

# Identification of Green Iguana (*Iguana iguana*) Hotspots in Urban Kaohsiung Using Citizen-Reported Geographic Information Dataset from the Kaohsiung City 1999 Call Center

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## Research Article

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## Abstract

29 The green iguana (*Iguana iguana*) is a widely distributed invasive alien species (IAS)  
30 in southern Taiwan. We analyzed 2025 sighting reports submitted by residents to the  
31 Kaohsiung City 1999 call center to identify spatial hotspots. We show clusters of  
32 sightings using the Getis-Ord Gi\* statistic, which reveal the concentration of green  
33 iguanas are in mid- and southern part of the study area in Kaohsiung City and are

expanding northwest. Buffer analysis indicates that the KP and SY bridges, which connect Pingtung County and Kaohsiung City, may serve as entry points, with more hotspots located within 9,750 meters of these bridge endpoints. Hotspots outside this area are mainly along waterways, including ditches, rivers, and canals. Hotspots in the JD and NH Districts indicate these areas are critical for further green iguana migration to Tainan City and may reflect the pattern observed in Pingtung County. The Kaohsiung City 1999 call center provides valuable but underutilized volunteered geographic information (VGI) for urban IAS monitoring and can support future control efforts in the urban areas.

Keywords: Invasive alien species (IAS), Volunteered geographic information (VGI), Kaohsiung City 1999 call center, Green iguana (*Iguana iguana*), Hotspot, Getis-Ord Gi\* analysis, Buffer analysis, Urban ecosystem

## 48 1. Introduction

49 The green Iguana (*Iguana iguana*) is one of the IAS in Taiwan, along with red  
50 imported fire ants (*Solenopsis invicta*), golden apple snails (*Pomacea maculata*), and  
51 others. IASs disrupt ecosystems, compete with native species, and cause economic  
52 losses (D'Antonio & Hobbie 2005; DiTomaso 2000; Dukes & Mooney 2004; Hobbs  
53 2000; Theoharides & Dukes 2007). The iguana is native to Central and South  
54 America, and it was introduced into Taiwan as a pet in 1986 under the influence of  
55 movies and pop culture, similar to the case in Florida, USA, in 1960 (Meshaka et al.  
56 2004), according to the CITES trade database (Lee et al. 2012). The peak import year  
57 was 2004, with more than 23,200 green iguanas imported from the USA and El  
58 Salvador. Some green iguanas were later abandoned as impulse buying waned and  
59 Fear of Missing Out (FOMO) faded. Subsequent release or escape of captive animals  
60 is generally regarded as the proximate source of free-living populations in Taiwan  
61 (Lee et al. 2012). The main habitats of green iguana in Florida are bays, canals, ponds,  
62 and ditches (near the forest fringe). Both low-lying urban and farmland environments  
63 are most suitable for green iguanas to breed and spread (Chuaynkern et al. 2025;  
64 Claunch et al. 2025; Lee et al. 2012; Meshaka et al. 2004; Pasachnik et al. 2012; van  
65 den Burg et al. 2020). Green iguana, like many other IASs, often occupied a few  
66 localized sites for long periods while slowly building population size, or until  
67 conditions are ripe for an explosion in numbers, with the latter ranging from nearly  
68 instantaneous to many years (Meshaka et al. 2004). In many studies, humans have  
69 broken down barriers to the long-distance dispersal of plants and animals, IASs have  
70 increasingly altered the composition and functioning of the Earth's ecosystems  
71 (Bernery et al. 2023; Bradley et al. 2024; Cordero et al. 2023; Davis et al. 2005;  
72 Dukes & Mooney 1999; Fricke & Olden 2023; Kang et al. 2022; Knapp et al. 2020;  
73 Milardi et al. 2019). Accurate spatial data on IAS distribution is essential for detailed

research and for developing effective removal strategies (Mu & Wang 2026; Roy et al. 2023; Saqib et al. 2025; Serva et al. 2024; Thomas et al. 2018; Vilà et al. 2011; Zhang et al. 2021). Mapping alien species hotspots in urban ecosystems supports effective management. In Geneva, Switzerland, a survey of 178 urban ponds identified areas with high concentrations of alien aquatic plants and produced a risk map to guide control efforts (Oertli et al. 2018). Human expansion and interference can cause significant habitat loss and fragmentation in natural environments through anthropogenic land-use change, a well-documented pattern (Fletcher et al. 2026; Fricke & Olden 2023; Gallardo et al. 2016; Hastings et al. 2005; Holway 1998; Hu et al. 2026; Liebhold et al. 2017; Yuan et al. 2024).

In contrast, IASs may enter recipient communities where competitors and natural enemies are absent, depleted, or poorly adapted, allowing rapid population growth and range expansion (Hellmann et al. 2008; Theoharides & Dukes 2007). Theoharides & Dukes (2007) describes invasion as proceeding through four stages: transport, colonization, establishment, and landscape spread. In this process, suitable habitat is progressively occupied and connected, rather than lost and fragmented (Fig. 1). This framework was developed primarily for plant invasions. Its application to a large-bodied, actively dispersing reptile should be considered a conceptual analogy. We use this framework in our study to organize the discussion.

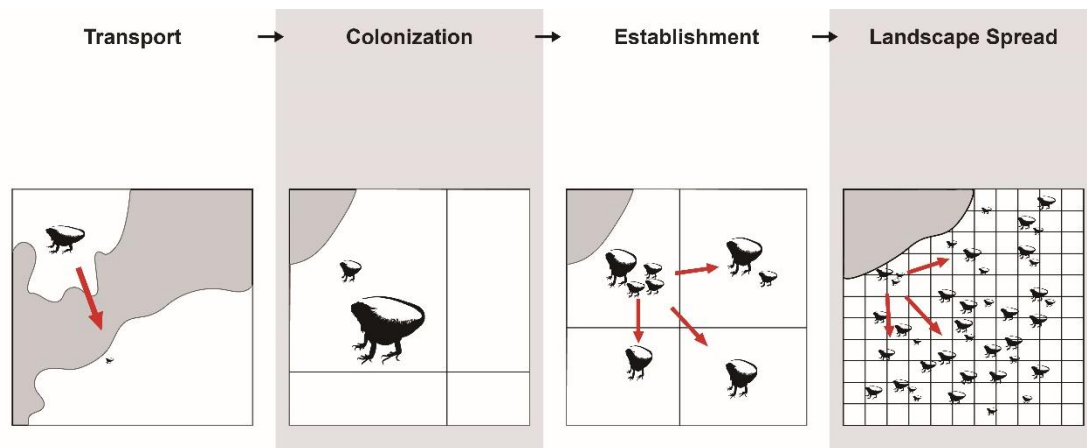


Fig. 1 IASs invasion stages (modified from Theoharides et al., 2007))

Sighting reports from Pingtung County and Kaohsiung City show that the green iguana population is expanding (Lee et al. 2012) (See Fig. 2). In Taiwan, green iguanas, as one of the IASs, have been breeding naturally without predators. The high temperatures in southern Taiwan make them common in Pingtung County, and they have recently begun to spread into Kaohsiung City. Our study analyzes green iguana sighting reports submitted by Kaohsiung City residents to the 1999 call center to examine spatial distribution patterns. Residents across Taiwan can report sightings to the 1999 call center or through the website, and the responsible agency must respond to and log each case.

Green iguana sighting reports submitted to the Kaohsiung City 1999 call center include the report date, a free-text description, and the location, provided as a street address or landmark. If the caller specifies the number of animals seen, we also record it. We used the national TGOS address-matching service (<https://tgos.tw/tgos/Addr>) to convert reported addresses into TWD97 coordinates. This service, completed in 2009, contains coordinates for over eight million addresses nationwide.

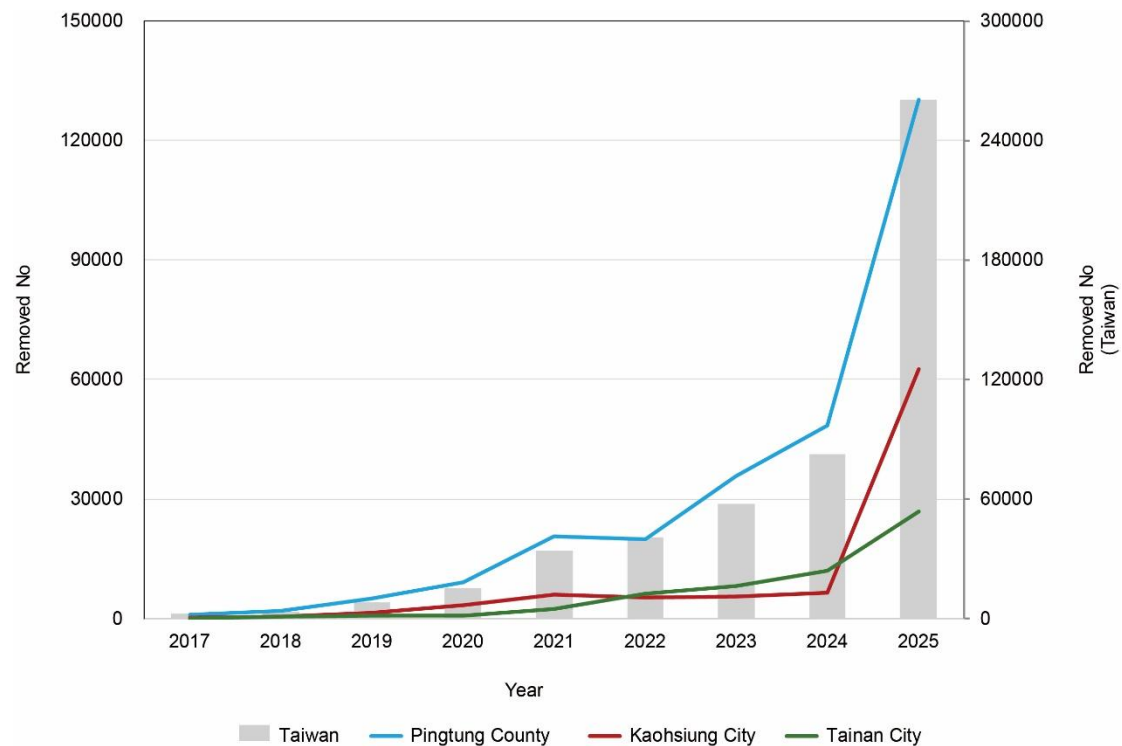


Fig. 2 The green iguana removal no. between 2017 and 2025 in Taiwan  
(Source: FNCA (2026))

These records represent VGI as Goodchild (2007) defines it: geographic content voluntarily contributed by non-specialist citizens. Each report is submitted by a resident, includes a specific location, and describes an observed phenomenon. The primary difference from typical VGI in the literature is the delivery channel. While platforms like OpenStreetMap and iNaturalist are designed for intentional geographic contributions, municipal service hotlines collect similar data as a byproduct of service requests. We refer to this dataset as citizen-generated administrative reporting data, treating it as VGI delivered through an administrative channel (Auguste 2020; Elwood et al. 2012; Goodchild 2007). This distinction affects data usage. Since contributors seek municipal services rather than participate in surveys, the data is continuous, unstructured, and demographically broad, but lacks a sampling design and effort measurement. Thus, it shares the typical strengths and weaknesses of VGI

(Elwood et al. 2012). The study uses green iguana sighting reports submitted by citizens to the Kaohsiung City 1999 call center as valuable VGI spatial data. A key advantage of this dataset is that address-based reports can be converted to coordinates effectively and accurately using the national TGOS address-matching service, providing a reliable basis for analysis.

IASs pose a significant risk to global biodiversity, ecosystem health, and economic stability. Effective early detection and ongoing monitoring are essential (Encarnação et al. 2021). Engaging citizens as environmental observers can expand the spatial and temporal coverage beyond what conventional surveys achieve (Larson et al. 2020; Pocock et al. 2024). In urban ecosystems, citizen-contributed records help document biodiversity and invasive species where traditional surveys are limited or unavailable. However, these records often face challenges such as uneven spatial coverage and unmeasured recording effort (Martoglio et al. 2025). The purpose-built platforms, such as iNaturalist or dedicated mobile applications, typically include submissions with a photograph and GPS coordinates and can be verified (Larson et al. 2020; Lehtiniemi et al. 2020). The green iguana locations in Kaohsiung City are from the 1999 call center dataset, and the residents are largely limited to the reporters.

Although app-based platforms dominate recent literature, VGI delivered through conventional administrative channels—telephone hotlines and direct reports to government agencies (in our study, the Kaohsiung City 1999 call center)—remains an important source of occurrence data and has the particular advantage of reaching contributors who would not use a dedicated application. In Florida, the Fish and Wildlife Conservation Commission maintains a Wildlife Impact Management Section database that consolidates public reports from the toll-free “IveGot1” hotline, direct telephone calls, emails, the “AskFWC” web portal, and mobile applications. This consolidated record forms the basis for much of the current knowledge about the

state's green iguana population (Claunch et al. 2025). Phone calls to the Hong Kong Agriculture, Fisheries and Conservation Department (AFCD) and to the rescue centers (NGOs) have similarly been used to reconstruct the spatiotemporal distribution of green iguanas (Mo & Mo 2023; Mo & Mo 2022). By lowering technological barriers, these systems capture local ecological knowledge from residents, including elderly individuals and those without internet access, who are often excluded from smartphone-based datasets (Encarnação et al. 2021). These precedents establish two things relevant to the present study. First, agency-held public reports have already supported descriptive spatial analysis of this species in two other places, so the approach adopted here is not without precedent. Second, in both cases the reporting channel was national or territory-wide and consolidated across several media. The Kaohsiung City 1999 call center extends this to a third setting. It differs in that it is a single municipal service line with mandatory case logging, which yields a more uniform record structure. We note, however, that all such datasets share the limitation that reporting effort is not measured. A similar challenge, where uneven recording effort reduces the reliability of ecological assessments, has also been observed in citizen science data from urban areas (Martoglio et al. 2025).

Through the Kaohsiung City 1999 call center (<https://soweb.kcg.gov.tw/#/report>), citizens can call or file a web report about any matter related to the city government. The city government uses the 1999 call center to engage citizens and provide more prompt service under the Research, Development and Evaluation Commission of the Kaohsiung City Government. Established in 2008, it provides 24-hour service and a follow-up tracing procedure to ensure citizens' complaints are properly processed. Citizens can provide feedback and report infrastructure malfunctions and emergencies that need immediate attention through the 1999 call center by phone or via its website. The 1999 call center can divert them to the appropriate department to address issues

promptly. This helps the city government serve citizens more effectively; therefore, the 1999 call center is an important unit in the city government. We used the 2025 green iguana sighting report collected by the Kaohsiung City 1999 call center as the VGI data source.

The Forest and Conservation Agency (FNCA) of the Ministry of Agriculture of Taiwan funds local government efforts to control the spread of green iguanas. In 2025, removals increased significantly, with over 260,000 individuals reported in Taiwan—about three times the 2024 total. Pingtung County accounted for the largest number at 130,288, followed by Kaohsiung City with 62,608 (Fig. 2). The high removal numbers in Pingtung County and its proximity to Kaohsiung have raised concerns about a possible green iguana migration from Pingtung County to Kaohsiung City. This study aims to show whether the spatial distribution of green iguana sightings in Kaohsiung City supports this connection. We use the 2025 dataset from the Kaohsiung City 1999 call center to identify spatial patterns and hotspots of green iguana clustering using the GETIS-Ord  $G_i^*$  in ARC GIS 10.2.

## 200 2. Methods

201 We obtained district boundaries from Taiwan Government Open Data  
202 (<https://data.gov.tw/dataset/7441>). This same area was used for grid construction,  
203 Getis-Ord Gi\* analysis, and all buffer analyses. We use the green iguana sighting  
204 reports collected by the Kaohsiung City 1999 call center from citizens in 2025 as  
205 proxy data for spatial distribution in this study. The sighting report includes the time,  
206 location (address or place), and the number of green iguanas observed. Addresses  
207 were converted to coordinates in Taiwan Datum '97 (TWD97, EPSG: 3826, ZONE  
208 121) using the TGOS national address-matching service in batch mode, which has a  
209 daily conversion limit of 10,000 records. In total, 3,005 reports documented 4,041  
210 green iguanas. Reports were accepted as submitted and not independently verified.  
211 Reported addresses have a potential accuracy of a few meters, and the base map scale  
212 was 1: 1,000.

213 We analyzed the green iguana spatial data using the Getis-Ord Gi\* statistic to identify  
214 spatial clusters. We determined grid size based on data density and converted sighting  
215 coordinates to this grid for hotspot analysis. After identifying hotspots, we conducted  
216 buffer analyses around schools, roads, and the endpoints of two bridges between  
217 Pingtung County and Kaohsiung City to assess the relationship between proximity to  
218 these features and spatial density. All spatial data were collected by the Kaohsiung  
219 City 1999 call center and are considered VGI data. Finally, we classified the spatial  
220 patterns of green iguana sightings according to the four stages of IAS invasion  
221 proposed by Hellmann et al. (2008) and Theoharides & Dukes (2007) to examine their  
222 spatial characteristics.

223

### 224 2.1. Study site

225 Kaohsiung City is a major harbor and industrial center located in southwestern  
226 Taiwan. It is Taiwan's third-largest city, with a projected population of 2.72 million in  
227 2025 and an area of 2,996.82 km<sup>2</sup>. The city borders Tainan City to the north, separated  
228 by the Erren River, and Pingtung to the east, separated by the Kaoping River (Fig. 3).  
229 Our analysis focused on the western, predominantly urbanized area, which includes  
230 28 districts. We selected this area because the northeastern districts are sparsely  
231 populated and produced few sighting reports or field records during the study period.  
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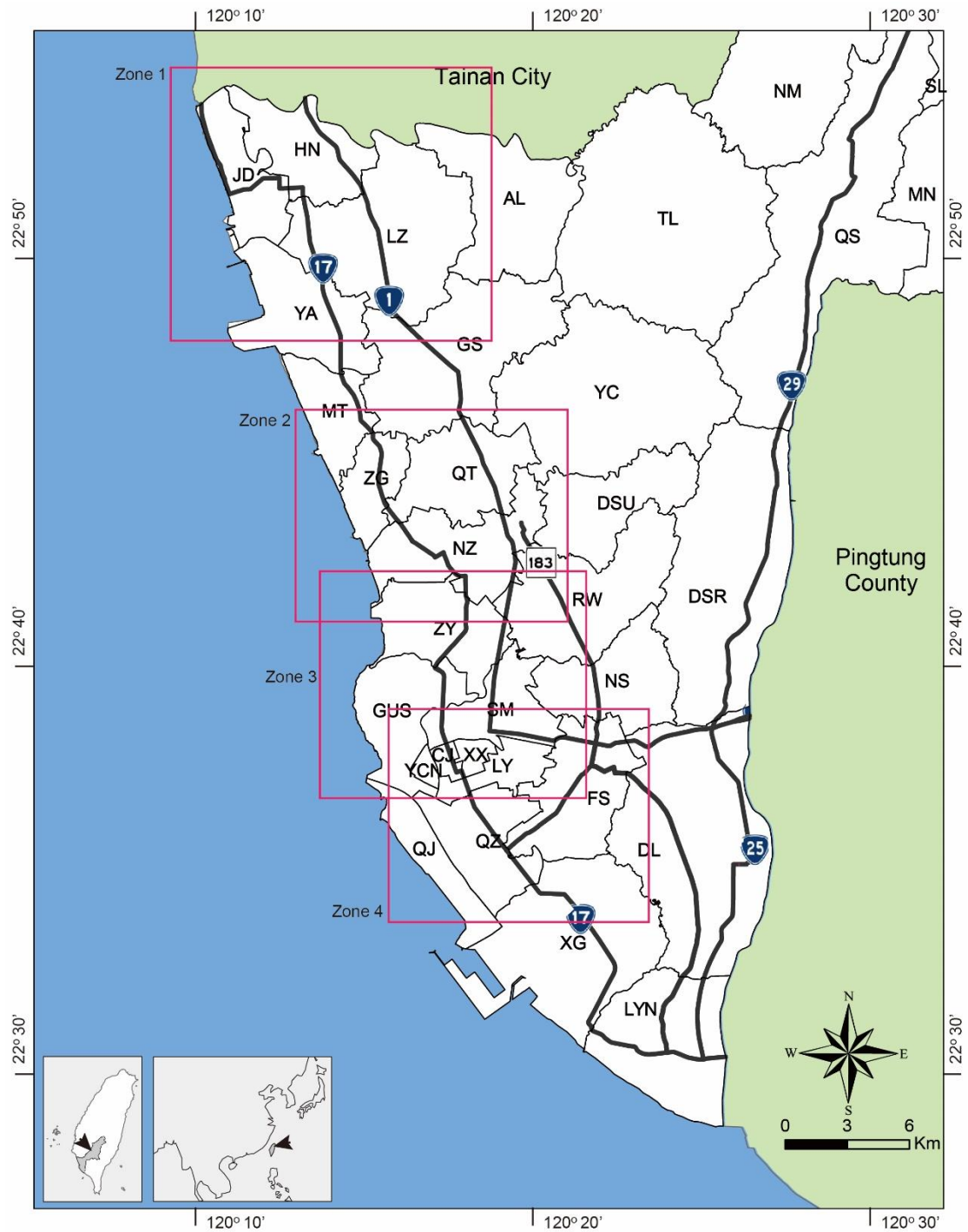


Fig. 3 The study area

## 2.2. The selection of proper spatial resolution

Grid size (pixel size, also known as spatial resolution) is an important determinant of the patterns recoverable from spatial analysis. Appropriate resolution depends on map

scale, positional accuracy, sampling density, spatial autocorrelation, and the complexity of the phenomenon (Hengl 2006). Finer grids (large-scale maps) require more detailed data, while coarser grids require less. Spatial analysis typically uses three types of datasets: point, contour, and polygon data. In this study, green iguana sighting reports from the Kaohsiung City 1999 call center are in address or location format. We can convert the spatial information to point data with spatial coordinates (TWD 97). The grid size estimation method proposed by Hengl (2005) is as follows:

$$p = 0.0791 \sqrt{\frac{A}{N}} \quad (1)$$

Where  $p$  is the grid size (in meters),  $A$  is the surface area of the study area (in square meters), and  $N$  is the number of independent points. Applying equation (1) with  $N = 3,005$ —the number of independent geocoded report locations—gives 43.1 m for the study area extent (891.9 km<sup>2</sup>) and 79.0 m for the whole municipality.

We note that these values differ from those obtained when the 4,041 reported individuals are substituted for  $N$ , which yields 37.2 m and 68.1 m. Because multiple individuals reported at a single address do not constitute independent spatial samples, the point-based values are appropriate and are used here. Alternatively, ArcGIS Pro derives a default cell size as the shorter side of the analysis extent divided by 250 (<https://pro.arcgis.com/en/pro-app/3.6/tool-reference/spatial-analyst/kernel-density.htm>)

### 2.3. The identification of hotspot by using Getis-Ord $G_i^*$ analysis

The Getis-Ord  $G_i^*$  statistic identifies statistically significant spatial clusters of high or low values (Getis & Ord 1992; Ghalhari & Roudbar 2018; Lin et al. 2018; Xie et al. 2021). It has been applied to gridded urban expansion data (Wang & Lin 2007),

healthcare accessibility (Liao 2013), landslide distribution (Jen et al. 2016; Lu et al. 2019), historical land use (Baics & Meisterlin 2016), vegetation productivity (Ren et al. 2020), carbon storage (Lin et al. 2018), thermal patterns (Ghalhari & Roudbar 2018) and patent activity (Choi et al. 2018). Among these, Wang & Lin (2007) is closest to the present application in that it applies Getis-Ord  $G_i^*$  to counts aggregated onto a regular grid of fixed cell size, which is the design adopted here. A positive and statistically significant  $G_i^*$  z-score indicates a cell with a high value surrounded by cells with high values.

In this study, we use the Getis-Ord  $G_i^*$  statistic for hotspot analysis, reporting the z-score and p-value for each grid cell to identify spatial clusters of high or low values. A statistically significant hotspot occurs when a feature has a high value and is surrounded by other high-value features. Statistical significance is determined when the observed local sum differs greatly from the expected local sum, beyond what would be expected by chance (<https://pro.arcgis.com/en/pro-app/3.6/tool-reference/spatial-statistics/what-is-a-z-score-what-is-a-p-value.htm>). Each feature's  $G_i^*$  statistic is reported as a z-score; higher positive z-scores indicate more intense clustering of high values (hotspots) (<https://pro.arcgis.com/en/pro-app/3.6/tool-reference/spatial-statistics/h-how-hot-spot-analysis-getis-ord-gi-spatial-stati.htm>). For this analysis, we defined spatial relationships using a fixed distance band and Euclidean distance of 300 meters. The 300-meter distance, equal to three cells, allowed each focal cell to be evaluated against its immediate neighborhood at an intermediate scale. We acknowledge this was a pragmatic choice; using incremental spatial autocorrelation or a predetermined ecological distance would provide a stronger basis. We did not assess the sensitivity of our results to the selected distance band.

## 2.4. Buffer analysis

We applied buffer analysis (cumulative distance bands) to assess how reported individual density changes with distance from selected features. Cumulative buffer gradients of this kind have been used to characterize spatial gradients in urban expansion (Jeong et al. 2014; Kacaw & Tsai 2023; Li et al. 2010; Liu & Zhou 2005) and in riparian planning (Xiang 1996), and we follow that descriptive convention here.

Three sets of bands were constructed: (i) around the two bridge endpoints connecting Pingtung County and Kaohsiung City (KP Bridge and SY Bridge), in 250 m increments; (ii) around road centerlines, at 100, 200, 300, 400 and 500 m; (iii) around school polygons, at 100, 200, 300, 400 and 500 m. All three sets are cumulative: the 200 m band comprises all area within 200 m of the feature, and therefore includes the 100 m band. Counts reported for successive bands are consequently cumulative totals, and the densities are cumulative. This distinction is important because total counts always increase with band distance, while a declining cumulative density indicates that the outer areas are less dense than the inner areas. Cumulative bands illustrate a gradient but do not directly test distance decay. We also calculate counts within each band to better assess the distance effect from the selected features.

Meshaka et al. (2004) and Lee et al. (2012) suggest that the primary habitats of green iguana are the bay, canal, pond, and ditch near the forest edge. Low-lying urban and farmland areas are most suitable for their breeding and spreading. We used buffer analysis to show spatial phenomena related to roads and schools. The road centerline and the school areas were used as the basis for the buffer analysis, with the hotspots of green iguana sighting identified by the Getis-Ord  $G_i^*$ .

We selected these features for specific reasons. The two bridges are the main road crossings of the Kaoping River between Kaohsiung City and Pingtung County,

making them relevant for assessing connectivity between populations. Roads and schools were included because the hotspot map (Fig. 6) indicated close proximity to both. Since roads and schools are closely linked to human activity, any distance gradient observed cannot be interpreted as habitat preference. We did not analyze parks, green spaces, canals, ponds, or ditches, although previous studies highlight the importance of waterside habitats for this species (Lee et al. 2012; Meshaka et al. 2004). Instead, we use other maps to illustrate the green iguana's expansion in relation to these features.

### 3. Discussion

#### 3.1. The spatial distribution of green iguana sighting report dataset

We use the TGOS address-matching service to obtain coordinates in the TWD97 datum, then create a sighting report map for 2025 using the Kaohsiung City 1999 call center sighting report dataset. There are 3,005 sighting reports (data points), and Kaohsiung City citizens observed 4,041 green iguanas (Fig. 4). This shows that the points are mostly concentrated in the mid- and southern parts of the study area, as well as the northwestern part. Very few points occur in the northern and northeastern parts. This pattern could imply that the green iguana invasion originates mostly from the southeast, which is closer to the source (Pingtung County). This indicates that more sightings occur in the region. Furthermore, a relatively small number of reports separates the northwestern concentration from the central-southern concentration. This gap may reflect genuinely low abundance, low residential density, or both, leading to low reporting.

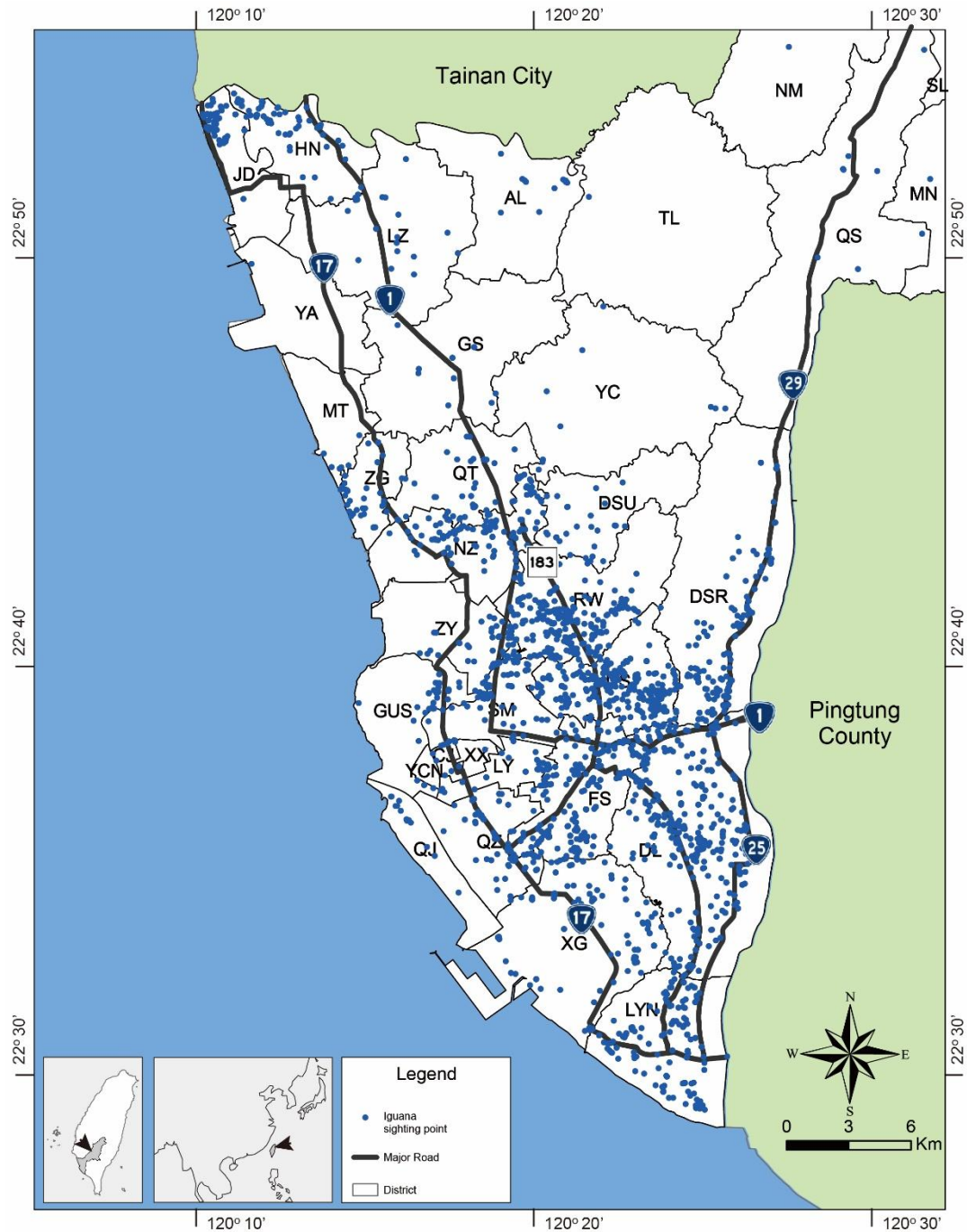


Fig. 4 Sighting report spatial distribution

### 3.2. Grid size

The grid size can be decided by the methods proposed by Hengl (2006) or ArcGIS Pro. We select the area and green iguana sighting report numbers for two scenarios: the study area or the whole Kaohsiung City, including suburban and rural areas. The

study area is about 89190.5 ha (28 districts; 51,333 m by 27,835 m), while the whole Kaohsiung City is about 299682.1 ha (38 districts; 123,407 m by 53,465 m). According to Hengl (2006), , the recommended grid size for the study area is about 37.3m, while for the whole Kaohsiung City it is about 68.1m. In ArcGIS Pro, the extents used here ( $51,333 \times 27,835$  m for the study area and  $123,407 \times 53,465$  m for the whole city) yield grid sizes of 111.3 m and 213.9 m, respectively. The two methods therefore bracket a range of roughly 43–214 m. We adopted a 100 m grid for three reasons: it falls within this range; it is the same order as the positional accuracy of address-level geocoding, and it yields a cell area ( $0.01 \text{ km}^2$  or 1 ha) that simplifies the density calculations reported below.

### 3.3. Hotspot pattern

We first create 100 m grids (select grid size) covering the whole study area, then join the green iguana sighting report numbers to each grid for the calculation of Getis-Ord  $GI^*$ , to reveal the hotspot of green iguana sighting in the study area from the Kaohsiung City 1999 call center dataset. In the Getis-Ord  $GI^*$ , we select fix distance band as the spatial relationship of the green iguana with 300 m of search distance (Euclidean distance), which is three times of the grid size (Fig. 5).

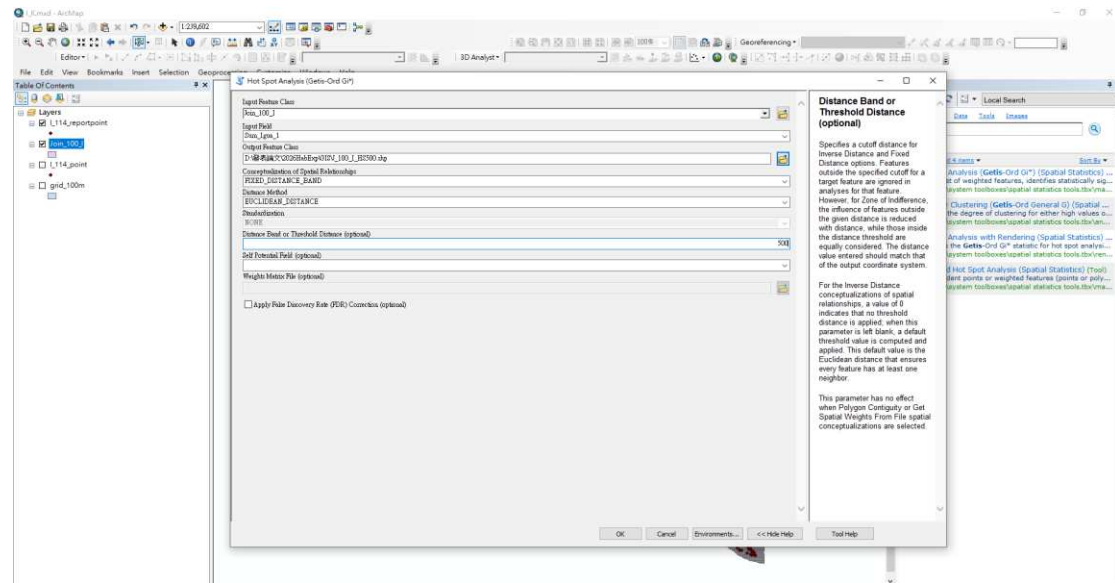
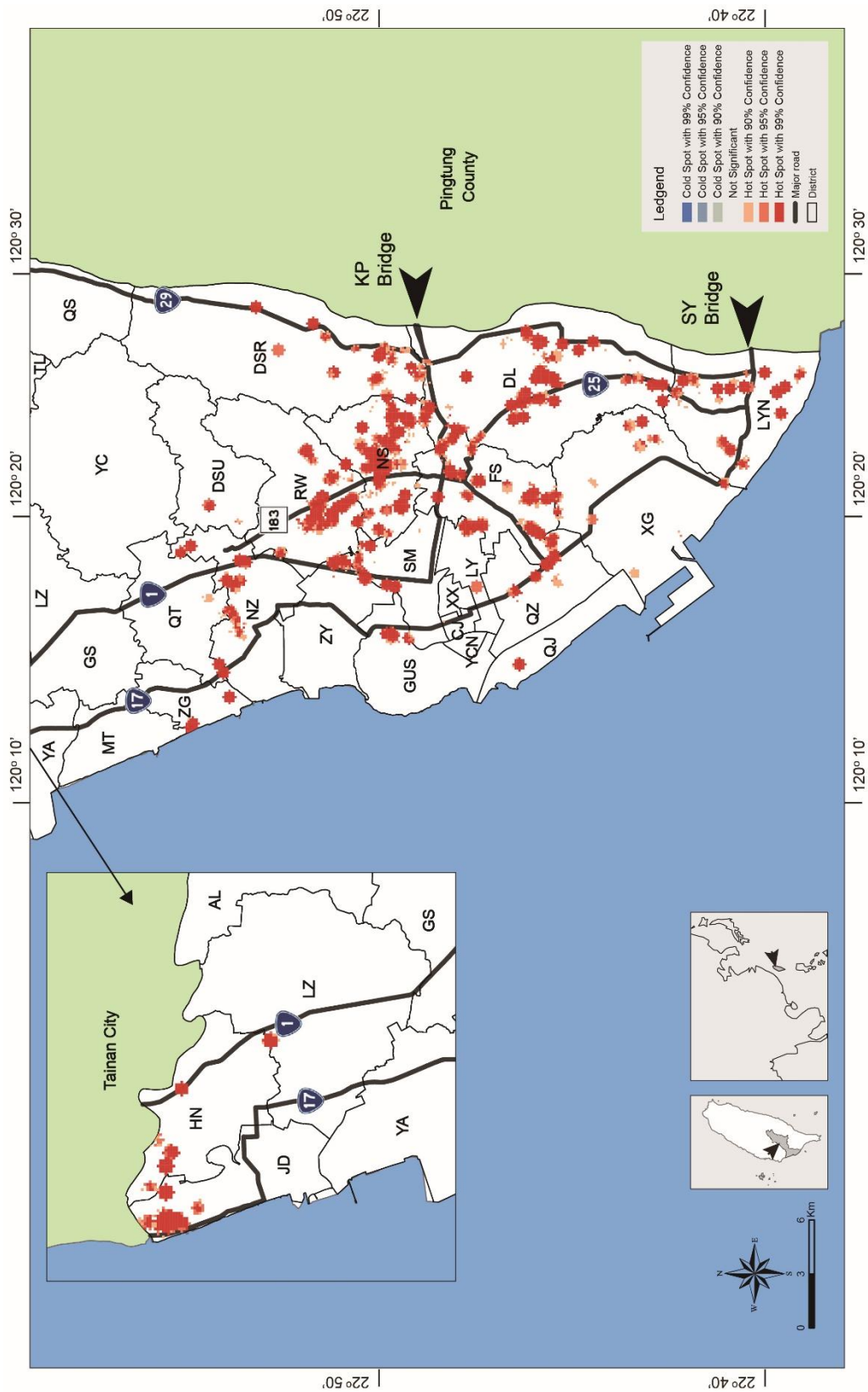


Fig. 5 Getis-Ord GI\* module in ARC Map 10.2

Fig. 6 shows the Gi\* results. Hotspots were concentrated in the central and southern districts, with a smaller cluster in the northwest. Hotspots were spatially associated with the main road network and with the endpoints of the two bridges connecting Kaohsiung City and Pingtung County. This association is consistent with the movement of animals from Pingtung County across these bridges: roads and bridge approaches are also areas of high human activity and therefore of high observation and reporting opportunity, and the present cross-sectional design cannot establish direction or timing of spread.



380

381 Fig. 6 Hotspots of green iguanas in the study area

Table 1 provides hotspot counts by district. The districts with the most hotspot cells were DL, NS, FS, RW, LYN, and DSR, located mainly in the southern and southwestern study area. Two northwestern districts, JD and HN, also contained hotspots. These districts are farther northwest of Kaohsiung City and distant from the green iguana source at KP Bridge and SY Bridge in the southwest, suggesting green iguanas are gathering there. These are the only green iguana hotspots in that region (see the upper-left part of Fig. 6).

Table 1 Hotspots in the districts of the Kaohsiung City

| District | Hotspot grid | Hotspot % | District area<br>(km <sup>2</sup> ) | Hotspot area<br>(km <sup>2</sup> ) | Ratio between<br>hotspot area and<br>district area |
|----------|--------------|-----------|-------------------------------------|------------------------------------|----------------------------------------------------|
| DL       | 823          | 18%       | 70.10                               | 8.23                               | 11.7%                                              |
| NS       | 742          | 16%       | 26.70                               | 7.42                               | 28.0%                                              |
| FS       | 499          | 11%       | 27.80                               | 4.99                               | 17.9%                                              |
| RW       | 452          | 10%       | 37.80                               | 4.52                               | 12.0%                                              |
| LYN      | 396          | 9%        | 35.80                               | 3.96                               | 11%                                                |
| DSR      | 313          | 7%        | 67.50                               | 3.13                               | 4.6%                                               |
| JD*      | 163          | 4%        | 17.00                               | 1.63                               | 9.6%                                               |
| SM       | 140          | 3%        | 16.00                               | 1.40                               | 8.8%                                               |
| SG       | 125          | 3%        | 53.90                               | 1.25                               | 2.3%                                               |
| HN*      | 108          | 2%        | 21.70                               | 1.08                               | 5.0%                                               |
| LY       | 74           | 2%        | 8.40                                | 0.74                               | 8.8%                                               |

Note: \* delineates the northwestern of the Kaohsiung City

The JD and HN districts, northwest of Kaohsiung City, each have hotspots where green iguanas gather. These are the only green iguana hotspots in the region (see the upper-left part of Fig. 6).

#### 3.4. Bridge endpoint, road, and school buffer analysis

Buffer analysis illustrates how reported green iguana density changes with distance from selected features. As described in the methods, the bands are cumulative; a decrease in cumulative density with distance only shows that outer areas have fewer reports than inner areas and does not confirm a distance effect. In this study, we identified hotspots near main roads, two bridge endpoints, and some schools. We selected the two bridge endpoints between Kaohsiung City and Pingtung County, as well as roads and schools, for buffer analysis to clarify the spatial distribution of these hotspots. The hotspot graph (Fig. 6) shows that the two bridges are the main entry points for green iguanas from Pingtung County. Accordingly, we performed buffer analysis from both bridge endpoints to examine how hotspot patterns relate to distance from each bridge.

Fig. 7 shows the results of the buffer analysis for the two bridge endpoints using a 250 m buffer zone. Fig. 7 (A) shows the result from merging the two bridge endpoints, while Fig. 7 (B) and (C) show the results for the KP Bridge endpoint and SY Bridge endpoint, respectively. The density of reported individuals was highest close to the bridge endpoints (approximately 13 no/km<sup>2</sup>), decreased to about 10, then rose again to about 12, and then fell below 8 (Fig. 7(A)). The profile is therefore bimodal, with local maxima at roughly 2,000 m and 7,000 m from the bridge endpoints. It implies three phenomena: (i) density decreases with distance from the bridge endpoint; (ii)

there are two main high-density zones: the area within 2,000 m of the bridge endpoint and the area within 7,000 m of the bridge endpoint. The two peaks could indicate that green iguanas from Pingtung County migrate in two waves (high-density peaks) separated by 5,000 m, then gradually fade outward; (iii) the innermost part should be in the landscape spreading proposed by Theoharides & Dukes (2007) and gradually transition to establishment and colonization further away. Accordingly, green iguana density could be a sound indicator of IAS invasion stages.

In addition, the two waves in the innermost part of the bridge endpoint buffer zone could reflect invasion migration patterns. The first wave should move into Kaohsiung City from Pingtung County before spreading outward, followed by a second wave. And the relatively low density near the two bridge endpoint areas could be affected by the high area ratio there.

Fig. 7B (KP Bridge) shows a single peak at approximately 6,750 m, while Fig. 7C (SY Bridge) shows a peak at about 5,000 m followed by a sharp decline. In all three panels, the number of reported individuals per band increases beyond 10 km, as expected in a cumulative design, and reflects the expanding band area rather than increased density. The distribution of green iguanas within each 250 m buffer zone varies: (A) and (B) are similar, but (C) is distinct. In (C), there are few green iguanas within 10 km, but more beyond this distance, with density peaks at 12 km and 14 km.

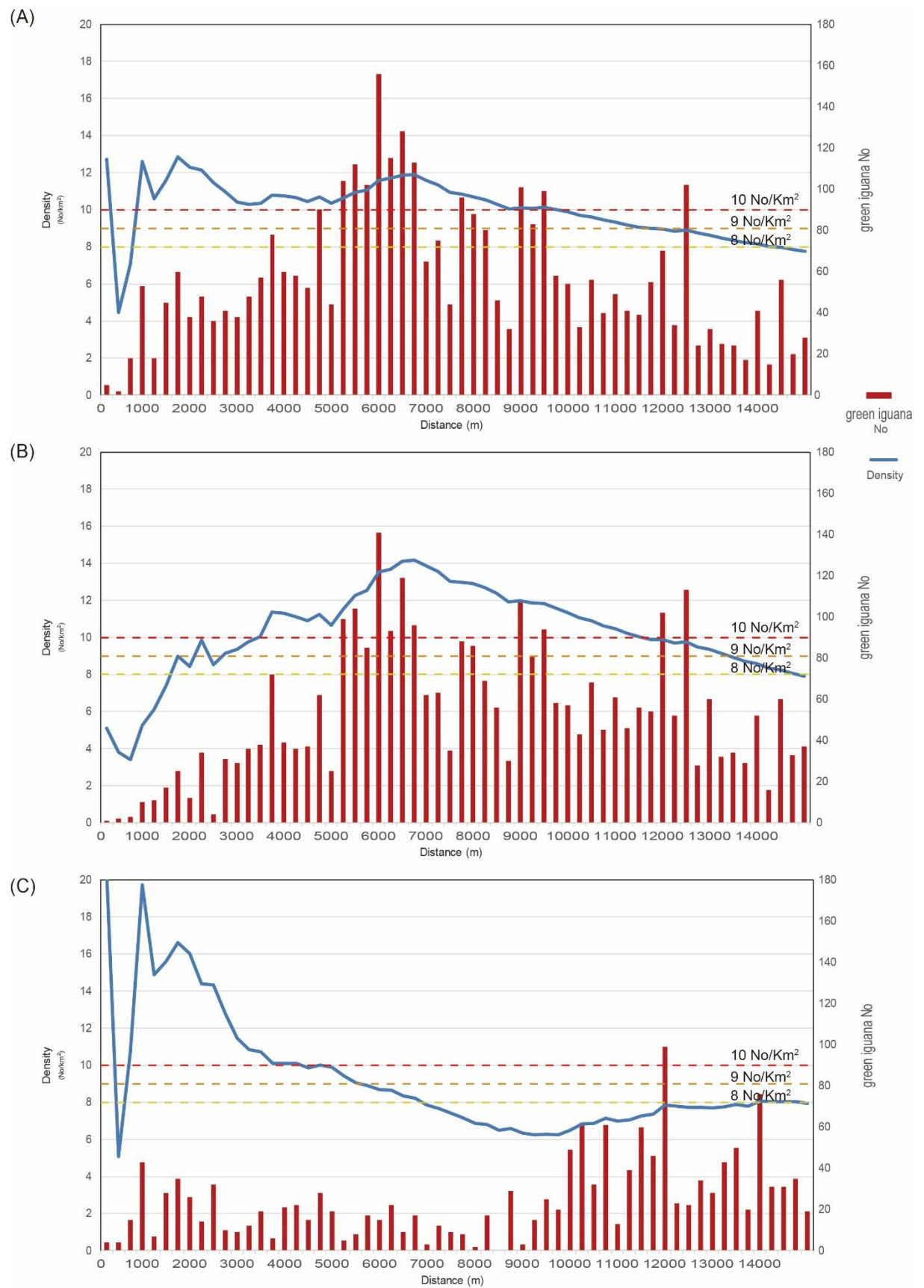


Fig. 7 The sighting report density and the green iguanas in each 250 m band from both bridge endpoints (A), KP Bridge endpoint (B) and SY Bridge endpoint (C)

441

442 Fig. 8 shows the cumulative density bands around the bridge endpoints together with  
443 the Gi\* hot-spot cells. Hot spots were more frequent and had higher density closer to  
444 the two bridge endpoints, except in the innermost bands immediately adjacent to the  
445 bridges. Beyond approximately 9,750 m from the bridge endpoints, hotspots became  
446 less frequent and cumulative density fell below 10 no/km<sup>2</sup>. Thus, we define 9,750 m  
447 from the bridge endpoints as the boundary between IAS invasion landscape spread  
448 (IV) and establishment (III). Areas between the 9,750 m buffer line and the  
449 administrative boundary (Kaohsiung City and Pingtung County) have more hotspots,  
450 whereas other areas have fewer. Further, some hotspots extend beyond the 9,750 m  
451 boundary. These could reflect the expansion of landscape spread (IV) to establishment  
452 (III). As mentioned above, roads could be the main conduit for green iguana  
453 migration between Kaohsiung City and Pingtung County, and within Kaohsiung City.  
454 We employ road buffer analysis to show the spatial pattern.

455

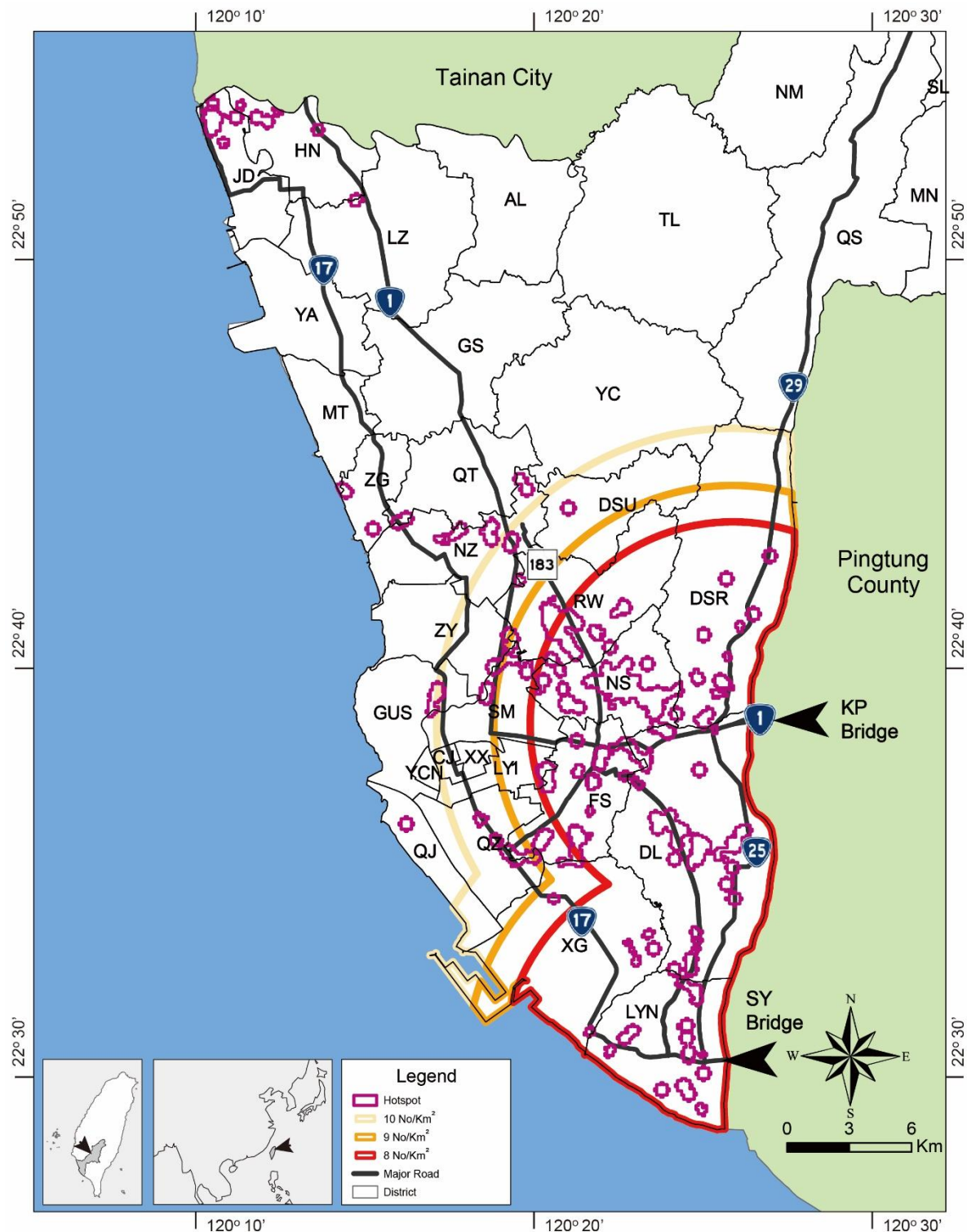


Fig. 8 The buffer analysis of the sighting report hotspots by the bridge endpoints between the Kaohsiung City and the neighboring Pingtung County

461 Table 2 Road buffer results

| Road buffer (m) | Road buffer band area (km <sup>2</sup> ) | Green iguanas (No) | %   | Density (No/km <sup>2</sup> ) |
|-----------------|------------------------------------------|--------------------|-----|-------------------------------|
| 100             | 243.2                                    | 1307               | 32% | 5.37                          |
| 200             | 456.4                                    | 1913               | 47% | 4.19                          |
| 300             | 641.1                                    | 2528               | 63% | 3.94                          |
| 400             | 799.7                                    | 2902               | 72% | 3.62                          |
| 500             | 943.8                                    | 3188               | 79% | 3.41                          |

462

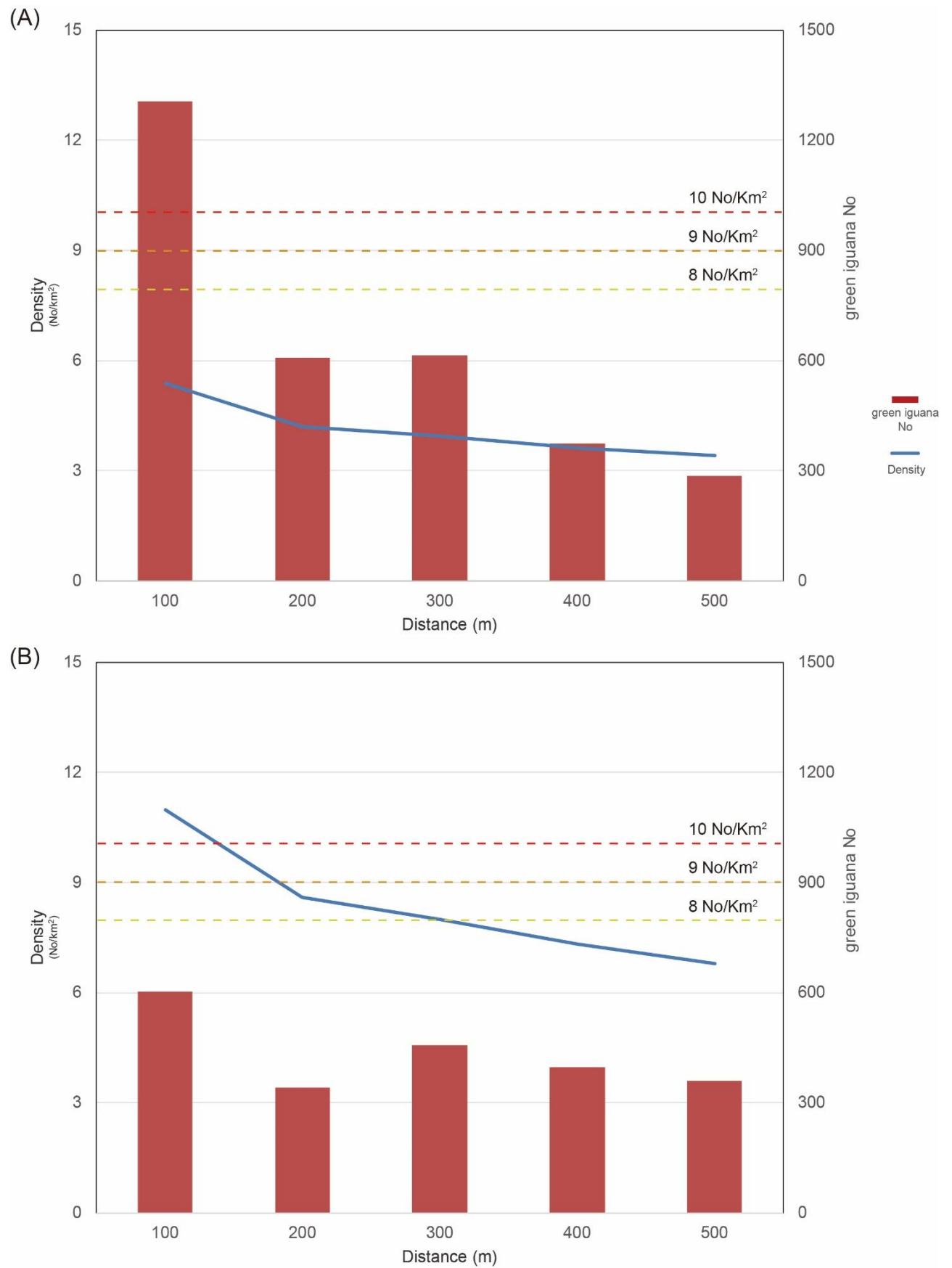
463 Figure 9 (A) and Table 2 present the road buffer analysis. The total number of green  
 464 iguanas increases with distance from the road, while density decreases. This increase  
 465 in total count results from the cumulative design, as each band includes the area of the  
 466 previous one, and does not reflect a distance effect. The decline in cumulative density  
 467 shows that outer bands are less densely reported than inner ones, indicating reports are  
 468 concentrated near roads. The number of green iguanas in each 100 m band is higher  
 469 than at the bridge endpoints because of the area difference. Besides, the density (blue  
 470 line) in the road buffer is much lower than at the bridge endpoints for the same  
 471 reason.

472 Figure 9 (B) and Table 3 display the results of the school buffer analysis. The total  
 473 number of green iguanas increases with distance from schools, while density  
 474 decreases in the same direction. Similar to the road buffer, the increase in total count  
 475 results from the cumulative construction of the bands and does not indicate a distance

effect. The number of green iguanas in each 100 m band is comparable to that in the road buffer but remains higher than at the bridge endpoints due to area differences. The density (blue line) in the school buffer is also lower than at the bridge endpoints for the same reason. The innermost 100 m band exhibits the highest cumulative density among the five school bands, with density declining in the outer bands.

Table 3 School buffer results

| School buffer<br>(m) | School buffer band<br>area (km <sup>2</sup> ) | Green iguanas<br>(No) | %   | Density<br>( No/km <sup>2</sup> ) |
|----------------------|-----------------------------------------------|-----------------------|-----|-----------------------------------|
| 100                  | 60.1                                          | 603                   | 15% | 11.0                              |
| 200                  | 110.0                                         | 945                   | 23% | 8.6                               |
| 300                  | 175.4                                         | 1401                  | 35% | 8.0                               |
| 400                  | 245.5                                         | 1797                  | 44% | 7.3                               |
| 500                  | 317.7                                         | 2156                  | 53% | 6.8                               |



483

484 Fig. 9 The sighting report density and the green iguanas no in each 100 m band from

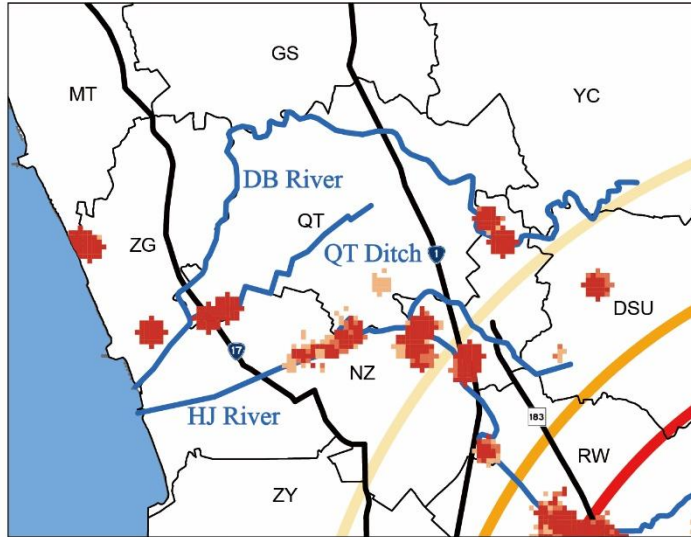
(A) road and (B) school buffer analysis

### 3.5. Spatial characteristics of the green iguana hotspots

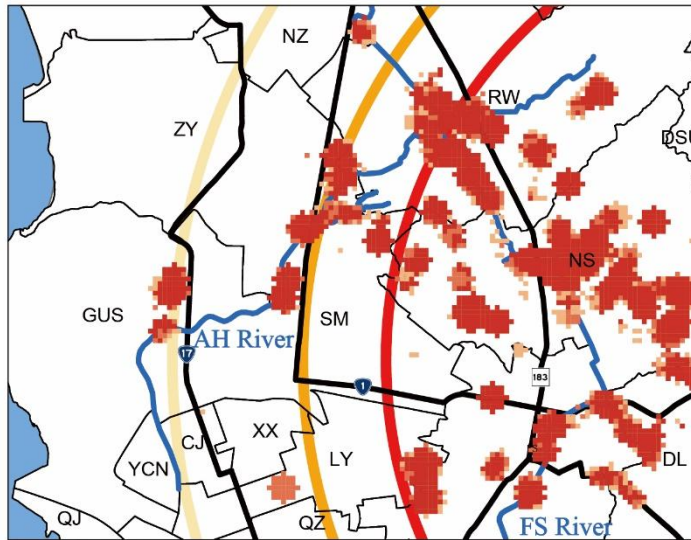
The analysis of hotspot spatial characteristics revealed two major patterns: the distance effects of bridge endpoints, roads, and schools. Hotspots were more concentrated near roads and schools, and the two bridges likely serve as primary routes for green iguana invasion from Pingtung County. Secondly, some green iguanas have already established many hotspots within 9,250 meters of the two bridge ends, as well as in the northwestern part of Kaohsiung City, specifically the JD and HN districts. This distribution suggests that green iguanas are undergoing landscape spread (IV), characterized by dense populations within 9,750 meters of the bridge endpoints, followed by outward expansion. A green iguana density of 10 individuals per square kilometer is defined as landscape spreading (IV). Three sites demonstrate the progression from landscape spreading to establishment (III) (see Fig. 11), and subsequently to outward colonization (II).

Beyond approximately 9,750 meters, hotspots were less dense and mainly located along river channels, canals, and ditches. Three areas were identified (Fig. 11): Zone 2, along the QT Ditch, DB River, and HJ River in the north (A); Zone 3, along the AH River in the center (B); and Zone 4, along the FS River and QZ Canal in the south (C). This pattern is similar to the association with canals and ditches observed in Florida populations (Meshaka et al. 2004) and aligns with findings from urban Geneva, where many urban waterbodies supported alien aquatic taxa, and hotspots were concentrated in urban areas (Oertli et al. 2018). However, we did not conduct a formal distance analysis for waterways, so this comparison is qualitative. Please refer to Fig. 3 for the locations of Zones 2, 3, and 4.

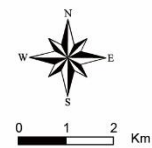
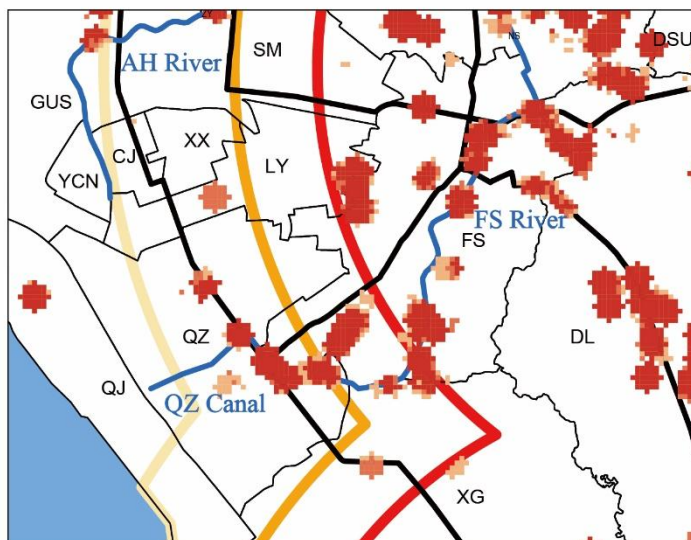
(A)  
Zone 2



(B)  
Zone 3



(C)  
Zone 4



#### Legend

- Hot Spot with 90% Confidence
- Hot Spot with 95% Confidence
- Hot Spot with 99% Confidence
- 8 No/Km<sup>2</sup>
- 9 No/Km<sup>2</sup>
- 10 No/Km<sup>2</sup>
- Major road
- waterway
- District

510

511 Fig. 10 The three zones that green iguanas expand from the landscape spread outward

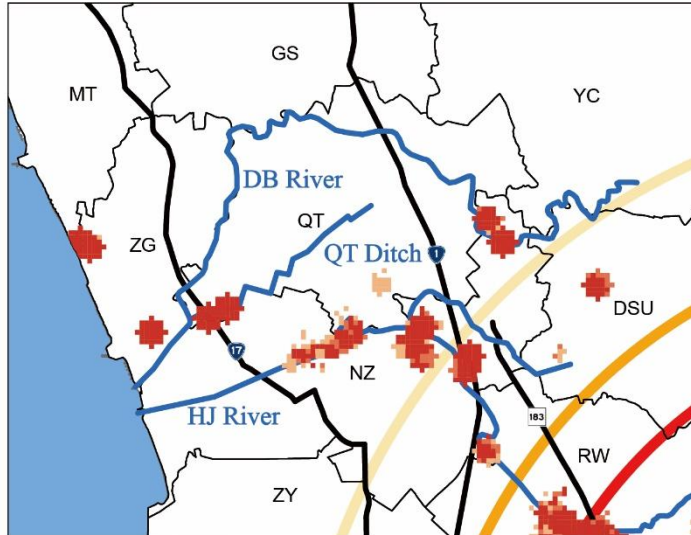
In the northwestern part of Kaohsiung City, the green iguana hotspots are located close to major roads, as well as to the bridges connecting Kaohsiung City with Tainan City, including Route 17 (ER Bridge), Route 17A (ND Bridge), and Route 1 (ECX Bridge), which could be possible conduits of green iguana expansion from Kaohsiung City to Tainan City to the north (Fig. 10). It also implies that the invasion of green iguanas into Tainan City could replicate the scenario that green iguanas are coming from Pingtung County and extend to Kaohsiung City. We choose these areas as high priority for confirmatory surveys in the near future. Their proximity to the northbound road and bridge network means that, if the species extends its range northward, these are locations where early detection would be most valuable. In 2025, FNCA has recorded the removal of 62,608 green iguanas, which is about 15.5 times the 4,041 individuals reported to the Kaohsiung City 1999 call center in Kaohsiung City (see Fig. 2). The Removal efforts are spatially and operationally selective, focusing on accessible and known locations.

Local teams pick random places and easy targets, encouraged by the FNCA green iguana removal reward system to remove as many as possible. In 2025, FNCA reported that 84% of removals were of iguanas less than 30 cm long from snout to vent, showing most were young and easy to catch. This implies the program may be less effective at preventing the green iguana population from increasing by removing fully grown adults, which could be a potential problem (FNCA 2026). Focusing removal efforts on areas where iguanas are often seen and aiming at adult green iguanas would improve invasive species control methods. Therefore, the removal efforts are influenced by size and location; the ratio of removals to reports does not show actual detection or removal rates. Also, placing hotspots over village boundaries helps us find villages with the highest green iguana populations. This location data can help hunters focus their work better. Villages with the most iguanas should be the

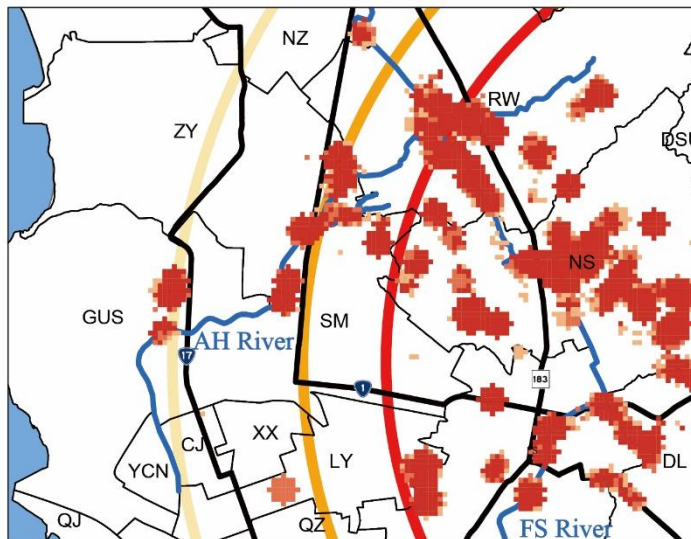
538 first priority for Kaohsiung City and green iguana hunters to get better results. It is a  
539 main contribution by this study benefited from the VGI collected by the Kaohsiung  
540 City 1999 call center and the efforts of the residents.

541 Areas with low green iguana numbers are mainly outside the 15 km radius of the two  
542 bridge endpoints and in northern Kaohsiung City. In contrast, the northwestern areas  
543 are green iguana hotspots (see Fig. 4 and 6). This spatial pattern may reflect both a  
544 lower overall population and fewer sightings in regions with fewer iguanas. Most  
545 hotspots in northwestern Kaohsiung City are near major roads leading to bridges that  
546 connect Kaohsiung City and Tainan City. This suggests that green iguana migration  
547 from Kaohsiung City to Tainan City may follow the same routes as migration from  
548 Pingtung County to Kaohsiung City via the KP and SY Bridges. If this is accurate, the  
549 most effective way to prevent further migration may be to block northward movement  
550 across the three bridges and increase government removal efforts in northwestern  
551 Kaohsiung City.

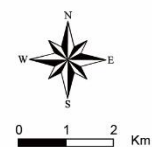
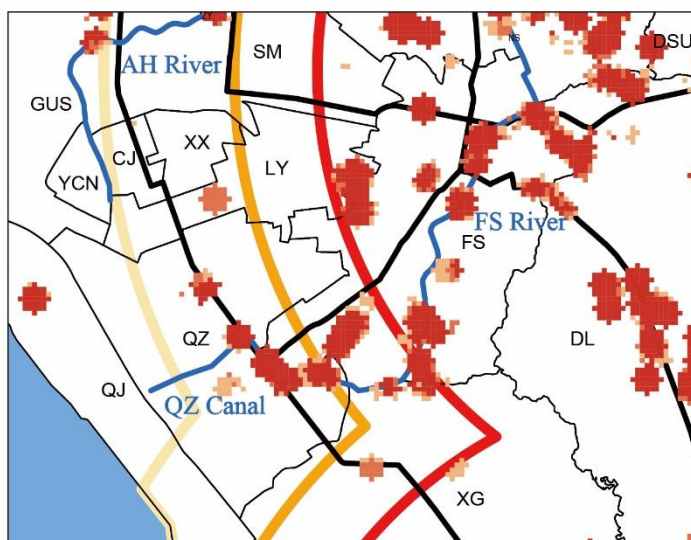
(A)  
Zone 2



(B)  
Zone 3



(C)  
Zone 4



#### Legend

- Hot Spot with 90% Confidence
- Hot Spot with 95% Confidence
- Hot Spot with 99% Confidence
- 8 No/Km<sup>2</sup>
- 9 No/Km<sup>2</sup>
- 10 No/Km<sup>2</sup>
- Major road
- waterway
- District

552

553 Fig. 10 The three zones that green iguanas expand from the landscape spread outward

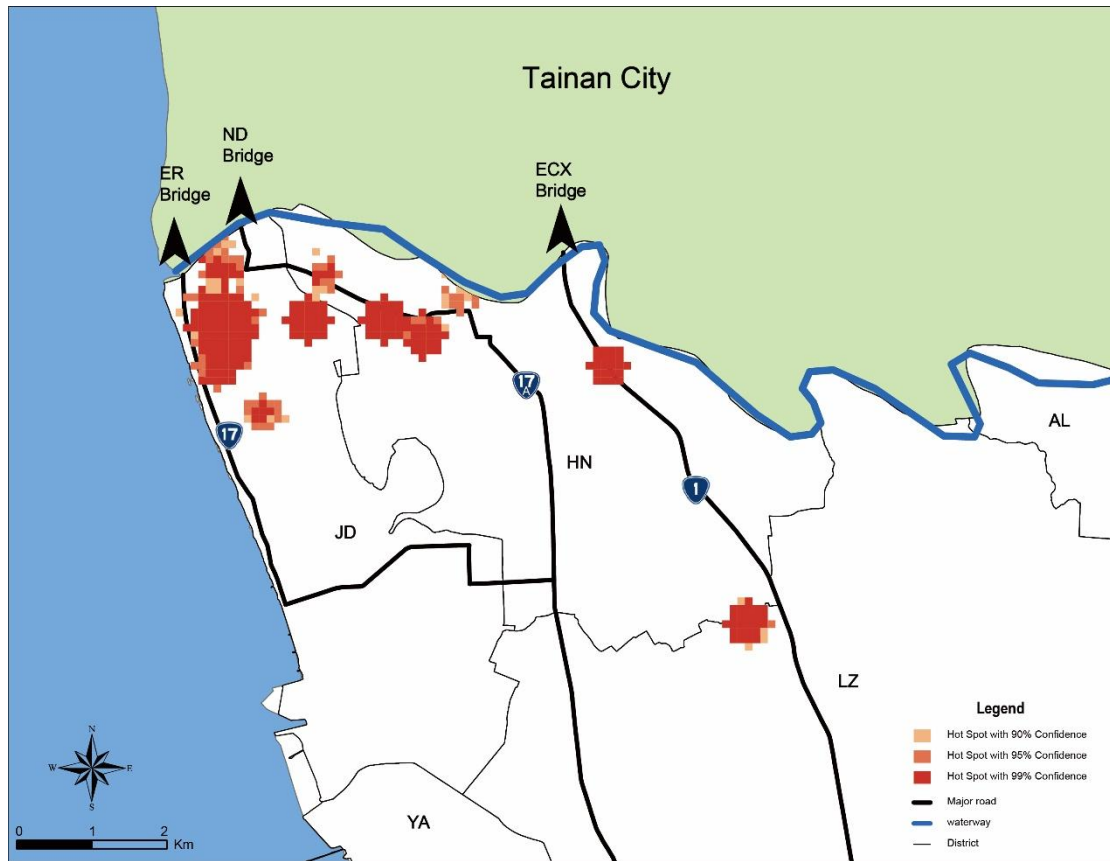


Fig. 11 The hotspots of green iguanas in northwestern Kaohsiung City and possible expansion route to Tainan City.

#### 4. Conclusions

In our study, the green iguana sightings by residents reported to the Kaohsiung City 1999 call center in 2025 were converted to TWD 97 Datum coordinate, and then analyzed using Getis-Ord GI\* and buffer analysis to identify spatial hotspots. The results show that hotspots were concentrated in the central and southern districts, with a secondary cluster in the northwest. There are many hotspots around the endpoints of the two bridges connecting Pingtung County and Kaohsiung City. Density decreases outward, falling below 10 individuals per km<sup>2</sup> at approximately 9.75 km, which marks the boundary between landscape spread (IV) and establishment (III). Beyond this distance, most remaining hotspots are along river channels and drainage ditches.

Hotspots in the northwestern JD and HN districts may indicate the frontier of green iguana expansion toward Tainan City via adjacent northbound roads and bridges, possibly reflecting earlier migration from Pingtung County to Kaohsiung City.

Our study shows that green iguana sighting reports collected by the Kaohsiung City 1999 call center are a significant yet underutilized source of VGI. These reports can be converted into valuable spatial data at low cost for detailed analysis. Participation is simple, requiring only a phone call or webpage submission. This approach also engages contributors not included in application-based datasets, making it a valuable complement to current app-based reporting systems. The hotspot information from the Getis-Ord GI\* and buffer analyses in this study could be used to form effective IAS control strategies in urban ecosystems.

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587

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590

591 Reference

592

- 593 Auguste RJ (2020) Using Citizen Science to Rapidly Determine the Distribution of  
594 Exploited Green Iguanas (*Iguana iguana*) across Urban Areas in Trinidad and  
595 Tobago. *Rept Amph* 27 (3), 419-421.  
596 <https://doi.org/10.17161/randa.v27i3.14859>
- 597 Baics G, Meisterlin L (2016) Zoning Before Zoning: Land Use and Density in Mid-  
598 Nineteenth-Century New York City. *Ann Am Assoc Geogr* 106, 1152–1175.  
599 <https://doi.org/10.1080/24694452.2016.1177442>
- 600 Bernery C, Marino C, Bellard C (2023) Relative importance of exotic species traits in  
601 determining invasiveness across levels of establishment: Example of  
602 freshwater fish. *Funct Ecol* 37, 2358–2370. [https://doi.org/10.1111/1365-](https://doi.org/10.1111/1365-2435.14393)  
603 [2435.14393](https://doi.org/10.1111/1365-2435.14393)
- 604 Bradley BA, Beaury EM, Gallardo B, Ibáñez I, Jarnevich C, Morelli TL, Sofaer HR, Sorte  
605 CJB, Vilà M (2024) Observed and Potential Range Shifts of Native and  
606 Nonnative Species with Climate Change. *Annu Rev Ecol Evol Syst* 55, 23-40.  
607 <https://doi.org/10.1146/annurev-ecolsys-102722-013135>
- 608 Choi HS, Sohn SY, Yeom HJ (2018) Technological composition of US metropolitan  
609 statistical areas with high-impact patents. *Technol Forecast Soc Change* 134,  
610 72-83. <https://doi.org/10.1016/j.techfore.2018.05.013>
- 611 Chuaynkern C, Khajitmathee N, Rongchapho P, Sribandit P, Phochayavanich R,  
612 Chuaynkern Y (2025) Distribution and Habitat Suitability of the Introduced  
613 *Iguana iguana* (Linnaeus, 1758) in Northeastern Thailand. *Ecol Montenegrina*  
614 88, 186-197. <https://doi.org/10.37828/em.2025.88.12>

615 Claunch NM, Jones PM, Khazan ES, Kluever BM (2025) State of knowledge for  
 616 invasive green iguanas in Florida reveals negative impacts and pervasive  
 617 research needs. *Front Amphib Reptile Sci*.  
 618 <https://doi.org/10.3389/famrs.2025.1529065>  
 619 Cordero S, Gálvez F, Fontúrbel FE (2023) Ecological Impacts of Exotic Species on  
 620 Native Seed Dispersal Systems: A Systematic Review. *Plants* 12, 261.  
 621 <https://doi.org/10.3390/plants12020261>  
 622 D'Antonio CM, Hobbie SE. (2005). Plant species effects on ecosystem processes. In D.  
 623 F. Sax, J. J. Stachowicz & S. D. Gaines (Eds.), *Species invasions: insights from*  
 624 *ecology, evolution and biogeography* (pp. 65–84). Sinauer Associates, MA,  
 625 USA.  
 626 Davis K, Chesson P, Harrison S, Inouye BD, Melbourne BA, Rice KJ (2005) Spatial  
 627 heterogeneity explains the scale dependence of the native-exotic diversity  
 628 relationship. *Ecology* 86 (6), 1602–1610. DOI 10.1890/04-1196  
 629 DiTomaso JM (2000) Invasive weeds in rangelands. Species, impacts, and  
 630 management. *Weed Sci* 48, 255–265  
 631 Dukes JS, Mooney HA (1999) Does global change increase the success of biological  
 632 invaders? *TREE* 14 (4), 135-139  
 633 Dukes JS, Mooney HA (2004) Disruption of ecosystem processes in western North  
 634 America by invasive species. *Rev Chil Hist Nat* 77, 411–437  
 635 Elwood S, Goodchild MF, Sui DZ (2012) Researching volunteered geographic  
 636 information: Spatial data, geographic research, and new social practice. *Ann*  
 637 *Am Assoc Geogr* 102 (3), 571–590  
 638 Encarnação J, Teodósio MA, Morais P (2021) Citizen Science and Biological Invasions:  
 639 A Review. *Front Environ Sci*. <https://doi.org/10.3389/fenvs.2020.602980>  
 640 Fletcher RJ, Bullock JM, Graham LJ, Kortessis N, Watts K (2026) Resurrecting habitat  
 641 fragmentation as a process over time. *Trends Ecol Evol*.  
 642 <https://doi.org/10.1016/j.tree.2026.03.009>  
 643 FNCA. (2026). Green iguana removing special area. In (Vol. 2026). FNCA.  
 644 Fricke RM, Olden JD (2023) Technological innovations enhance invasive species  
 645 management in the anthropocene. *Biosci* 73 (4).  
 646 <https://doi.org/10.1093/biosci/biad018>  
 647 Gallardo B, Clavero M, Sánchez MI, Vilà M (2016) Global ecological impacts of  
 648 invasive species in aquatic ecosystems. *Glob Change Biol* 22 (1), 151-163. doi:  
 649 10.1111/gcb.13004  
 650 Getis A, Ord JK (1992) The analysis of spatial association by use of distance statistics.  
 651 *Geogr Anal* 24, 189-206  
 652 Ghalhari GF, Roudbar AD (2018) An investigation on thermal patterns in Iran based

653 on spatial autocorrelation. *Theor Appl Climatol* 131, 189-206.  
 654 <https://doi.org/10.1007/s00704-016-2015-3>  
 655 Goodchild MF (2007) Citizens as sensors: The world of volunteered geographic  
 656 information. *GeoJ* 69 (4), 211–221  
 657 Hastings A, Cuddington K, Davies KF, Dugaw CJ, Elmendorf S, Freestone A, Harrison S,  
 658 Holland M, Lambrinos J, Malvadkar U, Melbourne BA, Moore K, Taylor C,  
 659 Thomson D (2005) The spatial spread of invasions: new developments in  
 660 theory and evidence. *Ecol Lett* 8, 91–101  
 661 Hellmann JJ, Byers JE, Bierwagen BG, Dukes JS (2008) Five Potential Consequences of  
 662 Climate Change for Invasive Species. *Conserv Biol* 22 (3), 534-543. DOI:  
 663 [10.1111/j.1523-1739.2008.00951.x](https://doi.org/10.1111/j.1523-1739.2008.00951.x)  
 664 Hengl T (2006) Finding the right pixel size. *Comput Geosci* 32, 1283–1298.  
 665 <https://doi.org/10.1016/j.cageo.2005.11.008>  
 666 Hobbs RJ. (2000). Land-use changes and invasions. In H. A. Mooney & R. J. Hobbs  
 667 (Eds.), *Invasive species in a changing world* (pp. 55-64). Island Press,  
 668 Washington, DC.  
 669 Holway DA (1998) Factors governing rate of invasion: a natural experiment using  
 670 Argentine ants. *Oecologia* 115, 206-212  
 671 Hu Y, Tian G, Chen Q, Xu E, Dong N (2026) Impact of urban habitat fragmentation on  
 672 habitat quality: A perspective of multi-scale grids analysis. *J Environ Manage*  
 673 397, 128350. <https://doi.org/10.1016/j.jenvman.2025.128350>  
 674 Jen CH, Lei HF, Chyi SJ, Hsueh MY. (2016). The Impact of Typhoon Morakot in 2009 on  
 675 Landslides, Debris Flows and Population in the Chishan River Catchment,  
 676 Taiwan. In M. Meadows & J. Lin (Eds.), *Geomorphology and Society*. Springer,  
 677 Tokyo.  
 678 Jeong S, Jung J, Kim S, Hong S, Sohn HG, Heo J (2014) Buffering-based approach to  
 679 fluctuation analysis of glacier calving fronts using LANDSAT-7 ETM+, with a  
 680 case study of Jakobshavn Isbræ. *Comput Geosci* 64, 115-125.  
 681 <https://doi.org/10.1016/j.cageo.2013.12.001>  
 682 Kacaw L, Tsai BW (2023) The Application of PPGIS to Telecoupling Research: A Case  
 683 Study of the Agricultural Landscape Transformation in an Indigenous Village in  
 684 Taiwan. *Sustain* 15, 1577. <https://doi.org/10.3390/su15021577>  
 685 Kang W, Kim GW, Park Y (2022) Habitat suitability and connectivity modeling predict  
 686 genetic population structure and priority control areas for invasive nutria  
 687 (*Myocastor coypus*) in a temperate river basin. *PLoS One* 17 (12), e0279082.  
 688 <https://doi.org/10.1371/journal.pone.0279082>  
 689 Knapp CR, Grant TD, Pasachnik SA, Angin B, Boman E, Brisbane J, Buckner SD,  
 690 Haakonsson JE, Harlow PS, Mukhida F, Thomas-Moko N, van den Burg MP,

691 Wasilewski JA (2020) The global need to address threats from invasive alien  
 692 iguanas. *Animal Conserv* 24 (5), 717-719.  
 693 <https://doi.org/10.1111/acv.12660>Digital  
 694 Larson ER, Graham BM, Achury R, Coon JJ, Daniels MK, Gambrell DK, Jonasen KL, King  
 695 GD, LaRacuenta N, Perrin-Stowe TI, Reed EM, Rice CJ, Ruzi SA, Thairu MW,  
 696 Wilson JC, Suarez AV (2020) From eDNA to citizen science: emerging tools for  
 697 the early detection of invasive species. *Front Ecol Environ* 18 (4), 194-202.  
 698 <https://doi.org/10.1002/fee.2162>  
 699 Lee SY, Ju HW, Chen TH (2012) Establishment of Feral Green Iguana (*Iguana iguana*)  
 700 Populations in Southern Taiwan: Evidences from Rescued and Wild-caught  
 701 Records. *Notes Newsl Wildl* 16, 2-10.  
 702 [http://dx.doi.org/10.6496/NOW.201203\\_16\(1\).0002](http://dx.doi.org/10.6496/NOW.201203_16(1).0002)  
 703 Lehtiniemi M, Outinen O, Puntilla-Dodd R (2020) Citizen science provides added value  
 704 in the monitoring for coastal non-indigenous species. *J Environ Manage* 267.  
 705 <https://doi.org/10.1016/j.jenvman.2020.110608>  
 706 Li X, Zhang L, Liang C (2010) A GIS-based buffer gradient analysis on spatiotemporal  
 707 dynamics of urban expansion in Shanghai and its major satellite cities.  
 708 *Procedia Environ Sci* 2, 1139-1156.  
 709 <https://doi.org/10.1016/j.proenv.2010.10.123>  
 710 Liao HC (2013) Spatial Accessibility to Pediatric Services in Taiwan. *J Public Adm* 44, 1-  
 711 39. [https://doi.org/10.30409/JPA.201303\\_\(44\).0001](https://doi.org/10.30409/JPA.201303_(44).0001)  
 712 Liebhold AM, Brockerhoff EG, Kalisz S, Nuñez MA, Wardle DA, Wingfield MJ (2017)  
 713 Biological invasions in forest ecosystems. *Biol Invasions* 19, 3437–3458. DOI  
 714 10.1007/s10530-017-1458-5  
 715 Lin Z, Chao L, Wu C, Hong W, Hong T, Hu X (2018) Spatial analysis of carbon storage  
 716 density of mid-subtropical forests using geostatistics: a case study in Jiangle  
 717 County, southeast China. *Acta Geochim* 37, 90-101.  
 718 <https://doi.org/10.1007/s11631-017-0160-8>  
 719 Liu H, Zhou Q (2005) Developing urban growth predictions from spatial indicators  
 720 based on multi-temporal images. *Comput Environ Urban Syst* 29, 580-594.  
 721 <https://doi.org/10.1016/j.compenvurbnsys.2005.01.004>  
 722 Lu P, Bai S, Tofani V, Casagli N (2019) Landslides detection through optimized hot spot  
 723 analysis on persistent scatterers and distributed scatterers. *ISPRS J*  
 724 *Photogramm Remote Sens* 156, 147-159.  
 725 <https://doi.org/10.1016/j.isprsjprs.2019.08.004>  
 726 Martoglio J, Cornier B, Monty A, Mahy G (2025) Urban brownfields and their  
 727 potential for nature conservation: what citizen science tells us? *Urban Ecosyst*  
 728 28, 182. <https://doi.org/10.1007/s11252-025-01791-7>

729 Meshaka WE, Bartlett BD, Smith HT (2004) Colonization success by green iguanas in  
730 Florida. *Iguana* 11, 154-161

731 Milardi M, Gavioli A, Soininen J, Castaldelli G (2019) Exotic species invasions  
732 undermine regional functional diversity of freshwater fish. *Sci Rep* 9, 17921.  
733 <https://doi.org/10.1038/s41598-019-54210-1>

734 Mo E, Mo M (2023) An assessment of potential vertebrate predators of the non-  
735 native Green Iguana (*Iguana iguana*) in Hong Kong. *Rept Amph* 30 (1).  
736 <https://doi.org/10.17161/randa.v30i1.18460>

737 Mo M, Mo E (2022) Frequency and Distribution of Reports of Free-living Green  
738 Iguanas (*Iguana iguana*) in Hong Kong. *Curr Herpetol* 42 (2), 149-162.  
739 <https://doi.org/10.5358/hsj.41.149>

740 Mu C, Wang J (2026) Predicting the Potential Spread of Invasive Reptiles From Hong  
741 Kong and Taiwan to Other Regions of China. *Ecol Evol* 16, e72947.  
742 <https://doi.org/10.1002/ece3.72947>

743 Oertli B, Boissezon A, Rosset V, Ilg C (2018) Alien aquatic plants in wetlands of a large  
744 European city (Geneva, Switzerland): from diagnosis to risk assessment.  
745 *Urban Ecosyst* 21, 245–261. <https://doi.org/10.1007/s11252-017-0719-5>

746 Pasachnik SA, Carreras De León R, Reynoso VH, Rupp E, León YM, Incháustegui SJ  
747 (2012) Green Iguana (*Iguana iguana*) in the Dominican Republic. *Rept Amph*  
748 19 (2), 132-134. <https://doi.org/10.17161/randa.v19i2.13895>

749 Pocock MJO, Adriaens T, Bertolino S, Eschen R, Essl F, Hulme PE, Jeschke JM, Roy HE,  
750 Teixeira H, de Groot M (2024) Citizen science is a vital partnership for invasive  
751 alien species management and research. *iScience* 27 (1).  
752 <https://doi.org/10.1016/j.isci.2023.108623>

753 Ren H, Shanga Y, Zhang S (2020) Measuring the spatiotemporal variations of  
754 vegetation net primary productivity in Inner Mongolia using spatial  
755 autocorrelation. *Ecol Indic* 112, 106108.  
756 <https://doi.org/10.1016/j.ecolind.2020.106108>

757 Roy HE, Pauchard A, Stoett P, Renard Truong T, Bacher S, Galil BS, Hulme PE, Ikeda T,  
758 Sankaran K, McGeoch MA, Meyerson LA, Nuñez MA, Ordonez A, Rahlao SJ,  
759 Schwindt E, Seebens H, Sheppard AW, Vandvik V. (2023). IPBES Invasive Alien  
760 Species Assessment: Summary for Policymakers. In (3 ed.), Bonn, Germany.

761 Saqib S, Ullah F, Omollo WO, Liu Y, Tao HY, Zaman W, Temur A, Liu B, Lai Y, Chen Z,  
762 Fang YP, Dong HJ, Wang WY, Zhao XM, Xiong YC (2025) Identifying hotspots  
763 and climate drivers of alien plant species for conservation prioritization across  
764 the Pan-Himalaya. *Biol Conserv* 302, 110994

765 Serva D, Cittadino V, Bernabò I, Biondi M, Iannella M (2024) Habitat suitability and  
766 connectivity modelling predict a latitudinal-driven expansion in the

767 Mediterranean basin for a historically introduced reptile. *Eur J Wildl Res* 70,  
768 27. <https://doi.org/10.1007/s10344-024-01780-9>

769 Theoharides KA, Dukes JS (2007) Plant invasion across space and time: factors  
770 affecting nonindigenous species success during four stages of invasion. *New*  
771 *Phytol* 176, 256–273. doi: 10.1111/j.1469-8137.2007.02207.x

772 Thomas ZA, Turney CSM, Palmer JG, Lloyd S, Klaricich JNL, Hogg A (2018) Extending  
773 the observational record to provide new insights into invasive alien species in  
774 a coastal dune environment of New Zealand. *Appl Geogr* 98, 100-109.  
775 <https://doi.org/10.1016/j.apgeog.2018.07.006>

776 van den Burg MP, Van Belleghem SM, De Jesús Villanueva CN (2020) The continuing  
777 march of Common Green Iguanas: arrival on mainland Asia. *J Nat Conserv* 57.  
778 <https://doi.org/10.1016/j.jnc.2020.125888>

779 Vilà M, Espinar JL, Hejda M, Hulme PE, Jarošík V, Maron JL, Pergl J, Schaffner U, Sun Y,  
780 Pyšek P (2011) Ecological impacts of invasive alien plants: a meta-analysis of  
781 their effects on species, communities and ecosystems. *Ecol Lett* 14 (7).  
782 <https://doi.org/10.1111/j.1461-0248.2011.01628.x>

783 Wang T, H., Lin J, C. (2007) Change of Pattern and Expansion in the Developed Area of  
784 Mid-Upper Course of Keelung River Catchment. *J Geogr Sci* 49, 23-38.  
785 <http://dx.doi.org/10.6161/jgs.2007.49.02>

786 Xiang WN (1996) GIS-based riparian buffer analysis: injecting geographic information  
787 into landscape planning. *Landsc Urban Plan* 34 (1-10).  
788 [https://doi.org/10.1016/0169-2046\(95\)00206-5](https://doi.org/10.1016/0169-2046(95)00206-5)

789 Xie H, Wen J, Chen Q, Wu Q (2021) Evaluating the landscape ecological risk based on  
790 GIS: A case-study in the Poyang Lake region of China. *Land Degrad Dev* 32,  
791 2762-2774. <https://doi.org/10.1002/ldr.3951>

792 Yuan R, Zhang N, Zhang Q (2024) The impact of habitat loss and fragmentation on  
793 biodiversity in global protected areas. *Sci Total Environ* 931, 173004.  
794 <https://doi.org/10.1016/j.scitotenv.2024.173004>

795 Zhang H, Song J, Zhao H, Li M, Han W (2021) Predicting the Distribution of the  
796 Invasive Species *Leptocybe invasa*: Combining MaxEnt and Geodetector  
797 Models. *Insects* 12, 92. <https://doi.org/10.3390/insects12020092>

798

799