

The global population status and distribution of the Indian Swiftlet: Implications for Conservation

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Abstract The current study aims to comprehend the population status and distribution of the Indian Swiftlet (*Aerodramus unicolor*, family: Apodidae) using primary and secondary data. We acquired the population data from the secondary literature and presence data from open source (GBIF.org). We conducted surveys to document the breeding and foraging locations of the species in the Western Ghats, West Coast and Offshore islands of Maharashtra. After estimating the population, we used the presence data to create a model predicting species distribution in current and future scenarios. The Indian Swiftlet's current distribution is from Southwest Maharashtra to Kerala and Sri Lanka. In future, the changing climate might restrict it to the southern Western Ghats and some pockets in Sri Lanka. Burnt Island, home to the largest known colony, deserves conservation attention. We recommend population surveys and immediate conservation efforts to ensure the survival of the Indian Swiftlet endemic to India and Sri Lanka.

Keywords: Apodidae, cave bird, climate change, conservation actions, edible nest, aerial insectivore

Összefoglalás Jelen tanulmány célja, hogy elsődleges és másodlagos adatok felhasználásával megvilágítsa a malabári szalángána (*Aerodramus unicolor*, Apodidae család) populációs helyzetét és elterjedését. A populációs adatokat a másodlagos szakirodalomból, a jelenléti adatokat pedig nyílt forrásból (GBIF.org) szereztük be és terepi felméréseket végeztünk a faj költő- és táplálkozóhelyeinek dokumentálására India Nyugati-Ghátok régiójában, a nyugati partvidéken és Maharashtra állam partmenti szigetein. A populáció becslését követően a faj jelenlegi elterjedését becslő és a jövőbeli elterjedését előrejelző modellt építettünk a jelenléti adatok felhasználásával. A malabári szalángána jelenlegi elterjedési területe Maharashtra állam délnyugati részétől Keraláig és Sri Lankáig terjed. A modell szerint a jövőben az elterjedés a változó éghajlat miatt a déli Nyugati-Ghátokra és Sri Lanka néhány zónájára korlátozódhat. A legnagyobb ismert kolóniának otthont adó Burnt-sziget külön természetvédelmi figyelmet érdemel. Az Indiában és Sri Lankán endemikus malabári szalángána fennmaradásának biztosítása érdekében az állományok részletes felmérését és azonnali védelmi erőfeszítéseket javasolunk.

Kulcsszavak: Apodidae, barlangi madár, ehető fészkek, klímaváltozás, levegőben vadászó rovarrevő, természetvédelmi beavatkozások

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Introduction

Most swiftlets of the family Apodidae and order Caprimulgiformes assemble their nests using saliva as a binding agent. However, saliva is the most crucial or the sole nesting material for a few species that built economically significant edible nests. The edible nests of swiftlets are among the costliest animal products in the world, costing anything from \$4,000 to \$10,000 per kilogram depending upon the saliva quality and quantity (Lau & Melville 1994 Sankaran 2001). Among the 39 species of swiftlets known worldwide (Ibrahim *et al.* 2009), many are exploited for profit (Hobbs 2004, Thorburn 2015). Because of their economic significance and large breeding colonies known from across their distribution range, the edible-nest swiftlets are never included in the list of conservation priority species, even after severe declines and local extinctions are documented (Sankaran 2001, Manchi & Sankaran 2014).

India is home to (i) the Himalayan Swiftlet (*Aerodramus brevirostris*) which is found throughout the Himalayas and mountains of North India from Himachal Pradesh East to South China (W Yunnan), Myanmar and Thailand and winters in Bangladesh, SW Thailand and the Malay Peninsula, and possibly Sumatra, (ii) the Plume-toed Swiftlet (*Collocalia affinis*), and (iii) the Andaman Edible-nest Swiftlet (*Aerodramus inexpectatus*) which are found throughout the Andaman and Nicobar Islands (Chantler & Boesman 2020), and iv) the Indian Swiftlet (*Aerodramus unicolor*) which occurs in the coastal region and the Western Ghats complex from about Ratnagiri in south Konkan region of Maharashtra to southward through Goa, western Karnataka, Tamil Nadu, Kerala (Chantler & Kirwan 2020). The Indian Swiftlet is endemic to India and Sri Lanka. Under British colonialism, edible nests in India were traded frequently by the early 1800s. Later, uncontrolled and illegal nest harvesting caused rapid population drop (Sankaran 2001, Mahabal *et al.* 2007). Conservation efforts largely halted the illegal edible nest collection in the Andaman and Nicobar Islands to restore the population (Manchi & Sankaran 2014, Manchi *et al.* 2022). The inaccessible breeding sites and difficulties in identifying the species in flight have limited scientific exploration of several swiftlet species (Kawalkar & Manchi 2023). Nonetheless, several studies undertaken over the years (Abdulali 1940, 1942, Gunawardana 1997, Katdare 2001, Pande 2001, Kumar 2006, Mahabal *et al.* 2007) were concluded independently, however, primarily concentrated on the population status, the scenario of illegal commerce and some aspects of biology. Apart from a few focused studies, information on the occurrence of the species throughout its distribution range was gathered through a citizen science approach (for example eBird forum), which can be found in the Global Biodiversity Information Facility (GBIF) database (GBIF.org, last access: 30 December 2023). Though a considerable quantity of data on species distribution is available, no attempts were made to collate the data to comprehend the species' population status, distribution pattern and habitat. The Indian Swiftlet's habit of nesting in dark caves and other similar habitats, the inaccessibility of these breeding sites, and the lack of expertise and interest to explore the inaccessible and overlooked cave habitats is the biggest constraint in exploring and estimating the breeding population of the cave-dwelling Indian Swiftlet in the WGS biodiversity hotspot.

Hence, we attempted to explore the Indian Swiftlet's current global population status, understand distribution pattern, the effect of climate on the species' distribution in current and future scenarios, and identify the potential habitats.

Materials and Methods

Study area

Our study was limited to the known global distribution range of the Indian Swiftlet, i.e., the West Coast & Western Ghats of India and Sri Lanka. The Western Ghats of India and Sri Lanka (WGSL), one of the 34 global biodiversity hotspots (UNESCO 2012), is extraordinarily rich in biodiversity and unique plants (Myers *et al.* 2000). The Western Ghats is a series of mountains that run through Kerala, Tamil Nadu, Karnataka, Goa, Maharashtra, and Gujarat, around 30–50 km inland and parallel to India's western coast. The sole breadth in this 1,600 km long mountain track, which encompasses around 140,000 km², is the 30 km Palghat Gap at about 11°N (UNESCO 2012). While the eastern part of the Western Ghats is in the rain-shadow region of the Peninsula, the western side is on the verge of southwest monsoon and receives rainfall of 203–254 cm. Despite being 400 km apart, the Western Ghats of India and the highlands in southwest Sri Lanka are remarkably similar in geology, climate, and evolutionary history. The WGSL is a geographically complicated biodiversity hotspot (Myers *et al.* 2000, Bossuyt *et al.* 2004) with a dense human population farming and altering the landscape for thousands of years (Bawa *et al.* 2007). The WGSL has a mountainous terrain (up to 2,700 m elevation) and a geographic barrier, the Palk Strait, which divides India's Western Ghats and Sri Lanka.

The West Coast of Peninsular India forms a narrow belt of low land, geologically of laterite formation, lying between the sea and the Western Ghats, which extends the whole length of the Peninsula, varying in width from 20 to 100 miles inland. The Western Ghats (WG) runs parallel to the entire western coast of the Indian peninsula and extends across Maharashtra, Karnataka, Goa, Kerala, and Tamil Nadu (Paul *et al.* 2018) (Figure 1). Paul *et al.* (2018) also

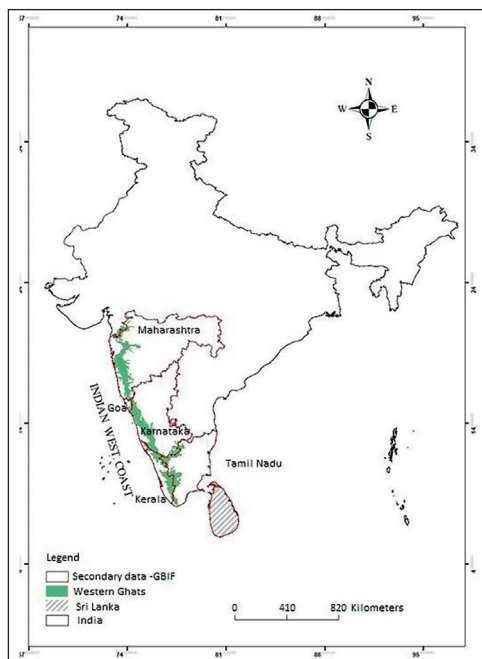


Figure 1. The global distribution range of the Indian Swiftlet is restricted to Western Ghats of India and Sri Lanka

1. ábra A malabári szalangána globális elterjedése India Nyugati-Ghátok régiójára és Sri Lankára korlátozódik

suggest that the forests of the West Coast in India supply 25–40% (average) of moisture to the southwest monsoon rainfall over the East Coast. The WGSL have five distinct regional forest types: (i) Tropical wet evergreen forest (comprising lowland and hill rain forests); (ii) Tropical semi-evergreen (monsoonal) and moist deciduous forest; (iii) Tropical dry deciduous forest and woodland; (iv) Tropical thorn scrub; (v) Tropical lower and upper montane forests (Champion & Seth 2005, Ashton *et al.* 2014).

Population status

We reviewed the secondary literature to understand the population status of the Indian Swiftlet across its distribution. Due to funding constraints, we could only conduct primary surveys in Western Ghats, West Coast and offshore islands of Maharashtra to document the roosting locations of the Indian Swiftlet. We surveyed the potential habitats (natural caves, rock-cut caves, forts) and rigorously checked for the direct and indirect evidence (for example nests or bird droppings) to confirm the birds' presence. Since the survey was conducted during the breeding season, wherever we documented Indian Swiftlet's presence, we meticulously searched the site/structure (for example cave) to locate the swiftlet nests. Once located, we used the nest count method to estimate the population (Sankaran 2001). Since swiftlets are known as monogamous, each nest was considered equal to a breeding pair, i.e. two birds (Manchi & Sankaran 2014, Gurjarpadhye *et al.* 2021). It allowed us to estimate the colony-wise breeding population of the species. These counts were conducted at the end of every month during the breeding season (from December to June) of the Indian Swiftlet. The maximum nest count obtained in a season was considered as the breeding population of the colony.

Species Distribution Modelling (SDM)

We collected the primary data (foraging and breeding location) from Western Maharashtra viz. Konkan region comprises six coastal districts (Palghar, Mumbai, Thane, Raigad, Ratnagiri, and Sindhudurg).

We conducted the distribution survey in Maharashtra between December 2020 and December 2022. Since swiftlets are well-known diurnal foragers (Manchi & Sankaran 2010, Brinkløv *et al.* 2013), the distribution survey was carried out during daylight hours, between 06.00 h and 18.00 h (Patil *et al.* 2021) to confirm the species' presence and identify the foraging locations. The survey's beginning and ending times were determined upon sunrise and sunset. We surveyed a total of 3,210 km in the six districts, using vehicles (two and four-wheeler) on the road and machine dingy to access the offshore islands. The aerial insectivores were tracked down and eventually identified at the species level. A handheld GPS (Garmin Montana 680) was used to mark these encounter locations, further referred to as the survey points. Totally we could mark 350 survey points during the study. We utilized a spotting scope (Endurance ED 20×85 Hawke) and binoculars (Nikon Monarch 10×42) to observe and identify the different aerial insectivorous birds foraging, including the study species. Additionally, we used cameras (Nikon D500 and Nikon Coolpix P900)

to photograph the foraging aerial insectivores whenever we could not confirm the species encountered using binoculars or spotting scope.

Based on the survey points located (foraging and roosting locations) and data from GBIF.org (n=28,049), we modeled the current and future distribution of the Indian Swiftlet in both India and Sri Lanka. For error-free analyses, we eliminated the stray (n=7; five from India and two from Maldives) and misidentified (n=5; three from Maharashtra, one from Gujarat, and one from Andhra Pradesh) records.

We used the SDM Toolbox v2.5 to obtain spatially rarefied occurrence data for SDMs to reduce spatial autocorrelation for thinning the entire data to reduce any possible bias. To minimize the impact of biased sampling, a spatial thinning of 10 km for India and Sri Lanka (Kawalkar & Manchi 2023) was performed between each occurrence point. After eliminating the duplicate records and minimising spatial autocorrelation, we obtained a total of 549 presence records for the modeling. We confirmed that this sample size would allow capturing the broadest possible range of species-habitat associations to make reliable predictions (Santini *et al.* 2019, Gaul *et al.* 2020).

Based on the most recent climatic data (1970–2000), retrieved from the WorldClim database v2.1 at a spatial resolution of 30 seconds (www.worldclim.org), we employed 15 bioclimatic variables (*Table 2*) out of the 19 (except Bio 8, 9, 18 and 19) to create the SDM (Booth *et al.* 2022) (*Table 1*). We utilized the spatial resolution of 30 seconds (~1 km) for the detailed and accurate measures of the climate variables. Swiftlets forage in a variety of habitats, including open, scrub, wetland, paddy land, forest habitats (dry deciduous, subtropical/tropical moist lowland, subtropical/tropical moist montane), shrubland (subtropical/tropical high altitude) and rocky offshore islands (Koon & Cranbrook 2002, Manchi & Sankaran 2010, IUCN 2016, Petkliang 2017, Chantler & Kirwan 2020). Swiftlets forage close to their nesting colonies (caves) throughout the incubation and nestling period (March-June) (Nguyễn & Voisin 1998, Manchi 2009); as a result, we additionally evaluated the Terrain Roughness Index as a covariate to represent the presence of the caves and crevices. To forecast the occurrence of the species, we employed 6 categorical habitat covariates (Evergreen Forest, Deciduous Forest, Mosaic forest, Cultivated and Managed Vegetation, Elevation, and Terrain Roughness/Ruggedness Index) (*Table 1*) from the EarthEnv repository (www.earthenv.org) with a spatial resolution of 30 arc-second per pixel (~1 km per pixel at the equator). Our analysis used the future climate data (2021–2040 and 2081–2100) for the minimum and maximum emission representative for carbon dioxide concentration predicted for two Shared Socio-economic Pathways (SSPs), 126 and 585, as predictors. The CMIP6 downscaled from the WorldClim v2.1 as baseline climate (www.worldclim.org) was used to download 15 global climate models (GCM-HadGEM3-GC31-LL) from a spatial resolution of 30 seconds. The Hadley Global Environment Model-3 (HadGEM3) is employed since it is a comparatively better model (Adhikari *et al.* 2024, Meher & Das 2024).

The 15 bioclimatic variables were initially checked for collinearity using the Pearson correlation variable coefficient analysis (Pearson 2007). Any variable with an r-value exceeding 0.6 was not considered for further analysis (*Table 1*). SDM was done using MaxEnt software Version 3.4 (Phillips *et al.* 2006). We used 10,000 random background

Table 1. The bioclimatic and habitat variables used for the Species Distribution Modelling of Indian Swiftlet (Note: The bioclimatic variables in bold were considered for modelling after eliminating the correlated variables)

1. táblázat A malabári szalagána faj-elterjedési modellezésében használt bioklimatikus és élőhelyi változók (Megjegyzés: a félkövérrel szedett bioklimatikus változókat használtuk a korreláló változók kizárását követően)

Codes	Environmental Variables	Unit
Bio1	Annual Mean Temperature	°C
Bio2	Mean Diurnal Range of monthly Temperature	°C
Bio 3	Isothermality (BIO2/BIO7) (*100)	°C
Bio 4	Temperature Seasonality (standard deviation *100)	°C
Bio 5	Max Temperature of Warmest Month	°C
Bio 6	Min Temperature of Coldest Month	°C
Bio 7	Temperature Annual Range (BIO5-BIO6)	°C
Bio10	Mean Temperature of Warmest Quarter	°C
Bio11	Mean Temperature of Coldest Quarter	°C
Bio12	Annual Precipitation	mm
Bio13	Precipitation of Wettest Month	mm
Bio14	Precipitation of Driest Month	mm
Bio15	Precipitation Seasonality (Coefficient of Variation)	mm
Bio16	Precipitation of Wettest Quarter	mm
Bio17	Precipitation of Driest Quarter	mm
Class 2	Evergreen Forest	Continuous
Class 3	Deciduous Forest	Continuous
Class 4	Mosaic forest (a mosaic of mixed forest, shrubland, and woody savannah)	Continuous
Class 7	Cultivated and Managed Vegetation (Agricultural land, plantations)	Continuous
Elev	Elevation	m
TRI	Terrain Roughness/Ruggedness Index (Topographic heterogeneity)	m

points as pseudo-absences, followed the sub-sampling technique, the Receiver Operating Characteristics curve (ROC) and 1,000 imitations to determine the Area Under the Curve (AUC). The model was run for five replicates with 5,000 iterations, with 70% of the species presence sites serving as training data for the model's evaluation and the remaining 30% serving as test data for the statistical significance (Parolo *et al.* 2008). The developed models were assessed based on the AUC statistics of ROC plots (Swets 1988). Following Wordley *et al.* (2015), we discarded all variables with poor predictive capabilities ($AUC \leq 0.5$) and retained the remaining variables for modeling. We continued this pruning process until the model yielded high AUC performance variables. The resulting SDMs were deemed to match the data well when their AUC value was >0.9 and poorly when it was <0.7 (Parolo *et al.* 2008). As MaxEnt models' outputs, the resulting suitability

classes were categorized into the default categories. To measure each variable’s relative and absolute contribution to the model, the jackknife test permitted the independent evaluation of the model’s accuracy.

Results

Population status of Indian Swiftlet

Even though the forts, human-made caves and rock-cut caves hold potential habitats for the nesting of the Indian Swiftlet, the renovation activities under regular maintenance have disrupted the suitable and potential habitats for birds and bats over the years. Another colony was known to be at Tiracol Fort (Maharashtra-Goa border), which was destroyed by a natural disaster (Mahabal *et al.* 2007). The Swiftlet cave (locally known as Pakoli Dhol) on Burnt Island is a sea cave, naturally formed by the interaction between the sea waves and

Table 2. Locations and sizes of known populations of the Indian Swiftlet in India and Sri Lanka
2. táblázat A malabári szalangána ismert állományainak helye és nagysága Indiában és Srí Lankán

Sr. No	Location	Region, State/ Province	Country	Population	Year	References
1	Burnt Island, Vengurla Rocks	Sindhudurg, Maharashtra	India	4,220	2023	Kawalkar & Manchi 2024
2	Old Lighthouse Island, Vengurla Rocks	Sindhudurg, Maharashtra	India	116	2023	
3	Tiger cave	Ooty, Tamil Nadu	India	250	2002	Katdare, 2002
4	Sacrifice rock	Thalassery, Kerala	India	200	1849	Jerdon 1862
5	South Travancore	Kanyakumari, Kerala	India	500	1953	Pravin Jaydevan 2006 (Personal comm with Mahabal <i>et al.</i> 2007)
6	Pakshi Pathalam caves	Wayanad, Kerala	India	Not estimated		Jerdon 1862
7	Netrani Is. or Pigeon Island	Uttara Kannada, Karnataka	India			
8	Mandaramnuwara Cave	Nuwara Eliya, Central Province	Sri Lanka	68	2013	Munasinghe & Ranawana 2013
9	Kosgala Dark Cave	Ratnapura, Sabaragamuwa	Sri Lanka	Not estimated		LICAS, 2017
10	Belilina tunnel	–	Sri Lanka			
11	Ravana tunnel	Ella, Uva	Sri Lanka			
12	Sthreepura Lena Cave	Ratnapura, Sabaragamuwa	Sri Lanka			
13	Railway tunnels	Ohiya to Idalgashinna, Uva	Sri Lanka	Not estimated		Ekanayake & Kudavidanage 2013

the hard igneous rock, whereas the Old Lighthouse is an old structure built using laterite and cobblestones (Manchi *et al.* 2022, Kawalkar & Manchi 2024, Manchi *et al.* 2024). The colony at Burnt Island, Vengurla Rocks, has been known at least since 1865 for more than 140 years (Mahabal *et al.* 2007), and the Old Lighthouse Island colony was discovered in 2001 by Mahabal *et al.* (2007). Worldwide, 13 known breeding colonies of the Indian Swiftlet are formally documented (seven in India and six in Sri Lanka), but only four of them in India and a single one in Sri Lanka have their populations estimated (Table 2). Recently, Kawalkar and Manchi (2024) documented that the Burnt Island of Vengurla Rocks in Sindhudurg, Maharashtra (India), is the largest colony of the Indian Swiftlet ever known. This population is known to have reached its peak and is identified as the ‘K’ population (Kawalkar & Manchi 2024). Therefore, it has the highest priority for conserving the Indian Swiftlet.

Distribution of the Indian Swiftlet

The present survey, from December 2020 to December 2022, throughout all the coastal districts of Maharashtra and comparatively much higher and repetitive sampling efforts (3,210 km and 350 survey points), confirmed that the current distribution of the Indian Swiftlet in Maharashtra is restricted to the coastal South Sindhudurg region ($n=11$ locations). Simultaneously, the GBIF database (1800–2022; 222 years) created based on the presence records from the region largely confirms the findings of the present study. Hence, the Indian Swiftlet’s current distribution in Maharashtra can be inferred from the presence data (Figure 4a).

Based on the results of Species Distribution Modelling, the Indian Swiftlet is currently widely distributed in India and Sri Lanka ($AUC=0.88\pm0.002$). In India, the species is distributed southward from Central Ratnagiri in Western Maharashtra through Goa, western Karnataka, Tamil Nadu, Kerala, and rocky offshore islets in the Arabian Sea (Figure 4a). Presently, in Sri Lanka it is distributed throughout except in the few regions of Northern and North Central Provinces. The Indian Swiftlet is predicted to have a wide distribution in the Western Ghats of India and mostly towards the southern region during 2021–2040 [ssp126

Table 3. The climatic factors with high percent contribution affecting the distribution of Indian Swiftlet under different scenarios

3. táblázat A malabári szalagána elterjedését magas százalékos magyarázóerővel befolyásoló klimatikus tényezők a különböző scénáriókban

Variables	Current (1970–2000)	2021–2040		2081–2100	
		ssp126	ssp585	ssp126	ssp585
Class 2 (Evergreen Forest)	37	-	-	-	-
Bio 3 (Isothermality)	20	-	-	-	-
Class 7 (Cultivated and Managed Vegetation)	16.2	-	-	-	-
Bio 4 (Temperature Seasonality)	-	58.3	56.5	46.4	76.2
Bio 5 (Max Temperature of Warmest Month)	-	24.1	27.9	20.5	-
Bio 12 (Annual Precipitation)	-	-	-	13.9	-

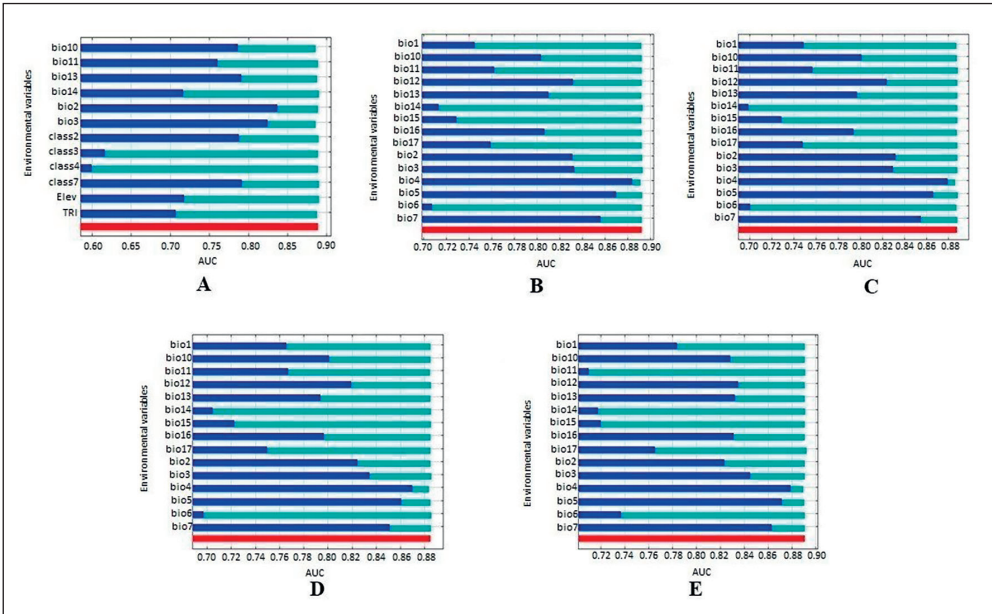


Figure 2. Results of the Jackknife test between the variables: (a) Current scenario, (b) 2021–2040 ssp126 (c) 2021–2040 ssp585, (d) 2081–2100 ssp126 and, (e) 2081–2100 ssp585

2. ábra A változók közötti jackknife-tesztek eredményei: (a) jelenlegi elterjedés alapján, (b) 2021–2040 között az ssp126 szcenárió alapján, (c) 2021–2040 között az ssp585 szcenárió alapján, (d) 2081–2100 között az ssp126 szcenárió alapján és (e) 2081–2100 között az ssp585 szcenárió alapján

(0.89 ± 0.003) and ssp585 (0.88 ± 0.004)]. The species distribution might shrink in Karnataka to concentrate in Tamil Nadu and Kerala during 2081–2100 [ssp126 ($AUC=0.88\pm0.004$) and ssp585 ($AUC=0.89\pm0.002$)]. In Sri Lanka, the distribution is concentrated in the central and southern regions, during both scenarios (Figure 4b, 4c). The Indian Swiftlet distribution, in the current scenario, is most influenced by the Evergreen Forest (Class 2), Cultivated and managed vegetation (Class 7) and Isothermality (Bio 3) (Table 3, Figure 2a–2e).

Discussion

The present study confirms that the current distribution of the Indian Swiftlet in Maharashtra is restricted to the coastal South Sindhudurg region. In contrast to Mahabal *et al.* (2007), the species was not encountered in Raigad and Ratnagiri districts or anywhere in the further northern parts of the coastal South Sindhudurg region of Maharashtra. However, the GBIF database (1800–2022; 222 years) created based on the contribution of several birders (Citizen Science) from the region largely confirms the findings of the present study. Based on the results of Species Distribution Modelling, the Indian Swiftlet is currently widely distributed in India and Sri Lanka. The Indian Swiftlet is predicted to have a wide distribution in the Western Ghats of India and mostly towards the southern region in the future scenarios.

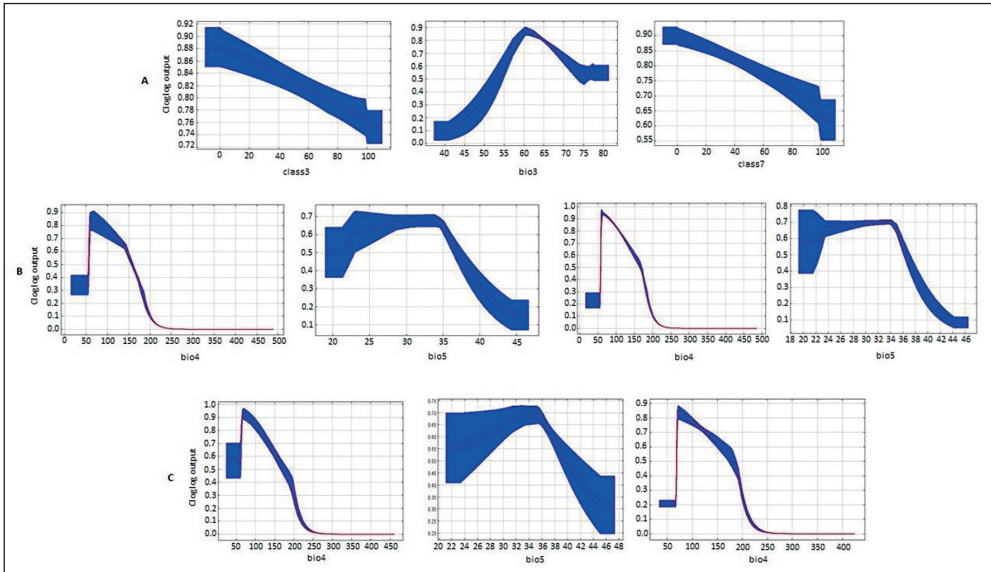


Figure 3. The area under the curve (AUC): (a) Current scenario, (b) 2021–2040 (ssp126 and ssp585), (c) 2081–2100 (ssp126 and ssp585)

3. ábra A görbe alatti terület (AUC): (a) a jelenlegi helyzet alapján, (b) 2021–2040 között az ssp126 és ssp585 scenáriók alapján, és (c) 2081–2100 között az ssp126 és ssp585 scenáriók alapján

The Indian Swiftlet distribution, in the current scenario, is most influenced by the Evergreen Forest (Class 2), Cultivated and managed vegetation (Class 7) and Isothermality (Bio 3). The Indian Swiftlet is recorded from the lowlands to 2,200 m over various habitats commonly seen over scrub and dry deciduous forests, and it frequents small rocky offshore islands and mainland habitats across its distribution range in India (Chantler 2010). In Sri Lanka, it is mostly an upland species (Chantler 2010), found in cloud forest (0.26%), cloud forest die-back (0.90%), and grasslands (Chandrasiri *et al.* 2018). During the primary survey in western Maharashtra, the Indian Swiftlet is primarily observed foraging with Little Swift and Red-rumped Swallow over mangroves, rocky islands, seashores (sandy beach, rocky shores), inland wetlands, laterite plateaus and mosaic of plantations (mango, cashew, areca-nut, and coconut) and various forests. Several studies (Lourie & Tompkins 2000, Nguyễn *et al.* 2002, Ponak 2004, Manchi & Sankaran 2010) concerning various members of *Aerodramus* also indicated the significance of the forest. As Nguyễn *et al.* (2002) mentioned, it might be due to food availability in the forest habitat, an important source of Hymenoptera, a significant diet component for swiftlets. According to Abdulali (1942), the gut content of four Indian Swiftlet individuals captured from Burnt Island, Vengurla Rocks was primarily composed of Hemiptera, Diptera and Hymenoptera. Moreover, the Hymenoptera comprised the largest proportion of food boluses collected from nestlings fed by swiftlets foraging over the forest canopy in eastern Thailand (Lourie & Tompkins 2000, Ponak 2004). As Manchi (2009) described, the Edible-nest swiftlet requires large areas to forage, which means that land-use changes at the landscape level may affect their population and the breeding chronology. Contrarily, the habitat alteration around the caves may not

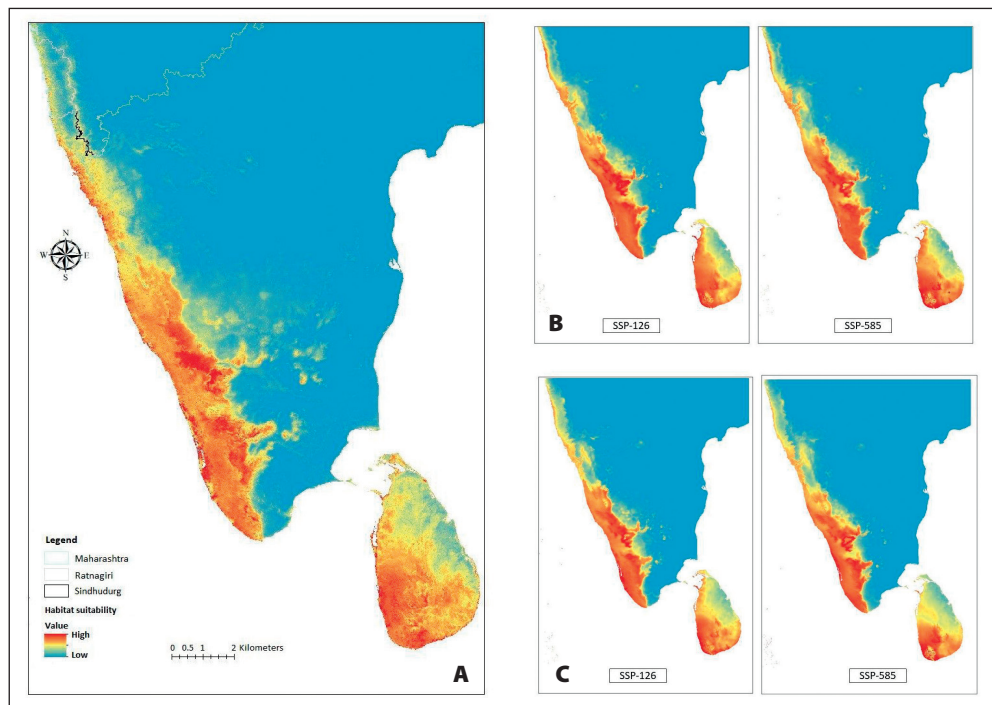


Figure 4. The global distribution of the Indian Swiftlet (a) current distribution, (b) future distribution in 2021–2040 (ssp126 and ssp585 scenarios) and (c) 2081–2100 (ssp126 and ssp585 scenarios)

4. ábra A malabári szalagánya globális elterjedése (a) jelenleg, (b) 2021–2040 között (ssp126 és ssp585 scenáriók alapján) és (c) 2081–2100 között (ssp126 és ssp585 scenáriók alapján)

have a visible effect on the foraging activities of Plume-toed Swiftlet, but could interfere with their natural routine and related biology and physiology (Manchi 2009, Manchi & Sankaran 2010). All these findings indicate the importance of forests for the survival of the swiftlets across their range of distribution. Hence, the usage of the forest habitat in different seasons should be assessed in greater detail.

Along with the Evergreen Forest, the Indian Swiftlet also shows affinity towards the cultivated and managed vegetation (Class 7) (Table 3). In Malaysia, where 99% of all bird nest farms are geared towards producing white edible nests, recently started to integrate swiftlet rearing in the oil palm plantations (Ibrahim & Baharun 2009). This highlights the benefits to the swiftlet nest farmer from the management of the plantations (Kamarudin 2009), particularly the availability of insects these birds feed on and support pest control (Rahman *et al.* 2016, Mursidah *et al.* 2020). Based on the observations during the survey in Sundhudurg, Maharashtra, Indian Swiftlet was seen foraging mostly on the mosaic of forest and cash crop plantations, which include mango (*Magnifera indica*), cashew (*Anacardium occidentale*) and coconut (*Cocos nucifera*). Also, 80% of Indian Swiftlet's gut content sampled from Vengurla Rocks by Ali and Ripley (1970) comprised two species of harmful mango hoppers (*Idiocerus niveosparsus*, *I. atkinsoni*), amply available on the

mango orchards in and around Sindhudurg. According to Munje and Kumar (2022), when forests are rapidly being cleared for plantations, the cultivated and managed vegetation serves as an important surrogate habitat for forest birds in the northern Western Ghats of India. However, further studies are apparent to understand the role of plantations (mango, coconut, cashew, etc.) as the foraging habitat and Indian Swiftlet's role in the pest management in the region.

In the future scenarios, 2021–2040 (ssp126 and ssp585) and 2081–2100 (ssp126 and ssp585) when the Indian Swiftlet distribution starts concentrating to the southern Western Ghats, the major factor which would influence the distribution is Bio 4 (Temperature seasonality). Temperature seasonality measures change in temperature over the year (O'Donnell & Igniziom 2012), and the isothermality (Bio 3) refers to the degree to which temperature varies throughout the year. Both temperature variables are one of the most critical bioclimatic predictors for understanding species distribution (Reside *et al.* 2010). The isothermality is also proven to affect the various breeding parameters in several species of bee-eaters in Europe (Abdul-Wahab *et al.* 2024). This is apparent as the changes and degree of change in climate over the year will directly affect the insect availability and have an adverse impact on the breeding success, chronology (Dunn & Møller 2019, Halupka *et al.* 2023). Hence, it is important to conduct long-term studies to understand influence of various temperature variables on the breeding biology of the swiftlets, particularly the Indian Swiftlet.

Temperature seasonality plays a vital role in shaping species distribution patterns, influencing the geographic ranges of species and the composition of ecological communities. According to many studies (Janzen 1967, Chan *et al.* 2016, Frishkoff *et al.* 2016, Srinivasan *et al.* 2018), tropical species that depend on forests are often associated with a narrow range of temperatures leading to significant change in the species' probability of occupancy with increasing variation in temperatures. According to Ramesh *et al.* (2022), after examining ~78% of species, the likelihood of birds' occupancy (n=43 out of 55) in the southern Western Ghats, is significantly associated with temperature seasonality. As a result of reduced temperature seasonality in the tropics, relative to temperate regions, the species exhibit narrow thermal niches. Hence, these birds are likely to be unable to shift their distributions to track future climate changes (Janzen 1967, Tewksbury *et al.* 2008). This helps us to understand why the Indian Swiftlet populations in southern Western Ghats might not get much affected. However, since no such studies are available for the northern Western Ghats, it is difficult to pinpoint the reason for the predicted shifting of the Indian Swiftlet population from the northern to the southern Western Ghats.

During the future climate scenarios (2021–2040 ssp126 and 585, and 2081–2100 ssp126 and ssp585), Bio 4 (Temperature seasonality) and 5 (Max Temperature of Warmest month) (Table 2, Figure 3) also influences the distribution of the Indian Swiftlet in its entire distribution range. In India, the warmest months are April-May, the peak of the Indian Swiftlet's breeding season, when the eggs hatch and growth of the nestlings begin. As swiftlets are insectivorous, and their foraging entirely depends on food availability, the temperature during the warmest month might play a crucial role in the growth of the chicks. However, this can have both direct and indirect impacts on the swiftlets. Johnson (1974)

suggested insects move upwards with increased ambient temperature. Hence, based on food availability, the birds also fly higher to forage (Tompkins 1999, Manchi & Sankaran 2010). This alteration in feeding habits can also influence its breeding chronology and success (Dunn & Møller 2019). The limited available knowledge is a caveat to comment firmly on this aspect, therefore, further studies are crucial.

Our study modelled the distribution and identified the potential/suitable habitats of the Indian Swiftlet based on the secondary and primary datasets for the current and future climate change scenarios. The results show that the species distribution is affected by the changing climate; species will henceforth remain in the southern Western Ghats and some pockets in Sri Lanka. This also indicates the disappearance of the largest known colony of the species from Burnt Island, located in the northern Western Ghats. The quality of the potential habitat decreases; hence, it is of utmost importance to draft the required strategies and implement the required measures to avoid future detrimental effects on the Indian Swiftlet distribution. The southern Western Ghats is the potential future habitat for the species. Hence, we recommend the identification of the breeding colonies and detailed documentation of the population status of the Indian Swiftlet in other states of India (Goa, Karnataka, Tamil Nadu, and Kerala) and Sri Lanka as paramount to undertake any conservation measures. The Indian Swiftlet colony at Burnt Island, Vengurla Rocks (Sindhudurg, Maharashtra), is the largest and most crucial colony globally. So, focused conservation attention must be provided to the colony to safeguard and manage. We recommend further population genetics studies and ex-situ measures for this oldest known colony of the species. Also, the isolation of the Sri Lankan population from the Indian populations and its considerable confinement to specific habitats (Sri Lankan uplands) makes it more vulnerable to ecological changes, anthropogenic pressures, and climate change, highlighting an Indian Swiftlet a priority species for research and conservation. Therefore, along with local and national efforts, we recommend international collaborative efforts from both India and Sri Lanka for the conservation of this unique cave-dwelling bird, a source of a distinctive natural resource.

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