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Research Article

Large-Scale Monitoring of Bird Communities along an Altitudinal Gradient in Two Central High Atlas Valleys

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Altitude is one of the determinant factors that influence the spatial distribution of birds and their species richness. However, few investigations studied its influence on African bird communities over a wide gradient in North Africa. Considering this knowledge gap, 194 sampling points were carried out along altitudinal gradient (773 to 2595 m) in two adjacent mountainous valleys in the Central High Atlas of Beni Mellal in Morocco, Aït Bouguemmaz (AB), and Ahançal (OA). Each valley was divided into three altitudinal intervals (low, medium, and high zones). For each spatial subdivision, we studied the phenological cycle, in the sense that each valley underwent a four-season monitoring, during 2018 and 2019. The results showed 131 species in the study area in 43 families; both valleys had similar community richness, but they differed by the phenological status of their species. Indeed, the increase in altitude led to a decrease in bird species richness, while it does not show any correlation with abundance. In addition, richness and abundance increased during the high-productivity seasons (i.e., spring and summer). Although these results were expected, they provide an opportunity to compare these results with higher latitude communities in Europe and to better focus future large-scale investigations on the combined influence of latitude and altitude on birds.

1. Introduction

Biological diversity has become a matter of high global concern, mainly in regions with high biodiversity [1], due to high human and climate pressures. In the Mediterranean region, Morocco is well known for the high richness of its flora, fauna, and habitats [2–4]. This richness is due to the high diversity of country landscapes, as they vary from Saharan ecosystems to high mountainous ones and include some 3,500 km of marine coast [5–7]. This diversity is well evidenced by both vegetal and animal communities [2, 8, 9], among which birds are excellent indicators of habitats' health [10–12]. However, this group is still poorly studied in the high mountains of Morocco, in comparison to low altitudes, where several studies have been carried out in forest ecosystems [13, 14], wetlands [15, 16], and man-made landscapes [17]. Indeed, Moroccan mountain ecosystems have received little attention, despite their large extension from the Mediterranean coast to the Southern hamada and desert [18–20].

Bird distribution is influenced by several factors, including altitude [21–23]. Through its influence on the climate features [24, 25], altitude determines the zoning of habitats along the elevational gradient, mainly influencing the vegetation cover [26–28], with consequences on the vertical distribution and abundance of avian species [29–31]. This affects the shifting of the breeding phenology of the species which are distributed along a wide altitudinal range,

following the availability of foraging resources [32]. Generally, birds shift their arrival, breeding, and departure dates in highlands to avoid the harsh weather conditions [33–36].

In the Mediterranean area, the effect of the altitudinal gradient on avian communities was largely addressed on the European side, where studies have demonstrated that species diversity declines with increasing altitudes due to the influence of climate and decreasing temperatures that affect productivity, a key factor driving the variations in species richness [37, 38]. In Morocco, few investigations targeted the impact of altitude on mountain bird communities, which in turn indicate a decrease in species richness with increasing altitude: Cuzin [39] in the Western High Atlas, Mounir et al. [20] in the Central High Atlas, Mansouri et al. [36] in the Middle Atlas, and Qninba et al. [40] in the Anti-Atlas.

The present study aims to specifically analyse the variation of avian communities according to altitude in the Central High Atlas (Morocco) during the entire year. This approach is supposed to give new insights into the spatio-temporal patterns of the mountainous bird communities in an important biodiversity hotspot in North Africa.

2. Materials and Methods

2.1. Study Zone. Our research was conducted in the valleys of Oued Ahançal and Aït Bouguemmaz located in the Central High Atlas of Morocco in M'Goun Geopark and designated as Ramsar sites [41, 42] (Figure 1). The study area is located between an altitudinal range of 800 and 2600 m above sea level being characterized by a warm and temperate climate with an average annual temperature of 15°C [43] and high variations (500–800 mm per year) in rainfall throughout the year [44, 45]. The valleys are known for their rich and complex hydrographic networks including rivers, springs, and lakes [41, 42]. The most important rivers are those of Oued Ahançal and Lakhdar-Aït Bouguemmaz whose flows are primarily determined by several permanent springs and tributaries, as well as some creeks that are heavily influenced by seasonal rainfall and snowmelt.

The landscape of both valleys comprises forest formations of broad-leaved and coniferous trees, high-mountain vegetation, and agricultural areas, which depend on the elevation level. The Ahançal Valley is known for its abundance of water resources, the limited expansion of agricultural areas, and the predominance of its forest ecosystems. Notably, *Tetraclinis articulata*, *Quercus rotundifolia*, and *Juniperus phoenicea* dominate the low-altitude section between Bin El Ouidane lake and Tilouguite village. Tamga forest at medium altitudes comprises woodlands of *Pinus halepensis* mixed with *Juniperus phoenicea*, along with woody shrubs such as *Buxus balearica* and *Pistacia lentiscus*, with *Populus nigra* forming the riparian vegetation [46]. In the high-altitude section of the valley, *Juniperus phoenicea* prevails, accompanied by shrubs of *Buxus balearica*, and *Salix* sp. dominates the riparian vegetation in Zaouiat Ahançal and Taghia villages.

In Aït Bouguemmaz, from Agouti to Zaouiat Oulmzi village, the valley bottom is dominated by agricultural lands including apple orchards, walnuts, and cereals [47, 48]. The riparian vegetation is dominated by *Salix* sp., while the foothills of the valley are covered by juniper woodlands *Juniperus phoenicea* and *Juniperus thurifera* [49]. In high altitudes above 2200 m, from Zaouiat Oulmzi to Izourar Lake, steppic formations of xerophytic plants colonize the rocky slopes of the mountains [50].

Before starting our field investigations, we divided the study area into three altitudinal sections (Table 1). This altitudinal division was based on topographic features, bioclimatic stages, and an upstream-downstream sectorization of each studied valley [51–53].

2.2. Data Collection. To investigate the avifauna distribution and diversity, we adopted the point-count method with unlimited distance [54, 55] for terrestrial birds. The surveys were carried out during 2018 and 2019, in both breeding and nonbreeding seasons. A total of 194 sampling points were selected in both valleys (120 points in Oued Ahançal and 74 points in Aït Bouguemmaz). For each point, all birds seen or heard were recorded for 10 to 20 minutes and within unlimited distance around each sampling point [56, 57]. We located points 300 meters to 1 km apart from each other to avoid double counting. During the breeding season (March to June), the surveys were carried out within the first five hours after sunrise and in favourable weather conditions, knowing that this period corresponds to the maximum vocal activity of breeding birds. During the nonbreeding seasons (July to February), we extended the survey into the evening, just before sunset. For waterbirds (in Bin El Ouidane reservoir and Izourar lake), we proceeded by exhaustive counts. Species were identified using binoculars or vocal characteristics, while waterbirds were sometimes counted using a spotting scope. We boosted our surveys using other counting techniques to increase bird detectability, especially during the nonbreeding seasons when most species become less detectable and difficult to hear. In order to increase the chance of detecting birds, including secretive species (e.g., moorhens, rails, and wetland songbirds), nocturnal species (e.g., owls and nightjars), and rare birds, we used a mini Bluetooth speaker during the count period of the point count as a playback method [58, 59]. This device was specifically employed within dense habitats and submerged vegetation along the river's edge, and it was used carefully to minimize the disturbance without affecting bird's behaviour [60]. In addition, for the need of precise identification, we used a high shooting speed camera with a telephoto zoom lens and a sound recorder for later identification of unrecognized bird calls. For each observation point, the altitude and geographic coordinates were determined using an Android GPS tracker.

2.3. Statistics. For each valley, we recorded the species with their phenological and conservation statuses, and we estimated the representativity of families, in terms of the number of species and abundance. Then, we calculated diversity indices (Shannon–Wiener and Equitability) in each valley. Based on these parameters, we compared communities of the two valleys, using the independent samples *t*-test

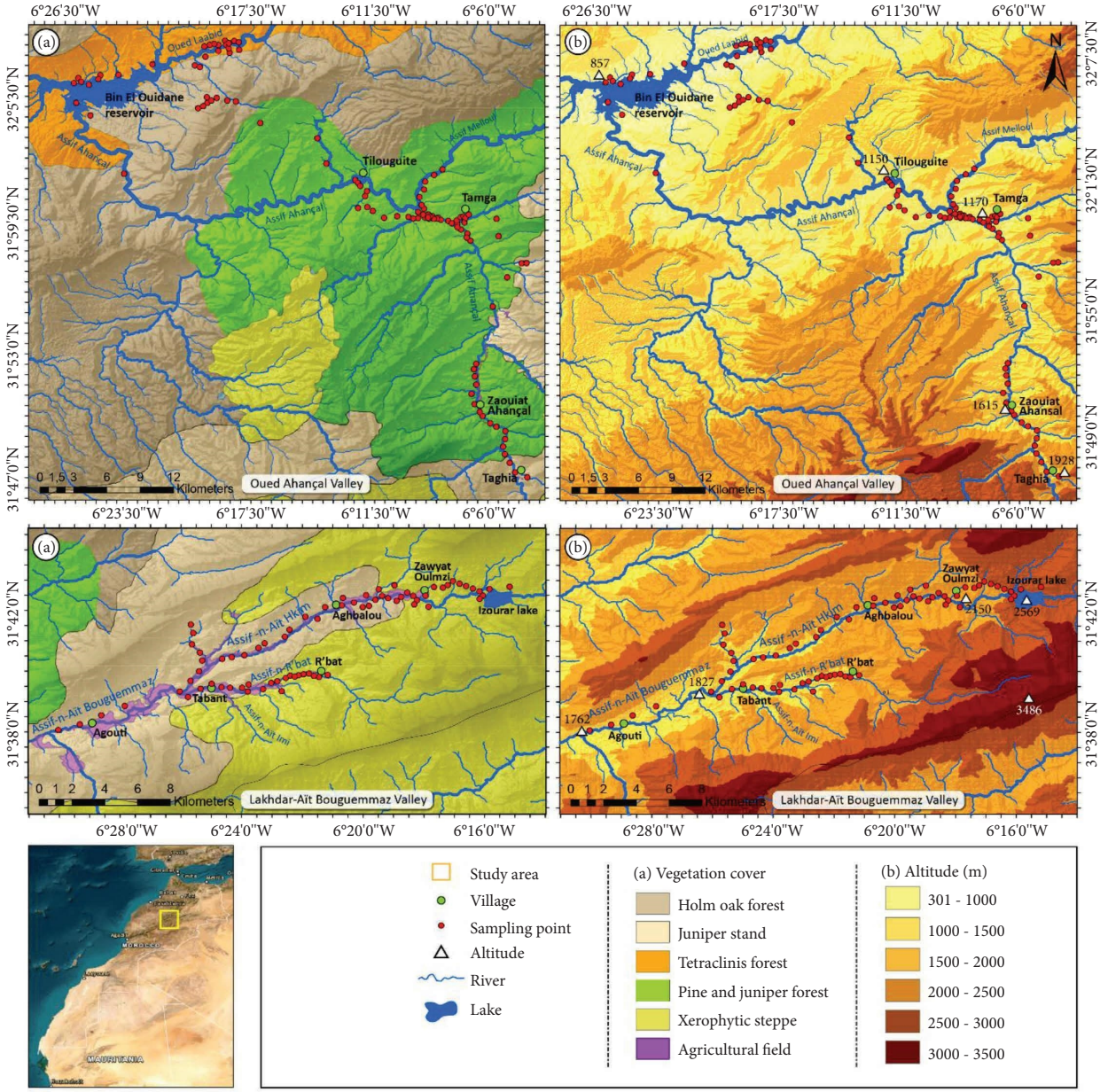

Figure 1: Location of the study area in Morocco showing vegetation covers (a) and altitude (b). Sampling points are shown with red dots.

Table 1: Altitudinal sections of each studied valley (Aït Bouguemmaz and Oued Ahançal).

Altitudinal section	Oued Ahançal (m)	Aït Bouguemmaz (m)
Low	773–1156	1826–2082
Medium	1156–1529	2082–2338
High	1529–1924	2338–2595

and the diversity of seasonal avian assemblages, using the ANOVA one-way test. This same method was also used to compare bird richness and abundance at fixed altitude sections. To evaluate the relationship between altitudinal gradient and both avian richness and abundance, we used a simple linear regression model, where altitudinal sections (ranges) were considered as the independent variable (Factor), while avian richness (number of species per altitudinal section) and population size (abundance of recorded species in each altitude section) were considered as dependent variables. To evaluate the spatiotemporal variation of distribution among studied species, we considered seasons ($n = 4$) and altitudinal sections as independent variables (factors) and the population sizes of avian species ($n = 131$) as dependent variables. Then, the data were analysed by factorial correspondence analysis (FCA) [61] using

the first two axes. Analyses were carried out in SPSS 21 [62], and significant values were considered at $p < 0.05$, while graphs were generated using GraphPad prism 8.3.0 [63].

3. Results

3.1. Status, Richness, and Abundance of the Avian Assemblages. During the two years, we recorded 131 bird species in both valleys, belonging to 43 families and 19 orders. Families with the highest richness were Muscicapidae (16 species), followed by Fringillidae (10 species) and Accipitridae (8 species). In contrast, Phalacrocoracidae, Meropidae, Coraciidae, Caprimulgidae, Upupidae, and Podicipedidae had the lowest richness, with one species each. Passeriformes recorded the highest richness, with 78 species, while the Suliformes, Caprimulgiformes, Bucerotiformes, and Ciconiiformes were the less diverse avian orders, with one species each (see Table 2).

Concerning the phenological status of the species, 104 of the recorded species are breeders in Morocco and 27 others are strictly visitors. Among the breeders, 72 species (69%) are residents, with five of them also being breeding migrants and/or passage migrants, with potential winterers, and 23 others are also winterers. The 32 other breeders (31%) are migrants, with passage visitors for nine of them only. Among the 27 strict visitors, seven only are strictly winterers and 20 are passage migrants, 11 of them having also wintering contingents (Figure SM A).

The most abundant species was *Fringilla coelebs* (4062 individuals), followed by *Cyanistes teneriffae*, *Pyrrhocorax graculus*, and *Pycnonotus barbatus*, with 1379 to 1093 individuals. High abundances were also recorded for seven species (*Serinus serinus*, *Passer domesticus*, *Pyrrhocorax pyrrhocorax, Ptyonoprogne rupestris, Turdus torquatus, Apus pallidus*, and *Columba palumbus*) (Figure SM B), while 101 species cumulated medium and low abundances (3–500 individuals) and 19 species were considered as accidental with 1-2 individuals (Figure SM C). Four species of conservation concern were recorded: two species are globally vulnerable (*Streptopelia turtur* and *Aythya ferina*) and two others are near-threatened species (*Lanius senator* and *Turdus iliacus*).

The independent samples *t*-test showed significant differences in terms of species abundance between the studied valleys (Table 3). In contrast, they were similar in terms of species richness, number of families, orders, and species of conservation concern. In addition, the phenological status varied between the two valleys in terms of resident breeders. However, breeding migrants, passage migrants, and winter visitors were not statistically different, even though Ahançal receives a higher number of visitors during migration periods, and Aït Bouguemmaz has more breeding migrants. Concerning diversity indices, no significant difference was observed, neither for the Shannon index nor for the equitability index.

3.2. Seasonal Variation. Seasonal variation of avian diversity in both studied valleys is displayed in Figure 2. The seasonal monitoring showed that the species richness in Oued Ahançal was significantly higher in spring (76 species), and summer (77 species) compared to winter (71 species) and autumn (54 species). The abundance was significantly higher in spring (4553 individuals), followed by autumn (3342) and winter (3187), while the summer season showed the lowest abundance (2861). Similarly, the species richness was significantly higher in summer (58 species) and spring (64 species) in Aït Bouguemmaz, compared to winter and autumn (47 and 42 species, respectively), while abundance was higher in spring (2405) and winter (2119), but that was lower in summer (792) and autumn (657).

Our comparative analysis with the ANOVA test did not show any significant differences in species richness in the Ahançal Valley ($F3.271 = 0.9514$, $P = 0.4162$) nor in species abundance ($F3.271 = 0.5984$, $P = 0.6166$). This suggests that the number of observed species and their abundance do not vary significantly from one season to another in this valley. However, in the Aït Bouguemmaz valley, the analysis revealed a difference in species richness between seasons ($F3.132 = 8.244$, $P < 0.0001$), while species abundance showed no difference ($F3.132 = 0.3055$, $P = 0.8214$).

3.3. Altitudinal Variation. The altitudinal variation of avian diversity in both studied valleys is presented in Figure 3. In Oued Ahançal, species richness was significantly higher in low altitudes (downstream part of the valley) compared to habitats of medium and high altitudes. In contrast, a higher abundance was recorded in high habitats (upstream part), followed by habitats of medium altitudes, and lowlands. In Aït Bouguemmaz, species richness was significantly higher in low altitudes (downstream part) compared to medium and high-altitude habitats, similar to Oued Ahançal Valley. However, the abundance of recorded species was significantly higher in low altitudes compared to medium and high altitudes.

The ANOVA test showed highly significant differences between the altitudinal sections for species richness (Ahançal: $F2.117 = 6.234$, $P = 0.0027$; Aït Bouguemmaz: $F2.71 = 13.24$, $P < 0.0001$) and for species abundance (Ahançal: $F2.117 = 10.89$, $P < 0.0001$; Aït Bouguemmaz: $F2.71 = 8.895$, $P = 0.0004$). This suggests that both species richness and abundance of birds vary significantly along the altitudinal gradient in the two studied valleys.

In both valleys, the species richness revealed a significant negative correlation with the increasing altitude, while no significant correlation was shown for the abundance (Figure 4 and Table 4).

3.4. Spatiotemporal Distribution. The distribution of avian species following altitudinal sections and seasons is presented in Figure 5. The first two axes of the FCA diagram accounted for 39.23% of the total variance. The first axis (explained by 20% of the variance) separated two groups of birds at the apex of the parabola (G2 and G3). The group (G3) includes species that are more commonly found at very high altitudes during the summer season, principally *Sylvia conspicillata*, *Rhodopechys alienus*, *Oenanthe hispanica*, *Anthus campestris*, and *Monticola saxatilis*. Group (G2)

Table 2: List of avian species recorded in both valleys (Aït Bouguemmaz and Oued Ahançal) of the Central High Atlas of Beni Mellal during 2018 and 2019.

Code	Scientific name	Common name	IUCN status	Phenology in Morocco				Total abundance
				RB	BM	PM	WV	
	Fringillidae							
FrCo	*Fringilla coelebs*	Common chaffinch	LC	✓			✓	4062
FrMo	*Fringilla montifringilla*	Brambling	LC				✓	7
CoC	*Coccothraustes coccothraustes*	Hawfinch	LC	✓			✓	125
LoxC	*Loxia curvirostra*	Red crossbill	LC	✓			✓	223
ChCh	*Chloris chloris*	European greenfinch	LC	✓			✓	103
LinC	*Linaria cannabina*	Common linnet	LC	✓			✓	333
CaC	*Carduelis carduelis*	European goldfinch	LC	✓			✓	196
SerS	*Serinus serinus*	European serin	LC	✓			✓	940
RhoS	*Rhodopechys alienus*	African crimson-winged finch	LC	✓				9
SpinS	*Spinus spinus*	Eurasian siskin	LC				✓	5
	Regulidae							
RegI	*Regulus ignicapilla*	Common firecrest	LC	✓			✓	50
	Malaconotidae							
TchS	*Tchagra senegalus*	Black-crowned tchagra	LC	✓				1
	Acrocephalidae							
HiP	*Hippolais polyglotta*	Melodious warbler	LC		✓			69
IdOp	*Iduna opaca*	Western olivaceous warbler	LC		✓			10
AcrBa	*Acrocephalus baeticatus ambiguus*	Barbary reed warbler	LC			✓		7
	Motacillidae							
MotC	*Motacilla cinerea*	Grey wagtail	LC	✓			✓	110
MotA	*Motacilla alba*	White wagtail	LC	✓			✓	74
MotFF	*Motacilla flava flavissima*	Western yellow wagtail	LC			✓		1
MotF	*Motacilla flava*	Western yellow wagtail	LC		✓			8
AnPr	*Anthus pratensis*	Meadow pipit	LC		✓	✓		7
AnCa	*Anthus campestris*	Tawny pipit	LC			✓		1
	Cettiidae							
CeC	*Cettia cetti*	Cetti's warbler	LC	✓				33
	Cisticolidae							
CiJu	*Cisticola juncidis*	Zitting cisticola	LC	✓				1
	Emberizidae							
EmSa	*Emberiza sahari*	House bunting	LC	✓				6
EmCia	*Emberiza cia*	Rock bunting	LC	✓			✓	338
EmCa	*Emberiza calandra*	Corn bunting	LC	✓			✓	100
EmCir	*Emberiza cirlus*	Cirl bunting	LC	✓				82
	Pycnonotidae							
PycB	*Pycnonotus barbatus*	Common bulbul	LC	✓				1093
	Corvidae							
GarG	*Garrulus glandarius*	Eurasian jay	LC	✓				122
CorM	*Corvus monedula*	Eurasian jackdaw	LC	✓				77
CorvC	*Corvus corax*	Northern raven	LC	✓				95
PyrP	*Pyrrhocorax pyrrhocorax*	Red-billed chough	LC	✓				889
PyrG	*Pyrrhocorax graculus*	Yellow-billed chough	LC	✓				1313
Pica	*Pica mauritanica*	Maghreb magpie	LC	✓				24
	Cinclidae							
CinC	*Cinclus cinclus*	White-throated dipper	LC	✓				18
	Alaudidae							
GT	*Galerida theklae*	Thekla's lark	LC	✓				51
LA	*Lullula arborea*	Woodlark	LC	✓				9
EA	*Eremophila alpestris*	Horned lark	LC	✓				29
	Sylviidae							
SylCons	*Sylvia conspicillata*	Spectacled warbler	LC	✓	✓	✓	✓	8
SyA	*Sylvia atricapilla*	Eurasian blackcap	LC	✓			✓	54
SyCo	*Sylvia communis*	Greater whitethroat	LC		✓			20
SyM	*Sylvia melanocephala*	Sardinian warbler	LC	✓				93
SyCa	*Sylvia cantillans*	Subalpine warbler	LC		✓			28

Table 2: Continued.

Code	Scientific name	Common name	IUCN status	Phenology in Morocco				Total abundance
				RB	BM	PM	WV	
	Turdidae							
TurTo	*Turdus torquatus*	Ring ouzel	LC				✓	596
TurM	*Turdus merula*	Eurasian blackbird	LC	✓				311
TurP	*Turdus philomelos*	Song thrush	LC				✓	46
TurI	*Turdus iliacus*	Redwing	NT				✓	1
TurVi	*Turdus viscivorus*	Mistle thrush	LC	✓			✓	14
	Hirundinidae							
HiRus	*Hirundo rustica*	Barn swallow	LC		✓			19
PtyRu	*Ptyonoprogne rupestris*	Eurasian crag martin	LC	✓			✓	656
CeDa	*Cecropis daurica*	Red-rumped swallow	LC		✓			3
DelU	*Delichon urbicum*	Northern house martin	LC		✓			166
	Oriolidae							
Oror	*Oriolus oriolus*	Eurasian golden oriole	LC		✓			38
	Paridae							
PerA	*Periparus ater*	Coal tit	LC	✓				203
ParM	*Parus major*	Great tit	LC	✓				320
CyT	*Cyanistes teneriffae*	African blue tit	LC	✓				1379
	Passeridae							
PasD	*Passer domesticus*	House sparrow	LC	✓				917
PEP	*Petronia petronia*	Rock sparrow	LC	✓				135
	Laniidae							
LanS	*Lanius senator*	Woodchat shrike	NT		✓			13
LanE	*Lanius excubitor*	Great grey shrike	LC	✓				5
	Phylloscopidae							
PhC	*Phylloscopus collybita*	Common chiffchaff	LC			✓	✓	36
	Muscicapidae							
ERu	*Erithacus rubecula*	European robin	LC	✓			✓	76
CeGa	*Cercotrichas galactotes*	Rufous-tailed scrub-robin	LC			✓		1
MuS	*Muscicapa striata*	Spotted flycatcher	LC		✓			86
Fs	*Ficedula speculigera*	Atlas flycatcher	LC		✓			7
OeL	*Oenanthe leucura*	Black wheatear	LC	✓				107
LusM	*Luscinia megarhynchos*	Common nightingale	LC		✓			79
PhoP	*Phoenicurus phoenicurus*	Common redstart	LC		✓			2
PhoM	*Phoenicurus moussieri*	Moussier's redstart	LC	✓				48
PhoO	*Phoenicurus ochruros*	Black redstart	LC	✓			✓	28
SaxBet	*Saxicola rubetra*	Whinchat	LC			✓		1
Saxbic	*Saxicola rubicola*	Common stonechat	LC	✓			✓	4
OeS	*Oenanthe seebohmi*	Atlas wheatear	LC		✓			13
OeH	*Oenanthe hispanica*	Black-eared wheatear	LC		✓			1
OeOe	*Oenanthe oenanthe*	Northern wheatear	LC			✓		1
MoSa	*Monticola saxatilis*	Rufous-tailed rock-thrush	LC		✓			7
MoSo	*Monticola solitarius*	Blue rock-thrush	LC	✓			✓	4
	Troglodytidae							
TrTr	*Troglodytes troglodytes*	Northern wren	LC	✓				74
	Accipitridae							
AqFa	*Aquila fasciata*	Bonelli's eagle	LC		✓			4
HierP	*Hieraaetus pennatus*	Booted eagle	LC		✓			8
CirAe	*Circus aeruginosus*	Western marsh harrier	LC	✓		✓	✓	2
AqCh	*Aquila chrysaetos*	Golden eagle	LC	✓				3
BuRu	*Buteo rufinus cirtensis*	Long-legged buzzard	LC	✓				14
MilM	*Milvus migrans*	Black kite	LC		✓			17
AcNi	*Accipiter nisus*	Eurasian sparrowhawk	LC	✓				15
CiPy	*Circus pygargus*	Montagu's harrier	LC			✓		1
CirGa	*Circaetus gallicus*	Short-toed snake-eagle	LC		✓	✓		4

Table 2: Continued.

Code	Scientific name	Common name	IUCN status	Phenology in Morocco				Total abundance
				RB	BM	PM	WV	
	Falconidae							
FalTi	*Falco tinnunculus*	Common kestrel	LC	✓		✓	✓	145
FalNa	*Falco naumanni*	Lesser kestrel	LC		✓			2
FalPe	*Falco peregrinus*	Peregrine falcon	LC	✓			✓	1
FalBi	*Falco biarmicus*	Lanner falcon	LC	✓		✓		1
	Rallidae							
GallC	*Gallinula chloropus*	Common moorhen	LC	✓				10
FulA	*Fulica atra*	Common coot	LC	✓			✓	182
RalA	*Rallus aquaticus*	Western water rail	LC	✓			✓	8
	Phalacrocoracidae							
PhCa	*Phalacrocorax carbo*	Great cormorant	LC				✓	15
	Meropidae							
MerA	*Merops apiaster*	European bee-eater	LC		✓	✓		121
	Coraciidae							
CoGa	*Coracias garrulus*	European roller	LC		✓	✓		95
	Strigidae							
AtNo	*Athene noctua*	Little owl	LC	✓				3
OtSc	*Otus scops*	Eurasian scops-owl	LC		✓	✓		2
StM	*Strix mauritanica*	Maghreb owl	LC	✓				2
	Cuculidae							
CuC	*Cuculus canorus*	Common cuckoo	LC		✓	✓		8
ClGl	*Clamator glandarius*	Great spotted cuckoo	LC			✓		3
	Recurvirostridae							
HimH	*Himantopus himantopus*	Black-winged stilt	LC			✓	✓	32
	Scolopacidae							
AcHy	*Actitis hypoleucos*	Common sandpiper	LC			✓	✓	24
TriOc	*Tringa ochropus*	Green sandpiper	LC			✓	✓	7
GalGal	*Gallinago gallinago*	Common snipe	LC			✓	✓	12
	Charadriidae							
ChDu	*Charadrius dubius*	Little ringed plover	LC	✓		✓	✓	13
	Caprimulgidae							
CapE	*Caprimulgus europaeus*	European nightjar	LC		✓			9
	Ardeidae							
ArCi	*Ardea cinerea*	Grey heron	LC			✓	✓	17
EgGa	*Egretta garzetta*	Little egret	LC			✓	✓	8
	Upupidae							
Upup	*Upupa epops*	Common hoopoe	LC		✓	✓		9
	Picidae							
DeM	*Dendrocopos major*	Great spotted woodpecker	LC	✓				45
PICv	*Picus vaillantii*	Levaillant's woodpecker	LC	✓				38
	Apodidae							
ApPa	*Apus pallidus*	Pallid swift	LC		✓	✓		515
ApAp	*Apus apus*	Common swift	LC		✓	✓		457
TacM	*Tachymarptis melba*	Alpine swift	LC			✓		66
	Phasianidae							
Abar	*Alectoris barbara*	Barbary partridge	LC	✓				97
CC	*Coturnix coturnix*	Common quail	LC	✓	✓		✓	15
	Columbidae							
Coli	*Columba livia*	Rock dove	LC	✓				445
CoP	*Columba palumbus*	Common woodpigeon	LC	✓				508
TurT	*Streptopelia turtur*	European turtle dove	VU		✓	✓		164
StrD	*Streptopelia decaocto*	Eurasian collared dove	LC	✓				37
SpilS	*Spilopelia senegalensis*	Laughing dove	LC	✓				1

Table 2: Continued.

Code	Scientific name	Common name	IUCN status	Phenology in Morocco				Total abundance
				RB	BM	PM	WV	
	Anatidae							
AnPl	*Anas platyrhynchos*	Mallard	LC	✓			✓	50
AnAc	*Anas acuta*	Northern pintail	LC			✓	✓	4
AnCr	*Anas crecca*	Eurasian teal	LC			✓	✓	32
Scly	*Spatula clypeata*	Northern shoveler	LC			✓	✓	48
AyFe	*Aythya ferina*	Common pochard	VU				✓	14
TadF	*Tadorna ferruginea*	Ruddy shelduck	LC	✓				293
	Ciconiidae							
CiCi	*Ciconia ciconia*	White stork	LC		✓			68
	Podicipedidae							
PodN	*Podiceps nigricollis*	Black-necked grebe	LC				✓	1

RB: resident breeder, BM: breeding migrant, PM: passage migrant, WV: winter visitor, LC: least-concern, VU: vulnerable.

Table 3: Independent samples *t*-test comparison between avian assemblages of the studied valleys.

Features	Oued Ahançal	Aït Bouguemmaz	*T* value	*P* value
Diversity				
Number of species	112	100	2.287	0.062
Number of families	41	36	0.333	0.750
Number of orders	18	16	0.187	0.858
Abundance	13943	5973	3.428	0.014
Conservation status				
Number of species	3	3	0.447	0.670
Phenological status				
Resident breeders	63	61	2.931	0.026
Breeding migrants	28	30	0.000	1.000
Passage migrants	28	18	1.490	0.187
Winter visitors	41	28	1.905	0.105
Diversity index				
Shannon_H	3.365	3.077	1.481	0.189
Equitability_J	0.713	0.668	0.657	0.536

comprises species recorded with higher abundances at high altitudes during the spring and autumn seasons, especially passerines (*Saxicola rubetra*, *Ficedula speculigera*, *Sylvia cantillans*, *Sylvia communis*, *Luscinia megarhynchos*, *Serinus serinus, Regulus ignicapilla,* and *Turdus merula*), birds of prey (*Falco tinnunculus*, *Falco naumanni*, and *Accipiter nisus*), and others (*Upupa epops*, *Gallinula chloropus*, and *Spilopelia senegalensis*). The second axis accounted for 19.24% of the variance, ordering avian species along an altitudinal gradient, forming a continuum from low to high altitudes showing a distinction of two groups at both ends of the scatterplot (G6 and G1). The group (G6) comprises winter visitors that visit low altitudes in this season, including ducks, shorebirds, and other waterbird species (*Anas acuta*, *Anas crecca, Aythya ferina*, *Spatula clypeata*, *Podiceps nigricollis*, *Gallinago gallinago*, *Fulica atra*, *Tringa ochropus*, *Phalacrocorax carbo*, *Egretta garzetta*, and *Circus aeruginosus*). The other group (G1) contains species that inhabit high-altitude habitats during winter, including winter visitor passerines such as *Fringilla montifringilla*, *Turdus iliacus*, and *Turdus torquatus*. The groups (G4 and G5) include species found at lower and medium altitudes, which are predominantly observable during spring, summer, and autumn, counting *Acrocephalus baeticatus ambiguus*, *Hippolais polyglotta*, *Iduna opaca*, *Oriolus oriolus*, *Tchagra senegalus*, *Spinus spinus*, *Motacilla flava*, *Coturnix coturnix*, and *Oenanthe oenanthe*. On the other hand, the middle of the diagram shows ubiquitous species such as *Fringilla coelebs*, *Chloris chloris*, *Emberiza cia*, and *Columba livia*, which occurred indifferently in all altitudinal sections and seasons.

4. Discussion

Here, we presented a pioneering contribution to the elucidation of avian diversity in the central regions of Morocco, where comprehensive investigations into mountain biodiversity are notably scarce. We integrated bird richness and abundance, and spatiotemporal distribution to examine avian zonation across altitudinal ranges in two Valleys of the Central High Atlas. Furthermore, this study provides new data on avian diversity and altitudinal zonation in mountainous habitats of global interest.

Our seasonal monitoring endeavours revealed that the Central High Atlas valleys of Morocco host an important avian diversity. In fact, 131 bird species were recorded in both studied valleys of Aït Bouguemmaz and Oued Ahançal, which represents nearly 23% of the total recorded species in the entire Morocco. This diversity is very similar to that mentioned in Moulouya valley between High Atlas and Middle Atlas of Morocco with 130 species [36] but higher compared to the 85 bird species recorded in the valley of Oued Bouhellou in the Eastern Middle Atlas [64], and 90 species recorded in Sefrou Mountains [65] and in other regions in Algeria: 78 species in Machroha Forest north-eastern part and 71 species in Merine forest, north-west of the country [66, 67]. However, it is still lower than the

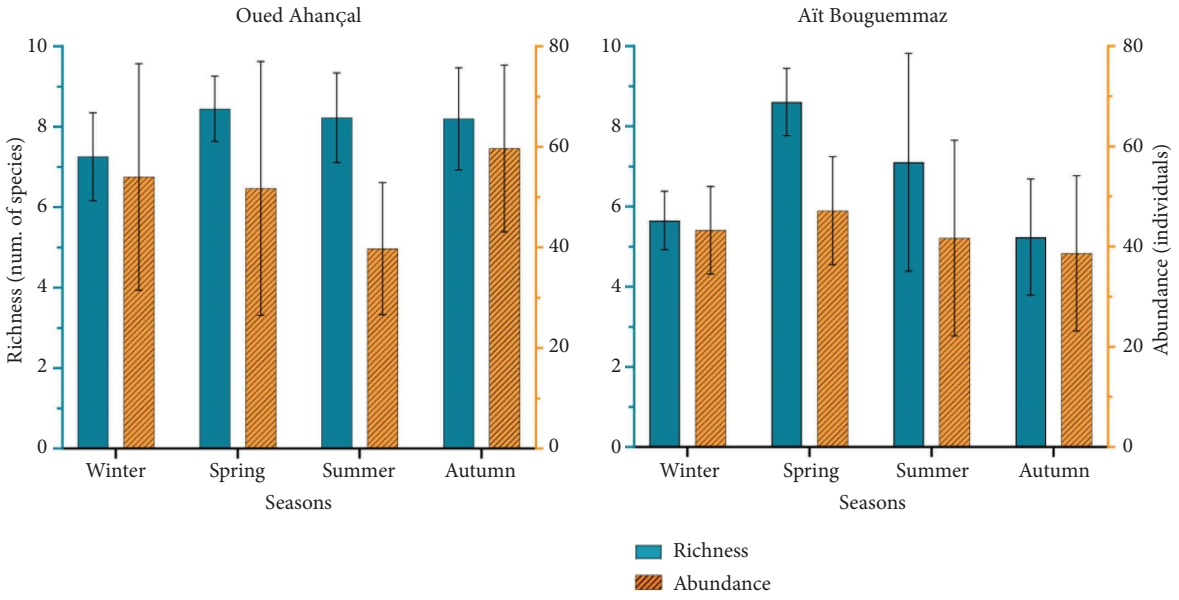

Figure 2: Seasonal variation of species richness and abundance in Aït Bouguemmaz and Ahançal valleys.

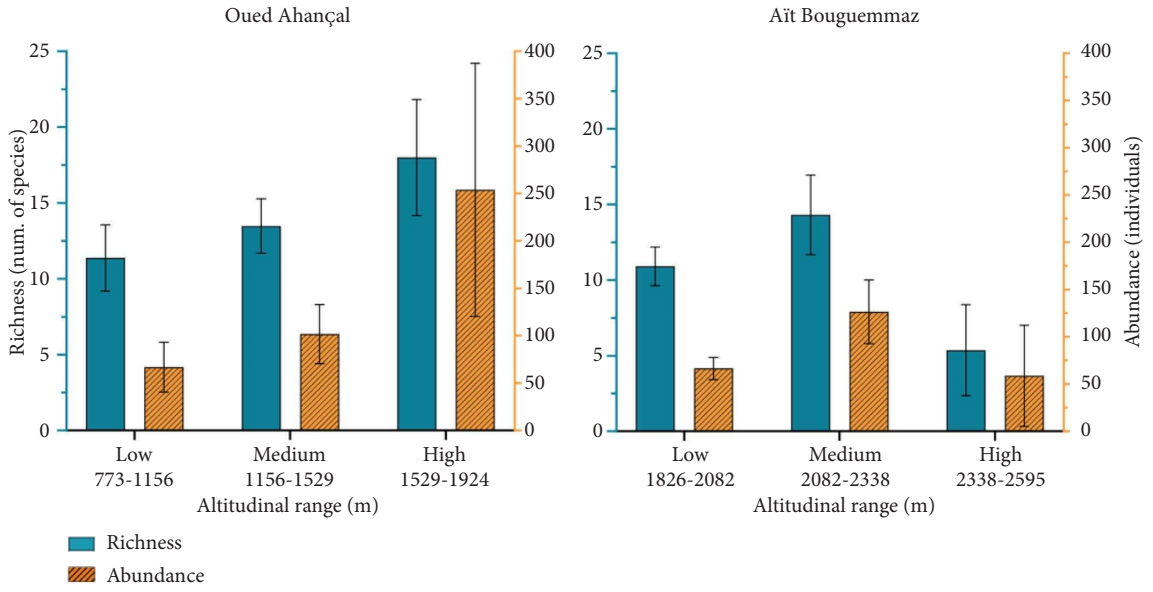

Figure 3: Altitudinal variation of species richness and abundance in Aït Bouguemmaz and Ahançal valleys.

diversity mentioned in other areas in Europe such as a Mediterranean semiarid region in Murcia (SE Spain) with 339 species recorded [68].

The most relevant findings are the records of the globally threatened species, such as the vulnerable *Streptopelia turtur* and *Aythya ferina* and the near-threatened *Lanius senator* and *Turdus iliacus*. *Streptopelia turtur* is widely recorded in central Morocco, counting Beni Mellal, in the High Atlas as a summer breeder [17, 20, 35]. *Turdus iliacus* is a regular winter visitor, typically found in moderate numbers across the Tangier Peninsula, Central Plateau, and Western Middle Atlas. Generally scarce and irregular further east and south, however, during some winters, it is more common in High Atlas valleys up to 2000 m above sea level [9, 69]. Concerning *Aythya ferina*, this is the first record in this high-altitude zone, but it was previously recorded in human-made reservoirs in the plain [16, 70]. These findings emphasize the need for immediate and thorough research to characterize their habitats in order to implement successful conservation strategies.

Both studied valleys are similar in terms of species richness, number of families, orders, and species of conservation concern, since both ecosystems are located in the same mountainous chain of the High Atlas [43, 71]. In contrast, species abundance and the phenological status of recorded birds were variable between valleys, with a higher number of resident breeders and winter visitors in Oued Ahançal compared to Aït Bouguemmaz Valley. This

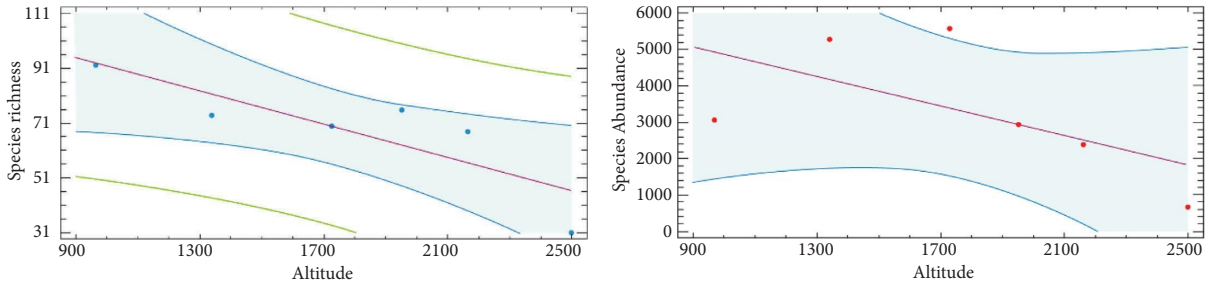

Figure 4: Relationship between species richness/abundance and altitudinal sections in the studied valleys of Aït Bouguemmaz and Oued Ahançal.

Table 4: Relationship between altitudinal sections, species richness, and abundance in Central High Atlas valleys.

Source	Sum of squares	*Df*	Mean square	*F* ratio	*P* value
Abundance	6.30*E* + 06	1	6.30*E* + 06	2.31	0.2029
Residual	1.09*E* + 07	4	2.72*E* + 06		
Richness	1452.48	1	1452.48	9.76	0.0354
Residual	595.015	4	148.754		

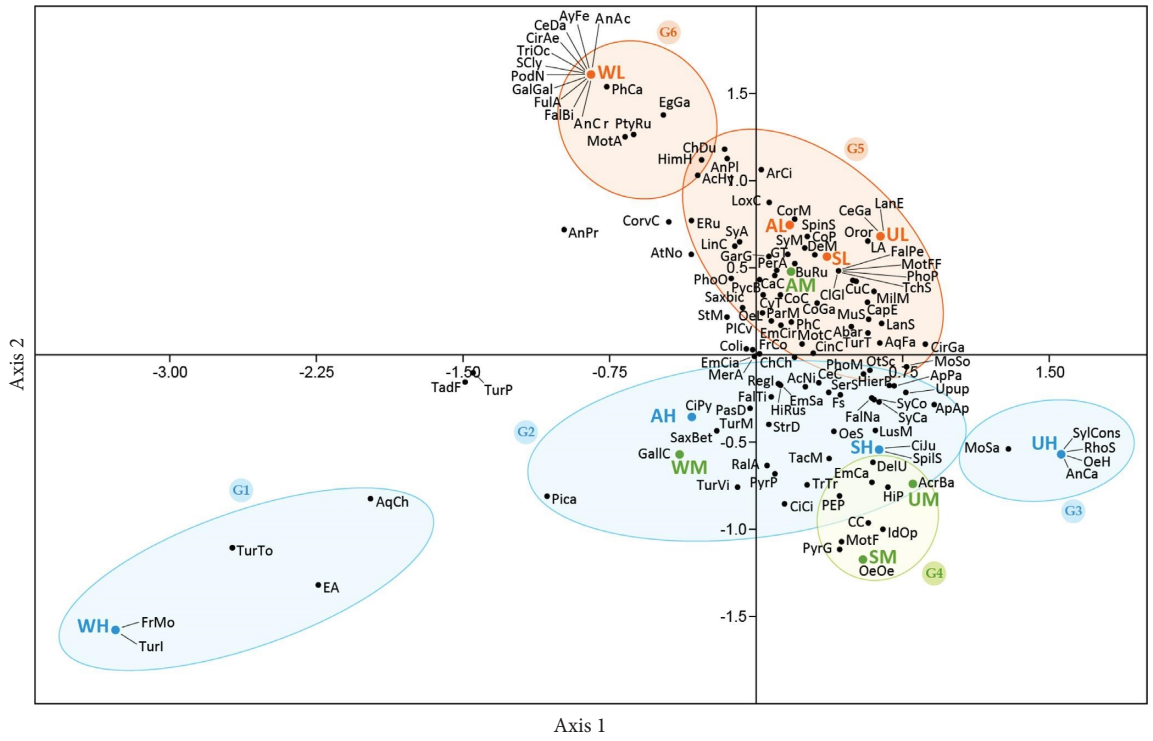

Figure 5: Ordination of avian species in the first two axes of a factorial correspondence analysis showing the global altitudinal and seasonal variation in Aït Bouguemmaz and Ahançal valleys (A-autumn, W-winter, S-spring, U-summer, L-low altitudes, M-medium altitudes, and H-high altitudes) (see Table 2 for full species names).

variation is governed by the features of the studied valleys. In Oued Ahançal, the higher numbers of winterers and resident breeders were closely related to the presence of aquatic ecosystems (springs, rivers, and the reservoir of Bin El Ouidane) and forest stands (mainly *Pinus halepensis*, *Juniperus phoenicea*, and *Populus nigra*) which are known for their roles in supporting European migratory birds during winter in Morocco, as well as providing foraging resources and nesting sites for local bird species that breed in forest ecosystems [20, 72]. In contrast, the existence of sparse and degraded juniper stands as well as the domination of agroecosystems in Aït Bouguemmaz [49, 73], such as apple

orchards and cereals are suggested to influence negatively the diversity of birds because of the reduction of breeding and foraging resources which are considered necessary elements for birds. In addition, the concentration of human habitations and the agricultural activities such as the use of pesticides in agricultural fields affect the abundance and diversity of many passerines such as *Turdus merula* and *Serinus serinus* [36, 74–76].

This study showed a seasonal variation of avian diversity between both valleys of the Central High Atlas, which was one of the neglected aspects of avian diversity studies in the High and Middle Atlas Mountains of Morocco, as well as in the entire North Africa [20, 64, 76].

In terms of species richness, the higher diversity of birds during spring and summer is possibly due to the abundance of breeding species that nest during spring and summer as mentioned by Mounir et al. [20] in the same valleys. The authors have recorded 92 breeding birds in spring and summer in 2018 and 2019. Equally, Mansouri et al. [77] and Wakass et al. [78] documented 98 breeding species in the spring and summer seasons in the east of High Atlas near Midelt, which is only about 120 km from our study area.

Our results showed significant variation of avian distribution in the Central High Atlas in studied valleys under the combination of altitudes and seasons factors. The first axis of the ordination diagram separates a group of resident and migrant species (G3) that occur in high-mountain xerophytes in summer including *Sylvia conspicillata*, *Rhodopechys alienus*, *and Monticola saxatilis*, from many species (G2) that occur in spring and autumn in the same altitudinal section, principally in juniper stands and agricultural fields of Aït Bouguemez valleys. The very low species richness in the high formations of xerophytic steppes is in agreement with previous studies carried out in the same valleys of the Central High Atlas [20] and in the Western High Atlas [39]. In this context, the stringent environmental conditions of high altitude (low temperature and lack of food resources) combined with the spatial dynamics described by certain theories such as the mid-domain effect hypothesis (MDE) could explain the low species diversity in these mountainous areas [22].

The second axis of the diagram shows that birds follow an altitudinal gradient from low to high altitudes. During winter, the Bin EL Ouidane reservoir situated in the low-altitude section attracts divers number of waterfowl and other waterbird species including Recurvirostridae, Scolopacidae, and Charadriidae (G6), as opposed to the mountain lake of Izourar located in high altitude at 2569 m above sea level, where *Tadorna ferruginea* was the only observable waterbird with more than 200 individuals. Even though this lake shows tens of visitors of this species following precipitation events, its neighbouring lands seem unfavourable as breeding habitat for this duck, in contrast to the Bin El Ouidane reservoir in lowlands, which contains submergent vegetations in the upstream part, offering favourable breeding or wintering grounds for many species including the globally vulnerable *Aythya ferina* [79, 80]. The other group (G5) includes more than 20 species with high abundance in low altitudes during spring, summer, and autumn (mainly *Spinus spinus*, *Periparus ater*, and *Sylvia atricapilla*) which were widely abundant in coniferous stands (*Pinus halepensis* and *Juniperus phoenicea*) and woody shrubs of *Buxus balearica* and *pistacia lentiscus*. This vegetation type has a high coverage in this altitudinal range, offering significant nesting substrates and foraging resources to these species. Similar results were reported by the authors of [81] who documented *Spinus spinus* in low-altitudinal ecosystems of Barcelona (500–600 m), Catalonia, north-eastern Spain, and [82] who mentioned the occurrence of diving waterbirds including the globally vulnerable *Aythya ferina* in Oued Fez (400 to 500 m, central Morocco). However, the seasonal variation of these species in this altitudinal section is a new aspect that needs more advanced investigations.

In medium-altitude habitats, 10 avian species (G4), principally *Acrocephalus baeticatus ambiguus*, *Hippolais polyglotta*, and *Iduna opaca*, were recorded during spring and summer. During our study, the three mentioned species of Acrocephalidae were recorded in dense vegetation along the river course (e.g., *Salix purpurea*, *Rubus ulmifolius*, and *Nerium oleander*). The high coverage of this riparian vegetation in such altitudinal range provides important sites for food and nesting for these species. This finding aligns with results mentioned in medium altitudes between the Western High Atlas and the Middle Atlas near Midelt for *Hippolais polyglotta* [36] during spring and summer. Additionally, similar observations were made for *Acrocephalus baeticatus ambiguous*, which was reported currently as a breeder in medium-altitudinal habitats of Arroyo Ardachón in southeast of Spain [83].

High-altitude habitats witness the arrival of winter passerines including *Fringilla montifringilla, Turdus iliacus,* and *Turdus torquatus*, in addition to the occurrence of other resident species with higher abundance in winter, counting *Eremophila alpestris* and *Aquila chrysaetos* (G1). These are in agreement with results reported by Cuzin [39], Sánchez-Zapata et al. [84], Clouet et al. [85], Bautista et al. [86], Mansouri et al. [36], and Shakya et al. [87] who characterized the habitats of these species in Mediterranean mountains including those of Morocco in the Southern Slope.

5. Conclusion

This study highlights for the first time the avian diversity and abundances according to the altitudinal and seasonal variations in two valleys of the Central High Atlas Mountains and Northwest Africa, which host important avian diversity and significant bird communities. However, bird richness and abundance vary seasonally and follow the altitudinal gradient. Despite the significant contribution of this paper to the knowledge of poor-studied mountainous avian communities in Morocco and North Africa, more investigations are needed to clarify the effects of habitat features, human presence, and agricultural practices on avian species in these mountainous areas.

Data Availability

The data used to support the findings of this study are included in the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Supplementary Materials

Figure SM A: phenological status of bird species observed in the two valleys of the Central High Atlas of Beni Mellal (Oued Ahançal and Aït Bouguemmaz). Figure SM B: abundance profile of avian species recorded in Oued Ahançal and Aït Bouguemmaz valleys. Figure SM C: abundance classes of avian species in the global avifauna assemblage of Oued Ahançal and Aït Bouguemmaz valleys. (*Supplementary Materials*)

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