DISTRIBUTION AND DISPERSAL OF THE SOUTH PACIFC TREE, *FAGRAEA BERTERIANA* (LOGANIACEAE)

ZACHARY R. HANNA

Environmental Science Policy and Management, University of California, Berkeley, California 94720 USA

Abstract. Tahitian legend states *Fagraea berteriana* is a gift of repentance from the god, Tane. The scientific community knows little more about this tree than its inter-island distribution in the South Pacific. I surveyed the island of Moorea to map an intra-island distribution of *F. berteriana* and quantify environmental characteristics surrounding the tree's growth. I tested dispersal hypotheses by collecting bird observations and conducting seed germination experiments that included a number of seed scarification treatments. The tree occurred in densities ranging from 44 to 244 trees/hectare and at elevations spanning from approximately 300 to 900 m. Density differed with significance between two sites, Tohiea and the Cross Island Trail. Tree density increased with greater elevations and more southerly aspects. Ninety-five percent of the trees sampled grew on slopes greater than 80%. There was no correlation between tree density and slope or between density and tree height. Tree density did not significantly differ between three substrate types: rock, rocky soil, and soil. I observed Silvereyes and Red-vented bulbuls consuming *F. berteriana* fruits and germination from seeds, although at a less than 1% rate. The germination success and bird observations served as a preliminary investigation of the dispersal of *F. berteriana* and fostered ideas concerning worthwhile future directions of study.

Key words: Fagraea berteriana; tree; distribution; Moorea, French Polynesia; density; elevational gradient; germination; bird dispersal;

INTRODUCTION

Many factors can influence the distribution of plants in the tropics (Clark et al. 2005). It can be difficult to parse out these factors. Islands can offer a solution to this dilemma.

Fagraea berteriana (A. Gray ex Benth), spelling as per Welsh 1998, is a little-known tree of the South Pacific. Currently, only broad distributional data exists for this organism. In order to obtain an understanding of how *F. berteriana* is distributed on the islands to which it is native, this study was conducted on Moorea, French Polynesia.

The belief of a number of Mooreans in rural agriculture occupations is that *F. berteriana* does not germinate from seed. Instead, the plant spreads asexually, growing

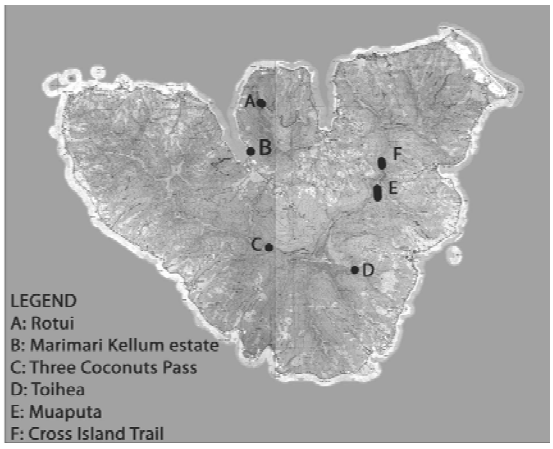

FIG. 1. Five sites sampled for *Fagraea berteriana* density and other associated environmental .variables on Moorea, French Polynesia.

from clippings of the plant's vegetative structure (Tapu, pers. comm.). One elder that was later interviewed believed that *F. berteriana* can grow from seed, but it takes much longer than growth from a clipping of the plant's vegetative structure. Mooreans thus prefer to use clippings when planting the tree in their gardens as part of their cultural tradition (Murphy, pers. comm.). A source in the agroforestry literature states that *F. berteriana* can be cultivated from seed (Elevitch and Wilkinson 2000). Steidl, in 2005, attempted to germinate 2840 seeds, scarifying 80 mechanically and 80 with an acid treatment and planting the seeds on various substrates. Steidl observed no germination (Steidl 2005).

Whether this tree germinates from seed is an integral piece of the study of this plant's distribution. Accordingly, this study sought to map the distribution, quantify associate environmental variables, germinate seeds, and study possible dispersal pathways of *F. berteriana*.

METHODS

Study organism

F. berteriana, in the family Loganiaceae, is a tree indigenous to the south Pacific. Its native range spans from French Polynesia west to Samoa and north to New Guinea (Welsh 1998, Elevitch and Wilkinson 2000). The plant's flowers are white and fade to yellow after five to six days (Hargreaves and Hargreaves 1970). It produces red, roughly-spherical, indehiscent fruits. Voucher specimens were deposited in the Jepson Herbarium, Univerisity of California, Berkeley.

Study sites

I conducted this study on Moorea, French Polynesia from 3 October – 15 November 2006. Moorea is a high, volcanic island in the Society archipelago in the South Pacific. Its tallest peak, Tohiea extends above 1000 m. The majority of native plants on islands in this region reside in the high elevation wet zone cloud forests and the subalpine zones at the high elevation ridges and peaks (Meyer and Florence 1996).

Previous study of this tree on Moorea documented its presence in the garden on the estate of Marimari Kellum located in southeast Opunohu Bay (Figure 1). I obtained all fruits supplying seeds for the germination experiment from Marimari Kellum's. The *F. berteriana* population on her property exceeds two-hundred individuals and these are hypothesized to be of the lineage of one tree planted in Kellum's garden thirty years ago (Steidl 2005, Kellum, pers. comm., Mishler pers. comm.).

Distribution

I searched for *F. berteriana* within 15 m of either side of the trails and roadways on Moorea (Figure 2). While searching, I used a GPS and compass to record the coordinates of all sites visited. This spatial data was then plotted on a map (produced by Ministere de L'Urbanisme des Transports Terrestres et de L'Administration Generale, 1989) from which I obtained elevational information.

Environmental Data

In addition to the distributional sampling of *F. berteriana*, I quantified a number of ecological variables associated with the plant's growth. At sites supporting populations of <10 individuals, I recorded the slope, aspect, height from ground to extent of canopy, growth substrate for the trees present, number of trees within a 5 m radius.

Where populations of >10 individuals were found, I also took density data by measuring the distance from a random point to the nearest *F. berteriana* individual (Cottam and Curtis 1956). This nearest *F. berteriana* individual was then my sample tree at which I logged the same environmental data previously mentioned as recorded at the sites

with <10 individuals. I took ten samples in each of five study sites, except for the Cross Island Trail, where the terrain conditions allowed me to only take seven samples.

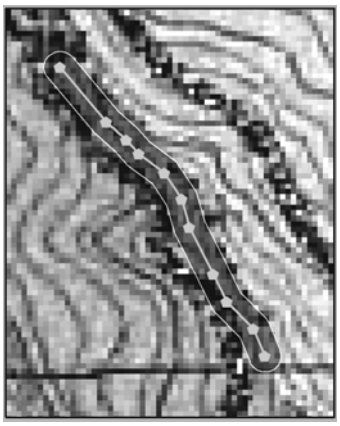

FIG. 2. Map of Rotui sample site on Moorea, French Polynesia. Points along line are the random points from which the distance to the nearest *F. berteriana* individual was measured. The buffer is the 15 m on either side of the trail that was searched.

Disperser observations

Fruit doves are present on Moorea and in order to see if they could be possible dispersers of *F. berteriana* seed, I observed birds on fruiting *F. berteriana* individuals at high and low elevation sites. On three days in November, beginning between 5:40 and 6:15 AM, I observed fruiting *F. berteriana* individuals for four hours. Observations were conduced at two high elevation sites, Three Coconuts Pass and Cross Island Trail, and at the low elevation site, Marimari Kellum's garden. On the tree being observed in Marimari's garden, I counted the total number of *F. berteriana* fruits present and the subset of these fruits that displayed evidence of consumption by birds.

Germination Experiment

I attempted to germinate individual seeds between moist filter paper in petri dishes by placing twenty-five seeds in each of six petri dishes, for a total of 150 seeds. These germinated from 10 October – 17 November 2006. Seed quantity was maximized in order to address the question of whether *F. berteriana* can propagate from seed. I approximated the number of seeds in *F. berteriana* fruits by first measuring the diameter of a fruit. I then weighed the flesh of the fruit, excluding the rind. A small section of this flesh was then weighed and the seeds were counted. I calculated that section's proportion of the total weight and used this to estimate the total number of seeds in the fruit. This procedure was repeated for 10 fruits and used to construct an approximate number of seeds per unit diameter of fruit.

I planted approximately 27,900 untreated seeds in soil and 28,600 spread out on coconut bark and these germinated from 27 October – 17 November. Approximately 16,400 seeds were spread out on a rock surface and these germinated from 6 November – 17 November.

To simulate passage through a bird's digestive tract, I treated seeds with 6 M HCl for 15, 30, and 45 second time intervals and followed the HCl treatment with rinsing. I treated approximately 10,200 seeds for 15 seconds with HCl, 11,900 seeds for 30 seconds, and 10,800 seeds for 45 seconds. I planted these seeds in soil on 8 November and they germinated until 17 November.

The final seed treatment was coffee. Seeds were submerged in a coffee solution for 19.5 hours and then rinsed. I spread approximately 17,500 seeds on rock, 17,100 seeds on coconut bark, and I planted 16,600 seeds in soil. These germinated from 7 November – 17 November.

I planted the seeds in 35x15 cm trays, which I placed in an area with partial shade and watered twice a day. I elevated the trays on brick with water moats surrounding them after an initial ant invasion resulting in the loss of a few seeds. Sterilized potting soil was utilized for the soil treatments and also in the trays under the rocks and coconut bark in treatments involving those materials. As a

control, I left one tray with just sterilized soil and no seeds.

In total, the germination experiments involved approximately 160,000 seeds.

Ant dispersal

Fire ants colonized the untreated seed experiments on 28 October, the second day of the experiment. For approximately 12 hours, they removed seeds from the experiment and carried them away along their ant trail. I counted the number of seeds that the ants carried past an arbitrary point on their ant trail. Beginning at 4:00 PM on 28 October, I counted seeds for five minutes and I replicated this interval 5 times, for a total of 25 minutes of observation.

Statistical analyses

I chose to use the continuous, plotless density measure of the distance between a random point and the nearest *F. berteriana* individual instead of the defined area measure of the number of trees within a 5 m radius of the sample tree because the plotless measure is able to pick up changes in density on a larger and finer scale than the fixed radius method. To test the validity of this, I ran a linear regression between the log of the distances and the number of trees in the plots. In order to obtain a normal distribution, I first applied a log transformation of the distances to the nearest *F. berteriana* individual. Henceforth, the distances to the nearest *F. berteriana* individuals will be referred to as density.

I ran linear regression analyses of density and elevation, density and aspect, density and height, and density versus slope. I ran ANOVA's for density versus substrate and density versus sample site and employed Student's t-test with a Bonferroni correction to reveal which categories differed with significance. All statistical analyses were computed with JMP IN version 5.1.2.

RESULTS

Distribution

Five sites supported populations of > 20 *F. berteriana* individuals. These five sites were the Cross Island Trail, Muaputa, Tohiea, Three Coconuts Pass, and Rotui (Figure 1). The *F. berteriana* individuals found at these sites was almost exclusively confined the ridge tops and just down from the ridgelines. The low end of the elevational range for natural populations of *F. berteriana* began at about 300 m and extended to 700 m. Scattered individuals occurred up to approximately 900 m elevation, such as just below the summit of Rotui. *F. berteriana* grew along the coast of Moorea, but the instances in which this was observed were all associated with cultivation of the plant as an ornamental (Appendix 1).

TABLE 1. *Fagraea. berteriana* densities at five sites on Moorea, French Polynesia.

Site	Tohiea	Three Coconuts Pass	Cross Island Trail	Rotui	Muaputa
Density (trees / ha)	244	44	50	67	118

Environmental data

F. berteriana density, as calculated using the nearest individual method, varied between the five sites supporting >10 individuals (Table 1). I found *F. berteriana* on three different substrates: rock, rocky soil (soil with numerous, large rocks), and soil. Out of the 47 trees at the five sample sites for which slope was measured, only 2 trees were growing on <80% slopes. Seventeen of the 47 trees were found on >150% slopes. Heights of

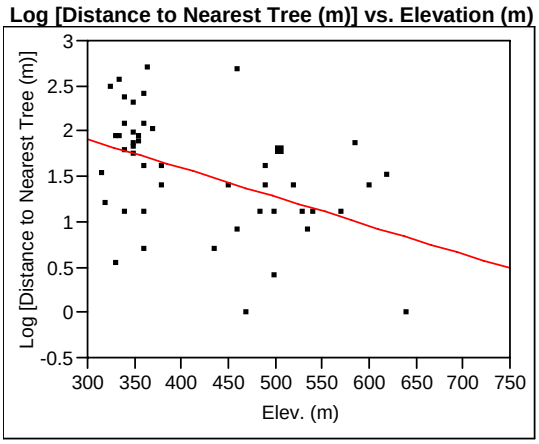

FIG. 3. The log of the distance from a random point to the nearest *F. berteriana* individual versus the elevation at which the measurement took place on Moorea, French Polynesia.

sampled *F. berteriana* ranged from 1 m to 12 m, but the average height was 4.3 m. Aspect measurements did not reveal that *F. berteriana* was strictly confined in its orientation to the sun.

Disperser observations

No birds were observed consuming *F. berteriana* fruits at either the Three Coconuts Pass or the Cross Island Trail site. While I did not sight any birds on or near the observation tree on Three Coconuts Pass, I did identify 5 Red-vented bulbuls, *Pycnonotus cafer*, and 9 Silvereyes, *Zosterops lateralis*, within a 5-meter radius of the tree observed at the Cross Island Trail site. At Marimari Kellum's garden, 6 Red-vented bulbuls and 5 Silvereyes consumed *F. berteriana* fruits. Eleven additional Red-vented bulbuls and 41 other Silvereyes were visitors to the observation tree. Out of 80 *F. berteriana* fruits on the observed tree, 40 displayed evidence of bird consumption.

Germination experiment

The average *F. berteriana* fruit size was 23.5 mm and this contained approximately 1200 seeds. *F. berteriana* can germinate from seed on Moorea. The untreated seeds were the only seeds that germinated. One untreated seed in soil sprouted on 7 November and a second on 12 November. One untreated seed on coconut bark germinated on 7 November and four germinated on 11 November. No other seeds germinated. The three HCl treatments exhibited the growth of a light green mold in the soil around and on the seeds.

Ant dispersal

The ants removed an average of 7 seeds per minute from the untreated seed experiments. Some ants were trapped on the trays when I isolated the experiment within a moat. These ants continued to move seeds around. By 17 November, they had removed virtually all of the seeds from the coconut bark and cashed them in the soil beneath the bark. Four of the five germinations that occurred with the coconut bark treatment took place under the bark after ants moved the seeds there. One occurred on the bark.

Statistical analyses

F. berteriana density was significantly correlated with elevation ($P=0.0013$, $R^2=0.2082$) (Figure 3) and aspect ($P=0.0458$, $R^2=0.0876$) (Figure 4). There was no significant correlation of density and tree height ($P=0.9129$, $R^2=0.0003$) or density and slope ($P=0.2758$, $R^2=0.0263$).

Mean *F. berteriana* density did not differ significantly by substrate type ($P=0.8924$, $R^2=0.0061$). Between some sites, density did vary significantly ($P=0.0113$, $R^2=0.2610$). Toihea differed significantly from Three Coconuts Pass ($P=0.0070$) and the Cross Island Trail ($P=0.0036$).

DISCUSSION

Moorea hosts natural populations of *F. berteriana* of considerable densities (Table 1).

The tree density at Tohiea, the densest site, was similar to the density of Douglas-fir (200 stems/ha) in an old-growth, mixed-conifer stand in the Sierra Nevada of California, USA (Ansley and Battles 1998). These natural *F. berteriana* populations were generally confined to at or just below ridge tops. Not once did I find natural populations on lowland slopes.

F. berteriana density increased with higher elevations and with a more southerly exposure to the sun (Figures 3 and 4). A rapid increase in rainfall corresponds with moving higher in altitude on high islands, such as Moorea (Meyer and Florence 1996). On Moorea, in the southern hemisphere, slopes facing the northwest receive the most intense solar radiation. This was the aspect with the lowest *F. berteriana* density. Higher *F. berteriana* densities were correlated with increased rainfall and shade conditions.

Density only differed significantly between two pairs of sites: Tohiea and Three Coconuts Pass and Tohiea and the Cross Island Trail. Tohiea's *F. berteriana* population reached 500 m, approximately 180 m higher than the populations at Three Coconuts Pass and the Cross Island Trail. This difference in elevation may correspond with a drastic difference in rainfall (Meyer and Florence 1996).

The observation that Red-vented bulbuls and Silvereyes will consume *F. berteriana* fruits is a first step in a study of its dispersal. The fact that these birds are also found where there are natural populations of *F. berteriana* allows for the possibility that the birds may be consuming the fruits there also. It is likely that the seeds of *F. berteriana* on Moorea will be viable after passing through a bird's digestive tract since the plant is documented as dispersed by pigeons in the Marquesas (Petard 1986, Whistler 2001). Red-vented bulbuls and Silvereyes are both introduced, non-native birds on Moorea (Meyer and Florence 1996). The bird that once may have dispersed *F. berteriana* on Moorea may now be extinct.

There are nine native ant species present on Moorea (Ledoux et al. 2006). Ant dispersal of *F. berteriana* does not explain the growth of the tree on rock substrate. I observed the ants removing seeds from a non-soil substrate (coconut bark) and storing them in the soil. Germination on rock would be unlikely in the case of ant dispersal.

Seven successful germinations out of approximately 160,000 seeds is quite a low germination rate. With 1200 seeds in the average fruit, it may be that the germination rate is really this low. Alternatively, it may be that the partially shaded conditions in which the experiment was conducted were not optimal for germination.

The distribution of *F. berteriana* on Moorea

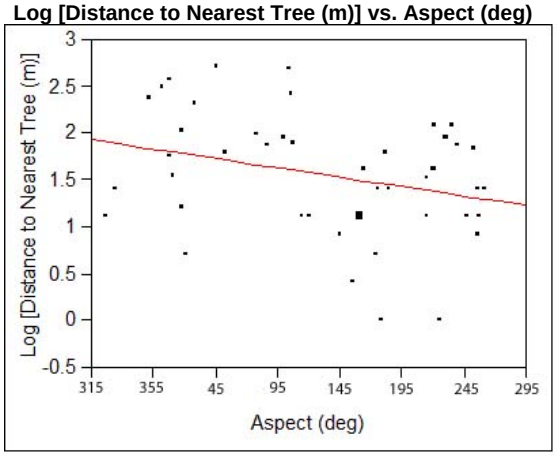

FIG. 4. The log of the distance from a random point to the nearest *F. berteriana* individual versus the aspect of the tree on Moorea, French Polynesia.

is a patchy one, which may be indicative of dispersal by frugivores (McConkey et al. 2004). The tree appears to thrive at high elevations with shade and ample rainfall. This study suggests that the germination rate of *F. berteriana* is quite low. If the tree is dispersed by birds, then very few of the dispersed seeds develop.

Why natural populations of *F. berteriana* are almost exclusively confined to the very tops of ridges still remains to be explained. Study of the viability of seeds after passage through Silvereyes and Red-vented bulbuls seems the next logical step that must be made

before gaining an idea of the dispersal of *F. berteriana*. This question of dispersal may play a key role in addressing the ridge top distribution phenomenon.

ACKNOWLEDGMENTS

I thank Tom Bell, Joel Nitta, Mike O'Dowd, and Jessica Castillo for field assistance. I thank the Gump Station for hosting me during my time in Moorea. Also deserving much gratitude is Marimari Kellum for allowing me to collect fruits on her property. Finally, I thank all of the GSI's and professors involved with the Moorea course for their encouragement and essential advice and inputs into this project.

LITERATURE CITED

Ansley, Jolie-Anne S. and John J. Battles. 1998. Forest Composition, Structure, and Change in an Old-Growth Mixed Conifer Forest in the Northern Sierra Nevada. *Journal of the Torrey Botanical Society* **125**: 297-308.

Clark, C. J., J. R. Poulsen, B. M. Bolker, E. Connor and V. T. Parker. 2005. Comparative Seed Shadoes of Bird-, Monkey-, and Wind-Dispersed Trees. *Ecology* **86**: 2684-2694.

Cottam, G., and J.T. Curtis. 1956. The use of distance measures in phytosociological sampling. *Ecology* **37**: 451-460.

Elevitch, Craig R. and Kim M. Wilkinson, Eds. 2000. *Agroforestry Guides for Pacific Islands*. Permanent Agriculture Resources: Holualoa, Hawaii.

Hargreaves, Dorothy and Bob Hargreaves. 1970. *Tropical Trees of the Pacific*. Hargreaves, Kailua, Hawaii.

Ledoux, Stephanie, Yohann Allouche, Jean-Yves Meyer, Rudolph Putoa and Herve Jourdan. 2006. An update of the ant fauna of Tahiti and Moorea (French Polynesia). http://iussi.confex.com/iussi/2006/techprogram/P2498.HTM

Mayfield M. M., D. Ackerly, and G. C. Daily. 2006. The diversity and conservation of plant reproductive and dispersal functional traits in human-dominated tropical landscapes. Journal of Ecology **94**:522-536 ER.

McConkey, Kim R., Hayley J. Meehan and Donald R. Drake. 2004. Seed dispersal by Pacific Pigeons (*Ducula pacifica*) in Tonga, Western Polynesia. *Emu* **104** : 369-376.

Meyer, Jean-Yves and Jacques Florence. 1996. Tahiti's native flora endangered by the invasion of *Miconia calvescens* DC. (Melastomataceae). *Journal of Biogeography*. **23**: 775-781.

Petard, Paul. 1986. *Quelques Plantes Utiles de Polynesie Francaise et Raau Tahiti*. Editions haere po no Tahiti. Papeete.

Steidl, Sara A. 2005. Biology of *Fagraea berteroana*: habitat specialization and conditions for biological success of an anomalous population. Moorea Biology and Geomorphology of Tropical Islands, Student Research Papers. University of California, Berkeley.

Welsh, Stanley L. 1998. Flora Societensis: a summary revision of the flowering plants of the Society Islands. E.P.S. Inc., Orem, Utah.

Whistler, W. Arthur. 2001. *Plants in Samoan Culture: The Ethnobotany of Samoa*. Isle Botanica, Honolulu, Hawaii.

APPENDIX A

Map of the sites searched on Moorea, French Polynesia. The white areas are where no *F. berteriana* was found and the black areas are where the tree was found.