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Silent Invaders: Biodiversity at Risk, Social Media findings into Exotic Pet Trade in Tamil Nadu and Invasion Modeling of *Iguana iguana* (Linnaeus, 1758)

Invasores silenciosos: biodiversidad en riesgo, hallazgos en redes sociales sobre el comercio de mascotas exóticas en Tamil Nadu y modelado de la invasión de *Iguana iguana* (Linneo, 1758)

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Abstract

This study investigates the exotic pet trade in Tamil Nadu by analyzing YouTube videos, which revealed the presence of 148 pet species being sold in pet shops. Among these, 12 species were classified as Endangered, 15 as Vulnerable, 3 as Near Threatened, 101 as Least Concern, and 18 as Not Assessed, according to the IUCN Red List. The CITES status of each species was also examined to assess their trade regulations. Additionally, the presence of invasive alien species recorded in the videos

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and already existing in the wild in India was mapped. Species distribution modelling using MaxEnt was conducted for *Iguana iguana* globally, evaluating both current and future habitat suitability. Results indicated a high potential for the species to establish itself and reproduce in India, posing a serious ecological threat. A questionnaire survey among pet shop owners disclosed limited awareness of pet trade regulations and breeding practices. Overall, the findings prioritize the urgent need for stricter enforcement of pet trade laws, increased public awareness, and proactive measures to prevent potential invasions by exotic species.

Keywords: Exotic pet fauna, Global Invasion, climate warming, Reptile SDM, Social Media, Regional conservation.

Resumen

Este estudio investiga el comercio de mascotas exóticas en Tamil Nadu mediante el análisis de videos de YouTube, que revelaron la presencia de 148 especies de mascotas vendidas en tiendas de mascotas. Entre estas, 12 especies fueron clasificadas como En Peligro, 15 como Vulnerables, 3 como Casi Amenazadas, 101 como Preocupación Menor y 18 como No Evaluadas, según la Lista Roja de la UICN. También se examinó el estatus CITES de cada especie para evaluar sus regulaciones comerciales. Además, se cartografió la presencia de especies exóticas invasoras registradas en los videos y que ya existen en la naturaleza en India. Se realizó un modelo de distribución de especies utilizando MaxEnt para *Iguana iguana* a nivel mundial, evaluando la idoneidad del hábitat actual y futuro. Los resultados indicaron un alto potencial para que la especie se establezca y se reproduzca en India, lo que representa una grave amenaza ecológica. Una encuesta entre propietarios de tiendas de mascotas reveló un conocimiento limitado de las regulaciones del comercio de mascotas y las prácticas de cría. En general, los hallazgos priorizan la urgente necesidad de una aplicación más estricta de las leyes sobre el comercio de mascotas, una mayor concienciación pública y medidas proactivas para prevenir posibles invasiones de especies exóticas.

Palabras clave: Fauna exótica como mascotas, invasión global, calentamiento climático, gestión de residuos sólidos para reptiles, redes sociales, conservación regional.

INTRODUCTION

The exotic pet trade, driven by the rising popularity of keeping wild, non-domesticated animals as companions, poses significant challenges to biodiversity, animal welfare, and ecosystem stability (Bush et al., 2014; Lockwood et al., 2019; Naito et al., 2024). Exotic pets encompass a diverse range of wild species that include reptiles, birds, small primates and invertebrates, often kept in private homes or displayed in commercial venues like roadside zoos and tourist attractions (Collard, 2020; Harrington et al., 2019). While humans have long interacted with wild animals (Driscoll and Macdonald, 2010; Mitchell, 2009), the past few decades have witnessed a surge in demand for exotic species, fueled by globalized trade networks and increasing consumer affluence, particularly in regions like Asia and South America (Grant et al., 2017; Mazzamuto et al., 2021). This growing trend of keeping wild animals as pets has increased the demand for exotic pets, a practice, which is often unsustainable (Bush et al., 2014; Lockwood et al., 2019; McMillan et al., 2021; Siriwat and Nijman, 2018; Smith et al., 2017; Tapley et al., 2011; Naito et al., 2024).

This demand drives a multibillion-dollar pet industry, with the illegal wildlife trade alone valued at approximately USD 20 billion annually (Alexander and Sanderson, 2017; Spee et al., 2019). The exotic pet trade has significantly contributed to the global wildlife trade, accounting for nearly 20% (Baker et al., 2013; Harrington et al., 2019). Reptiles, such as turtles, snakes, and lizards, are among the most heavily traded groups, yet only 8% of traded reptile species are regulated under the Convention on International Trade in Endangered Species (CITES) (Auliya et al., 2016; Pragatheesh et al., 2021). In India, the trade in exotic reptiles is a growing concern, with 84 species, including several threatened ones, reported in the pet market (Pragatheesh et al., 2021). Major cities like Bengaluru, Chennai, and Mumbai are hubs for the illegal trade of species such as the Indian Star Tortoise (Sekhar et al., 2004; D'Cruze et al., 2015;Pragatheesh et al., 2021). Reptiles have been popular as pets for decades, leading to their significant presence in the pet trade, even though such trade is often illegal (Aulia, 2003; Benabdallah et al., 2025). In addition to reptiles, the illegal bird trade is also widespread and globally, over 3,300 species of wild birds are part of the international trade, and in India alone, around 450 bird species including 42 that are threatened have been documented in illegal markets (Ahmed, 2004; Ahmed, 2012; BirdLife International, 2008; Ministry of Environment, 2024). Similarly, the illegal bird trade affects over 450 species in India, including 42 that are threatened (Ahmed, 2012; BirdLife International, 2008). Beyond direct impacts on traded species, the exotic pet trade facilitates the introduction of non-native species, a major driver of biological invasions (Hulme, 2009; Lockwood et al., 2019; Pratt et al., 2025).

One of the major ecological threats linked to globalization is the introduction and spread of non-native species into natural ecosystems (Hulme, 2009; Kwak et al., 2019). The non-native pet trade is now recognized as a significant pathway for such biological invasions (Mooney and Cleland, 2001; Krishnakumar et al., 2009; Engeman et al., 2011; Lockwood et al., 2019; Mohanty and Measey, 2019; Sinclair et al., 2021). Species that exist outside their native range are typically termed "exotic," "non-native," or "alien." When such species successfully reproduce, expand their range, and inflict ecological or economic damage in the introduced environment, they are classified as "invasive" (IUCN, 2019). Approximately 53% of invasive vertebrate species worldwide are linked to the pet trade, as escaped or deliberately released pets often establish invasive populations that threaten native biodiversity, public health, and national economies (Saul et al., 2017; Mazzamuto et al., 2021). The rising popularity of exotic pet ownership has led to increased releases of non-native species into the wild, accelerating the spread of invasive alien species (IAS) (Lockwood et al., 2019; Hulme, 2015; Mazzamuto et al., 2021). Once established, these species can severely disrupt ecosystems, transmit diseases, and impose significant economic burdens (European Environment Agency, 2013; Pimentel, 2005; Mazzamuto et al., 2021). Many invasive species also act as vectors for emerging infectious diseases, elevating risks to both wildlife and humans (Sato et al., 2015; Deng et al., 2016), and may transmit zoonotic diseases that further compound threats to native species and public health (Chomel et al., 2007; Smith et al., 2017; O'Hanlon et al., 2018; Sinclair et al., 2021). These challenges often strain public health systems and financial resources, underscoring the need for community involvement through citizen science initiatives (Encarnação et al., 2021; McCaffrey et al., 2025). Effective management requires the ability to predict which species are likely to become invasive when introduced beyond their native range, a core component of invasive species risk assessment (Lodge et al., 2016; Kumschick et al., 2024; Howeth et al., 2025). The green iguana (*Iguana iguana*) is such a globally widespread invasive species, yet comprehensive data on its ecological impacts and management remain scarce. Originally native to Central and South America, the species has expanded its range significantly since the 1990s, largely due to the exotic pet trade (Stephen et al., 2012). Today, it has become established in regions such as the Pacific islands, Florida, and the Greater Caribbean (Falcón et al., 2012; van den Burg et al., 2020; De Jesús Villanueva et al., 2021). In fact, the pet trade is recognized as the primary driver behind the emergence of non-native populations of *I. iguana* (Bock et al., 2018; Falcón et al., 2013; Kraus, 2009). Understanding how invasive species spread in a region relies on advanced scientific methods, especially the use of integrated species distribution models (SDMs) and environmental DNA (eDNA) analysis (López-González et al., 2025; Oskyrko et al., 2025).

Recent developments in SDMs include the use of ensemble modeling and varied environmental layers, allowing predictions that better reflect a species' ecological and physiological traits (Oskyrko et al., 2025).

Social media, particularly platforms like YouTube, plays a pivotal role in shaping public perception, influencing consumer preferences, and driving the exotic pet trade (Bush et al., 2014; Harrington et al., 2019).

With over two billion users, YouTube influences public behavior through unregulated content that often glorifies exotic pet ownership (Chen and Chang, 2019; YouTube, 2020). Weak regulatory frameworks struggle to manage the volume of content uploaded daily, allowing trends to proliferate unchecked (Kumar and Shah, 2019). Analyzing social media data offers a window into emerging markets, public perceptions, and potential threats to animal welfare and ecosystems (Harrington et al., 2019). In Tamil Nadu, the exotic pet trade is a growing concern, with endemic and endangered species increasingly at risk. This study focuses on the role of social media in promoting trade, the involvement of threatened species, and the potential ecological impacts of invasive species like the Green iguana. Integrating the social media analysis, distribution modeling, and stakeholder surveys this research aims to address the silent spread of invasive species and their broader implications for biodiversity conservation.

METHODOLOGY

YouTube videos were carefully analyzed to identify species featured within the content. Popular terms were used to search for videos included terms such as "exotic pets," "exotic pet shops," specific district names in Tamil Nadu, as well as species-specific terms like "exotic birds," "pet geckos," "pet tarantulas," "cute pets" and "pet fish". Only videos clearly filmed (above 360p) in Tamil Nadu were considered for data collection. For each video, the district location of the pet shop and the visually identifiable species being sold were recorded. To avoid duplication, data were organized district-wise using the names of pet shops and associated YouTube channels. Each identified species was then cross-verified on the IUCN Red List website to determine its conservation status. Additionally, the taxonomic classification including the class and family of each species was recorded for accurate categorization.

A total of 42 randomly selected pet shops were directly surveyed and shopkeepers were interviewed using a set of structured questions. We employed a questionnaire survey targeting 42 pet shops at Chennai. Chennai was selected based upon the significant count in number of shops and the sales it produces compared to other places in Tamil Nadu. Although similar shops exist in other regions of interest, logical and safety concerns, including instances of verbal threats and phone call intimidation limited the feasibility of conducting the fieldworks elsewhere.

The study thus handled a non-probability sampling method such that the sampling was intentionally selected according to the prevailing conditions as mentioned above. The survey involved in person interviews using direct and compliance related questions framed in a non-confrontational and factual tone. The survey was a voluntary participation and the participants were assured that their details and responses would be kept confidential and anonymized.

Furthermore, for non-native species, records were cross-checked on GBIF (2025) to determine whether they have been observed in the wild in India. This helped in mapping the occurrence of exotic species outside captivity. The 19 bioclimatic predictor variables and elevation data were sourced from the WorldClim database (http://www.worldclim.org). Multicollinearity was carried out and based on the known biology and ecology of the species (Bonato and Fracasso 2014; Romano et al. 2018; Giachello et al. 2025) ultimately, 10 bioclimatic variables were used for MaxEnt algorithm modelling such as bio 11 (Mean temperature coldest quarter), bio 12 (Annual precipitation), bio 17 (Precipitation of driest quarter), bio 3 (Isothermality), bio 5 (Minimum temperature warmest month), bio 16 (Precipitation of wettest quarter), bio 10 (Mean temperature warmest quarter), bio 15 (Precipitation seasonality), bio 6 (Minimum temperature coldest month), bio 1 (Annual mean temperature),

Before running the MaxEnt model, the following settings were made: 20 replicates, 10,000 background points, 1000 iterations, with a test percentage of 20. For reliable outcomes, an AUC score of 0.7 or higher was preferred. Values below 0.5 are deemed unacceptable and are not included in distribution model analyses (Swets 1988; Philip et al. 2006; Parolo et al. 2008; Salas et al. 2017; Kawalkar et al. 2024). For future model projections from the 2050s and 2070s bioclimatic layers were obtained from the WorldClim. The model projections were downloaded in 2.5 minutes' special resolution and HadGEM3-GC31-LL was used for both the most conventional emission pathway scenario (ssp 2.6) and worst emission scenario (ssp 8.5). Habitat suitability was classified based on the predicted probability values from the MaxEnt output. Areas with a probability >0.75 were considered highly suitable, values between 0.5 and 0.75 were categorized as moderately suitable, and those between 0.25 and 0.5 were defined as having low suitability. Regions with a probability value below 0.25 were classified as unsuitable. All statistical analyses were carried out in R-Studio 12.0 (2020), mapping was done using QGIS (version 3.40.2) to maintain spatial precision and clarity. The Spatial autocorrelation between sightings was addressed by thinning the data using the 'spThin' package (Aiello-Lammens et al., 2015) in the R-Studio, removing spatially auto correlated points and redundant occurrences with 10 km distance between occurrence.

Table 1. Displays the species diversity from different classes acquired through social media.

S. N°	Class	Number of families	Contribution of family (%)	Number of species	Contribution of species (%)	Total number of individuals
1	Amphibians	2	3.1	2	1.4	4
2	Arachnid	2	3.1	8	5.5	12
3	Aves	3	4.7	35	24.1	287
5	Mammals	9	14.1	14	9.7	79
6	Pisces	34	53.1	65	44.8	589
7	Reptiles	14	21.9	21	14.5	44

RESULT

A total of 115 shops videos were analyzed covering 140 videos. Based on insights gathered from video analyses, a total of seven animal classes were identified comprising 64 families, 145 species, and 1,015 individual records (Table 1).

Amphibians included 2 families (3.1%), 2 species, and 4 individual records (1.4%). Arachnids accounted for 2 families (3.1%), 8 species, and 12 individuals (5.5%). Aves were represented by 3 families (4.7%), comprising 35 species and 287 individuals (24.1%). Mammals contributed 9 families (14.1%), 14 species, and 79 individuals (9.7%). Pisces were the most dominant group, with 34 families (53.1%), 65 species, and 589 individuals (44.8%). Reptiles included 14 families (21.9%), 21 species, and 44 individuals (14.5%). Overall, Pisces had the highest proportion of records, followed by Aves, Reptiles, Mammals, Arachnids and Amphibians indicating a dominance of fish and bird species in the exotic pet trade observed through video content from Tamil Nadu (Table 5).

Among the individual species recorded, *Pyrrhura molinae* was the most frequently sold species in 82 shops (Table 5). Followed by *Carassius auratus* in 69 shops and *Melopsittacus undulatus* in 54 shops. *Cyprinus rubrofuscus* was found in 45 shops, while *Betta splendens*, *Poecilia reticulata*, and *Poecilia sphenops* were each observed in 43 shops. *Pterophyllum scalare* appeared in 38 shops, *Amphilophus* spp. in 36, and *Astronotus ocellatus* in 30. All other species were present in fewer than 30 shops.

The dataset presents the number of shops recorded across districts in Tamil Nadu (Figure 1). The highest number was reported from Chennai with 190 shops, followed by Coimbatore (76), Madurai (70), Tiruchirappalli (64), Vellore (42), Salem (40), Kanyakumari and Pudukottai (each with 31), Dindigul (29), Mayiladuthurai (28), Namakkal (27), Erode (26), Ranipet (25), Karur (24), Cuddalore and Tiruvannamalai each with 22, Ramanathapuram and Thiruvarur each with 21, and Thoothukudi (20). All other districts recorded lesser than 20 pet shops.

The conservation status of species across different classes (Figure 2, Table 5) shows that a total of 12 species are classified as Endangered, 15 as Vulnerable, 3 as Near Threatened, 101 as Least Concern, and 18 as Not Assessed.

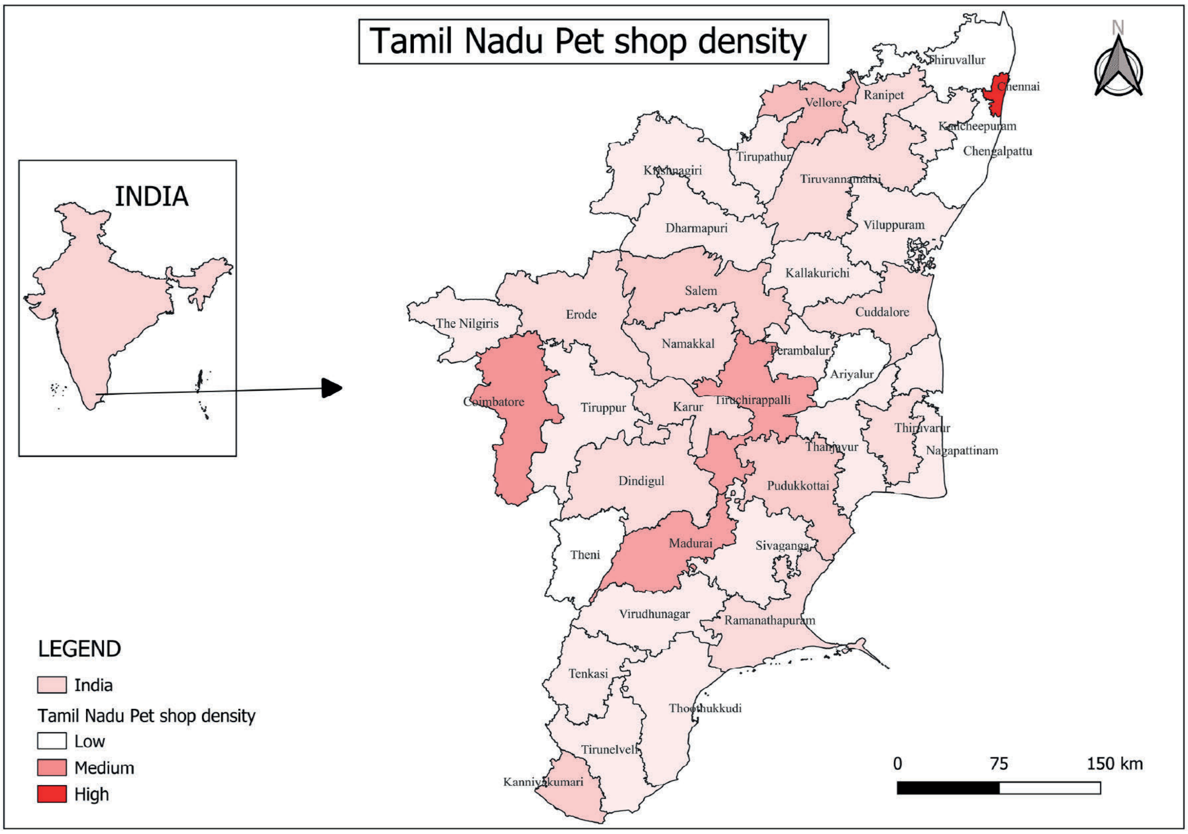

Figure 1. Illustrates the density of pet shops in Tamil Nadu based on videos.

Specifically, among the Amphibians, 2 species are Least Concern; among the Arachnids, 1 species is Vulnerable and 7 are Not Assessed; among the Aves, 6 species are Endangered, 2 are Vulnerable, and 29 are Least Concern; among the Mammals, 3 species are Endangered, 1 is Vulnerable, 10 are Least Concern, and 1 is Not Assessed; among the Pisces, 8 species are Vulnerable, 2 are Near Threatened, 47 are Least Concern, and 9 are Not Assessed; and among the Reptiles, 3 species are Endangered, 2 are Vulnerable, 1 is Near Threatened, 13 are Least Concern, and 2 are Not Assessed.

Insights from GBIF data (Figure 3) reveal that several species commonly sold in pet shops were also recorded in the wild. Among these, *Trachemys scripta elegans* (Red-eared Slider) leads with the highest number of observations, totaling 169, followed by *Poecilia reticulata* (Trinidadian guppy) with 66, *Cyprinus rubrofuscus* (Koi carp) with 33, and *Mastacembelus armatus* with 39. Other species such as *Pethia conchonius* (16 observations), *Melopsittacus undulatus* (Budgerigar) with 9, and several additional species like *Atractosteus spatula* (Alligator gar), *Epalzeorhynchos frenatum* (Rainbow shark), *Osphronemus goramy* (Giant gourami), *Agapornis fischeri* (Fischers lovebird), *Agapornis personata* (Yellow collared lovebird), *Agapornis roseicollis* (Rosy faced lovebird), *Aratinga solstitialis* (Sun conure), *Lonchura oryzivora* (Java sparrow), *Oryctolagus cuniculus* (European wild rabbit), *Osteoglossum*

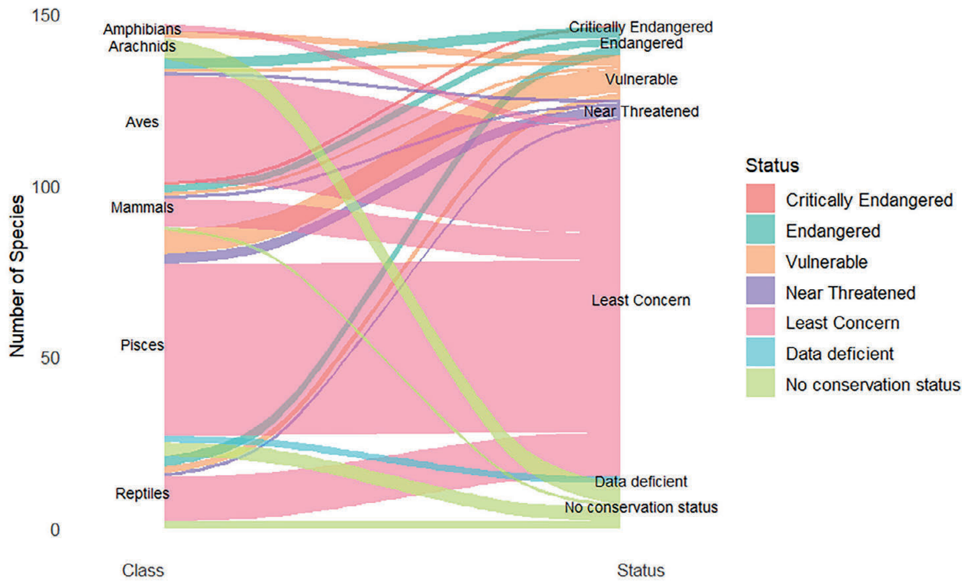

Figure 2. Illustrates the contribution of different classes to various IUCN status categories.

bicirrhosum (Silver arowana), *Poecilia sphenops* (Mexican Molly), *Taeniopygia guttata* (Zebra finch), and *Xiphophorus hellerii* (Green swordtail) have been recorded with 2 or 1 observations. These species, initially introduced through the ornamental and pet trade, are now observed in the wild which may pose a growing ecological challenge. Places such as Goa, Mumbai and Bangalore have high occurrences whereas in Kerala it is spread throughout the state.

Analysis of species to CITES status (Figure 4, Table 5) shows that Reptiles have been known to comprise a total of 21 species, with 1 species listed in Appendix I, 10 species in Appendix II, and 10 species not listed under CITES. The Pisces class accounted for 66 species, with 1 species in Appendix II, 1 species in Appendix III and 64 species not listed. For Aves, there were 35 species, including 21 species in Appendix II and 14 species not listed. The Mammals class had 14 species, with 2 species in Appendix II and 12 species not listed. Arachnids comprised 8 species, with 2 species in Appendix II and 6 species not listed. The Amphibians class had 2 species, both of which are not listed.

According to the current scenario, the predicted habitat distribution of *I. iguana* (Figure 5, Table 5)) showed a high performance with an AUC (Area Under the Curve) value of 0.959 ± 0.001 across the current scenario. Among the bioclimatic variables, elevation contributed the highest percentage of at 35.7 followed by bio 12, bio 1 with 22.2 and 11.6 while all other variables contributed below 9.4 percent. The Jackknife test reveals that all variables except bio 15 (precipitation seasonality) significantly influence the model performance ($AUC > 0.84$), with bio 10 (mean temperature of the warmest quarter) showing the highest explanatory power when used independently.

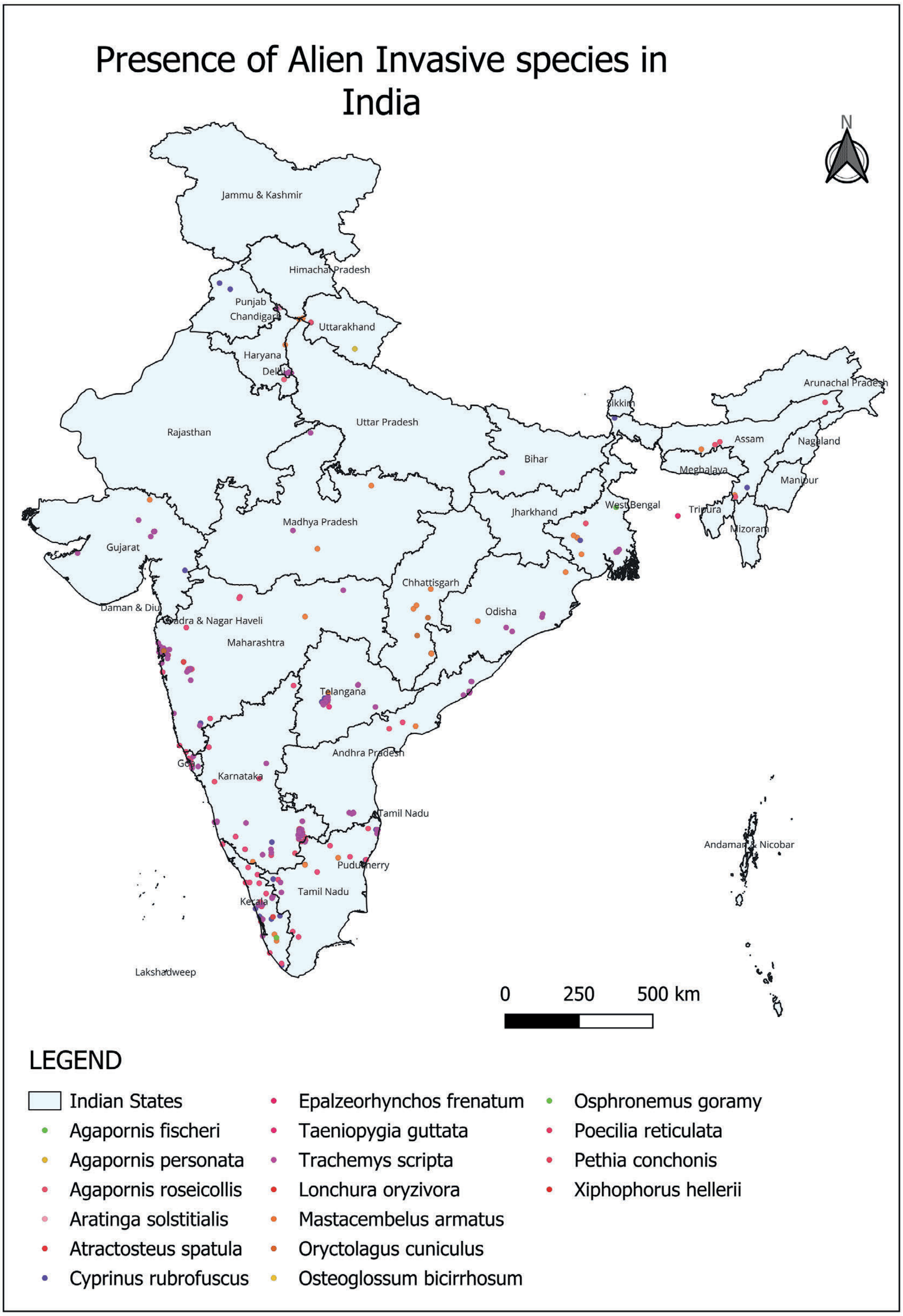

Figure 3. Illustrates the mapping of alien invasive species recorded in India.

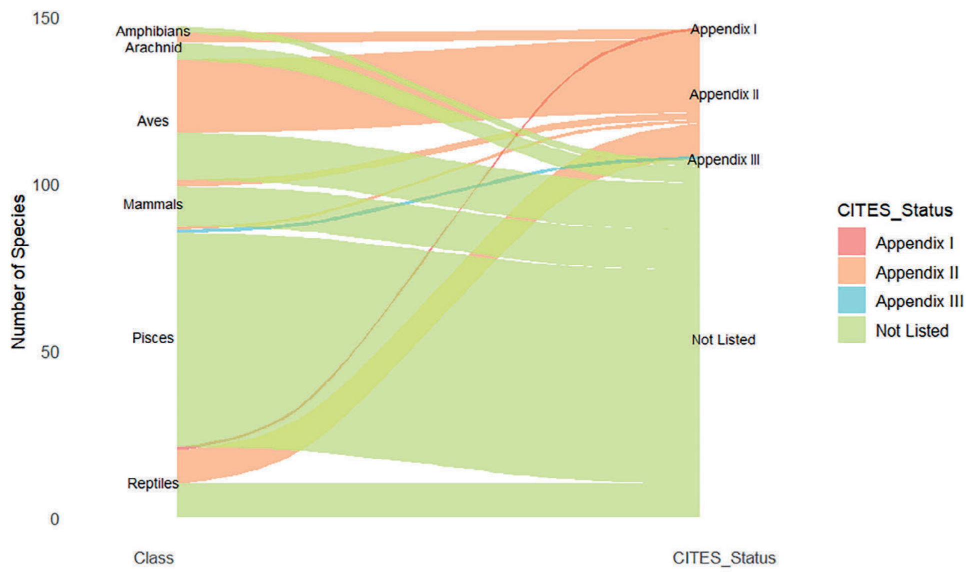

Figure 4. Illustrates the contribution of different classes to various CITES categories.

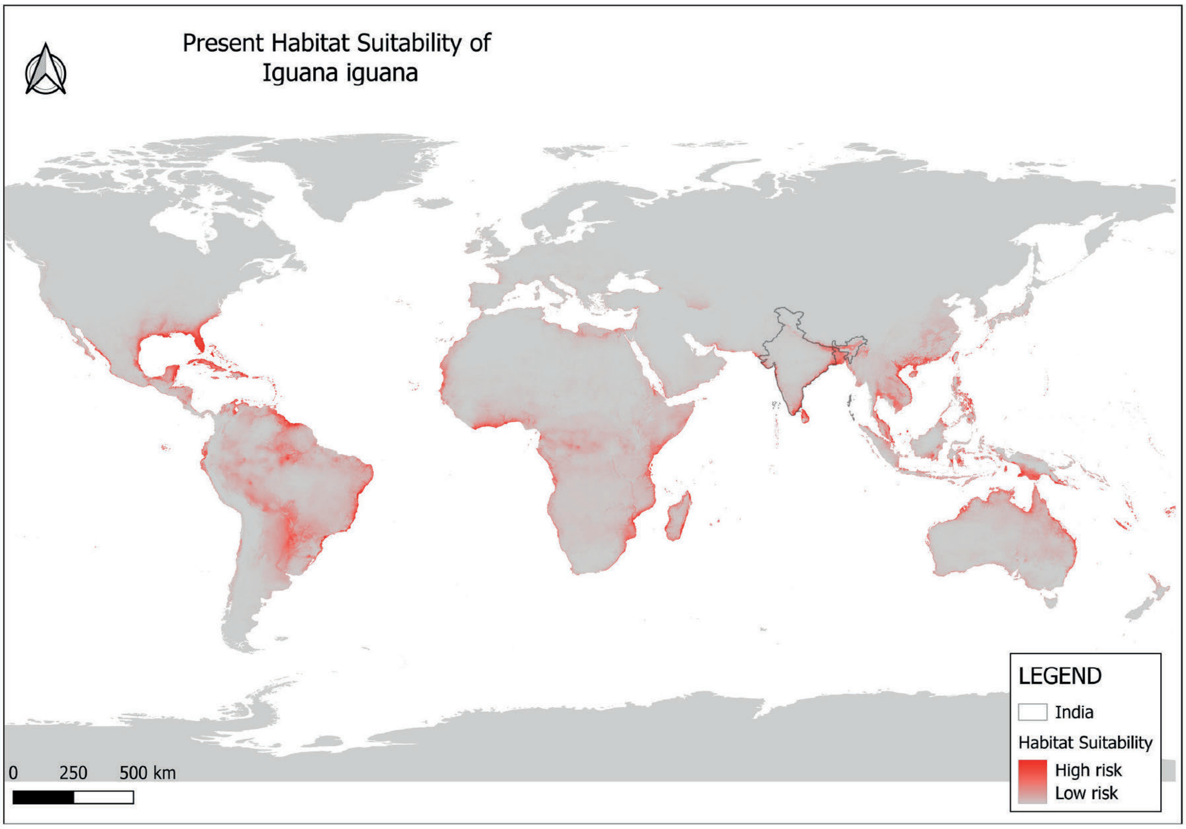

Figure 5. Illustrates the mapping of MAXENT modelling for present scenario for *Iguana iguana* for the world.

Under the HADGEM3 model for the year 2050 (Figure 6), the predicted habitat distribution of *I. iguana* demonstrates excellent predictive performance across climate scenarios. For the conventional emission pathway (SSP 2.6), the mean AUC is 0.955 ± 0.001, indicating strong discrimination between suitable and unsuitable habitats, with bio 11 (mean temperature of the coldest quarter) contributing the most at 37.3%, followed by bio 12 (annual precipitation) at 27%, bio 17 (precipitation of the driest quarter) at 14.2%, and other variables below 5%. Under the worst-case emission scenario (SSP 8.5), the mean AUC is 0.958 ± 0.001, also reflecting excellent predictive ability, with bio 11 leading at 43.6%, followed by bio 17 at 18.2%, bio 12 at 17.6%, and remaining variables below 5.6%. The Jackknife test indicates that all variables, except bio 15 (precipitation seasonality), significantly influence model performance (AUC > 0.83), with bio 10 (mean temperature of the warmest quarter) exhibiting the highest explanatory power when used independently, underscoring its critical role in shaping species distribution under both ssp 2.6 and ssp 8.5 scenarios.

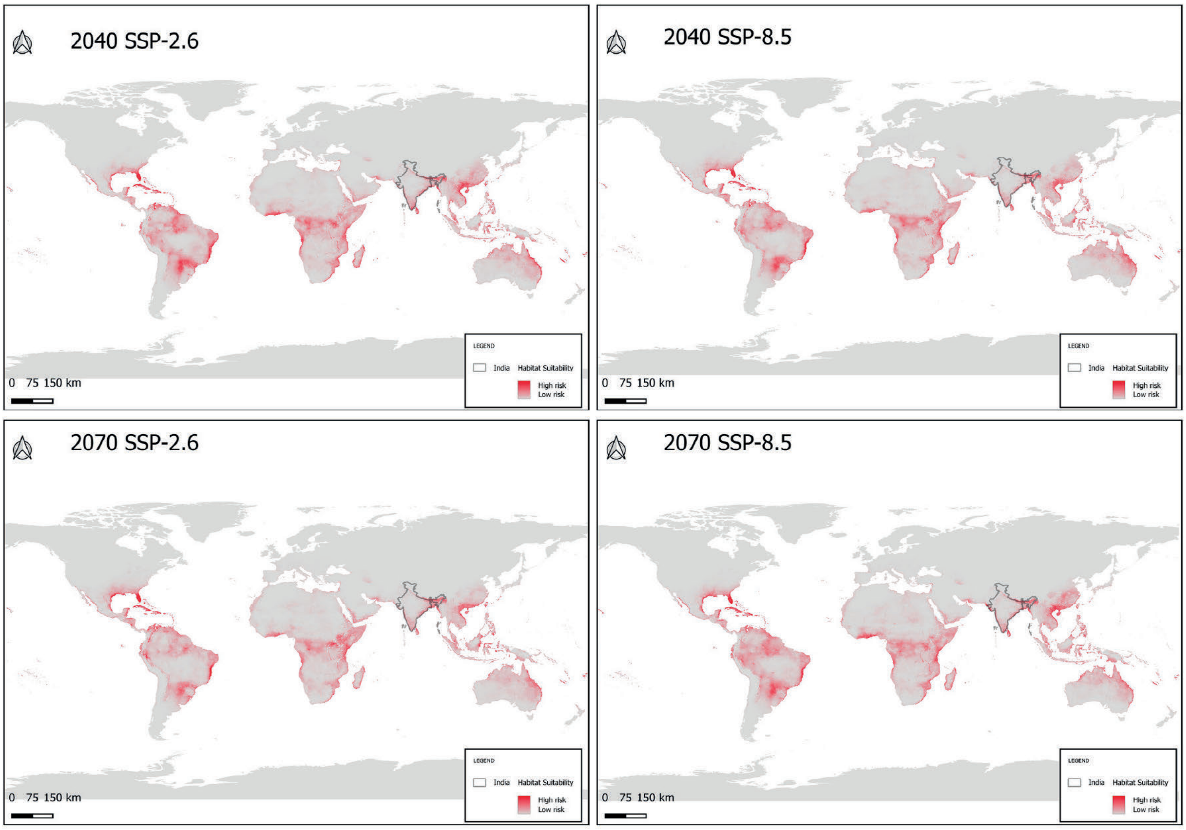

Figure 6. Illustrates the global predicted MaxEnt model under different climate scenarios for *Iguana iguana*.

Under the HADGEM3 model for 2070 (Figure 6), the predicted habitat distribution of *I. iguana* exhibits excellent predictive performance across climate scenarios. For the conventional emission pathway (SSP 2.6), the mean AUC is 0.956 ± 0.001, demonstrating strong discrimination between suitable and unsuitable habitats, with bio 11 (mean temperature of the coldest quarter) contributing the most at 37.7%, followed by bio 12 (annual precipitation) at 25.1%, bio 17 (precipitation of the driest quarter) at 15.4%, and other variables contributing less than 5%. Under the worst-case emission scenario (SSP 8.5), the mean AUC is 0.957 ± 0.001, also indicating excellent predictive ability, with bio 13 (precipitation of the wettest month) as the top contributor at 35.1%, followed by bio 17 at 19%, bio 12 at 11%, and other variables below 6.1%. The Jackknife test reveals that all variables, except bio 15 (precipitation seasonality), significantly influence model performance (AUC > 0.83), with bio 10 (mean temperature of the warmest quarter) showing the highest explanatory power when used independently, underscoring its pivotal role in shaping species distribution under both ssp 2.6 and ssp 8.5 scenarios.

Areas with high suitability for *I. iguana* are concentrated in Central and South America (Amazon Basin: Brazil, Colombia, Peru, Venezuela), Central America (Costa Rica, Panama, Nicaragua), and the Caribbean islands (Cuba, Hispaniola, Puerto Rico). Moderate suitability is observed in parts of Southeast Asia (Indonesia, Philippines, Thailand, Malaysia), sub-Saharan Africa (Congo Basin, Nigeria, Cameroon, Gabon), southern India, Sri Lanka, Bangladesh, Myanmar, northern Australia, and Papua New Guinea. Future habitat projections under various climate scenarios indicate that *I. iguana* will continue to find highly suitable habitats in tropical regions. In 2040 under ssp 2.6 (Figure 6), high suitability remains in South and Central America, parts of West and Central Africa, and Southeast Asia, with slight expansions into eastern Africa and India. Under ssp 8.5, suitability intensifies in West Africa, eastern South America, Southeast Asia, and northern Australia. By 2070, ssp 2.6 shows minor contraction in fringe zones but retains high suitability in core tropical regions such as the Amazon, Congo Basin, and Indo-Malay area. In contrast, ssp 8.5 for 2070 (Figure 6) predicts significant expansion in equatorial regions, Africa, South Asia, and northern Australia, while marginal zones like southern Brazil show contraction.

Globally, high suitability (Table 2) decreases from 803,660.60 km^2 in the present to 404,035.50 km^2 (SSP1-2.6) and 396,484.00 km^2 (SSP5-8.5) by 2070, while low suitability increases in all future scenarios. Habitat gain ranges from 33.99% to 37.55%, loss from 16.1% to 27.32%, and the stable range from 38.68% to 46.35%. In India, high suitability currently spans 13,553.91 km^2, dropping significantly under future scenarios, particularly to 215.14 km^2 by 2070 SSP5-8.5. Meanwhile, medium and low suitability areas expand, with habitat gains ranging from 30.73% to 35.44%, losses from 11.90% to 23.89%, and stable range percentages between 42.18% and 52.65%.

These findings suggest substantial spatial shifts in *I. iguana* habitat suitability in response to climate change, emphasizing the importance of region-specific monitoring and management.

In the present scenario (Table 2), the global area of high habitat suitability for *I. iguana* is 803,660.60 km^2, medium suitability is 1,969,232 km^2, and low suitability spans 5,576,615 km^2. Under the 2050 SSP1-2.6 scenario, high suitability decreases to 497,256.20 km^2, with an increase in medium (2,358,466 km^2) and low suitability (7,912,663 km^2), reflecting a habitat gain of 36.86%, loss of 18.56%, and a stable range of 44.58%. In 2050 SSP5-8.5, high suitability further drops to 427,206.20 km^2, while medium and low suitability reach 2,004,106 km^2 and 8,123,372 km^2, respectively, with a gain of 36.96%, loss of 20.31%, and 42.73% stable range. By 2070 under SSP1-2.6, high suitability declines to 404,035.50 km^2, medium suitability is 1,985,604 km^2, and low suitability rises to 8,828,778 km^2, with a gain of 37.55%, loss of 16.10%, and 46.35% stable range. In the 2070 SSP5-8.5 scenario, high suitability drops to 396,484.00 km^2, medium suitability reduces to 1,420,944 km^2, and low suitability is 7,375,584 km^2, with a habitat gain of 33.99%, loss of 27.32%, and a stable range of 38.68%.

In India, the present high habitat suitability (Table 3) for *I. iguana* is 13,553.91 km^2, with medium suitability of 83,797.56 km^2 and low suitability of 233,772.60 km^2. Under the 2050 SSP1-2.6 scenario, high suitability reduces sharply to 2,172.93 km^2, while medium and low suitability increase to 98,491.72 km^2 and 321,270.60 km^2 respectively, showing a habitat gain of 34.36%, loss of 16.36%, and a stable range of 49.28%. In 2050 SSP5-8.5, high suitability slightly increases to 2,237.47 km^2, with medium and low suitability at 85,669.29 km^2 and 293,560.40 km^2, resulting in 33.93% gain, 23.89% loss, and 42.18% stable range. By 2070 SSP1-2.6, high suitability expands to 6,088.50 km^2, medium suitability reaches 77,300.29 km^2, and low suitability increases to 368,472.60 km^2, reflecting a 35.44% gain, 11.90% loss, and 52.65% stability. In contrast, under 2070 SSP5-8.5, high suitability drops drastically to 215.14 km^2, medium suitability is 42,662.53 km^2, and low suitability is 325,724 km^2, with 30.73% gain, 22.89% loss, and 46.37% stable range. Geographically, regions such as the Western Ghats, Northeastern states, Eastern Himalayas, the eastern coast and places adjacent to it, as well as parts of the Andaman and Nicobar Islands, show high suitability for iguanas and the southern part of India, along with the western coast and adjacent regions, exhibits moderate suitability for both under the moderate emission scenario and high emission scenario projected for 2040 and 2070.

A questionnaire-based survey was conducted among random 42 pet shopkeepers to assess their awareness and compliance with pet trade regulations and animal welfare practices resulted as follows (Table 4): All 42 respondents (100%) reported that they have a valid license to operate but none of them was ready to show their license when asked, to avoid causing discomfort or disrupting the interview, we chose to proceed to the next question without further insistence.

Table 2. Illustrates the predicted potential habitat suitability and range dynamics of *Iguana iguana* for world.

Scenario	High Suitability (km²)	Medium Suitability (km²)	Low Suitability (km²)	Habitat Gain (%)	Habitat Loss (%)	Stable Range (%)
Present	8,03,660.60	19,69,232	55,76,615	-	-	-
2050 SSP1-2.6	4,97,256.20	23,58,466	79,12,663	36.86	18.56	44.58
2050 SSP5-8.5	4,27,206.20	20,04,106	81,23,372	36.96	20.31	42.73
2070 SSP1-2.6	4,04,035.50	19,85,604	88,28,778	37.55	16.1	46.35
2070 SSP5-8.5	3,96,484.00	14,20,944	73,75,584	33.99	27.32	38.68

Table 3. Illustrates the habitat suitability range of *Iguana iguana* in km², along with their stable range, habitat gain, and habitat loss for India.

Scenario	High Suitability (km²)	Medium Suitability (km²)	Low Suitability (km²)	Habitat Gain (%)	Habitat Loss (%)	Stable Range (%)
Present	13,553.91	83,797.56	2,33,772.60	-	-	-
2050 SSP1-2.6	2,172.93	98,491.72	3,21,270.60	34.36%	16.36%	49.28%
2050 SSP5-8.5	2,237.47	85,669.29	2,93,560.40	33.93%	23.89%	42.18%
2070 SSP1-2.6	6,088.50	77,300.29	3,68,472.60	35.44%	11.90%	52.65%
2070 SSP5-8.5	215.14	42,662.53	3,25,724	30.73%	22.89%	46.37%

Table 4. Illustrates the percentage of responses collected through the questionnaire survey.

Scenario	YES (Count)	NO (Count)	YES (%)	NO (%)
Do you have a license?	42	0	100.0%	0.0%
Are you aware of pet shop procedures, cage setup, and pet laws?	42	0	100.0%	0.0%
Do you know what is meant by legal and illegal pets, and why?	40	2	95.2%	4.8%
Do you ensure the animals sold are legal to trade?	42	0	100.0%	0.0%
Are you aware of CITES and IUCN, and can name examples?	2	40	4.8%	95.2%
Do you breed pets or are you a veterinarian?	37	5	88.1%	11.9%
Do you check the buyer's place for pet suitability?	5	27	11.9%	88.1%
Are you aware of the Parivesh app?	4	38	9.5%	90.5%

They claimed that they are aware of the procedures related to pet shops, including cage setup and relevant laws. Furthermore, 95.2% (40 out of 42) were able to explain the concept of legal and illegal pets, and why keeping illegal pets is prohibited. Every shopkeeper (100%) claimed to ensure that the animals sold in their shops are legal to trade. However, knowledge about CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora) and IUCN (International Union for Conservation of Nature) was remarkably low, only 2 respondents (4.8%) showed awareness and could provide examples. When it comes to pet breeding, 88.1% stated that they breed pets. In contrast, only 11.9% (5 respondents) reported that they check the buyer's premises to assess if it is suitable for the pet. Additionally, awareness about the Parivesh app, was limited to just 4 respondents (9.5%).

Table 5 (part 1 of 3). Displays the species records, including conservation status.

Class	S. N°	Family	Scientific name	Total N° of individuals	IUCN Status	CITES
Aves	1	Psittacidae	*Agapornis fischeri*	5	Near Threatened	Appendix II
	2	Psittacidae	*Agapornis personata*	18	Least Concern	Appendix II
	3	Psittacidae	*Agapornis roseicollis*	8	Least Concern	Not Listed
	4	Psittacidae	*Ara ararauna*	3	Least Concern	Appendix II
	5	Psittacidae	*Ara chloropterus*	2	Least Concern	Appendix II
	6	Psittacidae	*Aratinga jandaya*	1	Least Concern	Appendix II
	7	Psittacidae	*Aratinga nenday*	2	Least Concern	Appendix II
	8	Psittacidae	*Aratinga solstitialis*	22	Endangered	Appendix II
	9	Psittacidae	*Eclectus roratus*	3	Least Concern	Appendix II
	10	Psittacidae	*Eos Bornea*	7	Least Concern	Appendix II
	11	Psittacidae	*Forpus coelestis*	1	Least Concern	Appendix II
	12	Psittacidae	*Lorius lory*	1	Least Concern	Appendix II
	13	Psittacidae	*Melopsittacus undulatus*	54	Least Concern	Not Listed
	14	Psittacidae	*Myiopsitta monachus*	5	Least Concern	Appendix II
	15	Psittacidae	*Pionites melanocephalus*	1	Least Concern	Appendix II
	16	Psittacidae	*Poicephalus senegalus*	1	Least Concern	Appendix II
	17	Psittacidae	*Psittacus erithacus*	11	Endangered	Appendix II
	18	Psittacidae	*Pyrrhura molinae*	82	Least Concern	Appendix II
	19	Psittacidae	*Pyrrhura perlata*	2	Least Concern	Appendix II
	20	Psittaculidae	*Trichoglossus moluccanus*	1	Least Concern	Appendix II
	21	Estrildidae	*Lonchura oryzivora*	12	Endangered	Appendix II
	22	Estrildidae	*Taeniopygia guttata*	3	Least Concern	Not Listed
	23	Estrildidae	*Pyrrhula aurantiaca*	1	Least Concern	Not Listed
	24	Estrildidae	*Stizoptera bichenovii*	1	Least Concern	Not Listed
	25	Estrildidae	*Erythrura trichroa*	1	Least Concern	Not Listed
	26	Estrildidae	*Bathilda ruficauda*	3	Least Concern	Not Listed
	27	Estrildidae	*Chloebia gouldiae*	4	Least Concern	Not Listed
	28	Estrildidae	*Lonchura striata domestica*	10	Least Concern	Not Listed
	29	Estrildidae	*Amadina fasciata*	1	Least Concern	Not Listed
	30	Estrildidae	*Stagonopleura guttata*	2	Vulnerable	Not Listed
	31	Estrildidae	*Geospiza magnirostris*	1	Least Concern	Not Listed
	32	Estrildidae	*Poephila acuticauda*	3	Least Concern	Not Listed
	33	Cacatuidae	*Nymphicus hollandicus*	11	Least Concern	Not Listed
	34	Cacatuidae	*Eolophus roseicapilla*	2	Least Concern	Appendix II
	35	Cacatuidae	*Ara chloropterus*	1	Least Concern	Appendix II
	36	Cacatuidae	*Cacatua galerita*	1	Least Concern	Appendix II
Mammals	37	Callitrichidae	*Saguinus midas*	1	Least Concern	Appendix II
	38	Callitrichidae	*Cebuella pygmaea*	1	Vulnerable	Appendix II
	39	Caviidae	*Cavia porcellus*	14	Not evaluated	Not Listed
	40	Cricetidae	*Cricetulus griseus*	1	Least Concern	Not Listed
	41	Cricetidae	*Phodopus roborovskii*	6	Least Concern	Not Listed
	42	Cricetidae	*Cricetus cricetus*	8	Critically Endangered	Not Listed
	43	Cricetidae	*Cricetulus barabensis*	1	Least Concern	Not Listed
	44	Cricetidae	*Mesocricetus auratus*	10	Endangered	Not Listed
	45	Erinaceidae	*Erinaceus europaeus*	7	Near Threatened	Not Listed
	46	Gliridae	*Graphiurus murinus*	1	Least Concern	Not Listed
	47	Leporidae	*Oryctolagus cuniculus*	6	Endangered	Not Listed
	48	Muridae	*Meriones unguiculatus*	5	Least Concern	Not Listed
	49	Petauridae	*Petaurus breviceps*	14	Least Concern	Not Listed
	50	Sciurus	*Microsciurus flaviventer*	4	Least Concern	Not Listed
Reptiles	51	Agamidae	*Pogona vitticeps*	2	Least Concern	Not Listed
	52	Boidae	*Boa constrictor*	1	Least Concern	Appendix II

Table 5 (part 2 of 3). Displays the species records, including conservation status.

Class	S. N°	Family	Scientific name	Total N° of individuals	IUCN Status	CITES
Reptiles	53	Carettochelyidae	*Carettochelys insculpta*	1	Endangered	Appendix II
	54	Chelidae	*Emydura subglobosa*	1	Least Concern	Not Listed
	55	Chelydridae	*Chelydra serpentina*	1	Least Concern	Appendix II
	56	Colubridae	*Elaphe obsoleta lindheimeri*	1	No conservation status	Not Listed
	57	Colubridae	*Pantherophis guttatus*	4	Least Concern	Not Listed
	58	Colubridae	*Lampropeltis triangulum hondurensis*	1	No conservation status	Not Listed
	59	Colubridae	*Lampropeltis getula nigrita*	1	Least Concern	Not Listed
	60	Emydidae	*Trachemys scripta elegans*	6	Least Concern	Not Listed
	61	Eublepharidae	*Eublepharis macularius*	1	Least Concern	Not Listed
	62	Iguanidae	*Iguana iguana*	11	Least Concern	Appendix II
	63	Iguanidae	*Cyclura lewisi*	1	Endangered	Appendix I
	64	Kinosternidae	*Sternotherus carinatus*	1	Least Concern	Appendix II
	65	Lampropeltidae	*Lampropeltis triangulum*	1	Least Concern	Not Listed
	66	Pythonidae	*Python regius*	5	Near threatened	Appendix II
	67	Pythonidae	*Morelia spilota*	1	Least Concern	Appendix II
	68	Pythonidae	*Python bivittatus*	1	Vulnerable	Appendix II
	69	Teiidae	*Salvator merianae*	1	Least Concern	Appendix II
	70	Teiidae	*Centrochelys sulcata*	1	Endangered	Appendix II
	71	Trionychidae	*Pelodiscus sinensis*	1	Vulnerable	Not Listed
Arachnid	72	Theraphosidae	*Brachypelma hamorii*	1	Vulnerable	Appendix II
	73	Theraphosidae	*Aphonopelma seemanni*	1	No conservation status	Not Listed
	74	Theraphosidae	*Acanthoscurria geniculata*	1	No conservation status	Not Listed
	75	Theraphosidae	*Grammostola pulchripes*	4	No conservation status	Not Listed
	76	Theraphosidae	*Tapinauchenius plumipes*	1	No conservation status	Not Listed
	77	Theraphosidae	*Pterinochilus murinus*	1	No conservation status	Not Listed
	78	Theraphosidae	*Cyriopagopus albostriatus*	1	No conservation status	Not Listed
	79	Scorpionidae	*Pandinus imperator*	2	No conservation status	Appendix II
Amphibians	80	Salamandridae	*Salamandra atra*	2	Least Concern	Not Listed
	81	Ceratophryidae	*Ceratophrys cranwelli*	2	Least Concern	Not Listed
Pisces	82	Potamotrygonidae	*Potamotrygon motoro*	1	Data deficient	Appendix III
	83	Alestidae	*Hydrocynus goliath*	1	Least Concern	Not Listed
	84	Apteronotidae	*Apteronotus albifrons*	6	Least Concern	Not Listed
	85	Astacidae	*Protoreaster linckii*	1	Not evaluated	Not Listed
	86	Auchenipteridae	*Auchenoglanis occidentalis*	1	Least Concern	Not Listed
	87	Auchenipteridae	*Asterophysus batrachus*	1	Least Concern	Not Listed
	88	Balitoridae	*Sewellia lineolata*	1	Vulnerable	Not Listed
	89	Callichthyidae	*Megalechis thoracata*	1	Least Concern	Not Listed
	90	Chalceidae	*Chalceus macrolepidotus*	1	Least Concern	Not Listed
	91	Channidae	*Channa diplogramma*	1	Vulnerable	Not Listed
	92	Characidae	*Pygocentrus nattereri*	1	Least Concern	Not Listed
	93	Characidae	*Moenkhausia sanctaefilomenae*	1	Least Concern	Not Listed
	94	Characidae	*Paracheirodon innesi*	27	Least Concern	Not Listed
	95	Cichlidae	*Acarichthys heckelii*	1	Least Concern	Not Listed
	96	Cichlidae	*Amphilophus spp*	36	No conservation status	Not Listed
	97	Cichlidae	*Apistogramma spp*	25	No conservation status	Not Listed
	98	Cichlidae	*Cichla ocellaris*	2	Least Concern	Not Listed
	99	Cichlidae	*Symphysodon*	4	No conservation status	Not Listed
	100	Cichlidae	*Astronotus ocellatus*	30	Least Concern	Not Listed
	101	Cichlidae	*Pterophyllum scalare*	38	Least Concern	Not Listed
	102	Cichlidae	*Andinoacara rivulatus*	1	Least Concern	Not Listed
	103	Cichlidae	*hemichromis letourneuxi*	1	Least Concern	Not Listed

Table 5 (part 3 of 3). Displays the species records, including conservation status.

Class	S. N°	Family	Scientific name	Total N° of individuals	IUCN Status	CITES
Pisces	104	Cichlidae	*Trichogaster trichopterus.*	11	Least Concern	Not Listed
	105	Cichlidae	*Altolamprologus calvus*	2	Near Threatened	Not Listed
	106	Cichlidae	*Cyphotilapia frontosa*	1	Least Concern	Not Listed
	107	Cichlidae	*Heros efasciatus*	1	Least Concern	Not Listed
	108	Cichlidae	*Heterotilapia buttikoferi*	1	No conservation status	Not Listed
	109	Cyprinidae	*Myxocyprinus asiaticus*	2	Vulnerable	Not Listed
	110	Cyprinidae	*Carassius auratus*	69	Least Concern	Not Listed
	111	Cyprinidae	*Cyprinus rubrofuscus*	45	Least Concern	Not Listed
	112	Cyprinidae	*Barbonymus schwanenfeldii*	8	Least Concern	Not Listed
	113	Cyprinidae	*Pethia conchonius*	7	Least Concern	Not Listed
	114	Cyprinidae	*Epalzeorhynchos frenatum*	13	Least Concern	Not Listed
	115	Cyprinidae	*Puntigrus tetrazona*	23	Least Concern	Not Listed
	116	Gymnarchidae	*Gymnarchus niloticus*	1	Least Concern	Not Listed
	117	Lepisosteidae	*Atractosteus spatula*	10	Least Concern	Not Listed
	118	Lobotidae	*Datnioides undecimradiatus*	1	Vulnerable	Not Listed
	119	Loricariidae	*Baryancistrus xanthellus*	1	Near threatened	Not Listed
	120	Loricariidae	*Pseudorinelepis genibarbis*	2	Least Concern	Not Listed
	121	Loricariidae	*Ancistrus dolichopterus*	2	Least Concern	Not Listed
	122	Loricariidae	*Hypostomus plecostomus*	10	Least Concern	Not Listed
	123	Mastacembelidae	*Mastacembelus armatus*	2	Least Concern	Not Listed
	124	Mochokidae	*Synodontis eupterus*	2	Least Concern	Not Listed
	125	Muraenidae	*Gymnothorax polyuranodon*	2	Least Concern	Not Listed
	126	Nephropidae	*Homarus americanus*	5	Least Concern	Not Listed
	127	Notopteridae	*Chitala ornata*	3	Least Concern	Not Listed
	128	Osphronemidae	*Betta splendens*	43	Vulnerable	Not Listed
	129	Osphronemidae	*Osphronemus goramy*	1	Least Concern	Not Listed
	130	Osteoglossidae	*Osteoglossum bicirrhosum*	3	Least Concern	Not Listed
	131	Pimelodidae	*Pimelodus pictus*	1	Least Concern	Not Listed
	132	Pimelodidae	*Phractocephalus hemioliopterus*	3	Least Concern	Not Listed
	133	Pimelodidae	*Platystomatichthys sturio*	1	Least Concern	Not Listed
	134	Pimelodidae	*Pseudoplatystoma fasciatum*	4	Least Concern	Not Listed
	135	Poeciliidae	*Poecilia reticulata*	43	Least Concern	Not Listed
	136	Poeciliidae	*Poecilia sphenops*	43	Least Concern	Not Listed
	137	Poeciliidae	*Xiphophorus hellerii*	1	Least Concern	Not Listed
	138	Characidae	*Gymnocorymbus ternetzi*	2	Least Concern	Not Listed
	139	Polyodontidae	*Polyodon spathula*	1	Vulnerable	Appendix II
	140	Polypteridae	*Polypterus senegalus*	6	Least Concern	Not Listed
	141	Protopteridae	*Protopterus annectens*	2	Least Concern	Not Listed
	142	Scaridae	*Scarus psittacus*	23	Least Concern	Not Listed
	143	Siluridae	*Kryptopterus vitreolus*	2	Least Concern	Not Listed
	144	Stichodactylidae	*Brachaelurus colcloughi*	1	Vulnerable	Not Listed
	145	Tetraodontidae	*Dichotomyctere nigroviridis*	3	Least Concern	Not Listed

DISCUSSION

The exotic pet trade has been significantly reshaped by the widespread use of the internet, with social media playing a pivotal role in shaping consumer behavior and influencing public perception, thereby driving demand (Bush et al., 2014; Moloney et al., 2021). In India, which hosts a rich reptilian diversity with approximately 923 species (Uetz et al., 2025), the increasing popularity of exotic pets poses a growing threat to native wildlife. As the trade in non-native species expands, so does the risk of biological invasions and the transmission of novel diseases (Pragatheesh et al., 2021). The introduction of exotic species either deliberately or accidentally can have severe consequences for native ecosystems. These impacts include crop destruction, displacement of indigenous species, genetic mixing through hybridization, disease spread, and disturbances to both natural habitats and urban environments (Martin-Albarracin et al., 2015; Menchetti et al., 2016; Thibault et al., 2018; Sophonrat et al., 2019). Biological invasions generally proceed through four stages: transport, introduction, establishment, and spread. However, not all introduced species reach the stage of widespread invasion; some remain localized around their point of entry (Murgui, 2001; Sophonrat et al., 2019). The threat to biodiversity manifests in two major ways: by reducing local species richness and abundance, and by homogenizing species communities across regions, thereby eroding ecological uniqueness (Deacon et al., 2011). Species that exist outside their native range are typically termed “exotic,” “non-native,” or “alien.” When such species successfully reproduce, expand their range, and inflict ecological or economic damage in the introduced environment, they are classified as “invasive” (IUCN, 2019).

According to this study (Figure 2), a total of 12 species are classified as Endangered, 15 as Vulnerable, 3 as Near Threatened, 101 as Least Concern, and 18 as Not Assessed, which are popularized through videos, have shown declines in their native ranges due to the pet trade and habitat loss. *Agapornis fischeri*, once common in north-central Tanzania, has experienced a major population decline primarily due to wild bird trade, now persisting mainly around Ndutu and Serengeti National Park (Morton and Bhatia, 1992; Moyer, 1995; BirdLife International, 2025). *Aratinga solstitialis* shows some signs of recovery as trapping pressure lessens (Joyner and Ottema, 2020; BirdLife International, 2025), but overall numbers remain unknown and the species is still considered very scarce (Collar et al., 2020). The Java sparrow is severely threatened by the illegal pet trade and has likely suffered over a 30% population reduction in three generations due to habitat loss and hunting, particularly in Ecuador and Peru (TRAFFIC, 2019; IUCN, 2021). Burmese python numbers have declined due to harvesting for food, skin, and the pet trade, with over 300,000 exported to the U.S. since 1980 (Britannica, 2025).

Brachypelma smithi, known in the pet trade as the Mexican red-kneed tarantula, has faced significant depletion due to commercial collection, with hundreds of thousands exported and native colonies in Mexico largely wiped out (Smith, 1994; Mendoza and Francke, 2017).

The analysis (Figure 4) shows that many species involved in the exotic pet trade in India are either listed under CITES Appendices II and III or not listed at all. Only one reptile species, *Cyclura lewisi*, is under Appendix I, which highlights the limited representation of highly protected species. A large number of traded species fall outside strict international regulation, increasing the risk of illegal trade and poor monitoring. As noted by Pragatheesh et al. (2018), India, being a signatory to CITES, must take stronger preventive measures to control the trade of threatened species. According to CITES Article VII, Paragraph 4, Appendix I species bred in captivity for commercial purposes may be treated as Appendix II. However, this can create loopholes when proper documentation is missing. While some species are claimed to be captive-bred, there is often no clear evidence, especially for those that are threatened.

The present and future habitat suitability models (Figures 5 and 6) for *I. iguana* reveal distinct patterns of distribution that align strongly with tropical and subtropical climate zones, consistent with the species' known ecological preferences. The current distribution, as predicted by MaxEnt modeling, highlights Central and South America particularly the Amazon Basin as areas of high suitability, corresponding with the species' native range. Additionally, Caribbean islands, Southeast Asia, sub-Saharan Africa, and parts of southern India, Sri Lanka, and northern Australia are predicted to be climatically suitable, highlighting both naturalized and invasion-prone regions due to favorable ecological conditions.

The distribution modelling and climate projections for *Iguana iguana* reveal significant information into its potential invasive spread and adaptability under changing environmental conditions. While the species currently shows a vast global range of habitat suitability, with over 8.4 million km^2 identified as suitable, future scenarios suggest a marked decline in high suitability areas due to climate change. Under both moderate (SSP-2.6) and high-emissions (SSP- 8.5) scenarios (Figure 6), high suitability zones shrink considerably, though this is accompanied by an expansion of medium and low suitability areas. This trend suggests that while the species may lose optimal habitats, it could persist and adapt in suboptimal or marginal environments demonstrating both ecological flexibility and a potential for continued spread. The habitat turnover analysis supports this concern, indicating notable habitat gains (33–38%) despite the loss of up to 27.32% of its current range under extreme warming by 2070. In the Indian context, although the total suitable area is more limited compared to the global scale, the risk remains significant. High suitability areas decline steeply, especially under SSP 8.5, from 13,553 km^2 to just 215 km^2 by 2070, indicating increased vulnerability under extreme climatic conditions.

However, the persistence and expansion of medium and low suitability zones, particularly in higher-altitude, point to the species' potential to survive and establish in new environments. Importantly, these less suitable areas, while not optimal, may still function as ecological corridors, temporary refuges, or establishment sites, allowing the species to disperse, persist in fragmented populations, or gradually expand its range albeit with altered population dynamics compared to highly suitable zones. These findings raise important concerns for biodiversity conservation in India, as even marginally suitable areas could support population establishment if preventive measures are not enforced. The expansion towards higher elevation can extirpate endemic biota which can't further expand being climatic and habitat specialist, such as in the case of the sky island species of Western ghats to exemplify.

Invasive alien species (IAS) significantly impact biodiversity, agriculture, public health, and economies, with global costs estimated at $1.4 trillion annually (Pimentel et al. 2001, 2005; Paini et al., 2016; Zenni et al., 2021; De Jesús Villanueva et al., 2024). They reduce native species, disrupt ecosystems (Ricciardi and MacIsaac, 2011; Cucherousset and Olden, 2011; Britton et al., 2023), and are often introduced via the exotic pet trade a rapidly expanding sector in Asia and South America (Ding et al., 2008; McNeely et al., 2009; Alves et al., 2010; Lockwood and Welbourne, 2019) that enables transboundary movement of poorly screened wildlife. This trade has contributed to species extinctions and parasite introductions (Clavero and Berthou, 2005; Nijman et al., 2012; Poole and Shepherd, 2017; Kwak et al., 2019; Sinclair et al., 2021; Pratt et al., 2025; Gibbons et al., 2000). Disease outbreaks linked to pets include U.S. monkeypox via Gambian rats (Marano et al., 2007), turtle poxvirus in Taiwan (Liu et al., 2011; USFWS, 2018), and fungal infections (Egusa, 1970; Sinmuk et al., 1996). Co-invasion of parasites, such as *Ozolaimus megatyphlon* with green iguanas, highlights biosecurity risks (Kwak et al., 2019). Pet releases common for species that are large, long-lived, or costly often lead to invasions (Duggan et al., 2006; Keller et al., 2011; Lockwood et al., 2019; Stringham and Lockwood, 2018; Mazzamuto et al., 2021). IAS like raccoons and grey squirrels cause health and economic damage (Beltrán-Beck et al., 2012; Bertolino, 2008; Derbridge et al., 2016; Duscher et al., 2017). The Enemy Release Hypothesis (ERH) suggests IAS initially lose parasites but may later acquire or transmit native pathogens, increasing spillover risk (Romeo et al., 2014; Gozzi et al., 2013; Mazzamuto et al., 2016, 2021; Sato et al., 2015; Deng et al., 2016).

Based on insights gathered from GBIF (2025), pet shop records, and videos, it has been observed that several species, initially introduced through the pet trade, have now established themselves in the wild in India (Figure 3). These species, such as the Red-eared Slider (*Trachemys scripta elegans*) (Ramsay et al., 2007; Vyas, 2019; Aravind et al., 2023), Koi carp (University of Waikato, 2019), Trinidadian guppy (*Poecilia reticulata*) (Global Invasive Species Database, 2010), and others, have caused significant ecological impacts across various countries and regions globally. These species, which include both aquatic and terrestrial organisms, are not only competing with native species for resources but are also causing severe disruptions in habitat structures, leading to a decline in native biodiversity. The Red-eared Slider, for example, has been recognized as one of the most problematic invasive species globally, outcompeting native turtles and preying on other species (Lowe, 2004). Koi carp's feeding behavior, which stirs up riverbeds and lake bottoms, significantly increases water turbidity, disturbing habitats for native aquatic life (University of Waikato, 2019). Similarly, the Trinidadian guppy has been known to disrupt native fish communities (Global Invasive Species Database, 2010), and *Pethia conchonius* competes with native fish for food and habitat resources (Magalhães and Jacobi, 2013). Furthermore, *Osphronemus goramy* and *Xiphophorus hellerii* have shown potential to negatively affect freshwater ecosystems by displacing native species (Raghavan et al., 2008; Maddern, 2009), while the European wild rabbit (*Oryctolagus cuniculus*) has caused extensive disruption in both plant and animal communities (Lees & Bell, 2008). These observations highlight the growing concern regarding the ecological impacts of invasive species in India, underscoring the need for stronger regulatory measures to control the introduction and spread of non-native species in the country.

The Invasion of green iguana has also been facilitated by over-water dispersal during hurricanes and subsequent relief activities (Censky et al., 1998; van den Burg et al., 2020). As a generalist herbivore, the green iguana thrives across a wide array of vegetative landscapes, including tropical rainforests, dry forests, gallery forests, savannahs, and xeric shrublands (Bock et al., 2018). However, detailed studies on its dietary habits remain limited (De Jesús Villanueva et al., 2024). Stomach content analysis in Mexico revealed ingestion of plant species such as *Ipomoea* and *Tabebuia* (Lara-López and González-Romero, 2002), while studies in Puerto Rico utilizing seed germination and isotopic tracing techniques identified consumption of *Rhizophora mangle*, *Avicennia germinans*, *Annona glabra*, and *Peltophorum pterocarpum* (Govender et al., 2012; Burgos-Rodríguez et al., 2016). In Fiji, anecdotal evidence points to feeding on crops like *Ipomoea* and *Colocasia* (Dalo), though more robust research is needed to assess agricultural impact (Kern, 2009; Van Veen, 2011; Shah et al., 2020). Interviews with farmers in Puerto Rico indicated that iguanas consume over 30 cultivated species, including key crops like squash and tomato (De Jesús Villanueva et al., 2022), reinforcing the growing perception of the green iguana as a serious agricultural pest (López-Ortiz et al., 2012; López-Torres et al., 2012). The unchecked growth of green iguana populations has raised concerns about significant economic damage in affected areas, including harm to agricultural systems and infrastructure, as well as broader threats to biodiversity (Bock et al., 2018; Falcón et al., 2013).

Moreover, non-native populations of *I. iguana* pose direct threats to native fauna through aggressive physical interactions, dominance in ecological niches, and even hybridization events (Vuillaume et al., 2015; Moss et al., 2017; van den Burg et al., 2018; van Wagensveld and van den Burg, 2018). In non-native habitats, these iguanas can outcompete or displace native fauna through aggressive interactions, ecological dominance, and hybridization (Vuillaume et al., 2015; Moss et al., 2017; van den Burg et al., 2018; van Wagensveld and van den Burg, 2018). Notably, eDNA analyses have confirmed hybridization between *I. iguana* and the native Lesser Antillean Iguana (*I. delicatissima*), a process contributing to the latter's decline (van Kuijk et al., 2025). To effectively understand and manage such threats, it is crucial to combine multiple scientific methods. This integrated approach can improve conservation planning to prevent severe impacts on native biodiversity and human health, both of which are known to be at risk from invasive species (Benabdallah et al., 2025).

Reproductively, *I. iguana* is highly sensitive to seasonal climatic changes, particularly the transition between dry and wet tropical periods (Bock et al., 2018). Males begin territorial behavior at the onset of the dry season, females lay eggs mid-season, and hatching coincides with the rainy season when vegetation is most abundant and digestible for hatchlings (Hirth, 1963; Rand, 1968; Müller, 1968, 1972; Fitch and Henderson, 1977; Harris, 1982; Klein, 1982; van Devender, 1982; Casas-Andreu and Valenzuela-López, 1984; van Marken Lichtenbelt, 1993; Muñoz et al., 2003). Although this pattern is consistent, timing varies geographically due to hemispheric differences (Rand and Greene, 1982). Maxent modeling supports the likelihood of establishment in India's tropical and subtropical lowlands, where climatic conditions closely align with the species' reproductive requirements. Key variables influencing habitat suitability include mean temperature of the coldest quarter (bio 11), annual precipitation (bio 12), and precipitation of the driest quarter (bio 17), while mean temperature of the warmest quarter (bio 10) was the strongest independent predictor. These variables reflect the thermal and moisture cues that drive reproductive timing. Moreover, although individuals have been observed at elevations up to and beyond 1,000 m, successful reproduction in the wild is rare above this threshold limited to modified environments such as compost piles (Etheridge, 1982; Bock et al., 2018) supporting model predictions that elevations below 1,000 m in India offer the most suitable environments for both establishment and reproduction under current and future climate scenarios. The case of red necked slider can be exemplified with the rapid expansion of such species alarms the invasion of native ranges and their negative consequences to native biodiversity (Sarlin et al., 2025).

Exotic pets often require specialized care and controlled environmental conditions in captivity, which many owners may be either unaware of or unable to adequately provide (Grant et al., 2017; Warwick et al., 2018).

As a result, many exotic animals are eventually abandoned or handed over to rescue centers (e.g., Cheyne, 2009). In some cases, even species that are not currently threatened may suffer from overexploitation due to the high volume of trade (Nijman et al., 2018). The escape or release of non-native pets into natural habitats has been identified as a significant route for biological invasions globally for example, mammals in Brazil (Rosa et al., 2017), and amphibians and reptiles in the USA and Europe (Krysko et al., 2011; Hulme et al., 2008; Katsanevakis et al., 2018). These examples furthermore increase the urgent need for strict regulatory oversight and preventive action.

In India, a recent incident highlighted this risk when a green iguana was found roaming outside captivity in Bandirwada, Chapora, likely an escape or an intentional release. This case, reported by The Times of India newspaper on January 30, 2023, illustrates the real and present danger of exotic species establishing themselves in the wild, which could have serious ecological consequences. And the demand for Green Iguanas has increased in recent years, as reflected by multiple airport seizures in India. In July 2024, Chennai International Airport seized 402 individuals exported from Thailand (*The Hindu Bureau, 2024*), followed by another 52 iguanas smuggled from Malaysia later the same year (*The Indian Express, 2024*). In March 2025, 18 iguanas were intercepted at Madurai Airport from a consignment arriving from Bangkok (*Ramakrishnan, 2025*), and incidents mentioned by *Pragatheesh et al., 2021*. Despite increasing recognition of this threat, India continues to lack dedicated, comprehensive legislation focused on the control and management of invasive alien species (IAS) (Pande and Arora, 2014). The introduction of such species, whether intentional or accidental poses one of the greatest threats to biodiversity globally, endangering ecosystem function and native species diversity (Williamson, 1996; Mooney and Hobbs, 2000; Gaston et al., 2003; Lees and Bell, 2008). This highlights the pressing need for India to adopt strong and consistent implementation strategies to prevent future introductions and mitigate the risks posed by existing IAS.

The questionnaire survey revealed that all 42 pet shopkeepers claimed to possess valid licenses and demonstrated awareness of basic pet shop regulations, including legal requirements and appropriate cage setups. However, despite these assertions, none were willing to present their licenses for verification. Most respondents (95.2%) understood what legal and illegal pets are, and all stated that the animals they sell are legal to trade. However, awareness about international regulations like CITES and IUCN was very low (only 4.8% knew about them), showing a major knowledge gap in global wildlife protection laws. Most shopkeepers (88.1%) also said they breed pets themselves, but this brings another concern. If they are not trained or regulated properly, it may lead to poor breeding practices or health issues in animals. Very few respondents (11.9%) check the buyer's place before selling pets.

Awareness of government platforms like Parivesh, meant for mandatory registration of exotic species under the Live Animal Species (Reporting and Registration) Rules, 2024, was also very low (only 9.5%). Most shopkeepers were unaware of this rule, indicating that outreach and enforcement need improvement. These findings show that more awareness is needed, along with stricter enforcement and better education for pet shopkeepers. These findings support the urgent need for structured awareness campaigns, standardized licensing systems, and regular inspections. Without significant improvements in enforcement and education, the current gaps in regulation leave room for irresponsible trade practices and environmental risks.

CONCLUSION

This study accentuates the urgent need for enhanced regulation and public awareness regarding the exotic pet trade and pet shop practices in India. Pet buyers must be educated about the care requirements, potential risks, and responsibilities associated with raising exotic animals to ensure responsible pet ownership both directly and in videos. Pet shops should adhere to stringent guidelines, particularly concerning breeding practices and the sale of species with specialized needs. The lack of experience and proper understanding among pet shop owners in India exacerbates these issues, as many fail to inform customers adequately. For instance, pet shop owners should actively raise awareness about responsible pet ownership to mitigate risks associated with pet care and trade. In Tamil Nadu, pet bird breeding is frequently promoted by pet shop owners on social media, often without sufficient consideration of the consequences. Large-scale breeding, particularly in densely populated areas, occurs with limited awareness of potential zoonotic diseases, posing public health risks.

Our study findings such as low awareness of CITES/IUCN and Parivesh regulations, absence of buyer verification, and unregulated breeding directly support the need for stricter enforcement and structured education campaigns. Moreover, the presence of adaptable exotic species, such as *I. iguana*, which can thrive in Indian conditions, heightens the risk of these animals becoming invasive and threatening native biodiversity. Early detection and control strategies are critical to mitigating the ecological and economic impacts of potential invasions. A national study on invasive species is essential, supported by consistent monitoring and preventive measures to reduce their spread. Raising awareness about global citizen science initiatives is essential, as encouraging the public to observe and report species especially invasive ones, can play a crucial role in data collection. Promoting such awareness among all citizens would significantly enhance early detection and monitoring efforts.

To address the challenges posed by the exotic pet trade, India must adopt a multi-tiered strategy that combines legal reform, public engagement, and scientific research. Lessons from successful international frameworks should be adapted to India's unique ecological and socio-cultural context. Key actions include promoting responsible pet ownership, strengthening trade regulations, and increasing awareness among both sellers and buyers. At the regional level, state-specific action plans and digital platforms for reporting exotic species can enhance enforcement and early detection. Active citizen participation, including through citizen science initiatives, can further support long-term monitoring efforts. Finally, the lack of detailed data on the environmental and public health impacts of exotic pet trade in India underscores the need for targeted research. This study highlights the urgency of these interventions and advocates for an integrated national approach to ensure sustainability, ecological safety, and informed policy in India's pet industry.

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