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Borderless Lizards: Unveiling Overlooked Records and the Expanding Invasion of *Anolis sagrei* in Ecuador

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Abstract: We evaluated the global distribution of *Anolis sagrei* based on bibliographic records, GBIF, and iNaturalist data. Native to Cuba and the Bahamas, this lizard has spread across mainland America, particularly in the Caribbean, Central America, and parts of the U.S. It has also been introduced in Asia, and according to iNaturalist observations, it has been recorded in Israel, Canada, and northern South America. This species is especially abundant in the Caribbean and southeastern U.S., with high concentrations of records indicating a significant range expansion. In Ecuador, *A. sagrei* has been recorded along the coast and in the Amazon, with occurrences in Esmeraldas, Manabí, Guayas, Francisco de Orellana, and for the first time in Zamora Chinchipe (southern Amazon), specifically in El Pangui. The capture of 10 individuals confirmed their morphology, showing similarities with populations from Honduras and Cuba but differences in scalation and body size. In Ecuador, the fourth toe lamellae range from 29 to 33, consistent with those populations, while dorsal and ventral scales show variation (dorsal: 11–22, ventral: 10–25). Climate change favors its spread by enabling the colonization of new habitats. As an invasive species, it threatens local biodiversity, highlighting the need for monitoring and control in Amazonian Ecuador. An expanded abstract in Spanish is available, intended for local decision-makers.

Keywords: alien; biological invasion; citizen science; Dactyloidae; ecological impact; introduced species monitoring; invasive reptile; non-native herpetofauna; range expansion; tropical biodiversity; urban ecology

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1. Introduction

1.1. Global Context of Biological Invasions

The global biodiversity crisis is accelerating due to human-induced environmental changes, including climate change, habitat destruction, pollution, and overexploitation of natural resources [1]. Among these threats, biological invasions are one of the most pervasive yet underestimated drivers of biodiversity loss [2]. The introduction and establishment of species outside their native ranges have led to severe ecological, economic, and social

consequences, reshaping entire ecosystems, altering trophic interactions, and displacing native taxa [3–5].

Unlike other environmental threats, biological invasions are often irreversible [4]. Once an introduced species establishes a self-sustaining population, its eradication becomes highly challenging, if not impossible, particularly in ecosystems where native species lack adaptations to withstand novel competitors or predators [6–8]. Furthermore, invasive species rarely act in isolation; their impact is often amplified by other global stressors, such as habitat fragmentation and climate change. As species introductions continue to increase worldwide, understanding the ecological drivers, dispersal mechanisms, and long-term consequences of biological invasions is crucial for effective conservation efforts and ecosystem management [9].

1.2. Reptiles as Invasive Species

Biological invasions are not modern phenomena. Humans have been translocating species for at least 20,000 years, moving domesticated plants and animals across continents [10]. However, globalization, international trade, and increased human mobility have drastically accelerated the rate and scale of species introductions, leading to global homogenization of biodiversity [5]. This unprecedented intensity of human-mediated species exchange has blurred historical biogeographic boundaries and altered species interactions, ecosystem functions, and evolutionary processes [11]. The establishment of non-native species in new environments has led to the emergence of novel ecological interactions, often with unpredictable outcomes for the native communities.

Among vertebrates, reptiles, particularly lizards, have become highly successful invaders due to their high reproductive potential, behavioral plasticity, and adaptability to human-modified environments. Lizards often exhibit strong ecological opportunism, allowing them to colonize new habitats rapidly and, in many cases, outcompete native species [12]. One of the most widespread and ecologically disruptive reptilian invaders is the Cuban brown anole, *Anolis sagrei* (Duméril & Bibron, 1837) [13], which is native to Cuba and the Bahamas.

1.3. Invasion Dynamics of Anolis sagrei

The invasion of *A. sagrei* has been extensively documented across North America, the Caribbean, and parts of Asia, where it has rapidly expanded due to its aggressive behavior, high reproductive rate, and ability to exploit urban and suburban environments [14]. Unlike many native anole species, which tend to be habitat specialists, *A. sagrei* displays extreme ecological plasticity, allowing it to thrive in a wide range of conditions, including natural, urban, and peri-urban landscapes.

One of the most significant ecological impacts of *A. sagrei* invasion is the displacement of native anole species. Studies have shown that in regions where *A. sagrei* has been introduced; native anole populations are often forced into suboptimal microhabitats due to direct competition for space and resources [15]. Additionally, its opportunistic foraging behavior enables it to exploit a wide variety of prey, potentially altering local food webs and competing with native insectivores [16]. In invaded regions, *A. sagrei* has been linked to reductions in native lizard populations, shifts in invertebrate community structures, and disruptions in predator-prey dynamics [17].

1.4. Mechanisms of Competitive Success

Aggressive interactions and body size play central roles in structuring competitive hierarchies among *A. sagrei.* Larger males are more likely to dominate territorial encounters, perch higher, and display more challenging behaviors than smaller individuals, suggesting that size is a primary determinant of dominance and resource acquisition [18]. Further-

more, recent evidence highlights the relationship between head morphology and trophic competition, with head size and shape influencing dietary niche overlap and competitive interactions among lizard species [19]. In *A. sagrei*, larger head dimensions are associated with access to a broader range of prey, potentially enhancing competitive advantages over native species and facilitating successful establishment in novel environments [20].

1.5. Expansion of Anolis sagrei in South America

Despite extensive research on its invasion of North America, the Caribbean, and parts of Asia, the expansion of *A. sagrei* in South America remains poorly documented [21,22]. While its presence has been recorded in Brazil and Colombia [12], its ongoing invasion in Ecuador has received little attention [21,22]. This knowledge gap is particularly concerning given Ecuador's exceptional biodiversity, which includes many endemic reptile species that may be vulnerable to the competitive pressures exerted by *A. sagrei*.

In Ecuador, *A. sagrei* was first recorded in coastal provinces such as Guayas, Manabí, and Esmeraldas, where the environmental conditions closely resemble those of its native range [21,22]. However, recent records indicate that the species has expanded beyond these initial invasion sites, reaching the Amazonian province of Francisco de Orellana and, more recently, Zamora Chinchipe, a region within the Amazonian foothills. This southward expansion raises concerns about the species' ability to invade highland ecosystems, where it may pose new threats to native biodiversity.

Unlike the well-documented coastal invasions, the presence of *A. sagrei* in montane and Amazonian ecosystems suggests that this species possesses greater physiological tolerance and adaptability than previously recognized [22]. Its ability to persist in more humid, cooler environments raises concerns about its potential for further colonization of Andean and Amazonian habitats, where native anole species and other small vertebrates may be at risk. If *A. sagrei* is able to establish populations in montane forests, it could impact not only native lizard assemblages but also the broader ecological networks in these ecosystems.

1.6. Importance of Monitoring and Management

Ecuador hosts some of the highest levels of reptile diversity in the world, with many species occupying highly specialized ecological niches [23–25]. The continued expansion of *A. sagrei* could have long-term consequences for native species, particularly those with restricted distributions or limited dispersal abilities [14,15,17]. The mechanisms driving its dispersal into new environments remain poorly understood [12], highlighting the need for comprehensive ecological studies and long-term monitoring programs [22].

As *A. sagrei* continues its rapid expansion and its invasion of South America remains understudied, this study aims to document new records of its presence in Ecuador, particularly in the Amazonian foothills, while also analyzing overlooked records from biodiversity databases to assess the extent of its global spread. Additionally, this study seeks to evaluate the potential ecological interactions and dispersal mechanisms driving its expansion. By integrating field observations, citizen science databases, and ecological modeling, this research provides critical insights into the invasive dynamics of *A. sagrei* and reinforces the urgent need for monitoring and management strategies to mitigate its ecological impact in Ecuador and beyond.

2. Materials and Methods

2.1. Study Area

This study was conducted in El Pangui, Zamora Chinchipe Province, Ecuador (Figure 1). This area is located in the country's southeastern region and falls within the Amazon Basin. It is characterized by a humid tropical climate with an average annual

temperature of approximately 22 °C [26]. The landscape comprises urban areas, green spaces, and ornamental vegetation, providing suitable conditions for *A. sagrei* colonization.

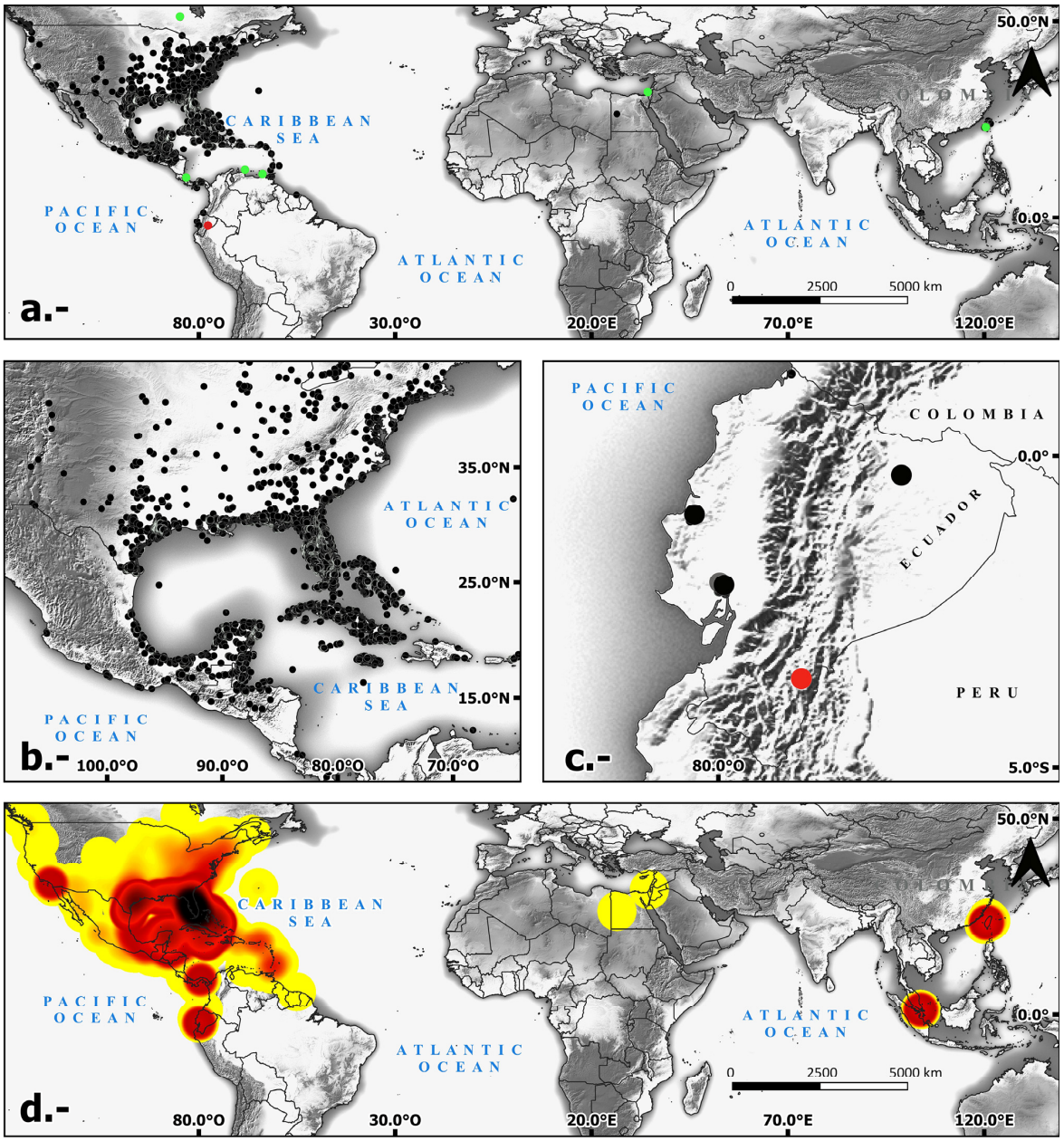


Figure 1. Global Distribution of *Anolis sagrei*; (**a**) Global Occurrence Records: Black dots indicate confirmed occurrences of *A. sagrei* across its native and introduced ranges, green dots indicate overlooked records. High-density records are concentrated in the Caribbean, southeastern United States, and parts of Central and South America. (**b**) Detailed distribution in North America and the Caribbean: This inset highlights records in the United States, Mexico, the Caribbean, and Central America, where the species is widespread. The orange rectangle delineates the approximate native range of *A. sagrei* within the Caribbean Basin. (**c**) Distribution in Ecuador: Black circles represent known records of *A. sagrei* in Ecuador from biodiversity databases and field observations. The red dot highlights a newly confirmed record in El Pangui, Zamora Chinchipe, marking a significant range expansion into the southern Amazon. (**d**) Kernel Density Map of *A. sagrei* Global Distribution: Areas in red and yellow indicate regions with a high density of occurrence records. The highest concentrations are in the Caribbean and southeastern United States, followed by secondary hotspots in Brazil, parts of Asia (Taiwan and Singapore), and isolated regions in the Middle East.

El Pangui lies at the foothills of the Cordillera del Cóndor, a transitional zone between the Tropical Andes and Amazonia hotspots, which is recognized for its exceptional biodiversity [27,28]. The region has undergone substantial anthropogenic transformation, primarily due to livestock grazing, subsistence agriculture, and, more recently, large-scale mining activities [29]. Urban expansion, mining concessions, and deforestation have created heterogeneous habitats that include deforested lands, disturbed urban environments, and remnants of native vegetation.

2.2. Data Collection

Daytime and nighttime field surveys were conducted in El Pangui to assess the presence of *A. sagrei* using entomological sweep nets and manual collection techniques [30,31]. Specimens were anesthetized before euthanasia using Roxicaina (i.e., 2% Lidocaine) to ensure a humane process [32]. They were then fixed in 10% formalin, preserved in 70% ethanol, and deposited in the herpetological collection of the Museo de Zoología de la Universidad Técnica Particular de Loja (MUTPL) in Ecuador.

Morphometric measurements were recorded using digital calipers with a precision of 0.1 mm. Fifteen standard variables were measured, including snout−vent length (SVL), head width, head height, femur length, and fourth toe length [33]. Scale counts were performed on the left side when applicable. Dorsal and ventral scale counts were performed within a 5-mm segment, and scalation patterns were compared with those of populations from Honduras, Cuba, and Taiwan [34,35]. Regenerated or broken tails were excluded from the total length measurements. Sex was determined based on everted hemipenes and enlarged post-cloacal scales in males.

2.3. Distribution

To assess the distribution of *A. sagrei*, we compiled data from three primary sources: (1) peer-reviewed literature, (2) open-access biodiversity databases (GBIF and iNaturalist), and (3) field observations in Ecuador. Records were downloaded and filtered until June 2025, prioritizing those with precise geographic coordinates [36]. The dataset was analyzed using QGIS 3.26 to generate kernel density maps to visualize the highest concentrations of *A. sagrei* occurrences globally and within Ecuador. The distribution patterns were further examined in terms of environmental and anthropogenic factors.

We categorized the *A. sagrei* records into three groups: (1) validated records from peer-reviewed studies, (2) unverified records from public databases, and (3) new occurrences documented in this study. To minimize misidentification errors, iNaturalist records were cross-verified with photographic evidence and compared to published morphological descriptions [14,31].

3. Results

Field surveys in El Pangui, Zamora Chinchipe, confirmed the presence of an established *A. sagrei* population at two urban sites: the municipal plant nursery and the central park. A total of 35 individuals were recorded in the study area, primarily concentrated in urban green spaces. The nursery, which supplies ornamental plants to public spaces, was identified as a probable introduction site, suggesting human-mediated transport as a potential dispersal mechanism. During fieldwork on 27 June 2024, three individuals (one adult male, MUTPL-R 552; one adult female, MUTPL-R 553; and one juvenile female, MUTPL-R 554) were captured in the nursery using entomological sweep nets and preserved, allowing for detailed morphometric and lepidosis analyses. Subsequent nighttime surveys in the central park (850 m a.s.l.) revealed a colony of approximately 35 individuals, confirming the establishment of a population. Seven additional specimens were captured.

Species from both locations were primarily found in urban green areas, particularly in ornamental vegetation such as *Chlorophytum* sp. (spider plants) and the pinnas of *Cycas* sp. (sago palms). *A. sagrei* individuals consistently perched on foliage at heights of 0.6 to 1.2 m. At night, the species was consistently found sleeping on these plants, facilitating manual collection. Nocturnal surveys provided a more accurate assessment of population size, revealing stable numbers across multiple sampling nights. The population structure included adult males, adult females, and juveniles, indicating active reproduction. In addition, the stable numbers observed across multiple sampling nights further support the establishment of the species in the area.

Due to methodological differences and the lack of raw data in previously published studies, we opted for a descriptive comparison of morphological traits across populations rather than formal statistical analyses. Morphometric analyses revealed significant variations in body size and scalation patterns in the El Pangui population. Table 1 summarizes the key morphometric measurements and lepidosis characteristics, including snout−vent length (SVL), dorsal and ventral scale counts, and the number of lamellae on the fourth toe. The Ecuadorian specimens exhibited similar SVL values to those from Honduras and Cuba, but dorsal and ventral scale counts were generally lower than those recorded in Taiwan and Mexico. In El Pangui, the number of dorsal scales within a 5 mm segment ranged from 11 to 22, and the number of ventral scales ranged from 10 to 25. These counts fall within the range documented for Cuban and Honduran populations but differ from the broader variability observed in Taiwan. The number of lamellae on the fourth toe varied between 28 and 33, consistent with Honduran and Cuban specimens but slightly lower than that of specimens from Taiwan. These patterns suggest potential regional differentiation in scalation traits, possibly influenced by genetic factors and environmental conditions.

Table 1. Summary of lipidosis †, morphometric measurements (mm), and coloration characteristics of *Anolis sagrei* in El Pangui, Ecuador, compared with populations reported in Honduras, Cuba, Taiwan, and Mexico.

Catalogue N°	Sample	Sex	Age Class	Interorbital Scales	Iterparietal/Interorbital Scales	Loreal Rows	Supralabials	Scales Between Second Canthals	Internasal Scales	Lamellae 4th Toe	Dorsal Scales in 5 mm	Ventral Scales in 5 mm	Head Length	Tibia Length	SVL
MUTPL-R 552		M	Adult	1	2	3	6	7	6	31	17	9	16.09	15.58	58.04
MUTPL-R 553		F	Adult	1	2	6	5	7	6	29	15	9	15.33	16	58.34
MUTPL-R 554		F?	Juvenile	1	2	6	5	7	6	28	21	11	10.18	9.34	38
MUTPL-R 557		M	Adult	1	1	5	4	7	6	31	21	12	14.40	13.91	51.87
MUTPL-R 558		F	Juvenile	1	1	5	5	6	7	33	21	13	10.74	10.60	39.67
MUTPL-R 559		F?	Juvenile	1	1	6	5	6	7	29	22	11	10.43	10.49	35.24
MUTPL-R 560		?	Adult	1	1	6	5	8	6	32	22	14	13.22	13.55	45.23
MUTPL-R 561		M	Adult	1	2	5	4	7	6	33	22	14	12.43	13.19	46.84
MUTPL-R 562		M	Adult	1	2	5	5	6	6	30	22	14	14.78	15.37	53.97
MUTPL-R 563		F?	Adult	1	1	5	5	6	6	33	20	12	12.25	12.72	43.45
Ecuador (Guayas)	2	M	Adult	1	3–4	4–5	5	6–7	6–7	35–37	14–21	10–15	11.1–15.5	8.6–14.5	38.6–54.2
Ecuador (Guayas)	3	H	Adult	1–2	2–3	4–5	5	6–7	6–7	35–37	16–18	11–13	11.8–12.6	9.4–9.9	42.3–43.4
Taiwan	15	M	Adult	1–2	2–3	4–6	5–6	4–7	5–6	29–35	11–17	8–12	13–17	11.6–14.9	47–62.1
Taiwan	16	H	Adult	1–2	2–4	4–5	4–6	4–7	4–6	28–34	17–25	11–15	10–11.9	7.7–10.05	34.9–44
Honduras	1	M	Adult	1	3	4	4–5	5	6	32	11	9	15.7	15.5	59.4
Honduras	1	H	Adult	1	3	4–5	4–5	6	6	30	14	12	12.7	12.1	48.1
Cuba M	4	M	Adult	0–2	2–3	4–5	4–6	5–6	5–7	29–33	10–16	9–12	11.2–16.2	9.5–16.7	38.8–62.7
Cuba H	1	H	Adult	2	2–3	5	5	6	6	31	19	13	10.7	9.2	38.2
Mexico M	1	M	Adult	1	3–4	4	5–6	7	7	33	17	13	12.2	10.2	41.2

† We followed the terminology of external characters previously proposed by [34]. Scale counts were performed on the left side, if applicable.

Males in the El Pangui population exhibited a well-developed, brightly colored dewlap with an orange-to-reddish hue and distinct marginal pigmentation. The dewlap is proportionally larger than that of females and juveniles, reinforcing pronounced sexual dimorphism. Males also have elongated limbs and broader head proportions, traits that are commonly associated with competitive behaviors and territorial displays. In contrast, females have a smaller and less vibrant dewlap with limited extension capacity. Their dorsal coloration is more uniform and predominantly brownish-gray with faint speckling, which enhances camouflage within ornamental vegetation. Female body proportions are more compact, with a relatively shorter head-to-body ratio and less pronounced limb elongation than those of males. These differences in body proportions and dewlap morphology are visually evident in the examined specimens (Figure 2).



Figure 2. Morphological variation in *A. sagrei* in El Pangui, Ecuador. From top to bottom: Adult male (MUTPL-R 552) displaying an extended dewlap; Adult female (MUTPL-R 553) with a less contrasting coloration pattern; and Juvenile female (MUTPL-R 554) exhibiting characteristic features of early developmental stages.

The juvenile female (Figure 2, bottom) exhibits a lighter overall coloration and finer scalation patterns. The dewlap was underdeveloped, and the body proportions were more gracile than those of adults. The dorsal pattern is variegated, featuring irregular blotches and faint transverse banding, possibly enhancing its crypsis in the environment. Variations in scalation patterns were observed across all individuals, particularly in dorsal and ventral scale counts, supralabial scales, and lamellae on the fourth toe (Table 1). The number of supralabial scales ranged from 5 to 7, and interorbital scales varied between 1 and 2. The dewlap structure in males was generally more robust, with higher pigmentation intensity, whereas in females and juveniles, it was smaller and less intense. These figures visually support the presence of sexual dimorphism and ontogenetic variation within the *A. sagrei* population of El Pangui. Differences in dewlap size, limb proportions, and body coloration

align with previously documented patterns in other invasive populations but also highlight the specific characteristics of the Ecuadorian specimens.

The species' global occurrence patterns (Figure 1a) indicate that its highest population densities are concentrated in the Caribbean, southeastern United States, and Mexico, whereas records in South America and Asia are more fragmented. A more detailed analysis of its North American and Caribbean distribution (Figure 1b) highlights that *A. sagrei* is particularly abundant in Florida, Cuba, and the Yucatán Peninsula, with additional scattered populations across Central and South America. Kernel density estimates (Figure 1d) revealed that while the Caribbean and southeastern United States harbor the most established populations, recent records suggest ongoing introductions into new environments, including urban and natural areas of South America and Asia.

Newly verified records from the GBIF and iNaturalist indicate that *A. sagrei* has expanded beyond its previously known global range (Table 2). These observations include new photographic records from Canada, Israel, Venezuela, and Ecuador, providing further evidence that its global distribution is more extensive than previously recognized (Figure 3). The presence of *A. sagrei* in these distant locations, combined with its rapid spread across multiple continents, suggests that human-mediated transport and natural range expansion are actively shaping its current worldwide distribution.

Table 2. Verified global records of *Anolis sagrei* from open-access biodiversity databases (GBIF and iNaturalist), including peer-reviewed studies when available. Native or resident status is noted by territory.

Territory		GBIF Records	Records from Peer-Reviewed Studies
Asia			
Israel	Resident	1	Overlooked record, but see [37]
Singapore	Resident	509	Overlooked record
Taiwan	Resident	692	[33]
Atlantic Oceanic Island			
Saint Helena, Ascension, and Tristan da Cunha	Resident	0	[38]
Saint Lucia	Resident	0	[39]
Caribbean Island			
Anguilla	Resident	3	[40]
Bahamas	Native	9604	[41]
Bermuda	Resident	6	[17]
Cayman Islands	Native	1352	[42]
Cuba	Native	3248	[13]
Grenada	Resident	28	[43]
Jamaica	Resident	1124	[44]
Saint Vincent and the Grenadines	Resident	15	[45]
Saint Maarten	Resident	1	[46]
Turks and Caicos Islands	Resident	6	[44]
Central America			
Belize	Resident	1040	[47]
Costa Rica	Resident	3	Overlooked record
Guatemala	Resident	57	[48]
Honduras	Resident	393	[49]
Panama	Resident	266	[50]
North America			
Canada	Resident	42	Overlooked records
Mexico	Resident	4307	[51]
USA	Resident	62,838	[52]
South America			
Brazil	Resident	510	[53]
Ecuador	Resident	357	[21–23]; this study
Suriname	Resident	1	Overlooked record
Venezuela	Resident	3	Overlooked record

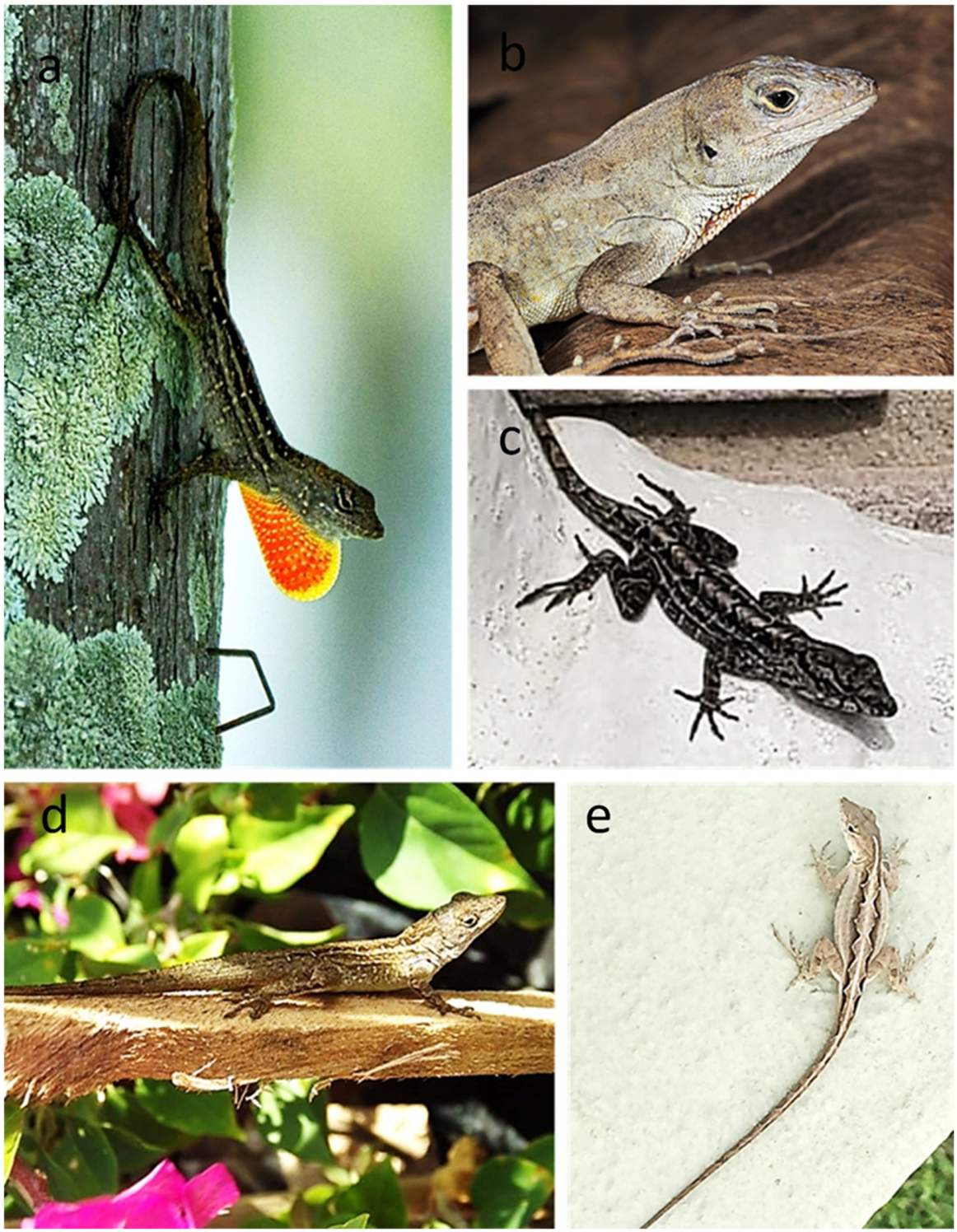


Figure 3. Previously overlooked records of *Anolis sagrei* in undocumented regions: (**a**) Suriname, (**b**) Ecuador, (**c**) Canada, (**d**) Venezuela, and (**e**) Israel. All images were sourced from the iNaturalist platform under a Creative Commons license (CC BY-NC), except for the Ecuadorian record, which features a specimen from Plaza El Pangui, Zamora Chinchipe province, photographed by Diana Székely for this study.

4. Discussion

Surveys in the central plaza of El Pangui confirmed a well-established population of *A. sagrei*, with at least 35 individuals recorded, 10 of which were collected for morphological analyses and taxonomic preservation. Although the morphological evaluation of the

El Pangui specimens fits the diagnostic characteristics of *A. sagrei*, comparisons with populations from other regions reveal subtle variations (Table 1). Snout–vent length (SVL) and fourth toe lamellae counts were similar to those reported for the Cuban and Honduran populations. However, dorsal and ventral scale counts were notably lower in Ecuadorian specimens than in those from Taiwan and Mexico. These morphological differences may reflect localized adaptation processes, environmental pressures, or founder effects associated with recent introduction. Further research is necessary to determine whether these patterns are consistent across broader Ecuadorian populations or whether they represent the early stages of phenotypic divergence.

The actual population size estimate is likely larger, but these findings indicate that *A. sagrei* is no longer a transient species in the area; it has settled in. The first individuals were observed in the municipal nursery, which supplies ornamental plants for public spaces in the town, including the central plaza. This strongly suggests that *A. sagrei* arrived via plant transport, likely from already invaded regions, such as Guayaquil or Francisco de Orellana. This pathway is consistent with other invasions of *A. sagrei*, where plant trade has facilitated its spread into urban and peri-urban environments [14,22,35]. Understanding this introduction route is key to designing prevention strategies before similar introductions occur in other regions.

Local gardeners maintaining the plaza reported that *A. sagrei* had not been observed in the area until roughly six months before our study. This supports the idea that the species was introduced recently and is still in its early stages of establishment. At this phase, there is a crucial window for intervention; once the species spreads further, control efforts become significantly more challenging [54]. To determine whether *A. sagrei* was expanding beyond El Pangui, we conducted systematic surveys in nearby towns, including Yantzaza, Gualaquiza, and Zamora, using identical sampling methods. However, we found no evidence of *A. sagrei* at any of these locations. This suggests that, at present, the invasion remains localized, likely originating from a single introduction event. These findings highlight the urgent need for monitoring and management before this species expands into other parts of the Ecuadorian Amazon.

Our findings confirm that *A. sagrei* has established a stable population in El Pangui, Ecuador, marking a significant expansion into the Amazonian foothills. This invasion poses a direct threat to native reptiles, as evidenced by the documented displacement of *Kentropyx pelviceps* (Cope, 1868). Field observations showed that once a *K. pelviceps* individual was removed for museum preservation, *A. sagrei* rapidly occupied the former refuge within 24 h. This immediate takeover suggests strong competitive abilities and high behavioral plasticity, raising concerns about the long-term impact of this species on local lizard populations [14,17].

Beyond direct competition, the presence of *A. sagrei* can trigger a cascade of ecological effects. The species primarily prey on arthropods, but reports from other invaded regions indicate opportunistic consumption of vertebrates, including juvenile Anolis [54,55]. If similar predation patterns emerge in Ecuador, native insectivorous reptiles and amphibians could face significant pressure due to prey depletion and competition for food resources. Such disruptions may alter local food webs, potentially affecting not only reptiles but also other insect-dependent taxa [56].

Ecological risks are further amplified by the adaptability of *A. sagrei* to urban and modified landscapes. This flexibility has facilitated its rapid expansion in regions like Florida and the Caribbean, where it has displaced native Anolis species from their preferred habitats [15]. Given Ecuador's high reptile diversity and the presence of many range-restricted species, the continued spread of *A. sagrei* could lead to severe biodiver-

sity loss, particularly in areas where native lizards have not evolved defenses against aggressive competitors [4,57].

Invasive species not only alter ecosystems but may also introduce pathogens, including helminths, that impact native fauna [58]. Helminths transported by introduced reptiles can establish themselves in new environments and modify local parasite communities [59]. Urban environments may further increase parasite burdens in invasive reptiles, with *A. sagrei* populations in urban areas exhibiting higher infection intensities than those in natural habitats [60]. In *A. sagrei*, *Cyrtosomum penneri* nematodes are sexually transmitted, with an elevated prevalence in reproductive individuals during the breeding season [61]. Experimental evidence indicates that the suppression of reproductive investment reduces parasite loads in *A. sagrei*, suggesting that reproduction incurs parasitic costs in this species [62]. These processes may confer competitive advantages to invasive species by directly affecting the health of native hosts or altering ecological interactions. Additionally, parasite loss, commonly observed in introduced populations, may further promote invasion success by reducing parasite-mediated constraints [63].

In contrast to long-established invasions, where eradication efforts are often impractical, the recently introduced population of *A. sagrei* in El Pangui may still be at an early stage in which containment remains feasible. The absence of confirmed records in nearby areas suggests a localized introduction, potentially enabling targeted management actions. Early intervention through removal programs, habitat monitoring, and control of human-mediated dispersal pathways, such as ornamental plant transport, could significantly reduce the risk of further expansion into the Amazonian ecosystems [21,22].

The most plausible introduction pathways for *A. sagrei* in El Pangui involve the transportation of ornamental plants from either Guayaquil (c.a. 150 km northwest) or Francisco de Orellana (c.a. 400 km northeast), both of which have previously documented populations of this species. Given that the municipal nursery in El Pangui sources plants from multiple regions, it is likely that *A. sagrei* was inadvertently introduced through this trade route. However, these two potential sources present different ecological and geographical challenges.

While Guayaquil is closer, the Andes Mountains form a significant dispersal barrier, making a natural, self-sustaining colonization from this region highly improbable. In contrast, Francisco de Orellana, located in the Ecuadorian Amazon, lacks such a topographic barrier and shares similar climatic and ecological conditions with El Pangui. This suggests that passive transport via plant shipments from Orellana is the most likely introduction route. Previous studies have documented *A. sagrei* in both Guayaquil and Orellana, reinforcing the role of human-mediated dispersal in the expansion of this species across Ecuador.

The expansion of *A. sagrei* is likely facilitated by human-mediated transport, habitat modification, and its ability to thrive in disturbed environments. As observed in other invasive reptiles, urban settings, ornamental vegetation, and human activities play critical roles in dispersal [35]. The species distribution in Ecuador suggests that accidental transport via trade and construction materials has enabled its spread. The confirmed presence of *A. sagrei* in the Amazonian foothills marks a notable shift in its known range, as it was previously recorded mainly in Ecuador's coastal regions (Guayas, Esmeraldas, and Manabí) and the northern Amazonian province of Francisco de Orellana. The new records from Zamora Chinchipe demonstrate that *A. sagrei* can establish itself in a broader range of environments, including humid montane forests, raising concerns about its potential expansion into other highland regions.

The observed expansion of *A. sagrei* in Ecuador is strongly associated with anthropogenically transformed habitats such as urban gardens, parks, and agricultural areas.

This pattern is consistent with broader ecological evidence showing that ecological generalists often thrive in disturbed environments. Losos et al. [14] demonstrated that habitat modification favors the establishment of ecologically similar invasive species by creating simplified, altered ecosystems where competition dynamics shift, and resource availability can facilitate colonization. In the case of *A. sagrei*, its success in degraded and urbanized landscapes may be attributed to its behavioral flexibility and tolerance of a wide range of microhabitats, which enhances its invasion potential.

Finally, behavioral observations indicate that *A. sagrei* prefers to rest on long-leafed plants, particularly species resembling spider plants (*Chlorophytum* sp.) or in the pinnas of sago palm (i.e., *Cyca* sp.). Nocturnal surveys were far more effective in capturing individuals, as they were consistently found sleeping on these structures. In contrast, daytime attempts were less successful than nighttime attempts. This microhabitat selection aligns with previous studies showing that *A. sagrei* uses ornamental vegetation as a refuge in urban environments. These insights are valuable for monitoring and control efforts, as they provide specific targets for detection and removal strategies.

Our analysis of open-access biodiversity databases, such as GBIF [54] and iNaturalist, identified multiple overlooked records of *A. sagrei* in regions where its presence had not been previously documented in the scientific literature. Specifically, iNaturalist records confirm occurrences in Canada, Israel, and Italy, while GBIF provides additional support for these observations. These citizen-science-based data expand the known global distribution of this invasive species beyond its previously recognized range. These findings suggest that *A. sagrei* may have established undetected populations or transient occurrences in regions far from its primary invasive hotspots.

The presence of *A. sagrei* in Ecuador has been well documented through direct field observations and in biodiversity databases. However, discrepancies in database accuracy pose challenges in determining the species' precise distribution. Data quality issues, including misidentifications and inconsistent geo-referencing, highlight the need for further verification. Integrating citizen science records with validated field data is essential for ensuring the reliability of distribution records.

The identification of these previously neglected occurrences underscores the need for a more comprehensive approach to monitoring invasive species on a global scale. The detection of *A. sagrei* in temperate regions, such as Canada, raises questions regarding its potential adaptability to non-tropical climates. Its presence in Israel and Italy suggests the possibility of additional introductions via human-mediated transport. Given the well-documented history of the rapid expansion and ecological impact of *A. sagrei,* recognizing and incorporating overlooked records into scientific assessments is crucial for improving our understanding of its invasive dynamics and preventing further range expansion.

Among these overlooked records, the presence of *A. sagrei* in Israel was formally reported to the Israeli Nature and Parks Authority in 2021. A detailed survey conducted by Bar and Shai documented a well-established population of *A. sagrei* in Rishon LeZion, Israel, with over 100 individuals observed at multiple locations. The report, although not yet published in peer-reviewed literature, provides valuable insights into the species' local distribution, habitat preferences, and potential dispersal mechanisms [54]. This highlights the importance of considering government reports and field surveys when assessing the true extent of the invasion of *A. sagrei*.

The continued expansion of *A. sagrei* in Ecuador underscores the urgent need for improved monitoring and management strategies. In other invaded ecosystems, *A. sagrei* has displaced native Anolis species, disrupted trophic networks, and reduced local biodiversity [14,17]. While its ecological impact in Ecuador remains largely unstudied, its

presence in the Amazon raises significant concerns, particularly for endemic reptile species that may face displacement or direct predation.

Given the rapid spread of *A. sagrei*, immediate intervention is crucial. Environmental authorities in Ecuador should prioritize control and mitigation measures before the species becomes further established. Experiences from other countries suggest that selective removal programs, restrictions on the transport of exotic species, and public education campaigns can help reduce the impact of invasive reptiles. Additionally, developing predictive models could help identify high-risk areas for future expansion, thereby enabling more proactive conservation efforts.

Citizen science platforms like iNaturalist provide valuable data for tracking the spread of *A. sagrei*. However, ensuring the accuracy of these records requires close collaboration between researchers and citizen scientists. Training initiatives aimed at improving species identification and reporting accuracy can significantly enhance data quality. Integrating citizen science with systematic field surveys will provide a more comprehensive understanding of the distribution of *A. sagrei* and its ecological effects, thereby strengthening conservation efforts.

Efforts to control *A. sagrei* in other regions have yielded mixed results [21,54]. Traditional eradication methods, such as direct removal and habitat modification, have been employed to limit population growth. However, the species' high reproductive rate and behavioral adaptability pose significant challenges for its eradication. In Ecuador, developing region-specific management plans tailored to different ecological zones is essential for mitigating ecological impacts.

Given that *A. sagrei* has only recently established populations in the Amazonian foothills, Ecuador still has a window of opportunity to prevent its further expansion. Immediate and well-coordinated action is key to minimizing the long-term consequences of this invasion.

The potential impact of climate change on the expansion of *A. sagrei* remains an important consideration. Rising temperatures and altered precipitation patterns could create more favorable conditions for its establishment in previously unsuitable areas [35]. Climate models predict increased temperature variability across Ecuador, which may facilitate the further dispersal of *A. sagrei* into montane forests and other highland ecosystems.

Understanding how *A. sagrei* responds to environmental changes is crucial for predicting future range expansion. Previous studies have demonstrated that invasive anoles exhibit rapid morphological and behavioral adaptations to new environments [14]. Monitoring these adaptations in Ecuadorian populations will provide insights into the species' potential to establish itself in diverse ecological settings.

5. Conclusions

The confirmed establishment of *A. sagrei* in El Pangui, Zamora Chinchipe, and the documented expansion of *A. sagrei* in Ecuador demonstrate its remarkable ecological adaptability, as it has successfully established itself in urban environments within the Amazonian foothills. Given its ability to thrive in both natural and human-modified landscapes, there is growing concern that its presence may alter local ecological dynamics. In other invaded regions, *A. sagrei* has been documented to displace native anoles, alter prey communities, and modify trophic interactions. While the long-term ecological consequences in Ecuador remain uncertain, its rapid establishment in El Pangui underscores the need for immediate monitoring efforts. Surveillance programs should target both urban and natural areas, particularly along potential dispersal corridors, to assess the continued spread of this species.

Field surveys and biodiversity database analyses indicate that *A. sagrei* continues to expand in Ecuador, primarily through human-mediated transport and habitat modification. Integrating citizen science data with verified field observations is crucial for accurately tracking its spread. However, the existence of overlooked records in other regions, such as Canada, Israel, and Italy, suggests that the invasion of *A. sagrei* may be occurring on a broader, global scale. This highlights the urgent need for improved taxonomic validation and standardized data collection protocols to enhance species monitoring and invasion risk assessments.

The species' high reproductive rate, aggressive behavior, and dietary plasticity reinforce its potential to become a dominant invasive reptile in Ecuador. Its ability to outcompete native lizards, disrupt trophic interactions, and thrive in diverse environmental conditions is a serious conservation concern. Effective control measures should be developed to mitigate its ecological effects, including population monitoring, habitat assessment, and targeted removal strategies. Additionally, preventive measures should be implemented to reduce the likelihood of further spread. Strengthening biosecurity protocols at nurseries, regulating the ornamental plant trade, and launching public awareness campaigns could help minimize unintentional introductions.

Beyond immediate conservation efforts, the rapid expansion of *A. sagrei* across multiple continents raises key questions regarding its evolutionary trajectory. Studies have shown that invasive populations can develop distinct morphological and behavioral traits over short timescales due to local selective pressures. In Ecuador, further research should explore potential phenotypic divergence among geographically separated populations and the role of founder effects and genetic adaptation in shaping its invasion success.

This study highlights the urgent need for proactive conservation and management strategies to curb the expansion of *A. sagrei* in Ecuador. Early intervention is critical, as the species is still in the early stages of establishment in some regions, offering a unique opportunity for control before it becomes unmanageable. Collaborative efforts between researchers, conservationists, and policymakers are essential for developing and implementing effective measures to limit the spread of this invasive species while ensuring the protection of Ecuador's native biodiversity.

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Institutional Review Board Statement: This study was conducted in accordance with the ethical standards for scientific research established by the Museo de Zoología de la Universidad Técnica Particular de Loja (MUTPL), Loja, Ecuador. Most of the data were obtained through non-invasive field observations without animal handling. Only a small proportion of the observed individuals were collected and deposited in the MUTPL as taxonomic vouchers to ensure accurate species identification and lepidosis analysis. These collection activities were properly authorized under research permit MAATE-DBI-CM-2021-0181 granted on 21 September 2021, by the Ministerio del Ambiente, Agua y Transición Ecológica (MAATE) of Ecuador. No additional ethical approval was required under Ecuadorian law for this type of research.

Data Availability Statement: All data supporting the findings of this study are either included within the manuscript or are publicly available through the Global Biodiversity Information Facility [35].

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Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Resumen Extendido para tomadores de decisión

La introducción de especies invasoras es una de las principales amenazas para la biodiversidad y la estabilidad ecológica. *Anolis sagrei*, un lagarto originario de Cuba y las Bahamas, ha demostrado una notable capacidad de expansión, estableciéndose en diversas regiones del mundo, incluidas Norteamérica, el Caribe, Asia y Sudamérica. En Ecuador, su presencia se ha registrado en provincias costeras como Guayas, Manabí y Esmeraldas, así como en la Amazonía norte (Francisco de Orellana).

Este estudio documenta, por primera vez, la presencia establecida de *A. sagrei* en Zamora Chinchipe, específicamente en El Pangui, en las estribaciones amazónicas del sur de Ecuador. Se confirmó una población reproductiva con al menos 35 individuos, principalmente en viveros municipales y zonas urbanas. La principal vía de introducción parece estar relacionada con el comercio de plantas ornamentales, lo que sugiere una dispersión facilitada por la actividad humana.

¿Por qué es un problema?

La presencia de *A. sagrei* representa una amenaza potencial para la fauna nativa, ya que puede desplazar a lagartos endémicos mediante competencia directa y depredación. Además, su capacidad de adaptación a hábitats urbanos y naturales podría acelerar su expansión a otras regiones del país, afectando la biodiversidad local y alterando las interacciones ecológicas.

Recomendaciones de Manejo y Prevención

- Para minimizar el impacto de *A. sagrei* en Ecuador, se proponen las siguientes acciones: Monitoreo y control temprano: Implementar programas de vigilancia en zonas urbanas y áreas naturales cercanas para detectar nuevas introducciones.
- Regulación del comercio de plantas ornamentales: Aplicar protocolos de inspección en viveros y transporte de especies vegetales, principal vector de dispersión.
- Concienciación y participación ciudadana: Capacitar a comunidades y autoridades sobre la importancia del problema y cómo reportar avistamientos.
- Investigación del impacto ecológico: Evaluar la competencia de *A. sagrei* con especies nativas y su posible efecto sobre la biodiversidad local.

Dado que la población de El Pangui aún está en una fase inicial de establecimiento, existe una oportunidad para prevenir su expansión irreversible. Es fundamental que las autoridades ambientales y municipales adopten medidas inmediatas para contener la invasión y proteger la biodiversidad ecuatoriana.

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