

Article

Mapping the Distribution of the Endemic Madras Hedgehog *Paraechinus nudiventris* in Tamil Nadu, India

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Abstract: Small mammals play important roles as ecological indicators, dispersers of seeds, food for various species, and contributors to a stable and healthy ecosystem. However, the lack of ecological data to inform their conservation remains a significant challenge in the protection of many rare and threatened species in their natural environments. Among the various small mammals at risk is the Madras hedgehog (*Paraechinus nudiventris*), endemic to a few districts in South India. To inform conservation initiatives for this species, distribution data and thorough investigations of the threats that the species is facing are of upmost importance. In this study, we focused on finding new distribution records for *P. nudiventris* through field visits and community interviews. Further, we compiled and analysed rescue data for *P. nudiventris* from the years 2012 to 2022 and used this information to further map the species' presence in selected districts. To supplement our findings, we gathered information from previously published sources, newspaper reports, and roadkill data. We conducted a questionnaire survey interviewing village residents between January 2021 and May 2022 to collect primary data on the presence of hedgehogs. Our efforts resulted in the recording of 230 sightings of *P. nudiventris* in a total of 19 districts in the state of Tamil Nadu, India. These discoveries contribute to a better understanding of the distribution of this species and will be useful in conservation planning and management at local and national levels.

Keywords: questionnaire survey; distribution mapping; citizen science; wildlife conservation; species distribution



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1. Introduction

Small mammals hold significant value in the ecosystem as ecological indicators [1]. Their distinct ecology, dietary habits, and behaviour, as well as seed dispersal abilities, play immense roles in the ecosystems they inhabit, and consequently, small mammals should be regarded as important research subjects. The orders Eulipotyphla and Rodentia encompass a diverse range of small terrestrial mammal species. These creatures have significant ecological importance, characterised by their high species richness, adaptability to various climatic conditions, and role as prey species for a wide array of predators [2]. Hedgehogs, classified under the order Eulipotyphla and family Erinaceidae (subfamily Erinaceinae), are characterised by the abundance of small spines covering their entire body, excluding the face, legs, and underbelly, as well as their pig-like snout [3]. Three species

of hedgehogs can be found in India: *Hemiechinus collaris* (Gray, 1830), commonly known as the Indian long-eared or collared hedgehog; *Paraechinus micropus* (Blyth, 1846), referred to as the Indian hedgehog; and *Paraechinus nudiventris* (Horsfield, 1851), recognised as the bare-bellied hedgehog or Madras hedgehog or South Indian hedgehog [4,5]. The Indian hedgehog is known to occur in the Desert National Park in Rajasthan and the Narayan Sarovar Sanctuary in Gujarat, whereas the collared hedgehog is primarily found in Rajasthan and the Desert National Park in India [5]. The Madras hedgehog (*P. nudiventris*) is, however, exclusively distributed in the arid zones of South Indian states (Tamil Nadu, Kerala, Karnataka, Telangana, and Andhra Pradesh), covering a range of habitat types, such as grasslands, savannah, open shrub lands, thorn forests, small hillock foothills, pasture lands, and urban areas. Madras hedgehogs primarily occur in the South Deccan Plateau dry deciduous forests and Deccan thorn scrub forests in Tamil Nadu.

P. nudiventris is a solitary species. Adult individuals generally reach a body weight ranging between 130 and 315 g. The species is distinguished by short, stiff, sharp spines on the back and soft white fur on the belly. Madras hedgehogs mainly forage at night or early in the morning and use daylight to rest. The spines are used by the hedgehogs as a defense against predators but also serve as protection against cuts and wounds when the species travels through harsh environments [6–8]. *P. nudiventris* mostly lives in thickets, small hills, and nearby hilly areas in Tamil Nadu and takes shelter in bushes or shrubs during the day. In the face of danger, it curls up into a spiky ball for protection. As a species with poor eyesight, the Madras hedgehog relies mainly on its sense of smell and hearing when navigating through the surroundings in search for food, shelter, and mates [8]. This species has developed adaptations to survive on a varied seasonal diet similar to *Atelerix algirus* [6]. The feeding habits of *P. nudiventris* include a variety of insects, such as beetles, ants, eggs, earthworms, termites, grass cakes, and plant materials [9]. Although it shows fast movement in its natural habitat, its speed slows down when confined to experimental enclosures, suggesting possible behavioural changes due to captivity [9–11]. Observations made in Tirunelveli suggest that *P. nudiventris* normally performs the behaviour of aestivation during the months of May and June [8], a type of dormancy survival strategy used to sustain factors such as lack of food and other extreme conditions, evident through weight reduction during these periods [8]. Hence, it is imperative for the species to undergo physiological acclimatisation to environmental conditions to maximise energy efficiency during critical periods. An important part of this survival strategy is the conservation of water in dry habitats, which is achieved by the secretion of concentrated yellow urine [8]. *P. nudiventris* is able to adapt to different climatic conditions, including dry plains, deserts (red sand dunes called *Theri Kaadu*), and bush-dominated landscapes.

Previous studies have recorded the presence of *P. nudiventris* in various districts of Tamil Nadu, including Villupuram, Theni, Salem, Ramanathapuram, Nilgiris, Karur, Virudhunagar, Namakkal, Dindigul, Madurai, Tirunelveli, Thoothukudi, Erode, Tirupur, and Coimbatore [11]. Other records of restricted distribution are found in the Western Ghats, especially in the protected highlands, such as the Kalakad Mundanthurai Tiger Reserve, the Moyyar Wildlife Sanctuary, and the Nilgiris. The species can also be found in the Periyar Tiger Reserve, with Thekkady and Coimbatore representing the western distribution and Kanyakumari, in the Maruthuvaalimalai foothills, representing the southern distribution [10].

P. nudiventris faces several threats to its survival. The species is used in traditional medicine and is hunted for its culturally and medically important meat, which is thought to help against whooping cough, especially in children [12]. Local people have historically used this species for a variety of purposes, including in traditional medicines to treat ailments, such as asthma and knee pain. This extensive exploitation, which has lasted more than a century, has contributed to the rapid decline in the population of *P. nudiventris* [9,10,12]. “Tree-based agroforestry”, defined as agricultural activities with a strong focus on growing trees, may contribute to a change in or the degradation of natural

habitats for *P. nudiventris*. This happens when natural vegetation is cleared to make way for fruits or when monoculture tree plantations replace diverse natural ecosystems, leading to habitat loss and fragmentation.

In addition, specific management practices associated with forest-based agroforestry systems, such as intensive land use or pesticide use, can further escalate habitat degradation and loss of biodiversity [9,10]. Invasive farming practices by people from neighbouring states unfamiliar with local sheep farming practices further alter the landscape, making it unsuitable for hedgehogs to survive. Random land conversion, turning suitable habitats into residential areas, contributes further to the challenge of habitat loss. One major threat is habitat degradation due to extensive land-use changes, such as real estate development and tree-based agroforestry [12]. Landscape changes have made habitats even more unsuitable for hedgehogs and other species. In addition, *P. nudiventris* has become a target of the pet trade. Local villagers often keep hedgehogs as pets, and their skins are traded openly in markets. The species has gained popularity as an exotic pet, increasing its vulnerability [8]. An additional and substantial threat is traffic, as vehicles cause casualties throughout the whole distribution area of the species [11]. Roadkill has been documented in various regions, highlighting the impact of road expansion on *P. nudiventris*. Extensive cattle grazing in areas such as South Tirunelveli and Thoothukudi adversely affects the habitat of several small mammals, including hedgehogs [13]. Grazing leads to the destruction of grass and shrubs, reducing important natural resources. In addition, limited distribution and persistent threats in the Tirunelveli and Thoothukudi districts, as well as other regions, have caused a rapid decline in the population of *P. nudiventris* [9,11], and these combined threats raise concerns about possible local extinction [9,14].

Previous studies by Kumar et al. (2018) [9,10] have confirmed the presence of the species in only a few locations in different regions of Tamil Nadu, providing limited distribution data, highlighting the critical conservation status of *P. nudiventris* and identifying it as one of the most threatened mammal species in India. This conclusion is also supported by Xuelong and Hoffman (2013) [15], who argued that *P. nudiventris* should be reclassified from “Least Concern” to “Vulnerable” in the IUCN Red List. It is important to note that there is a serious lack of studies on hedgehogs in India and so far, no long-term studies focusing on *P. nudiventris* have been conducted [16]. In addition, due to limited research on this elusive species of hedgehog in India, its full distribution is not yet understood. This indicates that extensive research and conservation measures are urgently needed for this species. Understanding the distribution, habitat requirements, and threats of *P. nudiventris* is vital to developing effective conservation strategies to ensure the species’ survival in the wild. Therefore, the objective of this study was to provide comprehensive information on the distribution of the elusive *P. nudiventris* in Tamil Nadu to meet the ultimate goal of conserving and ensuring the survival of this species.

2. Materials and Methods

2.1. The Study Area

Tamil Nadu, located in southern India, is a state that consists of 38 districts. It shares borders with Karnataka and Andhra Pradesh to the north, the Bay of Bengal to the east, the Indian Ocean to the south, and Kerala to the west. Geographically, it lies between 11.6428° N and 78.8076° E. Drought risk is a significant concern in Tamil Nadu, with nearly half of the state’s districts considered susceptible to drought conditions [17–19]. The occurrence and severity of drought situations in the region are influenced by several factors, including insufficient rainfall, high temperatures, groundwater reservoir levels, and crop conditions [18,20]. Over the past 25 years, Tamil Nadu has experienced below-normal rainfall during the southwest monsoon for approximately 30% of the year [21]. Tamil Nadu’s climate is tropical, showing minimal temperature variation between summer and winter. From April to June, the hottest period, temperatures can reach up to 40 °C, while from November to February, it is cooler, with temperatures around 20 °C. Rainfall occurs during the northeast monsoon, from October to December, with an annual average of

635–1905 mm. Coastal regions turn warm and humid in summer [22]. In line with the previous publication by Kumar et al. (2018) [9,10], a random selection was made from among the 16 districts mentioned in that study. Eleven districts were chosen for further investigation and analysis. These districts were selected based on their susceptibility to drought conditions, historical climate data, and the presence of hedgehog habitats. This selection was made to contribute to the existing research by examining specific districts within Tamil Nadu and their respective characteristics within ecological, climatic, and socio-economic factors relevant to the region. These characteristics were investigated with the purpose of enhancing our understanding of the dynamics and challenges associated with the selected districts in relation to hedgehog conservation and inform future strategies for sustainable development and resource management in Tamil Nadu.

Our interview surveys were conducted in the following 11 districts of Tamil Nadu: Erode (11.3410° N, 77.7172° E), Kanyakumari (8.0883° N, 77.5385° E), Madurai (9.9252° N, 78.1198° E), Tenkasi (9.9252° N, 78.1198° E), Ramanathapuram (9.3639° N, 78.8395° E), Salem (11.6643° N, 78.1460° E), Sivagangai (9.8433° N, 78.4809° E), Tirunelveli (8.7139° N, 77.7567° E), Thoothukudi (8.7642° N, 78.1348° E), Pudukkottai (10.3833° N, 78.8001° E), and Coimbatore (11.0168° N, 76.9558° E) (Figure 1). The districts fall in the ecoregions of the South Deccan Plateau dry deciduous forests and the Deccan thorn scrub forests. The preferred habitat types of *P. nudiventris* include pasture lands, agricultural field margins, shrublands, grasslands, urban areas, red sand dunes (Teris), savannahs, and small hillock foothills [9]. The study areas selected encompass a range of these landscapes, including arid zones, semi-arid grasslands, red sand dunes, and areas dominated by palmyra trees (*Borassus flabellifer*) and thorn trees (*Acacia nilotica*, *Accacia senegal*, and *Pithecellobium dulce*). *P. nudiventris* often seeks shelter under the fallen leaves of palmyra trees, with these trees playing a significant role in providing a habitat for the hedgehogs. The dried leaves that accumulate beneath the palmyra trees serve as a refuge for *P. nudiventris* [10]. The palmyra palm holds great significance in Tamil Nadu, having been designated as the state tree in the year of 1978. India has the highest prevalence of palmyra palms in the world [23], with the state of Tamil Nadu accounting for 60% (51 million) of the total 85.9 million palms and the Ramanathapuram district having the highest concentration in the state [24]. The Teri region (Thoothukudi) is considered one of the most arid geological areas within the basin and spans the southeastern coast between Tirunelveli and Thoothukudi, receiving an annual rainfall of 700–1000 mm, primarily during the northeast monsoon [25,26]. The Madurai district, receiving an average annual rainfall of 827.1 mm, is primarily dependent on agriculture and experiences a climate ranging from arid to semi-arid [27,28]. Along the coastline of the Kanyakumari district, from Kovalam to Manakudi, reddish-brown Teri sand dunes can be found, characterised by sub-tropical climatic conditions [29]. In the Salem district, the main types of soil range from red calcareous to hot tropical, creating a suitable habitat for hedgehogs in the dry regions [30]. Pudukkottai, located in the central part of Tamil Nadu, receives an average annual rainfall of approximately 900 mm and features a tropical marine and monsoon climate. The district's soil fertility is generally low, with some areas facing alkalinity issues [31]. The Sivagangai district is known for its hot climate and consists of semi-arid grasslands with palmyra trees, thorn trees (*Prosopis juliflora*), and large cacti. The Coimbatore district also exhibits semi-arid grassland patterns [32,33]. These districts were chosen to represent the diversity in habitat types and climatic conditions within the Tamil Nadu region to improve our understanding of the distribution and ecology of *P. nudiventris* in these specific regions, ultimately aiding in the development of effective conservation strategies.



Figure 1. Red sand dunes in the Theri Kaadu desert in Tuticorin. Photo: Abinеш Muthaiyan.

2.2. Study Design: Regional Questionnaire Survey

By using citizen science and conducting interviews across various districts and age groups, we aimed to obtain robust and accurate distribution records of *P. nudiventris*, shedding light on the species' presence and status in Tamil Nadu's landscapes. The data collection process involved citizen science, through interviews with local inhabitants in the 11 selected districts (Sivagangai, Erode, Tenkasi, Ramanathapuram, Tirunelveli, Thoothukudi, Kanyakumari, Coimbatore, Madurai, Salem, and Pudukkottai) of Tamil Nadu, in a total of 208 villages. Each of these regions offers unique ecological and environmental contexts that contribute to the broader understanding of the Madras hedgehog's distribution, habitat, behaviour, and conservation status.

To determine whether the local inhabitants identified the Madras hedgehog correctly, we first asked about the differentiation between the Madras hedgehog and the Indian crested porcupine (*Hystrix indica*). This was a prerequisite for the questionnaire survey because many people often confuse the Madras hedgehog with the porcupine due to their somewhat similar appearances. This confusion arises from several factors, including similarities in physical appearance, overlapping habitats, and a lack of awareness about the existence of two distinct species. In the Tamil language, "mullam-pandri" refers to the Indian crested porcupine and "mull-elli" refers to the Madras hedgehog. Some people who are not aware of the two species often get both their names as "mullam-pandri", which means "porcupine". At the taxonomic level, the Madras hedgehog and the porcupine belong to different families. The Madras hedgehog is a member of the family Erinaceidae, which includes hedgehogs and gymnures. Hedgehogs are small, spiny mammals known for their distinctive spines, which are modified hairs. The Indian crested porcupine, however, belongs to the family Hystricidae (Old World porcupines) [34]. Porcupines are larger rodents, characterised by their long, sharp quills, which are also modified hairs but are more pronounced. Despite belonging to different families, the Madras hedgehog and the porcupine share some superficial similarities that contribute to the confusion: both species can be found in similar habitats, such as grasslands, forests, and scrublands in South India. The Madras hedgehog is endemic to a few districts in South India, particularly in Tamil Nadu, where it co-exists with the Indian crested porcupine (*H. indica*). The co-existence of these species in the same geographical areas leads to increased risk of misidentification, especially among local populations who may not be familiar with the differences between them.

To gather information about the past and present distribution of the species, a specially designed questionnaire was used (Supplementary Material S1). The survey was conducted between January 2021 and May 2022, with the aim of obtaining insights into the presence and sightings of *P. nudiventris* in the respective villages and districts, both historically and recently. The questionnaire was carefully prepared in the local language, Tamil, to ensure easy understanding among the local population. The questions were read aloud during the survey for participants who were unable to read. A diverse range of participants from different backgrounds, including farmers, shepherds, auto drivers, hunters, forest officials, and village seniors, were selected for the data collection process. Visual distinction was made to classify participants into three age groups: mature individuals (41 to 70 years), adults (25 to 40 years), and young individuals (10 to 24 years). Each age group was expected to provide specific insights into the historical presence, current distribution, and conservation status of *P. nudiventris*. We expected that mature individuals would be able to provide information about the historical presence of *P. nudiventris* from the past to the present. People categorised as adults or young individuals may be engaged in nighttime hunting of hedgehogs and thus generally have a higher chance of spotting the hedgehogs in the wild during their activity period. Through these activities, they would be able to contribute with information about the present distribution and status of the hedgehog in their respective villages. The survey prioritised individuals such as farmers and local drivers, as they frequently traverse through the semi-arid lands during the night, covering significant distances. This increased their chances of encountering live or roadkilled hedgehogs along the road stretches of the region. Common gathering places within villages, such as large trees like the banyan tree (*Ficus benghalensis*); village houses; auto stands; bus stops; cattle grazing fields; and edges of arable and pasture lands, were chosen as locations for conducting the questionnaire surveys. Each interview lasted approximately 10 to 15 minutes. To ensure comprehensive coverage, the survey was conducted from 9 a.m. to 11 a.m. in the morning and 3 p.m. to 5 p.m. in the evening, targeting individuals with different occupations. This timing accommodated the schedules of farmers, allowing them to return home before dusk. The goal was to interview a minimum of 30 people in each village, aiming for solid and accurate distribution records of *P. nudiventris*.

2.3. Bike Surveys

Registering the roadkilled hedgehogs and thereby identifying areas with a higher likelihood of *P. nudiventris* presence contribute to our understanding of the distribution of the species. To document roadkilled hedgehogs, bike surveys were conducted, four surveys per month, approximately 20 times between January and May 2022. The survey involved riding a bike at an average speed of 10 km per hour, covering a distance of approximately 20 km per day. Over the course of the surveys, a total distance of approximately 420 km was covered. The bike surveys took place during the evening hours between 5:00 and 6:00 p.m., with each session lasting up to two hours. The bike survey was performed by two persons, focusing on a total of three survey stretches (routes) in the two districts Thoothukudi and Sivagangai.

Furthermore, we conducted a series of motorbike surveys to screen for roadkilled or live hedgehogs. The two districts chosen for the motorbike surveys were selected due to their different characteristics comprising ideal habitats for *P. nudiventris*. The surveys were conducted on three different routes. Route 1, a specific section of road from Mookuperi to Poochikaadu (8.5649 N, 77.9910 E) in the Thoothukudi district, was thoroughly examined. This road, which passes through the desert of Theri Kaadu (with red sand dunes), is characterised by its uneven terrain (Figure 1). When any movement or activity was detected in the forest or bushes along the road, the survey team would stop the bike and venture deeper into the forest for further investigation. Route 2, the Sivangangai district–Kanoor Road (9.8598 N, 78.6008 E), is considered an ideal habitat for hedgehogs. The road is flanked by a substantial number of palmyra trees, and the presence of red sand is predominant.

Maravamangalam, one of the villages located in the Sivagangai district, features a pond area that likely attracts hedgehogs. Route 3, in Manamadurai, another *taluk* within the Sivagangai district (9.7069 N, 78.4294 E), encompasses a large forest area alongside the road. This region is characterised by thorn forests dominated by *P. juliflora*, roads with red soil, and abundant palmyra trees. This particular survey stretch includes the village of Mangulam, situated along the Manamadurai Road, where roadkilled hedgehogs have previously been recorded. The motorbike surveys were conducted three times in the month of April during evening hours and lasted two hours each.

By systematically covering specific routes on a regular basis, the bike and motorbike surveys, in tandem with information on roadkilled hedgehogs obtained during the interviews for the questionnaire survey, contributed to a better understanding of the impact of roadways on hedgehog populations and helped identify potential conservation measures to mitigate road-related threats.

2.4. Inclusion of Previously Collected Data and Data from Local Newspapers

In our study, we enhanced our understanding of the distribution of *P. nudiventris* by incorporating previously published distribution data. These data sources, referenced as Kumar et al. (2018) [9,10], provided valuable insights into the geographical distribution of *P. nudiventris*, which were integrated into our map (see the Results section, Figure 2). By including this information, we were able to build upon existing knowledge and establish a detailed overview of the species' distribution across the study area. To gather additional data on *P. nudiventris* sightings and rescue efforts, we examined five different regional newspapers written in the Tamil language: *Daily Thanthi*, *Dinamalar*, *Dinakaran*, *Dinamani*, and *The Hindu Tamil*. It is common practice in Tamil Nadu for newspapers to report hedgehog sightings, roadkill, and observations in villages, as well as on roads and in common gathering areas, regularly in district-wise news sections. The forest officials of Tamil Nadu conduct rescues regularly, responding to calls from locals. The distinct appearance of this spiny mammal prompts regular coverage in local newspapers, raising awareness and facilitating action from the Tamil Nadu Forest Department. These newspapers covered the period from 2020 to 2022, allowing us to collect rescue data specifically related to *P. nudiventris* in the selected districts of Tamil Nadu. This dataset enabled us to analyse the number of hedgehogs rescued in each of the 11 districts during the specified time frame.

Additionally, 36 cases of rescue data for *P. nudiventris* were gathered from newspapers covering the period 2012–2022.

2.5. Mapping of Hedgehogs

To visualise the distribution of *P. nudiventris*, various data sources, including questionnaires, newspapers, bike surveys, and previous publications, were used. The obtained data, consisting of GPS coordinates, were plotted using ArcGIS version 10.3 software from ESRI (Redlands, CA, USA). By integrating the collected data, a detailed distribution map of *P. nudiventris* was created (see the Results section, Figure 2). The map incorporated information about the species' presence across the surveyed areas. To ensure consistency and comparability, the variables were created at different resolution scales and subsequently re-sampled to a resolution of 1 km.

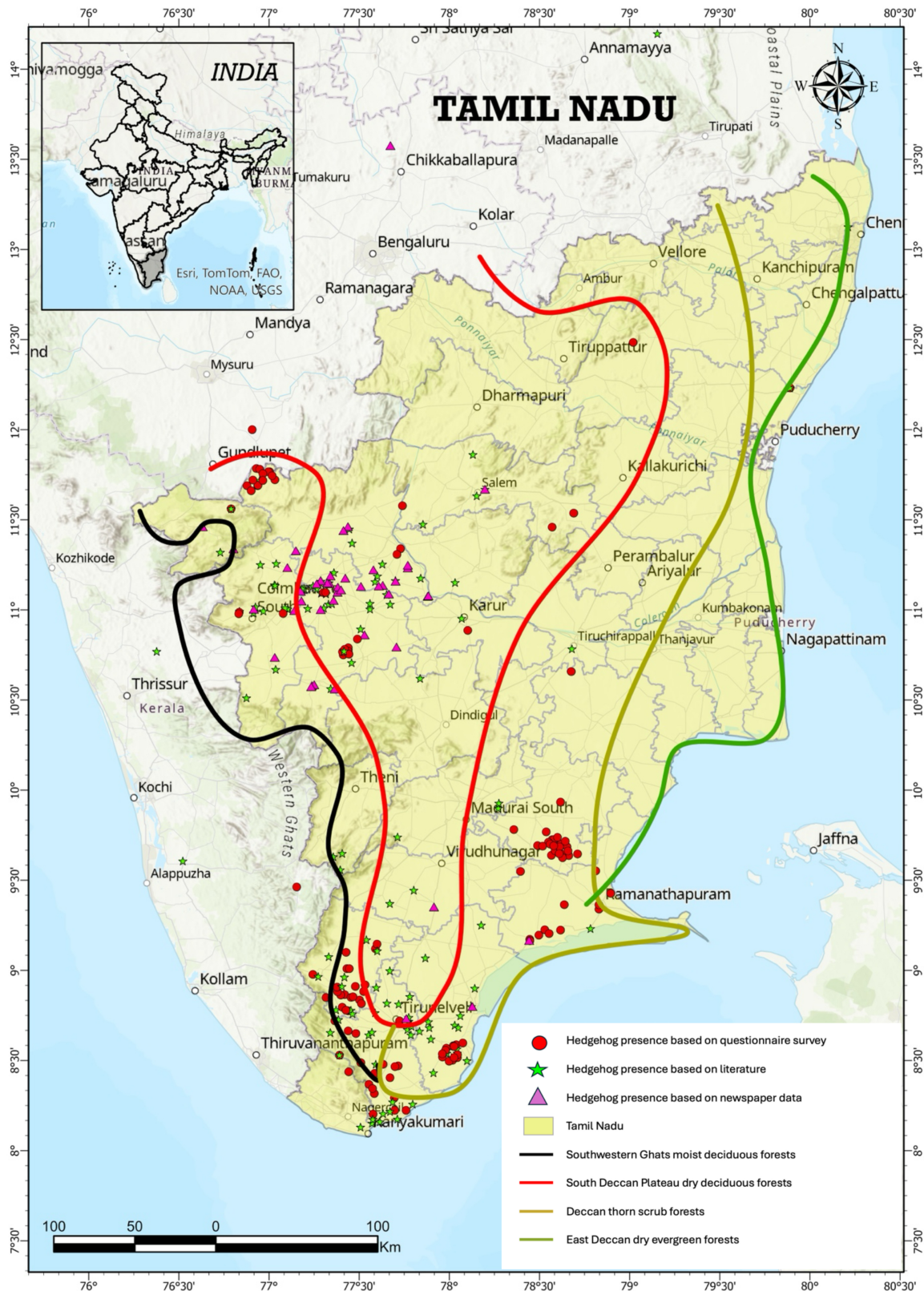


Figure 2. Distribution of *P. nudiventris* in the state of Tamil Nadu, India, covering a total of 19 districts: (1) Tirunelveli, (2) Thoothukudi, (3) Ramanathapuram, (4) Sivagangai, (5) Pudukkottai, (6) Thiruchirappalli, (7) Namakkal, (8) Salem, (9) Villupuram, (10) Chennai, (11) Thiruvallur, (12) Erode, (13) Nilgiris, (14) Tirupur, (15) Dindigul, (16) Theni, (17) Madurai, (18) Virudhunagar, and (19) Kanyakumari. References: Kumar et al. (2018) [9,10].

3. Results

A comprehensive distribution mapping of *P. nudiventris* in Tamil Nadu was made based on interviews, bicycle and motorcycle surveys, newspapers, and previously published data. The findings were compiled into a distribution map that visually represents the presence of *P. nudiventris* in the region (Figure 2). A total of 230 records of *P. nudiventris* were documented in 11 districts of Tamil Nadu: Erode, Kanyakumari, Madurai, Tenkasi, Ramanathapuram, Salem, Sivagangai, Tirunelveli, Thoothukudi, Pudukkottai, and Coimbatore. These records were obtained from newspapers (N = 43), previous field studies [9], bicycle and motorcycle surveys (N = 1), and community interviews using questionnaires (N = 122). The findings provided significant insights into the spatial distribution of the species in Tamil Nadu.

3.1. Regional Questionnaire Survey

The study lasted 17 months and covered 11 districts and 30 *taluks* (geographically administrative areas of districts), consisting of 208 villages. In total, we surveyed 2744 people ($N_{\text{Males}} = 1718$, $N_{\text{Females}} = 542$, and $N_{\text{Unknown}} = 312$), of which 2304 satisfactorily answered the questions and 440 did not answer the survey. A total of 1124 people witnessed hedgehogs in their village between 1950 and 2022. Additionally, 1257 people saw hedgehogs in other villages within the same districts, and 28 participants reported seeing hedgehogs in other districts of Tamil Nadu. Others (N = 759) stated that they had encountered hedgehogs in their villages only 30–50 years ago but not recently. Some answered that there might be hedgehogs in their villages, while others said that hedgehogs live all over the villages, although, in some cases, they had never personally seen a hedgehog in their life. Those individual responses where people had not seen hedgehogs themselves were not recorded as hedgehog sightings. A total of 125 people saw hedgehogs before 2000 (125 of the surveyed age groups 25–40 and 41–70 years); in the years 2000–2010, a total of 148 people saw hedgehogs (61 in the age groups of 25–40 and 41–70 years); and between 2011 and 2022, 979 people saw hedgehogs. Some records of hedgehog sightings were excluded from the study because participants could not remember the year (or decade) of the sighting or the location of the sighting. We collected positive results from a total of 122 villages (Table 1). During the interviews, we also collected information about sightings of roadkilled hedgehogs in the area.

3.2. Bike and Motorbike Surveys

During bicycle and motorcycle surveys, we recorded only one hedgehog roadkill in May 2022 in the Peryakannanore village located in the Sivagangai district.

3.3. Inclusion of Previously Collected Data and Data from Local Newspapers

We examined newspaper records from 2020 to 2022 and identified seven hedgehog sightings in four districts (Erode, Coimbatore, Virudhunagar, and Tirupur). In addition, rescue data for 36 *P. nudiventris* cases covering 12 districts of Tamil Nadu were collected from newspapers for the period 2012–2022 (Figure 3). The most extensive rescue records of *P. nudiventris* were especially in Tirupur and Erode regions.

Rescue data for Madras hedgehogs from 2012 to 2022

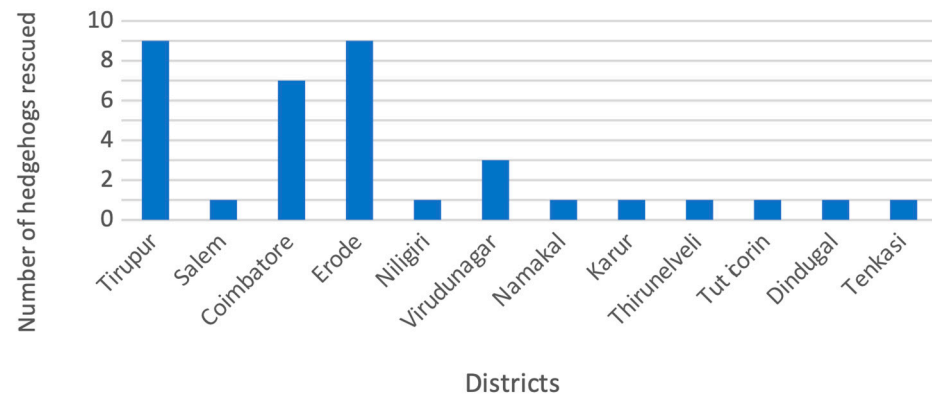


Figure 3. Information about the presence of hedgehogs based on rescue data extracted from newspapers.

Table 1. A comprehensive record of hedgehog sightings based on information retrieved from questionnaires.

S.no	District	No. of Villages Represented in the Interview Surveys Conducted	No. of People Attesting to Hedgehog Presence		No. of People Who Witnessed Hedgehog Presence in Their Villages	No. of People Who Witnessed Hedgehog Absence in Their Villages	No. of Villages with Hedgehog Presence	No. of People Sighting Hedgehogs in the Villages Before the Year 2000	No. of People Sighting Hedgehogs in the Villages from 2000 to 2010	No. of People Sighting Hedgehogs in the Villages from 2010 to 2022
			Within Districts	Other Districts						
1	SVG	29	476	1	466	121	27	36	39	402
2	ERD	18	175	0	157	381	18	13	17	3
3	TNK	40	181	2	131	203	22	16	37	115
4	RMP	15	102	0	95	7	15	2	3	94
5	TNV	7	69	1	27	51	3	14	3	53
6	TTC	18	213	4	193	24	16	44	26	147
7	KN	46	132	16	46	109	17	28	21	74
8	CBE	6	44	4	0	106	0	1	2	41
9	MDU	4	9	0	9	0	4	1	0	8
10	SLM	24	6	0	0	572	0	0	0	2
11	PDK	1	40	0	0	55	0	0	0	40
Total		208	1257	28	1124	1629	122	125	148	979

Abbreviations used: SVG—Sivagangai; ERD—Erode; TNK—Tenkasi; RMP—Ramanathapuram; TNV—Tirunelveli; TTC—Tuticorin; KN—Kanyakumari; CBE—Coimbatore; MDU—Madurai; SLM—Salem; PDK—Pudukkottai.

4. Discussion

A comprehensive assessment of the distribution of *P. nudiventris* in Tamil Nadu using various data sources revealed remarkable insights into its ecology and conservation. The distribution map illustrates different regional patterns (Figure 2), while the 230 records documented in the 11 regions provided valuable demographic information (Table 1). A questionnaire survey covering 208 villages in 11 districts yielded observations and encounters from 2744 respondents, including anecdotal data from 1950 onward.

The data obtained from the questionnaire survey from the year 2000 to 2022 regarding hedgehog sightings in different districts, villages, and time periods help to gain a better un-

derstanding of the distribution and trends of hedgehog populations in the area. According to the data, a total of 1257 people attested to the presence of hedgehogs within their districts of Sivagangai, Erode, Tenkasi, Ramanathapuram, Tirunelveli, Tuticorin, Kanyakumari, Coimbatore, Madurai, Salem, and Pudukkottai; in contrast, only a total of 28 people from Sivagangai, Tenkasi, Tirunelveli, Tuticorin, Kanyakumari, and Coimbatore reported the prolonged absence of Madras hedgehogs in these districts. From the questionnaire surveys, the numbers reveal that 1124 people from 208 villages in the 11 districts witnessed a hedgehog presence in their villages, while 1629 people from all the districts except Madurai reported their absence. The number of people who reported sighting hedgehogs in their villages before the year 2000 was 125, while it increased to 148 between 2000 and 2010. However, the most significant increase was observed from 2010 to 2022, with 979 people reporting hedgehog sightings during this period. The Tuticorin district has the maximum sightings ($N = 44$) recorded before 2000, followed by Sivagangai ($N = 39$ from 2000 to 2010). The Sivagangai district has the highest number of hedgehog sightings recorded ($N = 479$), followed by Tuticorin ($N = 213$) and Tenkasi ($N = 181$). The Madras hedgehog's populations are not evenly distributed across all villages, but their presence may be influenced by various factors, such as habitat availability, food sources, and human activities, which limits the temporal trends of hedgehog sightings in the region. To further understand the dynamics of hedgehog populations in the area, additional research is needed, such as conducting field surveys, analysing habitat characteristics, and investigating the impact of human activities on hedgehog populations, which will provide a foundation for future studies and contribute to the understanding of hedgehog ecology in the region.

Surveys conducted on motorbike over 21 nights identified only one roadkill in Sivagangai. This information was supplemented by anecdotal roadkill records gathered through the questionnaire interviews and indicated a potentially negative influence of traffic on the conservation of the species. The lack of hedgehog carcasses detected during the road surveys on bike and motorbike may have been influenced by timing, as the nocturnal Madras hedgehogs may have been killed on the road at night, leaving plenty of time for scavengers to eat or remove the carcasses before the bike surveys were conducted (from 5 p.m. to 6 p.m.). However, we did not record scavenging activities in the survey areas included in this study.

In addition to the data collected through questionnaire and bike surveys, press records and rescue information between 2012 and 2022 highlighted the role of the media and regional rescue efforts, and there was extensive rescue information for the Tirupur and Erode regions (Figure 3). These results contribute to the understanding of regional differences in species distribution, temporal changes, and conservation implications for *P. nudiventris*, highlighting the need for targeted conservation strategies and further research.

4.1. Evaluating the Threats to and Conservation Status of the Hedgehogs in India

South Indian states, such as Tamil Nadu, Kerala, Karnataka, Telangana, and Andhra Pradesh, represent the previously known distribution of *P. nudiventris*. The historical distribution of *P. nudiventris* documented in earlier papers extended to the states of Tamil Nadu, Kerala, Karnataka, and Andhra Pradesh [10]. However, current surveys show a significant decline in its range, with recent sightings concentrated mostly in Tamil Nadu. This change in distribution indicates a worrying trend and prompts further investigation into the factors contributing to this decline. One of the main challenges is the limited research efforts in Kerala, Karnataka, and Andhra Pradesh, which prevents a comprehensive population assessment of hedgehog species in these regions. Without adequate information about these states, determining the current status of hedgehog populations and implementing targeted conservation measures remain challenging. However, studies in Tamil Nadu provide many valuable insights. This variation in abundance between states may indicate how different ecological factors could be influencing the distribution patterns of *P. nudiventris*. Factors such as habitat suitability, anthropogenic pressures, and interactions with other species could potentially be responsible for the observed changes in the hedgehog population

distribution in the state. Understanding these dynamics is critical to developing effective conservation strategies aimed at mitigating increased declines and ensuring the long-term survival of the species. Based on research results, it can be suggested that Tamil Nadu may be the only place in India where *P. nudiventris* is currently found. Through this study, we identified a total of 19 districts in Tamil Nadu where *P. nudiventris* was detected.

The two other species of hedgehog found in India are the Indian hedgehog (*P. micropus*) and the Indian long-eared hedgehog (*H. collaris*). The Indian long-eared hedgehog can also be found in the Khyber Pakhtunkhwa province of Pakistan (NW Frontier) and the Indian state of Uttar Pradesh, where both species coexist in southeastern Pakistan, northeastern India, and the Thar Desert [35,36]. Similar to *P. nudiventris*, both hedgehog species are hunted locally, serving as a source of food and traditional medicine in India [37,38]. As a consequence, these species are at risk of extinction. Other factors that are believed to contribute to the decline are rapid urbanization, human-induced expansion, landscape fragmentation, habitat degradation due to firewood collection, and other factors that generally threaten Indian mammal populations and species diversity [39,40].

The three main causes of habitat destruction for *P. nudiventris* are logging, agriculture, and urbanisation. Habitat loss is a significant threat to hedgehog conservation, as suitable hedgehog habitats are limited because they are either partially or completely removed due to human-induced development, such as the closure of green spaces, resulting in reduced accessibility due to fragmentation [9,10]. Obstacles, such as roads, walls, and fences, that hedgehogs cannot cross can cause fragmentation [41,42]. In this study, we found one roadkilled hedgehog in the Peryakannanore village located in the Sivagangai district, on a newly constructed road passing through a scrub forest area, which is a suitable habitat for hedgehogs. In the Thoothukudi district, where we did not observe cases of roadkilled hedgehogs, we detected herbaceous shrubby habitats between forest areas, groves, and farmland. These natural barriers probably prevented the hedgehogs from entering the road and thereby the risk of death in traffic, and could even act as a natural dispersal corridor.

Emerging ecological costs from previous habitat degradation are referred to as an “extinction debt” [43]. A hypothetical extinction debt might make the situation more complicated. Although habitat isolation and fragmentation do not immediately result in a species’ extinction, they do cause reduced, potentially inbred subpopulations in smaller habitat islands that may no longer be well adapted to the environmental conditions and may experience inbreeding depression [44,45].

Furthermore, the placement of industrial products, such as windmills, is destroying hedgehog habitats [11]. Most researchers agree that the biggest environmental threat of our day is climate change, which is brought on by rising greenhouse gas (GHG) emissions [46,47]. Despite the clear environmental advantages of wind energy, its effects need to be carefully considered [48,49]. The impacts on animals may intensify when more wind farms are built and larger wind turbines are gradually installed [50,51]. Tamil Nadu is one of the states in India with a high prevalence of wind energy resources, especially in the Kanyakumari district, which has attracted more investment in wind energy [52]. This location is close to the Tirunelveli district, which has the highest detection frequency of *P. nudiventris*, as shown in previous publications [9,10] and in the questionnaire data in this study. It is noticeable that there are few records of *P. nudiventris* in the Kanyakumari district, with a high prevalence of windmill farms.

Our questionnaire showed that many people are unaware of hedgehogs dwelling in their landscapes, while some have heard about them but have not seen one in person. Additionally, a few have hunted *P. nudiventris* and were not interested in disclosing that information. In general, people who were illegally hunting hedgehogs did not respond to our questionnaire, but some hunters did respond and admitted their illegal hunting, either intentionally or mistakenly.

Despite the severe data deficiency on *P. nudiventris*, it is classified as of “Least Concern” on the IUCN Red List due to its apparent abundance within its small distribution, leading to the evidence-deprived assumption that the species comprises a large population and

the belief that its habitat is not likely to decline quickly enough to warrant listing in a more threatened category. Later research conducted by Kumar et al. [8–11] provided records of the limited distribution of *P. nudiventris* in the state of Tamil Nadu in general, thereby highlighting the critical status of *P. nudiventris*, identifying it as one of India's most threatened mammal species. This conclusion is further supported by Xuelong and Hoffman (2013) [15], who argued that *P. nudiventris* should be reclassified from “Least Concern” to “Vulnerable” on the IUCN Red List. Therefore, supported by the data made available by this study, we urge the re-evaluation of the conservation status of *P. nudiventris* on the IUCN Red List.

4.1.1. The Role of Invasive Species in *P. nudiventris* Habitats

Invasive species encompass exotic, foreign, non-indigenous, or non-native organisms intentionally or unintentionally introduced outside their native habitats that cause negative effects on the local, endemic species [53]. It is suggested that invasive species pose the second-biggest threat to biodiversity on Earth [54]. The potential influence of invasive species on native animals varies depending on the traits of the invasive species in question and the quality of the native environment [55]. The mesquite, *Prosopis juliflora* (Sw.) DC., is an introduced tiny tree or shrub that thrives in dry and semi-arid tropical climates and is widely distributed in India. It poses a threat to accessible grassland and woodland habitats, as well as water supplies, in the ranges where it has been introduced. The plant is thought to be one of Tamil Nadu's most impactful invasive species, negatively affecting both natural and man-made ecosystems, as well as regional biodiversity. *Seemai karuvelam* is the local name for *P. juliflora*, which is found throughout Tamil Nadu's districts [48,56]. We found *P. juliflora* in all 11 districts. It is particularly prevalent in the districts of Ramanathapuram and Sivagangai. When the mesquite proliferates in the habitat, it often forms dense thickets, crowding out native vegetation. This reduction in native plant diversity not only diminishes the availability of suitable nesting materials for hedgehogs but also alters the overall habitat structure and composition. As a result, hedgehogs may struggle to find suitable sites for constructing their nests, which are typically made from dry grasses, leaves, and other plant materials. Furthermore, the invasion of the mesquite can lead to changes in the ecological dynamics of the habitat, potentially affecting the availability of food resources for hedgehogs. A decline in native plant species may also lead to a reduction in the species of insects, small vertebrates, and plant matter that hedgehogs rely on for food. This disruption in the food chain can further impact the survival and reproductive success of hedgehog populations. This could be one of the factors causing the observed decline in *P. nudiventris* numbers in Tamil Nadu.

4.1.2. The Effects of a Possible Reduction in Natural Food Items

The quality of the available habitat is related to the quality of food and its accessibility. Madras hedgehogs eat a diverse range of molluscs and arthropods [49]. Therefore, insectivorous mammals, like hedgehogs, are expected to be impacted by the recently described global decrease in insect biomass [57]. Additionally, the semi-arid savannah and grasslands face ongoing conversion to forests by various government and non-government agencies. This tree-centric approach poses a threat to the natural habitat of *P. nudiventris*, leading to a reduction in habitats that sustain the species' natural food sources. The continuous conversion of these ecosystems disrupts the delicate balance of food availability for the Madras hedgehog, further exacerbating the challenges faced by the species in its native environment. Efforts to conserve the natural habitats and biodiversity and maintain the ecological integrity of semi-arid savannah and grasslands are crucial for ensuring the long-term survival of *P. nudiventris* and other wildlife dependent on these ecosystems.

4.1.3. The Impact of Hunting and Traditional Medicine on the Population of *P. nudiventris*

In many countries, including India, hedgehogs are specifically listed as a protected species under wildlife protection laws, which means that excellent legal protection is in

place within the species' range [58]. However, the strict enforcement of these laws is still missing in many districts of India. As a result, there may not be explicit legal restrictions on hunting or using hedgehogs for traditional medicine in these areas.

P. nudiventris is frequently hunted either opportunistically by hand or with the aid of dogs. The hunters bring the hedgehog back to the village, where the flesh is consumed locally and the skins are traded. Since *P. nudiventris* is a nocturnal species that spends most of its time underground/under the leaves, the species is largely elusive to humans. Hedgehog collectors and sellers include the itinerant nomadic tribe of Nari Kuruvaars, who sell live and dried hedgehogs for medicinal purposes [11].

In the districts of Thoothukudi, Sivagangai, Ramanathapuram, Tirunelveli, and Madurai, questionnaire survey participants attested to people hunting hedgehogs for skin and flesh. A previous study identified several cases of individuals preparing medicine based on *P. nudiventris* (two in the district of Thoothukudi, three in Erode, and three in Tirunelveli) [12]. Hedgehog oil was being sold in a well-known Ayurvedic medicinal store in Nagercoil, the southernmost city in India [12]. Hedgehog skins were previously a common commodity in the weekly markets of the Nagercoil and Dindigul districts, often traded for medicinal purposes, according to information shared by Bharathidasan and Kumaran Sathasivam (pers. comm. to Brawin Kumar). However, the presence of hedgehog skins in households in various districts of Tamil Nadu provides documentation that this tradition still persists today.

4.2. Important Next Steps for the Conservation of *P. nudiventris*

The overuse of natural resources and our ever-increasing dependence on them have led to a loss of biodiversity, which is crucial to the welfare of hedgehog populations. In general, the preservation of natural resources is a matter of great concern to the entire globe today, sustaining the structure and functions of the eco-system and ensuring real advantages in terms of fuel, fodder, and other resource-based demands. Therefore, it is important to mitigate the rapid loss of hedgehog habitats caused by, for example, urbanisation, agricultural expansion, and logging. By collaborating with local communities and policymakers and advocating for habitat preservation, restoration, and sustainable land-use practices, it should be possible to create a harmonious co-existence between human settlements and hedgehog habitats. It is also essential to raise awareness among local communities, schools, and stakeholders about the ecological importance of hedgehogs to dispel misconceptions, discourage the hunting for hedgehogs and the collection of skins and use of hedgehogs for medicinal purposes, and promote responsible behaviours towards hedgehog conservation.

More research on the distribution of and threats to the species is urgently needed, given its narrow geographic range—which is the lowest of all hedgehog species—and the lack of data [38]. Therefore, we encourage future studies on the distribution, home range, and behavioural ecology to inform and improve the conservation of *P. nudiventris*, including an updated status for the species on the IUCN Red List. The distribution map from this study contributes to our understanding of the geographic range and occurrence of *P. nudiventris* in Tamil Nadu. This information is crucial for informing conservation strategies and implementing targeted efforts to protect and preserve this species within the region.

Due to climate change, the mean annual temperature in Tamil Nadu has exhibited a consistent upwards trend, contributing to shifts in the timing of planting and harvesting seasons for various crops. These temperature changes are found to have a considerable impact on crop yields and growth patterns [59] and animals in this landscape [60]. Research and collaborations are imperative for developing comprehensive strategies that ensure the resilience and adaptability of these unique creatures in the face of ongoing climate changes. As climate patterns continue to shift, hedgehog habitats and behaviours may be significantly impacted, affecting their survival and overall population dynamics. Exploring the specific responses of hedgehogs to changing temperatures and precipitation patterns, in addition to habitat alterations, is crucial for their conservation. Future research initiatives

focused on understanding hedgehog behaviour, migration patterns, and reproductive cycles in the context of evolving climate conditions will inform targeted conservation strategies. By identifying areas of vulnerability and potential disruptions to hedgehog habitats, interventions can be designed to mitigate the negative effects and support the survival of the Madras hedgehog. The integration of innovative technologies and citizen science initiatives can enhance our understanding of hedgehog ecology and facilitate data collection across broader geographical scales. By working together, we can develop adaptive strategies that not only support the resilience and adaptability of hedgehogs but also contribute to the overall conservation of biodiversity in a changing climate.

To ensure the conservation of the Madras hedgehog in the dry semi-arid forests of the southern Deccan Plateau and the thorn forests of the Deccan, there are several important steps to be taken. First, to preserve the hedgehogs' natural habitat, we must focus on habitat protection and the restoration of grasslands, including the establishment of protected areas in the plains. At the same time, systematic surveys and monitoring programmes are important to assess population size, distribution, and trends and provide critical data for conservation planning. Research efforts should focus on the ecology, behaviour, and habitat requirements of hedgehogs to inform conservation strategies. In addition, identifying and mitigating threats, such as habitat loss, poaching, and roadkill, is critical. Education and community engagement programmes are essential to raise awareness about and gain support for hedgehog conservation among communities, stakeholders, and policymakers. It is also important to advocate for policy and legislative reforms to strengthen legal protection for the Madras hedgehog and its habitats. Finally, cooperation and networking will promote knowledge sharing and joint conservation efforts, contributing to the long-term survival of the Madras hedgehog in its native habitat in Tamil Nadu.

5. Conclusions

This comprehensive study provided a detailed assessment of the conservation status of *P. nudiventris*, including a discussion of the distribution and threats to the species in Tamil Nadu, India. Combining a variety of sources, including interview surveys, bike surveys, newspaper notes, and previously published data, this study presented a total of 230 *P. nudiventris* records from 11 districts, with a higher prevalence of rescue records in the Erode and Tirupur districts. Factors such as habitat degradation due to deforestation, agriculture, and urbanisation and the impact of invasive species, such as *P. juliflora*, in addition to pesticide use, are likely causing the population decline observed for *P. nudiventris*. In addition, hunting for medicinal purposes and the trade of hedgehog skins should be considered a serious threat. Critical conservation strategies emphasise the importance of conserving habitat through public and governmental cooperation, establishing educational awareness programmes to prevent poaching, encouraging sustainable land-use policies, and funding research. We encourage urgent action to protect *P. nudiventris* in changing environmental conditions, as well as contributing to the preservation of this unique species by restoring biodiversity throughout the region.

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