

EFFECT OF URBANIZATION AND ARCHITECTURAL STYLE ON GECKO POPULATION DYNAMICS

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Abstract. Urban expansion and development may result in changes in topographic complexity due to the use of industrial building materials and the resource clumping that is associated with artificial light. This study assesses the impact of these variables on gecko population dynamics and species composition, focusing on the species *Hemidactylus frenatus*, *Lepidodactylus lugubris*, and *Gehyra oceanica*. This observational study utilized a timed sampling method to count and identify all gecko organisms to species on twelve distinct roofs of varying substrates on Mo'orea, French Polynesia. Both artificial concentrated light and the level of topographic complexity of building substrates affect the abundance of these species. These variables affect levels of interspecific communication and may have implications for the success of the invasive species *H. frenatus*. Biodiversity, as measured by species richness, is improved on naturalized substrates with greater topographic complexity and lower levels of concentrated artificial light.

Key words: *gekkonids; Gekkonidae; gecko; lizard; invasion; urbanization; interspecific competition; biodiversity; French Polynesia*

INTRODUCTION

Urbanization is an ongoing process worldwide, resulting in a widespread reconfiguration of the landscape (McKinney, 2002). This process provides a challenge to conservation in a number of ways, including habitat transformation, which encourages the success of a unique community of introduced and native species, interacting largely due to anthropogenic changes (Alberti, 2003). Sprawl of urban space has the potential for "biotic homogenization" due to the replacement of native species with "weedy," non-native species (McKinney, 2002; Olden, 2006). While there are many vehicles for habitat loss, changes due to development of the built environment are among the longest lasting (McKinney, 2002) and have the ability to delay the inertia of nature (Groth, 2007).

Such large-scale land-use decision making, however, is not a modern fabrication and have existed globally since before European contact (Kirch, 2007). A common misconception exists regarding indigenous cultures as being environmentally low-impact (Kirch, 1997). This is evident, for example, by past irrigation and agroecosystems identified on various Polynesian islands (Kirch, 2007). As this trend continues, it is important to note the continual impact of current levels of

development. Operating on a global scale, modern cities often require an "ecologically productive area" up to 300 times as large as itself (Alberti, 2003), demonstrating that impacts of past civilizations continue to be underappreciated. This study works within a paradigm of "urban ecology" that does not partition humans and ecological processes into separate domains, but instead identifies humans as "components of [an] ecosystem" (Alberti, 2003).

A study on impacts of the built environment and development on Mo'orea, French Polynesia provides a useful perspective for understanding patterns of change due to urbanization worldwide. Considering oceanic islands as a model system in which to study these processes and impacts, Mo'orea, French Polynesia provides a location characterized by "a useful compromise of complexity and tractability" (Vitousek, 2002). Phases of anthropogenic change through introduction and naturalization have existed on Mo'orea beginning with the first wave of Polynesian migration, a later phase of European and Asian introductions (Kirch, 2010), and the current state of movement via globalization (Morel et. al., 2001; McMichael, 2000). Land use studies conducted on Mo'orea during 2004 and 2005 modeled unconstrained buildout using geographic information

systems based on growth patterns between 1986 and 2001. These models predicted ten-fold expansion of the existing built environment in 50 years (Boutillier and Duane, 2005).

Potentially due to its synanthropicity, species of the family Gekkonidae are widely studied organisms, particularly through the lens of invasion biology and development. These organisms' adaptation to cohabitation with humans is evident, as geckos are commonplace among built structures (Mai, pers. obs.). As a result, questions regarding the effect of urban sprawl and development on gecko population dynamics have been explored in the past. Studies in Brisbane, Australia have noted the success and invasion of the "cosmopolitan" *Hemidactylus frenatus* (*H. frenatus*, Hf) in urban and suburban environments (Griffith and Jones, 2007). Native to Southeast Asia, the first sighting of *H. frenatus* on the Society Islands occurred in 1989 in Papeete (Case et. al, 1994). Another study conducted on Mascarene identified favorability for endemic species *Nactus coindemirensis* and *Nactus durrelli* over *H. frenatus* on substrates with a greater amount of loose surface material due to the *H. frenatus*' specialized toes well adapted for gripping smooth materials—ubiquitous in urban environments (Cole, Jones, and Harris, 2005; Petren and Case, 1994).

H. frenatus and its invasion have been widely researched throughout the Pacific, often framed by its interaction with other gecko species, including *Lepidodactylus lugubris* (*L. lugubris*, Ll). Studies in Fiji and Hawaii demonstrated the strong negative effect of *H. frenatus* presence on abundance of *L. lugubris* and not vice versa (Case et. al, 1994). This dominance is due to *H. frenatus*' superior foraging ability (Petren and Case, 1996) and the former's ability to prey on the latter (Bolger and Case, 1992). Studies on Oahu, Hawaii explore two factors that impact interspecific competition between *H. frenatus* and *L. lugubris*—habitat topographic complexity and resource clumping. The former, level of structure in an area, affects species spatial distribution and sight impediment, thus altering chances for predator and prey encounter. The latter increases interspecific communication, and resultantly competition (Petren and Case, 1998). A variety of Gekkonids are present on Mo'orea besides *H. frenatus* and *L. lugubris*,

including *Gehyra oceanica*, *Gehyra mutilata*, *Phelsuma laticauda* (Reeder, 2005). Not all gekkonid species interact aggressively the way *H. frenatus*' interactions have been described (Reeder, 2005). Such levels of interspecific competition are not as apparent between *L. lugubris* and *Gehyra oceanica*, as studies have shown these species have a tendency to avoid one another (Reeder, 2005).

Past studies, such as those conducted by Kenneth Petren and Ted Case on these gecko species raises a number of questions necessitating research while allowing an application of knowledge and methods in situ to the existing built environment and associated human activities. How do these concepts of varying topographic complexity and resource clumping affect biodiversity and interspecific competition when applied to gecko population dynamics on Mo'orea, French Polynesia? In the present day, the built environment of Mo'orea boasts homes utilizing a wide variety of roofing material, characterized by different levels of topographic structure, including but not limited to corrugated metal, wooden shingle, *Pandanus* spp. leaves (Mai, pers. obs.), leading to some inquiries regarding the impact of these highly varied roofing materials on gecko population dynamics and species composition. I hypothesize a higher diversity of gecko species and lower dominance of invasive *H. frenatus* on building substrates with greater topographic complexity. Concentrated artificial light will increase abundance of the assessed species and promote the dominance of *H. frenatus* over the other two species most drastically on substrates of lower complexity. Due to clumping of resources, more aggressive *H. frenatus* will be found closer to concentrated light sources than others.

METHODS

Study site

This assessment considers the effect of three roofing substrates: wooden shingle, *Pandanus* spp., and corrugated metal. These substrates were chosen due to their widespread usage on study site Mo'orea, French Polynesia (17°30'S, 149°50'W) (Mai, pers. obs.) (Fig. 1). The roof is an ideal part of the structure to study due to the continuity of substrate across a large area. Of the three substrates that will be assessed in this study,

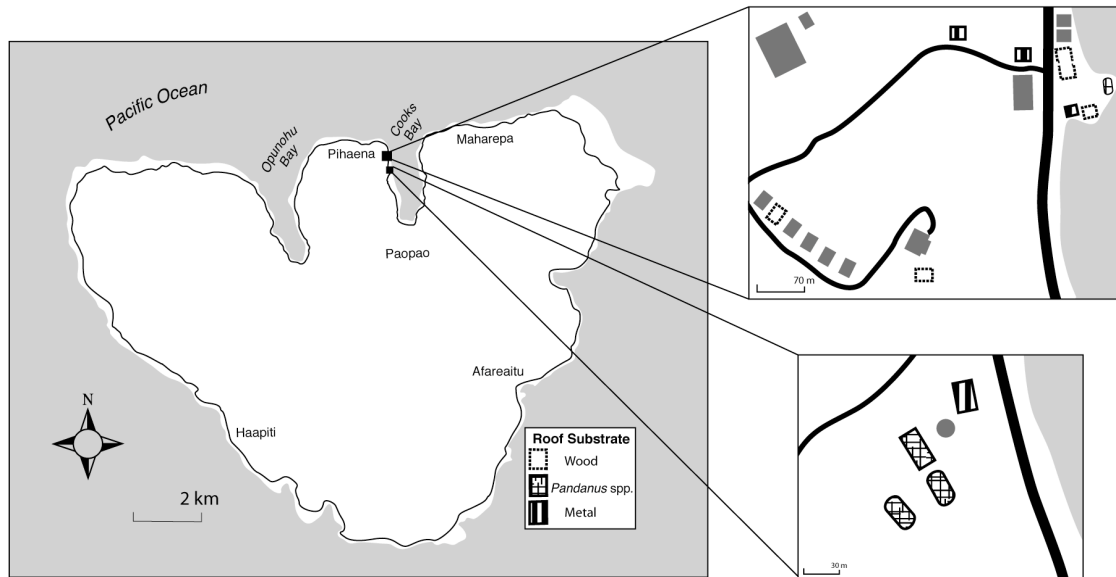


Figure 1. Study site located on Mo'orea, French Polynesia (17°30'S, 149°50'W). Structures of interest highlighted in context map with appropriate substrate noted.

the level of mentioned topographical complexity is based on amount of material surface area per half meter squared. This was calculated by identifying five .5 meter quadrats were haphazardly on each replicate to count number of shingles. The surface area of five haphazardly chosen shingles of each substrate type was measured using Image J software.

$$\text{Topographic Complexity (TC)} = \frac{\text{Mean Surface Area}}{.5 \text{ m}^2}$$

Sites utilized are restricted to the coastal zone (0-100 m above sea level). Choice of elevation is derived from the concentration of the built environment (Boutillier and Duane, 2005) and cohabitation of all three species within this zone (Reeder, 2005). Because of the absence of *H. frenatus* in non-built environments (Reeder, 2005), this study did not utilize a naturalized forest area as a control site and instead emphasizes a comparison of each roofing substrate in different lighting environments.

Study subject

H. frenatus can be visually characterized by a presence of blunt tail tubercles, pale 'V' shaped markings at the top of its spine, and light translucent color (Fig. 2). This species has a wide variety of measurements. Its distinct call is described as a 'chuck, chuck, chuck' and

is strongly audible. There is a severely reduced digit present in the 3-4 position of its toes in the front foot and 4-5 position of the hind foot; this digit lacks deep cleft that dividing subdigital lamellae of the other digits (Newbery and Jones, 2007).

G. oceanica has a snout-vent length (SVL) of up to 18 cm. Its color is usually mottled brown and pale brown with broad pale bands on tail. Its feet are characterized by wide, oval toe pads and its tail is tapered steadily from the base (Fig. 3). It is audibly recognized via a low growling noise (CINH, 2007).

L. lugubris has a SVL of approximately 45 mm. The organism can be visually identified with its moderately long tale, smooth skin, and distinct pattern. *L. lugubris* has a ground color of creamy fawn and variegated dark brown/beige zig-zag pattern. The undersides are beige and are sometimes speckled (Fig. 4). The call is a loud single syllable chirping noise "chik chik chik" (GGA, 2001).

Assessing differences amongst roofing substrates and light treatment

Visual and auditory sampling techniques were combined, using a hand-held flashlight, binoculars, and unaided listening (Griffith and Jones, 2007). Geckos were observed on the external surface of roofs and identified to species (Fig. 5) utilizing a timed effort



Figure 2. Full length *H. frenatus*



Figure 3. Full length *G. oceanica*



Figure 4. Full length *L. lugubris*

sampling for 20 minutes between 18:00 and 22:00 (Griffith and Jones, 2007). When possible, geckos were identified by their call and recorded if located visually. This study assessed four replicates of a 30 square meter area of each substrate (Fig. 5) for a total of 12 replicates (distinct roofs), each of which was sampled three randomized times between October 10 and November 15.

Applying concentrated artificial light

The roofs after application of light treatment was observed utilizing a combination of auditory and visual sampling techniques via hand-held flashlight, binoculars, and unaided listening (Griffith and Jones, 2007). A halogen bulb lamp was affixed to the external surface of each of the 12 mentioned sites for insect

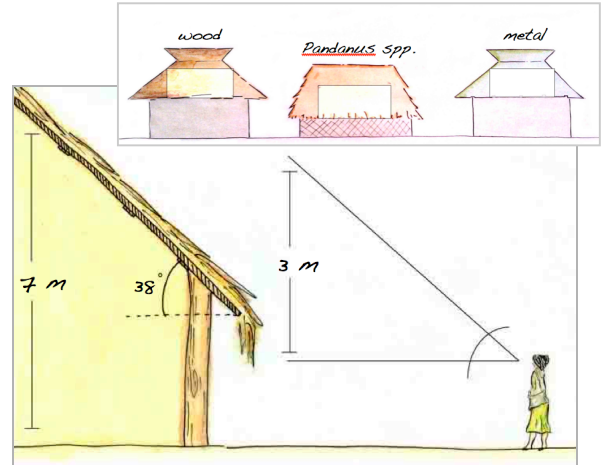


Figure 5. Concept diagram demonstrating size of observation area and methods

attraction and resource clumping. This component of the assessment utilized the timed effort sampling method defined above (Griffith and Jones, 2007) to identify any present geckos to species. Four replicates of an 80 square meter area of each substrate were observed (a total of 12 replicates). Each roof was sampled three consecutive days five days after the light was applied between October 10 and November 15. Distance of each organism from the light (in meters) was approximated (to minimize amount of impact on timed sampling) and recorded.

Pilot Study: Resource clumping and assessment of temporal scale

Pilot studies were conducted to determine the amount of time needed to wait after applying concentrated light to the study areas. Organism abundance began to level off after three days, but five days was utilized in experimental design to conservatively work against confounding variables.

To quantify the abundance of insect resources present on each substrate, sticky traps were placed on each substrate type under light treatment (Petren and Case, 1994). One trap was placed 0.01 m from trap and another 3 meters from the trap. Results upheld findings from past studies of increased insect abundance in closer proximity to concentrated artificial light (Fig. 6). Concerns regarding potential injury of gecko organisms via sticky trap did not prove to have any effect on gecko traffic of structures observed.

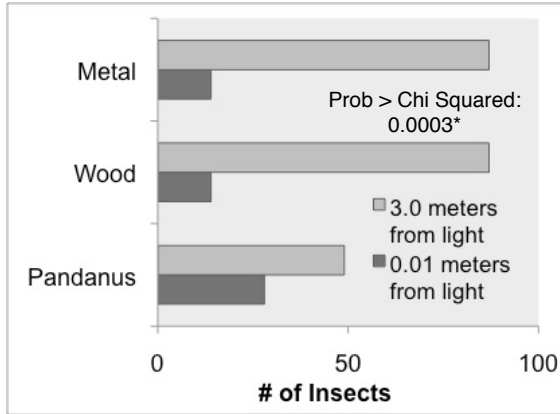


Figure 6. Reconnaissance study testing evaluating resource clumping by concentrated light via sticky trap method of Petren and Case study, 1994

Surrounding vegetation and built environment

Other variables were measured and assessed to ensure maximum consideration of potential patterns. Such variables include assessment of vegetation, other buildings, surface temperatures (near and far from concentrated lights), and air temperatures. The vegetation survey involved categorical quantification of herbs, trees, and lawn without taxonomic identification. Percent of roof touching vegetation was estimated and an accurate distance to closest building and tree reaching roof height was measured. Surveying was not conducted on nights with active heavy rainfall due to its effect on temperature and activity (Petren, 2010).

Statistical Analysis

To test the effects of light, substrate, and species present on total abundance, a 3-Way Analysis of Variance will be utilized. 2-Way Analysis Variance will be used to test the response of abundance of each species to light and substrate as well as an relative abundance (RA) of each species. An ArcSIN transformation will be utilized to normalize the percentage values (Zar, 1974). Linear regression analysis will be used to consider potential correlation between species richness (number of species present) and topographic complexity as a continuous variable.

$$RA = \text{ArcSIN} \left(\sqrt{\frac{\# \text{ organisms species } X}{\text{Total } \# \text{ organisms}}} \right)$$

RESULTS

Study site: measuring topographical complexity

Level of topographical complexity was calculated across metal, wood, and *Pandanus* spp. substrates demonstrating increasing levels in each category respectively. The amount of shingles counted in each of five haphazardly identified .5 meter quadrats was found to be greatest in the *Pandanus* spp. roofs and least in corrugated metal. Using ImageJ software, *Pandanus* spp. thatch and wooden shingles were found to have comparable surface areas (averaging .11112556 meter/shingle and .12123796 meter/shingle respectively) and corrugated metal surface area of .7 square meters per .5 square meter (Table 1).

Table 1. Mean topographic complexity of three assessed roofing substrates

Roofing Substrate Type	Avg. # of shingles	Mean Surface Area/shingle	Average Topographic Complexity
<i>Pandanus</i> spp.	90.6	0.11	10.07
Wooden shingle	21.65	0.12	2.62
Corrugated metal	1	1.40*	1.40

*in .5 m² due to continuous shingle characteristic

Assessing effects of topographic complexity and concentrated light

Concentrated light, roofing substrate, and species present had a significant effect on total counts of each organism. Using a 3-Way Analysis of Variance (ANOVA), the response of total observed geckos was tested against the effect of three mentioned variables producing significant results (Fig. 7). Species other than those assessed in this study were observed on the *Pandanus* spp. thatch roof and aggregated into an "other" category. All variables have significant effect on this continuous variable (Table 2). However, not all variables must be considered dependently in order to make predictions on numbers of organisms of each species observed (such as substrate with light treatment or all three variables in conjunction) (Table 2).

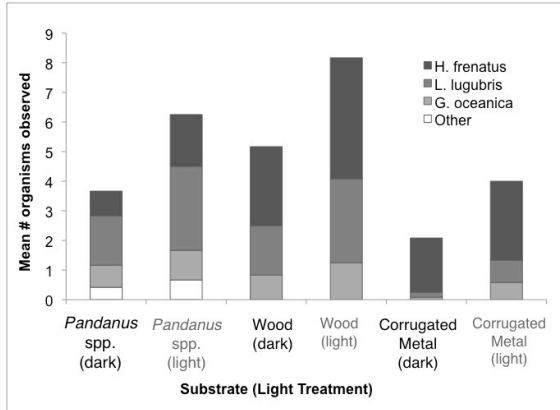


Figure 7. Average number of organisms observed on each substrate under light treatments identified to species. Statistical significance of effect of light and substrate on total counts and individual species *Hf* and *Ll* using analysis of variance

Diversity in topographical complexity quantified continuously has varying effects on gecko population dynamics. Increased substrate structure, defined by topographical complexity, has an effect on relative abundance of *H. frenatus* and *L. lugubris* (Fig. 8). This study demonstrates a significantly positive relationship between *L. lugubris* relative abundance and increase in topographical complexity (linear regression analysis, $R^2 = .53$; parameter estimate, $\text{prob} | t | < .0001$) and significantly decreasing relationship between relative abundance of *H. frenatus* with increasing topographic complexity (linear regression analysis, $R^2 = .66$; parameter estimate $\text{prob} | t | < .0001$). This assessment takes into consideration only replicates with applied artificial concentrated light. This was done in order to maximize abundance of observed organisms and ensure accuracy of observation and identification. Such significant patterns were not observed regarding *G. oceanica*'s relationship with this index. Using a 2-Way ANOVA, the effects of light and substrate and potential variable dependency were tested by assessing response of total abundance of *H. frenatus* and *L. lugubris*, respectively. Results demonstrate significant effect on both species by substrate (2-Way ANOVA for *Hf* and *Ll* respectively; F-ratio: 14.77, 24.40; $\text{Prob} > F$: $< .0001$, $< .0001$) and light (2-Way ANOVA for *Hf* and *Ll* respectively; F-ratio: 11.35, 14.01; $\text{Prob} > F$: 0.0012, 0.0004) (Fig. 7).

Table 2. Results of 3-Way ANOVA testing response of total counts to roofing substrate, species present, and light treatment

Variable	DF	Sum of Squares	F Ratio	Prob > F
Substrate	2	39.47	18.7	<.0001*
Species	3	192.03	60.8	<.0001*
Light Treatment	1	28.13	26.7	<.0001*
Substrate* Species	6	75.37	11.9	<.0001*
Substrate* Light Treatment	2	0.90	0.4	0.6540
Light Treatment *Species	3	11.79	3.7	0.0118*
Substrate* Species* Light Treatment	6	2.10	0.3	0.9192

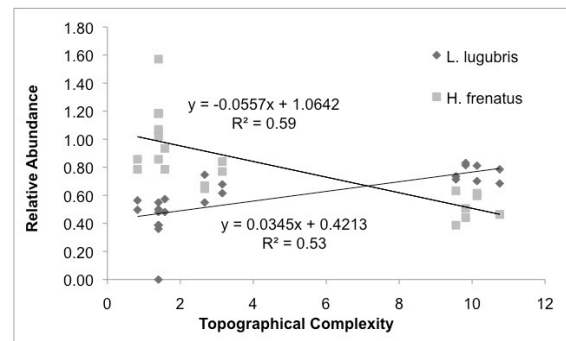


Figure 8. Linear regression analysis of relative abundance of *H. frenatus* and *L. lugubris* demonstrate significant patterns of correlation. Such significance of substrate on relative abundance proved through analysis of variance

The effects of light, substrate and potential variable dependency on relative abundance of *H. frenatus* and *L. lugubris* were also tested using 2-Way ANOVA. Results showed significant effect on both species by substrate (2-Way ANOVA for *Hf* and *Ll* respectively; F-ratio: 64.55, 40.95; $\text{Prob} > F$: $p < .0001$, $p < .0001$) (Fig. 8). This ANOVA demonstrated lack of significance for the effect of light treatment. This shows that light as a variable may not contribute to effect of one species directly on the other.

Surrounding vegetation and built environment

There are notable differences between each replicate in terms of surrounding vegetation, characteristics of the building and surrounding built environment (Appendix A). Wood and cement is a common substrate for eaves and walls respectively for all buildings. Microhabitats vary greatly amongst the buildings due to their varying uses and architectural style. Surrounding vegetation for most buildings are purely landscaped, while others are in close proximity to more naturalized forested areas. All buildings are over 3 meters from and within 100 meters of another inhabited building. There were no immediate data outliers due to these varying characteristics across replicates. For this reason, further investigation of the effects of microhabitat variability did not seem necessary for this study.

DISCUSSION

Adjusting for time and emergence

The temporal scale, while carefully considered via pilot studies, proved not to be a crucial facet to consider in the effect of concentrated artificial light on gecko population dynamics. Adjustment of resource level and compression of sampling proved not to produce unwanted variability of results.

The study considered the effect of time and application of light on emergence of gecko individuals in two ways. First, the pilot study's immediate increase and plateau in population after three days demonstrate a quick emergence time. This may be support assumptions of high general gecko abundance of all environments on Mo'orea, French Polynesia. Emergence of new individuals was tested in a second, opportunistic manner. Due to the study site's urban setting, experimental interruption by users of the space was a risk and resulted in high levels of lizard capture from three replicates in one instance. However, timed sampling was conducted within the parameters of set methods after this removal, producing results without detectable difference from "unaffected" sampling instances. This leads to a question of which of these organisms regained their territory and which organisms managed to find solace in the emptied roof due to niche-freeing. Future studies could focus on this aspect of gekkonid behavior through mark and capture of

Organism distance to light

There is a significant effect on in each species' distance to the resource-rich light area on each assessed substrate (2-Way ANOVA substrate, species, and variable interaction respectively; F ratio: 9.3324, 20.7833, 7.2374; Prob > F: 0.0001, <.0001, 0.0010) (Fig. 10). The significance of the interaction of species type and substrate on distance to light demonstrates that these variables must be dependently considered when predicting an organism's distance to light.

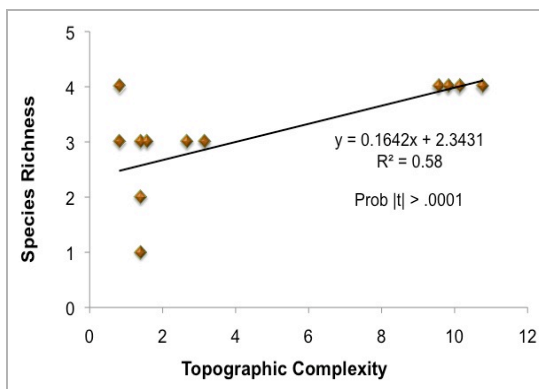


Figure 9. Linear regression analysis of correlation between species richness and topographic complexity

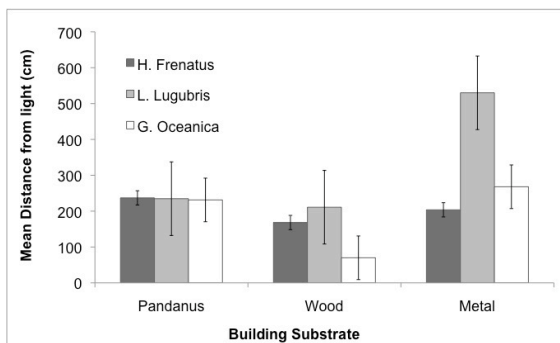


Figure 10. Distance to light of three gecko species in cm on each substrate

individuals, removal, and assessment of the origin of the organisms that re-emerge.

Assessing effects of topographic complexity and concentrated light

Substrate type (characterized both categorically and on a continuous gradient) and concentrated light showed significant effect on not only total gecko abundance, but relative abundance and species richness as well. A much higher proportion of aggressive *H. frenatus* is present on metal roofs, characterized by much lower complexity. Only on highly structured, *Pandanus* spp. roofs is the "other" category observed (made up of an aggregation of all species not identified as three species of focus). A study on Mo'orea of these three gecko species' distribution showed an absence of *H. frenatus* in non-built areas. Presence of more gecko species on the thatch roof may imply a mimicry effect by a naturalized *Pandanus* spp. roof of a more naturalized environment. In effect, this may produce what Cole, Jones, and Harris describe as "enemy-free space" for other gecko species (2005).

The affect of applying concentrated light has varying affects on gecko population dynamics. Due to clumping of resources around the lamp, increase in total abundance of gecko organisms was observed (Chi-Squared analysis, Prob > Chi-squared: 0.0003). Through analysis of variance, it is apparent that light and substrate do not need to be dependently considered in predicting the amount of observed individuals both in terms of total abundance and relative abundance.

Application of light did not significantly affect the relative abundance of *H. frenatus* and *L. lugubris*. This is surprising due to past findings on the negative effect of resource clumping on *L. lugubris*' body condition through interspecific competition with *H. frenatus* (Petren and Case, 1998). The contrary insignificance may be due to the size of observation area designated in this study. Resources may have been clumped into an area much smaller than the boundaries of designated study area. Future studies may find more success in assessing relative abundance within a smaller area to keep the scope of study within a precisely calculated area of resource clumping. More replicates would also contribute to larger sample size to

more accurately demonstrate effects of resource clumping.

Access to resources: distance to light

The significant differences of individuals' distance to light across the three observed species supports past assessments of this effect of resource clumping. There were a significantly higher number of insects observed on sticky traps .01 m from the light compared to sticky traps placed 3 meters from the light. Past studies have observed a decline in *L. lugubris* body condition in experiments under concentrated light treatments similar to that applied in this study (Petren and Case, 1998). Operating within the assumption of resource as a limiting factor away from the light, it can then be expected, that gecko individuals situated far from the light have disproportionately lower access to resources. *L. lugubris* is significantly further from the light source on metal roofs than wooden roofs or *Pandanus* spp. thatch roofs. The more structured *Pandanus* spp. substrate demonstrates comparable distance of each species to the light. Such a significant pattern cannot be identified in the context of *G. oceanica*. Further investigation of these *L. lugubris*' body condition through assessment of maintenance ratio would provide further grounds for conclusion of the effect of resource clumping and *L. lugubris*' indirect competitive disadvantage to *H. frenatus*.

Characterizing topographical complexity

Characterizing substrate by a continuous level of topographic complexity proved to be both useful and problematic. Understanding this level of topographic complexity demonstrated that the three substrates studied, produced clumped results around the respective substrates' roofs. When paired in a linear regression with species richness, such a correlation may be attributed by an underlying force by high species richness and relatively much greater topographic complexity on *Pandanus* spp. roofs. However, this apparent uneven gradient of topographic complexity in commonly used building substrates raises questions as to how medium ranges of topographic complexity of substrates may affect species richness and improve biodiversity.

Identifying other potentially useful substrate characteristics may aid future studies in the effect of architectural choice on

gecko population dynamics. Geckos rely on the Van der Waals force between their toe pads and surfaces to move forward and stay grounded, making the *H. frenatus* much less successful than native geckos of the Mascarene islands on certain substrates (Cole, 2005). Because *L. lugubris* and *G. oceanica* have been found in higher elevation forested sites absent of *H. frenatus* (Reeder, 2005), a similar relationship may exist with between these species as with those identified on Mascarene. This past study could provide a good model for studying the foot morphology of geckos found on Mo'orea and how building substrate presence affects population dynamics.

Level of insect resource on each substrate would be a valuable variable to quantify for the substrates assessed in this study. *Pandanus* spp. thatch and wood shingle roofs share a characteristic in being constructed of plant-derived materials (Mai, pers. obs.). Furthermore, the reconnaissance study of the effect of light and resource clumping on insect presence also showed notable differences in levels of resources across substrates. This could be tested for statistic significance in conjunction with topographic complexity between different substrates of three equally varying levels of structure. This would partition the effect of topographic complexity and substrate material in order to more clearly understand substrate effect on insect resources.

Predation and competition

Observations of interspecific and intraspecific gecko interactions demonstrate *H. frenatus* as a major player in observed acts of aggression. All three species were found in close enough proximity to assume interspecific communication on most roofs studied. However, instances of aggression and competition were only observed on wooden substrates between *H. frenatus* individuals and *H. frenatus* and *L. lugubris* when the resources were clumped due to artificial light. Further studies could quantify understand the factors contributing to the existence of these interactions.

Conclusions

Because urbanization may be an inevitable process, due to human population dynamics (Morel et. al., 2001) and cultural steadfastness,



Figure 11. Community-oriented method of building using local materials (*Cocos nucifera* thatch) on Huahine, French

alternative building practices and smart growth is a valuable option for mitigating the negative effects of our built environment on biological processes. Development operates on a variety of scales and methods (Fig. 11) (Morel et. al., 2001). However, while housing shortages worldwide require continuous streams of construction (Morel, et. al., 2001), industrialized building practices result in high levels of pollution from the energy consumed from extraction and movement of raw materials (Morel et. al., 2001). For example, this energy makes up nearly 8% of total energy used in the United Kingdom compared to 50% of energy used in occupation of homes (Morel et. Al., 2001). These numbers provide implications for shifting away from current practices for future efficiency.

Architectural style may be influenced by a number of factors including lifestyle, economic status, and convenience. Understanding the impact of human choices on ecosystem population dynamics is a valuable variable to consider on both a personal level and community-wide scale. This study sheds light on the effects of certain building practices through the lens of invasion biology and population dynamics, defining ways to mitigate the effects of urban sprawl and contribute to the progress of sustainable development.

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Appendix A: Site info for twelve structures observed in study

Site #	Location	Dimensions	Low Lying Herbs	Tree	Lawn	Cement	% Roofing touching vegetation	Dist. to near branch	Dist. to Building	UTM GPS N	UTM GPS W	Slope of Roof	Elevation (m)	Ground Substrate	Wall Substrate	Eaves Substrate
P1	Gump Dorm	11 x 7	1	2	3	0	4	0	18.65	199878	8063944	38	9.8	Lawn, Sand	No walls	Wood
P2	Atitia	12 x 6	3	1	3	0	0	0.6	4.9	199801	8063701	38	14.6	Lawn, Concrete	Pandanus	Wood
P3	Atitia	11 x 9	1	2	3	0	0	1.9	150	199791	8063662	38	22.9	Sand, Lawn	No walls	Wood
P4	Atitia	11 x 9	2	2	3	0	0	N/A	4.9	199809	8063693	38	14.6	Lawn, Concrete	No walls	Wood
M1	Gump Dive locker	12 x 7	1	1	3	2	0	N/A	3.3	199839	8063939	25	10.6	Lawn, Concrete	Concrete	Wood
M2	Atitia Bioclimatic	15 x 5	3	2	3	0	0	6.2	27.65	199813	8063752	25	24.9	Lawn	Plastic composite	Wood, Metal
M3	Gump Tool Shed	9 x 5	2	1	3	1	1	0.01	28.8	199786	8063982	25	7.9	Lawn, Concrete	Plastic composite	Wood
M4	Gump Tool Shed 2		3	2	3	1	8	0	24.25	199750	8064000	25	16.2	Lawn, Concrete	Wood	Wood
W1	Gump Wet Lab	12 x 7	1	1	3	2	0	N/A	3.3	199860	8063938	25	5.2	Lawn, Concrete, Sand	Concrete	Wood
W2	Maito Hillside Bungalow	8 x 6	3	3	3	1	0	2.1	101.2	199740	8063870	25	46.0	Lawn, Concrete, Wood	Wood	Wood
W3	Dorm dark	36 x 24	3	2	3	3	8	0	7.75	199844	8063996	25	1.2	Lawn	Concrete	Wood
W4	Totara Hillside Bungalow	8 x 6	2	3	3	1	0	N/A	12.3	199581	8063833	25	51.2	Lawn, Wood, Flagstone	Wood	Wood