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Author-formatted, not peer-reviewed document posted on 14/02/2025

DOI: <https://doi.org/10.3897/arphapreprints.e150220>

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

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1 **Borderless lizards: Unveiling overlooked records and the expanding invasion of**  
2 ***Anolis sagrei* in Ecuador**

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21

22 **Abstract:** Based on bibliographic records and data from GBIF and iNaturalist, we evaluated  
23 the global distribution of *Anolis sagrei*. This lizard, native to Cuba and the Bahamas, has  
24 now spread across mainland America, particularly in the Caribbean, Central America, and  
25 parts of the United States. It has also been introduced in Asia, and, according to some  
26 iNaturalist observations not covered in previous literature, it has been observed in Israel,  
27 Canada, and northern South America. The species is especially abundant in the Caribbean  
28 and southeastern United States, with high concentrations of records in these regions and  
29 parts of Mexico, indicating significant range expansion. In Ecuador, *A. sagrei* has been  
30 recorded both along the coast and in the Amazon, with notable occurrences in Esmeraldas,  
31 Manabí, Guayas, Francisco de Orellana, and, for the first time, in Zamora Chinchipe  
32 (southern Amazon), specifically in El Pangui. The capture of 10 individuals in this area  
33 (deposited at the Zoology Museum of Universidad Técnica Particular de Loja) confirmed  
34 typical *A. sagrei* morphology, with a scale pattern similar to populations in Honduras and

35 Cuba but showing variations in scalation and body measurements. In Ecuador, the number  
36 of lamellae on the fourth toe ranges from 29-33, consistent with individuals from Honduras  
37 and Cuba but differing from those in Taiwan. Additionally, dorsal and ventral scale counts  
38 within the 5 mm range show variations (dorsal: 11-22 and ventral: 10-25), suggesting  
39 environmental adaptations or natural variability. Climate change favors its spread, enabling  
40 the colonization of new habitats through increased temperatures and altered precipitation  
41 patterns. As an invasive species, *A. sagrei* impacts local biodiversity by competing with  
42 native species and disrupting ecological balance. This study underscores the need for  
43 monitoring and control programs in Ecuador, particularly in the Amazon, to protect native  
44 biodiversity.

45

46 **Keywords:** alien species, biological invasion, invasive reptile, Dactyloidae, range  
47 expansion, ecological impact, urban ecology

48

## 49 **Introduction**

50

51 The global biodiversity crisis is accelerating due to human-induced environmental changes,  
52 including climate change, habitat destruction, pollution, and overexploitation of natural  
53 resources (Kleespies et al. 2024). Among these threats, biological invasions stand out as  
54 one of the most pervasive yet underestimated drivers of biodiversity loss (Senior et al.  
55 2024). The introduction and establishment of species outside their native ranges have led  
56 to severe ecological, economic, and social consequences, reshaping entire ecosystems,  
57 altering trophic interactions, and displacing native taxa (Hofman and Rick 2018; Simberloff  
58 et al. 2013; Vantarová et al. 2023).

59

60 Unlike other environmental threats, biological invasions are often irreversible (Simberloff et  
61 al. 2013). Once an introduced species establishes a self-sustaining population, its  
62 eradication becomes highly challenging, if not impossible, particularly in ecosystems where  
63 native species lack adaptations to withstand novel competitors or predators (Capinha et al.  
64 2015; Rai and Singh, 2020; Ramsey et al. 2023). Furthermore, invasive species rarely act  
65 in isolation; their impact is often amplified by other global stressors, including habitat  
66 fragmentation and climate change. As species introductions continue to increase  
67 worldwide, understanding the ecological drivers, dispersal mechanisms, and long-term

68 consequences of biological invasions is critical for conservation efforts and ecosystem  
69 management (Seebens et al. 2017).

70

71 Biological invasions are not a modern phenomenon. Humans have been translocating  
72 species for at least 20,000 years, moving domesticated plants and animals across  
73 continents (Boivin et al. 2016). However, globalization, international trade, and increased  
74 human mobility have drastically accelerated the rate and scale of species introductions,  
75 leading to a global homogenization of biodiversity (Vantarová et al. 2023). This  
76 unprecedented intensity of human-mediated species exchanges has blurred historical  
77 biogeographic boundaries, altering species interactions, ecosystem functions, and  
78 evolutionary processes (Winter et al. 2009). The establishment of non-native species in  
79 new environments has led to the emergence of novel ecological interactions, often with  
80 unpredictable outcomes for native communities.

81

82 Among vertebrates, reptiles, particularly lizards, have gained prominence as highly  
83 successful invaders due to their high reproductive potential, behavioral plasticity, and  
84 adaptability to human-modified environments. Lizards often exhibit strong ecological  
85 opportunism, allowing them to colonize new habitats rapidly and, in many cases, to  
86 outcompete native species (Kolbe et al. 2014). One of the most widespread and  
87 ecologically disruptive reptilian invaders is the Cuban brown anole, *Anolis sagrei* (Duméril  
88 and Bibron, 1837), a species originally native to Cuba and the Bahamas.

89

90 The invasion of *A. sagrei* has been extensively documented across North America, the  
91 Caribbean, and parts of Asia, where it has exhibited rapid expansion due to its aggressive  
92 behavior, high reproductive rate, and ability to exploit urban and suburban environments  
93 (Losos 2009). Unlike many native anole species, which tend to be habitat specialists, *A.*  
94 *sagrei* displays extreme ecological plasticity, allowing it to thrive in a wide range of  
95 conditions, including natural, urban, and peri-urban landscapes.

96

97 One of the most significant ecological impacts of *A. sagrei* invasions is its displacement of  
98 native anole species. Studies have shown that in regions where *A. sagrei* has been  
99 introduced, native anole populations are often forced into suboptimal microhabitats due to  
100 direct competition for space and resources (Stuart et al. 2014). Additionally, its opportunistic  
101 foraging behavior enables it to exploit a wide variety of prey, potentially altering local food

102 webs and competing with native insectivores (Schoener and Schoener 1984). In invaded  
103 regions, *A. sagrei* has been linked to reductions in native lizard populations, shifts in  
104 invertebrate community structures, and disruptions in predator-prey dynamics (Stroud et al.  
105 2017).

106

107 Despite extensive research on its invasion in North America, the Caribbean, and parts of  
108 Asia, the expansion of *A. sagrei* in South America remains poorly documented (Amador et  
109 al. 2017; Narváez et al. 2024). While its presence has been recorded in Brazil and  
110 Colombia (Kolbe et al. 2014), its ongoing invasion in Ecuador has received little attention  
111 (Amador et al. 2017; Narváez et al. 2024). This knowledge gap is particularly concerning  
112 given Ecuador's exceptional biodiversity, which includes a high number of endemic reptile  
113 species that may be vulnerable to the competitive pressures exerted by *A. sagrei*.

114

115 In Ecuador, *A. sagrei* was first recorded in coastal provinces such as Guayas, Manabí, and  
116 Esmeraldas, where environmental conditions closely resemble those of its native range  
117 (Amador et al. 2017; Narváez et al. 2020). However, recent records indicate that the  
118 species has expanded beyond these initial invasion sites, reaching the Amazonian province  
119 of Francisco de Orellana and, more recently, Zamora Chinchipe, a region within the  
120 Amazonian foothills. This southward expansion raises concerns about the species' ability to  
121 invade highland ecosystems, where it may pose new threats to native biodiversity.

122

123 Unlike the well-documented coastal invasions, the presence of *A. sagrei* in montane and  
124 Amazonian ecosystems suggests that the species possesses greater physiological  
125 tolerance and adaptability than previously recognized (Narváez et al 2024). The ability to  
126 persist in more humid, cooler environments raises concerns about its potential for further  
127 colonization into Andean and Amazonian habitats, where native anole species and other  
128 small vertebrates may be at risk. If *A. sagrei* is able to establish populations in montane  
129 forests, it could impact not only native lizard assemblages but also the broader ecological  
130 networks in these ecosystems.

131

132 Ecuador hosts some of the highest levels of reptile diversity in the world, with many species  
133 occupying highly specialized ecological niches (Torres-Carvajal et al. 2019; Arteaga 2024;  
134 Cruz-García et al. 2024). The continued expansion of *A. sagrei* could have long-term  
135 consequences for native species, particularly those with restricted distributions or limited

136 dispersal abilities (Losos 2009; Stuart et al. 2014; Stroud et al. 2017). The mechanisms  
137 driving its dispersal into new environments remain poorly understood (Kolbe et al. 2014) ,  
138 highlighting the need for comprehensive ecological studies and long-term monitoring  
139 programs (Narváez et al. 2024).

140

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

150

## 151 **Methods**

152

### 153 ***Study Area***

154

155 This study was conducted in El Pangui canton, Zamora Chinchipe province, Ecuador  
156 (Figure 1). This area is in the country's southeastern region and falls within the Amazon  
157 basin. It is characterized by a humid tropical climate, with an average annual temperature of  
158 approximately 22°C (Vélez-Abarca et al. 2023). The landscape comprises urban areas,  
159 green spaces, and ornamental vegetation, providing suitable conditions for *A. sagrei*  
160 colonization. Given its location in the Amazonian foothills, El Pangui represents a strategic  
161 site for assessing the species' expansion into previously undocumented areas.

162

### 163 ***Data Collection***

164 To assess the presence of *A. sagrei*, daytime, and nighttime field surveys were conducted  
165 in El Pangui using entomological sweep nets and manual collection techniques (Dodd,  
166 2016, McCranie and Köhler, 2015). Specimens were anesthetized before euthanasia using  
167 Roxicaina (i.e., 2% Lidocaine) to ensure a humane process (British Herpetological Society  
168 2017) They were then fixed in 10% formalin, preserved in 70% ethanol, and deposited in

169 the herpetological collection of the Museo de Zoología de la Universidad Técnica Particular  
170 de Loja (MUTPL) in Ecuador.

171

172 Morphometric measurements were recorded using digital calipers with a precision of 0.1  
173 mm. Fifteen standard variables were measured, including snout-vent length (SVL), head  
174 width, head height, femur length, and fourth toe length (Williams et al. 1995; Poe 2004).  
175 Scale counts were taken on the left side when applicable. Dorsal and ventral scale counts  
176 within a 5-mm segment were performed, and scalation patterns were compared with  
177 populations from Honduras, Cuba, and Taiwan (Norval et al. 2016; Tan and Lim 2012).  
178 Regenerated or broken tails were excluded from total length measurements. Sex was  
179 determined based on everted hemipenes and enlarged postcloacal scales in males.

180

### 181 ***Distribution***

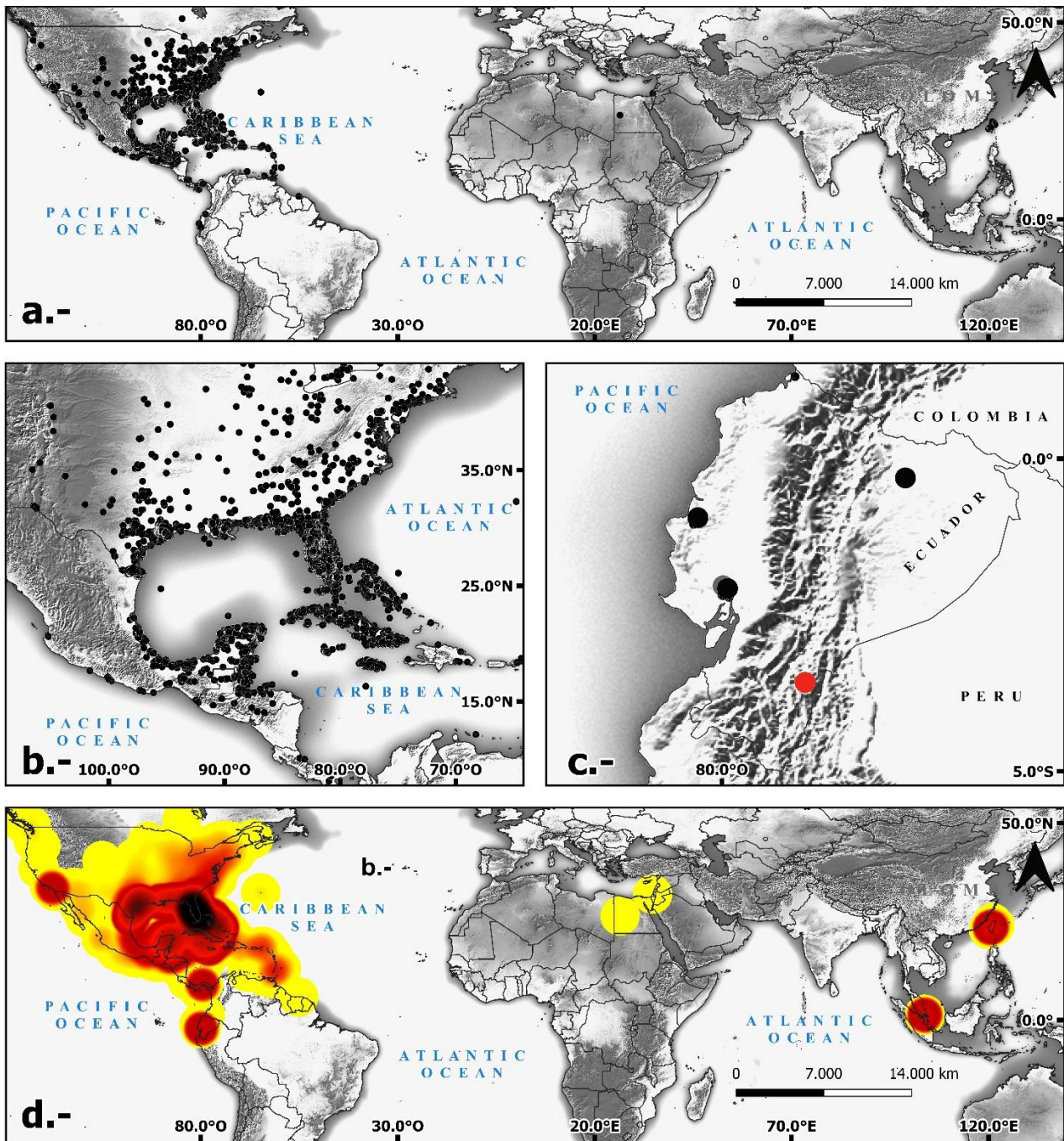
182

183 To assess the distribution of *A. sagrei*, we compiled data from three primary sources: (1)  
184 peer-reviewed literature, (2) open-access biodiversity databases (GBIF, iNaturalist), and (3)  
185 field observations in Ecuador. Records were downloaded and filtered until June 2024,  
186 prioritizing those with precise geographic coordinates (GBIF, 2024). The dataset was  
187 analyzed using QGIS 3.26 to generate kernel density maps that visualize the highest  
188 concentrations of *A. sagrei* occurrences globally and within Ecuador (Hijmans et al. 2017).  
189 The distribution patterns were further examined in terms of environmental and  
190 anthropogenic factors.

191

192 We categorized *A. sagrei* records into three groups: (1) validated records from peer-  
193 reviewed studies, (2) unverified records from public databases, and (3) new occurrences  
194 documented in this study. To minimize misidentification errors, iNaturalist records were  
195 cross-verified with photographic evidence and compared to published morphological  
196 descriptions (Losos, 2009; McCranie and Köhler, 2015). The complete dataset used for  
197 spatial analysis is provided as supplementary material.

198



199

200 **Figure 1:** Global Distribution of *Anolis sagrei*; (a) Global Occurrence Records: Black dots  
 201 indicate confirmed occurrences of *A. sagrei* across its native and introduced ranges. High-  
 202 density records are concentrated in the Caribbean, southeastern United States, and parts  
 203 of Central and South America; (b) Detailed Distribution in North America and the  
 204 Caribbean: Close-up of *A. sagrei* occurrence records in the United States, Mexico, the  
 205 Caribbean, and Central America. The species is widespread in Florida, Cuba, and  
 206 surrounding regions, with scattered records in northern South America; (c) Distribution in  
 207 Ecuador: Black circles represent known records of *A. sagrei* in Ecuador from biodiversity  
 208 databases and field observations. The red dot highlights a newly confirmed record in El

209 Pangui, Zamora Chinchipe, marking a significant range expansion into the southern  
210 Amazon; (d) Kernel Density Map of *A. sagrei* Global Distribution: Areas in red and yellow  
211 indicate regions with a high density of occurrence records. The highest concentration is in  
212 the Caribbean and southeastern United States, followed by secondary hotspots in Brazil,  
213 parts of Asia (Taiwan, Singapore), and isolated regions in the Middle East.

214

## 215 **Results**

216

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

228

229 Specimens in both locations were primarily found in urban green areas, particularly in  
230 ornamental vegetation such as *Chlorophytum* sp. (spider plants) and the pinnae of *Cycas*  
231 sp. (sago palms). *A. sagrei* individuals consistently perched on foliage at heights of 0.6 to  
232 1.2 meters. At night, the species was consistently found sleeping on these plants,  
233 facilitating manual collection. Nocturnal surveys provided a more accurate assessment of  
234 the population size, revealing stable numbers across multiple sampling nights. The  
235 population structure included adult males, adult females, and juveniles, indicating active  
236 reproduction. Also, the stable numbers observed across multiple sampling nights further  
237 support the establishment of the species in the area.

238

239 Morphometric analyses revealed significant variation in body size and scalation patterns  
240 within the El Pangui population. Table 1 summarizes key morphometric measurements and  
241 lepidosis characteristics, including snout-vent length (SVL), dorsal and ventral scale counts,  
242 and the number of lamellae on the fourth toe. The Ecuadorian specimens exhibited SVL

243 values similar to those from Honduras and Cuba, but dorsal and ventral scale counts were  
 244 generally lower than those recorded in Taiwan and Mexico. In El Pangui, dorsal scales  
 245 within a 5 mm segment ranged from 11 to 22, while ventral scales ranged from 10 to 25,  
 246 falling within the range documented for Cuban and Honduran populations but differing from  
 247 the broader variability observed in Taiwan. The number of lamellae on the fourth toe varied  
 248 between 28 and 33, consistent with Honduran and Cuban specimens but slightly lower than  
 249 those from Taiwan. These patterns suggest potential regional differentiation in scalation  
 250 traits, possibly influenced by genetic factors or environmental conditions.

251

252 Table 1. Summary of lepidosis<sup>†</sup>, morphometric measurements (mm), and coloration  
 253 characteristics of *Anolis sagrei* in El Pangui, Ecuador, compared with populations reported  
 254 in Honduras, Cuba, Taiwan, and Mexico.

Catalogue N°	Sample	Sex	Age Class	Interorbital scales	Iterparietal/interorbital	Loreal rows	Supralabials	Scales between	Internasal scales	Lamellae 4th toe	Dorsal scales	Ventral scales	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

255 †We follow previously proposed terminology for external characters by Williams et al.  
 256 (1995) and Poe (2004). Scale counts were made on the left side if applicable.

257  
 258 Males in the El Pangui population exhibit a well-developed, brightly colored dewlap with an  
 259 orange-to-reddish hue and distinct marginal pigmentation. The dewlap is proportionally  
 260 larger than in females and juveniles, reinforcing pronounced sexual dimorphism. Males also  
 261 have elongated limbs and broader head proportions, traits commonly associated with  
 262 competitive behaviors and territorial displays. In contrast, females have a smaller, less  
 263 vibrant dewlap with limited extension capacity. Their dorsal coloration is more uniform,  
 264 predominantly brownish-gray with faint speckling, which enhances camouflage within  
 265 ornamental vegetation. Female body proportions are more compact, with a relatively  
 266 shorter head-to-body ratio and less pronounced limb elongation compared to males. These  
 267 differences in body proportions and dewlap morphology are visually evident in the  
 268 examined specimens (Figures 2a–2c).

269



270

271 Figure 2. Morphological variation of *Anolis sagrei* in El Pangui, Ecuador. (a) Adult male  
272 (MUTPL-R 552), displaying an extended dewlap; (b) Adult female (MUTPL-R 553) with a  
273 less contrasting coloration pattern. (c) Juvenile female (MUTPL-R 554) exhibiting  
274 characteristic features of early developmental stages.

275

276 The juvenile female (Figure 2c) exhibits lighter overall coloration and finer scalation  
277 patterns. The dewlap is underdeveloped, and the body proportions are more gracile than in  
278 adults. The dorsal pattern is variegated, featuring irregular blotches and faint transverse  
279 banding, possibly enhancing crypsis in its environment. Across all individuals, variations in  
280 scalation patterns were observed, particularly in dorsal and ventral scale counts, supralabial  
281 scales, and lamellae on the fourth toe (Table 1). The number of supralabial scales ranged  
282 from 5 to 7, while interorbital scales varied between 1 and 2. The dewlap structure in males  
283 was generally more robust, with higher pigmentation intensity, whereas in females and  
284 juveniles, it was smaller and less vibrant. These figures visually support the presence of  
285 sexual dimorphism and ontogenetic variation within the *A. sagrei* population in El Pangui.  
286 Differences in dewlap size, limb proportions, and body coloration align with previously  
287 documented patterns in other invasive populations but also highlight specific characteristics  
288 of the Ecuadorian specimens.

289

290 A comparison of the El Pangui specimens with *A. sagrei* populations from other regions,  
291 summarized in Table 1, reveals that while SVL and fourth toe lamellae counts are similar to  
292 those in Cuban and Honduran populations, Ecuadorian specimens exhibit notably lower  
293 dorsal and ventral scale counts compared to populations in Taiwan and Mexico. These  
294 differences could be linked to local adaptation or founder effects in newly established  
295 populations.

296

297 The updated distribution analysis confirms that *A. sagrei* has expanded its range into  
298 Zamora Chinchipe, marking a significant southward incursion into the Amazonian foothills  
299 of Ecuador (Figure 1c). Previously, the species was primarily recorded in coastal provinces  
300 (Guayas, Manabí, Esmeraldas) and in the Amazonian region of Francisco de Orellana.

301

302 The species' global occurrence patterns (Figure 1a) indicate that its highest population  
303 densities remain concentrated in the Caribbean, southeastern United States, and Mexico,  
304 whereas records in South America and Asia remain more fragmented. A more detailed

305 analysis of its North American and Caribbean distribution (Figure 1b) highlights that *A.*  
306 *sagrei* is particularly abundant in Florida, Cuba, and the Yucatán Peninsula, with additional  
307 scattered populations across Central and South America. Kernel density estimates (Figure  
308 1d) reveal that while the Caribbean and southeastern United States harbor the most  
309 established populations, recent records suggest ongoing introductions into new  
310 environments, including urban and natural areas of South America and Asia.

311

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

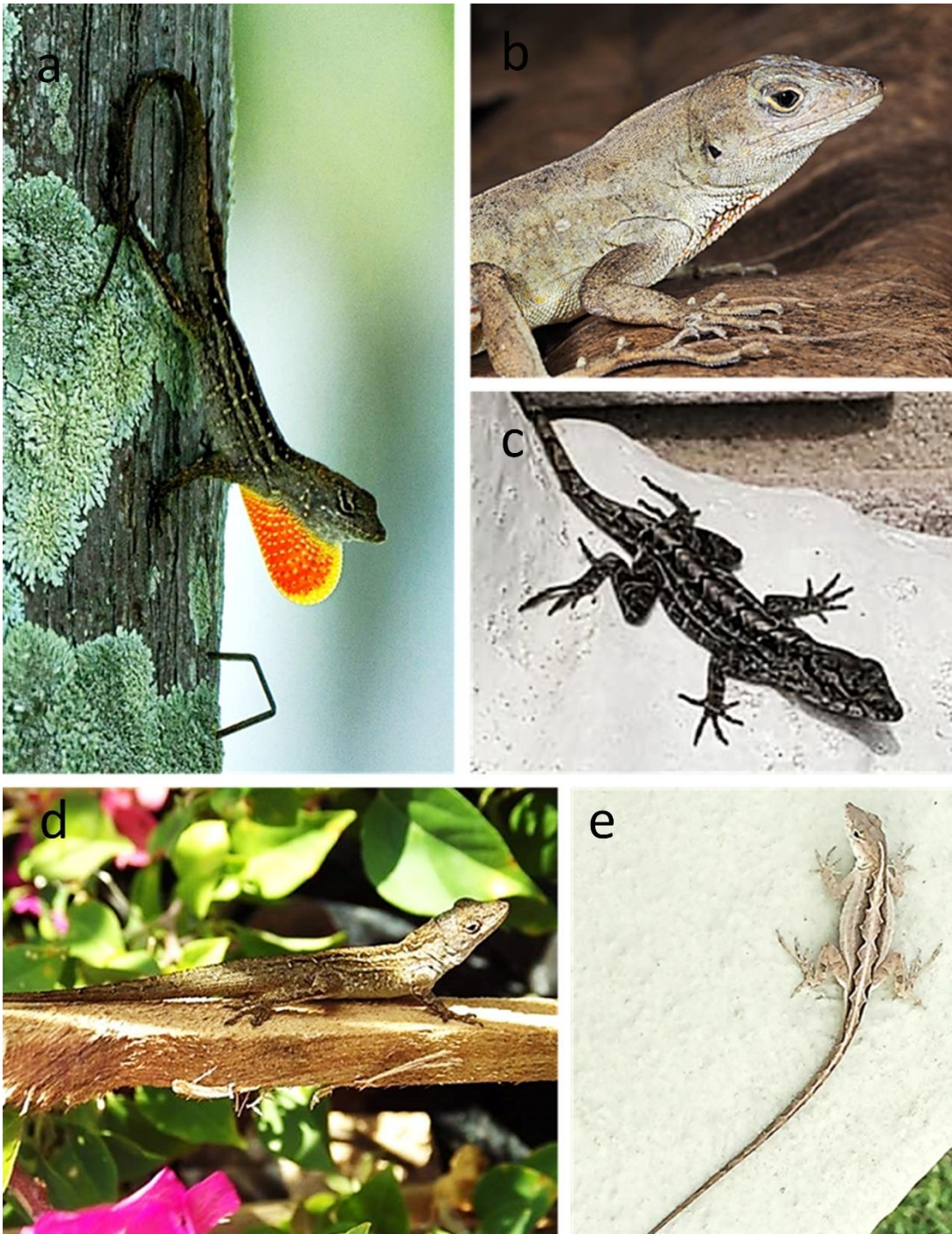
319

## 320 Discussion

321

322 Surveys in the central plaza of El Pangui confirmed a well-established population of *A.*  
323 *sagrei*, with at least 35 individuals recorded, 10 of which were collected for morphological  
324 analysis and taxonomic preservation. The actual population size is likely larger, but these  
325 findings indicate that *A. sagrei* is no longer a transient species in the area, it has settled.  
326 The first individuals were observed in the municipal nursery, which supplies ornamental  
327 plants for the town's public spaces, including the central plaza. This strongly suggests that  
328 *A. sagrei* arrived via plant transport, likely from already invaded regions such as Guayaquil  
329 or Francisco de Orellana. This pathway is consistent with other invasions of *A. sagrei*,  
330 where plant trade has facilitated its spread into urban and peri-urban environments (Losos  
331 2009; Tan and Lim 2012, Narváez et al. 2024). Understanding this introduction route is key  
332 to designing prevention strategies before similar introductions occur elsewhere.

333



334

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

340 Table 2. Additional records of *Anolis sagrei* in Ecuador, obtained from open-access  
341 biodiversity databases (GBIF, iNaturalist), verifying its presence in the country. Includes  
342 geographic coordinates, observation numbers, and validation status

<b>Territory</b>		<b>GBIF Records</b>	<b>Records from peer-reviewed studies</b>
<b>Asia</b>			
Israel	Resident	1	Overlooked record, but see Bar 2021
Singapore	Resident	509	Overlooked record
Taiwan**	Resident	692	Norval et al., 2016
<b>Atlantic Oceanic Island</b>			
Saint Helena, Ascension and Tristan da Cunha	Resident	0	Stroud et al. 2018
Saint Lucia	Resident	0	Morton and Cox, 2011
<b>Caribbean Island</b>			
Anguilla	Resident	3	Wagensveld and van Questel 2018
Bahamas	Native	9604	Reynolds et al. 2018
Bermuda	Resident	6	Stroud et al. 2017
Cayman Islands	Native	1352	Losos et al. 1993
Cuba	Native	3248	Duméril, and Bibron 1837
Grenada	Resident	28	Greene et al. 2002
Jamaica	Resident	1124	Burgess, 2012
Saint Vincent and the Grenadines	Resident	15	Treglia et al. 2018
Saint Maarten	Resident	1	Fläschendräger, A 2010
Turks and Caicos Islands	Resident	6	Burgess 2012
<b>Central America</b>			
Belize	Resident	1040	Sexton and Brown, 1977
Costa Rica	Resident	3	Overlooked record
Guatemala	Resident	57	Campbell, 1999
Honduras	Resident	393	Antúñez-Fonseca et al. 2022
Panama	Resident	266	Batista et al. 2019
<b>North America</b>			
Canada	Resident	42	Overlooked records
Mexico	Resident	4307	Perez-Delgadillo et al. 2024
USA	Resident	62 838	Fisher et al.2020
<b>South America</b>			
Brazil	Resident	510	Oliveira et al. 2018
Ecuador	Resident	357	Amador et al. 2017; Cruz-García et al. 2023; Narváez et al. 2024; this study
Suriname	Resident	1	Overlooked record
Venezuela	Resident	3	Overlooked record

343

344 Local gardeners maintaining the plaza reported that *A. sagrei* had not been seen in the  
 345 area until roughly six months before our study. This supports the idea that the species was  
 346 introduced recently and is still in the early stages of establishment. At this phase, there is a  
 347 crucial window for intervention; once the species spreads further, control efforts will become

348 significantly more challenging (Narvez et al., 2020). To determine whether *A. sagrei* was  
349 expanding beyond El Pangui, we conducted systematic surveys in nearby towns, including  
350 Yantzaza, Gualaquiza, and Zamora, using the same sampling methods. However, we found  
351 no evidence of *A. sagrei* in any of these locations. This suggests that, for now, the invasion  
352 remains localized, likely originating from a single introduction event. These findings  
353 highlight the urgent need for monitoring and management before the species expands into  
354 other parts of the Ecuadorian Amazon.

355

356 Our findings confirm that *A. sagrei* has established a stable population in El Pangui,  
357 Ecuador, marking a significant expansion into the Amazonian foothills. This invasion is a  
358 direct threat to native reptiles, as observed in the documented displacement of *Kentropyx*  
359 *pelviceps* (Cope, 1868). Field observations showed that once a *K. pelviceps* individual was  
360 removed for museum preservation, *A. sagrei* rapidly occupied its former refuge within 24  
361 hours. This immediate takeover suggests strong competitive abilities and high behavioral  
362 plasticity, raising concerns about its long-term impact on local lizard populations (Losos  
363 2009; Stroud et al. 2017).

364

365 Beyond direct competition, the presence of *A. sagrei* could trigger cascading ecological  
366 effects. The species primarily preys on arthropods, but reports from other invaded regions  
367 indicate opportunistic consumption of vertebrates, including juvenile *Anolis* (Piovia-Scott et  
368 al. 2017; Narvez et al. 2020). If similar predation patterns emerge in Ecuador, native  
369 insectivorous reptiles and amphibians could face significant pressure due to prey depletion  
370 and competition for food resources. Such disruptions may alter local food webs, potentially  
371 affecting not only reptiles but also other insect-dependent taxa (Meshaka, 2011).

372

373 The ecological risks are further amplified by the adaptability of *A. sagrei* to urban and  
374 modified landscapes. This flexibility has facilitated its rapid expansion in regions like Florida  
375 and the Caribbean, where it has displaced native *Anolis* species from their preferred  
376 habitats (Stuart et al. 2014). Given Ecuador's high reptile diversity and the presence of  
377 many range-restricted species, the continued spread of *A. sagrei* could lead to severe  
378 biodiversity losses, particularly in areas where native lizards have not evolved defenses  
379 against aggressive competitors (Blackburn et al. 2011; Simberloff et al. 2013).

380

381 Unlike long-established invasions, where eradication is often unfeasible, the recently  
382 introduced population in El Pangui presents a unique opportunity for early intervention. The  
383 lack of records in surrounding areas suggests a localized introduction, making containment  
384 efforts still viable. Immediate action through targeted removal programs, habitat monitoring,  
385 and regulation of ornamental plant transport could prevent further expansion into vulnerable  
386 Amazonian ecosystems (Amador et al. 2017; Narváez et al. 2024).

387

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

395

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

403

404 The expansion of *A. sagrei* is likely facilitated by human-mediated transport, habitat  
405 modifications, and its ability to thrive in disturbed environments. As observed in other  
406 invasive reptiles, urban settings, ornamental vegetation, and human activity play a critical  
407 role in dispersal (Tan and Lim, 2012). The species distribution in Ecuador suggests that  
408 accidental transport via trade and construction materials has enabled its spread. The  
409 confirmed presence of *A. sagrei* in the Amazonian foothills marks a notable shift in its  
410 known range, as it was previously recorded mainly in Ecuador's coastal regions (Guayas,  
411 Esmeraldas, and Manabí) and the northern Amazonian province of Francisco de Orellana.  
412 The new records from Zamora Chinchipe demonstrate that *A. sagrei* can establish itself in a  
413 broader range of environments, including humid montane forests, raising concerns about its  
414 potential expansion into additional highland regions.

415

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

424

425 Our analysis of open-access biodiversity databases (GBIF, iNaturalist) identified multiple  
426 overlooked records of *A. sagrei* in regions where its presence had not been previously  
427 documented in the scientific literature. Notably, occurrences were recorded in Canada,  
428 Israel, and Italy, expanding the known global distribution of this invasive species beyond its  
429 previously recognized range. These findings suggest that *A. sagrei* may have established  
430 undetected populations or transient occurrences in regions far from its primary invasive  
431 hotspots.

432

433 The presence of *A. sagrei* in Ecuador has been well documented through direct field  
434 observations and biodiversity databases. However, discrepancies in database accuracy  
435 pose challenges in determining the species' precise distribution. Data quality issues,  
436 including misidentifications and inconsistent georeferencing, highlight the need for further  
437 verification. The integration of citizen science records with validated field data is essential to  
438 ensure the reliability of these distributional records.

439

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

448

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

457

458 *Conservation and management Implications: Rapid actions are required*

459

460 The continued expansion of *A. sagrei* in Ecuador underscores the urgent need for improved  
461 monitoring and management strategies. In other invaded ecosystems, *A. sagrei* has  
462 displaced native *Anolis* species, disrupted trophic networks, and reduced local biodiversity  
463 (Losos 2009; Stroud et al. 2017). While its ecological impact in Ecuador remains largely  
464 unstudied, its presence in the Amazon raises significant concerns, particularly for endemic  
465 reptile species that may face displacement or direct predation.

466

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

474

475 Citizen science platforms like iNaturalist provide valuable data for tracking the spread of *A.*  
476 *sagrei*. However, ensuring the accuracy of these records requires close collaboration  
477 between researchers and citizen scientists. Training initiatives to improve species  
478 identification and reporting accuracy could significantly enhance data quality. Integrating  
479 citizen science with systematic field surveys will offer a more complete understanding of the  
480 distribution of the *A. sagrei* and its ecological effects, strengthening conservation efforts.

481

482 Efforts to control *A. sagrei* in other regions have yielded mixed results (Amador et al. 2017;  
 483 Narváez et al. 2020). Traditional eradication methods, such as direct removal and habitat  
 484 modifications, have been employed to limit population growth. However, the species' high  
 485 reproductive rate and behavioral adaptability pose significant challenges for eradication. In  
 486 Ecuador, developing region-specific management plans tailored to different ecological  
 487 zones will be essential for mitigating its ecological impact.

488

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

492

493 The potential impact of climate change on the expansion *A. sagrei* remains an important  
 494 consideration. Rising temperatures and altered precipitation patterns could create more  
 495 favorable conditions for its establishment in previously unsuitable areas (Tan and Lim  
 496 2012). Climate models predict increased temperature variability across Ecuador, which may  
 497 facilitate further dispersal of *A. sagrei* into montane forests and other highland ecosystems.

498

499 Understanding how *A. sagrei* responds to environmental change is crucial for predicting  
 500 future range expansion. Previous studies have demonstrated that invasive anoles exhibit  
 501 rapid morphological and behavioral adaptations to new environments (Losos 2011).  
 502 Monitoring these adaptations in Ecuadorian populations will provide insights into the  
 503 species' potential to establish in diverse ecological settings.

504

## 505 **Conclusions**

506

507 Our study confirms the establishment of *A. sagrei* in El Pangui, Zamora Chinchipe, marking  
 508 the species' southernmost record in Ecuador. The discovery of a stable population in the  
 509 central park, alongside evidence of recent introduction via the municipal nursery, strongly  
 510 suggests that human-mediated transport of ornamental plants is the primary dispersal  
 511 mechanism facilitating its expansion. This pathway aligns with previous records of *A. sagrei*  
 512 in Ecuador, particularly in Guayaquil and Francisco de Orellana, two key urban centers  
 513 involved in the plant trade. The Andes Mountains likely act as a natural dispersal barrier,  
 514 making colonization from Guayaquil by active movement unlikely, whereas passive  
 515 transport from Orellana appears to be the most plausible introduction route.

516

517 The documented expansion of *A. sagrei* in Ecuador demonstrates its remarkable ecological  
518 adaptability, as the species has successfully established itself in urban environments within  
519 the Amazonian foothills. Given its ability to thrive in both natural and human-modified  
520 landscapes, there is growing concern that its presence may alter local ecological dynamics.  
521 In other invaded regions, *A. sagrei* has been documented displacing native anoles, altering  
522 prey communities, and modifying trophic interactions. While the long-term ecological  
523 consequences in Ecuador remain uncertain, its rapid establishment in El Pangui  
524 underscores the need for immediate monitoring efforts. Surveillance programs should target  
525 both urban and natural areas, particularly along potential dispersal corridors, to assess the  
526 species' continued spread.

527

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

536

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

546

547 Beyond immediate conservation efforts, the rapid expansion of *A. sagrei* across multiple  
548 continents raises key questions about its evolutionary trajectory. Studies have shown that  
549 invasive populations can develop distinct morphological and behavioral traits over short

550 timescales due to local selective pressures. In Ecuador, further research should explore  
551 potential phenotypic divergence among geographically separated populations and the role  
552 of founder effects and genetic adaptation in shaping its invasion success.

553

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

561

## 562 **Acknowledgments**

563

564 We sincerely thank the municipal gardeners of El Pangui for sharing their insights on local  
565 plant trade practices and providing valuable information that contributed to understanding  
566 the possible introduction pathways of *A. sagrei* in the region. Their firsthand perspective on  
567 ornamental plant distribution was essential in shaping our analysis. We also express our  
568 gratitude to Diana and Paul Szekely for their collaboration in acquiring photographic  
569 documentation of *A. sagrei* specimens collected in Pangi, which enriched the visual records  
570 supporting this study. Special thanks to Amarú Loaiza, curator of the reptile collection at the  
571 Museo de Zoología de la UTPL (MUTPL), for his support in the definitive housing of the  
572 preserved specimens and for training one of us (JS) in scale count (lepidosis) techniques,  
573 which was essential for the accuracy of our morphological analyses. This research was  
574 conducted under collection permit MAATE-DBI-CM-2021-0181 and mobilization guide No.  
575 2324 (dated July 24, 2024), granted by the Ministerio del Ambiente, Agua y Transición  
576 Ecológica (MAATE) of Ecuador.

577

578 Based on our findings, we formally communicated the presence of this invasive species in  
579 El Pangui to the municipal authorities and the Office of Biodiversity at MAATE, ensuring  
580 that the relevant institutions are informed and can take appropriate management actions.  
581 To facilitate access to key findings for local stakeholders, an extended summary in Spanish  
582 is available in the supplementary materials, providing a comprehensive analysis of the  
583 species' presence, its potential impacts, and recommended management strategies.

584

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