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Distribution patterns, acoustic-external features, and ecological niche modelling of the pale bent-wing bat, *Miniopterus pallidus* (Chiroptera: Miniopteridae) in Iran

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Abstract

In this review, we summarize the historical and recent knowledge on the distribution and ecology of the pale bent-wing bat (*Miniopterus pallidus*) in Iran. We revisit earlier records and incorporate 14 newly identified localities documented between 2014 and 2017. To explore the species' ecological preferences, a presence-only niche model was developed using MaxEnt, which showed strong predictive performance (AUC = 0.85; regularized gain = 0.67), with annual precipitation contributing 81.7% to the model. The predicted distribution aligns closely with montane regions of the Zagros and Alborz Mountains, highlighting the role of topography and climate in shaping the species' range. We further review available data on the species' acoustic characteristics and present new echolocation call parameters from 44 individuals across six localities. The recorded FM-type calls suggest adaptation to relatively open habitats. Additionally, external morphological measurements from 96 individuals at ten localities showed no significant sexual dimorphism across 13 traits. This integrative review provides updated insights into the spatial ecology, bioacoustic features, and potential habitat suitability of *M. pallidus* in Iran, emphasizing the value of combining historical data with recent field records and modelling approaches for conservation-oriented assessments.

Keywords: distribution, niche modelling, morphological, acoustic, echolocation.

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INTRODUCTION

The bat fauna of Iran has been increasingly studied over the years, with the number of recorded species rising steadily. Earlier studies reported about 38 species (DeBlase, 1980), which later increased to 45 species (Karami et al., 2008) and subsequently to 49 species (Benda *et al.*, 2012). The first record of Nathusius' Pipistrelle, *Pipistrellus nathusii* (Naderi *et al.*, 2017), brought the total to 50 species. The most recent assessment of bat diversity in Iran reports a total of 51 species, with the latest addition being *Rousettus leschenaultii* (Chiroptera: Pteropodidae) reported by Mohammadi *et al.* (2022).

Since early 21st century, research on bats in Iran has gone beyond simply listing species. More focus has been put on their biology and ecology, including distribution patterns, acoustic features, external morphology, habitat suitability modeling, and phylogeography and phylogeny (e.g., Sharifi *et al.*, 2000; Akmali *et al.*, 2015; Sharifi & Javanbakht, 2017; Mehdizadeh *et al.*, 2018; Shahabi *et al.*, 2019; Yousefi & Sharifi, 2020; Mehdizadeh *et al.*, 2021). These studies have helped improve our understanding of the life history and conservation needs of species like *Miniopterus pallidus*, which is the main focus of this study.

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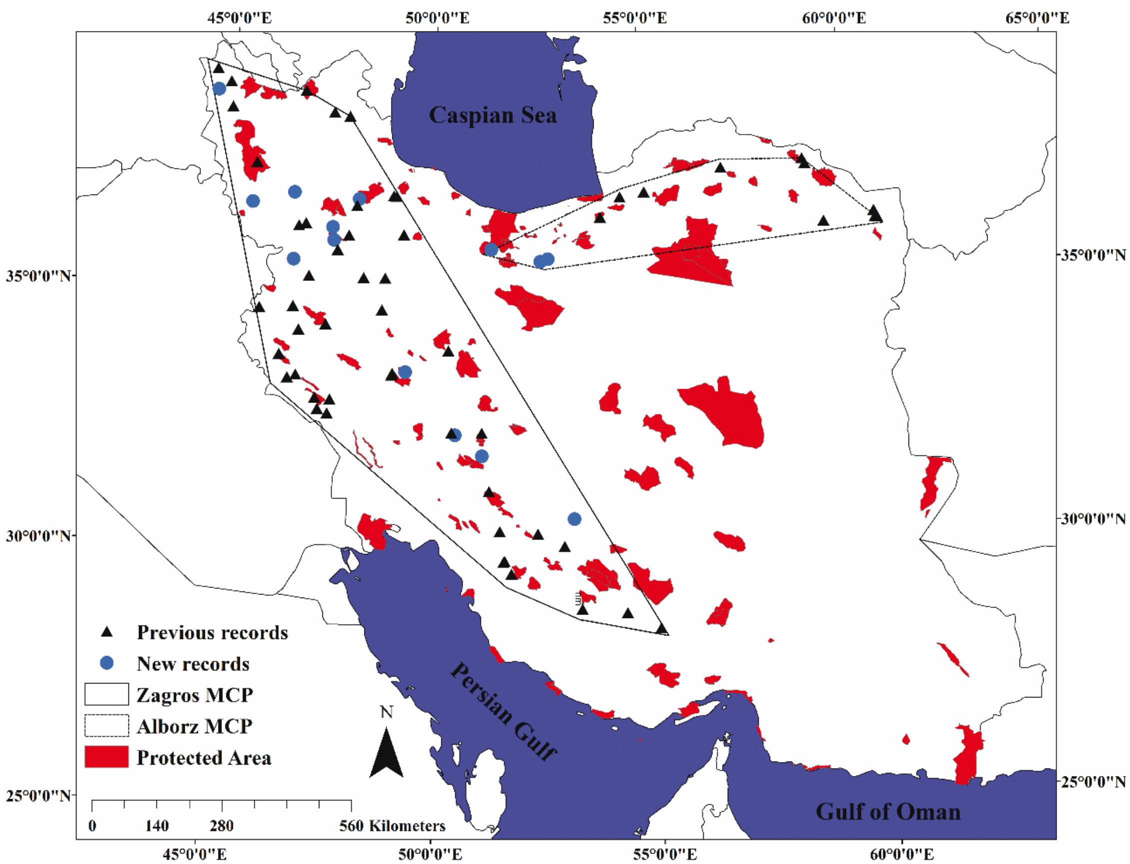

FIGURE 1. Geographical distribution of *Miniopterus pallidus* in Iran portrayed by two separate minimum convex polygons (MCP) encompassing all localities along Zagros and Alborz Mts. Blue circles illustrate new record (Appendix I) obtained in present study and black triangles present previous records (Appendix II) from published data. Areas depicted with red representing protected areas.

The Miniopteridae family comprises a singlegenus, *Miniopterus*, which includes around 30 recognized species (Monadjem *et al*., 2020). Members of this genus, commonly known asbent-winged bats, are distinguished by their unique wing morphology—specifically, the second phalanx of third finger is approximately threetimes longer than first (Nowak, 1994). These bats have short, slightly rounded ears with a moderate posterior fold and a short, blunt tragus curved slightly forwards (Srinivasulu *et al*., 2010). Their fur is typically black or dark brown, occasionally displaying reddish patches or entirelyreddish coloration (DeBlase, 1980). All *Miniopterus* species are medium-sized insectivorous bats with strong morphological similarities, which can make species-level identification difficult (Francis & Barrett, 2008). While forearm length and body weight may help distinguish individuals,skull measurements are often required for definitive identification (Francis & Barrett, 2008). Although pelage coloration may varybetween some species (Harrison, 1956), there is also considerable variationwithin species (Lewis & Harrison, 1962). The pale bent wing bat, *Miniopterus pallidus*, was first recordedby Thomas (1907), who identified it as *Miniopterus schreibersii* near Bandar-i-Gaz in northern Iran. Later, Lay (1967) described it as as *M. schreibersii pallidus* based on specimens from Shiraz (Shahpur cave) in southwestern Iran. In 1980s, DeBlase expanded its known distribution by listing additional localities inwestern and northwestern Iran. Subsequent records were provided by Benda *et al*. (2006, 2012) and Fathipour *et al*. (2014, 2016). Historically, there has been considerable uncertainty regarding thetaxonomic status of *M. pallidus* in Iran and neighboring countries. However, recent studies suggest that *M. schreibersii* species complex in southwestern Palaearctic and supraSaharan Africa comprises two main lineages: the nominotypical *M. schreibersii*, distributed in Europe, supra-Saharan Africa, western Asia Minor, and *M. pallidus* found in southwestern Asia (including Iran, eastern Asia Minor), and eastern Afghanistan (Bilgin *et al*., 2008; Furman *et al*., 2010; Šrámek *et al*., 2013; Akmali *et al*., 2015). In Iran, *M. pallidus* has beenreported from various regions including the north, west, northeastern (DeBlase, 1980; Benda *et al*., 2006, 2012; Akmali *et al*., 2015; Malekpourfard & Akmali, 2022).

Species distribution models (SDMs) are widely used tools for predicting suitable habitats based on environmental variables and presence records, and are increasingly important in conservation biology (Tsoar *et al*., 2007; Elith & Leathwick, 2009). Among these, MaxEnt (Phillips *et al*., 2006) is one of the most effective methods, particularly suitable for species with limited occurrence data (Wisz *et al*., 2008; Engler *et al*., 2004). In recent years, these approaches have been increasingly applied in Iran to study the distribution and ecological preferences of various bat species, which play critical roles in maintaining ecosystem balance. For instance, Najafi *et al*. (2018) used SDMs to estimate the potential distribution of the Mediterranean horseshoe bat (*Rhinolophus euryale*), while Shahabi *et al*. (2019) focused on the greater horseshoe bat (*Rhinolophus ferrumequinum*), both highlighting habitat suitability patterns based on present climatic variables. In another study, Kafaei *et al*. (2021) assessed the ecological niche breadth and projected future range shifts of *Rhinopoma muscatellum* under various climate change scenarios, revealing the heightened vulnerability of arid and semi-arid mountain ecosystems in Iran. Furthermore, Mehdizadeh *et al*. (2018) combined molecular markers and environmental data to study population structure *Miniopterus pallidus*, showing that climatic variables such as temperature and precipitation influence genetic differentiation by limiting gene flow and promoting local adaptation. Collectively, these studies demonstrate the value of SDMs for understanding habitat dynamics, identifying conservation priorities, and predicting species responses to climate change, particularly in biologically diverse and climatically sensitive regions like Iran.

In present study our main objectives were (i) to delineate the species range and present additional records of *M. pallidus* from Iran, (ii) to characterize information on the external characteristics and acoustic features of the species in different parts of the country and (iii) to generate predicted habitat with only existing presence records using MaxEnt software.

MATERIAL AND METHODS

Study Area and Distribution

Iran, encompassing approximately 1,648,195 km², is geographically positioned at the intersection of Mediterranean and arid Central Asian climatic zones. The country's topography is dominated by prominent mountain ranges, including the Zagros Mountains—extending over 2,000 km from Turkey to the Strait of Hormuz—the Alborz Mountains, characterized by an elevated (>5000 m), narrow (~100 km wide) belt along the southwestern and southern coasts of the Caspian Sea, and the Kopet Dag range, a linear mountain belt spanning approximately 700 km from the southeastern Caspian Sea to the Afghanistan border (Tavakoli, 2007; Hollingsworth *et al*., 2006). These montane systems harbor extensive cave networks, which constitute critical habitats for diverse bat species, including the pale bent-wing bat, *Miniopterus pallidus*.

Between 2014 and 2017, systematic field surveys were conducted targeting caves and crevices within the mountainous regions of western, northern, and eastern Iran. In total, 24 caves were examined, 14 of which were surveyed for the first time. All records were mapped and are included in Appendix 1. Geographical position for each cave was recorded using a Garmin GPS unit (GPSMAP 60CSx; Garmin International, Inc., city, state, USA). Bats were netted with mist nets (6 × 3 m) placed on caves entrances or collected using hand nets. In addition, air temperature and humidity were measured in the field and inside caves using a digital thermo-hydrometer. Minimum convex polygons (MCPs) for species localities were created using ArcGIS 10.3 software. The extent of MCPs and their associated protected areas encompassing the Zagros and Alborz Mts. were calculated separately. Published data for *Miniopterus pallidus* were compiled from the scientific literature, including DeBlase (1980), Karami *et al*. (2008), Benda *et al*. (2012), and Fathipour *et al*. (2014, 2016).

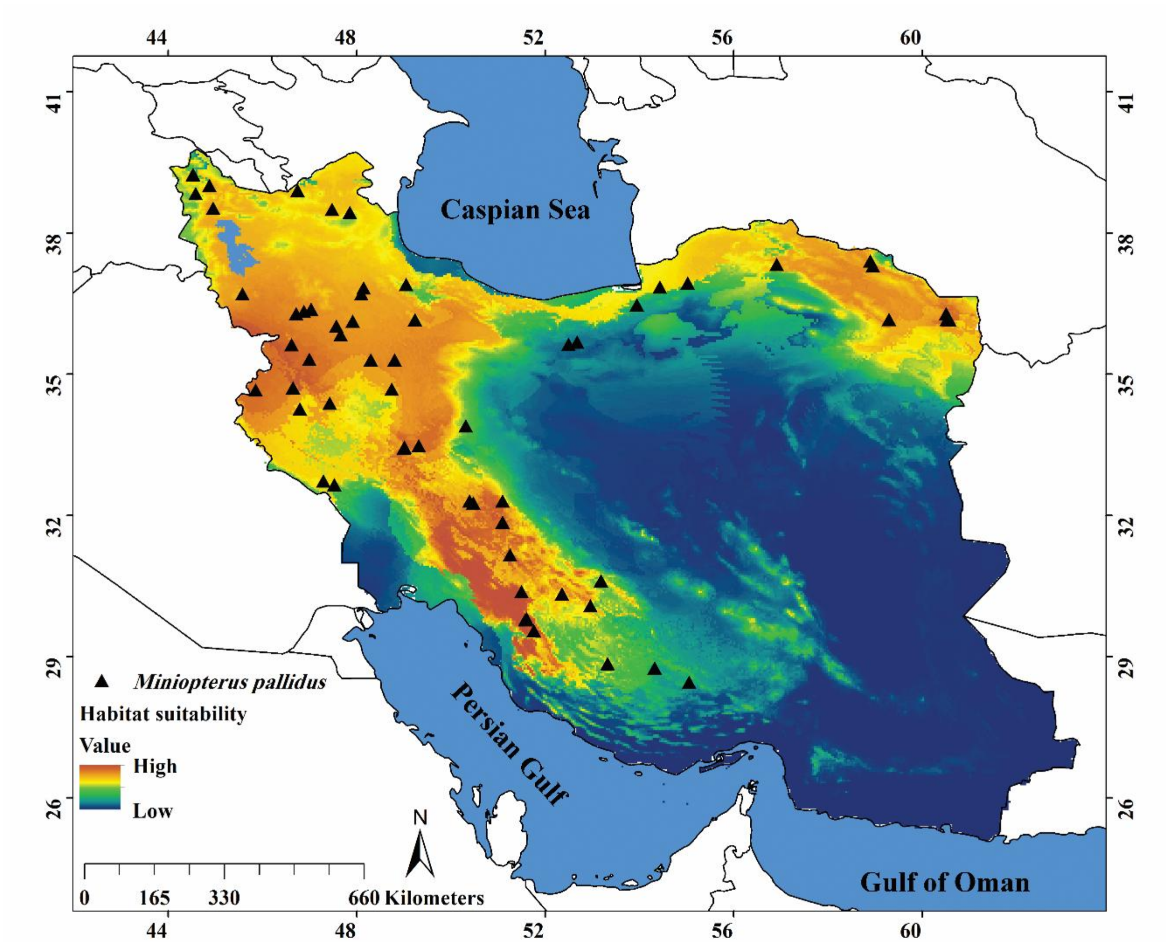

FIGURE 2. Presence records (triangles) in Iran considered for the development of a maximum entropy model (MaxEnt) predicting habitat suitability for *Miniopterus pallidus*.

Ecological niche modelling

We used SDM with the program MaxEnt (Phillips *et al*. 2006) in order to predict the distribution of suitable habitat for *M. pallidus*. The distribution records of *M. pallidus* in Iran were based on 64 localities shown in Figure 1. Climatic data representing contemporary climate conditions (~ 1960–1990) were obtained from WorldClim, version 1.4 (http://www.worldclim.org/) at a spatial resolution of 2.5 arc-minutes (~ 4.5 km). We used all 19 standard bioclimatic variables (BIO1–BIO19), which describe various aspects of temperature and precipitation relevant to ecological and evolutionary processes. These variables were subsequently processed usingArcGIS 10.3 to derive the bioclimatic variables. A full description of the variables is available on the WorldClim website. We used experiment designer ENMTools software version 1.3 to detect correlation values higher than 0.8. The following environmental variables were included in the models: BIO2 (Mean Diurnal Range, Mean of monthly), BIO3 (Isothermality (BIO2/BIO7) (*100)), BIO4 (Temperature Seasonality), BIO5 (Max Temperature of Warmest Month), BIO8 (Mean Temperature of Wettest Quarter), BIO12 (Annual Precipitation), BIO15 (Precipitation Seasonality) and BIO18 (Precipitation of Warmest Quarter).We ran 10 model replications and selected replicate with the highest test and train AUC percentages as the appropriate model. Model performance was evaluated based on the area under the curve (AUC) of the receiver operator characteristics (ROC) value. AUC values between 0.7 and 0.8 indicate acceptable model performance, values between 0.8 and 0.9 indicate good performance, and values above 0.9 indicate excellent performance (Elith *et al*. 2006; Phillips *et al*, 2006).

TABLE 1. New records of the pale bent wing bat, *Miniopterus pallidus*, with other bat species in 14 caves in Iran. Presence of bats is depicted by present records (+) and ■ previous records.

No	Cave	*M. pallidus*	*M. blythii*	*M. capaccinii*	*P. macrobullaris*	*R. ferrumequinum*	*R. hipposideros*	*R. mehely*	No Species
1	Alisheikh	+	+		+	+	+		5
2	Dehbokr	+	+	+		+		+	5
3	Jabiglu	+				+			2
4	Kamtaran	+				+		+	3
5	Katale khor	+	+			+	■		4
6	Ghar Darwish Olia	+				+			2
7	Salavatabad	+				+			2
8	Nesar	+	+			+			3
9	Rudafshan	+	■						2
10	Bornik	+	+						2
11	Imamzadeh Davood	+							1
12	Ghar-e-Agha seyyed isa	+				+			2
13	Eshkaft-e Zolaikha	+	■				■		3
14	Shoparak	+	+			+		+	4

TABLE 2. External body measurements (mm) of male and female *Miniopterus pallidus* sampled in present study. n, number of bats which were measured.

External features	n	Male	Number	Female	p-value
HB	27	53.48 ± 2.47	26	53.58 ± 2.38	0.38
T	22	59.09 ± 1.67	26	58.56 ± 1.52	0.74
HF	31	21.09 ± 0.50	18	21.12 ± 0.94	0.12
E	17	10.46 ± 0.46	13	10.29 ± 0.66	0.57
Tr	13	5.12 ± 0.31	9	5.27 ± 0.40	0.52
D4P1	27	10.20 ± 0.58	12	9.80 ± 0.62	0.18
D4P2	25	17.46 ± 0.94	12	18.10 ± 0.53	0.65
D3P1	27	11.10 ± 0.34	12	11.20 ± 0.72	0.12
D3P2	27	37.80 ± 0.92	12	37.76 ± 0.67	0.23
D4M	24	41.37 ± 0.74	9	42.20 ± 0.61	0.46
D3M	30	42.93 ± 0.77	27	42.80 ± 0.19	0.59
FA	52	46.40 ± 0.95	34	46.37 ± 0.98	0.07
WE	11	7.45 ± 0.29	5	7.64 ± 0.36	0.06

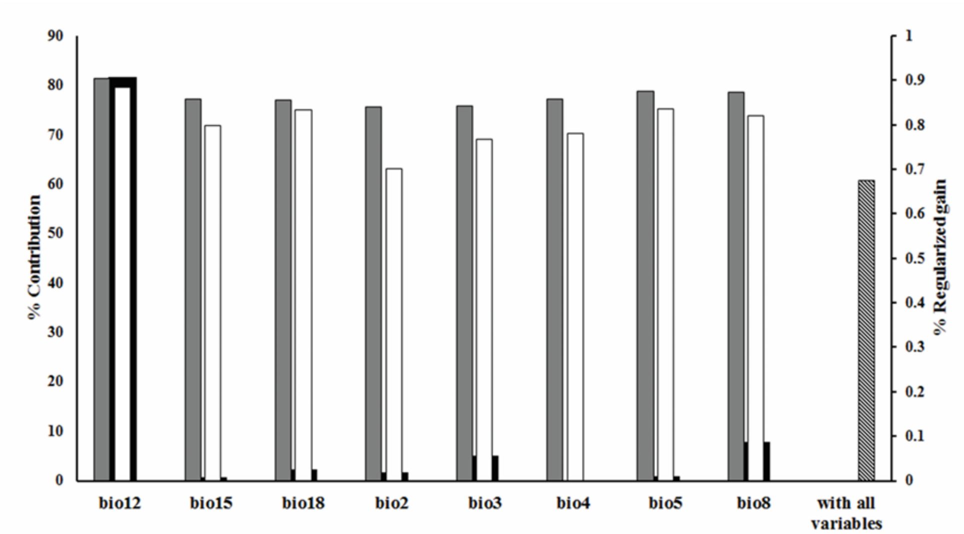

FIGURE 3. Contribution provided by the eight environmental variables considered to develop the MaxEnt model for *Miniopterus pallidus*. Black bars show the percentage contribution of each variable to the model and corresponding values are given on the left axis. Jackknife results for the model (values on the right axis) are also shown for single variables (white), for all variables except the one selected (grey) and for all variables (diagonal shade).

The MaxEnt model produced continuous habitat suitability maps for *Miniopterus pallidus*. These maps were reclassified into binary presence-absence maps, where areas with suitability values above a selected threshold were classified as suitable (presence = 1), and those below as unsuitable (absence = 0). This classification enabled identification of regions with favorable climatic conditions for *M. pallidus* populations.

External features

Live bats were sexed, aged and their external characteristics measured at ten sites including, Alisheikh, Dehbokr, Karaftu, Kilasefid, Mahidasht, Cara Tarik, Ghanjekuh, Mozduran, Sarab, and Tadovan caves (Table1, Appendix 1). Bat species identification was based on the criteria described by DeBlase (1980). Following body measurement and echolocation recording, all bats were released to their roost. Thirteen external body measurements were taken from 96 live bats using calipers. These measurements included: length of forearm (FA); length of ear (EAR); width of ear (WE); length of head to body (HB), length of tail (T); length of hind foot (HF); the metacarpal of the third and fourth digit (D3M, D4M); first phalange of the third and fourth digit (D3P1, D4P1); two phalange of the third and fourth digit (D3P2, D4P2); Length of tragus from base to tip (Tr).

Acoustic recordings

Acoustic recordings were carried out using an ultrasonic bat detector (Petterson Ultrasound Detector D240x) connected to an ultrasound recorder (EDIROL R-09), employing a time expansion of 10× to 1.7 seconds. We recorded calls of adult bats at Alisheikh, Mahidasht, Ghanjekuh, Mozduran, Sarab and Tadovan caves (Table 3). The recording microphone was placed 20 cm in front of bats inside a white bag. When necessary, bats were gently stimulated by a finger touch during recording to observe vocalizations changes in response to the stimuli. Recorded calls were analyzed using BatSound software (Pettersson Elektronik AB, Uppsala) with spectrogram setting of 512 and a Hanning window. For acoustic analysis, at least 10 pulses were randomly selected from each individual. Four parameters were measured for each pulse tocharacterize echolocation calls: call duration (CD), defined as the time between the start and end of a pulse in milliseconds (ms) from the oscillogram, peak frequency (PF), representing the frequency withthe greatest amplitude in kilohertz (kHz) from the power spectrum, start (SF); and end (EF) frequency of the pulse from the spectrogram, both in kHz.

Table 3. Frequency modulate (FM) echolocation calls of adult *Miniopterus pallidus* from 6 localities in Iran. Values are given as Mean ± SD for start frequency (SF), end frequency (EF), peak frequency (PF), call duration (CD), and inter-pulse interval (IPI). n, number of bats which were recorded.

Location	n	PF (kHz)	SF (kHz)	EF (kHz)	CD (ms)	IPI (ms)
Tadovan	6	57.27 ± 1.49	102.67 ± 4.49	51.26 ± 1.04	3.67 ± 0.47	101.95 ± 25.65
Sarab	10	59.48 ± 1.50	100.77 ± 4.22	51.12 ± 0.65	3.30 ± 0.44	93.63 ± 14.23
Alisheikh	9	57.04 ± 1.38	104.30 ± 3.57	49.41 ± 0.74	3.24 ± 0.27	69.32 ± 32.53
Mahidasht	3	58.19 ± 1.79	104.66 ± 2.35	48.44 ± 1.02	3.02 ± 0.28	99.50 ± 4.61
GanjeKuh	4	55.34 ± 3.55	94.43 ± 4.48	49.57 ± 1.71	3.53 ± 0.29	105.07 ± 57.93
Mozduran	12	57.12 ± 1.08	98.30 ± 5.99	48.82 ± 0.97	2.95 ± 0.38	80.89 ± 28.73

TABLE 4. Typical and continuous distress calls parameters from *Miniopterus pallidus*: start frequency (SF), end frequency (EF), peak frequency (PF), call duration (CD), and inter-pulse interval (IPI). Values are given as Mean ± SD.

Distress calls	PF (kHz)	SF (kHz)	EF (kHz)	CD (ms)	IPI (ms)
Typical (90)	22.40 ±3 .57	31.62 ± 4.20	13.15 ± 4.36	2.68 ± 0.58	4.16 ± 1.22
Continuous (14)	24.20 ± 2.98	29.43 ± 4.13	19.29 ± 3.07	45.74 ± 12.34	-

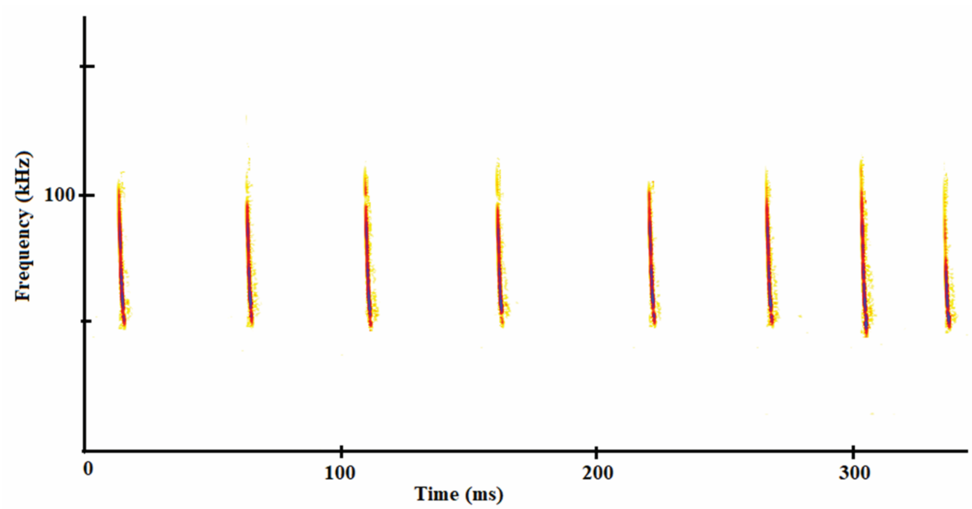

FIGURE 4. A typical echolocation calls of male *Miniopterus pallidus*.

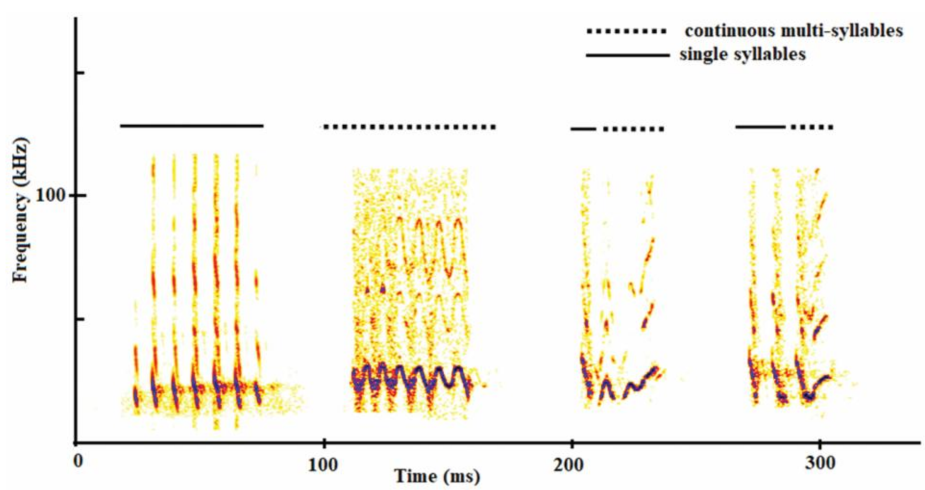

FIGURE 5. Sonogram of distress calls (single syllables) and continuous distress calls (continuous multi-syllables) from adult individuals of *Miniopterus pallidus*.

Descriptive statistics were calculated separately for each geographic group and sex, includig the mean (M), minimum (min), maximum (max), and standard deviation (SD). Sexual size variation was analyzed using an independent samples t-test. All analyses were conducted using SPSS 20.0 and Excel 2013.

RESULTS

Distribution

The occurrence points of *M. pallidus* reported in the present study were shown in Figure 1 and described in Appendix 1. on the 24 *M. pallidus* localities documented in this study, 14 were reported for the first time. Of these new localities, only three were located in the Alborz Mountains and while the remainingwere in the Zagros Mountains. A reviewot the scientific literature revealed 54 previously published records of the species across various regions of Iran (Figure 1, Appendix 2). Over 75% of localities reported for *M. pallidus* belong to the Zagros Mountains. No specimens have been reported from major biogeographical regions such as the central deserts of the Iranian Plateau, the Persian Gulf littorals, the eastern and southeastern territoriesand the southern Caspian Sea coastal areas. *Miniopterus pallidus* was observed in mountainous area ranging in elevation from 745 m a.s.l (Bazangan cave) to 2581 m a.s.l (Sarab cave). Minimum convex polygons (MCP) for all localities in Zagros and Alborz Mountainswere conveniently separated (Figure 1). The extend of the MCPs for the Zagros and Alborz Mountainswas approximately 452,370 km^2 and 107,578 km^2, respectively.

Among the 14 new localities reported for *M. pallidus* in this study, three were identified asnursery colonies: Dehbokr Cave (West Azerbaijan Province), Katalekhor Cave (Zanjan Province) and Nesar Cave (Lorestan Province). The largest bat aggregationwas recorded in Dehbokr Cave, where with *M. pallidus* the most abundant species, with anestimated population of approximately of one thousand individuals. Bat assemblages that included*M. pallidus* alongside other cave-dwelling bat species are summarizedin Table 1. Large summer aggregations in caves often consisted of two or more bat species, most commonly *M. pallidus*, *Rhinolophus ferrumequinum*, and *M. blythii*. In addition, *Miniopterus pallidus* was found to co-occur with *Plecotus macrobullaris*, *Myotis emarginatus*, *M. capaccinii*, *Pipistrellus kuhlii*, *P. pipistrellus*, *R. hipposideros*, *R. euryale*, *R. mehely*, *R. blasii*, *Rhinopoma microphyllum* and *R. muscatellum* (Table 1).

Ecological niche modelling

The ecological niche modelling using MaxEnt closely matched the known distribution of *Miniopterus pallidus* across Iran (Figure 2), confirming the robustness of the model. Notably, the model did not predict suitable habitats in central and southeastern Iran—regions where the species has not been recorded—highlighting its ecological fidelity. The model yielded a high Area Under the Curve (AUC) value of 0.85, indicating strong predictive performance, and a regularized gain of 0.67, suggesting a good fit to the presence data. Among the environmental variables tested, Annual Precipitation (Bio12) was the most influential, contributing 81.7% to the model, followed by Mean Temperature of the Wettest Quarter (Bio8, 7.8%), Isothermality (Bio3, 5.0%), and other temperature and precipitation-related variables (Figure 3). These results emphasize the key role of precipitation in shaping the distribution of *M. pallidus*, and suggest that climate-driven environmental heterogeneity may act as a limiting factor for the species' range in Iran.

External feature

Biometric data for *M. pallidus* specimens are presented in Table 2. The external body measurements obtained from live bats include the length of the forearm, length and width of ear, head to body length, tail length, hind foot length, length of the third- and fourth-digit metacarpal, first and second phalange of the third and fourth digit, and length of tragus (from base to tip). No statistically significant differences were found between males and females in any of the thirteen external morphological traits (Table 2).

Echolocation features

The echolocation calls of *M. pallidus* recorded in this study were classified as FM/QCF (frequency modulated/quasi-constant frequency) type. These calls typically swept from a maximum frequency of approximately 104 kHz to a minimum of around 48 kHz (Figure 4). The species emitted broadband calls characterized by a quasi-constant frequency tail, which carried the highest energy. This dominant tail frequency ranged between 47.13 and 52.32 kHz across the sampled individuals in Iran (n = 44). Average pulses of *M. pallidus*, which were recorded in different localities in Iran are shown in Table 3. A total of 906 echolocation calls were analyzed from 44 adult individuals across six localities in Iran, with each bat contributing between 3 to 37 calls (Table 3).

In addition to echolocation, adult *M. pallidus* individuals also produced rapid sequences of, referred to as distress calls (Figure 5). These calls typically consisted of three to eight pulses per sequence, although the number could range from 3 to 30. Compared to echolocation pulses, distress calls were shorter in duration and exhibited lower frequencies (Table 4). Furthermore, *M. pallidus* was observed to emit distinctive distress pulses, either as continuous multi-syllabic sequences or discrete single pulses, differing in form from the typical distress calls (Figure 5). Continuous distress calls, recorded from four males and two females, displayed similar frequency ranges to discontinuous calls but were of shorter duration. These vocalizations may reflect prolonged anxiety or agitation in this species (Table 4).

DISCUSSION

Until the present study, *Miniopterus pallidus* had been recorded across much of Iran, with the exception of the southeastern and central regions (DeBlase, 1980; Benda *et al*., 2012). As expected, most of the newly documented localities align well with the predicted distribution from our ecological niche model (Figure 2). The majority of *M. pallidus* records are concentrated in the elevated Zagros Mountains, with only three from the Alborz range (Rudafshan and Bornik caves, and Imamzadeh Davood; Appendix 1, Figure 1). Except for Imamzadeh Davood—where bats were collected from a fissure in a building wall—all specimens were found roosting in natural caves.

Our species distribution model identified key environmental variables shaping the range of *M. pallidus* across a highly heterogeneous landscape in western and eastern Iran. The model demonstrated high predictive accuracy (AUC > 0.85; Elith, 2002), improving our understanding of the species' ecological requirements and informing future conservation planning. Nonetheless, it is important to note that the model does not account for biotic interactions, climate change, or anthropogenic pressures, which may influence habitat suitability. Despite these limitations, the model remains a valuable tool for identifying priority areas in poorly surveyed regions and guiding protected area design. Both this ecological niche modeling study and the previous mitochondrial DNA analysis (Mehdizadeh *et al*., 2018) independently highlight the key role of climatic variables in shaping the distribution and genetic structure of *Miniopterus pallidus* in Iran. These findings demonstrate that climate plays a central role in both the current and historical patterns of this species, reinforcing the importance of considering environmental heterogeneity in conservation planning.

Echolocation data collected in this study revealed considerable variability and structural complexity. Distinct differences were observed between single distress calls and multi-syllabic continuous sequences, particularly in call duration (Table 3). These variations likely reflect different types of social signaling in response to capture or disturbance. Similar complexity in distress vocalizations has been reported in other bat species, where such calls convey individual identity and serve as warnings to conspecifics (e.g., *Pipistrellus nathusii*, *P. pipistrellus*, *P. pygmaeus*, Russ *et al*., 2004; *Cynopterus sphinx*: Mariappan *et al*., 2013; *Saccopteryx bilineata*, Eckenweber & Knörnschild, 2016).

Our findings confirm that *M. pallidus* is predominantly associated with high-elevation mountainous habitats in Iran, particularly the Zagros and Alborz Mountains. This distribution pattern aligns with the species' morphological traits. The long and narrow wings of *M. pallidus* are characteristic of fast, energy-efficient flight in open or semi-open environments at higher altitudes (Norberg & Rayner, 1987), likely enhancing maneuverability between cliffs and roosting sites.

Acoustic data support this ecological interpretation. The species' FM/QCF echolocation calls, with dominant constant-frequency tails around 47–52 kHz, are well-suited to open and moderately cluttered habitats. Broadband FM components enable precise spatial resolution and prey detection, which are essential for navigation and foraging in complex mountainous terrains (Schnitzler & Kalko, 2001). The absence of pure constant-frequency calls—typical of species foraging in dense vegetation—further supports the adaptation of *M. pallidus* to relatively open environments.

The ecological niche model also highlights the influence of climate, particularly annual precipitation, on the species' distribution. The mountainous regions inhabited by *M. pallidus* experience unique precipitation regimes, which likely affect prey abundance and roosting microclimates. The species' absence from central deserts and low-precipitation zones suggests a preference for cooler, wetter environments, consistent with its physiological and behavioral adaptations. Together, the morphological, acoustic, and environmental data present a coherent picture of *M. pallidus* as a mountain-adapted species, employing specialized flight and echolocation strategies optimized for life in high-elevation ecosystems. Conservation efforts should therefore prioritize these habitats, which support the largest populations and most critical nursery colonies.

The first attempt to assess the conservation status of Iranian bats by Sharifi et al. (2000) categorized *M. pallidus* as common based on relative abundance data, including geographic range, number of localities, and specimen counts. However, the species has yet to be assessed globally by the IUCN. Quantitative population estimates for Iranian bats remain scarce due to limited data availability. Historical records from the 1960s document large aggregations of bats, including *M. pallidus*, such as the >1,500 individuals reported from Gara Tarik Cave (DeBlase, 1980). Recent surveys in the same and nearby sites have shown steep population declines. For example, no bats were observed in Azad Khan and Moghan caves despite past reports (Etemad, 1964–1984; DeBlase, 1980; Benda et al., 2012; Akmali et al., 2015). These declines raise serious concerns about the long-term viability of *M. pallidus* populations and highlight the urgent need for systematic monitoring and conservation action.

CONCLUSION

Our findings show that *Miniopterus pallidus* is closely associated with mountainous habitats in Iran, especially in the Zagros and Alborz ranges. Its morphological and acoustic traits reflect adaptations to open, high-elevation environments. Ecological niche modeling confirmed the key role of precipitation in shaping its distribution. Notably, declines in historical roost sites raise concerns about population trends. This study provides essential data for future research and highlights the need for conservation efforts focused on protecting critical habitats of this species.

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