

MOOREA'S NEWEST INVASIVE SPECIES: THE DISTRIBUTION AND BEHAVIOR OF *PHELSUMA LATICAUDA*

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Abstract. Invasive species can have devastating biological consequences that without early intervention can do irreparable damage to the ecosystems they invade. Oceanic islands have native flora and fauna that develop without much competition for resources, niches or habitats. As a result, invasive species often can outcompete natives. The recent introduction of *Phelsuma laticauda* to Moorea, French Polynesia, raises concerns over how the biodiversity on the island may be affected by this alien species. The introduction of the invasive gecko, *Hemidactylus frenatus*, less than twenty years ago, led to the displacement of both native gecko species on the island, as it proved to be behaviorally dominant in regards to resources and habitat. This study aimed to investigate whether *P. laticauda* had successfully invaded Moorea, whether the population was spreading, and finally, if *P. laticauda* could be considered more aggressive than the other four gecko species on the island (*Hemidactylus frenatus*, *Lepidodactylus lugubris*, *Gehyra oceanica* and *Gehyra insulensis*). This was done with an island wide in-person and online survey, to determine where existing populations are, as well as a series of experimental trials to determine the behaviors of *P. laticauda*, when in competition with other gecko species. The results suggest that there are several existing populations of *P. laticauda* on the island, and these populations are spreading. Behaviorally, the *P. laticauda* acts more aggressively than the also invasive *H. frenatus*, which raises questions over how the gecko populations may be affected by the presence of two dominant gecko species.

Key words: invasive species; Gekkonidae; distribution; behavior; Moorea, French Polynesia

INTRODUCTION

Island ecosystems are vastly different from continental ecosystems- the flora and fauna are much less diverse, extinction rates higher, and undeveloped ecological niches more likely (Vitousek 1988, D'Antonio and Dudley 1995). Native species typically evolve without many predators or competitors, and are often left defenseless against introduced species, so the arrival of an invasive alien species can have devastating consequences (Reaser et al. 2007). For example, in the late 1940's, a predatory brown tree snake (*Boiga irregularis*) was introduced to Guam, and in less than forty years, 8 out of 11 of the native bird species were extirpated from the island (Wiles et al. 2003). On Christmas Island, the invasive yellow crazy ant was introduced and began killing large populations of land crabs. By eradicating the land crab populations, fallen leaves were no longer being eaten at the same rate, leading to dramatic perturbations in the food web (Reaser et al. 2007). Over the last four hundred years, over half of the 724

recorded animal extinctions have been island species due, in part, to the effects of invasive species (Clout and Veitch 2002).

Past gecko invasions on oceanic islands have been very successful due to various reasons (2014): adaptability to living in human disturbed areas (2011, 2013), saltwater resistant eggs (1957) and aggressive behavior that could displace native species (Bolger et al. 1992). As a result, geckos can be introduced and spread quickly and successfully in unfamiliar territory. On islands adjacent to New Zealand, where predators of the introduced lizards are sparse, there can be up to 1390 lizards per acre (Bolger et al. 1992).

Phelsuma laticauda (gold dust day gecko) is a species of diurnal gecko, from the genus *Phelsuma*, often referred to as day geckos. Native to Madagascar, the gecko's adaptability to a wide range of habitats has led to its successful invasion of several islands, including Hawaii, Mauritius and Reunion Island. In 2012, the extermination of three

Phelsuma species was legalized in Reunion Island, after the government concluded that the native gecko populations were at risk (Bohm 2011).

The gold dust day gecko was recently discovered on the island of Moorea in French Polynesia (Ota 2006). Moorea has a typical high island ecosystem, with low diversity and undeveloped ecological niches (Vitousek 1988, D'Antonio and Dudley 1995). By studying the presence of this invasive species on Moorea, we may be able to better conserve and protect the native species. There are four other established gecko species on Moorea: *Gehyra oceanica*, *Gehyra insulensis*, *Lepidodactylus lugubris*, and *Hemidactylus frenatus*. *Gehyra oceanica* and *L. lugubris* are the only gecko species that are thought to have arrived naturally, while the other three (including the gold dust day gecko) are thought to have arrived due to human transportation (Gillespie 2008). *Gehyra oceanica* has the smallest population size on the island (Pearlman, 2014). It was also found that *G. oceanica* and *L. lugubris* live in a range of habitats, while *H. frenatus* only lives on man made structures (Reeder 2005). These findings suggest that all four other gecko species are potentially vulnerable to displacement by *P. laticauda*.

H. frenatus invaded Moorea in the 1970's (Gillespie 2008) and since has displaced both geckos species (*G. oceanica* and *L. lugubris*) who inhabit the same human disturbed areas as *H. frenatus* (Pearlman 2015). The somewhat recent introduction of *H. frenatus* has already resulted in a dramatic decrease in population size of *L. lugubris* and *G. oceanica*, because of competition for niche space, territory, and resources (Case 1991). No conservation efforts have focused on the minimization of the spread of *H. frenatus* across the island. Therefore, mapping the distribution of *P. laticauda* on Moorea and studying its behavior is crucial to potential intervention to prevent further displacement of the native gecko species

Introduced species have the most negative effects on native species when they are competing for resources, habitats, or niches (Cole 2005). The new invasive *P. laticauda* has been known to live on both man-made structures and a range of wild habitats, including banana and palm trees. Territorial behavior, ability to live in various habitats, and adaptation of the *Phelsuma* species to be both nocturnal and diurnal, could enable the

geckos to quickly take over island territory, displace the other geckos, and disrupt the native ecosystem.

Due to previously published literature citing the *P. laticauda* as aggressive, I hypothesized that the *P. laticauda* would show dominant behavior over all other species of geckos. I also hypothesized that there would be several established populations of this gecko living around the original site of introduction in Haapiti (Ota 2006).

METHODS

A survey was conducted between October 19, 2015 and November 7, 2015 to determine the distribution of the *Phelsuma laticauda* on Moorea, French Polynesia. Following the survey, a series of behavioral trials were run to determine if *P. laticauda* could be considered more aggressive than the other four gecko species on the island. These trials were run from November 5-18, 2015.

Distribution survey

The distribution survey of this research project was conducted to create a comprehensive map of the existing *P. laticauda* populations using CartoDB 2015. This map can serve as a reference point in coming years as the population continues to spread. The survey covered the entirety of the island, starting at the Moorea Airport (Kilometer marker 0), and continuing along the main road. The survey continued west from Kilometer 0, and reaching Kilometer marker 36 past the town of Haapiti (Appendix A). Heading east from the Kilometer marker 0 at the airport, the kilometers continued counting upward to Kilometer 24, meeting the 34 marker just before Haapiti. A survey was conducted at each even kilometer marker, interviewing six people at each site, using a photo of *P. laticauda* for reference. Both residential houses and businesses were interviewed, in Tahitian and French, and then translated (Table 1).

TABLE 1. Survey questions for the in-person survey.

-
1. Have you seen this lizard before here?
 2. Have you ever seen it somewhere else?
 3. If yes, when and where did you see it?
 4. Did you see any other types of lizards before, during or after the time you saw the green one?
-

Another survey was sent out online, to gather additional data (Appendix B). The survey was translated from French.

Study organisms

The five species of the family Gekkonidae presently known from Moorea, *Hemidactylus frenatus*, *Gehyra oceanica*, *Gehyra insulensis*, *Lepidodactylus lugubris* and *Phelsuma laticauda*, were the focus of this study (Appendix C). With the exception of *G. oceanica* and *L. lugubris*, all gecko species were introduced by humans to French Polynesia (Gillespie 2007). *H. frenatus* invaded French Polynesia in the 1970's, and spread aggressively and successfully. A study in 2005 showed that the *H. frenatus* had displaced both *L. lugubris* and *G. oceanica* populations from their territories in Moorea (Reeder 2005). *Gehyra insulensis* is thought to have been introduced to French Polynesia sometime before 1922 (Gill 1993). *Phelsuma laticauda* is a diurnal gecko, while the other four gecko species are nocturnal.

Behavioral trials

A series of thirty minute observed trials were conducted, between *P. laticauda* and the other four gecko species present on Moorea, to determine if the *P. laticauda* could be considered more aggressive than the other species.

All five gecko species were caught using a gloved hand, and kept separately in small buckets before the experiment. The *P. laticauda* geckos were caught the same day as the trials, while the other four species were caught the previous night. All trials were conducted at the Gump Station (17°29'20.12"S, 49°49'33.04). The four species (*G. oceanica*, *G. insulensis*, *L. lugubris* and *H. frenatus*) were collected at the station, between the hours of 18:00 and 23:00. The *P. laticauda* geckos were caught between Les Teapaniers and Haapiti, between the hours of 10:00 and 18:00 (Fig. 1). These sites were selected as collection areas due to the fact that they were the five most densely populated *P. laticauda* sites. The geckos were acclimated for a minimum of five hours prior to being subjected to experimental trials. Geckos were identified to species, measured, photographed, and sexed within the first three hours of captivity. Sexing was done by appearance of hemipenes and preanal pores at the base of the vent, identifying males. All

geckos were fed a small piece of papaya and some water at 16:00 on the day of the test. The tests were run between 18:00 and 23:00. All geckos were returned within 24 hours of being captured, with only 12 of those hours being observations, per the Institutional Animal Care and Use Committee (IACUC) Animal Utilization Guidelines.



FIG. 1. Collection sites of *P. laticauda*.

Each trial consisted of one *P. laticauda* versus one of the other four species. All pairs were made with comparable sizing, up to one centimeter difference, from snout to end of tail. Trials were run in a 40 cm diameter arena, covered with glass (Appendix D). The two geckos were dropped in the container simultaneously to avoid any adjustment to the territory. Each trial was thirty minutes long, and was filmed. A series of behaviors were pre-determined as aggressive, after consulting gecko experts and previously published literature. During the trial, notes were taken on each behavior exhibited by the two geckos, noting the time and behavior of each. If there was any interaction between the geckos that appeared to be causing harm to either party, the geckos were removed. The videos were then re-watched and analyzed, and the aggressive maneuver count was tallied, summed and averaged.

The number of trials run for each separate species varied, due to different population sizes at the Gump Station. Both *G. oceanica* and *H. frenatus* had large populations, so ten trials were run for each. *Lepidodactylus lugubris* had four trials run, and *G. insulensis* had seven trials.

For the data that was normal and homoschedastic, I ran paired t-tests (R Team 2015). For the data that did not meet assumptions for normality and

homoschedasticity, a Wilcoxon rank sum test was run. To account for multiple comparisons, I used the Benjamini and Hochberg correction to adjust the p-values. The aggressive maneuvers were summed, and an average taken for each species as a whole, and compared on a dot plot with mean and error bars.

All research conducted for this study was in accordance with the Institutional Animal Care and Use Committee (IACUC) Animal Utilization Guidelines for this class.

RESULTS

Island survey

The island survey showed that *P. laticauda* has successfully invaded Moorea. Of the 184 surveys taken, there were 22 “yes” responses to Question 1 (“Have you seen this gecko here, at the interview site?”). These 22 “yes” responses were spread over eight of the thirty interview sites (Fig. 2). The location of these sites ranged from Haapiti, up the western coast, and across the northern side of the island. The online survey responses yielded very similar results to the in person survey. All but one of the reported sightings of these geckos were in areas that the in person survey also had confirmed populations (Appendix E).



FIG. 2. Each confirmed *P. laticauda* site from in person interview.

After confirming that the *P. laticauda* does exist in Moorea, French Polynesia, the second part of the island survey confirmed that the population is spreading (Fig. 3). The combined responses from both in person and online showed that in the twelve years between 1999-2012, 36% of those who responded had seen the gecko for the first time. In only 2013, 2014 and 2015, 63% of the survey respondents had seen the gecko for the first time (Fig. 4) (Appendix F).



FIG. 3. Sightings reported in online survey from before 2000- 2001 (A), sightings from 2004-2005 (B), and sightings from 2010-2015 (C).

Behavioral trials

The series of behavioral trials run between *P. laticauda* and the other gecko species present in Moorea showed that the *P. laticauda* had heightened aggressive behavior towards one of the four species.

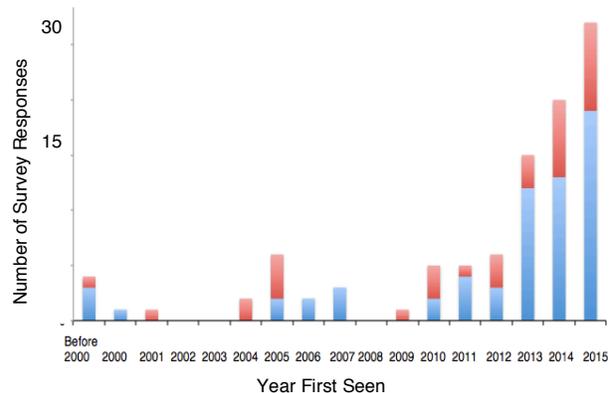


FIG. 4. Online (red) and In Person (blue) survey responses for the year the interviewee first saw a *P. laticauda* in Moorea.

Phelsuma laticauda had on average double the amount of aggressive maneuvers (5.7 ± 3.8 SD) than the native *Gehyra oceanica* (3.5 ± 2.8 SD), but statistically was not significant with the amount of trials run (T-test, $p > 0.05$, $df = 9$). *P. laticauda* had a slightly higher number of aggressive maneuvers (6.25 ± 6.2 SD, $p > 0.05$, $df = 3$) over the native species, *Lepidodactylus lugubris* (4.0 ± 3.6 SD). Against an invasive species, *Gehyra insulensis* (0.7 ± 1.2 SD), *P. laticauda* had on average six times the number of aggressive maneuvers, and was approaching statistical significance (T-test, $p > 0.055$, $df = 6$) (4.3 ± 4.2 SD). Finally, *P. laticauda* had more than double the number of aggressive maneuvers (7.8 ± 4.0 SD) that *Hemidactylus frenatus* had (3.6 ± 3.5 SD), and it was statistically significant (T-test, $p > 0.05$, $df = 9$) (Fig. 5) (Appendix G).

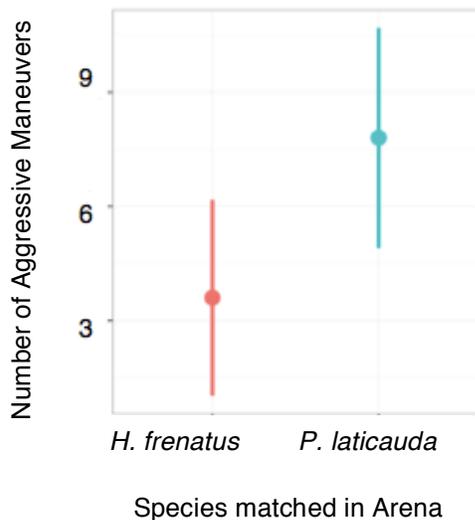


FIG. 5. Average aggressive maneuvers of one species matchup, across ten trials.

DISCUSSION

Phelsuma laticauda's successful invasion of Moorea, and its aggressive tendencies against other gecko species calls for immediate containment or eradication of the population. The original hypothesis that *P. laticauda* was more aggressive than all four other species was incorrect, however it proved to be more aggressive than *Hemidactylus frenatus*.

This observation is of the utmost importance because *H. frenatus* was found to be behaviorally dominant to several other species (1992), and to have successfully

displaced other gecko populations when introduced to new islands. Not long after its introduction to Moorea, about 20 years ago, *H. frenatus* successfully displaced both *G. oceanica* and *L. lugubris* (Reeder et al. 2011). *H. frenatus* was also introduced to the Mascarene Islands, and caused both *Nactus durelli* and *Nactus coindemirensis* populations to go extinct (Cole et al. 2005). It was also found that on numerous islands across the tropical Pacific, *L. lugubris* was 800% more prevalent when *H. frenatus* was not also living on the island (Case et al. 1994).

H. frenatus is a gecko that lives mainly in areas of high human disturbance, while *G. oceanica* and *L. lugubris* live on both man made structures and in more natural areas (Reeder 2005). *Phelsuma laticauda* has the same habitat as *G. oceanica* and *L. lugubris*, so if it has the ability to displace *H. frenatus*, it could also affect the *G. oceanica* and *L. lugubris* populations by competing for habitat. Also, if *H. frenatus* is succeeding in displacing other gecko species because of heightened aggression, and *P. laticauda* can now be considered more aggressive, *H. frenatus* populations may be affected.

However, since *P. laticauda* did not show significant aggression towards the two native species (*G. oceanica* and *L. lugubris*), there is a possibility that these two species and *P. laticauda* could cohabitate. *P. laticauda* could also potentially decrease the *H. frenatus* population on Moorea, if its aggressive behavior holds true in natural settings. This could be an indirect, yet beneficial, population control maintained by *P. laticauda*. Further studies need to be done to see if these results are true in the wild, and what the consequences may be if *H. frenatus* populations are affected by *P. laticauda*.

The behavior of the diurnal *P. laticauda* at night is also something that should be considered in the future. If indeed *P. laticauda* is adapted to be both diurnal and nocturnal in tropical habitats, then the risk of resource competition and displacement of the other gecko species is higher. A future study may also consider further testing *L. lugubris* against *P. laticauda*. The lack of statistical significance may be due to the low number of trials run, since the population of *L. lugubris* was sparse at the collection site.

The current distribution found by this study across the west and northwest sides of Moorea is vital to potential conservation efforts. Reports of the introduction,

establishment and continued spread all confirm continued growth of the *P. laticauda* population. An invasive population of concern can be chosen to be contained or exterminated completely, and the ideal time to do this is when the population is not widespread (Veitch 2005). Small, localized populations are easily contained and exterminated, especially on small islands, (Veitch 2005, Sinclair et al. 2005). Past exterminations of invasive island species have proved to be successful; in less than 12 years the entire population of invasive rats was removed from Kapiti Island, New Zealand (Sinclair et al. 2005). The growing population of *P. laticauda* should be considered for similar action by French Polynesia, to minimize both biological and economic consequences.

Oceanic islands are particularly vulnerable to invasive species, making research and active management especially important in preserving the ecological integrity of island systems. The beginning of the spread of *P. laticauda* across Moorea seems to be following a typical invasive species pattern, in its establishment of a growing number of small, localized populations. This study highlights the invasion success and aggression of an emerging alien species, that suggests significant potential for further spread around French Polynesia and the Pacific.

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APPENDIX A



FIG. 7. Start point (KM 0), and mid point (KM 36) of in-person survey.

APPENDIX B

TABLE 2. Questions asked in the online survey.

-
1. Have you seen this lizard before?
 2. Where did you see this lizard?
 3. Please explain exactly where you saw it- the address, description of house, etc.
 4. What year did you see this lizard?
 5. How many of these lizards did you see at each location? Please state the place and number of lizards.
 6. Did you notice anything about how this lizard behaved? Comment anything about its behavior, habitat, etc.
 7. Have you seen other types of lizards at the same place, before, during or after the time you saw this lizard?
 8. What types of lizards did you see?
-

APPENDIX C

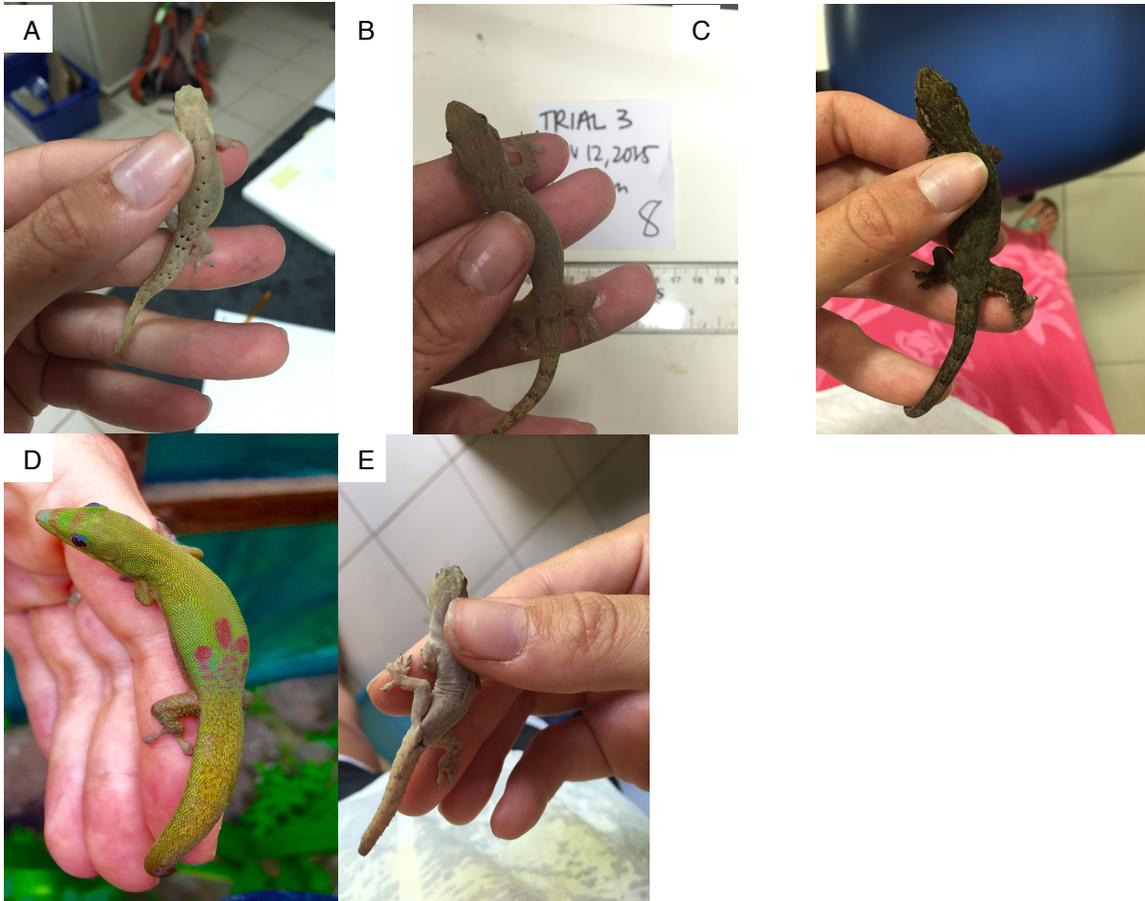


FIG. 8. Species identification: *Lepidodactylus lugubris* (A), *Gehyra insulensis* (B), *Gehyra oceanica* (C), *Phelsuma laticauda* (D), *Hemidactylus frenatus* (E). Photos taken by author, Ingrid Lund, November 2015.

APPENDIX D

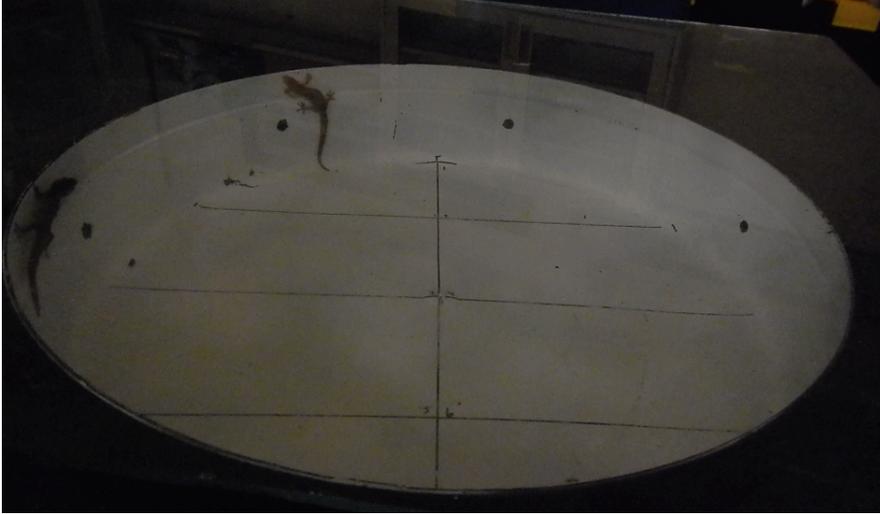


FIG. 9. Arena used for behavioral trials.

APPENDIX E

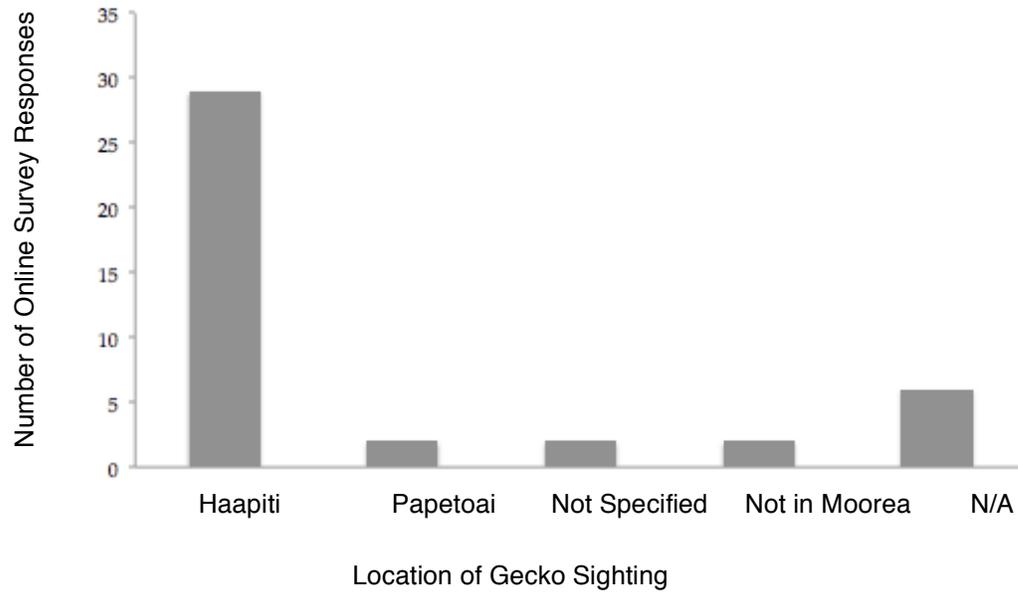


Fig. 10. Location of first *P. laticauda* gecko sighting in Moorea, by each person interviewed online.

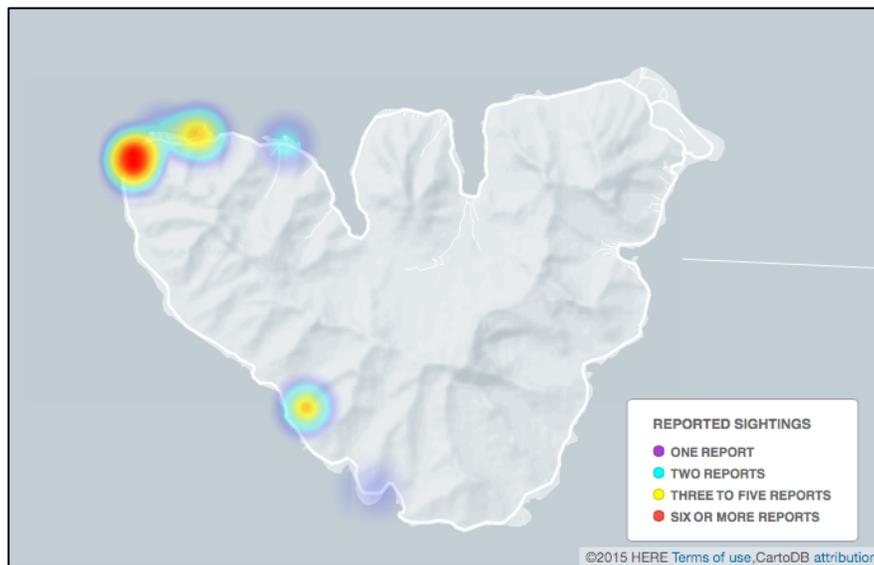


FIG. 11. Location of first sighting of *P. laticauda* by those interviewed online.

APPENDIX F

TABLE 3. Online and in-person survey results by year.

| Year First Seen | Percent of Total Surveyed (Online) | Year First Seen | Percent of Total Surveyed (In Person) |
|-----------------|------------------------------------|-----------------|---------------------------------------|
| Before 2000 | 2.94% | Before 2000 | 4.68% |
| 2000 | 0% | 2000 | 1.56% |
| 2001 | 2.94% | 2001 | 0% |
| 2002 | 0% | 2002 | 0% |
| 2003 | 0% | 2003 | 0% |
| 2004 | 5.88% | 2004 | 0% |
| 2005 | 11.76% | 2005 | 3.12% |
| 2006 | 0% | 2006 | 3.12% |
| 2007 | 0% | 2007 | 4.68% |
| 2008 | 0% | 2008 | 0% |
| 2009 | 2.94% | 2009 | 0% |
| 2010 | 8.82% | 2010 | 3.12% |
| 2011 | 2.94% | 2011 | 6.25% |
| 2012 | 8.82% | 2012 | 4.68% |
| 2013 | 8.82% | 2013 | 18.75% |
| 2014 | 20.58% | 2014 | 20.31% |
| 2015 | 23.52% | 2015 | 29.68% |

APPENDIX G

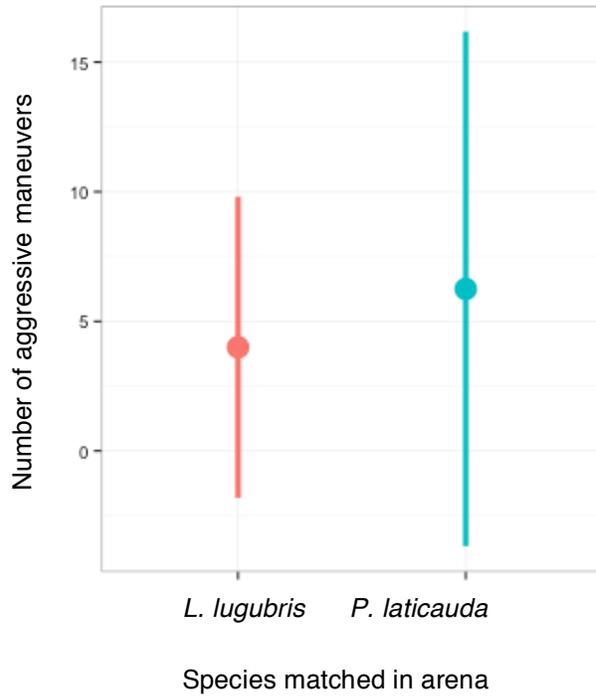


FIG. 12. Mean aggressive maneuvers for one species matchup, over four trials.

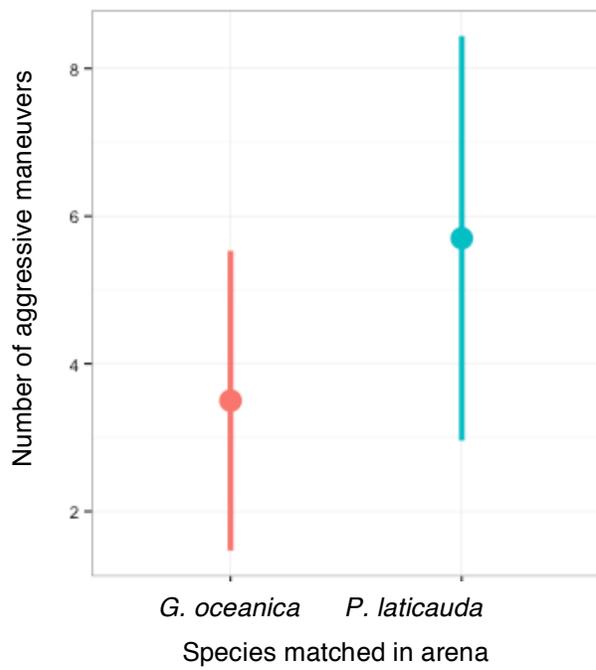


FIG. 13. Mean aggressive maneuvers for one species matchup, over ten trials.

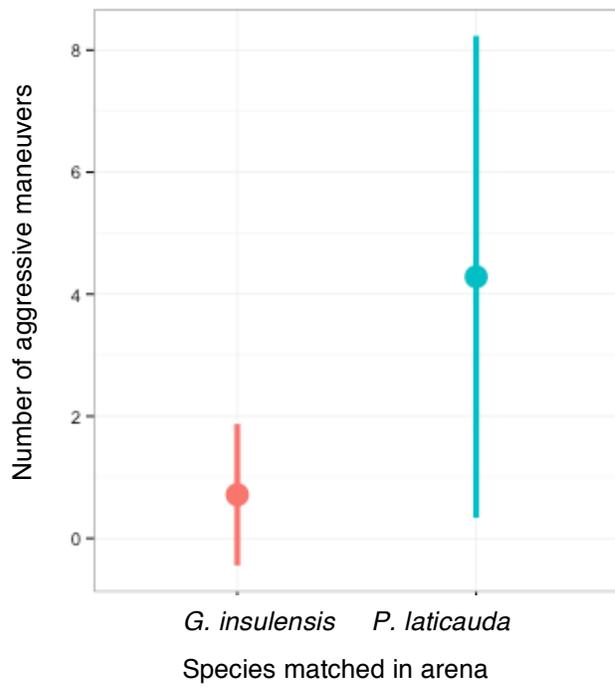


FIG. 14. Mean aggressive maneuvers for one species matchup, over seven trials.