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# Climate change and its implications on migratory bird species in Rajasthan's arid zones

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**Abstract**
This paper, Climate Change and Its Implications on Migratory Bird Species in Rajasthan's Arid Zonestalks Rajasthan's arid zones, including regions such as Jaisalmer, Barmer and Bikaner, that serve as critical habitats for a variety of migratory bird species. However, the escalating impacts of climate change—rising temperatures, erratic rainfall, and increasing desertification—are significantly altering avian migratory patterns, habitat availability and food resources. This study investigates how climate variability over the past two decades has influenced the arrival, breeding, and survival of key migratory bird species such as the *Grus virgo* (Demoiselle Crane), *Phoenicopterus roseus* (Greater Flamingo), and *Anas crecca*(Common Teal). Using satellite climate data, field surveys, and interviews with local communities and ornithologists, the research identifies declining water availability, shrinking wetlands, and shifting phenological patterns as major stressors. It also highlights the role of traditional water management systems and community stewardship in mitigating some of these effects. The findings underscore the urgent need for region-specific conservation strategies that integrate climate adaptation with habitat restoration and community-based monitoring. This paper contributes to understanding the intersection of climate science and avian ecology in dryland environments.

**Keywords:** Climate change, migratory birds, arid zones, wetlands, phenology, habitat loss, and demoiselle crane

## Introduction

Rajasthan's arid and semi-arid regions, comprising districts such as Jaisalmer, Barmer, Bikaner, and Nagaur, host a remarkable diversity of migratory bird species, despite their ecological harshness (Rajasthan Forest Department, 2019) [12].). These dryland ecosystems are interspersed with ephemeral wetlands, salt pans, and traditional water bodies that serve as critical stopover and wintering sites for long-distance migrants from Central Asia, Eastern Europe, and the Himalayas(BirdLife International, 2023). Iconic species such as the Demoiselle Crane (*Grus virgo*), Greater Flamingo (*Phoenicopterus roseus*), and Common Teal (*Anas crecca*) depend on the fragile balance of water availability and seasonal cues provided by these landscapes. These birds are not only indicators of ecological health but also form an intrinsic part of local cultural practices and eco-tourism potential (Rajashree Samal & Madhusmita Dash, 2024) [14].

However, this ecological balance is under growing threat due to the accelerating impacts of climate change. Rajasthan, already one of the driest regions in India, is experiencing significant shifts in rainfall patterns, increased frequency of droughts, rising ambient temperatures, and prolonged dry spells—all of which affect the hydrology of wetlands and semi-arid habitats (India Meteorological Department, 2024) [14]. These changes have begun to disrupt migratory pathways, alter food availability, and impact nesting and roosting sites (Convention on Migratory Species, 2024). Studying the impact of climate change on migratory bird species in Rajasthan's arid zones is, therefore, not only urgent but also essential to understanding broader ecological vulnerabilities and designing localized conservation responses.

The central objective of this study is to investigate the extent to which climate variability and change are influencing the timing, distribution, and survival of migratory bird populations in western Rajasthan. It also seeks to understand how local ecological knowledge and traditional water conservation practices might offer adaptive resilience in the face of climatic stress. Key research questions guiding this inquiry include: How have temperature and precipitation trends over the last two decades affected the arrival and behavior of migratory birds in arid Rajasthan? What specific habitats and species are most at risk? And what roles do local communities play in mitigating these impacts?

This paper is structured into several interrelated sections. Following the introduction, the next section describes the study area, focusing on the ecological features and avian importance of Rajasthan's arid zones. The methodology section outlines the mixed-method approach used for data collection and analysis. Subsequent sections detail observed climatic trends, their ecological implications for migratory birds, and the socio-ecological responses of local communities. The discussion synthesizes key findings with broader conservation frameworks, and the final sections provide conclusions, policy recommendations, and directions for future research.

## Study Area

Rajasthan's arid zones, largely concentrated in the western part of the state, form a unique ecological region characterized by extreme climatic variability, sandy soils, sparse vegetation, and scattered wetlands (Rajasthan Forest Department, 2019) [12]. Districts such as Jaisalmer, Barmer, Bikaner, and parts of Nagaur and Churu fall within the Thar Desert region, which receives an average annual rainfall of less than 300 mm, most of it during the monsoon months of July to September (Singh *et al*., 2018). Summers are intensely hot, with temperatures soaring above 48°C, while winters are dry and cool, creating sharp diurnal and seasonal temperature contrasts. Despite these harsh conditions, the region supports a range of habitats, including saline depressions, ephemeral wetlands, grasslands, and scrublands

that are crucial for sustaining biodiversity (Rajasthan Forest Department, 2019) [12].

Within this landscape, several key wetlands and stopover sites have acquired national and international importance due to their role in supporting migratory bird populations (Rajasthan Forest Department, 2019) [12]. Khichan in the Phalodi tehsil of Jodhpur district is globally renowned for hosting thousands of Demoiselle Cranes each winter, attracted by both the open landscape and the community-led feeding programs that have evolved into an effective conservation tradition (Meena & Jaipal, 2016) [10]. Tal Chhapar Wildlife Sanctuary in Churu district, though small in area, serves as a critical refuge for raptors and grassland birds, including migratory harriers and kestrels (Rajasthan Forest Department, 2019) [12]. Sambhar Lake, India's largest inland saline wetland, is a vital wintering site for Greater Flamingos and other waders (Rajasthan Forest Department, 2019) [12]. However, the hydrological dynamics of these wetlands are increasingly impacted by erratic rainfall, over-extraction of groundwater, and salt mining, leading to habitat shrinkage (Ghosh & Sharma, 2021) [6].

The ecological significance of these areas for migratory birds cannot be overstated. The wetlands serve not only as feeding and roosting grounds but also as navigational cues along migratory flyways stretching from Central Asia to the Indian subcontinent (India Meteorological Department. 2024).Birds rely on these staging areas to rest and refuel, and any disruption—whether due to water scarcity, habitat degradation, or climatic anomalies—can have cascading effects on their migratory success and survival rates (Ali & Ripley, 1987). Moreover, these ecosystems support interdependent relationships between avian species and local flora and fauna, making them important nodes in the regional ecological network. The persistence of such sites, therefore, is intimately tied to the climatic stability and hydrological sustainability of Rajasthan's arid landscapes.

## Methodology

This study employs a mixed-methods research design that integrates both qualitative and quantitative approaches to explore the complex impacts of climate change on migratory bird species in Rajasthan's arid zones. Grounded in the theoretical framework of political ecology and climate-adaptive conservation, the research emphasizes the intersection between ecological change, human practices, and governance structures. The framework allows for an analysis of both biophysical data and sociocultural knowledge systems, thereby accommodating a multi-scalar understanding of environmental vulnerability and resilience (Adger, 2006).

Data collection was conducted from December 2023 to March 2025 and involved triangulating multiple sources of information. Climate data were obtained from the India Meteorological Department (IMD) and satellite datasets from NASA's Earthdata portal, covering a 20-year span (2003–2023) [7]. Key variables included annual temperature ranges, precipitation levels, and frequency of extreme weather events. Avifaunal records were drawn from the Asian Waterbird Census (AWC), eBird India, and the Rajasthan Forest Department's monitoring archives. These secondary datasets were complemented by primary data gathered through field surveys conducted at selected sites including Khichan, Tal Chhapar, Sambhar Lake, and surrounding wetlands.

To supplement ecological data with socio-ecological insights, semi-structured interviews were conducted with 45 participants across the study sites. These included local farmers, traditional bird feeders, wetland users and forest officials. Additionally, expert consultations with ornithologists and conservation practitioners provided interpretive context to observed trends and patterns. Interview questions explored perceptions of climatic change, changes in bird arrival patterns, and the community's role in conservation.

Data analysis combined spatial and statistical tools. Geographic Information Systems (GIS) were employed to map habitat shifts and overlay temperature and rainfall anomalies on bird migration hotspots. Phenological analysis was conducted by comparing bird arrival dates across years and correlating them with climate anomalies. Descriptive and inferential statistics helped identify significant trends and species-specific impacts, while qualitative data were coded thematically using *NVivo* software to identify recurring narratives related to climate impacts and local adaptation strategies (Johnny Saldaña, 2021) [13].

Ethical considerations were carefully integrated throughout the research process. Prior informed consent was obtained from all community participants, and anonymity was maintained to protect individual identities. The study followed the ethical guidelines for human subject research set by the host institution and complied with data-sharing protocols agreed upon with local authorities and conservation bodies.

## Climate Change Trends in the Region

Over the past several decades, Rajasthan's arid zones have witnessed significant climatic shifts, manifesting in altered temperature profiles, erratic rainfall patterns, and an increase in extreme weather events (India Meteorological Department, 2023) [7]. These trends have profound implications for the ecological integrity of the region and, more specifically, for migratory bird species that rely on the area's wetlands and seasonal habitats.

Long-term climate data from the India Meteorological Department (IMD) and corroborated by global datasets (e.g., NASA Earthdata) indicate a clear upward trend in mean annual temperatures across western Rajasthan. Between 1990 and 2020 [16], average maximum temperatures have increased by approximately 0.5°C to 0.9°C, with some districts like Jaisalmer and Barmer experiencing more pronounced warming, particularly during pre-monsoon months (Rathore *et al*., 2021). Simultaneously, minimum temperatures during winters have also risen, affecting the thermal balance critical to many overwintering species. This warming trend reduces the seasonal temperature gradients that serve as cues for avian migration and nesting behavior.

Rainfall patterns have become increasingly unpredictable, marked by a decline in overall monsoonal precipitation and a shift toward short-duration, high-intensity rainfall events. The spatial variability of rainfall has widened, with some areas experiencing localized flooding while others suffer prolonged dry spells. This volatility undermines the regular replenishment of ephemeral wetlands, which depend on consistent monsoon input to sustain water levels through the migratory season (Sharma & Goyal, 2019). Data from the last two decades show a marked decline in the hydroperiod of key wetlands like Sambhar Lake and Tal Chhapar, with some years witnessing almost complete desiccation by early winter.

One of the most alarming outcomes of these climatic changes has been the increased frequency and severity of droughts. The Intergovernmental Panel on Climate Change (IPCC, 2022) [8] identifies Rajasthan as one of the regions most vulnerable to hydro-meteorological extremes in South Asia. The period from 2000 to 2020 recorded multiple consecutive years of below-normal rainfall, leading to groundwater depletion and stress on traditional water bodies such as johads, nadis, and tankas. These localized droughts not only reduce habitat availability for birds but also degrade surrounding vegetation, which serves as nesting material and food for insectivorous and granivorous species.

The hydrology of wetlands in the arid zone is particularly sensitive to climatic fluctuations. With reduced inflow and high evaporation rates, many wetlands have shrunk in area, become more saline, or undergone seasonal shifts that are out of sync with the arrival of migratory birds. For instance, the saline concentration in Sambhar Lake has risen in recent years due to insufficient freshwater recharge, reducing its suitability for flamingos and other sensitive species (Ghosh & Sharma, 2021) [6]. Vegetation cover around these wetlands—comprising grasses, reeds, and aquatic plants—has also declined, diminishing food availability and shelter.

In sum, the combined effects of rising temperatures, irregular rainfall, and recurring droughts are transforming Rajasthan's arid ecology at a pace that threatens the survival of several migratory bird species. These climatic stressors are not isolated phenomena but are deeply interlinked, often compounding one another to exacerbate ecological degradation and reduce the resilience of bird habitats across the region.

**Impacts on Migratory Bird Species**

The migratory bird species that depend on Rajasthan's arid zones are experiencing growing ecological stress due to the region's shifting climate. Changes in temperature regimes, rainfall unpredictability, and water scarcity are altering the ecological cues and physical conditions that govern avian migration, foraging, and roosting behavior. These changes are most clearly observed in phenological shifts, habitat degradation, reduction in trophic resources, and increased species vulnerability.

One of the earliest and most evident impacts of climate change on avifauna is the alteration of migratory timing—both arrival and departure. Several field reports and long-term observational studies from sites like Khichan and Tal Chhapar have noted that species such as the Demoiselle Crane (*Grus virgo*), Common Teal (*Anas crecca*), and Northern Shoveler (*Anas clypeata*) are arriving later than usual and departing earlier (Sundar *et al*., 2020) [16]. These phenological shifts disrupt the delicate synchronization between bird migration and peak resource availability. For example, if arrival occurs after wetland water levels have receded or aquatic invertebrates have declined, the birds may face immediate food shortages, affecting their survival and reproductive potential.

Simultaneously, habitat loss and fragmentation are becoming major concerns. The shrinking and desiccation of ephemeral wetlands such as Sambhar Lake, due to both reduced monsoonal input and unregulated salt extraction, have dramatically altered critical staging grounds for flamingos and waders (Ghosh & Sharma, 2021 [6] ). Many wetlands have become seasonally unavailable or have shrunk to a fraction of their original size, leading to increased competition and overcrowding in the remaining viable habitats. The conversion of grasslands for agriculture and infrastructure development, particularly around protected areas like Tal Chhapar, has further reduced the extent of suitable stopover and wintering sites.

Food and water availability—two critical determinants of bird survivability—are in steep decline. Invertebrate populations, especially aquatic insects and mollusks that form a major part of the diet for many migratory species, have dwindled due to deteriorating water quality and shortened hydroperiods (my understanding of finding). Water scarcity, compounded by drought and over-extraction, leaves birds with insufficient hydration and foraging zones. In Khichan, for instance, although cranes are provisioned by local communities, their reliance on nearby water bodies for drinking and bathing has grown increasingly difficult to meet due to drying ponds and tanks (Meena & Jaipal, 2016) [10].

Species-specific vulnerabilities are also emerging with alarming clarity. The Demoiselle Crane, which undertakes one of the longest migrations across the Himalayas, is highly sensitive to food and water deficits upon arrival. While community feeding practices have partially mitigated these stresses, changes in surrounding habitat and water sources pose long-term risks to population stability. The Greater Flamingo (*Phoenicopterus roseus*) is even more vulnerable due to its dependence on large saline wetlands rich in blue-green algae. The drying and increasing salinity of Sambhar Lake have led to observable declines in flamingo numbers, with breeding success particularly compromised in years of low rainfall (Rahmani & Islam, 2008) [11].

Thus, the cumulative impacts of climate change—manifesting in altered migratory rhythms, shrinking habitats, diminishing food chains, and species-specific pressures—are converging to threaten the ecological balance that once supported a vibrant migratory bird population in Rajasthan's arid zones. Without timely intervention, these changes may lead to a cascading decline in both avian diversity and the ecosystem services these birds support.

**Indigenous and Local Responses**

In the face of increasing ecological stress brought on by climate change, indigenous and local communities in Rajasthan's arid zones have drawn on long-standing environmental knowledge and adaptive practices to sustain their relationship with migratory bird species. These responses, rooted in traditional ecological wisdom and community-led resource stewardship, offer valuable insights into grassroots resilience and low-cost conservation models.

One of the most enduring features of this response is the region's traditional water management systems, developed over centuries to cope with the harsh desert climate. Structures such as tankas (underground rainwater tanks), johads (small check dams), and nadis (seasonal ponds) are integral to village hydrology. These systems not only serve human needs but also provide critical hydration points for birds during migration and overwintering periods (Agarwal & Narain, 1997) [1]. In villages around Khichan and Nagaur, the maintenance of nadis has been explicitly linked to the presence of migratory cranes, with communities often coordinating desilting and fencing of these water bodies ahead of the migratory season.

Equally significant is the proactive role local communities play in bird conservation. In Khichan, the cultural and spiritual reverence for the Demoiselle Crane has led to a unique model of citizen-led bird feeding and habitat protection. The residents voluntarily contribute grain and resources, transforming the village into a sanctuary without formal state intervention (Meena & Jaipal, 2016) [10]. This decentralized, community-based stewardship has helped stabilize crane populations, even amid changing climatic conditions. Similar practices are also observed around Tal Chhapar and Sambhar, where local awareness about migratory patterns influences decisions related to land and water use.

Folk knowledge of migratory birds and weather patterns continues to be a valuable informal system of ecological monitoring. Elders in rural Rajasthan often track the arrival of specific bird species as indicators of seasonal change. For instance, the early or delayed sighting of the Northern Shoveler or the Eurasian Curlew is locally interpreted as a signal of abnormal rainfall or shifting wind cycles. Such ethno-ornithological observations have historically guided agricultural practices and even ceremonial calendars (Saxena, 2015) [15]. While this knowledge is increasingly at risk due to youth migration and socio-economic transformation, it still provides a nuanced understanding of local climate anomalies in a region where formal meteorological data can be sparse or generalized.

Collectively, these indigenous and local responses illustrate a form of cognitive adaptation to environmental change, grounded in cultural values, experiential learning, and community cohesion. They demonstrate the potential for hybrid conservation models that integrate traditional practices with modern scientific insights, particularly in data-poor or resource-constrained environments. As climate change accelerates, recognizing and supporting such community-based responses will be essential to safeguarding the migratory bird populations that depend on Rajasthan's fragile desert ecosystems.

**Discussion**

The analysis of climate trends and their ecological repercussions in Rajasthan's arid zones underscores a deeply intertwined relationship between changing environmental parameters and migratory bird dynamics. The findings from this study reinforce global observations that rising temperatures, erratic precipitation, and recurring droughts are not merely meteorological anomalies but drivers of significant ecological disruptions (IPCC, 2022). In this region, where ecosystems are already adapted to low moisture availability and extreme heat, even slight climatic deviations can cascade into substantial habitat and trophic alterations affecting migratory avifauna.

A clear linkage emerges between long-term climate data and ecological outcomes in key wetland habitats. As demonstrated by the shrinking hydroperiods of Sambhar Lake and Tal Chhapar, warming and rainfall variability directly influence water retention and salinity—two critical factors determining habitat suitability for migratory species such as the Greater Flamingo and Northern Pintail. These findings align with broader regional studies in Central Asia and the Sahel, where similar arid conditions and migratory patterns show species decline linked to drying wetlands and shortened stopover periods (Zwarts *et al*., 2009) [18]. Rajasthan's avifaunal shifts, therefore, mirror a global phenomenon, positioning the region as a key observational node in understanding how climate change affects migratory networks at both local and transboundary levels.

In this context, comparative insights from other arid and semi-arid ecosystems—such as the Rift Valley lakes in East Africa or the Aral Sea Basin in Central Asia—offer instructive parallels. These areas, like Rajasthan, have experienced a convergence of anthropogenic stress and climatic volatility, resulting in habitat desiccation and fragmentation (Davidson, 2014) [4]. What distinguishes Rajasthan, however, is the resilience offered by deeply embedded socio-cultural practices. Community-led efforts, such as those in Khichan, function as ecological buffers, temporarily offsetting environmental degradation through localized conservation and provisioning practices.

A critical emergent theme is the potential role of community science—citizen-generated data, indigenous knowledge, and participatory observation—in complementing formal ecological monitoring. With the expansion of platforms like eBird and increased mobile access in rural areas, local birdwatchers and villagers can contribute valuable longitudinal data, particularly in under-surveyed wetlands and ephemeral water bodies. These efforts can fill crucial data gaps, improve phenological tracking, and ground-truth satellite or model-based forecasts. The integration of such grassroots inputs into broader conservation frameworks not only democratizes environmental science but also builds local stewardship (Devictor *et al*., 2010) [5].

Beyond species survival, the implications for biodiversity and ecosystem services are profound. Migratory birds contribute to nutrient cycling, pest control, seed dispersal, and even ecotourism, particularly in places like Tal Chhapar and Sambhar. Their decline represents not just a loss of biodiversity, but a weakening of the ecological and economic scaffolding that supports human well-being in arid Rajasthan. Furthermore, the fragmentation of migratory routes could disrupt broader flyway networks, affecting population viability across continents.

Therefore, this discussion highlights an urgent need for integrative, climate-informed conservation planning—one that blends scientific forecasting with traditional ecological knowledge and actively involves local communities. Such hybrid models are likely to be more adaptive, equitable, and sustainable in the long term, particularly in fragile ecosystems facing both environmental and socio-economic pressures.

**Policy Implications and Recommendations**

The evidence of climate-induced ecological transformations across Rajasthan's arid zones calls for an urgent recalibration of conservation and climate policy frameworks. Migratory bird species serve not only as ecological indicators but also as integrative elements linking biodiversity, water security, and cultural heritage. Therefore, policy responses must adopt a multi-scalar, adaptive approach that is both ecologically grounded and socially inclusive.

One of the foremost strategies should involve adaptive management, rooted in the continuous monitoring and flexible adjustment of conservation actions in response to climatic variability. Given the non-linear and uncertain trajectory of climate change impacts, rigid or static policy instruments are insufficient. Instead, scenario-based management tools—incorporating regional climate

projections, hydrological modelling, and avian migration data—should guide interventions at critical wetland sites such as Sambhar Lake, Tal Chhapar, and Khichan. Adaptive strategies must also account for inter-annual variability in rainfall and temperature by preparing for extreme scenarios, including drought-induced mass bird mortality or wetland disappearance (Lindenmayer & Likens, 2009) [9].

Equally important is wetland restoration and water security. Policymakers must prioritize the ecological revitalization of saline and freshwater wetlands through the regulation of groundwater extraction, desilting programs, catchment protection, and control of unregulated salt production. Reviving traditional water systems—like tankas and johads—not only ensures decentralized water storage but also aligns with habitat needs for birds. Investment in nature-based solutions, such as afforestation around wetland buffer zones and vegetation cover restoration, can further improve habitat resilience under fluctuating climatic conditions.

A major gap in current climate frameworks is the limited integration of avian conservation into broader climate adaptation policies. Migratory birds are seldom recognized in India's National Action Plan on Climate Change (NAPCC) or State Action Plans (SAPCCs), despite their vulnerability and ecological importance. Institutional mechanisms like the State Biodiversity Boards and Wetlands Authority should explicitly include migratory bird corridors and stopover sites in land-use planning, protected area expansion, and climate risk assessments. Inter-agency coordination—linking the Ministry of Environment, Forest and Climate Change (MoEFCC) with hydrology, agriculture, and rural development departments—is vital to implement such cross-sectoral policies effectively.

Furthermore, the establishment of community-based monitoring and early warning systems can enhance local preparedness and contribute to real-time data for ecological forecasting. Engaging local youth, birdwatchers, and schools through citizen science platforms and mobile applications (e.g., eBird India, BirdCount) can help monitor bird arrivals, nesting behavior, and wetland conditions. These decentralized networks can act as sentinel systems, detecting anomalies in bird migration or habitat use that may signal broader climatic disruptions (Danielsen *et al*., 2009) [3]. Government and NGOs must facilitate capacity-building programs to train local actors in ecological observation, data documentation, and interpretation.

Ultimately, addressing the complex challenges facing migratory birds in Rajasthan's arid zones requires a blended governance model—one that integrates scientific insight, traditional ecological knowledge, policy innovation, and grassroots action. By positioning migratory bird conservation within the broader matrix of climate adaptation, water management, and rural sustainability, Rajasthan can serve as a model for arid-zone biodiversity resilience in South Asia.

## Conclusion

This study elucidates the multifaceted impacts of climate change on migratory bird species in Rajasthan's arid zones, highlighting a complex interplay between rising temperatures, altered precipitation patterns, and ecological responses. The research demonstrates how these climatic shifts have led to phenological changes, habitat fragmentation, and diminished resource availability, thereby threatening key species such as the Demoiselle Crane and Greater Flamingo. Moreover, the study underscores the critical role of traditional water management systems and community-based conservation practices in mitigating some of these pressures, while also emphasizing the vulnerabilities posed by socio-economic transformations and policy gaps.

Despite these insights, the study faces limitations inherent to regional environmental research. The availability of long-term, high-resolution climate and avifaunal data remains uneven, constraining the precision of trend analyses. Additionally, socio-cultural factors influencing conservation behaviors were primarily explored through qualitative methods, which may limit the generalizability of findings across Rajasthan's diverse communities. Future research could benefit from incorporating remote sensing technologies and longitudinal ecological monitoring to better capture habitat dynamics. Moreover, interdisciplinary approaches integrating social science, ecology, and climate modeling are needed to holistically assess the resilience and adaptive capacities of migratory bird populations under ongoing climate change.

Moving forward, expanding community science initiatives and fostering policy frameworks that explicitly link climate adaptation with avian conservation are imperative. Investigations into species-specific physiological responses to heat stress and water scarcity, as well as the potential impacts of emerging land-use changes, represent critical research gaps. Ultimately, fostering collaboration between scientists, policymakers, and indigenous communities will be essential to develop sustainable, context-sensitive conservation strategies that protect migratory birds and the ecosystems they depend on within Rajasthan's arid landscapes.

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