

Review article

Impact of Climate Change on Migratory Birds in Asia

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ABSTRACT

Climate change is not something that has never happened before. However, it has recently been reported that climate change has affected living things such as humans, animals and plants. Among the animals that may be vulnerable to the effects of climate change are migratory bird species. Therefore, this review paper will emphasise the checklist of migratory bird species found to be affected by climate change. Data for bird migration species in Asia are obtained from the Birdlife Data Zone. At the same time, the data for Global land surface temperature (1910-2020) and Asia land surface temperature (1910-2020) were taken from National Oceanic and Atmospheric Administration for Environmental information. These papers showed that climate warming could affect species differently, but there are still species from certain populations not affected at all. This paper also reviewed that approximately 169 species of migratory birds in Asia are affected by climate change and severe weather. Of the total, 5 species (2.96%) are critically endangered, 8 (4.73%) endangered, 21 (12.43%) vulnerable, 27 (15.98%) near threatened and 123 (63.91%) least concern.

Keywords: Asia, climate change, migratory birds, species, temperature

ARTICLE INFO

Article history:

Received: 27 April 2021

Accepted: 30 July 2021

Published: 28 October 2021

DOI: <https://doi.org/10.47836/pjst.29.4.38>

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INTRODUCTION

Overharvesting may be one of the most persistent threats to migratory birds because of human exploitation of their biology, including predictable spatiotemporal peaks in large quantities at various scales (Shuter et al., 2011). Nevertheless, today, overharvesting is no longer the only major threat to migratory birds because of the

emergence of a new threat that may have occurred over a long period. However, it has not been realised at that time that is climate change. Turrin and Watts (2016) assessed and calculated the sustainable harvest threshold for Asia-Pacific migratory shorebirds. Global climate change has a significant effect on the phenology of seasonal events (Lehikoinen et al., 2004; Ahas & Aasa, 2006; Menzel et al., 2006), and it has the potential to alter migration phenology (Both & te Marvelde, 2007; Rubolini et al., 2007).

Climate change can cause specific problems for migratory birds living in different parts of the annual cycle in other world regions (Silllett et al., 2000). One of the most crucial concerns is climate change when global surface temperatures have warmed at an average of 0.16°C to 0.18°C per decade since the 1970s (Solomon et al., 2007). The 2013 Intergovernmental Panel on Climate Change predicts that if the present pattern in emissions continues, global temperatures are expected to rise by 2°C or as much as 4.8°C by 2100 (Collins et al., 2013; Pachauri et al., 2014).

One of the most interesting facets of birdlife is migration. They get the ability to migrate hundreds or thousands of kilometres across geographical boundaries to other parts of the globe in response to changes in habitat, food availability, climate, and other factors. For example, there are almost 828 species of migratory birds in Asia, while in Europe, there are 429 species. However, many migration birds, mammals, fish, and invertebrates have experienced population loss in previous centuries (Wilcove & Wikelski, 2008; Gilroy et al., 2016). Therefore, a large number of migratory birds use flyways as their flight path. A flyway is a biological system consisting of entire types of migratory bird species, related communities of species, or different populations of one species that migrate annually from breeding areas to non-breeding areas, including a stopover and feeding areas as well as migration areas (Bridge et al., 2007).

The Eastly-Australasian Flyway (EAAF) is an important flyway in Asia that is also one of the nine major routes used by migratory birds. This EAAF flyway, which crosses three continents and 22 countries, is one of the world's biggest and most species-rich migration corridors (Turrin & Watts, 2016). Apart from the EAAF, the West Pacific Flyway and West Asian Flyway are two of the three flyways available in Asia. As a consequence, determining the migration paths and stopovers of migratory animals is important for effective population management and habitat conservation (Hutto, 2000; Faaborg et al., 2010). However, this review will not concentrate on a single migratory bird route in Asia but the total migratory birds observed in Asia from different flyways. First, the purpose of this study is to identify and list the species of avian (migratory birds) found in Asia that affected reference to previous studies that analysed the relationship between climate change and migratory birds. Second, the goal of this study was to identify migratory bird species in Asia that are sensitive to the impact of climate change, which may contribute to species loss. This information is essential for designing new conservation strategies and prioritising the endangered species and critically endangered species.

THE CLIMATE-CHANGING SINCE 1910-2020

The primary data sources for migration bird checklists found in Asia used in this article are obtained from the Birdlife Data Zone. Species threat data on climate change and extreme weather for birds migrating in Asia were also collected from the Birdlife Data Zone. All data observed are the latest updated until 23 February 2021. Meanwhile, data for Global land surface temperature (1910-2020), Asia land surface temperature (1910-2020) were taken from NOAA National Centers for Environmental information (2021). According to the International Union for Conservation of Nature (IUCN), the conservation status of migratory bird species was identified.

The earth's climate has changed over a long period until now, which has seen a very significant change. The tropopause, the border between the stratosphere and the troposphere, has climbed several hundred metres in height since 1979. Human-induced increases in ozone and mixed greenhouse gases account for approximately 80% of the simulated tropopause height increase from 1979 to 1999 (Santer et al., 2003). One of the most commonly used measures of global climate change is the global average temperature, and it has shown a series of increases since the early twentieth century. Natural processes, as well as certain impacts from human activity, lead to year-to-year temperature changes.

Figures 1 and 2 show the global land temperature anomalies from January to December for 1910 to 2020. Based on Figure 1, the negative anomaly (colder than normal) occurred around 1910 to 1937 before it fell to a positive anomaly (warmer than normal) in 1938 to 1944. The decline from negative anomalies in 1910 to 1937 to positive anomalies in a subsequent year shows evidence that there had been changes in terms of global climate around the 90s. Since then, annual anomalies for global surface temperatures have been seen as erratic and often change almost every year. For example, several other negative anomalies have occurred before 2000, namely in 1945 to 1946, 1949 to 1952, 1954 to 1957, 1960, 1964 to 1966, 1968 to 1969, 1971 to 1972 and 1974 to 1976. While the positive anomalies that occurred before the year 2000 were in 1947 to 1948, 1953, 1958 to 1959, 1961 to 1963, 1967, 1970, 1973, 1975, 1977 to 1999. Then, from 2000 to 2020, all those years recorded only positive anomalies marked since the beginning of the 20s era of global surface temperature conditions were warming. Therefore, based on all the data shown and proved from 1910 to 2020, there has been a change in global climate. In conclusion, climate change has occurred globally, increasing land temperature anomaly from -0.36°C (cold) in 1910 to 1.59°C (hot) in 2020.

Figure 2 shows the Asia land temperature anomalies from January to December for the years 1910-2020. In Asia, around 1910 to 1976 (66 years), the majority of those years were to record the negative land temperature anomaly. However, there were still some years that showed warmer than normal conditions (positive anomaly). The hot years were 1914, 1925, 1932, 1938 to 1939, 1943 to 1944, 1948, 1951, 1953, 1959, 1961 to 1963, 1967, 1971,

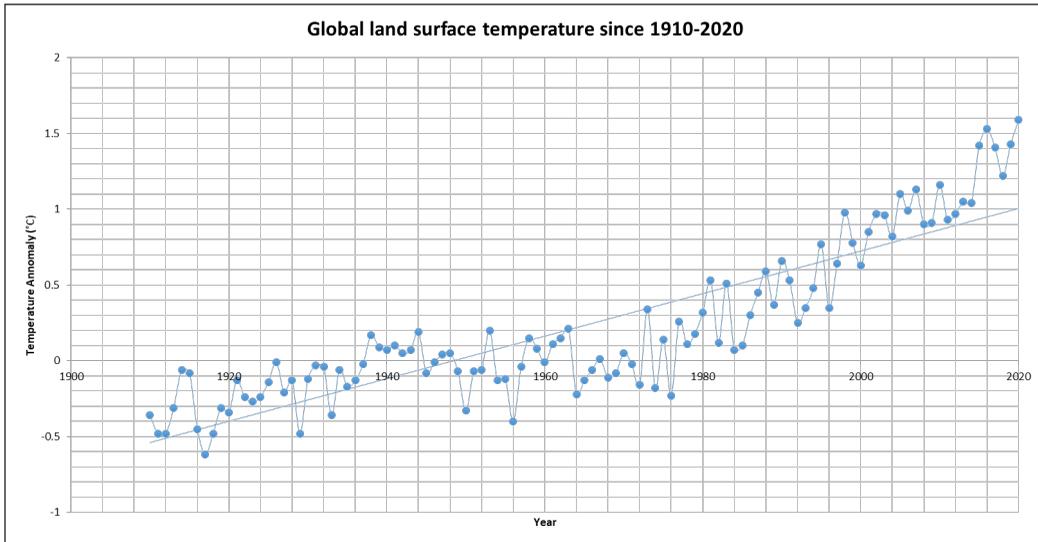


Figure 1. Global land surface temperature anomalies from 1910 to 2020

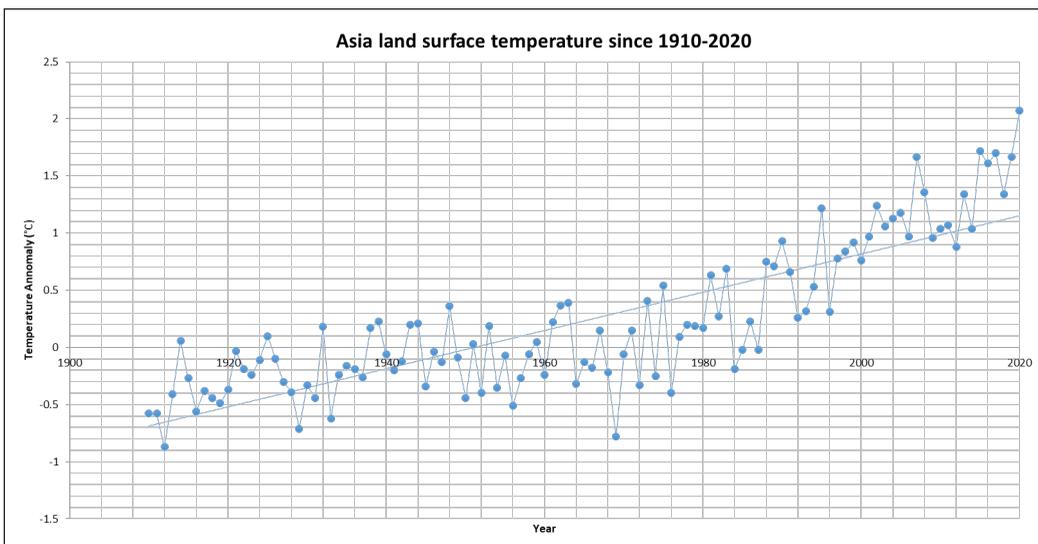


Figure 2. Asia's land surface temperature anomalies from 1910 to 2020

1973 and 1975. Later in the year, 1977 to 1983 also showed positive anomalies before the next two years recorded negative anomalies in 1984 to 1985. From 1988 to 2020, all these years recorded a positive anomaly which means that the land surface temperature in Asia is warming up in the 20s. It can be concluded here that there has been climate change in Asia when there was an increase in land temperature anomaly from -0.58°C (cold) in 1910 to 2.07°C (hot) in 2020. Land temperature anomaly in 2020 is quite high if compared to previous years because it has exceeded 2°C .

THE CATASTROPHE OF CLIMATE CHANGE ON MIGRATORY BIRDS- THE EVIDENCE

For decades, researchers have studied the impact of daily weather variations on the number of birds that have avoided migration. During the 1960s and 1970s, when some radar and visual experiments on migration were performed, the research was particularly active (Richardson, 1990). Rising temperatures are the most significant factor affecting bird migration trends, forcing birds to migrate a little early each spring and change the return journey by less than two days per decade (Richardson, 1990; Horton et al., 2020). As a result, migratory species may need to adapt their seasonal and annual migration patterns to avoid entering areas with extreme climates such as too cold, too hot, too low humidity, too high humidity, and to use new habitats in areas with previously low temperatures and humidity. In response, the distribution of species may vary (Langham et al., 2015). For example, it has been found that large bustard migration patterns of males (but not females) are closely related to extreme temperatures during the summer breeding season (Alonso et al., 2009).

In addition to forcing birds to migrate a little earlier, changes in temperature associated with climate change are expected to result in a reduction in body size, a primary determinant of animal physiology and ecology (Weeks et al., 2019). Thus, climate change, regarded as one of the most serious threats to biodiversity and ecosystems, may impact migratory bird distribution and survival (Liang et al., 2018). Additionally, a number of additional studies have forecasted changes in species richness or distribution in China as a result of climate change scenarios (Hu et al., 2017; Liang et al., 2018). It may also be concluded that animals have evolved to withstand extreme temperatures, and climate change has had a significant effect on species physiology, including increases in exposure to elevated temperatures, differences in sex ratios in species with temperature-dependent sex, and increased metabolic costs associated with living in a warmer environment (Scheffers et al., 2016).

However, trying to forecast which components of climate have the most influence on species distribution is one of the issues confronted by ecologists and conservation biologists (Bateman et al., 2015). Furthermore, the potential consequences of climate change on bird distribution have been explored extensively today, such as polar or short-range winter breeding distances by La Sorte et al. (2017) and Wauchope et al. (2017). The influence of climate change on food sources and the habitat of migratory bird species has been highlighted as one of the most critical components in migratory bird research (Walther et al., 2002). It is proven that the consequences of recent climate change have been discovered to affect migratory bird migration patterns (Both et al., 2006; Harris et al., 2013). According to Harris et al. (2013), climate change causes a shift in migration time for some birds in Southeast Asia. The reason for this delay of long-distance migrants is that warmer temperatures allow species to stay in northern breeding sites longer. Delayed arrivals in winter places may have a tiering influence on migratory species' yearly cycles,

such as changing the arrival date in breeding places, which can influence fitness. Harries et al. (2013) discovered a 1 to 3 days arrival delay in the Japanese sparrowhawk *Accipiter gularis* and the sandpiper curlew *Calidris ferruginea*, but no change in the arrival date for the other species.

As a result, the timing of bird migration has served as a useful framework for researching how natural processes react to climate change (Hurlbert & Liang, 2012; Jonzen, 2006). It was discovered that animals arriving late in the migration phase might have difficulty developing breeding areas or finding compatible partners (Møller, 2001; Pulido, 2007; Faaborg et al., 2010). According to a number of surveys have been done by Hughes (2000), McCarty (2001), Ottersen et al. (2001), and Wuethrich (2000), the current climate change has affected a diverse range of animals with geographically distributed regional ranges. Pacifici et al. (2017) showed that climate change has already impacted a significant number of endangered species populations by modelling the interaction between observed and inherent responses and spatial properties. Climate change could have harmed at least 47% of non-terrestrial endangered mammals (873 species) and 23.4% of endangered birds (1,272 species) in at least part of their range, according to the study's findings (Pacifici et al., 2017).

According to atmospheric conditions in the 21st century, the ideal migration site between Japan and China occurred in the East China Sea (2006-2013) (Figure 3) (Nourani et al., 2017). According to their findings, the expected changes in atmospheric conditions

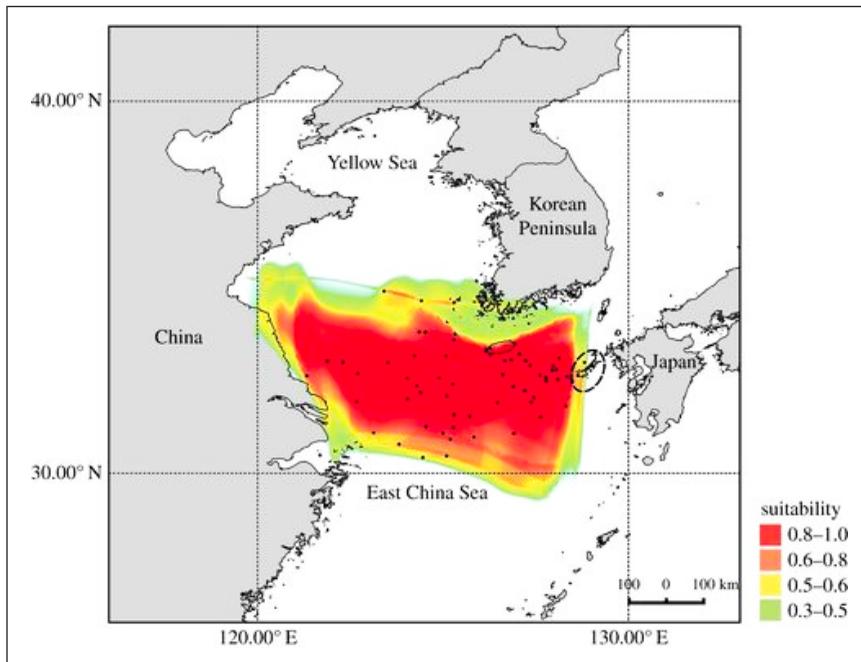


Figure 3. Ensemble model projections for suitable atmospheric conditions for the fall migration of Oriental honeybuzzards (2006–2013) (Nourani et al., 2017)

caused by climate change may have a negative impact on the suitability of traditional bird migration routes. Under the RCP4.5 scenario, suitable areas will move northward in the middle of this century. Highly suitable areas' scope and connectivity will suffer greater loss (Figures 4a & 4b), resulting in more severe conditions. However, by the turn of the century, the model identified a suitable area in the eastern part of the Korean Peninsula under RCP4.5 (Figure 4c) and a moderately small area under RCP8.5 (Figure 4d). Both deviate from the traditional route and cannot provide a complete route from Japan to China. Thus, it can be said that climate change has changed the best wind-dependent flight routes for bird migration.

Warren et al. (2013) undertook a global study of potential climate range transitions from common and prevalent species. They found that, there would be $57 \pm 6\%$ of plants without mitigation, and $34 \pm 7\%$ of animals would lose 50% of their climate range by the 2080s. However, if emissions plateau in 2016, losses are reduced by 60%, and if emissions peak

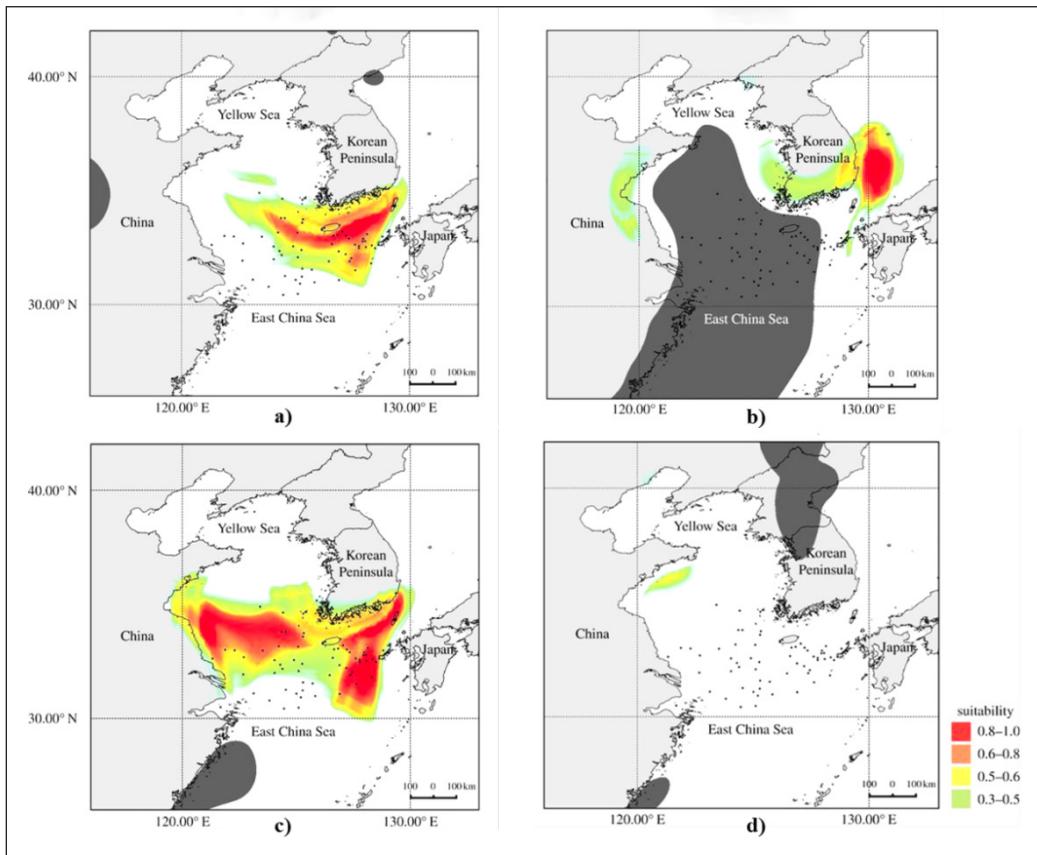


Figure 4. Ensemble model projections for suitable atmospheric conditions for the fall migration of Oriental honeybuzzards: (a) mid-century (2046 to 2055; RCP4.5 scenario), (b) mid-century (2046 to 2055; RCP8.5 scenario), (c) late century (2091 to 2100; RCP4.5 scenario), and (d) late century (2091 to 2100; RCP8.5 scenario) (Nourani et al., 2017)

in 2030, losses are reduced by 40%. With the influence of rising temperatures on animal species due to climate change, it can be projected that migratory birds are also likely to suffer the same fate or even worse. Because migratory birds are not a species in the areas they visit, they will face problems adapting to places other than their area of origin. Thus, it can be argued that migratory birds found in Asia may need help adapting to climate change to survive or live in an area. Table 1 shows the impact of climate change on different animal species that have occurred. Other animals such as turtles, whales, sharks, dolphins, and avian species are also affected by this climate change. Each animal was found to be affected by different climatic factors (Table 1).

Table 1
Climate change's effect on certain animal species (Trouwborst, 2012)

Climate Impact	Impact on Animal Species	Animal Species
Temperatures are rising	a) Melting sea ice has resulted in habitat destruction;	a) <i>Balaena Mysticetus</i>
	b) Zooplankton density has changed; and	b) <i>Cetorhinus Maximus</i>
	c) Sex ratios have changed.	c) <i>Dermodochelys Coriacea</i>
Changes in Precipitation	a) Wetland habitat for breeding and feeding is vanishing;	a) <i>Calidris Canutus Rufa</i>
	b) Grazing habitat for terrestrial mammals is vanishing; and	b) <i>Addax Nasomaculatus</i>
	c) Rainfall changes affect breeding performance.	c) <i>Gavialis Gangeticus</i>
Weather Extremes	a) Extremes of temperature;	a) <i>Platanista Gangetica</i>
	b) Storm frequency and severity have increased; and	b) <i>Tadarida Brasiliensis</i>
	c) Precipitation extremes have increased.	c) <i>Trichechus Senegalensis</i>
Increasing Sea Levels	a) The loss of low-lying marine habitat; and	a) <i>Anser Cygnoides</i>
	b) The disappearance of nesting areas.	b) <i>Chelonia Mydas</i>
Acidification of the Oceans	a) Food web affected; and	a) <i>Eubalaena Japonica</i>
	b) Habitat degradation.	b) <i>Eretmochelys Imbricata</i>
Ocean Circulation Changes	a) Shifts in food distribution and abundance; and	a) <i>M e g a p t e r a Novaeangliae</i>
	b) Migration-related impact.	b) Hawksbill Turtle
Spatial and Temporal Responses	a) Biome shifts;	a) <i>Puffinus Mauretanicus</i>
	b) Phenological shifts; and	b) <i>Caretta Caretta</i>
	c) Destruction of habitat.	c) <i>Grus Leucogeranus</i>
Existing Threats are Getting Worse	-	a) <i>Acrocephalus Griseldis</i>

The highest number of endangered migratory bird species has been identified in many locations. For example, the East Asia-Australasia Region has the highest percentage of endangered migratory waterbirds, which is 20%. Although Africa, Eurasia, Central Asia, and East Asia-Australasia have the highest percentage of endangered birds (roughly 30% each), America, Africa, Eurasia, and East Asia-Australasia have the highest percentage of endangered seabirds (roughly 30% each). The East Asia-Australasia flyway has the highest

number of endangered migratory waterbirds (19%) when it comes to flyways. Though the Black Sea-Mediterranean, East Asia-East Africa, Central Asia, and East Asia-Australasia have the highest percentages of vulnerable soaring birds (between 24 and 34%), the Black Sea-Mediterranean, East Asia-East Africa, Central Asia, and East Asia-Australasia have the lowest (Galbraith et al., 2014). Globally, 317 (14%) migratory bird species are classified as endangered or near-threatened. According to the 2010 IUCN Red List, there are 17 critically endangered migratory bird species, 50 threatened migratory bird species, vulnerable migratory bird species, and near-threatened migratory bird species out of 317 migratory bird species (122). According to an overview of the number of species moving between Red List categories since 1988, 53 species have decreased in status, and only nine have improved (Galbraith et al., 2014).

Then, Hu et al. (2010) found that the black-faced spoonbill (*Platalea minor*) is an endangered migratory species confined to East Asia due to climate change. They also predicted that by 2080, the population of black-faced spoonbills in various regions in Asia, including northeastern Vietnam, Taiwan, and coastal areas around the South China Sea, might be drastically reduced. They also indicated that the centre of the expected spoonbill range will migrate northwards by as much as 240 km by 2020, 450 km by 2050, and 600 km by (2080). Finally, Liang et al. (2018) utilised species distribution models (SDM) and climate data to forecast future changes in migratory birds species distribution and how the geographical expansion of these endangered birds may adapt to changing climates by 2050 under current and future climate scenarios in China. The findings suggest that migratory bird hotspots would likely remain downstream and in the centre of China's Yangtze River. At the same time, more species will likely dwell in the coastal areas of Bohai Bay and the Yellow Sea in the future. Also, according to the findings, the proportion of all migratory bird species distribution or hotspots for all endangered migratory bird species protected by national nature reserves (NNRs) in China is still low in 2050.

Besides that, Runge et al. (2015) found that only a small fraction of migratory birds receive appropriate protection across their breeding and wintering ranges throughout the world. Given that over half of the world's migratory bird populations are dropping, these findings, according to them, highlight the urgency with which we must work to protect migratory birds during their entire migratory cycle. According to the study, only 9% of 1451 migratory birds are sufficiently protected by sheltered locations at all phases of their yearly cycle, compared to 45% of non-migratory species (Runge et al., 2015). The long-distance migrating birds, which rely on an endogenous circannual rhythm to trigger their migration, face unique hurdles in reacting to changes due to their extensive seasonal movements (Briedis et al., 2017).

Climate change has been shown to alter morphology in butterflies, dragonflies, and birds, which results in colour changes (Karell et al., 2011; Kingsolver & Buckley, 2015; Roulin, 2014; Zeuss et al., 2014). In addition, climate change can influence the timing of

migratory species' arrival on breeding grounds or the initiation of breeding activities, as well as the availability of resources required for successful reproduction (Burgess et al., 2018; Franks et al., 2017; Møller et al., 2008; Mayor et al., 2017). When all of those phenological incompatibilities exist, it may result in lower reproductive success and population decline (Møller et al., 2008; Miller-Rushing et al., 2010; Dunn & Møller, 2013). However, Mayor et al. (2017) suggest that migratory birds could be among the species most readily suited to climate change because of their ability to migrate fast over long distances. Again, Mayor et al. (2017) argue that migration responds to annual climate change, so additional annual climate change is unlikely to pose a challenge in terms of adaptation.

Perhaps climate change might not be the only factor affecting these migratory birds; human actions such as economic activities also play a role in migratory bird species disruption. For example, considering China as a case study, which is a country with fast-rising economic activity, it has a significant impact on migratory bird stopover habitat (Ma et al., 2014; Kamp et al., 2015), resulting in dropping migratory bird populations (Runge et al., 2015). However, generally speaking, that economic activities are happening in China, and other countries in the world may also be among those contributing to climate change. Therefore, it suggests that indirectly the economic activities that have contributed to climate change will likely also contribute to the disruption of the stopover of migratory birds, their food and so on. The situation may worsen when the area that should be used as a stopover has lost the characteristics and to needs these migratory birds need while living in the areas even if only for a while.

According to Kamp et al. (2015), persecution and over-exploitation by humans are also one of the major causes of species extinction. Between 1980 and 2013, the Yellow-breasted Buntings (*Emberiza aureola*) population dropped by 84.3% to 94.7%, and the species' range shrank by 5000 kilometres. Quantitative data gathered during police raids revealed that the species was illegally trapped along its East Asian flyway in China. As the consumption of Yellow-breasted Bunting and other songbirds has grown, it is once again suggested that causes of economic development and prosperity in East Asia are the reason for the decline (Kamp et al., 2015). It has been proven that climate change is not the only cause of the current disturbance and reduction in the population of migratory bird species; other causes may also be at play.

The Condition of Asia Migratory Bird Affected by Climate Change and Severe Weather- Birdlife Data Zone and IUCN Lists

The latest data from the Birdlife Data Zone shows that approximately 169 migratory birds in Asia are affected by climate change and severe weather. Of the total, five species (2.96%) of migratory birds occupy the critically endangered category in the Global IUCN Red List, namely Siberian Crane (*Leucogeranus leucogeranus*) from the family Gruidae (Cranes), Christmas Frigatebird (*Fregata andrewsi*) from the family Fregatidae (Frigatebirds),

Sociable Lapwing (*Vanellus gregarius*) from the family Charadriidae (Plovers), Spoon-billed Sandpiper (*Calidris pygmaea*) from the family Scolopacidae (Sandpipers, Snipes, Phalaropes) and Chinese Crested Tern (*Thalasseus bernsteini*) from the family Laridae (Gulls, Terns, Skimmers). In addition, there are eight species (4.73%) in the endangered category, such as White-headed Duck, Lesser Frigatebird, Barau's Petrel, Abbott's Booby, Great Knot, Far Eastern Curlew, Rufous-headed Robin and Pallas's Fish-eagle. While there are 21 species (12.43%) that fall in the vulnerable category, 27 species (15.98%) are near threatened, and 123 species (63.91%) are in the least concerned category (BirdLife International, 2021).

Critically Endangered Species. Referring to Table 2, the Siberian Crane or Siberian White Crane or Snow Crane (*Grus leucogeranus*) is one of the critically endangered migratory species. According to the IUCN Red List, the Siberian Crane was classified as threatened in 1988, endangered in 1994 and 1996, and critically endangered from 2000 to 2018 (BirdLife International, 2021). According to research by Ming-Qin & Hong (2014), low water levels in spring and early summer in Lake Poyang have reduced food availability for many water birds that have migrated to the area in recent years. They also discovered that the Siberian Cranes' distribution pattern was impacted by a lack of food availability that could feed all of the cranes in Banghu. Meanwhile, the Siberian Crane's departure time from Lake Poyang was reported as being slower, which might be attributed to a delay in the winter season as a result of climate change. Therefore, it is essential to study and focus on this species in the Poyang lake area, where more than 98% of their population overwinters in the lake.

Table 2

Asia migratory birds affected by climate change and severe weather (BirdLife International, 2021)

Species	Global (IUCN) status
<i>Leucogeranus leucogeranus</i>	Critically Endangered
<i>Fregata andrewsi</i>	Critically Endangered
<i>Vanellus gregarius</i>	Critically Endangered
<i>Calidris pygmaea</i>	Critically Endangered
<i>Thalasseus bernsteini</i>	Critically Endangered
<i>Oxyura leucocephala</i>	Endangered
<i>Sypheotides indicus</i>	Endangered
<i>Pterodroma barau</i>	Endangered
<i>Papasula abbotti</i>	Endangered
<i>Numenius madagascariensis</i>	Endangered
<i>Calidris tenuirostris</i>	Endangered
<i>Haliaeetus leucorhynchus</i>	Endangered
<i>Larvivora ruficeps</i>	Endangered

It has been proven that the Poyang lake area is the most important wintering ground for the globally critically endangered Siberian crane (Chen et al., 2016). In 2011–2012, the total population of Siberian Cranes in the Poyang Lake basin was projected to be 3,500–4,000 individuals. In December 2011, there were 4577 Siberian Cranes (*Grus leucogeranus*), 302 Hooded Cranes (*Grus monacha*), 885 White-naped Cranes (*Grus vipio*), and 8408 Eurasian Cranes (*G. grus*). In February 2012, there were 3335 Siberian Cranes, 110 (Hooded Cranes), 283 (White-naped Cranes), and 2205 (Eurasian Cranes). Thus, the number of Siberian Cranes counted had fallen by 1242 in February 2012. Similarly, Hooded Cranes declined by 192, White-naped Cranes (602) and Eurasian Cranes (6203) (Li et al., 2012).

The effective population size for Christmas Island frigatebirds (*Fregata andrewsi*) is around 5,000 (Morris-Pocock et al., 2012), and this species is listed as Critically Endangered by the IUCN (Birdlife International, 2021). For a long time, the status of the Christmas Island Frigatebird in India was unclear until Praveen et al. (2013) discovered few previous reports of Great or Lesser Frigatebird misidentification. It indicates a flaw in earlier researchers' documentation, which resulted in a paucity of data for this bird species. The first record of Christmas Island Frigatebird *Fregata Andrewsi* in Timor was in 1986, which was found flying along the coast near Kupang, Timor (McKean, 2011). *Fregata andrewsi* has also been discovered in southern New Guinea (Simpson, 1990). In July 2012, there were 209 individuals of this species in Indonesia. In contrast, in May 2013, 113 individuals of this species were discovered using the Jakarta Bay to obtain food, relax in Sero, and Pulau Rambut at night (Tirtaningtyas & Jordan, 2017). McMaster et al. (2015) in 2014 found an adult female Christmas Frigatebird and an unconfirmed juvenile Christmas Frigatebird in the Nightcliff foreshore, Darwin, Australia.

Several anthropogenic threats to Christmas Island Frigatebirds have been identified in Jakarta Bay, Indonesia, including the unintentional involvement of fishing gear, as well as capture, poisoning, and shooting (Tirtaningtyas & Hennicke, 2015). It has also been revealed that climate change can impact the population of this species, with severe storms likely to cause fatality in juveniles and adults (Hill et al., 2004). The situation is anticipated to deteriorate if severe storms become more common as a result of climate change (Harley et al., 2006). This catastrophic storm occurrence will almost certainly increase storm-related fatalities of this species. In addition, higher sea surface temperatures linked with climate change have been shown to impact marine productivity (Harley et al., 2006), which is thought to affect food availability for Christmas Island frigatebirds.

According to Watson et al. (2006), the *Sociable Lapwing Vanellus gregarius* is a critically endangered species likely to experience a decline in its total population, i.e. from 5000 pairs to 500 pairs, within 11 years. The decline of this species is likely due to climatic and societal changes that cause nesting habitat for the *Sociable Lapwing Vanellus gregarius* to be more extensively grazed (Shevchenko, 1998). In 1988 this species was

listed as threatened, vulnerable from 1994 to 2000, and critically endangered from 2004 to 2018 (BirdLife International, 2021). The number of nests of *Sociable Lapwing Vanellus gregarius* discovered in the 14 core colonies of the Korgalzhyn region, in the other colonies of the Korgalzhyn region, and in the other colonies of the Pavlodar region increased from 2005 to 2007, but then declined from 2008 to 2012. The 330 *Sociable Lapwing Vanellus gregarius* nests discovered in 2007 were reduced to 137 in 2008, 122 in 2009, 131 in 2010, 105 in 2011, and 44 in 2012 (Sheldon et al., 2012). Watson et al. (2006) expressed worry about the increasingly dry climate in breeding and wintering ranges, which might endanger semi-desert species. The drier climate in its breeding and wintering areas may influence this species, although it is uncertain whether this benefits or harms this semi-desert species (Watson et al., 2006). So, additional research on the link between climate, breeding size, and population size for this species is required. However, contrary to the findings of Jayendra et al. (2014), low rainfall attracts more birds to winter in Gujarat.

Since 1977 and 2000, the breeding population of the critically endangered Spoon-billed Sandpiper *Calidris pygmaeus* has declined dramatically (Tomkovich et al., 2002). The decrease has indeed continued, with the rate of decline estimated to be 25% per year (Zöckler et al., 2010a; Zöckler et al., 2010b). This species has declined rapidly throughout the winter range from 2005 to 2013 with current estimates putting the breeding population at less than 120 pairs (242 to 378 individuals) (Zöckler et al., 2016). At the same time, Clark et al. (2018) estimated the spoon-billed sandpiper breeding population in 2014 to be 210 to 288 pairs, with a total post-breeding population of 661 to 718 individuals. Waterbird surveys in early 2018 yielded no Spoon-billed Sandpiper sightings throughout a 243.8 kilometre stretch of coast in North Sumatra Province, from Langkat District to Asahan District (Putra & Hikmatullah, 2018). Meanwhile, one Spoon-billed Sandpiper was discovered at the end of 2018 (2-4 November) in Seunodon Sub-district, North Aceh District, Aceh Province, Sumatra, Indonesia. It demonstrates that the Spoon-billed Sandpiper is highly endangered and has lacked protection status in Indonesia (Putra et al., 2019). The spoon-billed sandpiper population in China has declined from 2,000 to 2,800 breeding pairs in the 1970s to around 220 in 2010 (Yang et al., 2017). In 1988 this species was listed as threatened, vulnerable from 1994 to 2000, endangered in 2004 and critically endangered from 2008 to 2018 (BirdLife International, 2021). Climate change in their breeding locations has produced soil moisture and vegetation changes in breeding grounds (Tomkovich et al., 2002; Zöckler et al., 2003). This species' population is declining due to hunting and loss of appropriate habitat in trail and winter locations, as well as disturbance, pollution, and the impacts of climate change (Clark et al., 2018; Syroechkovskiy et al., 2010; Tomkovich et al., 2002; Zöckler et al., 2016).

The Chinese Crested Tern *Thalasseus bernsteini* has less than 50 individuals (Chen et al., 2015) and is the most critically endangered seabird species in Asia (Hung et al.,

2018). This species is not just one of Asia's most endangered species, but it is also one of the world's most endangered seabird species, with only a small breeding population of approximately 100 individuals (Gu et al., 2021; Lu et al., 2020). In their study, Lu et al. (2020) discovered a worldwide population of this species that exceeded 100 for the first time in history, with breeding grounds restricted to East China and the Yellow Seas. In 1988 this species was listed as threatened and critically endangered from 1994 to 2018 (BirdLife International, 2021). It is unclear which causes, such as habitat loss, overexploitation, marine pollution, egg harvesting, climate change, restricted biological niches, or even inherent rarity, are causing the reduction in the population of Chinese Crested Tern species (Brook et al., 2008; Chen et al., 2009; Davies et al., 2004; Liu et al., 2009). Another major factor that may contribute to the near extinction of the endangered Chinese Crested Tern is poachers in the market selling seagull eggs and terns during the breeding season (Chen et al., 2015). Additionally, natural calamities pose a threat to the population of this species since summer hurricanes in coastal areas frequently cause Chinese Crested Tern breeding failure (Chen et al., 2015).

Endangered Species. In 1988, White-headed Duck (*Oxyura leucocephala*) was listed as threatened, Vulnerable in 1994 & 1996, and endangered from 2000 to 2017 (BirdLife International, 2021). At the turn of the 21st century, the global population of the White-headed Duck was estimated to be approximately 8,000 to 13,000 individuals (Li et al., 2003). In 2016, more than 20 000 individuals were recorded, while in 2017, around 7500 individuals (Koshkina et al., 2019). In Turkey, the breeding population of the White-headed Duck was estimated to be 200 to 250 pairs from 1996 to 2001, but current observations suggest that the number of such species presently does not surpass 80 to 125 pairs, representing a 50% drop in two decades. Meanwhile, the non-breeding winter population ranges from 8,500 to 10,000 individuals, with Burdur Lake once housing more than 90% of the population but no longer serving as a prominent resting site. From more than 10,000 birds in the early 1990s to a few hundred in the early 2000s, this number began to fall (Gürsoy-Ergen, 2019). In addition, climate change has caused the wetlands that once housed White-headed Ducks to dry up in 2018 and 2019. White-headed Ducks, for example, are among the species most impacted when wetlands in Çavuşlu ponds or parts of Lake Mogan, Turkey, begin to dry up early as a result of climate change (Özgençil & Uslu, 2021).

For at least 50 to 60 years, Lesser Florican *Sypheotides indicus* has been declining. From 1982 to 1989, its population declined by approximately 60%, but by 1994, it had recovered by 32% to 2,206 individuals (Kasambe & Gahale, 2010). Raghavendra (2011) found the first record of the Lesser Florican *Sypheotides indicus* female at dry Lake Bed, Hesarghatta, Bangalore in 2011; and this species is an endangered endemic group in the Indian subcontinent. India is said to have 90% of the world's population of the Lesser

Florican and therefore plays an important role in its protection and conservation (Sankaran et al., 1992). Dutta et al. (2018) stated that threats to this species include the presence of unpredictable and changing rainfall patterns as a result of climate change. Perhaps the consequences of climate change are unproven but probable to happen in the future. The evidence in Dutta et al. (2018) indicates that the lesser florican will become extinct in the world within the next 20 years, and conservation is needed to protect this species. Apte et al. (2020) also argue that the impacts of climate change, particularly erratic rainfall, pose an indirect risk to this species. This Lesser Florican is a monsoon breeder. It changes its breeding sites depending on the monsoon conditions, making conservation challenging. Climate changes and unpredictable rainfall in several areas of its distribution range have resulted in its extinction, or irregular presence in typically frequented sites.

Barau's petrel (*Pterodroma barau*) is an endangered tropical seabird (Pinet et al., 2011). The Barau's petrel is an endemic species on Reunion Island that has been listed as endangered by IUCN since 2008, and its population is believed to be declining (Dufour et al., 2016). According to Pinet et al. (2009), the extinction of the Barau petrel happened in less than 100 years owing to the unavailability of cat predation control in this species' temporary breeding colonies. Meanwhile, Le Corre et al. (2002) reported that metropolitan illumination has resulted in large and seasonal light-induced mortality of Barau's petrel fledglings. According to Le Corre et al. (2002), projections concerning population decrease were erroneous due to a lack of precise data on this species' life history. One study shows, because the Petrel Barau species is endemic and strongly philopathic the existing Petrel Barau winter habitat may become less suitable in the future (Pinet et al., 2009). According to Legrand et al. (2016), a large number of Barau petals may have difficulties altering their migratory routes and tactics in a fast-changing world (including climate change). Furthermore, most Intergovernmental Panel on Climate Change (IPCC) models predict that appropriate habitat size will be reduced by the end of the twenty-first century.

Then, the winter area's carrying capacity is diminished, which might lead to increased intra and inter-specific competition for prey. Legrand et al. (2016) undertook one of the first studies to utilise current detection data and habitat modelling to anticipate the long-term impacts of climate change on seabirds (Petrel Barau). Figure 5a depicts how climate change scenarios RCP 2.6, RCP 4.5, and RCP 8.5 forecast a 33%, 19%, and 5% decline in suitable habitat size, respectively. Figure 5b depicts all of the scenarios indicating the westward shift, including RCP 2.6 (5°), RCP 4.5 (7°), RCP 6.0 (11°), and RCP 8.5 (9°). Meanwhile, RCP 4.5, RCP 6.0, and RCP 8.5 forecast a 3°, 5°, and 7° southerly shift, respectively (Figure 5c). Based on the graph in Figure 5c, the most optimistic climatic scenario is (RCP 2.6), which anticipated a 2° northward shift until 2020, followed by stagnation until 2100. Based on this data, Legrand et al. (2016) determined that suitable habitats are expected to decline and move westward and southward by the end of the twenty-first century.

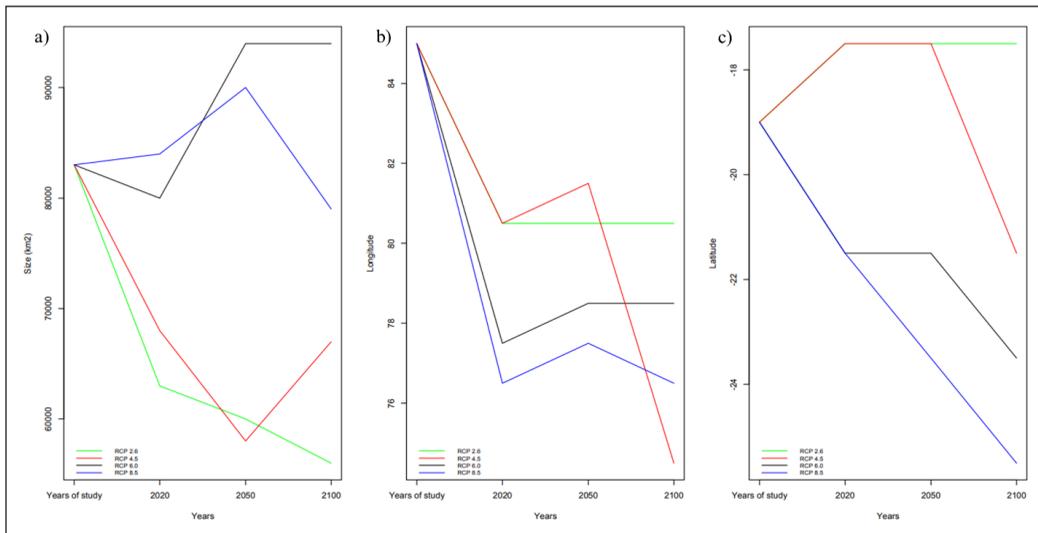


Figure 5. The evolution through time of (a) the size, (b) longitude, and (c) latitude of suitable wintering areas for Barau's petrels under climate change scenarios; Representative Concentration Pathway (RCP 2.6, RCP 4.5, RCP 6.0, RCP 8.5) (Legrand et al., 2016)

Records suggest that between 1970 and 1983, at least 400 couples of Abbott's Booby vanished from the reproductive population (Yorkston & Green, 1997). In 1988 this species was listed as threatened, Vulnerable in 1994 & 1996, critically endangered in 2000 and 2004. Then this species came back out of the critical situation from critically endangered to endangered from 2005 to 2019 (BirdLife International, 2021). Christmas Island was the only breeding colony location of Abbott's Booby until 1991, with an estimated population of 2,500 pairs (Yorkston & Green, 1997). Now, the effective population size for Abbott's Booby is likewise approximately 2,100 individuals on Christmas Island (Morris-Pocock et al., 2012). Rising sea surface temperatures (due to anthropogenic greenhouse gas emissions), stochastic events (storms and hurricanes), and global warming are all potential threats to Abbott's booby (Department of the Environment and Heritage, 2004). This situation likely will cause declination in the population. In addition, climate change, especially rising sea surface temperatures, has reduced marine productivity in Abbott's Boobies foraging near Christmas Island. As a result, it may be claimed that climate change is already impacting the seabird food chain in the Christmas Frigatebird nesting region (Hennicke & Weimerskirch, 2014).

In 1988, the Far Eastern Curlew (*Numenius madagascariensis*) was listed as lower risk/least concern, lower risk/near threatened in 1994 & 2000, least concern in 2004 to 2009, vulnerable in 2010 & 2012 and endangered in 2015 & 2016 (BirdLife International, 2021). In 1992 and 2008, the Far Eastern Curlew was reported to decline steadily in Australia, at 2.4% each year in Moreton Bay (Wilson et al., 2011). Meanwhile, in Tasmania since

the 1950s, this species has declined by more than 65% (Reid & Park, 2003). Hunting, pollution, changes in water regimes, disturbances, and the influence of climate change on breeding sites all pose threats to the species (Harding et al., 2007). In Australia, the species was recently classified as endangered under Australian Government law because of its ongoing population reduction due to its breeding grounds. Decreases in the species have been documented from almost every place monitored along the Australian coast, and local extinction is projected in certain areas over the next thirty years (Lilleyman et al., 2016).

Nearly 425,000 Great Knot individuals are currently known to exist (Hansen et al., 2016). However, the research done by Rogers et al. (2006) and Clemens et al. (2016) revealed that the species' total population in Australia has declined since it was found that this species may have had a greater total population a few decades ago. The same total population loss of 1.8% each year was seen across the continent (Clemens et al., 2016). Since 2015 and 2016, this species has been categorised by the IUCN as an endangered species (Bird Life International, 2021). According to Piersma et al. (2016), survival during the migration and breeding seasons of red knot *Calidris canutus piersmai*, great knot *Calidris tenuirostris*, and bar-tailed godwit *Limosa lapponica menzbieri* began to fall in 2011. According to them, the three species will suffer an annual loss of 20%. By 2012, actual survival for the bar-tailed godwit was as low as 0.71, 0.68 for the great knot, and 0.67 for the red knot. According to Clemens et al. (2016), the reduction in migratory shorebird populations (including the Great Knot) along the East Asian – Australasian Flyway (EAAF) was most probably triggered by factors outside of Australia. There is also has a strong relationship between the decrease bird species that use wetlands on the land continent and unsuitable water levels, a hazard that tends to rise with climate change (Finlayson, 2013).

In 1988 Pallas's Fish Eagle (*Haliaeetus leucoryphus*) was listed as threatened, Vulnerable in 1994 to 2016, and critically endangered from 2017 and 2018 (BirdLife International, 2021). In addition, several migratory bird species and subspecies have been identified as endangered in China, including Long-Tailed Duck (*Clangula hyemalis*), Black-Winged Kite (*Elanus caeruleus vociferus*), Pallas's Fish Eagle (*Haliaeetus leucoryphus*), Himalayan Griffon (*Gyps himalayensis*), Demoiselle Crane (*Anthropoides virgo*), White-Breasted Waterhen (*Amaurornis phoenicurus phoenicurus*), Eurasian Collared Dove (*Streptopelia decaocto decaocto*, *Streptopelia decaocto xanthocyclus*), Chestnut-Winged Cuckoo (*Clamator coromandus*), Barn Owl (*Tyto alba javanica*, *Tyto alba stertens*), and Light-Vented Bulbul (*Pycnonotus sinensis sinensis*, *Pycnonotus sinensis formosae*, *Pycnonotus sinensis hainanus*) (Wu & Shi, 2016). According to them, the species or subspecies is categorised as endangered as a consequence of climate change, as evidenced by changes in the distribution centre's latitude and longitude, as well as the southern, northwestern, and eastern boundaries of migrating birds (Wu & Shi, 2016). Pallas's Fish Eagle populations also reported decreased in Bangladesh, and it is now seldom seen outside of the haors (Sourav et al., 2011).

While field surveys conducted between 2013 and 2016, as well as data from earlier observers in Rajiv Gandhi Orang National Park, India, suggest that Pallas's Fish-eagle is one of the five endangered species (Chakdar et al., 2019). Comprehensive research was conducted in the Bundelkhand region of India between 2006 and 2010. *Haliaeetus leucoryphus*, *Ichthyophaga ichthyaetus*, *Aquila helica*, *Ictinaetus malayensis*, and *Aquila chrysaetos* were determined as migratory species to be the rarest in Panna National Park (Gupta & Kanaujia, 2012). Based on a study done by Gupta and Kanaujia (2012), climatic conditions are one of the greatest risks to eagles in the Bundelkhand Province. Extreme temperatures define the Bundelkhand area, with temperatures ranging from mid to over 40°C in the summer and as low as 1°C in the winter. As a result, there are documented deaths over the summer. It was also discovered that *Haliaeetus leucoryphus* in Mongolia is small, and there is evidence of decreasing occupancy. The fall in the population of these species might also be attributed to a long-term decline in accessible surface water, which has resulted in lower water levels in many lakes and the drying up of several major rivers drains for *Haliaeetus leucoryphus* in Mongolia (Sternberg, 2008; Sukh, 2011). Long-term climate models suggest that this trend will likely continue, potentially leading to habitat loss for this species in the future (Simonov & Dahmer, 2008).

The Rufous-headed Robin *Larvivora ruficeps* is one of the world's rarest and least-studied birds. For the first time in many years, no singing males of *Larvivora ruficeps* were recorded at Jiuzhaigou, China, in 2016 (Zhao et al., 2016). Rufous-headed Robin *Luscinia ruficeps* is only known to breed in the Min Shan region of northern Sichuan province and the Qinling Shan range in southern Shaanxi province of China but has not been observed in the latter since 1905. On November 16, 2012, a brown-coloured *Luscinia* was discovered in an urban garden in central Phnom Penh, Cambodia, the second record outside its breeding range (Mahood et al., 2013). There is very little information on this species' population, although it is likely to exist at very high densities in suitable habitats; nevertheless, a dearth of records implies that it may be relatively limited in distribution and may have a tiny population (Mackinnon, 2001). However, this species was classified as endangered on the IUCN list in 2013 and 2016 and as a migratory bird threatened by climate change (BirdLife International, 2021) No research has been conducted to demonstrate a link between these species and climate change effects. It is most likely owing to the scarcity of data on the population and existence of this species.

CONCLUSION

Migratory birds are particularly vulnerable to environmental changes such as climate change because they are susceptible to ongoing changes that may be adversely correlated. Conservation measures for maintaining the survival of migratory bird populations are crucial as they are key to good ecosystem health (Bauer & Hoye, 2014). Relevant parties

and world leaders need to be more sensitive to climate change that has disrupted the lives of these migratory birds to ensure that they do not become extinct. Based on the literature review results, researchers can conclude that migratory birds are currently stressed by environmental changes, especially climate change that has changed the temperature of the earth's surface. Therefore, it is important to understand how these migratory bird species adapt to ongoing climate change and its impact on the bird itself.

ACKNOWLEDGEMENT

This research was financed by Short Term Grant (USM) and got cooperation from the Department of Wildlife and National Parks Peninsular Malaysia regarding information and data needed.

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