in comparison to birds at lower elevations (Martin 2001). Although it may not seem worth it to inhabit alpine ecosystems, alpine birds have the advantage of a decreased exposure to parasitism or disease; they also tend to be short-migrating species, which means their breeding sites are closer in proximity to their winter habitats (Martin and Wiebe 2004). Because alpine birds are highly specialized organisms, any changes in their habitats can have a drastic impact on their population densities.

High-elevation regions are extremely vulnerable to changes in climate and are particularly at risk of disappearing due to anthropogenic global warming (Scridel et al. 2018). Historically, alpine habitats are logistically challenging to research and monitor due to their extreme weather conditions and rugged terrain, so the data on alpine species is scarce. However, anthropogenic climate change has become an increasingly prevalent topic in the field of conservation because of the enormous threat it poses for species and entire ecosystems. As a result, in the past two decades, more and more research has been focusing on the ecological responses of alpine and mountain species to changing temperature and precipitation patterns (Chamberlain et al. 2016).

The **heterogeneity**[1] in responses to changing **biotic**[2] and **abiotic**[3] factors due to climate change has been identified as a common trend in modern ecological research (Walther et al. 2002). Since 1880, the Earth's temperature has increased by approximately 0.8°C; most of the warming has occurred since 1975 (Earth Observatory). This could have the potential to drastically change the ecosystem dynamics of alpine habitats considering that climate is the main determining factor in their distribution. Alpine habitats are also threatened by habitat loss and degradation due to urbanization, farming and recreational activities (Chamberlain et al. 2016). Monitoring entire alpine ecosystems proves to be an arduous task, but because birds are known to be great bioindicators of environmental change, scientific efforts are paying more attention to the climate change responses of alpine birds (Siegel et al. 2010). In this review, I will be discussing the abiotic and biotic responses of alpine ecosystems to climate change, and more importantly the biology and responses of alpine birds to these changes.

Biology of Alpine Birds

Phenology and Migration

Alpine birds are highly specialized organisms that evolved to survive in the harsh conditions of alpine ecosystems. Most alpine birds tend to be altitudinal migrants, which means they inhabit lower mountain elevations during the colder winter months and migrate to the highest elevations to breed (Lovette and Fitzpatrick 2016). Just like most migratory birds, alpine species use their biological clocks and **photoperiods**[4] to decide when and how to migrate back to their breeding sites. Birds are incredibly capable of monitoring time through light cues, changes in day length, and changes in hormone levels (Lovette and Fitzpatrick 2016). Additionally, young nestlings calibrate their biological clocks to the earliest setting required by advancing seasons through the photoperiods they experience in the nest before their first migration (Both 2010). The majority of alpine birds are short-distance migrants that typically only partake in vertical migration, and their winter and breeding habitats tend to be close in proximity.

Physiology and Morphology

Because they live in high elevations for a large part of their lives, alpine birds have developed adaptations to withstand the arid, hypoxic, icy, and windy conditions of the alpine life zone (Martin 2001). To prevent predation, most alpine bird species have developed **cryptic coloration**[5] and other behaviors to enhance camouflage in a habitat that is sparsely vegetated and has few hiding locations. Certain species, such as the white-tailed ptarmigan (*Lagopus leucura*), have a higher red blood cell concentration at higher elevations to endure the hypoxic conditions. Alpine birds must expend more energy to survive due to their relatively small body size and lower ability to store energy. Fortunately, many of these species have evolved fat deposits and extra feathers for increased insulation (Martin 2001). However, they also face overheating during the day due to varying ground temperatures; this is another reason why these species move up to cooler, higher elevations during the summer months. Alpine perching birds have evolved long pointed wings and shallowly forked or square-ended tails to increase stability and flight efficiency in the strong, irregular winds of high elevations. Various alpine birds such as the Gray-crowned rosy-finch (*Leucosticte tephrocotis*) (Figure 1b) take shelter from the winds under or beside rocks and cliffs.

Reproduction and Life History

Surviving the alpine ecosystem requires extraordinary adaptations, and many researchers have found that alpine birds' behavioral plasticity is what allows them to thrive, especially in regard to breeding. In comparison to other migrating birds, alpine birds tend to have a low annual reproductive potential due to slow laying rates, few eggs laid per nest, lengthy periods of development, and a higher chance of reproductive failure (Martin 2001). Furthermore, alpine birds' breeding seasons tend to be scheduled three to six weeks later than related lower elevation species. This means breeding occurs in a habitat that is still mostly covered in snow (Antor 1995). Alpine habitats tend to be easier to endure for larger animals that can store greater amounts of energy—alpine birds, which have a relatively small body size, must work much harder to incubate and protect their small eggs from cold and strong winds. During the breeding season, some alpine species build their nests in rock crevices or cliffs (e.g., rosy finches and bluebirds), while others nest on highly exposed tundra slopes (e.g., pipits and horned larks). Although the nests in crevices and cliffs experience less exposure to predators and extreme climate, they do tend to experience colder environments than nests in the tundra (Martin 2001). The young nestlings tend to hatch helpless and require the care of both parents. Because snow is still abundant, parents inhabiting the highest elevations tend to feed their nestlings arthropods found on the snow (Antor 1995). Fortunately, alpine birds tend to be reproductively resilient, which means they can still maintain normal biological processes like breeding when experiencing some sort of disturbance. Martin and Wiebe (2004) summarize the various coping mechanisms that breeding alpine birds may carry out when faced with extreme environmental conditions or disturbances. They mention that some short-term responses might include not breeding, risking their own survival to breed in the same way, or limiting the parental investment of the eggs or offspring. On the other hand, long-term responses might include shifting the timing of breeding site migration by using different environmental cues or developing a higher tolerance to stress. Alpine birds may carry out short-term responses or long-term behavioral or physiological adaptations depending on the severity and length of the environmental disturbance. We could expect that, in the face of climate change, alpine birds will experience amplified reproductive failure due to their pursuit of short-term responses to temporary drastic environmental change.

Foraging Ecology

Alpine zones have a very patchy distribution of resources, and selection of foraging microhabitat for alpine birds is extremely dependent on the varying environmental conditions of this habitat (Martin 2001; Brambilla et al. 2018). Above the tree-line, plant productivity decreases with increasing elevation, so fallout (organic material blown in by wind currents from lower elevations) is an ecologically valuable resource in the arid alpine habitat. Further, alpine habitats have both low insect biomass and low vegetative biomass (Antor 1995). However, foraging resources can be quite abundant, even though they are present for short periods of time and only in conducive environmental conditions. Alpine birds tend to eat seeds and insects, but their foraging patterns are flexible and vary seasonally. In the spring, they feed on **arthropod fallout**,[6] which can be relatively nutritious and abundant when snowfields are still intact. In the summer, on the other hand, alpine birds feed on food sources (e.g., insects and grains) that become uncovered as the snow fields recede (Martin 2001). A study by Antor (1995) that was focused on alpine birds breeding in the Pyrenees found that the exploitation of snowfields for foraging increases with elevation. He also found that alpine bird species that are more accustomed to lower elevations forage in alpine tundra because alpine tundra provides larger, higher-quality arthropods than snowfields (Antor 1995). However, another study demonstrated that birds prefer to forage in substrates where they can detect prey most feasibly instead of where prey is most abundant (Getty and Pulliam 1993). Therefore, snowfields can actually be significantly profitable for alpine birds because they are local sources, and prey are easy to detect and capture against the white substrate (Figure 1). The strong hind limbs, small feet and wing characteristics previously mentioned are what help alpine birds be extraordinarily mobile for ground foraging and exploiting localized, variable resources (Antor 1995).

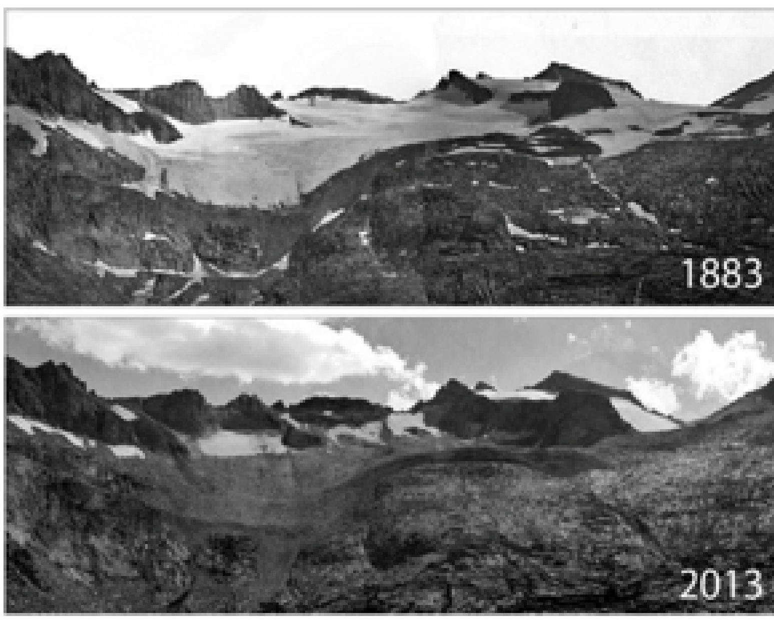
Figure 1 Examples of alpine birds that forage on snowfield arthropods are (a) the white-winged snowfinch (*Montigringilla nivallis*), (b) the gray-crowned rosy-finch (*Leucosticte tephrocotis*), (c) the alpine accentor (*Prunella collaris*), and (d) the American pipit (*Anthus rubescens*).

Abiotic Factors Affected by Climate Change

Temperature and Precipitation

Climate change, as mentioned before, has become a major threat to alpine ecosystems because of its global effect on temperature and precipitation. Overall, climate change has brought about increased temperatures and precipitation, as well as increased variability in climate across the board. In the alpine zone, these shifts in climate are most drastic in the autumn and winter months and less drastic in the summer months (Bjork and Molau 2007). Although temperature and precipitation are already quite variable in the alpine, climate change is causing even more pronounced and uncertain variability in precipitation patterns.

Moreover, the increased temperatures are causing more precipitation as rain rather than as snow, especially in the winter season (Bjork and Molau 2007; Lapp et al. 2004). Because temperatures are increasing, snow cover and snowpack are intact for a significantly shorter duration. A study in the Swiss Alps found that the winter season was terminating 50-60 days earlier at the higher elevations and 110-130 days earlier at the medium elevations close to 1000 m in altitude (Beniston et al. 2003). Snow accumulation and shrinkage models in Lapp et al. (2004) showed that climate change is also resulting in a substantial decline in over-winter accumulation of snow. In general, climate change is reducing snowpack depths and shifting snow melting dates to earlier in the spring (Bjork and Molau 2007). Changing temperature and precipitation patterns are key predictors for the future distribution of alpine habitat and alpine species.



Abiotic/Ecological responses	Effects on alpine birds
Increased temperature	Upslope shift
Increased precipitation	Downslope shift
Disjunction of low and high elevation cues/phenology	Early arrival to breeding site before snow melt
Grasslands colonized by forest/shrubs	Decreased/changed foraging habitat
Decrease in snowpack	Decreased foraging

Figure 2 The ecological changes and effects on alpine birds due to climate change are summarized above. However, there is evidence that responses are heterogenous depending on the behavioral plasticity of the species. Photographs are of Lyell Glacier in Yosemite National Park (National Park Service 2019).

Glacial and Snowpack Shrinkage

In the past century, there have been two major periods of glacial shrinkage: one from the 1920s to the 1950s, and the other from the 1980s to present day. Based on satellite data and photographic analyses, glaciers are still receding and are expected to disappear in the next 50 to 250 years if current deglaciation rates persist (Singh 2008; Basagic and Fountain 2011). A study at the Nanda Devi Biosphere Reserve (NDBR) gathered satellite data showing a significant reduction of ice and snow cover. Area of snow and glaciers in the Himalayas was reduced from 90% area cover in 1986 to 35% area cover in 2004 (Singh 2008). Similarly, in the Sierra Nevada, glaciers are receding at a rate of about 0.0012 $km^2 y^{-1}$ (Basagic and Fountain 2011). Scientists have been observing comparable trends in other glacial areas such as the mountains of Nepal and Tibet and the European Alps since the beginning of the twentieth century (Singh 2008). Evident deglaciation is shown in the two photographs of Lyell Glacier in Yosemite Falls (Figure 2), taken 130 years apart (National Park Service 2019).

It is evident that climate change is reducing glaciers and snowpack—abiotic factors that serve an incredibly important role in alpine ecosystems—which thus threatens the flora and fauna that depend on them (ACIA 2005). Alpine hydrology is extremely dependent on the runoff and streamflow from glaciers during the warmer months. Shrinkage of glacial reservoirs is leading to earlier and decreased spring runoff and drier summer conditions (Basagic et al. 2011). Unfortunately, glacial retreat and changes in runoff not only affect alpine ecosystems, but also increase stream water temperatures and the possibility of summer droughts in lower elevations. Increased summer precipitation and earlier snow melt is causing more hydrological disturbances (i.e. flooding) and, therefore, increasing the amounts of bare ground and reviving vegetation. All of these situations have the potential to cause lower elevation flora and fauna to migrate upslope in search of better conditions. Increasing temperatures are also causing the degradation of permafrost, which leads to increased debris flow and landslides that could damage alpine bird habitat (Cannone et al. 2007). All of these changes in snowpack, glaciers, and climate are changing alpine terrain and impacting the abiotic and biotic resources available to alpine species.

Ecological Responses to Climate Change

Through my review of literature, there has been a lack of consensus as to how the changes in abiotic factors and the ecological responses to climate change affect alpine birds. Most recent literature suggests that there is extensive variability in the responses that alpine birds experience to changing climatic conditions (Scridel et al. 2018; Tingley et al. 2012). Conversely, studies from the early 2000s suggest there is some heterogeneity in responses by all bird species, but alpine and mountain bird species tend to respond in more consistent ways such as migrating upslope (Walther et al. 2002; Crick 2004). Furthermore, alpine bird responses to climate change have been found to be shaped by microhabitat properties (Brambilla et al. 2018). A short summary of the most important responses and effects are shown in Figure 2. In this section, I will discuss ecological responses to climate change and the varying responses of alpine birds that have been mentioned in previous studies.

Changes in Vegetation

Plant productivity in mountain ecosystems decreases with increasing elevation above the tree-line, which makes food sources relatively scarce for alpine and nesting birds. We are realizing that climate change is progressively threatening these food sources that alpine birds highly depend on. It is known that vegetation responds immensely to climatic changes, and this is no different in alpine ecosystems. Research collectively shows that forests, shrubs, and mountain flora in general are responding to climate change—specifically increasing air temperatures—by shifting upwards and invading alpine grasslands and tundra (Singh 2018; Bjork and Molau 2007; Cannone et al. 2007; Chamberlain et al. 2013; Scridel et al. 2018). Alpine grasslands are incredibly important foraging microhabitats for alpine birds during the breeding season. A study in the European Alps found that this colonization of forests and shrubs severely impacts the distribution of alpine bird species in open habitats (Chamberlain et al. 2013). A similar study in the European Alps found that alpine plants are shifting upwards in elevation by one to four meters per decade (Walther et al. 2002). The upward migration of plants is one of the earliest responses of fast climate change, and this can lead to the loss of many nival plant species (species of the permanent snow zone) and high alpine plant species (Singh 2018; Pauli et al. 2003). This shift can produce major changes in community dynamics and distribution of alpine vegetation, as well as in foraging habitats of alpine birds (Cannone et al. 2007; Figure 2).

Effects of Snowpack Change

Similarly, there is evidence that alpine grasslands are migrating upwards and replacing snowbeds—lands covered in snow for long periods— that are important sources of fallout arthropods for birds (Cannone et al. 2007; Brambilla et al. 2018). Late in the growing season, after food in the tundra has lowered in quality and become less abundant, snowbeds provide alpine birds with wind-dispersed invertebrates and high-quality food sources at the melting margins of snowfields (Bjork and Molau 2007; Brambilla et al. 2018). Unfortunately, increasing temperatures due to climate change decrease snowpack in the winter and cause early melting of snowfields in the spring and summer (Brambilla et al. 2018; Lapp et al. 2004). This leads to the possibility of invasion by plant communities that can physiologically establish in intermediate snow cover, which may decrease snowbed habitat. Additionally, the shortening of the snow cover season is reducing the overall surface area of frost-sensitive, snowbed plant species (Pauli et al. 2003). Increasing temperatures lead to drier soils in the final stages of the growing season, significant water loss, and degradation of permafrost, which can create landslides, debris flow, and changes in plant community dynamics (Bjork and Molau 2007; Cannone et al. 2007). Based on this information, foraging habitat of alpine birds can therefore be reduced not only by forest and shrub invasion of grasslands, but also by decreased snow cover and grassland invasion of snowbed communities (Figure 2). However, a study in the Colorado Rocky Mountains observed no change in the timing of snowmelt or in the beginning of the growing season from 1973 to 1999 (Inouye et al. 2000). It would be interesting to see if this observation has changed since the study was conducted.

Phenological Mismatch

Alpine birds are also threatened by the disjunction between phenology—the timing of biological events such as breeding and migration—and climate change responses among regions. One study found that climate change triggers responses at distinct rates among different levels of the food chain, meaning organisms and their food are developing a growing mismatch in their phenology (Both et al. 2009). Based on this study, birds' breeding phenology will not match the time of peak abundance of their food source (Figure 2). Another study conducted by the same leading author discussed the inflexibility of migration due to photoperiod, which is another reason for the disjunction between a bird and its food source. Changes in photoperiod can only occur through evolution of genetic material, so birds have not been able to match the phenology of their food source because they cannot change their genetics as rapidly (Both 2010; Figure 2). However, this study was general and did not focus specifically on alpine species. This topic was not widely present in studies on specialist alpine birds, but is important to understand regardless because of the underlying need for alpine birds to evolutionarily adjust to the changing environment. Conversely, a study by Inouye et al. (2000) found no evidence of flowering phenology changing in high elevations due to climate change. This means there is asynchrony between the low and high elevation cues, causing the phenology of altitudinal migrants to be mismatched with the phenology of higher elevation ecosystems (Inouye et al. 2000). In consequence, alpine birds will migrate to higher elevations for breeding and, upon arrival, find that higher elevations are still experiencing winter conditions (Figure 2). If they run out of food rapidly after they arrive at the higher elevations, then alpine birds are forced to wait at slightly lower elevations until more snow starts to melt (Inouye et al. 2000; Both et al. 2009; Crick 2004). Therefore, the disjunction between low and high elevation environmental cues and phenology is causing alpine birds to arrive to breeding sites both before enough snow has melted and before food sources become readily available (Figure 2). Phenology and environmental cues are extremely important to the behavior of alpine birds, and shifts in these cues can be detrimental on the individual and population levels.

Heterogeneity in Range and Migration Shifts

Another observation presented is that responses to climate change by alpine birds are heterogenous and therefore unpredictable on a species level. Scridel et al. (2018) found a lack of consistent elevational shifts by mountain bird species due to climate change. Likewise, another study conducted in western North America found that there are elevational shifts of birds' breeding distributions, but the shifts are not unidirectional—51% of the birds studied showed a statistically significant range shift upslope (Tingley et al. 2012). The inconsistency in direction and magnitude of these elevational shifts is due to changes in temperature and precipitation. Tingley et al. (2012) found that increasing temperatures drive alpine bird species to shift their breeding range upslope to seek refuge in the cooler temperatures of higher elevations. On the contrary, increasing precipitation drives certain species to shift their breeding range downslope, likely because lower elevations have more access to physical refuge from precipitation (Tingley et al. 2012). To generalize this, if alpine ecosystems are experiencing more pronounced increases in temperature than in precipitation, one would expect alpine birds to shift their distribution to higher elevations (Figure 2). Alternatively, if increases in precipitation are more pronounced than increases in temperature, one would expect alpine birds to shift their distribution to lower elevations (Figure 2). These observations spark concern in the scientific community because there are limited ways to conserve alpine birds due to different responses to climate change and, consequently, different conservation needs.

Discussion

A diversity of ecosystems depends on alpine ecosystems for their water reservoirs and other resources. Climate change is threatening alpine ecosystems as increasing temperatures and precipitation change the biotic and abiotic factors that these regions contain and depend on (Basagic and Fountain 2011; Brambilla et al. 2018; Cannone et al. 2007; Lapp et al. 2005). The scientific community has few diverse sets of evidence that show how alpine birds are affected by and therefore respond to changing environmental conditions. Fortunately, as the scientific community and the public become increasingly concerned with climate change, researchers are focusing more and more on montane and alpine habitats and species.

In this section, I hope to synthesize the evidence and trends that have been presented by studies on alpine birds and their habitats. Multiple studies conclude that the upwards elevational shift of vegetation immensely decreases the foraging habitat of open habitat alpine birds (Brambilla et al. 2018; Cannone et al. 2007). The decrease of alpine tundra due to the invasion of forest and shrub vegetation shrinks ground foraging habitat (Brambilla et al. 2018; Chamberlain et al. 2013; Singh 2018). Additionally, the invasion of snowbed communities by alpine grasslands can decrease snowpack distribution and, therefore, decrease arthropod fallout foraging opportunities for alpine birds (Bjork and Molau 2007; Brambilla et al. 2018; Cannone et al. 2007). Glacial and snowpack shrinkage due to climate change will also impact the foraging and breeding habitats available to alpine birds, especially in the coming decades if retreating rates persist (Cannone et al. 2007; Brambilla et al. 2018). Moreover, phenological shifts are occurring among the different levels of the food chain and along the elevational gradient; these shifts could be affecting the distribution and breeding habitat of alpine birds (Inouye et al. 2000; Both et al. 2009; Both 2010). Further, the changing temperature and precipitation patterns appear to be greatly impacting the direction and magnitude of the elevational shifts of the birds' breeding habitats (Tingley et al. 2012; Scridel et al. 2018). Variability in alpine bird responses to climate change is what makes this issue so complex.

Directions for Future Research and Conservation

In their review, Scridel et al. (2018) discussed the conservation strategies presented by various studies that focused on the impact of climate change on mountain and alpine birds. It is evident that there is a need for more detailed studies of alpine birds and their habitats. Because responses to climate change can be quite heterogenous and species-specific, understanding the ecology of alpine bird species is essential to knowing what conservation efforts to implement. Some studies encourage studying physiological tolerance and ecological needs of species, while others find it important to invest in researching the climate and habitat factors, such as the effects of weather variability on habitat suitability (Scridel et al. 2018; Brambilla et al. 2018). Researchers could also work to understand if there is a difference in energetic values provided by food sources from snowpack compared to those of alpine grasslands. If climate change affects the foraging habitats of alpine birds, this information could help us know if alpine birds would be able to survive on only one of those food sources (Scridel et al. 2018). Furthermore, alpine birds should be monitored to see if climate change will have an effect on their population size, distribution, reproductive success, and overall survival rates.

Land and habitat management are also incredibly valuable strategies for the conservation of alpine birds. Various studies suggest that better management and restoration of alpine grasslands and open habitats can be beneficial to the conservation of alpine bird species and their foraging habitats (Scridel et al. 2018; Brambilla et al. 2018; Chamberlain et al. 2018). Because forest and shrub vegetation and tall grasses are starting to invade alpine tundra due to increased temperatures, researchers believe shrub clearance and targeted grazing of alpine tundra will help maintain the low sward habitat necessary for foraging (Chamberlain et al. 2016). Restoring their foraging habitat would be beneficial in increasing the resistance and resilience of alpine birds as they face various other climate change-induced threats. Policymakers and scientists should strive to develop habitat restoration plans for mountain regions to maintain bird habitat. It would be particularly advantageous to restore microhabitats of alpine birds that are developed or near human developments. For example, we could increase the amount of protected high-quality alpine habitat, as well as restrict future construction of ski resorts and leisure infrastructure in these areas.

Implementing legislation that protects alpine birds and their habitats, including those that restrict anthropogenic stressors, will improve mountain species' resistance and resilience through climate change. A combination of all these conservation strategies will be needed to successfully help alpine birds and their habitats withstand climate change (Scridel et al. 2018). However, scientists and politicians must invest in research for these high elevation specialists in order to make accurate conservation decisions. Overall, we should pursue conservation strategies to improve the situation for alpine birds and understand how climate change will affect not only their habitats, but ecosystem services we also depend on.

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Notes

[1] **Heterogeneity:** State of being diverse; variability
[2] **Abiotic:** Nonliving physical and chemical components of the environment
[3] **Biotic:** Living components of the environment
[4] **Photoperiod:** Period of daily light exposure received by an organism and its physiological reactions to it
[5] **Cryptic coloration:** Tactic used to disguise and blend into surroundings
[6] **Arthropod fallout:** Dead invertebrates carried by the wind currents and deposited at the top of mountains