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Diversity of avian species, their ecosystems and climate conditions in two zones of High Atlas (central Morocco) for ecotouristic purposes

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Abstract The analysis of avian diversity and their natural ecosystems at a regional scale is the first step to understanding and classifying a specific region's ecological importance and, therefore, adopting sustainable economic activities and implementing suitable conservation measures. This study investigated the avian richness and natural ecosystems in Eastern and central High Atlas between 2015 and 2021. Transects and point-count methods were used to identify and estimate populations of birds and to delimit the nature of ecosystems. A total of 175 bird species among resident-breeders, migrant-breeders, migrant-winterers, and accidental-visitors were documented. These birds belong to 19 orders and are grouped into 51 families. Among recorded birds, 20 species were categorized as species of ectouristic interest due to their roles in birdwatching, hunting, racing sports, and trade activities. These species were observed in natural and human-made ecosystems, with the majority in wetlands. The abundance of a wide range of ecosystems and various bioclimatic stages is suggested to be behind the avian richness of these mountainous areas. Finally, these natural landscapes and their avian richness could be used for ecotouristic purposes. Visitors could profit from the view of landscapes and observation of the most iconic and rare animal species, which is suggested to increase the income for local populations and ensure the sustainable use of natural resources.

Keywords: avian richness, ecosystems, climate, ectouristic potential, High Atlas

1. Introduction

The investigation and knowledge of animal diversity on a regional scale is a crucial step in conservation efforts (Dobson 2005). Configurations of species ranges, geographic distribution, richness, and abundance must be studied and defined principally in areas characterized by various ecosystems and climates (Martínez-Ortega et al 2004). Inventories of ecosystems must be conducted to determine local and regional levels of diversity and integrate them into a national view of spatial distinction in endemism and diversity (Colwell and Coddington 1994). Equally, the variety of animal species can be related to climatic, physical, and geo-topographical structures of the environment to produce a synthetic understanding of determining factors of biological diversity patterns (Poff and Ward 1990).

The Mediterranean Basin hotspot, which includes North Africa and Morocco, is one of the planet's ecologically richest and most threatened terrestrial ecoregions (Médail 2017; De Michele et al 2019). As a result, it supports the highest levels of marine biodiversity and the second-highest concentration of animal and plant diversity in the Mediterranean Basin (Teixeira et al 2018; Squalli et al 2022). There are more than 31.000 species in Morocco, with roughly 11% being endemic (Bouahim et al 2010; Natij et al 2014). Among the animal diversity of Morocco, around 500 different bird species can be found, including breeding, migratory, and wintering species (Dakki et al 2001; Maggini and Bairlein 2011; Cherkaoui et al 2016; Douini et al 2022; Squalli et al 2022). This species richness is the result of the diversity of natural ecosystems (Dakki et al 2020; Fouzi et al 2020; Kusi et al 2020), climate circumstances (Tramblay et al 2012), and geographical situation (Mensour et al 2019). Regarding

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natural ecosystems, Morocco is characterised by Saharan lands in the South and East, coastal lines of the Mediterranean Sea and Atlantic Ocean, and Mountainous chains of Atlas and Rif (Ozer et al 2020; Mansouri et al 2021; Nogueira et al 2022). These characteristics provide favorable conditions for a variety of animal and plant species. Actually, Morocco contains 160 Sites of Biological and Ecological Interest, 38 RAMSAR wetlands, and 10 National/Natural Parks, three of which have maritime areas (SBEI) (Dakki et al 2016). Climate conditions vary from the Mediterranean humid climate in the North and on top of the Mountains to the Saharan and arid climate in the Southern provinces (Souad and Bendriss Amraoui 2020; Depreux et al 2021; Mansouri et al 2022a; El Ouali et al 2022). These elements are of great importance for biological diversity and can be useful for developing sustainable economic activities such as ecotourism.

In Morocco, avian species are widely distributed in different ecosystems, counting forests, wetlands (Squalli et al 2022), farmlands (Mansouri et al 2020; El Hassani et al 2021), and urban areas (Douini et al 2022). However, most ornithological research was realised in lowlands, while in high altitudes, investigations are rare and fragmentary. Mansouri et al (2021) revealed an important population of migrant and resident birds in the upper Moulouya. Similarly, important breeding populations were mentioned currently in forests located in high altitudes of Beni Mellal (Mounir et al 2022). On the other hand, these studies neglected the socioeconomic roles of this avian diversity, particularly in link with a diversity of natural ecosystems. Because the use of natural landscapes and their biological diversity in green activities such as ecotourism, geotourism, and other sustainable forms of tourism is suggested to increase the incomes of local populations and ensure the valorisation of natural resources (Štrba et al 2020; Marafa 2021; Chaudhary et al 2022). As consequence, the valorisation of biological and geological resources is suggested to ensure the protection of natural landscapes and the conservation of their living species (Israel and Timar 2018; Rodríguez et al 2022).

In this study, we aimed to investigate the richness of avian species and the diversity of ecosystems in the High Atlas Mountainous chain. We surveyed the richness of avian species and their abundance in natural and human-made habitats; then, we identified the birds of ecotouristic potential and their behavioral selection of occurrence habitats. In parallel, we identified the nature of encountered ecosystems in the Central and Eastern High Atlas. These elements are suggested to play a great role in encouraging sustainable tourism in the mountains, which will be useful to increase the incomes of local populations and ensure the conservation of both natural landscapes and biological diversity.

2. Materials and Methods

2.1. Study area

This study was carried out in Central and Eastern High Atlas, central Morocco (Figure 1). The study area extended from Beni-Mellal and Azilal in the west to Midelt and Missour in the east. These mountainous areas are located in high altitudes ranging between 900 and 3700 m above sea level (Mansouri et al 2021, Mounir et al 2022). The study areas are located under various bioclimatic stages, counting semi-arid (low altitude), humid, and sub-humid (high altitude). The average rainfall in Central High Atlas was 500 to 800 mm/year, and the average temperature varies between 2 and 33 °C. In Eastern High Atlas, the average rainfall was 235 to 330 mm /year while the average temperature was 29°C. In altitudinal areas of both sites, the rainfall regime is marked by highly variable and irregular rainfall, stormy precipitation brings eroded materials upstream, and sometimes the region receives snowfall.

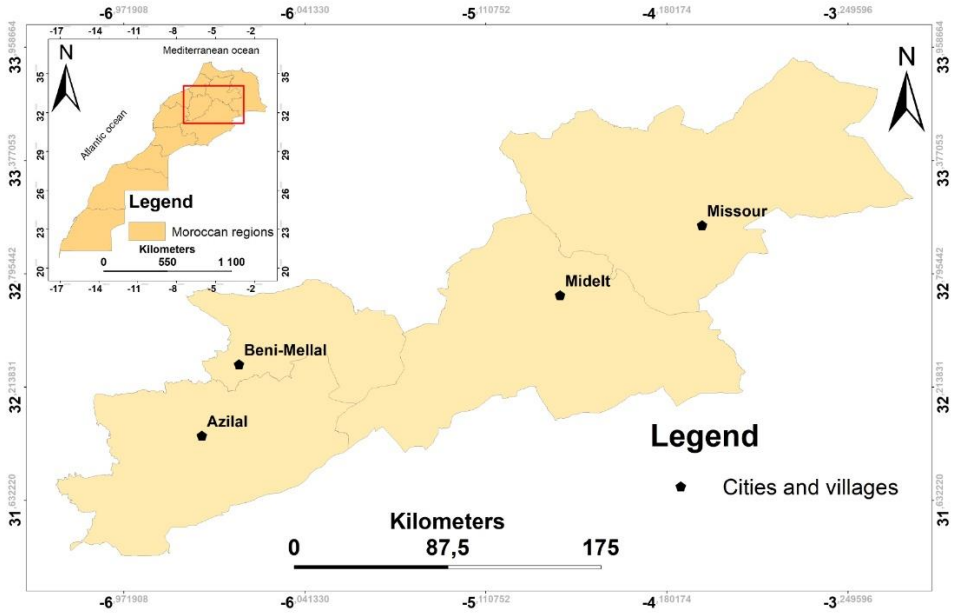

Figure 1 Geographical location of the study zone.

2.2. Surveys of avian populations

To estimate the populations of avian species, we realized field visits from October 2015 to October 2021. Data counting bird species and abundance were collected via transects of nearly 10 km, and each transect was divided into observation points separated by nearly 300 to 500 m. This is an effective method for sampling bird species (Ibhi et al 2013) because it permits extensive surveying of sample areas and the neighboring landscapes (Giuliani et al 2017; Mansouri et al 2018). Our transects took around 12 hours of walking, from 06:00 to 18:00, and each observation took 15 to 20 minutes to identify and count birds; we used binoculars and telescopes during observations, while in dense areas (i.e., forests and dense vegetation) we based on acoustic calls to identify avian species and to estimate their populations.

To identify species of ectouristic interest, we used the following criteria: i) species appreciated by visitors for birdwatching; ii) species used for sports racing; ii) species used for trade by local populations; and/or iv) species considered as game by Moroccan hunting federation.

2.3. Occurrence habitats and diversity of landscapes

The study area was divided into natural and human-made ecosystems. The natural ecosystems were divided into aquatic habitats, including rivers, springs, lakes, and terrestrial systems, counting forests, gorges, canyons, mountains, and steppes. Equally, human-made systems were divided into aquatic habitats counting dams and irrigation systems and terrestrial systems counting farmlands (i.e., apples, olives, prunes, cereals, etc.) and urban centers, including cities, municipalities, small agglomerations, and landfills. In these ecosystems, we observed species of ectouristic roles and their abundance to investigate the behavioural occurrence and link between birds and their habitats.

2.4. Data analysis

Recorded species were divided following the phenological and conservation statuses. The conservation status was based on the latest red list of UICN. Species diversity indexes (Margalef and Shannon-Wiener) were calculated to compare the species richness between the Central and Eastern High Atlas. The species richness, families, and relative abundance were compared using t-test (after assessing the normality of variances). The annual means of temperatures and precipitations were calculated and were compared between study sites with Independent-Samples t-test. To investigate the occurrence habitats of birds of ectouristic interest, recorded species were considered as dependent variables (n=20 species), while the occurrence habitats were considered as independent variables (n=6), and data was analysed with Detrended Correspondence Analysis (DCA). Only axis with eigenvalue superior to 1. All analyses were performed using SPSS 18 (SPSS IBM, 2009), and results were considered significant at $P < 0.05$.

3. Results

3.1. Avian richness

The avian diversity of the High Atlas Mountains is presented in Table SM. In total, 175 avian species were recorded in study sites. In Eastern High Atlas, 135 avian species belonging to 45 families were recorded. Further, Accipitridae (15 species), followed by Muscicapidae and Alaudidae (with nine species each), were the most abundant families. In contrast, only one species was recorded for Alcedinidae, Otididae, Upupidae, and Coraciidae families. In terms of species, *Serinus serinus* and *Linaria cannabina* were the most observed birds, with 105000 and 81000 birds respectively. In contrast, *Neophron percnopterus*, *Gypaetus barbatus*, *Plegadis falcinellus*, and *Aquila chrysaetos* were the less observed species. The vulnerable *Streptopelia turtur*, *Chlamydotis undulata sensu stricto*, *Chersophilus duponti*, the near-threatened *Gypaetus barbatus,* and *Aythya nyroca*, and the endangered *Neophron percnopterus* were the species of conservation concern recorded in the Eastern High Atlas.

In the central High Atlas, 125 avian species belonging to 43 families were recorded. Further, Muscicapidae (16 species), Fringillidae (11 species), and Accipitridae (7 species) were the most abundant families. In contrast, only one species was recorded for Oriolidae, Phalacrocoracidae, Prunellidae, Pycnonotidae, Recurvirostridae, Regulidae, Troglodytidae, and Upupidae families. In terms of species, *Fringilla coelebs* (4062 birds), *Cyanistes teneriffae* (1379 birds), *Pyrrhocorax graculus* (1313 birds), *Pycnonotus barbatus* (1093 birds), and *Pyrrhocorax pyrrhocorax* (889 birds) were the most abundant species in the Central High Atlas. The vulnerable *Streptopelia turtur*, the near-threatened *Gypaetus barbatus*, and *Aythya nyroca*, and the endangered *Neophron percnopterus* were the species of conservation concern recorded in the Central High Atlas.

3.2. Species of touristic importance and habitat use

Avian species of ecotouristic interest and their habitat use are summarised in Table 1. Further, 20 avian species were classified as birds of ecotouristic interest. They are used by local and international tourists in various activities, counting sport hunting, bird watching, racing sport, and trade. Equally, the recorded species were observed in different landscapes, including forests, Mountains, farmlands, wetlands, steppes, and urban landscapes. However, the habitat use varied among cited birds.

The occurrence of avian species and their habitat use in High Atlas are presented in Figure 2. In wetlands, 11 avian species, counting *Anas clypeata*, *Aythya nyroca*, *Podiceps cristatus*, *Tachybaptus ruficollis*, *Egretta garzetta*, *Anas crecca, Mareca Penelope, Anas platyrhynchos,* and *Tadorna ferruginea* were observed. Three avian species, including *Neophron percnopterus*, *Aquila chrysaetos*, and *Gypaetus barbatus* were recorded in high mountains. Two species counting *Streptopelia turtur* and *Carduelis carduelis* were recorded in farmlands.

Only one species *Chersophilus duponti* was recorded in steppes. On the other hand, three species were observed in various habitats. *Columba palumbus* was commonly observed in forests, farmlands, and mountains. *Upupa epops* was commonly observed in farmlands, wetlands, and steppes. *Ciconia ciconia* was recorded in wetlands and urban landscapes.

Table 1 Avian species of ecotouristic interest and their habitat use.

Species	Occurrence habitat	Touristic importance
Streptopelia turtur	Farmlands, forests, wetlands	Hunting and birding
Columba palumbus	Forests and wetlands	Hunting
Columba livia	Farmlands, forests, wetlands, and urban landscapes	Hunting, birding, racing sport
Carduelis carduelis	Farmlands, forests, wetlands	Birding and trade
Chersophilus duponti	Steppes	Birding
Upupa epops	Farmlands, forests, wetlands	Birding and trade
Tadorna ferruginea	Wetlands	Birding
Anas platyrhynchos	Wetlands	Birding
Mareca penelope	Wetlands	Birding
Anas crecca	Wetlands	Birding
Anas clypeata	Wetlands	Birding
Aythya nyroca	Wetlands	Birding
Podiceps cristatus	Wetlands	Birding
Podiceps nigricollis	Wetlands	Birding
Tachybaptus ruficollis	Wetlands	Birding
Egretta garzetta	Wetlands	Birding
Gypaetus barbatus	Forests and high mountains	Birding
Neophron percnopterus	Forests and high mountains	Birding
Aquila chrysaetos	Forests and high mountains	Birding
Ciconia ciconia	Wetlands, farmlands, and	Birding

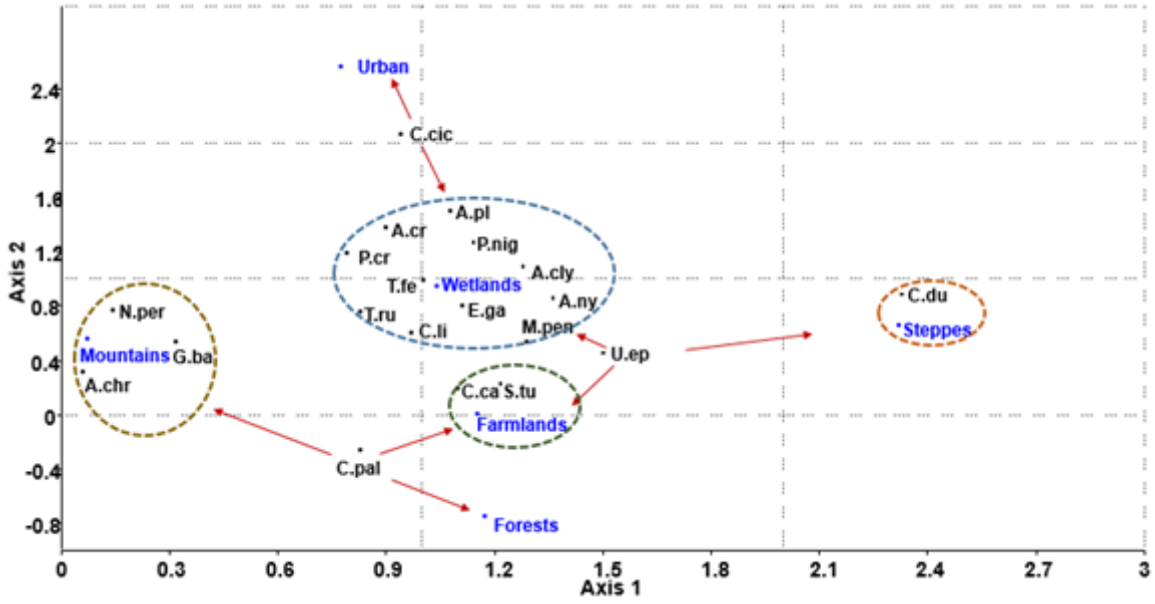

Figure 2 Occurrence of avian species and habitat use in High Atlas.

3.3. Diversity of ecosystems and diversity of birds

Figure 3 summarises the recorded natural ecosystems in the Central and Eastern High Atlas. In total, three lakes counting Isli, Tislit, and Azourar were recorded in the study area. Five dams, including Hassan II, Tamaloute, and Bin El-Ouidane, and 7 principal rivers, including upper Moulouya, Ansegmir, Outat, and Lakhder were also documented. Equally, a diversity of forests was encountered in study area. The most important forests were *Pinus halepensis, Cedrus atlantica, Juniperus oxycedrus, Juniperus thurifera,* and *Pistacia lentiscus.* At the same time, the most remarkable steppes were *Retama monosperma, Pistacia lentiscus, Artemisia herba-alba,* and *Stipa tenacissima.* Equally, seven tops of Mountains were included in the study area, including El Ayachi, Tissli, and Oumaasker in Eastern High Atlas, as well as Tisselmit, Taghia, Rat, Sraghna, and Tignousti. On the other hand, four Ramsar sites counting Tislit-Isli lakes, Assif M'Goun, Assif Ahansal, and Upper Oued Lakhdar, as well as three sites of ecological and biological interest counting Jbel Taghioult, bel Ayachi, and Tamga were located in these parts of High Atlas. Further, Todgha, Tabouazant, Taghia gorges, and canyons are also included.

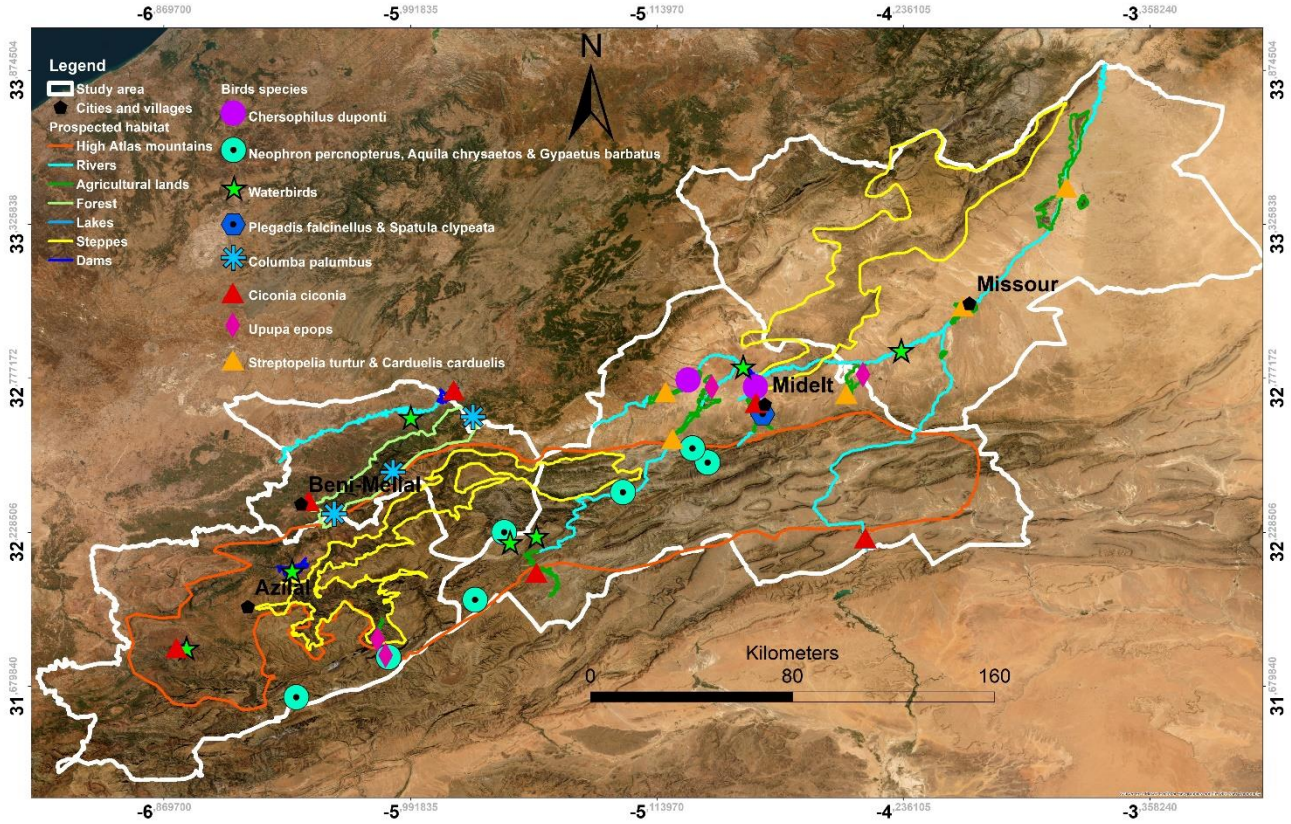

Figure 3 Diversity of ecosystems and the occurrence location of avian species.

The geographical distribution of species of ecotouristic interest is presented in Figure 3. *Streptopelia turtur* and *Carduelis carduelis* were primarily observed in farmlands of Eastern and central high Atlas. They were observed in apples, olives, and cereals. The 11 waterbirds were recorded in aquatic ecosystems counting dams, lakes, and rivers. During field visits, *Tadorna ferruginea* was recorded in lakes of Isli, Tislit, and Azourar located in high altitudes (2000-3000 m). On the other hand, accidental birds of *Plegadis falcinellus* and *Spatula clypeata* were observed in a sewage treatment plant near Midelt city. *Columba palumbus* was limited to forests of *Pinus halepensis, Cedrus atlantica, Juniperus oxycedrus,* and *Juniperus thurifera. Ciconia ciconia* was documented in dams, rivers, and urban centers, while *Upupa epops* was primarily observed in fruit groves (i.e. olives, apples, and oranges) and riparian vegetation. *Chersophilus duponti* was limited to the high plain of Moulouya near Zaida city. Birds of prey *Neophron percnopterus, Aquila chrysaetos,* and *Gypaetus barbatus were limited to* High altitude mountains of El Ayachi, Midkane, Oumaasker, Bab Nouyad in Eastern High Atlas, as well as Taghia, Taghrote, and Azourki in central High Atlas.

3.4. Climatic conditions

The climate conditions (precipitations and temperatures) in the studied zones are presented in Figure 4. The average rainfall was 355±17.91 mm in Central High Atlas and 294±8.17 mm in Oriental High Atlas (n=12, t=-0.894, P = 0.380). In contrast, the average temperature was significant inferior in Central High Atlas (14.11± 7.44 °C) compared to Oriental High Atlas (19.25± 3.33 °C) (n=12, t=-2.183, P = 0.04).

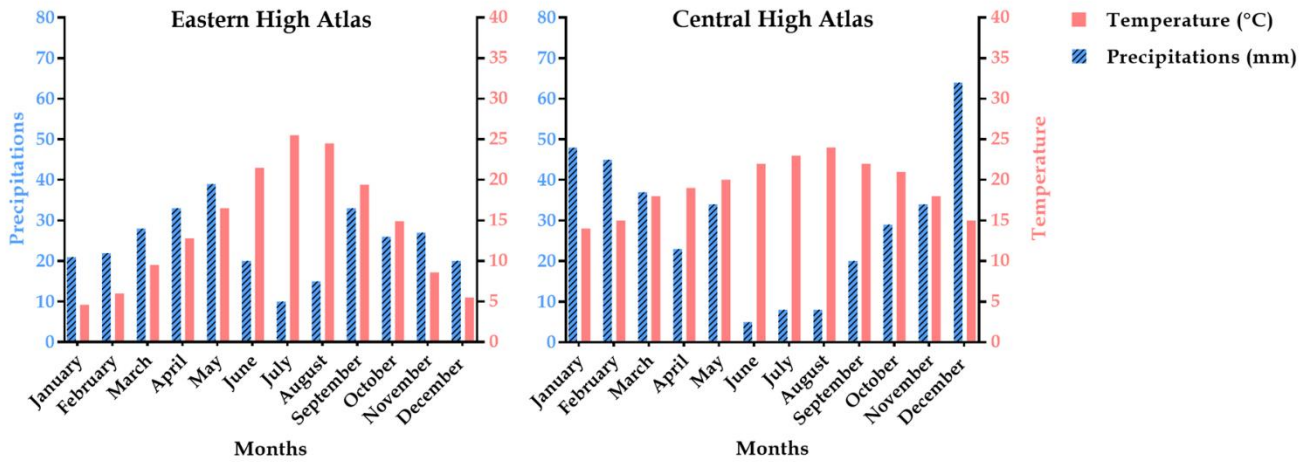

Figure 4 Annual precipitations and temperatures in Eastern and Central High Atlas.

4. Discussion

This investigation presents new data on avifainistic and ecosystem diversity in Central and Eastern High Atlas, central Morocco. Our primary purposes were to investigate the richness of birds, their occurrence habitats, and the diversity of ecosystems in this mountainous area. We gained novel and valuable data describing the avian richness, their occurrence habitats, and the diversity of natural ecosystems in High Atlas Morocco. These results are of great interest for implementing ecotouristic projects and socioeconomic development.

Our field surveys revealed 175 avian species in High Atlas (125 in Central and 125 in central High Atlas). These species were divided among resident-breeders, migrant-breeders, migrant-winterers, and accidental-migrants. In Eastern High Atlas near Midelt province, there were similar results by Mansouri et al (2021), who reported 131 avian species, and in the Central High Atlas where Mounir et al (2022) documented 92 breeding species. Equally, Nekhla et al (2022) and Achiban et al (2022) have mentioned an important avian richness in the mountains of the Middle Atlas. In our case, Passeriformes, with 68 species grouped in 16 families, and Accipitriformes, with 13 species and one family, were the most dominant orders. Equally, Muscicapidae, Accipitridae, Fringillidae, and Alaudidae were the most prevalent families, respectively. These results agree with those of Mansouri et al (2021) in Eastern High Atlas and those of Mounir et al (2022) in central High Atlas. These authors reported Passeriformes and Accipitriformes orders and Accipitridae and Muscicapidae families as dominant. In comparison with other Mountainous areas, ATER et al (2008) reported 90 avian species in Oued Laou (Rif Mountains), 88 avian species were recorded in Jbel Saghro (Anti-Atlas, Morocco) (Qninba et al 2013), while Cuzin (2010) documented only 23 birds in the High Atlas of Marrakech. In our case, this avian richness is suggested to play a great ectouristic role, principally in birding activities (Tamalene et al 2022).

In this study, 20 avian species were considered birds of ectouristic interest. They are used for various activities, including birdwatching, hunting, racing sport, and trade. This link between ecotourism activities and avian diversity is the first in the study area and the entire of Morocco. Similar results were reported in Spain (North of the Mediterranean), where National parks were among the ectouristic destinations due to their richness in birds (Carrascosa-López et al 2021). Similarly, watching avian species was recorded as a recreational activity in Turkey (Duzgun and Kurt Dündar 2021; Aydin Yönet and Yirmibeşoğlu 2022). Birdwatching activities is an emerging touristic activity known for higher and sustainable incomes (Czeszczewik et al 2019).

In our case, some species, such as *Columba livia, Columba palumbus*, and *Streptopelia turtur* are essential in hunting activities (Mansouri et al 2022b). These species are highly appreciated by local and international hunters (De Vries et al 2022; Mansouri et al 2022b). This is suggested to increase the economic incomes, particularly in these mountainous areas known for their poor populations (Thys et al 2019).

In addition to the diversity of avian species, the Eastern and Central High Atlas host a significant diversity of ecosystems and natural sites. We recorded rivers, dams, and lakes as aquatic ecosystems and forests and tops of Mountains as terrestrial ones. Similar results were mentioned in both parts of the High Atlas (Ibouh et al 2014; Mansouri et al 2021; Mounir et al 2022). The abundance of aquatic ecosystems and forests is supported by the higher rainfall rates in these Mountains considered among the humid areas of Morocco (Alaoui Haroni et al 2009; Marchane et al 2017). The diversity of natural and human-made ecosystems is suggested to support the avian richness with forage and breeding resources. These are in agreement with results recorded by Mansouri et al (2022), who recorded the breeding and feeding sites of five game species counting *Columba livia, Alectoris barbara, Columba palumbus, Streptopelia turtur,* and *Streptopelia decaocto* in various

habitats including steppes, forests, farmlands, rivers and dams in the eastern High Atlas. Equally, these natural landscapes and their avian richness could be used for ecotouristic purposes. Visitors could profit from the view of landscapes and observation of the most iconic and rare species. These experiences are very popular in Asia, for example, visitors to Thailand benefit from the urban green spaces and their avian population which supports ecotourism activities (Boruah et al 2021). Similarly, tree species and Cenderawasih bird activities are used by ecotourists in forests of Jayapura, Papua, Indonesia (Lahallo et al 2022). In our case, avian species were observed in various ecosystems. For example, *Streptopelia turtur* and *Columba livia* were observed in farmlands, including apples, olives, and cereals, while *Alectoris Barbara* was observed in steppes and wetlands. *Columba palumbus* was limited to forests, while *Neophron percnopterus, Aquila chrysaetos,* and *Gypaetus barbatus* were limited to high altitudes, and these are suggested to attract excursionists such as the visitors of Jbel El Ayachi and canyons of Jaafar in Eastern High Atlas.

5. Conclusions

In conclusion, this study added to our knowledge of the bird variety, their habitats, and the natural ecosystems in Morocco's eastern and High Atlas Mountains. This study offers the first and only in-depth analysis of the variety of ecosystems, the abundance of bird species, and species of interest to ecotourists in the High Atlas region of Morocco and throughout the entire Northwest of Africa. This study identified considerable populations of breeding migrants and residents, including key birds of ectouristic importance. Equally, we demonstrated the diversity of natural and human-made ecosystems and their roles toward avian species. These results could be of great interest for the implementation of future long-term monitoring and conservation measures, primarily to protect habitats and the most endangered bird populations, in addition to their potential importance for a potential future large-scale comparative investigation of biological diversity and its ecotouristic potential in other Moroccan and North African zones.

Ethical Considerations

We followed ethical guidelines for animals in the research.

Conflict of Interest

The authors declare no conflict of interest.

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