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Climate Change and Its Impacts on Saker (Falco cherrug) and Peregrine (Falco peregrinus) Falcons: How the Changes Will Affect Their Migration, Diet, Offspring, and Conservation Efforts

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Abstract

Climate change is considered as a real danger to many birds including raptors such as the Saker falcons (Falco cherrug) and Peregrine falcons (Falco peregrinus). This article answers the question of how climate change shifts the migration, feeding, and breeding habits of these raptors. These migratory birds keep facing disturbances in their yearly cycle due to recent changes in temperature, precipitation patterns, and pollution. This results in changes in the migration points, as they travel for longer or shorter distances, especially to make their nestlings, and changes in their prey availability, affecting their migration pattern. Also, air pollution affected them significantly, where mercury (Hg) and lead (Pb) levels in their feathers were significantly high. Fortunately, it has not affected their general health yet. As for their reproduction success, it was interrupted, making it necessary to take conservation initiatives and tactics to save these species amid climate-induced alterations by analyzing ecological interconnections and evolutionary mechanisms. The findings highlight the necessity of mitigating climate change effects on migrating raptors to guarantee their survival rate is high and satisfy ecological system equilibrium.

Keywords: *Climate change, Saker falcon, Peregrine falcons, Ecological balance, Migratory raptors.*

Introduction

Climate change refers to long-term changes in temperature, rain, Air current patterns, and other things related to the Earth's climate system. Global warming, which is a part of climate change, is the increase in Earth's average temperature due to rising levels of greenhouse gases (i.e., Carbon Dioxide (CO_2), Methane (CH_4), Nitrous Oxide (N_2O), Fluorinated Gases (HFCs, PFCs, SF_6, NF_3)). Historically, Earth's climate naturally varied due to factors such as volcanic activity, changes in solar radiation, and natural carbon cycle variations that helped shape the Earth to be more and more fit to live in. Nowadays, they are due to natural and human activities, such as the Industrial Revolution. This was the start of a significant impact on the climate, with the burning of fossil fuels (coal, oil, and natural gas) and deforestation resulting in over 75% of global emissions, leading to the increase in concentrations of greenhouse gases like (CO_2), (CH_4), and (N_2O) in the atmosphere. These gases trap heat, which results in creating a 'greenhouse effect' that warms the planet. The greenhouse effect was not originally a problem as it helps keep the heat from the sun trapped in Earth's atmosphere that significantly contributes to keeping the Earth's temperature at a normal level suitable for living, but the increase in the industrial usage and releasing of the gases to the atmosphere in an uncontrolled manners especially during the industrial revolution during the last Century is the main reason why greenhouse gases is now a problem that need to be addressed and dealt with. Figure 1 shows the emissions of the United States alone in 2022 was of about 6,343,000,000 Metric ton of CO_2 equivalent (United States Environmental Protection Agency (2024).

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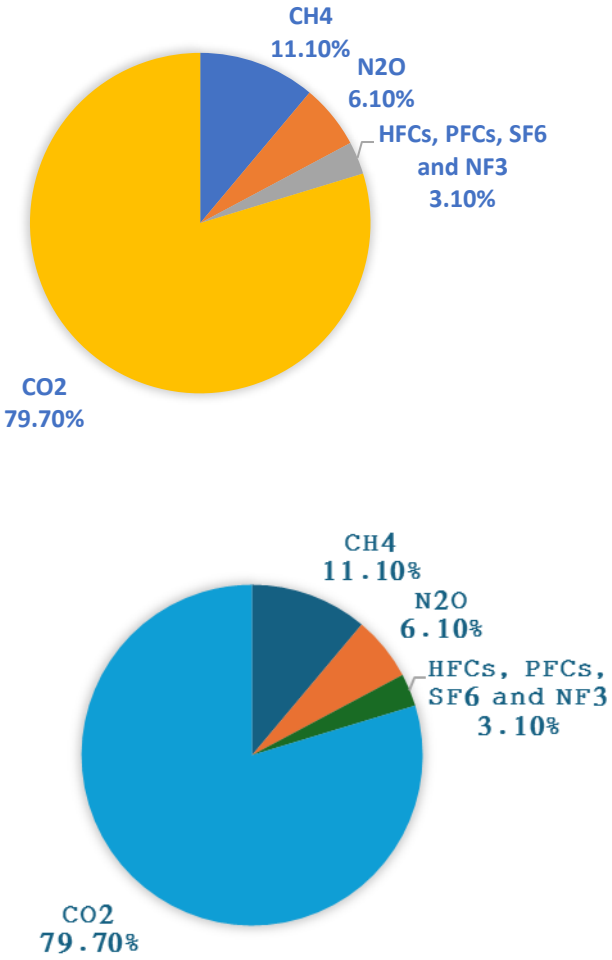

Figure 1. Total U.S. Emissions in 2022 that equals 6,343 million Metric Tons of CO_2 equivalent, Chart showing different types and percentages of greenhouse gases in the atmosphere, highlighting the relative contributions of carbon dioxide, methane, nitrous oxide, and fluorinated gases.

Source: United States Environmental Protection Agency, (2024).

It was reported by The Intergovernmental Panel on Climate Change (IPCC) that the Earth's surface temperature has risen by approximately 1.1 degrees Celsius since the late 19th Century, with warming effect accelerating quickly during these recent decades (IPCC, 2021). The World Meteorological Organization (WMO) states that the past decade (2011-2020) was the warmest, which should emphasize the urgency of addressing human-caused climate change (World Meteorological Organization, 2021).

Climate and weather significantly change how air pollutants are distributed and concentrated, such as ozone O_3 (found at ground level) and $PM_{2.5}$, with higher temperatures, due to global warming, accelerating their formation. Weather systems, through winds, vertical mixing, and rain, further affect the dispersion of these pollutants, which are expected to rise in future climate scenarios (Kinney, 2018). Studies on some bird species say that air pollution, including nitrogen and heavy metals, have a negative impact on their fitness traits like reproductive output, DNA integrity, survival rate, foraging behavior, coloration, and body size. This resulted in the declining number of birds and even the loss of 1.5 billion birds (nearly 20%) across the US in the last four decades (Barton et al., 2023; Liang et al., 2020). These environmental changes result in

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many bird species shifting their breeding and wintering ranges poleward or to higher altitudes. Migration patterns are also affected, where they have an early arrival to breeding grounds and changes in travelling routes. In addition, breeding starts earlier in the year, often resulting in increased clutch sizes, although not necessarily higher breeding success (Fiedler, 2021). Thus, climate change really has a significant impact on bird ecology in one way or another.

The Saker Falcon (*Falco cherrug*) and the Peregrine Falcon (*Falco peregrinus*) are two of the most iconic raptors, known for their mind-blowing hunting skills and very long migratory routes. The Saker Falcon, a large and powerful raptor, lives in a wide range of land across Asia and parts of Europe. This species is noted for its long-distance migration routes, which are mandatory for its survival and reproduction process. (SakerGAP, 2011). As for the Peregrine Falcons, they pose a vast distribution as it could be found in many continents and different climates in addition to their impressive speed. Although both have their ways to adapt in tough environments, they face many challenges with the rapidly changing climate. Climate change is considered a real danger to these raptors, impacting things like feeding, migration, and breeding. Reallocation in the geographic distributions of their prey is because of rising temperatures and changed weather patterns, leading to a mismatch between the falcons' hunting time and prey availability. The Environmental changes resulted in disturbing the Saker falcons' annual cycle. For the sake of adaptation, they are forced to change their migration routes, either traveling for longer or shorter distances in order to search for appropriate food and place for nestling. Similarly, Peregrine falcon have to shift their migration routes and make adaptation in their timing in order to find the right food. For this study we want to see how much climate change shifts the Saker and Peregrine falcon's lifestyle and how future turns in climate may affect them further. We are discussing this through answering these important questions:

- in what way does climate change affects the breeding and migration patterns of these falcons?
- How does climate change indirectly affect these falcons by affecting the animals like small mammals and smaller birds they prey upon?
- What conservation methods, such as the use of artificial nests, have been implemented, and how effective are they in altering these climate-driven impacts?

Understanding the picture as a whole of how climate change impacts these falcons is the first step for developing effective conservation strategies. The general health of the Saker Falcon and the Peregrine Falcon is indicative of ecological health as they are top raptors. Their decline could be an indicator that something is wrong in their ecosystems, highlighting the urgency of focusing on climate change and how to deal with it to ensure the survival of these species and the maintenance of ecological balance. But even in a controlled environment the smallest mistake can lead to a disaster, especially if put into consideration the food cycle of predators like the falcons that actually feed on small mammals like rats and rabbits that could quickly spread deadly diseases. The Black Death (1347–1351) that was mainly spread by rats or Australian Rabbit Plague (Late 19th to 20th Century) which was caused by rabbits over breading with no natural predators like the mentioned falcons and could led to economical disasters by feeding on corps.

The major significance of this study is to make appropriate efforts that target the protection of these raptors. We should achieve this by analyzing ecological interactions, reproduction success and the health of these raptors before and after climate change and predict the way of progress in these factors through the following years as climate changes are predicted by more than one organization including NASA (NASA, 2024). According to these findings we should make the best decisions regarding how to preserve a healthy ecological system and biodiversity.

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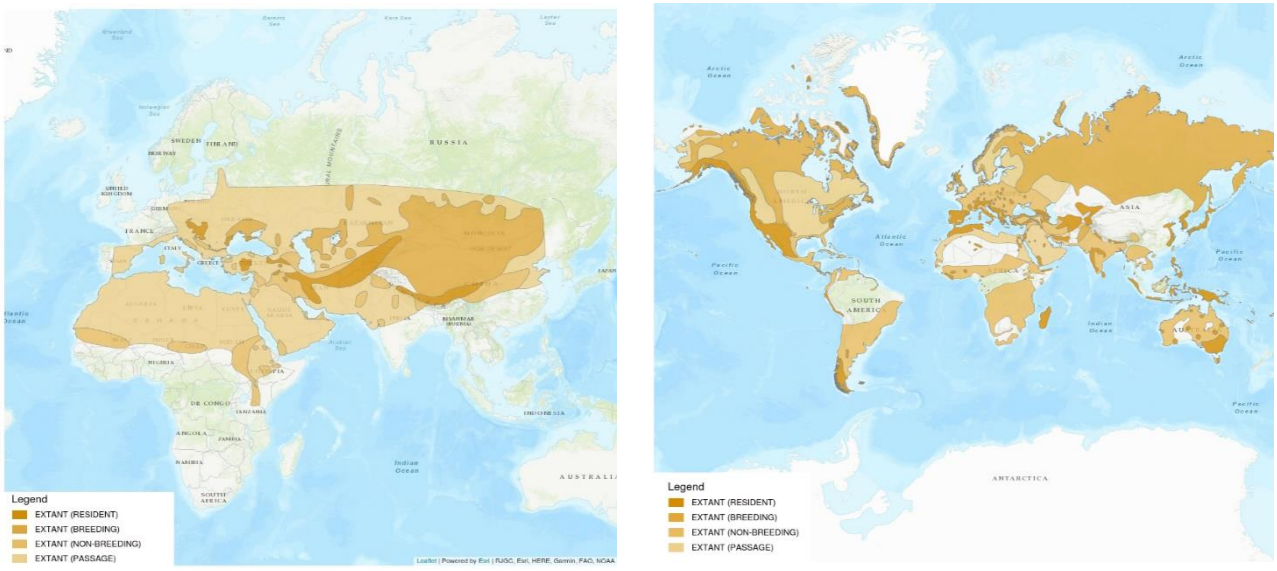
Methodology

This research focuses on the Saker Falcon (*Falco cherrug*) and Peregrine Falcon (*Falco peregrinus*) due to their ecological significance and complex migratory patterns and also given their importance for the food cycle and consideration that they are endangered species. The study areas encompass critical breeding and wintering habitats across Western Asia and some Arctic regions. These areas are chosen for their importance in supporting the life cycles of these raptors, providing essential insights into how climate change impacts their migration, feeding, and breeding behaviors as shown in figure 2 (a & b) the cycle of the two species Saker and Peregrine respectively.



(a) (b)

Figure 2. a: Map shows the distribution of the Saker Falcon, pointing out regions where the species reside, breeds, non-breeding areas, and migratory pathways, **b:** shows the same but for Peregrine Falcon

Source: Birdlife International. (2022). The IUCN Red List of Threatened Species 2022.

To conduct this study, researchers utilized climate data from two primary sources. Future daily temperature projections from 2020 to 2100 were obtained from the NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP) dataset (NASA, 2024). This dataset provides high-resolution climate projections essential for understanding potential future climate scenarios. Additionally, present and palaeo-bioclimatic variables were sourced from the WorldClim database, which offers comprehensive climate data for various time periods. These datasets enabled the researchers to model and predict the impacts of climate change on the Saker Falcon's habitat and behavior (WorldClim, 2024).

By conducting field observations, focusing on breeding habits, feeding behaviors, and migration patterns. Breeding habits were monitored by tracking nest success rate and eyases survival, while feeding behaviors were documented by recording prey types and hunting success rates. Migration patterns were tracked using GPS tags to map the falcons' migration routes, but harness-mounted satellite transmitters have proven to be somehow dangerous to the falcons a study was made to address this issue and it was found that the falcons with harness-mounted satellite transmitters have decreased survival rates and have proven to make a sense of discomfort the falcon based on the falcons' behavior of removing the tracker or the satellite attached to them so another approach were used is to setup artificial nests that could serve two purpose 1-

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provide nests for the falcon so it could breed and lay eggs. 2- could be used to monitor the falcons by setting the nests up with cameras.

Data analysis was carried out using various statistical methods. Regression models were employed to predict future changes in falcon populations based on climate projections. Moreover, GIS mapping was used to visualize changes in habitat distribution and migration routes. Also, all the research were conducted ensuring ethical guidelines were followed for wildlife studies. Necessary permits were obtained for fieldwork, and measures were taken to minimize disturbance to the falcons.

Results and Discussion

How does climate change affect the breeding and migration patterns of these falcons?

In the following study, a large-scale migration tracking system was developed using satellite technology to monitor 56 peregrine falcons (Falco peregrinus) from six different breeding populations in the Eurasian Arctic. The predicted changes in breeding and wintering areas of peregrine falcons between the present and the year 2070 under the Representative Concentration Pathway (RCP) 8.5 scenario, which assumes continued high greenhouse gas emissions. Figure 3b shows the area changes in breeding and wintering habitats for six peregrine populations.

There is a correlation between the longitudes of wintering and breeding sites for the tracked peregrine falcons. The linear regression analysis illustrated in figure 3 (a) shows a high degree of migratory connectivity ($R^2 = 0.86$, $P < 0.001$), indicating that there is a strong relationship between where the birds breed and where they winter. This suggests that the migration routes are constant and that the falcons develop strong relation with their wintering locations. In addition, Figure 3 (b) indicates a significant poleward shift in both breeding and wintering distributions due to climate change. Specifically, breeding areas are expected to move northward by an average of 2.08° latitude, while wintering areas will shift by 1.47° latitude. This shift is consistent with the general trend observed in many Arctic species as they adapt to warming temperatures. The most significant reduction in suitable breeding habitats is predicted for the Kolguev and Kola populations, with Kolguev losing 100% and Kola losing nearly 93% of their current breeding areas.

This reduction points out the vulnerability of these populations to climate change. Additionally, the figure shows that short-distance peregrines may experience a much shorter migration route in the future, with an average reduction of 655 km (95% confidence interval, 442–868 km). In contrast, long-distance peregrines may have a slightly longer migration route, with an average increase of 286 km (95% confidence interval, 56–515 km). Overall, Figure 3 points out the noticeable impact of global warming on the migratory behavior and habitat availability of peregrine falcons, that have the potential to lead to significant changes in their migration routes and population distribution (Gu et al., 2021).

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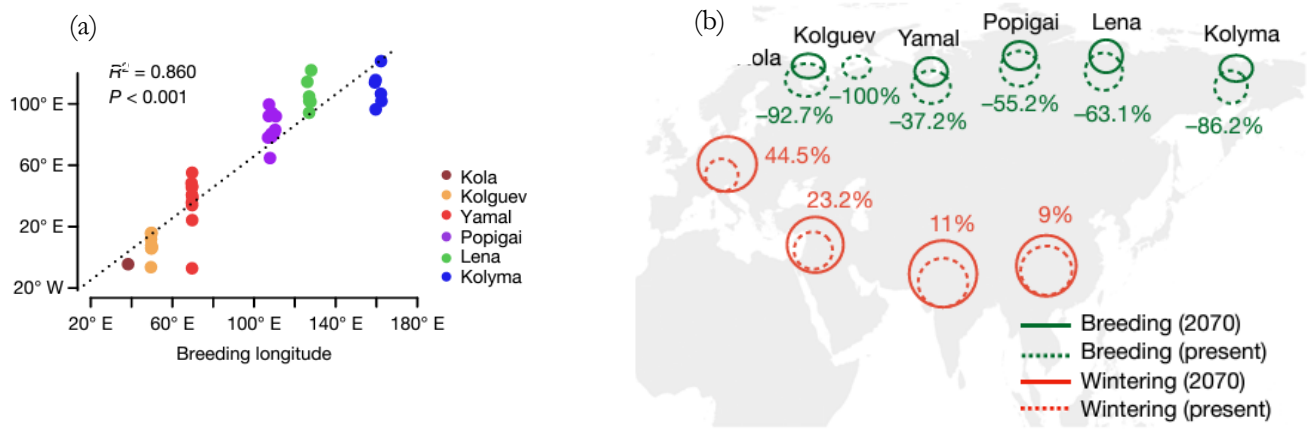

Figure 3. (a) migration shift for 6 different populations of peregrine falcons and population decline due to global warming, (b) regression model for the relation between wintering longitude and breeding longitude. Source: Gu et al., 2021.

Climate change poses significant threats to the Saker Falcon as well, primarily through alterations in temperature and habitat availability. As global temperatures rise, the grasslands of the Qinghai-Tibetan Plateau may undergo substantial changes. After the study of 8 females of the migrations of Saker falcons fitted with satellite- received transmitters from 1998 till 2011 it was shown that the winter home range area of each falcon varied greatly due to climate change. As for Saker Falcons, they have homes in areas with more than 50% grassland cover, making them with a smaller home range but higher prey availability, (Dixon et al.,2016). Future shifts in this grassland area and the degradation of it due to climate change is said to reduce breeding success and altered migration routes for the Saker Falcon. These changes may force the falcons to adapt to new habitats or face population declines. Making sure to address this problem is vital for planning how to create a better environment for them suitable for living.

In general, both species face noteworthy challenges due to climate change. So, the need for adaptive conservation strategies is needed. In other words, Increased mortality, habitat loss, and migratory route changes that usually become longer are dangers that could arise the problem of population decline. The efforts needed to be made should be in the direction of reversing the impact of climate change by habitat protection, artificial nesting sites, and other adaptive measures to ensure the survival of these raptors.

The Impact of Climate Change on Saker and Peregrine Falcon Feeding

The effect of climate change on the feeding habits of Saker and Peregrine Falcons is indirect. By rising temperatures and changed rain patterns, the geographic distribution of their prey, such as small mammals and birds, are changed (Rushing et al., 2020). As previously specified, these changes lead to mismatch between the falcons and their prey. This makes them adapt in one of two ways either by targeting less suitable prey species or traveling longer distances to find suitable prey. Climate change affects the availability of prey species, especially birds, which are crucial for the falcons' diet (Carey, 2009; Dixon et al., 2016). This is caused by the change of arrival of migratory birds that falcons feed on or the time that mammals end their hibernating. This mismatch may lead to falcons not having suitable prey species available that coincide with the time of their breeding seasons. Thus, resulting in reduction of food available for nestlings, and affecting their eyases survival rates (Both et al., 2019; Trautmann, 2018).

Habitat loss is another factor that affects small birds and mammals, reducing their population. This also affects the falcons who hunt birds that might reach a point where a specific bird species is no longer found available. For example, The Saker Falcon primarily preys on plateau pikas, which thrive in rich grasslands. Degradation of grasslands reduces the plant biomass that supports densities of pikas, thereby decreasing the availability of these key prey species for falcons. So, to adverse the decline of prey availability, conservation efforts such as creating artificial nesting sites and protecting key foraging areas, are crucial to

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mitigate these impacts and support the Saker and Peregrine Falcon populations in adapting to the changing environment (Rahman et al., 2014).

Climate change and air pollution effect on birds and on saker and peregrine falcons

Climate and weather significantly influence the spatial and temporal distribution of air pollution. For example, higher temperatures can increase the emissions of substances that lead to the formation of Tropospheric (ground-level) ozone and $PM_{2.5}$, which refers to delicate particulate matter that is less than 2.5 micrometers in diameter. Ground-level ozone forms more rapidly as temperatures rise, which can cause numerous health problems for humans and birds. A Study suggests that even if anthropogenic air pollution was halted, the effects of climate change and rising temperatures would still lead to increased ozone production and associated health issues in populated regions, (kinney,2018; Agathokleous, 2023). Another study indicates that although ground-level ozone is decreasing in Europe, under the RCP 8.5 scenario, the levels are expected to increase and offset the positive effects, becoming harmful (Doherty et al., 2017).

Data from the Giant Mountains in the Czech Republic was recorded for 25 years and analyzed, this analysis revealed that ozone gas (O_3) exposure affects the population growth rates of upland bird species in the alpine zone above the treeline (Reif et al., 2023). Birds exposed to air pollutants, including O_3, carbon monoxide (CO), heavy metals, smoke, and sulfur dioxide (SO_2), undergo oxidative stress, which forces them to use energy to detoxify and get rid of harmful reactive chemical species. This stress can lead to respiratory issues, immunosuppression, illness, behavioral changes, and impaired reproductive success (Sanderfoot and Holloway, 2017). A study that was conducted in US found that air pollution has caused the death of nearly 1.5 billion birds over the past 40 years (Liang et al., 2020). another research was conducted in China on a specie called Eurasian Tree Sparrows in Shijiazhuang city that have high percentage of pollution compared to Chengde city that are less polluted showed that birds in Shijiazhuang had greater lung particle retention, toxic metal accumulation in feathers, reduced antioxidants, immune capacities, and signs of anemia, despite similar overall body conditions (Li et al., 2021). concerning the direct impact of pollution on Saker and Peregrine falcons, both showed high concentrations of heavy metals such as mercury (Hg) and lead (Pb) in their feathers.

Saker falcons' tests showed high levels of these heavy metals, with Hg concentrations nearing 3.00 mg/kg and Pb concentrations at 4.10 mg/kg in primary feathers. These levels are concerning as they are about to reach the threshold of 5mg/kg which is known for causing negative effects on reproduction and behavior. The elevated metal concentrations in these raptors indicate significant bioaccumulation through the food chain that shows that pollution has affected smaller birds and small mammals as well, reflecting the broad environmental contamination in their habitats. This pollution is a serious threat to their health and survival that stresses on the need for monitoring the migration cycle of the raptors and efforts to overcome the effects of the pollution on these raptors, (Zolfaghari, 2023). Reducing pollution is essential to ensure that small mammals and smaller birds can migrate on time and maintain healthy populations. By improving the quality of their habitats and reducing pollutants we can help these species to achieve better health and a larger population that could provide falcons with a stable food supply. This approach not only improves the health and survival rate of falcons but also ensures a better ecosystem overall by completion of the whole food cycle (Mariyappan et al., 2023).

Impact of Climate Change on Nesting Sites

Nesting sites of Saker and Peregrine Falcons are another thing affected by climate change. Nesting sites are critical for falcons breeding success. They also ensure that their population is stable. Fluctuations in temperature, rain patterns, and extreme weather are factors that can destroy these sites. This results in both decreasing reproduction success and increasing mortality rate of eyases. Heavy rainfall directly caused over one-third of the recorded nestling mortalities, with eyases being particularly affected by rainstorms of 8 mm or more per day. Nestlings that were sheltered from rainfall by a nest box had significantly higher survival rates. This highlights the fact that the major factor of declining the falcon's nestling survival rate is the significant increase in the frequency of heavy rain during the last three decades. leading to decreasing

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the annual breeding productivity of falcons. This was first experimented by a recent study that illustrated the direct correlation between rainfall and survival rate in birds. This highlights the fact that these top predictors can by greatly affected by changes in rain patterns. In addition to precipitation patterns, intense storms can result in nest flooding or nest structure damage. making it a real threat to the survival of eggs and eyases (Anctil et al., 2014).

Habit degradation due to climate change not only affects prey availability, but it also affects the availability of nestling sites as well as its quality. For example, the nestling site of a Saker Falcon on cliff or on a tree can't be suitable if many Greenland degradation is caused. This will result in a less suitable location for nestling. Similarly, Peregrine Falcons, which also need tall structures for nestlings will find it hard to get a suitable location as their nestling site after these climate changes caused by human activities. Strong storms have the ability to destroy nests or displace material used for nests. Alternatively, droughts can reduce the availability of prey near their nestling sites, making them travel longer distances in search of their food leaving their nests unprotected. These are all factors leading to higher eyases mortality rate and lower breeding success. To prevent these climate changes from affecting the Falcons' nests, studies of artificial nestling sites were introduced and implemented. These artificial nests provided a safe and stable environment for breeding.

The potential use of artificial nests

The use of artificial nests to manage and sustainably utilize Saker falcons (*Falco cherrug*) in central Mongolia were applied to be tried. Artificial nests were made from steel drums cut in half, fitted with a lid, and mounted on steel poles. They were arranged in grids with nests spaced at 1 km intervals. The study compares the success of breeding Saker falcons in artificial nests in flat steppe landscapes with those in natural nests on rocks and cliffs in adjacent hills, (Rahman et al., 2014). There was no significant difference in daily nest survival during the egg and nestling stages between artificial and natural nests. However, overall nest survival was higher at artificial nests, primarily due to higher survival rates during the egg stage. Although artificial nests produced an average of 3.2 fledglings compared to 2.3 at natural nests, the difference was not statistically significant. Also, there were no significant differences in offspring sex ratios and fledgling mass between artificial and natural nests. The breeding density increased in areas with artificial nests, and there was a high degree of territory fidelity among breeding pairs.

Artificial nests can increase the range, size, and productivity of saker falcon breeding populations, which is beneficial for a globally endangered species. They provide secure nest sites, leading to higher nest survival rates, especially during the egg stage. Although this would be very useful in monitoring falcons' population, the main limitation for this is that the technique is most effective in areas where nest site availability is the primary limiting factor and there are non-breeding adults available to occupy the nests. It may not be as helpful in areas where population declines are due to other factors.

.*Other methods to face the endangerment of the falcons*

The first thing that could be done to save not only the falcons but also other species, and I could go as far as to claim that it could save the planet itself by regaining the balance, is to reforest the habitants of the falcon that once were destroyed, that could provide a place for the falcons to nest and breed and also a place for the falcons' prey to exist restoring the food cycle. Also, artificial feeding systems could be addressed that could provide the falcons with prey artificially if they couldn't be found in nature. This could be done by literally letting small mammals and rodents roam in the habitats of the falcon, but of course, in very controlled manners to avoid any unwanted complication or even disasters like the mentioned before the Australian Rabbit Plague. Better tracking devices could be developed to better assess and monitor the migration route of the falcon, providing better monitoring of the flacons and evading the problems that are caused by the nowadays technology, from decreasing survival rate to getting rid of the devices by the falcon due to the discomfort of the falcons.

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Conclusion

This study shows the importance of considering effects of climate change in Saker Falcons (Falco cherrug) and Peregrine Falcons (Falco peregrinus), concentrating on their migratory pattern, feeding preference, and general viability changes due to climate change. The used migratory monitoring system indicated significant poleward relocations in breeding and wintering habitats, related to increasing temperatures. These changes put reproductive success at risk, especially for peregrine populations in Kolguev and Kola, where we face significant habitat loss. It also disturbs the feeding behaviors of these raptors by altering the availability and distribution of their food, The mismatch between prey availability and the breeding seasons of falcons may result in a diminished food supply for nestlings as well as affecting their survival rates. Habitat degradation results in prey population decline, urging falcons to make modifications in their migration routes such as traveling longer to find a suitable place for nestling or food.

Another impact of climate change is decreasing reproduction success. Elevated temperatures, modified precipitation patterns, and extreme weather phenomena can affect reproduction success and decrease survival rate of eyases. Air Pollution cased lead (Pb) and mercury (Hg) concentration to increase in falcons' feathers nearly reaching the threshold that shouldn't be exceeded for falcons to be in good health. Conservation methods, including the establishment of artificial nests and habitat restoration initiatives, are essential to alter these effects and ensure safe breeding habitats.

Future Directions

Effective conservation strategies are needed to keep falcons from being endangered. These include but are not limited to building artificial nests, protecting important feeding areas, and keeping track of their migration path and feeding habits till making sure everything returned to normal. In order to achieve that, the right monitoring device must also be developed as the current tracking systems are a bit threatening to their survival rate. The threats resulting from climate change must be addressed and a suitable plan should be implemented to make progress that changes the future predicted by the continuous climate changes and air pollution. An active and forward-looking strategy, conservationists can secure the survival of Saker and Peregrine Falcons, saving their ecological functions and sustaining biodiversity in an increasingly healthy environment.

As for climate change, future conservation efforts must prioritize suitable management approaches that address current and projected climate change. This also includes but are not limited to monitoring climate impacts on nesting sites, enhancing birds' habitat, and endorsing policy changes that limit greenhouse gas emissions. By addressing the underlying causes of climate change and implementing targeted conservation strategies, we can facilitate the survival and stability of not only Saker and Peregrine Falcon populations but also different birds species that are endangered with population declination.

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