Establishment of brown anoles (*Anolis sagrei*) across a southern California county and their interactions with a native lizard species (#43887)

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Establishment of brown anoles (*Anolis sagrei*) across a southern California county and their interactions with a native lizard species

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The brown anole, *Anolis sagrei,* is a native species to the Caribbean, however, *A. sagrei* has invaded multiple parts of the United States, including Florida, Louisiana, Hawai'i, and more recently, California. The biological impacts of *A. sagrei* invading California, are currently unknown. However, evidence from the invasion in Taiwan shows that they spread quickly and when immediate action is not taken, eradication stops being a viable option. In Orange County, California, five urban sites, each less than 100 ha, were surveyed for an average of 49.2 min. Approximately 200 *A. sagrei* were seen and verified across all survey sites. The paucity of native lizards encountered during the surveys within these sites suggest little to no overlap between the dominant, diurnal lizard species the western fence lizard, *Sceloporus occidentalis,* and *A. sagrei* in localities where *A. sagrei* has invaded and established viable populations. This notable lack of overlap could indicate a potentially disturbing reality that *A. sagrei* are driving local extirpations of *S. occidentalis*.

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Abstract

The brown anole, *Anolis sagrei,* is a native species to the Caribbean, however, *A. sagrei* has invaded multiple parts of the United States, including Florida, Louisiana, Hawai'i, and more recently, California. The biological impacts of *A. sagrei* invading California~~,~~ are currently unknown. ~~However,~~ evidence from the invasion in Taiwan shows that they spread quickly and when immediate action is not taken, eradication stops being a viable option. In Orange County, California, five urban sites, each less than 100 ha, were surveyed for an average of 49.2 min. Approximately 200 *A. sagrei* were seen and verified across all survey sites. The paucity of native lizards encountered during the surveys within these sites suggest little to no overlap between the dominant, diurnal lizard species the western fence lizard, *Sceloporus occidentalis,* and *A. sagrei* ~~in localities where *A. sagrei* has invaded and established viable populations~~. This notable lack of overlap could indicate a potentially disturbing reality that *A. sagrei* are driving local extirpations of *S. occidentalis*.

Keywords: Invasive species, *Anolis*, *Anolis sageri*, *Sceloporus*, *Scelopourus occidentalis*, California

Introduction

The Brown Anole, *Anolis sagrei,* is a recently reported invasive species to California (Mardt, Ervin, & Nafis, 2014). While this species is a native to Cuba and the Bahamas, *A. sagrei* has also recently invaded Taiwan likely by way of the plant trade (Norval et al., 2016). The invasion in Taiwan is increasingly widespread and eradication is seemingly no longer an effective option (Norval et al., 2016). In the United States *A. sagrei* has invaded multiple states; including Florida, Louisiana, and Hawai'i (Kolbe et al., 2004; Kraus, 2008). The Citizen Scientist tool iNaturalist, (https://www.inaturalist.org/; verified July 15, 2019) shows approximately 25 states in the USA with verified records of *A. sagrei*, although not all states have confirmed established populations.

The first published record of *A. sagrei* from California in 2014 indicated a breeding population with many individuals detected rapidly at the initial site, and adjacent houses (Mardt, Ervin, & Nafis, 2014). Due to the rapid growth of citizen science reporting tools, we assessed Orange County for localities for this species and found there are less than ten reports of *A. sagrei* in iNaturalist, two from H.E.R.P. (http://www.naherp.com/), and one from HerpMapper (https://www.herpmapper.org/: verified July 15, 2019; Spear, Pauley & Kaiser, 2017). Studies show that *A. sagrei* is a robust invertebrate and small lizard predator who is known to change the behavior of lizards in similar ecological niches (Losos & Spiller, 1999; Kamath & Stuart, 2015; Stroud, Giery & Outerbridge, 2017). In its invasive range in Taiwan, *A. sagrei,* has also been known to change native ant communities as well as feed on native lizard species (Norval, 2007; Norval et al., 2016). In Bermuda where *A. sagrei* is an invasive, they have been estimated to have a population of approximately 2200 individuals in a 2.27-ha site (Stroud, Giery, & Outerbridge, 2017). Furthermore, *A. sagrei* is a highly adaptive lizard, able to obtain larger population densities (>12,000 per ha) in as few as four years when it is introduced (Campbell & Echternacht, 2003). To illustrate how dramatic of an irruption this is, Campbell & Echternacht started with less than twenty *A. sagrei* per uninhabited island, and after four years the *A. sagrei* population of one island was reported to have over 500 estimated individuals (Campbell & Echternacht, 2003). Additionally, *A. sagrei* is shown to be able to exponentially expand its range allowing for large increases in the areas they reside (Kolbe et al., 2004). Invasive *A. sagrei* have the seeming potential to change how the natural community functions in the habitats where they typically invade. This is especially worrisome in California, a biodiversity hotspot, that is highly susceptible to reptile invasions (Li et al., 2016).

There is concern that in California *A. sagrei* will change the biodiversity of the urban ecological communities where they currently reside and continue to spread into native habitats. One specific concern is that the scrublands and chaparral of Southern California will match well with *A. sagrei's* native habitat and their "trunk-ground" ecomorphology, indicating that it is well suited to these native microhabitats (Losos, 2011). These habitats are heavily utilized by the native California western fence lizard, *Sceloporus occidentalis,* in particular, which occupies a similar niche as *A. sagrei* does in its native range (Ashbury & Adolph, 2007; Losos, 2011). Additionally, *S. occidentalis* is also well known to occur in the same type of urban areas as *A. sagrei* in California (Grolle, Lopez & Gerson, 2014; Sparkman et al., 2018). Our paper focuses on the question of whether *A. sagrei* is able to obtain these high-density populations locally within this short period of occupancy in southern California, and if there is any evidence of its displacement of native *S. occidentalis* within the urban areas that *A. sagrei* have already occupied.

Materials and Methods

Surveys were conducted throughout Orange County sites (Figs. 1–5) based on observations from iNaturalist (July 20, 2019), as well as a new population discovered through a separate survey of lizards. We used daytime visual encounter surveys at the various study sites, at which *A. sagrei* had been detected within the past five years. While *A. sagrei* has been noted at as many as eight separate localities, this study only looked at five main invasion sites where observations for *S. occidentalis* were recorded nearby via iNaturalist (June 20, 2019). All localities were urban sites within Orange County. The five Orange County study localities are: Site 1, 33.721487, -117.826076 (Fig. 1), a 1.7-ha business complex next to a stream culvert; Site 2, 33.700801, -117.787705 (Fig. 2), a 90-ha residential neighborhood; Site 3, 33.799126, -117.800109 (Fig. 3), a 20-ha neighborhood patch bordering native habitat; Site 4, 33.701028, -117.91848 (Fig. 4), a hospital and shopping complex, 10 ha in size; and Site 5, 33.881758, -117.828688 (Fig. 5), a different 20-ha residential neighborhood patch. Each site within Orange County was surveyed once for a minimum of 40 min. Surveys were conducted from 30 June 2019 to 1 August 2019. Observations took place from 11:20 am to 8:30 pm. The main objective of the survey was to seek out and record any signs of high-density *A. sagrei*. When a population was observed, we walked around the site to map (circumscribe) the size of the minimum convex polygon of the occupied patch. Our secondary objective was to map the locations of *S. occidentalis* relative to these invasive lizards as evidence for expropriation. We also recorded all additional squamates encountered during the surveys.

Results

Of the five localities surveyed, *A. sagrei* were detected at all ~~five sites~~ (Table 1 and Figs. 1–5). ~~A mix of~~ all size classes of *A. sagrei* were also observed at each site. We found plant nurseries were present within the invaded areas for three of the five sites. Across all sites there were no spatial overlap detected between *A. sagrei* and *S. occidentalis*. The closest proximity in which we found the two species was 10 m apart at Site 5 on the outskirts of the suspected invasion front. We also found no *A. sagrei* perching higher than 2.5 m with most perching at a height of 0–1.0 m, a trend followed by *S. occidentalis* as well. At other sites where both species were detected *S. occidentalis* could be found within ~~the marginal bounds of~~ the occupied area, but never within the main area occupied by *A. sagrei*. The *A. sagrei* individuals appeared to be continuously distributed within these invaded urban habitats. We detected over 50 ha of habitat occupied by this species across the five sites. Below are the specific results for each site.

At Site 1 (surveyed on June 30th), *A. sagrei* were detected throughout the small area and were extremely quick to seek cover. The survey lasted 40 min beginning at 6:05 pm and ending at 6:45 pm, 30 *A. sagrei* were recorded, at a rate of approximately 0.75 per min. Conversely, we recorded 14 *S. occidentalis*, at a rate of 0.07 per min from 3:25 pm to 6:45 pm. There was no overlap between the *A. sagrei* patch and *S. occidentalis,* which was only detected around the boundaries of the occupied patch. This site was calculated to be approximately 0.8 ha (Fig. 1). Site 2 (surveyed July 5th) was searched for 68 min beginning at 12:53 pm and resulted in 41 *A. sagrei* at a rate of 0.6 per min, and two total *S. occidentalis* at a rate of 0.03 per min. This site had a minimum area of 26 ha (Fig. 2). Site 3 (surveyed on July 22nd) was searched for 42 min starting at 11:20 am and resulted in 57 total *A. sagrei* at a rate of 1.36 per min, with 7 total *S. occidentalis* detected at a rate of 0.17 per min. This site had minimum area of 10 ha and contained a plant nursery (Fig. 3). Site 4 (surveyed on July 5th) was searched for 43 min starting at 2:34 pm and a total of 14 *A. sagrei* were recorded at an average of 0.33 per min. At this site we found zero *S. occidentalis*. This site had minimum of 8.5 ha and contained a plant nursery within the site (Fig. 4). Site 5 (surveyed on August 1st) was searched for 53 min at 6:45 pm. A total of 60 *A. sagrei* were recorded at a rate of 1.13 per min plus 15 *S. occidentalis* were recorded at a rate of 0.25 per min. This site had a minimum area of five ha and contained a plant nursery within the focal area. For this site we mapped ~~out~~ all anole locations to illustrate how dense they were within the invaded area (Fig. 5). We compared our rates of discovery against those of the previous California study (Mahrdt et al. 2014); their rate of finding *A. sagrei* averaged 0.23 per min whereas our rate averaged 0.55 (range 0.33–1.36) *A. sagrei* per min.

Discussion

Our results show that established populations of *A. sagrei* existed at these five sites, and these populations appeared to be expanding. We measured over 50 ha total of invaded land across these five study sites, within which the largest population utilized at least 26 ha. Furthermore, our results show a lack of *S. occidentalis* within the core areas of *A. sagrei* occupancy, but *S. occidentalis* are detectable on the boundaries of the invasion epicenters. There was no direct overlap in distribution at less than 5 m, and no interactions were observed between these two species. We also found that we had a discovery rate of almost double the amount *A. sagrei* per min than the previous study by Mahrdt et al., possibly suggesting that as the various populations become more established the number of individuals is continuing to increase and detectability is also going up.

Sceloporus occidentalis is a widespread species in southern California but has been shown to be impacted by road fragmentation leading to genetic changes across habitat patches (Delaney, Riley & Fisher, 2010; Brehme et al., 2013). Although *S. occidentalis* is a common urban lizard, anything that impacts its ability to navigate these landscapes could further fragment these urban and native populations. This native species also has a significant role in the tick-lyme disease dynamics on the west coast of the United States, particularly within California (Lane & Quistad, 1998). While *S. occidentalis* is a key species in which the *Ixodes pacificus* tick nymphs feed, it is also controls the spread of lyme disease by killing the spirochete *Borrelia burgdorferi* with chemical elements in their blood when the *I. pacificus* nymphs feed on them (Lane & Loye, 1989; Lane & Quistad, 1998). Any negative interactions from this anole invasion may have the potential to change mechanisms of the tick-lyme disease interaction in southern California (Swei et al., 2011). There is some evidence to suggest mechanisms could be changing with Lyme disease detected in dog sera of urban San Diego dogs in the highest prevalence, compared to natural habitats, suggesting that changes in *S. occidentalis* populations could be relevant to disease prevalence change over time, even in the urban landscape (Olson et al., 2000).

While there are a few reported records of *A. sagrei* on the west coast of the United States, no large spatial population estimates have been previously mapped out and documented. The only published record documents an establishment within an acre of invaded area and mentions that it is expanded to additional properties (Mardt, Ervin & Nafis, 2014). It is possible that within the urban environment, road size is helping to act as a delimiter for how fast and far *A. sagrei* can spread, as this is the case for *S. occidentalis* (Campbell & Echternacht, 2003; Delaney, Riley & Fisher, 2010). The closest documented large population to California of *A. sagrei* is located more than 1500 km away in Texas. There are also large established populations in Hawai'i, which could be contributing to the spread of *A. sagrei* through lack of strong biosecurity on plant shipments coming into California, especially given the correlation between sites with *A. sagrei* containing nurseries. This species has been intercepted by biosecurity authorities as far as New Zealand, precluding establishment there (Chapple et al., 2016).

Determining solutions to contain and manage *A. sagrei* in southern California will be an important step in controlling this species. Further steps would include determining the invasion pathways for source populations, which likely includes nursery plants as has been previously reported (Norval et al., 2002; Kraus 2008). Three of our five study sites have nursery areas located within the invasion area, which seem to be a good indicator of the presence of *A. sagrei*, supporting this hypothesis. The literary evidence of plant nurseries helping to move and bring in invasive species could help prompt the creation of quarantine areas. Looking at the specific impacts *A. sagrei* will have on the southern California ecological landscape will be an important research aid in the management of this invasive species. We hypothesize that one way to understand the trophic role of *A. sagrei* is to use isotopes to look at their trophic level within the urban landscape, to determine if they are serving as spider specialists, as described in the literature (Norval et al., 2010). Potential investments of money and time might need to be made to look at the true extent and potential for removal of *A. sagrei* in southern California. Finally, continual monitoring and mapping out of *A. sagrei* invaded sites as well as their spread will aid in the long term as these strategies are developed.

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Figure Legends:

Figure 1. Site 1 surveyed for *A. sagrei* and S. *occidentalis*. The red polygon represents the minimum convex polygon where *A. sagrei* was found in the invaded areas. The green dot represents *S. occidentalis* individuals detected during these surveys.

Figure 2. Site 2 surveyed for *A. sagrei* and S. *occidentalis*. The red polygon represents the minimum convex polygon where *A. sagrei* was found in the invaded areas. The green dots represent *S. occidentalis* individuals detected during these surveys.

Figure 3. Site 3 surveyed for *A. sagrei* and S. *occidentalis*. The red polygon represents the minimum convex polygon where *A. sagrei* was found in the invaded areas. The green dots represent *S. occidentalis* individuals detected during these surveys. The blue dot identifies a plant nursery.

Figure 4. Site 4 surveyed for *A. sagrei* and S. *occidentalis*. The red polygon represents the minimum convex polygon where *A. sagrei* was found in the invaded areas. The blue dot identifies a plant nursery.

Figure 5. Site 5 surveyed for *A. sagrei* and S. *occidentalis*. The red polygon represents the minimum convex polygon where *A. sagrei* was found in the invaded areas. This figure illustrates all of the anole locations (red dots), each dot could represent up to three observations of anoles. The green dots represent up to three *S. occidentalis* individuals detected during these surveys. The blue dot identifies a plant nursery.

Table Legends:

Table 1. Sites surveyed for *Anolis sagrei* and *Sceloporus occidentalis* from Orange County, California, and published data from San Diego County.

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Competing interests

We acknowledge we have no competing interests.

Author contributions

S.R.F designed study, collected data, analyzed data, wrote and revised manuscript, created figures 1–5. L.A.D.P designed study, collected data, analyzed data, wrote and revised manuscript. R.N.F designed study, collected data, analyzed data, wrote and revised manuscript.

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Table 1(on next page)

Sites surveyed for *Anolis sagrei* and *Sceloporus occidentalis* from Orange County, California, and published data from San Diego County.

Table 1. Sites surveyed for *Anolis sagrei* and *Sceloporus occidentalis* from Orange County, California, and published data from San Diego County.

Site	Name	County	Coordinates	Nearest Site (Km)	Date Surveyed	Survey effort (min)	Total Brown Anoles Seen	Brown Anole/ minute	Total Sceloporus	Sceloporus/ min	Minimum Area of Population (ha)	Date from source; first record	Data from Source	Original Source	Record Number
Site 1	Starbucks Edinger	Orange	33.721487, -117.826076	4	30-Jun-19	40 / 200	30	0.75	14	0.07	0.8	30-Jun-19	30	This study	-
Site 2	Irvine High School	Orange	33.700801, -117.787705	4	5-Jul-19	68	41	0.6	2	0.03	26	8-Sep-17	2 records	iNaturalist	8004416
Site 3	Bond Ave	Orange	33.799126, -117.800109	9	22-Jul-19	42	57	1.36	7	0.16	10	18-Jun-16	~4 dozen	H.E.R.P.	259001
Site 4	Macarthur	Orange	33.701028, -117.91848	9	5-Jul-19	43	14	0.33	0	0	8.5	16-Apr-18	1	iNaturalist	11177594
Site 5	Yorba Linda	Orange	33.881758, -117.828688	9.5	1-Aug-19	53	60	1.13	15	0.25	7	20-Jul-19	5+	iNaturalist	29180552
Previous Study	Escondido	San Diego	33.17544, -117.23656	77.5	19-Jul-14	120	28	0.23	-	-	-	19-Jul-14	28	Marhdt et al. 2014	-

Figure 1

Site 1 surveyed for *A. sagrei* and S*. occidentalis*.

The red polygon represents the minimum convex polygon where *A. sagrei* was found in the invaded areas. The green dot represents *S. occidentalis* individuals detected during these surveys.

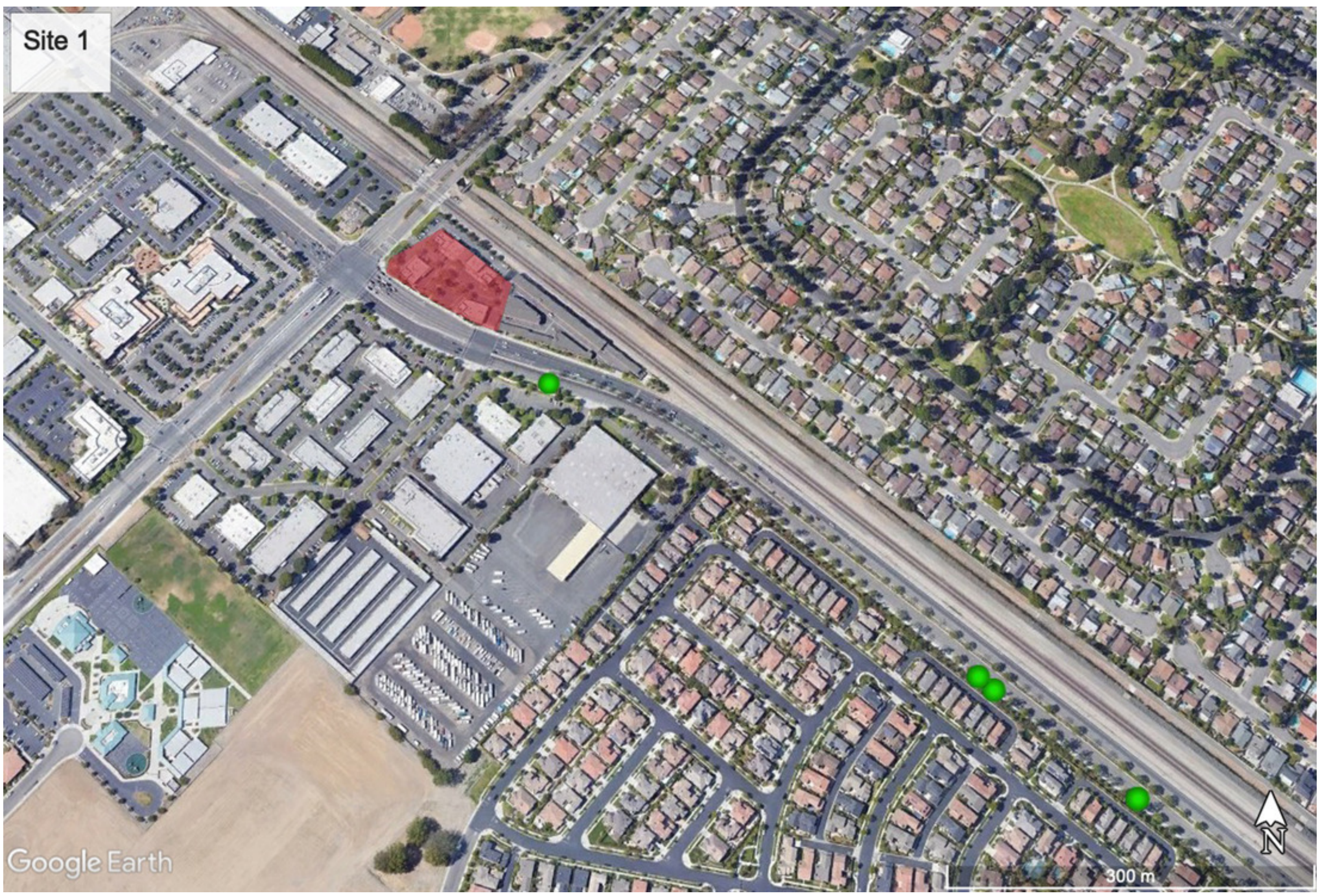

Figure 2

Site 2 surveyed for *A. sagrei* and S*. occidentalis*.

The red polygon represents the minimum convex polygon where *A. sagrei* was found in the invaded areas. The green dots represent *S. occidentalis* individuals detected during these surveys.

Figure 3

Site 3 surveyed for *A. sagrei* and S*. occidentalis*.

The red polygon represents the minimum convex polygon where *A. sagrei* was found in the invaded areas. The green dots represent *S. occidentalis* individuals detected during these surveys. The blue dot identifies a plant nursery.

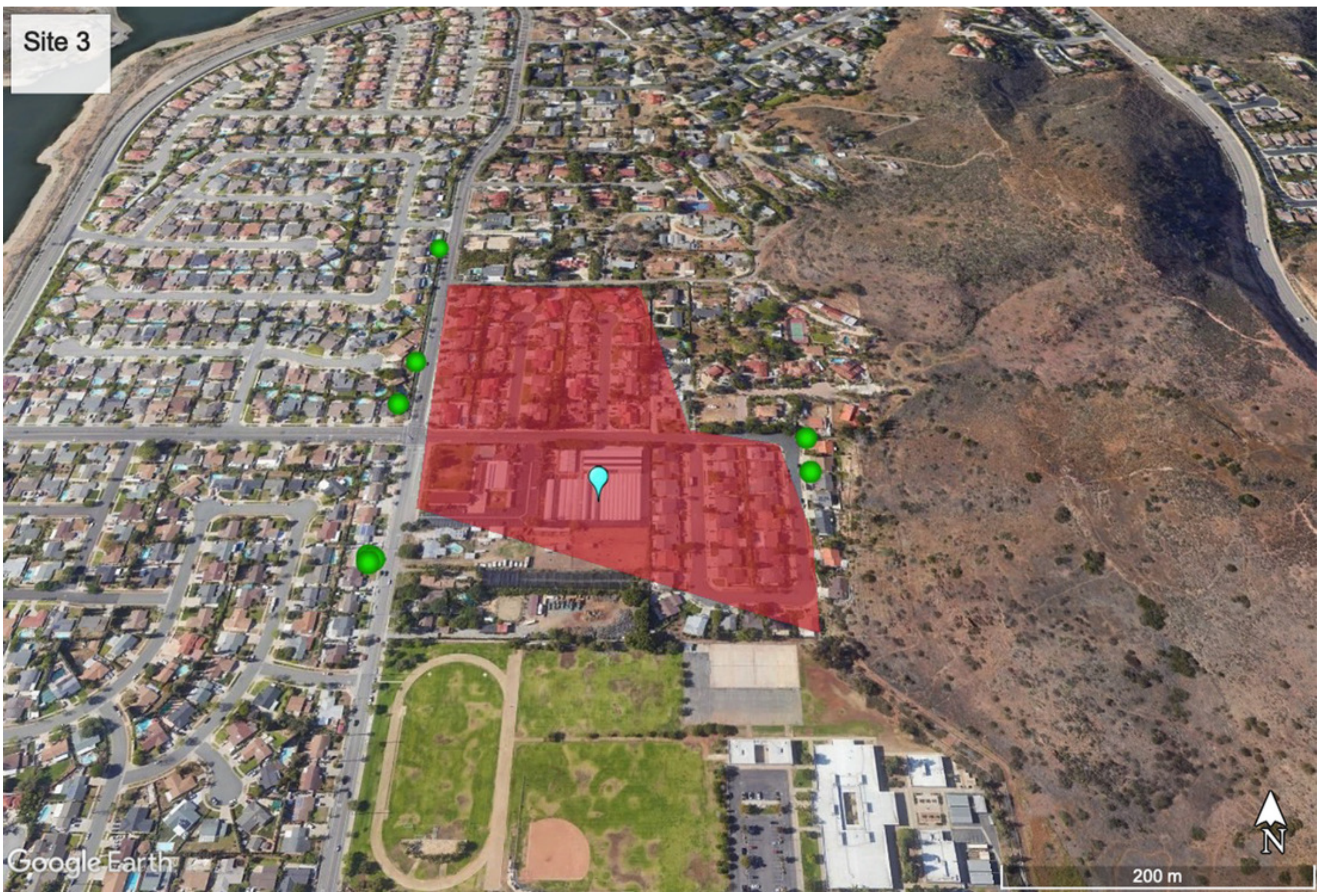

Figure 4

Site 4 surveyed for *A. sagrei* and S*. occidentalis*.

The red polygon represents the minimum convex polygon where *A. sagrei* was found in the invaded areas. The blue dot identifies a plant nursery.

Figure 5

Site 5 surveyed for *A. sagrei* and S*. occidentalis*.

The red polygon represents the minimum convex polygon where *A. sagrei* was found in the invaded areas. This figure illustrates all of the anole locations (red dots), each dot could represent up to three observations of anoles. The green dots represent up to three *S. occidentalis* individuals detected during these surveys. The blue dot identifies a plant nursery.