REPTILES & AMPHIBIANS

Using the iNaturalist Application to Identify Reports of Green Iguanas (*Iguana iguana*) from Mainland US States other than Florida

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Abstract.—Presently, the only established populations of invasive Green Iguanas (*Iguana iguana*) on the mainland USA occur in Florida. We examined observation data from the online citizen-science application iNaturalist to determine the frequency of reports of free-living Green Iguanas in Florida and identify where iguanas have been reported in other parts of the mainland USA. Observations from Florida comprised 99.6% of the 5,929 verified Green Iguana observations from the mainland USA. The largest proportion were observations from 2016 to 2021, corresponding with an increasing number of application users contributing to the dataset during this period. The majority of Green Iguana observations from latitudes of 27–41°N in 11 other mainland states were from California. However, we noted no obvious concentrations of sightings to indicate the presence of established populations in any of those 11 states. The majority of observations from outside Florida were adults and were most frequently reported from suburbia and urban parks, suggesting that released or escaped pets were the likely source. More than one third of iguanas reported outside Florida were near water, which is worrisome because iguanas are known to use waterways to disperse. This study clearly demonstrates the value of public participation in assembling sighting records of non-native animals, and we encourage engagement campaigns that leverage reports from members of the public to achieve early detections of potentially invasive species.

An immense interest in reptiles as exotic pets over the last century has grown into a billion-dollar industry in the USA alone (Collis and Fenili 2011); however, the private keeping of reptiles has resulted in some challenges for wildlife conservation. In many parts of the world, populations of different reptilian species have become established outside their natural ranges, and a large proportion of these can be traced to the deliberate or unintentional liberation of captive animals (Kraus 2009; Krysko et al. 2011; Capinha et al. 2017; Lockwood et al. 2019). To mitigate establishment risks, some jurisdictions have opted to ban the importation and keeping of exotic reptiles by members of the public and have restricted private keeping of reptiles to native species. However, the private keeping of exotic reptiles persists to a large extent even within jurisdictions where such legislation exists (e.g., McFadden et al. 2017).

The Green Iguana (*Iguana iguana*), a large lizard native to the Neotropics, has long been popular in captivity (Mitchell and Shane 2000). The legal international trade in juvenile Green Iguanas was estimated at 4.5 million individuals between 2001 and 2008 alone (Stephen et al. 2011). However, some evidence is suggestive of a reduction in the trade in Green Iguanas over the last decade in favor of other reptilian species (Valdez 2021). Nevertheless, invasive populations of the Green Iguana have been confirmed on islands of the West Indies outside of their natural range, the USA including Hawaii, Fiji, Taiwan, and Japan (Thomas et al. 2011; Knapp et al. 2021; Perry et al. 2021), with sporadic reports in Singapore, Thailand, and Hong Kong indicating that established populations in those countries may be looming (van den Burg et al. 2020a). Liberated captive animals were a primary mechanism in the majority of these invasions (De Jesús Villanueva et al. 2021). In particular, in Buddhism, releasing captive animals is believed to build spiritual merit (Agoramoorthy and Hsu 2005; Ng and Lim 2010). The invasions in the West Indies are, however, also traced to stowaways in construction and horticultural materials (van den Burg et al. 2020b; Perry et al. 2021) and iguanas surviving over-water dispersal on floating debris (Censky et al. 1998).

Green Iguanas in Florida are possibly the most studied invasions of this species (e.g., McKie et al. 2005; Smith et al. 2006, 2007; Meshaka et al. 2009; Campbell and Maple 2012). At this time, the only confirmed breeding populations of Green Iguanas on the mainland USA are in Florida (Fig. 1).

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Fig. 1. iNaturalist observations of Green Iguanas (*Iguana iguana*) from established populations in Florida comprised 99.6% (n = 5,905) of the verified observations from the mainland USA. This adult (left) and juvenile (right) were on Big Pine Key, Monroe County, Florida. Photographs by Robert Powell.

Although free-living individuals were first observed in Florida in the 1960s (King and Krakauer 1966), evidence of self-sustaining populations came only decades later (Meshaka et al. 2004). During the 1990s, populations in southern Florida expanded exponentially (Krysko et al. 2007), likely taking advantage of plentiful food and few predators (Townsend et al. 2003). Today, iguanas are found in most of Florida's coastal areas, reaching the highest densities in frost-free areas (Meshaka et al. 2004). In one case, 824 iguanas were removed from a state park in 2003, with no signs of a subsequent population decline (Krysko et al. 2007). Adults and hatchlings have been reported in Cameron County in southern Texas, but no breeding populations had been confirmed by 2004 (Meshaka et al. 2004). This information highlights the benefits of invasive species detection by members of the public reporting their observations to scientists and government officials.

Citizen science involves members of the public participating and collaborating in gathering scientific information (Gallo and Waitt 2011; Larson et al. 2020). With the globalization of the internet, online citizen-science applications provide a stage for sharing individual observations (e.g., Aristeidou et al. 2021; Unger et al. 2021), which have been useful for detecting species outside their natural range (e.g., Liebgold et al. 2019; Werenkraut et al. 2020). Complementary to this, mobile telephones are now equipped with cameras, which enable more people to record photographic evidence of unusual sightings (Graham et al. 2011). A number of research studies have leveraged citizen-science data for studying the distributions of species (e.g., Auguste 2020; Calzada Preston and Pruett-Jones 2021; Cull 2021).

In this study, we used observation data from the online citizen-science application iNaturalist to (1) determine the frequency of reports of free-living Green Iguanas in Florida, and (2) identify where Green Iguanas have been reported in other states of the mainland USA.

Methods

iNaturalist is a joint initiative between the California Academy of Sciences and the National Geographic Society (2021) that gathers crowdsourced spatiotemporal data on observations of organisms or evidence of their presence (e.g., tracks, nests, or sloughed skin) by means of registered application users uploading photographs from the field. The community of application users reviews uploaded photographs and contributes suggestions for identifying organisms to the lowest taxonomic rank possible. iNaturalist applies a data-quality assessment in which observations are classified as verifiable if the observation is dated, georeferenced, has photograph/s or audio recording/s, and is a free-living organism (not a captive animal or cultivated plant or fungus). Verified observations attain "research grade" status when a majority of at least three application users agree on the species identity.

On 8 December 2021, we performed a search in the iNaturalist application for verified observations from the mainland USA that were identified by application users as Green Iguanas or signs of this species' presence. We considered all research grade observations to have accurate species identification. For observations that were not research grade, we reviewed the photographs and removed any dubious observations from our dataset. We then used this dataset to examine the frequency of Green Iguana reports in Florida in conjunction with the numbers of contributing application users each year.

We investigated verified observations of Green Iguanas from other mainland states in greater detail. By reviewing photographs uploaded by application users, we categorized

Fig. 2. Types of land use: Wilderness (top left), remnant wetland (top right), urban park (bottom left), and suburbia (bottom right). Remnant wetlands are watercourses surrounded by human settlement but larger than an urban park.

an iguana as an adult if the jowl scale was visibly larger than the tympanum or a juvenile or hatchling if the jowl scale and tympanum were similar in size (Falcón et al. 2013); and subsequently examined the proportion of sightings of each age class. We did not attempt to distinguish adults and subadults due to the difficulty of differentiating them from photographs. When possible, we identified adult males by the proportionately larger heads and dewlaps (Dugan 1982). When available, we determined the type of land use (wilderness, remnant wetland, urban park, suburbia; Fig. 2) for each observation using geographic coordinates when recorded within an accuracy of less than 50 m, or alternatively by observing the land use apparent in photographs or descriptive notes provided by application users. We subsequently examined the frequency of observations in each type of land use. We also examined temporal metadata to determine the frequency of observations in different months of the year.

Results

As of 8 December 2021, iNaturalist users identified Green Iguanas or signs of their presence in 5,929 verified observations from the mainland USA, of which 5,910 were research grade. Of the 19 observations that were not research grade, we were able to confirm live Green Iguanas in at least three observations, whereas another four observations were of lizards that were difficult to accurately identify due to having been photographed at a distance. The remaining 12 observations that were not research grade were observations of egg clutches (n = 4), skeletal remains (n = 3), sloughed skin (n = 3), and footprints (n = 2) that application users believed to be from Green Iguanas.

Observations from established populations in Florida comprised 99.6% (n = 5,905) of the verified observations from the mainland USA. The largest proportion of these were observations from 2016 to 2021, during which between 225 and 1,943 verified observations accrued per annum, corresponding with an increasing number of application users contributing to the dataset in those years (Fig. 3). In contrast, fewer than 100 verified observations accrued annually between the earliest reported observation in 2000 and 2015. During this period, far fewer application users contributed observations than in more recent years.

Twenty-four verified Green Iguana observations from 11 other states (Table 1) at latitudes of 27– 41°N included the most northerly observations in Illinois and Pennsylvania (Fig. 4). All observations were of live iguanas except for one dead animal reported during early winter from Topanga State Park, California. A large proportion of observations were from California (Fig. 5), four in Orange County, four in Los Angeles County, and two in Ventura County. Californian reports were dispersed within an area of approximately 3,622 km^2, with the closest reports within about 5 km of each other (Fig. 6). The closest report to the Florida populations was a single report of a hatchling iguana in a suburban area of Mississippi, 640 km northwest of the nearest Florida population. The remaining reports were three observations in Texas, one in Arizona, one in Colorado, one

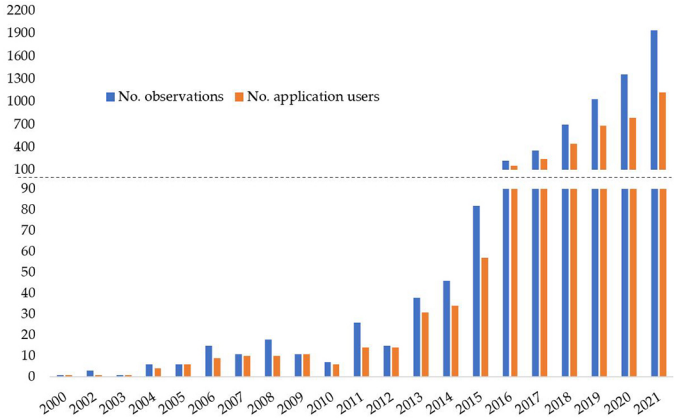

Fig. 3. Annual frequency of verified Green Iguana (*Iguana iguana*) observations in Florida (including observations of indirect signs of the species) and the number of application users contributing these data each year.

Fig. 4. Locations of verified Green Iguana (*Iguana iguana*) observations in 11 U.S. states. Florida is shaded in red.

Table 1. Chronology of records of free-living Green Iguanas (*Iguana iguana*) from mainland US states other than Florida.

	Date of Observation	Description	Location
1	9 July 2014	Live, adult male	Boulder, Colorado
2	17 August 2014	Live, adult male	Mission Viejo, California
3	28 October 2015	Live, adult male	Point Mugu State Park, California
4	9 September 2016	Live, hatchling/juvenile	Biloxi, Mississippi
5	2 December 2016	Dead, adult	Topanga, California
6	14 October 2017	Live, adult	Fullerton, California
7	9 September 2019	Live, adult	Laguna Woods, California
8	17 September 2019	Live, adult	Pioneer Woods, Illinois
9	1 November 2019	Live, juvenile	La Cañada Flintridge, California
10	19 August 2020	Live, adult	Garland, Texas
11	25 August 2020	Live, adult	Lillington, North Carolina
12	28 October 2020	Live, adult male	Tucson, Arizona
13	14 November 2020	Live, adult male	Durham, North Carolina
14	29 November 2020	Live, adult male	Richland County, South Carolina
15	4 December 2020	Live, adult male	El Paso, Texas
16	April 2021 (exact date not recorded)	Live, adult	Norfolk County, Virginia
17	26 April 2021	Live, adult male	Newport Beach, California
18	28 May 2021	Live, juvenile	Philadelphia, Pennsylvania
19	27 July 2021	Live, hatchling/juvenile	Germantown, Pennsylvania
20	11 September 2021	Live, adult	Potomac, Maryland
21	22 September 2021	Live, juvenile	Laredo, Texas
22	October 2021 (exact date not recorded)	Live, adult	Los Angeles County, California
23	18 October 2021	Live, adult male	Santa Paula, California
24	4 December 2021	Live, adult	Long Beach, California

in Maryland, one in Virginia, two in North Carolina, and one in South Carolina.

The majority of the 24 observations outside of the Florida populations were adults (n = 19), nine of which were identifiable as males (Fig. 7). The remaining five iguanas were hatchlings or juveniles (Fig. 7). The majority of observations were made during summer and fall (Fig. 8). The most iguanas were observed in suburbia (n = 10), followed by urban parks (n = 6), wilderness (n = 4), and remnant wetlands (n = 2) (Fig. 9). Nine iguanas were near streams or bodies of water (Fig. 10).

Discussion

The establishment of non-native populations of Green Iguanas in numerous countries highlights the adaptability and invasiveness of this species (De Jesús Villanueva et al. 2021; Knapp et al. 2021). The discovery of free-living Green Iguanas in 11 mainland US states (excluding Florida) is therefore noteworthy. Currently, the relatively small number (24) of verified observations are scattered widely, lacking any obvious concentrations that might indicate the presence of established populations. The majority were in suburban or urban areas, suggesting that liberated or escaped stock from private collections is the most likely source of these animals (Perry et al. 2021). However, we cannot rule out a bias toward observations of iguanas in suburban and urban areas because such areas have regular human traffic and hence a greater likelihood of iguanas being noticed by an application user (Boakes et al. 2010). Despite past reports of adult and hatchling Green Iguanas in Cameron County, Texas (Meshaka et al. 2004), we found no Green Iguana observations in that region. The only observation in southern Texas was a juvenile in Laredo, approximately 250 km northwest of Cameron County.

Despite the currently low number of reported Green Iguanas outside of Florida, surveillance for new observations in the USA is worthwhile. During the 1960s, iguana sightings in Florida were also sporadic and the present populations materialized progressively after two to three decades (Krysko et al. 2007) and are today difficult to control (Townsend et al. 2003; Meshaka et al. 2007). This highlights the importance

Fig. 5. A subadult Green Iguana (*Iguana iguana*) recorded at Gilman Park, Fullerton, Orange County, California, on 14 October 2017. Photograph by Thomas A. Benson.

Fig. 6. Locations of verified Green Iguana (*Iguana iguana*) observations in California (red dots). Numbers indicate distances (km) between locations.

Fig. 7. An adult male Green Iguana (*Iguana iguana*) recorded in Point Mugu State Park, Ventura County, California, on 28 October 2015 (left), and a juvenile recorded in suburban Germantown, Philadelphia County, Pennsylvania, on 27 July 2021 (right). Photographs by Jeff Stauffer (left) and David Milson (right).

of gathering information useful for wildlife managers to investigate early incursions and initiate pre-emptive interventions.

We found that more than a third of the 24 verified observations outside of the Florida populations were in localities adjacent to streams or bodies of water. Green Iguanas frequently are associated with water, which is a key predictor of their presence in their natural range (Falcón et al. 2012). The proportion of reports near watercourses could reflect people discarding iguanas near water or a pattern in which iguanas liberated near water survive at higher rates than those released in other situations. Regardless, the proportion of iguana observations near water is worrisome given that Green Iguanas are known to use waterways to disperse (Rivero 1998; Meshaka et al. 2004).

This study further demonstrates that citizen-science observations of non-native animals can assist in the early detection of potentially invasive species (e.g., Mo 2019). Many examples of past invasions of Green Iguanas have been characterized by local residents regularly encountering individuals for extensive periods of time before that knowledge reached scientists and government officials (e.g., Johnson 2020). Citizen-science applications such as iNaturalist attempt to provide a conduit between members of the public and the scientific and government sectors (Aristeidou et al. 2021). Thus, this model of collecting opportunistic observations from a broad group of contributors provides a valuable tool for wildlife managers seeking to address biosecurity incursions before invasive populations can become established. Citizen science is particularly effective for the surveillance of Green Iguanas in the USA due to the absence of other iguanas, with the notable exception of invasive populations of spiny-tailed iguanas (*Ctenosaura* spp.) in Florida (Krysko et al. 2003; Townsend et al. 2003), largely circumventing the challenges of morphologically similar species being misidentified by citizen scientists (Vantieghem et al. 2017). We therefore encourage engagement campaigns that motivate members of the public to report observations of non-native animals, especially species, such as the Green

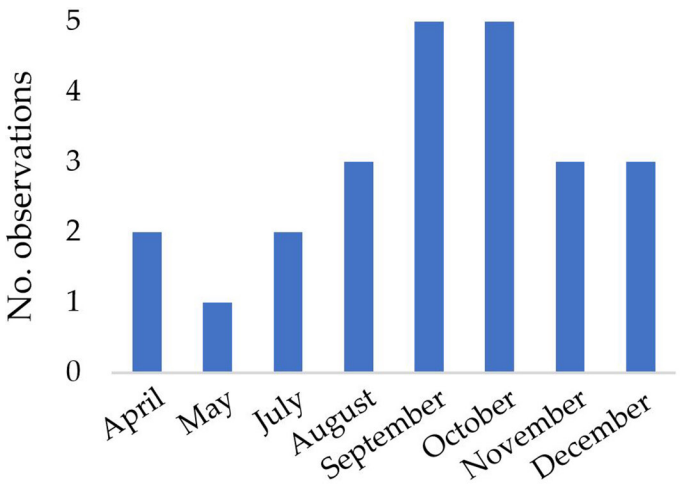

Fig. 8. Monthly frequency of verified Green Iguana (*Iguana iguana*) observations from mainland US states other than Florida.

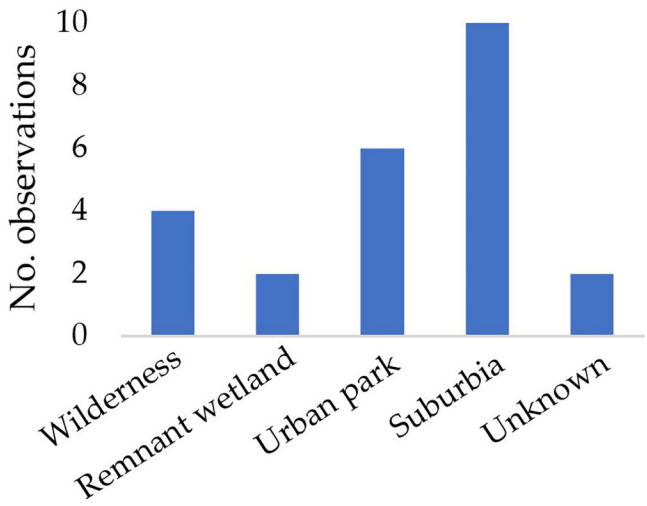

Fig. 9. Frequency of different types of land use in verified Green Iguana (*Iguana iguana*) observations from mainland US states other than Florida.

Fig. 10. An adult Green Iguana (*Iguana iguana*) recorded at a creek in Pioneer Woods, Cook County, Illinois, on 17 September 2019 (left), and an adult male recorded at the Patterson Place constructed wetland, Durham County, North Carolina, on 14 November 2020 (right). Photographs by Mark Kluge (left) and Will Bennett (right).

Iguana, with documented histories of establishing invasive populations.

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