Round Island Plant Survey 2017-18

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compiled by
Phil Lambdon

with contributions from
Luke A'Bear, Jo Chambon, Martine Goder, Beth Govier, Aurelie Hector & Nik Cole

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Contents

1 Acknowledgements

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2 Introduction

Environmental concerns, such as climate change, habitat loss and the spread of invasive species rank amongst the most pressing issues facing the world today. Natural habitats are disappearing to agriculture, logging and urbanization at an unprecedented rate. Remote islands such as Mauritius are particularly under threat because they possess high levels of endemism, and experience severe pressures from an expanding human population in a very confined area. Native Mauritian vegetation has been reduced to 5% of its original cover, resulting in the loss of many endemics: flowering plants (11%), birds (63%) and reptiles (31%) (Florens et al., 2012; Florens, 2013).

The need to halt, and even reverse, some of the declines is urgent. The Round Island initiative has long been a flagship of efforts to achieve this goal in the Mascarenes. Round island is a small (219 ha) islet, lying approximately 22 km off the north coast of Mauritius. It is remarkable for the high concentration of endemic fauna, which have long since vanished from the mainland and are now found nowhere else. These include three surviving species of lizard (Durrell's night gecko *Nactus durrellorum*, Günther's gecko *Phelsuma guentheri* and Telfair's skink *Leiolopisma telfairii*) and one snake (keel-scaled boa *Casarea dussumieri*). There are also regionally important seabird populations, including a unique hybrid petrel complex (the 'Round Island petrel').

The ecosystem of Round Island was largely destroyed following the introduction of rabbits (*Oryctolagus cuniculus*) and goats (*Capra hircus*) in the early 1800s. By the time vertebrate grazers were eradicated in the late 20th century (by 1986), most of the vegetation cover had disappeared. Only the latan palm (*Latania loddigesii*) remained in viable numbers (1,500 individuals), with few other tree species (*Hyophorbe lagenicaulis*, *Dictyosperma album*, *Fernelia buxifolia* and *Gagnebina pterocarpa*), all reduced to less than ten specimens (North & Bullock, 1986; Bullock et al., 2002).

Efforts to 'rewild' the island began soon after the eradication. In 2002, a permanently-manned field station was established with a yearly programme of large-scale plant cultivation and restoration, which has been in operation ever since. Notable success resulted. Many tens of thousands of *L. loddigesii* reappeared, together with an encouraging increase in the bottle palm, *H. lagenicaulis*. Due to the almost total eradication of any propagules to spark a natural return, hardwood recovery has only been possible with human intervention, but several thousand shrubs and trees have been planted back onto the island. However, maintaining the effort has, at times, been a struggle. As numbers of established plants increased, it has proved increasingly difficult to keep track of which species had survived, where and how many. This information is essential to determine whether a particular approach has succeeded.

Problems are exacerbated by the fact that habitat restoration in the very dry environments present on Round Island can be extremely challenging. Conditions are harsh, leading to heavy sapling mortality. Furthermore, it has been necessary to recreate most elements of the ecosystem from scratch. There is little habitat structure to create shade, and numerous non-native weeds have spread rampantly with little to stop them. Some species have proved more difficult to establish than others. Despite the challenging nature of the task, there has been little opportunity to review progress since the start of the planting programme. It is unlikely that approaches will always 'get things right' at the first attempt, so progress reviews are sometimes necessary to refine techniques.

To address these issues, funding was sought from the Mohammed Bin Zayed Foundation in 2017 for the current project. The aims were firstly to advance the practical conservation of key plant species, but also to conduct a scientific review of progress based on updated evidence. The results of the review, and a summary of resulting recommendations, are presented below.

3 Approaches

3.1 Rewilding activities

Restoration planning was focused around four key species: *Coptosperma borbonicum* (bois de rat), *Diospyros egrettarum* (white ebony), *Eugenia lucida* (bois clou) and *Polyscias maraisiana* (bois de boeuf). These species were selected because they: (a) are scarce or threatened on Mauritius, (b) they are functionally important and have much potential to contribute to the restoration of Round Island's ecosystem, and (c) have previously proved difficult to establish. For each, a minimum of 500 seedlings were reared in cultivation between June and October 2017. In addition to the target species, eight further 'lower-value' tree/shrub species were grown in varying quantities to provide cover, improve habitat structure and increase the diversity of the planting sites. An additional cohort of *D. egrettarum* was kindly supplied by the National Parks and Conservation Service, grown in their facility on mainland Mauritius.

Plants were reared either on Round Island or, where there was insufficient capacity, in the nursery on Ile aux Aigrettes. In the latter case, they were transported to Round Island in March-April 2018 according to established biosecurity protocols. The plants were bare-rooted to avoid transferal of soil, visually inspected to remove insect pests or diseased foliage, and treated with fungicide. They were wrapped in wet paper, placed in sealed barrels and transferred to the island by boat within five hours. On arrival, the propagules were immediately re-potted after a further visual inspection, and the foliage was trimmed heavily to reduce transpiration while they re-established.

From February 2018 onwards, a process of hardening began, designed to acclimatize the plants to field conditions. Once large enough, they were subjected to increasing exposure to sun, starting at one hour per day and building to several hours. Watering was also reduced. Any plants showing visible signs of stress were temporarily removed from the programme to recover.

Planting took place between May and June 2018, as this is the coolest, wettest part of the year. Only some individuals were considered large enough or sufficiently well-hardened to be used, with the remainder retained in the nursery until 2019. A site on the western side of the island was chosen to provide suitable conditions for establishment. Plants were inspected for pests before released, and each was then introduced to a moderately sheltered micro-habitat with a good depth of soil. The location was marked using a GPS unit and the plant labelled with a coded metal tag. Immediately, the soil was well watered and a *Pandanus* leaf litter mulch applied. Except during periods of heavy rain, the site has subsequently been visited at weekly intervals to re-water and remove invasive weeds.

3.2 The plant census

The plant census started on 11th November 2017 and finished on 12th July 2018. The primary objective was to build an up-to-date catalogue of surviving trees and shrubs on Round Island. A comprehensive survey was impossible given that there are many tens of thousands of palms now flourishing on the western slopes, so the four most problematic species (*L. loddigesii*, *Pandanus vandermeeschii*, *Dracaena reflexa* and *Scaevola taccada*) were omitted. Naturally regenerating individuals were only recorded if they had reached a height of at least one metre.

All extant specimens located were GPSed and assigned an identification code. This recording system will henceforth be maintained by the Round Island management programme to monitor performance, track the provenance of seed collections and to influence the spatial design of future planting programmes. In addition, some simple descriptive parameters were collated to assess the performance and environmental status of the plant. These included height, longest breadth, and simple categorical scores for plant health, insect damage and exposure (to sun and wind).

3.3 Soil survey

Soils are important determinants of plant health and community composition, but very little is known about those on Round Island. The objective of this survey was to obtain some preliminary information on substrate depth and chemical composition in key habitats.

Two belt transects, each 50 m wide × 880 m long, were established along an altitudinal gradient from the Field Station plateau to the summit ridge. Within the transect area, soil depth was sampled every 4 m by inserting a steel probe down to the bedrock. The spacing of the sample points was monitored by GPS. Approximately along the line of the transects, thirteen 5 × 5 m quadrats were also selected, representative of a range of conditions. Twelve of the quadrats had combinations of: (a) deep or shallow soils, (b) open, sparse or closed tree canopies, and (c) shearwater burrows absent, sporadic or at high densities. The final quadrat was selected in an open area exposed to high tortoise-grazing pressure. At four random positions within the boundaries, the soil composition was sampled by taking a 7.5 cm diameter core to a depth of approximately 15 cm. Any leaf litter overlying the sample was removed before collection.

The soil samples were obtained on 1st June 2018 and immediately stabilized in dry ice at the Field Station to prevent microbial decomposition. They were shipped back to the mainland on 2nd June and transferred to a freezer for storage. Bulked samples from each site were analysed at the Mauritius Sugarcane Industry Research Institute for pH and total organic carbon, according to the Walkley-Black chromic acid oxidation method (Schulte, 1988). Individual replicate samples were analysed using a basic soil fertility test kit (SK200, Palintest, Gateshead, UK). This permitted an estimation of pH, total NO_3^{2-}, PO_4^{2+} and K^+, given to an approximate range by comparison of reagent colour changes against a colour chart. To perform the tests, soils were crushed and thoroughly mixed in commercially-purchased deionized water, after pre-testing to ensure that the water contained negligible levels of contamination.

3.4 Data analysis

Data on the number and species planted on Round Island since 2002 are stored electronically on CD in the MWF offices, Vacoas. However, following regular changes in the team personnel and management structure over this period there have been considerable variations in recording effort and methodology, and there are numerous gaps. A review of the data set was undertaken, and the information compiled into a single MS Access database so that it could be made more easily available. The aim was to identify the original planting year of as many current specimens as possible, so that the growth rate could be calculated (as a measure of performance) and survivorship assessed for each year and species.

All spatial data processing was conducted using QGIS 3.2.2 and GRASS GIS 7.4.1. Topographical data were obtained from a 1 m resolution contour map of the island, created from drone footage shot by Annette Stephani in 2017. The line contour layer was rasterized into a digital elevation model. From this, altitude, slope and aspect rasters were derived using built-in GRASS functions. For the soil transects, substrate depth was modelled using an interpolated surface raster, created using the "v.surf" function in GRASS with an inverse distance-weighted smoothing function. To reduce spatial mis-matching, all mapped parameters were overlain with a 20 m grid and averages taken for each cell.

All statistical analyses were conducted in R3.5.1 (R Foundation for Statistical Computing). The volume of each plant was assumed to be a hemispheroid defined by the height and breath. Two indices of 'restoration success' were examined:-

(1) Plant performance was measured by the rate of lifetime growth, calculated as (volume / no. of years since planting).
(2) Survivorship was calculated as the proportion of specimens in the original planted cohort to have survived to the present day. Separate values were obtained for each planting site and each year.

The relationship between 'success' and the various factors affecting it were investigated using general linear models with appropriate statistical structure. Using the final multivariate equations from the above analyses, predictive spatial maps were finally generated by interpolating an expected success score to every cell in the 20 × 20 m grid. More details on these analyses are given in an additional, comprehensive report (Lambdon, 2019a).

3.5 Habitat survey

Fieldwork was conducted during the winter when most species were in good condition (April – July 2018). The island was divided into a grid of 100 × 100 m (i.e., 1 ha) cells, each of which was searched for 3-4 hours. Transects were walked through the cell and a list of vascular plant species was compiled. At the end, an abundance score was allocated to each species according to a six-point scale (Very rare, Rare, Frequent, Abundant, Dominant). The abundance of each habitat type encountered across the cell was also recorded as a % of the total area. Habitats were classified into 14 types, modified from Johansson (2003).

Within each grid cell, three smaller-scale quadrats were selected to be representative of the most characteristic habitats in the cell. Quadrats were typically 5 × 5 m, but size varied according to the extent of the vegetation. In each case, a species list was compiled, and % cover estimated for each taxon. Additional data to describe the physical structure of the habitat were also compiled. Species were classified into one of three categories based on their status: (1) Round Island native, (2) Mauritian native, or (3) Alien, based on evidence presented in the Flore des Mascareignes (Bosser et al., 1980-2014). For further details of definitions used in the habitat survey, see (Lambdon, 2019a).

4 Achievements and findings

4.1 Rewilding

In total, 1,000 trees were established at the planting site during 2018 (Plate 1). These included 63 *C. borbonicum*, 86 *D. egrettarum*, 76 *E. lucida* and 125 *P. maraisiana*. The remainder were companion species designed to improve habitat structure and diversity.

The total number of target species planted was somewhat less than the original number of seedlings germinated. This was partly due to mortality. Some deaths occurred for unknown reasons during propagation, and some were associated with the hardening process. It is likely that mealy-bug infestations in the Round Island nursery were a contributory factor in both stages, although considerable effort has been maintained at keeping pest outbreaks under control and their impact was not substantial. Further losses inevitably occurred after transfer of bare-rooted individuals from Ile aux Aigrettes, but leaf-trimming seemed to reduce the level of stress caused by this traumatic treatment. Deaths during the seedling stage are to be expected, but after re-potting the overall mortality rate was under 15%.

The remainder of the saplings not introduced to the wild were retained in the nursery for an additional season, either because they had not reached sufficient size to be planted or because they were deemed to be insufficiently hardened. It was considered safer to adopt this cautious approach rather than risk losing valuable resources by trying to fast-track them. All four target species are relatively slow-growing, and few develop far enough within a year to be resilient. This means that substantial stocks should be available for future planting. In addition to the *D. egrettarum*, which were held back, almost 300 additional individuals were transferred from the NPCS nursery in April, only a few of which were planted. As a result, there were 400 of this species held in the nursery in June 2018. There are over 100 of each of the other target species available for 2019, with further seed sown in recent months.

Initial observations suggest that survivorship has been reasonably good, although formal monitoring will not be conducted until mid-2019.

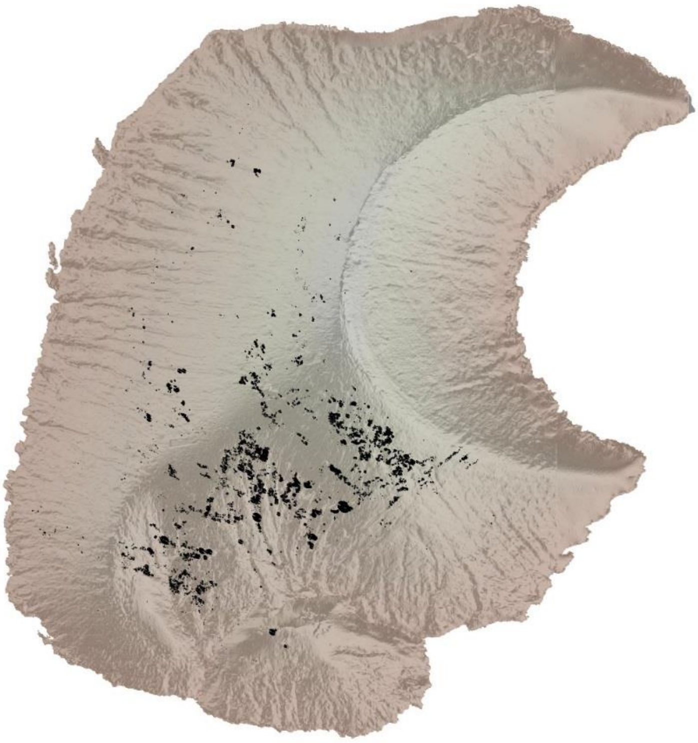
4.2 Plant census - overview

In total, 10,620 trees and shrubs were documented during the plant census, 7,747 of which were considered likely to have been planted and 2,873 were assumed to be natural regens. A further 561 individuals could not be assigned to either group with certainty. Their abundance and distribution have been recreated in Fig. 1. Since the 1990s, at least 29,745 plant specimens have been established on Round Island. These have been mostly trees and shrubs except for 82 individuals of the critically endangered herb *Aerva congesta* and approximately 100 of the native grass *Chryopogon argutus*. For woody species, the overall survival rate has been 26.2%.

4.3 Lifetime growth rates

Due to small sample sizes, it was only possible to include the 18 most abundant species in the analysis. These differed substantially in their mean lifetime growth rates (Table 1). To some extent, this enables us to identify which species ‘perform’ best on Round Island, although on its own this is too simplistic. We might expect that early successional species grow faster than later successional species, but both groups are needed in the ecosystem. The rank order generally reflects ecological expectation, although *C. borbonicum* and *Volkameria heterophylla* may be performing poorer than this trend might predict. Closer studies are needed to determine why this should be.

Figure 1 Map of Round Island showing the positions of all surveyed trees and shrubs. Individual specimens have been plotted as an ellipse, of area proportional to the plant volume and approximately equivalent to the footprint of the plant in real terms.



General linear models were used to determine which environmental parameters had most effect on growth rate. Seven explanatory variables had a significant influence which was thought to be reasonably independent, i.e., not heavily correlated with one of the other effects (Fig. 2):-

(a) *Exposure.* Growth rates increased reasonably strongly for plants in sheltered conditions, but when the plant became too sheltered the performance declined again. The only species for which this did not hold was *Psiadia arguta*, which seemed more sensitive to shading.
(b) *Interference*. Smothering by vines had a generally negative effect on growth rate, and this was again consistent between species. According to model predictions, an 'average' 15 year-old plant in the High interference category accumulated less than half the biomass than a that of a free-growing individual.
(c) *Altitude*. This was the most efficient explanatory variable, accounting for almost 50% of the spatial effect. There was an increase in growth rate with increasing planting altitude, peaking near 200 m and then declining again on approaching exposed ground near the summit. *Psiadia arguta* was again the only species to demonstrate variation from the general trend, peaking in performance at a lower altitude (100-150 m).
(d) *Slope*. The Slope effect was less consistent, but still showed a clear effect. 'Average' plants on steep slopes were predicted to reach almost three times the volume of plants grown on level or very shallow slopes after 15 years' growth.
(e) *Total palm cover*. This test demonstrated modest explanatory power and differences between categories were not particularly consistent. However, plants showed a tendency to grow more quickly as Palm density increased. The growth rate declined again above 25% cover.
(f) *Tall weed cover*. Although explanatory power was similar to that for Total palm cover, the differences between categories were small. Plants generally grew faster when there were more tall weeds growing in the vicinity. This is probably because both weeds and trees fare better in moist conditions on good soils.
(g) A*spect*. The Aspect effect was small. There was little difference in growth rate except for a markedly increased growth rate observed on southerly slopes.

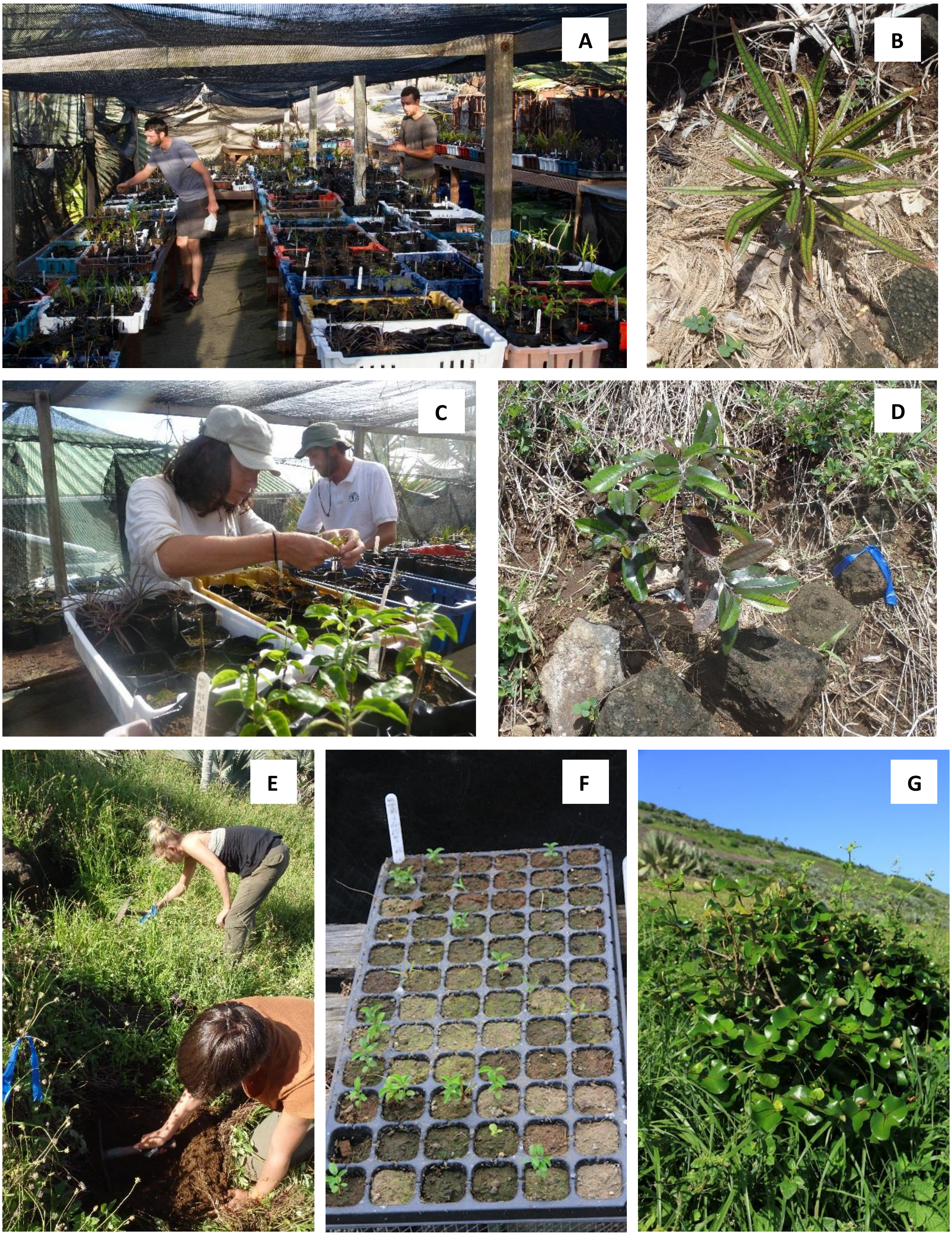


Plate 1 Rewilding activities: (**A**) Round Island nursery, (**B**) Recently planted *Polyscias maraisiana*, (**C**) Mealybug control in nursery, (**D**) Recently planted *Diospyros egrettarum*, (**E**) Preparing planting sites, (**F**) Seedling germination, (**G**) Young *Eugenia lucida*. Images supplied by Round Island staff.

Table 1 Mean lifetime growth rates of the 18 most abundant planted species on Round Island.

Species	Estimated lifetime growth rate (m^3/year)	Standard error of estimate
Dodonaea viscosa	3.1399	-0.4534/+0.5189
Premna serratifolia	1.8206	-0.2404/+0.2722
Gagnebina pterocarpa	1.7034	-0.2225/+0.2515
Terminalia bentzöe	1.5667	-0.4177/+0.529
Hilsenbergia petiolaris	1.1429	-0.1517/+0.1719
Stillingia lineata	1.0588	-0.6299/+1.0046
Psiadia arguta	0.7357	-0.1471/+0.1764
Maytenus pyria	0.6509	-0.0948/+0.1086
Margaritaria anomala	0.6426	-0.1061/+0.1237
Cassine orientalis	0.6264	-0.0843/+0.0956
Diospyros egrettarum	0.5701	-0.0907/+0.1051
Polyscias maraisiana	0.5669	-0.1643/+0.2119
Hyophorbe lagenicaulis	0.4461	-0.086/+0.1026
Volkameria heterophylla	0.2182	-0.0431/+0.0517
Coptosperma borbonicum	0.1075	-0.022/+0.0265
Foetidia mauritiana	0.0946	-0.0427/+0.0621
Eugenia lucida	0.0898	-0.0143/+0.0166
Fernelia buxifolia	0.0474	-0.0135/+0.0174

Once all these factors had been assessed, the significant variables were added to a more complex combined model. Maps were then generated to show which how performance was predicted to vary across the island. These are included in Appendix 1A.

Key conclusions:

- Data have been compiled to indicate which species are performing best on Round Island. These can be used to guide the planning of rewilding efforts, but must be interpreted with an understanding of the species' ecology.
- By determining how physical characteristics of the environment affect plant growth, predictive maps have been constructed to guide suitable planting sites. These can also be used to guide future rewilding efforts.
- Most species were affected by similar factors, which probably indicates that most plants grow better in moist, sheltered sites.
- *Psiadia arguta* performed better in open areas and is better adapted to 'savannah-like' situations.
- Despite the fact that many of the planted trees on Round Island have the appearance of being heavily 'wind-clipped', wind exposure was not a significant variable in any analysis. In fact, weather data for the year also suggest that the wind is rarely strong enough to be the cause of this stunting. The more likely reason is drought stress, which can cause branches on the 'downwind' side of the plant to die more quickly than on the 'upwind' side.

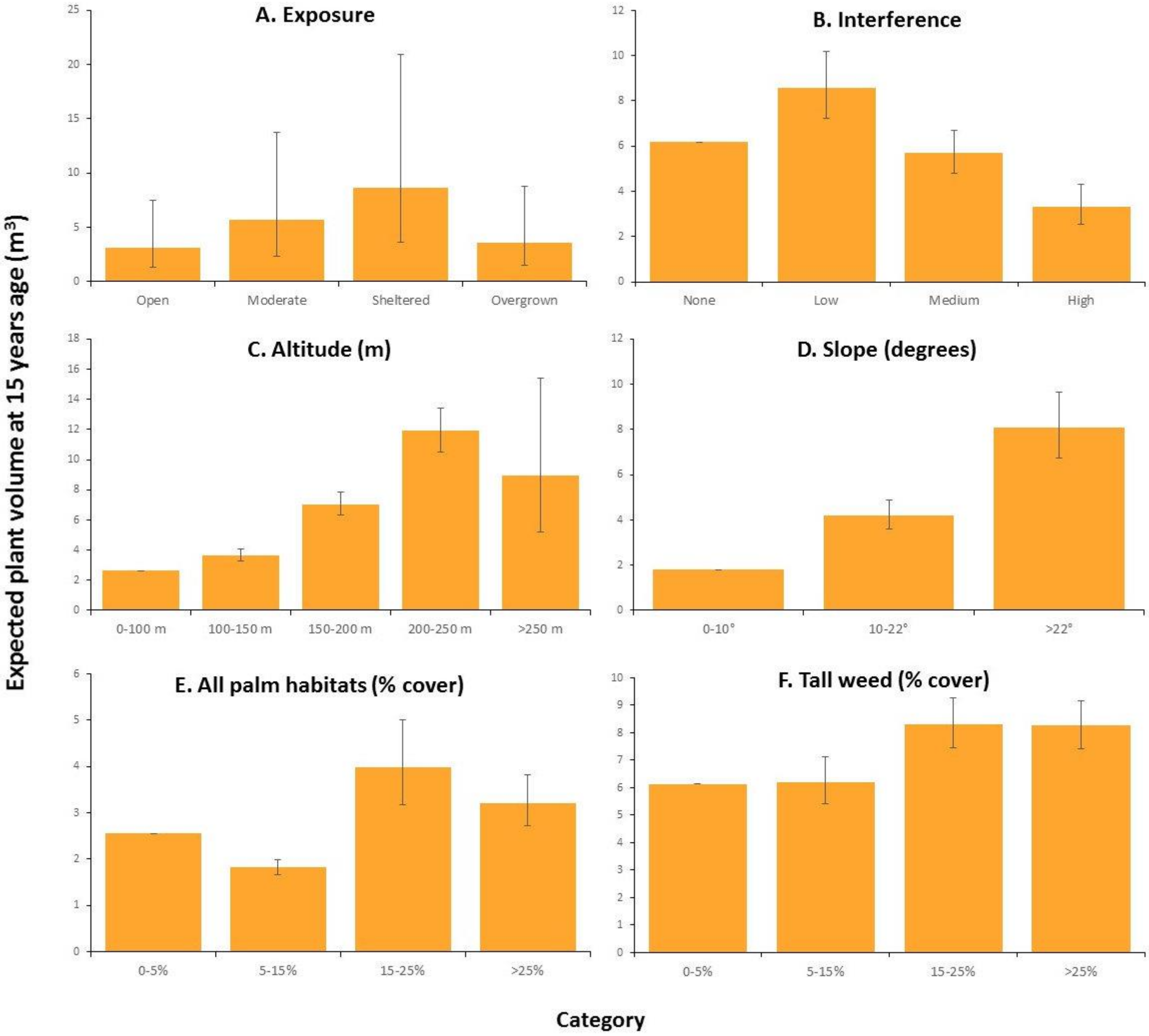


Figure 2 Effects of significant explanatory parameters, as modelled in GLM analyses. Data have been reconstructed assuming a mean Species term. Error bars represent 95% confidence limits.

4.4 Survivorship

A full list of all species grown on Round Island since the rewilding began, and the survivorship attained by each of these, is provided in Table 2. *Asparagus umbellulatus*, *Premna serratifolia* and *G. pterocarpa* appear to be performing particularly well, and appear very hardy despite seasonally dry conditions. However, there is a reasonably sharp disjunction between good and bad performers: whereas 13 taxa had a survival rate above 40%, only 19 species had a survivorship greater than 15%. It is also apparent that a number of species were only ever planted in very small cohorts. Nine taxa were represented by less than 30 individuals, and 17 by less than 100 individuals. Given average survival rates, it is unlikely that any of these would persist in viable numbers.

Because it was difficult to identify which years some species had been planted, differences in survivorship across the island could only be examined in a simplified way. Ultimately, 134 areas were identified which could be separated reasonably clearly.

Overall, the survivorship analysis had poor explanatory power. The most simple model tested explained only 11.3% of the possible pattern, which indicates a high degree of random variation. Nevertheless, both Species and Year were significant. In many sites, the survivorship has been moderate, particularly on the lower slopes. There was a tendency towards strong performance on the upper part of the East Ridge and to a lesser extent on other steep slopes below the summit area. Identifying the reasons for this is difficult, as there are several potential biases, which must be considered. The best areas were largely established between 2008 and 2011, and it could be that the planting occurred during favourable wet periods during these years rather than being related to physical characteristics of the sites.

The only geospatial explanators to exert a significant influence were Altitude, Aspect and Total palm cover. However, for most variables, the overall form of the relationship appeared to be similar to the patterns described for growth rates. It may therefore be safest to assume that plants do better under the same conditions for both measures of success. In Figure 3, the spatial correspondence between mean growth rate and % survivorship is shown. Many sites with high survivorship were located in more peripheral areas, but this is somewhat misleading, because they generally represented large expanses of terrain where few individuals had been added at low densities. However, for the smaller planting sites appearing in both Fig. 3A and B, the relationship is reasonably reliable.

Key conclusions:

- Survivorship was more of a barrier to performance than growth rate. Many species fared poorly. It is important to take this into account, along with growth rates, in determining future rewilding plans.
- The differences may not only be due to the suitability of the species, but also to the choice of planting site, techniques of after-care and weather in the period after planting. The importance of these influences is difficult to unravel due to a lack of data.
- Since mortality appears to be very important in the success of the rewilding, greater effort should be invested in keeping plants alive rather than growing and planting large numbers.

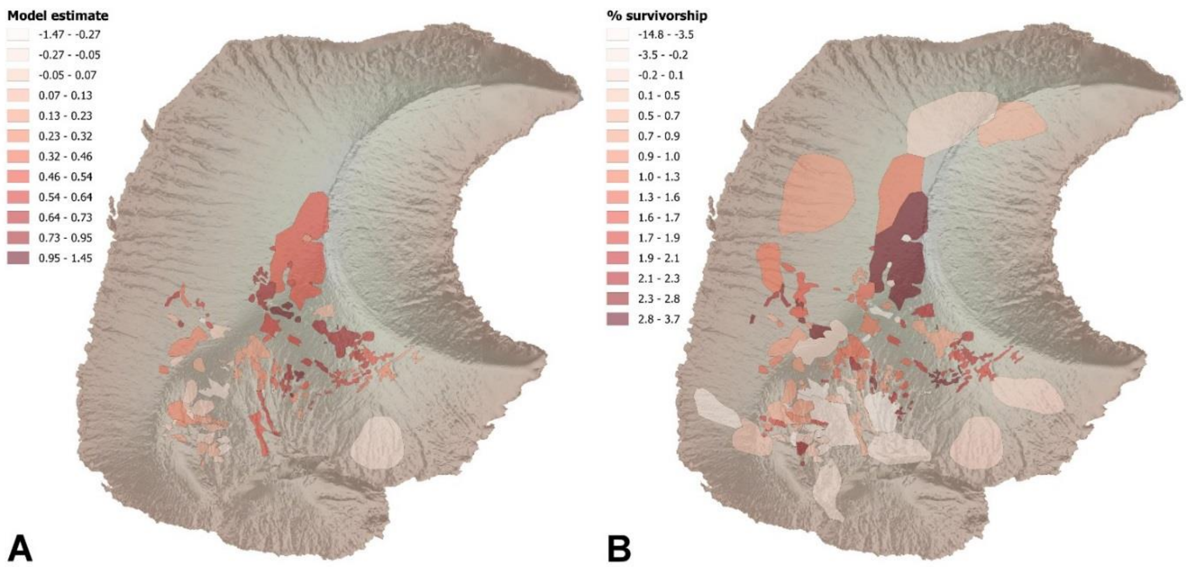


Figure 3 Spatial distribution of performance indices based two measures of performance: (A) Plant growth rates and (B) Survivorship. Results were obtained from general linear models with Site and Species as explanatory variables. Negative values represent poor performance and positive values represent good performance. For (A), missing planting blocks contained no target species.

Table 2 Species known to have been introduced to Round Island since 1990. The number of recorded plantings and survival success are indicated.

Species	Planted	Surviving	% survivorship	Species	Planted	Surviving	% survivorship
Asparagus atusbellatus	157	168	107	*Ficus rubra*	262	23	8.8
Premna serratifolia	1345	912	67.8	*Stadmania oppositifolia*	61	5	8.2
Gagnebina pterocarpa	1972	1318	66.8	*Stillingia lineata*	193	15	7.8
Psiadia arguta	356	183	51.4	*Coptosperma borbonicum*	2635	206	7.8
Hilsenbergia petiolaris	2025	1033	51	*Barleria observatrix*	191	13	6.8
Maytenus pyria	1381	696	50.4	*Polyscias maraisiana*	1210	66	5.5
Scolopia heterophylla	20	10	50	*Myoporum mauritianum*	300	10	3.3
Margaritaria anomala	577	272	47.1	*Erythroxylum sideroxyloides*	171	5	2.9
Terminalia bentzöe	149	69	46.3	*Diospyros tessellaria*	182	5	2.7
Cassine orientalis	1413	652	46.1	*Coffea myrtifolia*	136	3	2.2
Alöe tormentorii	176	78	44.3	*Dracaena concinna*	3156	29	0.9
Volkameria heterophylla	417	183	43.9	*Aerva congesta*	82	0	0
Dodonaea viscosa	1557	628	40.3	*Protium obtusifolium*	2	0	0
Trochetia parviflora	4	1	25	*Diospyros melanida*	44	0	0
Foetidia mauritiana	107	26	24.3	*Erythroxylum hypericifolium*	19	0	0
Ficus reflexa	22	5	22.7	*Dombeya mauritiana*	24	0	0
Diospyros egrettarum	2080	349	16.8	*Turraea thouarsiana*	78	0	0
Eugenia lucida	2655	438	16.5	*Badula crassa*	1	0	0
Hyophorbe lagenicaulis	1163	186	16	*Ixora nitens*	3	0	0
Dictyosperma album var. *album*	27	4	14.8	*Scaevola taccada*	687	?†	0
Zanthoxylum heterophyllum	14	2	14.3	*Chrysopogon argutus*	?*	?†	-
Ludia mauritiana	8	1	12.5	*Latania loddigesii*	?*	?†	-
Tournefortia argentea	513	62	12.1	*Pandanus vandermeeschii*	?*	?†	-
Fernelia buxifolia	593	70	11.8	*Phyllanthus casticum*	0**	2	-
Hornea mauritiana	42	4	9.5	*Hibiscus tiliaceus*	0**	0	-
Hibiscus fragilis	97	9	9.3	*Thespesia populnea*	0**	6	-

† Surviving plants not distinguishable from wild or self-sown individuals.
* Numbers of planted individuals confused by direct seed spreading and translocation of wild seedlings.
** There are no verified records of these species having been deliberately planted on Round Island, although the surviving individuals are almost certainly not native in origin.

4.5 Regeneration

Numbers of 'sapling' regens per species (i.e., self-seeded plants over 1 m in height) are given in Table 3, excepting the four taxa omitted from the survey. These totals suggest strongly that regeneration is a major barrier to successful ecosystem restoration. Of the 53 species that have been introduced to the island since planting efforts began, only 22 have produced saplings, although small seedlings were observed from some further species (*Phyllanthus casticum*, *V. heterophylla*). Furthermore, only five of these can be said to have self-seed in relatively healthy numbers, and only three are now present in greater quantities than were originally introduced. Interestingly, all five of the successes are native to the northern Mauritian islets. These plants may be particularly well adapted to Round Island's conditions.

No species other than the top five had more than a 5% success rate. There are perhaps a further four cases where natural recruitment is proven and occurring to some extent. These at least demonstrate a potential for becoming integrated into the natural flora of the island, but further improvements in success will be necessary to achieve it. The approximate area covered by regenerating plants has been plotted in Fig. 4, and indicates that the footprint of the wild restored vegetation is very small.

Although apparently performing well, possible cause for concern was noted over the native *Alöe tormentorii*. Aloes are still present in moderate numbers on the northern slopes below the summit. It is possible that a large proportion of the population is wild, but numerous plantings have also been made. Almost no seedlings have been found and nearly all individuals range from 60 to 110 cm in height. This could suggest that recruitment has been poor for at least a decade.

Table 3 Summary of regeneration rates per species. Only regens more than 1 m in height were included.

Species	Planted	Surviving	Regens	% of planted	% of surviving
Gagnebina pterocarpa	**3252**	**1233**	**1059**	**32.56**	**85.89**
Asparagus umbellulatus	**605**	**144**	**316**	**52.23**	**219.44**
Hyophorbe lagenicaulis	**1578**	**148**	**291**	**18.44**	**196.62**
Alöe tormentorii	**463**	**78-172**	**234-328***	**50.5-70.8**	**136.0-420.5**
Psiadia arguta	**622**	**158**	**139**	**22.35**	**87.97**
Dodonaea viscosa	**2265**	**565**	**85**	**3.75**	**15.04**
Premna serratifolia	**2071**	**871**	**64**	**3.09**	**7.35**
Hilsenbergia petiolaris	**2713**	**950**	**45**	**1.66**	**4.74**
Diospyros egrettarum	**2415**	**296**	**23**	**0.95**	**7.77**
Maytenus pyria	2055	646	9	0.44	1.39
Thespesia populnea	?	6	8	?	133.33
Terminalia bentzöe	163	60	4	2.45	6.67
Ficus rubra	262	8	3	1.15	37.5
Eugenia lucida	3377	406	3	0.09	0.74
Barleria observatrix	195	8	2	1.03	25
Dictyosperma album var. *album*	27	4	1*	3.7	25
Ficus reflexa	87	2	1	1.15	50
Stillingia lineata	216	15	1	0.46	6.67
Tournefortia argentea	556	59	1	0.18	1.69
Fernelia buxifolia	744	70	1*	0.13	1.43
Margaritaria anomala	791	245	1	0.13	0.41
Cassine orientalis	1862	611	1	0.05	0.16

* Includes one or more wild individuals predating the restoration programme rather than recent regens.

For five species, individual GLM models were used to explore the drivers of regen density. In all cases, nearby propagule pressure was the most important of these, accounting for 16 – 42% of model deviance. This indicates that seedlings tend not to spread far from where they were planted. Conditions favouring regeneration for each of the five taxa were substantially different, and they also differed from the general patterns predicted for maximum growth rates. Maps of the best regen sites on the island are presented in Appendix 1B (for five species only).

Key conclusions:

- Regeneration is essential to rewilding: if plants cannot reproduce and survive unaided then there will never be a natural ecosystem.
- Out of all the species introduced to Round Island, only four are regenerating well in the wild. This suggests that there are substantial issues to resolve.
- Model results suggested that the conditions necessary for seedlings to survive are substantially different from those which are needed for adult plants to grow fast. This is not surprising: all species fit into different parts of the ecosystem, and it is critical to understand these differences.
- Seedlings tended to be mainly found close to their parents, so it is necessary to plant each species in sites appropriate to their ecological requirements.
- Since only five species were regenerating in sufficient numbers to study the requirements, additional work will be needed to improve understanding of this complex problem.

Figure 4 Map of Round Island showing the positions of all regens. Individual specimens are plotted as ellipses of area proportional to the plant volume (approximately equivalent to the footprint of the plant in real terms).

4.6 Insect damage and plant condition

Insect attack (predominantly caused by the weevil *Cratopus punctum*) was an important constraint on performance. A few species were almost resistant to insects (Fig. 5A), but *Maytenus pyria* sustained mean losses of up to 25% of total foliage during peak months, and *Terminalia bentzöe* suffered even heavier impacts, averaging 71.4% in March. This deciduous species recovered some of the losses by dropping all its leaves shortly after, remaining dormant until the following winter. Similar seasonal patterns were observed for all species (Fig. 5B). There was typically a decline during the wettest period of the year, but damage levels increased subsequently and reached their maximum in June-July.

A number of spatial parameters appeared to influence the level of insect damage, although these effects were mostly rather weak. Overall, growth rate was the best explanator, with fast-growing plants more vulnerable than those growing slowly.

A similar trend was found in plant condition scores. These also varied throughout the year, but the patterns were somewhat complex and differed according to the life history of the species. When seasonal effects were controlled in a general linear model, a strong inverse relationship between the health of the plant and the lifetime growth rate was revealed, accounting for more of the total explanatory power of the model than all other tested parameters. Contrary to expectations, this implies that faster growing plants suffered from poorer health and sustained more insect damage than slower-growing ones.

Key conclusions:

- Stresses can affect plant performance substantially. At least in the case of insect damage, levels were often sufficient at certain times of the year to impair growth.
- Although it is desirable for plants to grow fast in order for rewilding to proceed more quickly, fast-growing plants tended to be in poorer condition and to be more vulnerable to insect pests.
- The most likely explanation is that fast-growing plants invest more energy into growth and less into adaptations, which make them robust to stress, whether resulting from insect herbivory, drought or some other factor.
- One way to reduce this problem is by better hardening of plants in cultivation, which should prepare them for stresses later in life.
- A second way to reduce the problem is by lessening stresses in the natural environment, which could be achieved by a variety of measures, e.g. planting in more sheltered sites, adapting planting locations to fit the species' ecology better, improving soils or introducing new biocontrol agents to reduce pest loads.

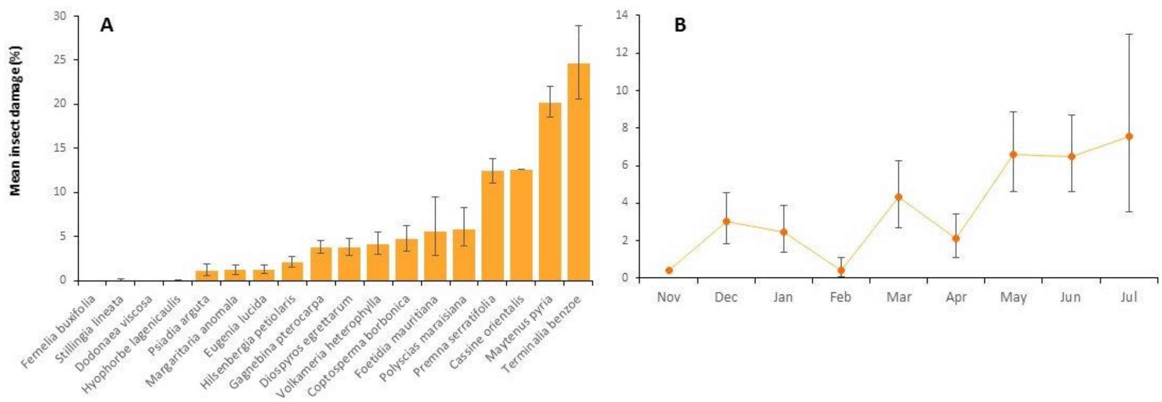


Figure 5 Differences in mean insect damage scores: (**A**) by species and (**B**) throughout the season. Estimates have been recreated from GLM results. Error bars represent 95% confidence limits.

4.7 Soil depth

In general, soils on Round Island are extremely shallow. Within the surveyed belt transects, 40.9% of test depths were less than 10 cm, 93.2% were less than 20 cm and only 2% reached more than 30 cm. No measurements exceeded 66 cm. Furthermore, the deeper accumulations were very localized, occurring at the heads of gullies and in obvious fissures running along the island's contours at higher altitudes (Fig. 6A). These are very obvious on the ground as they are marked by lines of dense arborescent vegetation.

The distribution of planting sites has been heavily constrained by this limitation (Fig. 6B). Restoration sites have been crammed in to the best soil pockets. Almost all useable hollows have been exploited, with very few trees in the interstitial gaps. Given the limited options, 40.9% of trees were planted in areas averaging less than 10 cm depth. Only 11.7% corresponded to depths greater than 20 cm, and just 2.9% exceeded 25 cm. In many shallower soil areas, roots have been forced to run very close to the surface, with few crevices for deeper anchorage in the sheet-like basalt.

There was a strong, positive relationship between soil depth and plant growth rate (Fig. 7). Modelled results indicated that plants in soils deeper than 20 cm attained an expected volume 5.06 times greater than those in soils shallower than 20 cm after 15 years' growth. Unfortunately, there are very few places where this sort of deep-soil planting was possible. This suggests that almost all plants are placed under substantial limitation by Round Island's shallow soils.

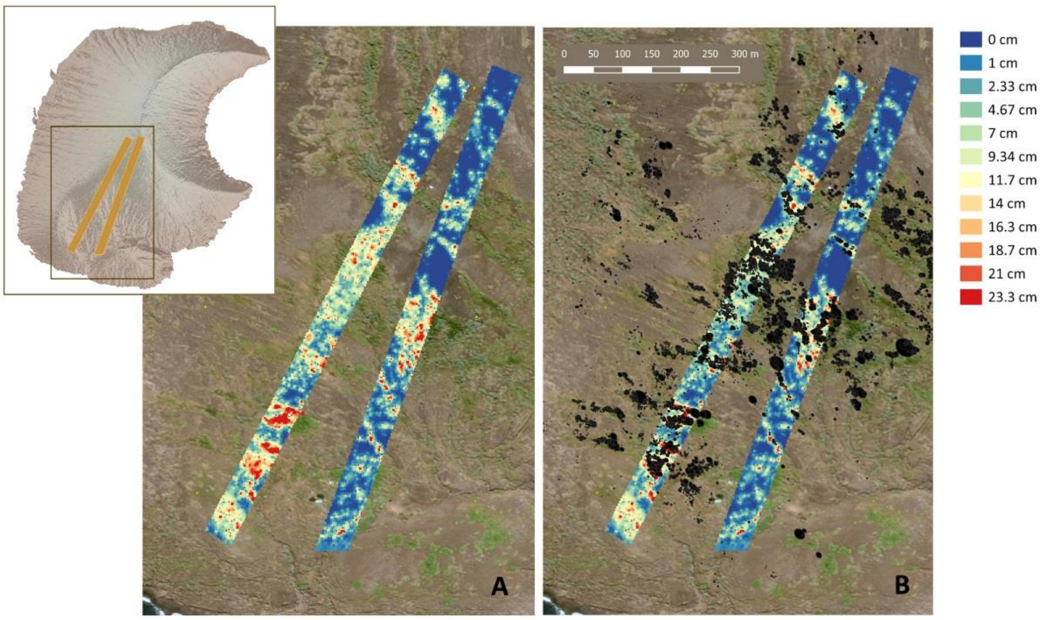


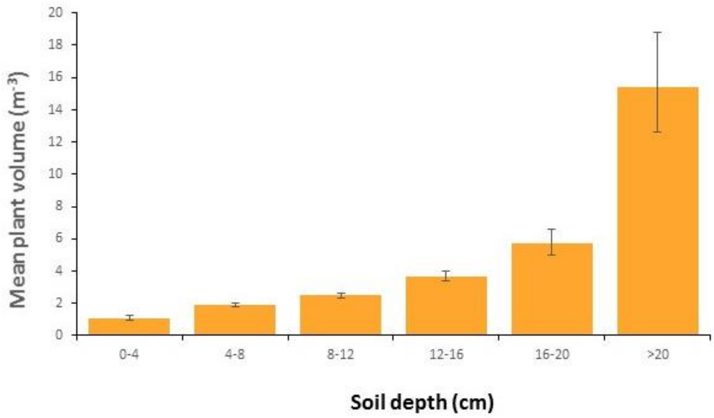
Figure 6 Soil depth, as plotted along two belt transects, with their location detailed in the inset. (**A**) indicates the unobscured depth profile and (**B**) has the locations of trees and shrubs superimposed over it. The background is a satellite image created using Google Earth data from 30th September 2015: ©Digital Globe 2018.

Key conclusions:

- Much of the soil on Round Island is extremely shallow and many trees are very shallowly-planted.
- Shallow soils appear to impose a strong limitation on growth.
- This effect is likely to be related to drought stress. In dry tropical areas, surface layers of the substrate can dry-out very quickly. In a study from Costa Rica, Borchert (1994) reported that the upper 30-40 cm dried out completely within a month of the last heavy rainfall.

- As a result, it seems likely that plants on Round Island are subject to much higher levels of drought stress than is evident from the climate alone. This may impose severe limitations on survival.
- Under mild drought, plants may suffer from a shut-down of photosynthesis, increasing to leaf cell death and eventually to cavitation (air bubbles developing in the conduction vessels) as stress increases. Cavitation is largely irreversible and leads to death of leaves, branches and stems. Symptoms of severe drought stress were regularly noted during fieldwork.
- Different species vary in their ability to tolerate drought, and this may depend on how well they are acclimatised to stress. Selection of very stress tolerant plants and careful hardening during the cultivation process is recommended.

Figure 7 Lifetime growth rate of plants in relation to soil depth along two belt transects. Results are taken from the general linear model controlling for Age and Species. Error bars represent 95% confidence limits.



4.8 Survivorship vs time

There was a high degree of random variation in survival probabilities between years and sites, but with appropriate statistical treatment, it was possible to identify a clear general trend in the relationship between plant age and mortality, with the model explaining 29.7% of total deviance. The change in survivorship did not appear to be smooth over time, but there was a sharp drop within the first few years followed by a slow continued decline (Fig. 8). The slope of the relationship varied significantly between species, more or less corresponding to the lifetime survivorship patterns described in Table 2. For the best performing taxa (*G. pterocarpa*, *Hilsenbergia petiolaris* and *P. serratifolia*), most of the predicted mortality was limited to the first 1-2 years, after which the curve levelled almost to a plateau. However, for others, ongoing deaths continued for the remained of the simulated 15-year observation period, albeit at a reduced rate. Taking an average over all 12 species investigated, 67.0% of all mortality occurred within the first two years (maximum = 85.1%, minimum = 55.9%). That is, approximately twice the number of plants were predicted to die within the first two years post-planting, as were predicted in the following 13 years.

Key conclusions:

- Two-thirds of plant mortality occurs in the first two years after planting. Survivorship could perhaps be improved by more intensive after-care during this extended period.
- In at least some species, mortality continues throughout life. The number of deaths during this phase is quite significant, and efforts to reduce them may be beneficial. The causes are unknown, but may include vine infestations, and inappropriate planting locations: individuals on

very shallow soils or in excessively open situations may suffer increased drought stress as an adult.

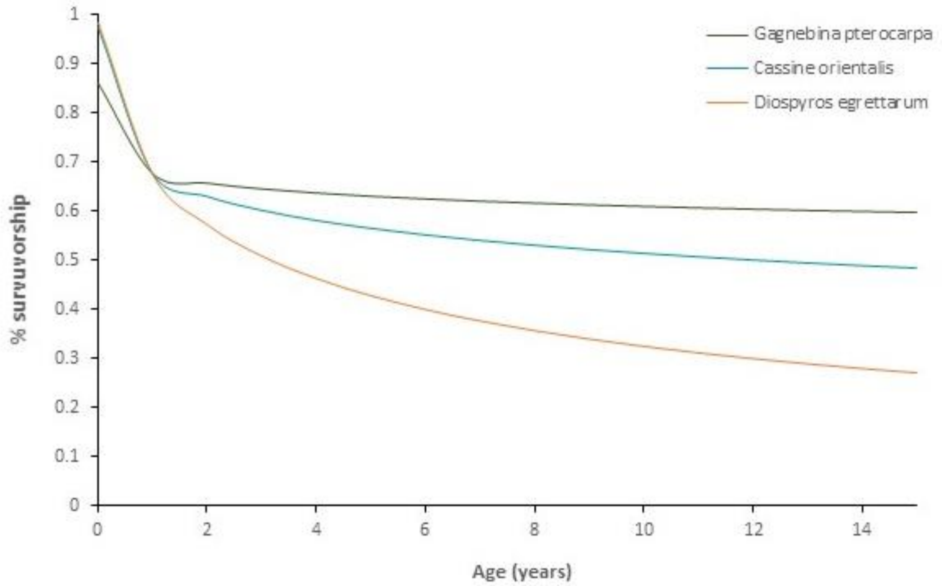


Figure 8 Modelled predictions of decline in survivorship over time, obtained from yearly Round Island survival monitoring combined with plant census data. Examples of three species with high, moderate and low lifetime survivorship are shown.

4.9 Interference from neighbouring vegetation

'Moderate' or 'heavy' interference was noted on 7.6% of surveyed plants, but a further 5.7% suffered from 'mild' interference, which could potentially become worse over time. The latter group are not included in Table 3. The causes of interference can be divided into three broad groups:-

(1) Vines, accounting for 97.5% of total cases. There are two vine species present on Round Island, with *Tylophora coriacea* recorded twice frequently as the non-native *Passiflora suberosa*. In the worst cases, they may smother the 'host' almost entirely, supressing any possibility of photosynthesis and occasionally breaking limbs through their sheer weight. *Hyophorbe lagenicaulis* was substantially the worst effected tree species.

(2) Dominant trees or shrubs, which competed aggressively with younger, more vulnerable planted specimens. The small number of observations is perhaps not surprising, because most plantings were situated in open areas away from other trees. Relatively few individuals were positioned in the shade of palms to increase protection from the sun, and in these cases interference often resulted either from physical damage caused by their edges whipping against branches in the wind (32 cases), or when smaller saplings became buried under leaf litter as the fronds were shed (30 cases).

(3) Vigorous, herbaceous weeds, which also smothered planted species in situations where they were able to grow more rapidly (e.g., *Achyranthes aspera* and *Bidens pilosa*). These primarily formed tall, dense stands, but also included the straggling *Boerhavia coccinea*. Due to their smaller stature, species in this group were generally only problematic to small or young planted individuals, and the effect was generally more seasonal, with competition dying back during drier months.

Key conclusions:

- Smothering by vines is a significant cause of mortality in older plants. Better management of vine infestations would help to improve survivorship.
- Trees planted too close to palms are likely to suffer adverse interactions, despite the shade benefits.

Table 3 Number of plants suffering interference from neighbouring vegetation. Totals are broken-down by species affected and the intensity/nature of the interference effect.

By species		
Species	**no. plants**	**%**
Hyophorbe lagenicaulis	579	19.0
Alöe tormentorii	410	15.6
Foetidia mauritiana	26	15.4
Asparagus umbellulatus	679	12.4
Terminalia bentzöe	73	12.3
Tournefortia argentea	63	11.1
Diospyros egrettarum	371	10
Fernelia buxifolia	71	9.9
Dodonaea viscosa	741	9.9
Maytenus pyria	719	9
Eugenia lucida	440	6.8
Hilsenbergia petiolaris	1099	5.6
Premna serratifolia	989	5.4
Gagnebina pterocarpa	2439	4.8

By species		
Species	**no. plants**	**%**
Margaritaria anomala	274	4.7
Volkameria heterophylla	184	4.4
Cassine orientalis	654	3.7
Coptosperma borbonicum	206	3.4
Polyscias maraisiana	66	3
Psiadia arguta	365	2.5
Volkameria heterophylla	184	4.4

By intensity category		
Intensity	**no. plants**	**%**
None	9310	87.7
Mild	505	4.8
Moderate	597	5.6
Heavy	173	1.6

4.10 Soil chemistry

There were clear differences in soil chemistry between the selected sample sites (Table 4), but in most cases these differences were difficult to interpret. There was no relationship with soil depth in any variable. Organic carbon % increased slightly as canopy cover increased, but the trend was not significant. The clearest influence appeared to be related to the density of shearwater burrows. On going from 'Low' through 'Medium' to 'High ' densities, there was a continual and reasonably strong decline in pH, an increase in nitrate, phosphate and potassium and a strong decrease in organic carbon content. In each case, at least one of the between-category contrasts was significant ($p < 0.05$). The single 'Tortoise lawn' site investigated was moderately high in pH, low in mineral nutrients and with average levels of organic carbon, but there is no guarantee that this is representative.

An obvious inference from these findings is that the degree of spatial variation, even in ecologically similar microhabitats, was high. With only thirteen independently replicated sites, each of the categories assessed above were only sampled three or four times, and thus it was difficult to elucidate general trends above the background noise.

Key conclusions:

- Soil chemistry analyses are useful to understand ecological processes, and to see how the 'health' of the environment is changing over time.
- It is recommended that measurements should be repeated at intervals of 5-10 years according to a structured sampling programme. The number of samples included in the pilot study was not sufficient to detect statistically significant differences between the different soil chemistry parameters. An expanded programme is therefore advisable.

- More nitrogen in the soil could help plants to grow more quickly, and more organic carbon could improve the water retention capacity of the substrate, thus buffering against the stresses caused by drought.
- Soil nutrient levels result from the balance between input into the system (from dead leaves and animal faeces), decay (caused by invertebrate detritivores and microbes), take-up by plants and microbial respiration (the last two processes return nutrients back to the environment). At present, carbon and nitrogen levels are low, indicating that this cycling is occurring slowly. There are various options for influencing the balance, particularly by selecting species with faster leaf turn-over, and by improving conditions to speed-up decay.

4.11 Habitat survey

Sixty-two vascular plant species were recorded from wild situations on Round Island, excluding those introduced deliberately for rewilding efforts. Two additional species may be present but were not found during the searches. The alien weed *Lycopersicon esculentum* (tomato) is subject to active control whenever detected, but still germinates sporadically from the seedbank. The extremely threatened endemic *A. congesta*, also a seedbank annual (or short-lived perennial), was planted on the Wasteland in 2003 and 2017, and could still reappear in very small numbers. A single individual was found by wardens in 2018, but had died by the start of the Habitat Survey. If the rewilded species are also taken into account, a total of 114 taxa are thought to be present, but with varying levels of success.

Of the wild component, only three species (4.5%) were pteridophytes (all of which were scarce), 18 (27.3%) were graminoids (grasses and sedges), eight (12.1%) were woody monocots and the remainder (56.1%) were dicots. Woody taxa were uncommon, comprising 11 species and only four 'hardwoods' (i.e., dicotyledonous species), three of which were very rare.

The list in Table 5 comprises 25 Round Island natives, 15 species that are otherwise native to Mauritius and 24 alien species. Although the most dominant species on the island are a mix of all three categories, many more aliens are moderately common than natives and Mauritian natives (Fig. 8). As a result, the mean abundance score of aliens is 1.58 times higher than that of natives and 2.34 times higher than for Mauritian natives. Furthermore, a number of native species are now very rare, presumably having been pushed to the brink of extinction by the historical impact of browsing mammals and/or competition from the new arrivals.

Fig. 9 shows the dominance of natives, Mauritian natives and aliens within each habitat. Some categories are still predominantly native in character (*Ipomoea* sward, Palm thicket and Palm glade), but the effect is attributable to just one or two highly influential species: *L. loddigesii* and *P. vandermeeschii* in palm areas and *Ipomoea pes-caprae* in *Ipomoea* sward. Despite dramatic changes in community composition over the past 40 years, these remain Round Island's most important keystone plants. Latans create shelter, stabilize soils and start to break-up rocky substrate, whereas *Ipomoea* is an excellent colonist, establishing ground cover in barren areas, which in turn facilitates the colonization of other early-succession taxa. However, it is often alien species that make use of the opportunities they create: the understorey of palm glade is dominated by several characteristic shade-tolerant species from around the world. Furthermore, the influence of natives in an overall context appears to be diminishing. Xeric weed is the only remaining habitat which still holds a reasonable diversity of predominantly native elements, providing a final refuge for several very rare species.

Table 4 Summary of soil sampling locations with mean values obtained for total nitrate (NO_3^{2-}), phosphate (PO_4^{2-}), potassium (K^+), total organic carbon (C) and soil texture (T). Carbon was measured as a % of dry weight whereas inorganic ions were approximated to $\mu g.g^{-1}$, assuming a bulk soil density of 1 $kg.L^{-1}$. Statistics in parentheses are standard errors.

Site	Description	Soil depth	Canopy	Shearwaters	Long	Lat	pH*	NO_3^{2-}	PO_4^{2-}	K^+	C	T
1	Deep soil below path	Deep	Sparse	Sporadic	57.78469	-19.8557	6.8 (±0.43)	0.5 (±0.13)	0.42 (±0.07)	3.34 (±0.74)	4.04	0.81
2	*Premna* thicket shearwater colony	Deep	Open	Dense	57.78521	-19.8557	4.3 (±0.15)	1.72 (±0.56)	1.82 (±0.41)	2.81 (±0.45)	1.57	0.94
3	Mixed Weed mature canopy	Medium	Closed	None	57.78643	-19.8525	6 (±0.73)	0.33 (±0.13)	2.25 (±0.22)	4.55 (±0.67)	3.53	0.88
4	TERBEN/CASORI woodland	Deep	Closed	Sporadic	57.78723	-19.8537	4.6 (±0.17)	0.67 (±0.19)	3.42 (±0.89)	4.98 (±0.76)	3.25	0.94
5	DODVIS/CASORI woodland below Slab	Deep	Closed	None	57.78744	-19.8532	7.7 (±0.33)	0.47 (±0.08)	0.79 (±0.31)	2.03 (±0.39)	5.31	1.42
6	House shearwater colony	Deep	Open	Dense	57.78545	-19.8564	4.3 (±0.1)	2.39 (±0.74)	1.13 (±0.13)	3.87 (±1.01)	1.76	1.12
7	TERBEN/*Premna* thicket	Deep	Closed	Dense	57.78535	-19.8549	4.8 (±0.09)	1.41 (±0.49)	1.81 (±1.08)	4.52 (±0.86)	3.21	0.81
8	Lower Mixed Weed plantings	Medium	Sparse	Sporadic	57.78554	-19.854	7.2 (±0.58)	0.63 (±0)	0.58 (±0.19)	2.58 (±0.26)	4.81	0.94
9	Middle Mixed Weed plantings	Medium	Sparse	Sporadic	57.78593	-19.8533	5 (±0.17)	0.12 (±0.06)	2.11 (±0.57)	5 (±1.32)	2.96	0.81
10	Soil seam below summit	Medium	Open	None	57.78752	-19.8505	7.4 (±0.55)	0.41 (±0.09)	0.94 (±0.57)	3.18 (±0.6)	4.73	0.94
11	PANVAN/LATLOD thicket below summit	Deep	Closed	None	57.78705	-19.8513	6.9 (±0.18)	0.42 (±0.14)	0.5 (±0.13)	1.83 (±0.14)	6.14	1.00
12	Savannah above Mixed Weed	Medium	Open	None	57.78684	-19.8519	7.7 (±0.33)	0.13 (±0.06)	0.33 (±0.07)	2.5 (±0.54)	5.97	1.00
13	Mixed Weed tortoise lawn	Medium	Open	None	57.78606	-19.8541	7.3 (±0.24)	0.38 (±0.13)	0.43 (±0.09)	3.07 (±0.25)	4.69	1.12

* Data displayed are from test kit results

Perhaps of equal concern, the three man-made habitat types (Restoration areas, *Scaevola* scrub and Tortoise-grazed sward) are all amongst the most heavily dominated by introduced taxa. *Scaevola taccada* is a Mauritian native well suited to the environment, and there seems to have been a logical rationale for its inclusion in restoration plans. However, the dense shrubby stands have spread rapidly, and control measures are currently being considered due to their dominating nature. The species is one of the main threats to Xeric weed, and removes potential habitat for reptiles.

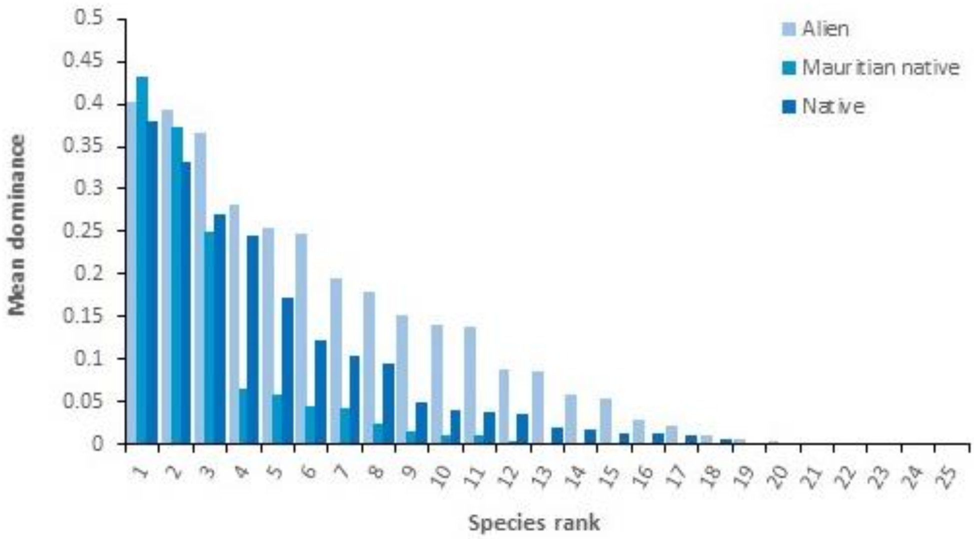


Figure 8 Distribution of mean dominance scores for species separated into three status categories. The distributions have been plotted in rank order.

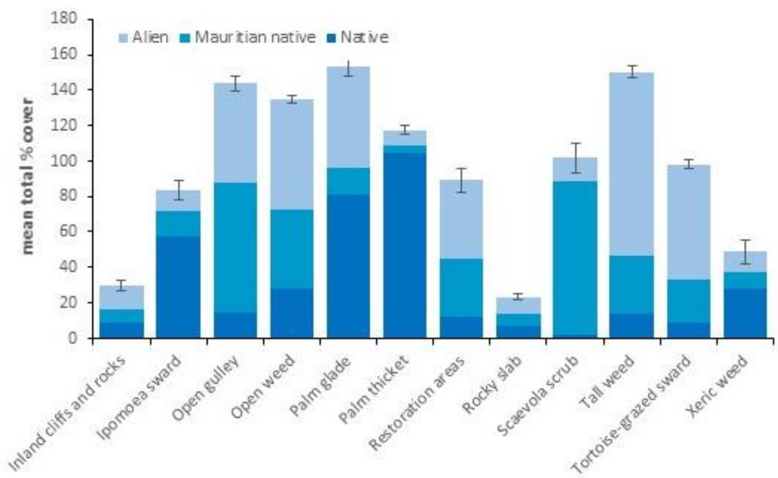


Figure 9 Diversity statistics representing the mean of the summed % covers for each habitat. The contribution of Native, Mauritian native and Alien species is indicated. Error bars represent standard errors, calculated for all species regardless of status.

Table 5 Species recorded from wild situations during the habitat survey. The range size is the number of 1 ha grid cells in which the species occurred. Dominance is e^a of the abundance score, *a*, re-scaled to a maximum of 1, ± standard errors. Statuses are as follows: N = Native, MN = Mauritius native, A = Alien.

Species	Status	Range size	Mean dominance	Species	Status	Range size	Mean dominance
Dactyloctenium ctenoides	MN	164	0.43 (±0.026)	*Selaginella obtusa*	N	17	0.02 (±0.006)
Boerhavia coccinea	MN	164	0.37 (±0.023)	*Phyllanthus mauritianus*	MN	16	0.02 (±0.005)
Achyranthes aspera	A	159	0.39 (±0.026)	*Lepturus repens*	N	15	0.02 (±0.007)
Ipomoea pes-caprae	N	158	0.38 (±0.025)	*Hyophorbe lagenicaulis*	N	34	0.03 (±0.008)
Passiflora suberosa	A	156	0.25 (±0.017)	*Boerhavia diffusa*	MN	32	0.02 (±0.005)
Chloris barbata	A	155	0.28 (±0.019)	*Euphorbia thymifolia*	A	28	0.03 (±0.007)
Tridax procumbens	A	153	0.4 (±0.027)	*Amaranthus viridis*	A	26	0.02 (±0.006)
Latania loddigesii	N	149	0.33 (±0.026)	*Fimbristylis cymosa*	N	25	0.04 (±0.01)
Digitaria horizontalis	MN	149	0.25 (±0.018)	*Adiantum rhizophorum*	N	19	0.01 (±0.004)
Cenchrus echinatus	A	148	0.36 (±0.026)	*Selaginella obtusa*	N	17	0.02 (±0.006)
Tylophora coriacea	N	145	0.27 (±0.019)	*Phyllanthus mauritianus*	MN	16	0.02 (±0.005)
Desmodium incanum	A	140	0.25 (±0.019)	*Lepturus repens*	N	15	0.02 (±0.007)
Solanum americanum	A	132	0.18 (±0.016)	*Chromolaena odorata*	A	15	0.01 (±0.003)
Commelina benghalensis	A	129	0.19 (±0.017)	*Cyperus dubius*	MN	12	0.01 (±0.004)
Sonchus oleraceus	A	129	0.14 (±0.012)	*Sida pusilla*	N	10	0.01 (±0.005)
Cymbopogon caesius	N	120	0.24 (±0.023)	*Aloe tormentorii*	N	10	0.01 (±0.005)
Abutilon indicum	N	119	0.17 (±0.016)	*Crassocephalum rubens*	MN	9	0.01 (±0.004)
Portulaca oleracea	N	110	0.1 (±0.01)	*Nicotiana tabacum*	A	9	0.01 (±0.002)
Pandanus vandermeeschii	N	98	0.12 (±0.014)	*Sporobolus virginicus*	N	4	0.01 (±0.004)
Bidens pilosa	A	89	0.15 (±0.02)	*Euphorbia prostrata*	A	4	0.00 (±0.002)
Desmanthus virgatus	A	84	0.14 (±0.018)	*Chenopodium murale*	A	3	0.00 (±0.001)
Cyperus exilis	N	80	0.1 (±0.012)	*Withania somnifera*	A	3	0.00 (±0.001)
Conyza bonariensis	A	75	0.09 (±0.012)	*Stenotaphrum micranthum**	N	3	0.00 (±0.001)
Phyllanthus amarus	A	66	0.05 (±0.007)	*Dichondra repens**	N	3	0.00 (±0.001)
Ageratum conyzoides	A	64	0.09 (±0.013)	*Lepturus radicans*	MN	3	0.00 (±0.001)
Chrysopogon argutus	MN	61	0.07 (±0.01)	*Chloris filiformis**	N	2	0.00 (±0.001)
Asparagus umbellulatus	N	54	0.05 (±0.008)	*Leucaena leucocephala*	A	1	0.00 (±0.001)
Oxalis corniculata	A	49	0.06 (±0.01)	*Heteropogon contortus*	A	1	0.00 (±0.001)
Gagnebina pterocarpa	N	38	0.04 (±0.008)	*Fernelia buxifolia*	N	1	0.00 (±0.001)
Scaevola taccada	MN	37	0.06 (±0.012)	*Phyllanthus revaughanii**	N	1	0.00 (±0.001)
Cyperus compressus	MN	36	0.05 (±0.01)	*Pteris vittata**	MN	1	0.00 (±0.001)
Dracaena concinna	MN	36	0.04 (±0.009)	*Sesuvium ayresii**	N	1	0.00 (±0.001)
Hyophorbe lagenicaulis	N	34	0.03 (±0.008)	*Zoysia matrella* var. *tenuifolia*	MN	1	0.00 (±0.001)
Boerhavia diffusa	MN	32	0.02 (±0.005)	*Dictyosperma album* var. *album**	N	1	0.00 (±0.001)
Euphorbia thymifolia	A	28	0.03 (±0.007)	*Brachiaria serpens**	MN	1	0.00 (±0.001)
Amaranthus viridis	A	26	0.02 (±0.006)	*Aerva congesta**	N	0	0
Fimbristylis cymosa	N	25	0.04 (±0.01)	*Lycopersicum esculentum*	A	0	0
Adiantum rhizophorum	N	19	0.01 (±0.004)				

* Native species deemed to be in immediate danger of local extinction.

In contrast to this deliberate introduction of *Scaevola*, Restoration areas and Tortoise-grazed sward seem to be creating inadvertent opportunities for aliens to establish. Both habitat types are associated with at least moderate levels of disturbance. With no natives brought in as part of the rewilding to exploit this, there has been little managed control over the colonization process. In addition, the numerous human visits to managed sites bring inherent risks of seeding the areas with further propagules attached to clothing.

Although the survey was not completed, 78.8% of the island footprint was successfully covered. The habitat composition of this area is detailed in Table 6. The omitted portion includes the least accessible cells, which are mainly dominated by cliff and expanses of rock.

Table 6 Distribution of habitats across Round Island. The % area refers to surveyed 1 ha grid cells only. Range size is the number of cells in which the habitat was recorded.

Habitat	% area	Range size
Rocky slab	27.7	152
Open weed	21.6	151
Coastal rocks	13.1	64
Tall weed	8.7	132
Palm thicket	6.4	118
Ipomoea sward	4.1	75
Palm glade	3.5	52
Restoration areas	3.3	37
Inland cliffs and rocks	2.9	82
Xeric weed	2.3	15
Tortoise-grazed sward	1.6	38
Scaevola scrub	0.9	18
Open gulley	0.6	45

Much of Round Island presents an inhospitable environment for trees and shrubs. Rocky slab and Coastal weed are largely bare. A very small proportion of the island has been densely planted thus far (Restoration areas covered just 3.3% of the surveyed area and 2.6% overall), and perhaps only the Tall weed and limited Open weed areas offer favourable conditions for new sites. This would suggest that a realistic maximum target for future planted forest of scrub habitats is no more than 10% of the total area. However, it must be noted that not all restoration need involve larger, woody species, and that other habitats could be improved through management, or by working with additional functional plant types.

The current extent of *L. loddigesii* represents a substantial increase from the historical low of the 1980s. If there were 1,500 specimens present at that time, and assuming that an average tree covered approximately 10 m^2, they would have occupied just 0.67% of the island's area. This indicates that there has been well over a ten-fold expansion in 40 years. The fortunes of Xeric weed are less favourable. As the only, diverse native-dominated habitat remaining, it appears to have experienced considerable declines, now confined to just 2.7 ha in a very limited region of the south coast.

Aldabra giant tortoises (*Aldabrachelys gigantea*) now occur reasonably widely over certain parts of the island and their range and movements have been monitored since they were introduced in 2007. However, there have previously been no measures of the extent of their impact, in terms of the habitat grazed. The current estimate indicates that 1.2% of the total island footprint has been converted to tortoise-grazed sward, though they may feed elsewhere (e.g. in *Ipomoea* sward) during the dry season. Their maximum possible habitat availability is potentially up to 20% of the island area, or 18 times the current extent, although the true value is perhaps somewhat lower as some suitable sites may be difficult to access.

Further details on the spread of alien species and the decline of natives are provided in the full report (Lambdon, 2019b). A strong positive outcome of the increased management effort is that there seems to have been a decline in the rate of new alien introductions over the past 15 years (from 29 species between 1975 and 2003 to six since 2003, only two of which have survived). This is good evidence that biosecurity protocols have been successful: and highly cost-effective as a great deal of time and expense is dedicated to managing existing problems.

One pressing concern is that there are currently nine natives deemed to be in danger of local extinction on Round Island (see Table 5). These are represented by a handful of individuals and they are threatened by invasive weeds. In some cases, the Round Island population represents almost the last relict of their world populations. Others on the list may still survive elsewhere on Mauritius, but it is desirable to maintain the local provenance as this may be a source of unique genetic diversity.

Key conclusions:

- A review of the species occurring wild on the island shows that aliens have gained an increasing foothold over the past 20 years, and there is no reason to assume that this spread has ceased. The problem is predominantly due to non-woody taxa. At the same time, a number of native species have become very rare.
- Rewilding efforts create new colonization opportunities of alien species. This is a particular concern because there is scope to greatly increase the area under management in the long-term. The capacity for expansion of tortoise-grazed habitats is considerable: 10-20 times the current area could eventually be exploited.
- There are limited options for halting the advance of aliens. One key element is the maintenance of biosecurity protocols, which have been highly effective over recent years.
- Another option is to fill the ecosystem 'gaps' with selected native species to compete with and hopefully resist further invasion by the less desirable alternatives. Thus far, reintroduction efforts have only focused on trees and shrubs and have ignored other elements of the community, even though these are often critical for ecosystem function.
- It is estimated that Round Island has capacity for at least another 30 – 40 species, with previously ignored functional types most in need of addressing.
- The unique native habitat type 'Xeric weed' is decreasing rapidly. Eight native species are in imminent danger of local extinction and measures are urgently needed in order to preserve these. It would be difficult to claim the Round Island project as a success if 32% of the original native flora were to be lost in the near future.

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6 Recommendations

6.1 Aims

Restoring an entire ecosystem from a very degraded state is a considerable challenge, particularly in a dry, hostile environment where plants are vulnerable to high mortality and slow growth. To do this effectively, it is important to identify clear aims, and practical ways of achieving them. The aims are informed by three principles:

- Although a landscape populated with trees and shrubs may look like a rewilded habitat, it is necessary for the species present to flower and fruit successfully, and for seedlings to regenerate naturally at a sustainable rate, before the landscape can be considered as approaching a wild state.
- Growing and planting specimens in wild situations is therefore not a goal per se, but is a step along the road to achieving one. Numbers of planted individuals alone do not provide a measure of rewilding success.
- Stimulating natural regeneration is a much more difficult task than simply planting trees. Self-seeded individuals do not appear in convenient, well-tended locations; they grow wherever the seed lands. Here they have to survive the full hostility of the environment and competition from other plants. Each species can be expected to succeed only in a narrow range of conditions suited to its ecology.

Based on these principles, there are two reasons for planting: (1) to introduce founder populations in order to supply the seeds, which will spark recovery, and (2) to create the right conditions in which seedlings will thrive. Thus far, work on Round Island has concentrated on the former aim. Whilst this has achieved some success, it is now important to shift the focus towards the second aim. To deliver it, the following approach is suggested:

- Identify which species will succeed under which conditions.
- Grow and plant founder populations of each species in areas where they are likely to regenerate.
- The main purpose of this first generation is to provide seed crops. They need not be treated as fully 'wild' at this stage. In fact, they can be tended and encouraged to grow strongly and healthily where this will maximize their yield, but there is a difficult balancing act: they should not become so soft that they are unequipped to survive drought and other stresses.
- Where necessary, use additional planting to create suitable environments (e.g., shaded forest canopies or open, weed-free savannah) to spark and then maintain the process of regeneration.
- Consider what other ecosystem processes are needed to facilitate the populations' long-term sustainability: do we need more pollinators, grazers, detritivores, dispersers, mycorrhizal partners, biocontrol agents etc.?

Note that not all plantings will be trees and shrubs. It is important to ensure that the full range of functional groups required to sustain an ecosystem are in place.

6.2 Planning

A long-term restoration plan is needed. More research is still required to assess which species should be appropriately included in a natural community on Round Island, for two main reasons:

- This report identifies some species which are doing well and others which are not, although it remains difficult to make definitive decisions: the failure of the latter group could be because appropriate conditions have not yet been provided.
- The original list has been unconsciously narrowed by experience to a current set of 'successful' (i.e., robust and fast-growing) species, but these belong to a relatively narrow range of ecological groups, mostly mid-successional trees and shrubs. There are arguably too many candidates for these roles, and little to fill the remaining gaps. A wider range of functional types is essential to confer diversity and resilience to the ecosystem.

How should the most appropriate species list be decided? Decisions should be evidence-based. Three sources of evidence are available:

- Ongoing experiments on Round Island should attempt to nurture new habitat conditions and examine how regeneration progresses within them.
- Observations from elsewhere on Mauritius should be used to inform the exact conditions under which species grow naturally. It should be considered to what extent these will be replicated on Round Island now or in the future.
- Efforts should be guided by the historical information on Round Island's original wild communities before rabbits and goats were introduced. Although such evidence is not definitive and it will be impossible to replicate the past exactly, it does suggest which species are likely to be well-adapted, and what sorts of vegetation structure the island can support.

A further review does not necessarily mean 'reinventing the wheel': previous lists were defined along similar criteria and will no doubt form the backbone of ongoing efforts. However, there has been little attempt to refine this list in subsequent years in response to evidence, or to the changing demands of the project. A useful document should be subject to periodic updates as new information becomes available, and this process should continue well into the future. Moreover, the original list did not provide the precise ecological details to determine how different species fitted into the ecosystem, and this information is essential for the efforts to work.

At present, there is no consensus vision of what Round Island should look like. There is a need for a greater understanding of the historical plant community composition. This could be partly answered through palaeoecological research within soils that exist on neighbouring islands or from northern coastal sites on the main island. In 2018, with the assistance of Swansea University, UK, soils were sampled from the neighbouring island Gunner's Quoin, to determine the existence of pollen and to trial genetic extraction techniques. It is too early to tell whether the palaeoecological approach will be successful, but the collection of samples from other sites has been planned. The community characteristics and functional traits of the species currently on Round Island requires investigation and comparison to typical Mauritian plant communities to identify potential gaps.

The plant restoration plan should ultimately include a map, where areas suitable for different community types are identified. It should also specify the necessary steps to engineer conditions for the habitat to exist, which species should be introduced, and the time frame for development. Clearly, some of the details must be flexible, and adapted to the successes and failures as experiments progress. However, the current plant survey results provide much of the evidence to support initials steps.

6.3 Rewilding

Several actions are needed to implement a successful long-term approach:-

- A genetic diversity strategy should be established. This will ensure that Round Island populations are: (1) genetically healthy, (2) not excessively mixed, and (3) play a role in conserving wider genetic resources. Seed collections should come from targeted provenances based on informed goals.
- Over the past year, attempts have been made to rationalize a seed collection strategy. Collections should be adequately recorded. When transferring seed from the mainland to Round Island and vice versa, biosecurity is necessary to prevent introduction of seed pests. Short-term seed storage facilities should be maintained (up to 5 years), so that stocks can be built up and used as and when required, rather than being forced to plant whatever is available for harvesting at a particular moment. A planned seed collection programme is needed to achieve this, with time and resources set aside for visits to donor sites.
- The creation of seed orchards should be considered for key target species. These would involve planting groups of trees close together in a managed environment, representative of selected appropriate and diverse genetic provenances, which can form a future convenient resource to supply seed for restoration work. Wild harvesting of seed can be inconvenient, unpredictable and, in the worst cases, could harm natural recruitment.
- The current work has highlighted drought as a particular issue. Drought-tolerance should be ranked highly amongst the selection criteria of community members, as it is likely that the local environment lies near the extreme of conditions experienced on Mauritius. Where less tolerant species are required, these must be used in situations where the likelihood of stress is minimized. Efforts should be made to harden plants very effectively before introduction to the wild.
- Although hardening is critical to surviving harsh environments, it is recommended that after-care, including weed removal and watering, should be maintained for two years, to reduce mortality. If the surrounding soil dries-out completely, the sapling will die no matter how well hardened, so the aim is not to soften the plants but to limit exposure to critical conditions. Watering frequency should be based on evidence: how long does it take soils to dry completely to an appropriate rooting depth?
- More use should be made of successional planting methods. Early successional species should be planted several years in advance of later successional species, which will survive better in the resulting more sheltered conditions. There is no imperative to rush planting plans through in one year.
- Plants will generally survive less well in open situations at low densities, but frequently undergo severe competition at excessively high densities. 'Nursery' plantings could be used to obtain better control over this problem. These should make use of benign, short-lived but hardy species, which would provide protection for other species for a few years, without creating longer-term competition.
- When selecting micro-environments for planting, the criteria should respect the needs of the adult plant and not just the young sapling. Whereas a sapling may perform well for a few years under palms or in very shallow soils, the conditions will impose increasing stresses as it becomes older and larger.
- In general, it is more important to maintain existing rewilding sites in good condition than to plant more trees. Sites should be visited even after the aftercare period to check and remedy issues. Vine infestations should be managed. Where sites have experienced high mortality, the gaps need to be remedied in future planting seasons rather than moving on to new areas.

- All individual plants must be GPSed when they are planted and their performance monitored, at least once every 7-10 years, to assess the success or failure of a given area and restoration approach. Some measure of the structure and natural community composition of planting sites should also be recorded at similar intervals, to examine how this changes over time.

6.4 Communities and ecology

- Much more focus should be given to establishing native herbaceous ground cover species within planting sites. These may be essential for reducing erosion, trapping soil moisture, creating a barrier to invasive weeds and providing habitat for fauna. Herbaceous community structure is currently very rudimentary on Round Island, particularly in planting sites. Yet, it may be critical to natural regeneration of woody species in certain habitats.
- Four of Round Island's seven fern species have become locally extinct, with the survivors all scarce. There is a strong argument for reinstating the pteridophyte flora, not least because several species are very shade tolerate and could provide ecological benefits as understorey species. Trials of these reintroductions could be attempted reasonably quickly.
- Local planting numbers and densities must be considered on an ecological basis. Where only one or two individuals of a species have established in a given area, there is relatively little possibility that these will cross-pollinate to produce fertile seed crops, especially where self-incompatibility mechanisms operate. Even where few parents still manage to produce seed in reasonable numbers, resultant genetic diversity of the offspring will be poor. Ideally, suitable founder population sizes should be prescribed during the planning stage, and repeated plantings made to compensate for mortality until the desired target has been reached.
- At present, a practice of moving naturally-regenerating seedlings to new areas is often used as a quick and easy way of increasing planting numbers. It is recommended that this approach should be used more cautiously. Even if there are relatively many seedlings at a site, natural mortality may be high in wild situations (only one in many individuals may be expected to reach adulthood) and harvesting may impact the prospects of successful recruitment. Furthermore, such seedlings have often, by chance, landed in good conditions for their survival. Transferal risks death though the trauma caused by uprooting, or because the final location may be less suitable than the original. We do not yet understand seedling requirements well enough to assess the latter question. Ultimately, natural regeneration, even if it looks 'untidy', is vital to the success of the project, and supressing it in favour of boosting planting numbers is merely delaying the success of the project.
- Studies into the functional role played by pollinator, detritivore, and mycorrhizal communities on Round Island are suggested, to assess what limits these are imposing on ecosystem function and how any issues could be remedied.
- Monitoring of habitat quality should be conducted every seven to ten years, to assess diversity, community structure and the spread of alien species.
- Monitoring of soil quality should be conducted every five to ten years, in order to examine changes to substrate structure and chemical composition. It is recommended that an expanded factorial sampling programme should be adopted, targeting key processes and habitats. Sample size should be considered carefully, to account for high spatial variability.

6.5 Management of alien species

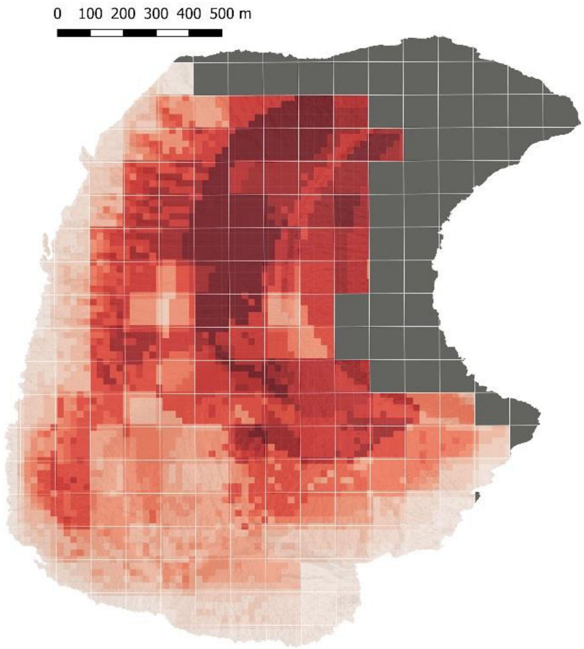
- It is important to maintain the strictest possible biosecurity on Round Island, in order to prevent introduction of further alien species. The cost of incursions could rapidly out-weight the efforts currently invested in preventing them if a new species was to become established.

- Similarly, ongoing efforts to manage existing weed problems should be maintained. These are time-consuming, but even a brief lapse may be sufficient for a species such as *Chromolaena odorata to* expand beyond the point when control is practical. The resulting impacts on habitat quality could negate any gains made through rewilding efforts.
- Incursions of new pathogens and invertebrate pests present a comparable risk to those posed by invasive plants, yet there are few data to assess the success at preventing them. Introduction of new plants from Ile aux Aigrettes nursery offer an obvious pathway for such pests to arrive. Though a convenient means of increasing production, reliance on Ile aux Aigrettes should be minimized or eliminated. For infestations of smaller species such as mealy bug, is almost impossible to be totally sure of removing all individuals from living vegetation, even after bare-rooting. Endophytic pathogens are similarly difficult to eliminate.
- Native ground cover should be used where possible to combat the spread of existing alien plant species on Round Island. Dense herbaceous vegetation may reduce the ability of undesirable seedlings to germinate and survive, thus supressing dominating stands of tall weeds. Experiments designed to test these possibilities could be very instructive.
- Where alien species are the only options currently present on Round Island to fill functional 'gaps' in the ecosystem, it may be beneficial to introduce more desirable natives to displace them. One overall goal is to make the Round Island ecosystem more Mauritian in character, and hopefully to improve ecosystem function by exerting control over community characteristics.
- Trials with tortoise-grazing on Round Island appear to show much promise, and offer substantial opportunities for management and conservation of threatened flora. However, tortoise impacts could expand considerably, and the ecological implications are profound. Anticipation of these changes need full consideration and long-term planning. Suitable tortoise-grazing communities are currently not present on the island, and must be created if the project is to attain its potential.
- Monitoring of alien incursions, and of control efforts, has been of a high standard over the past year. It is important that this continues.

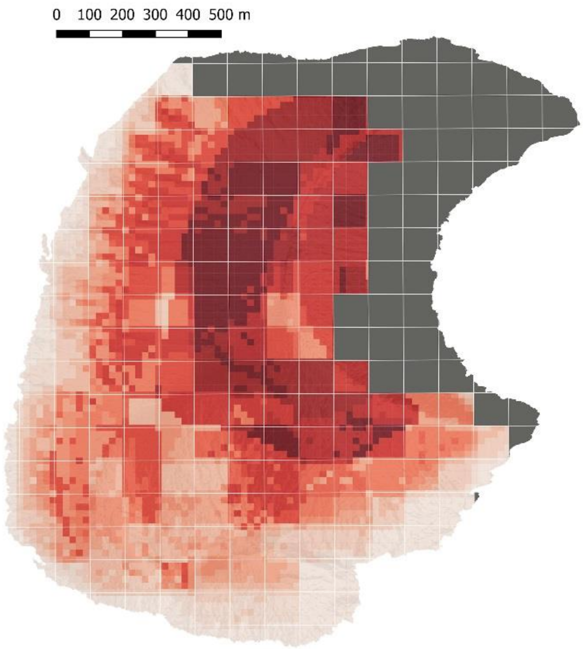
6.6 Conservation

- Nine Round Island native species are currently extremely threatened. It is important to preserve any unique genetic diversity residing in these populations, and their conservation should be treated as an urgent priority. A series of action plans are needed to map-out a path to recovery.
- Further consideration should be given to the use of Round Island as a conservation resource. Numerous lowland dry forest species are severely threatened with extinction on Mauritius due to competition and herbivory by non-native species. These threats are difficult to manage in mainland situations, and offshore translocations have been used successfully in other parts of the world to preserve populations in a safe environment. Such a translocation would only be practical if a species was likely to fit well with the Round Island ecosystem, but, assuming some meet the criteria, it is recommended that one or more additional options are considered.
- A number of vertebrate introductions have been proposed on Round Island. If plans are to be developed for these, it is important to consider the ecosystem impacts and requirements of the species, to examine how these are fulfilled by the current flora and fauna, and what further steps are necessary to meet the requirements. Additional planning may be required at least 10 years in advance of any release taking place.

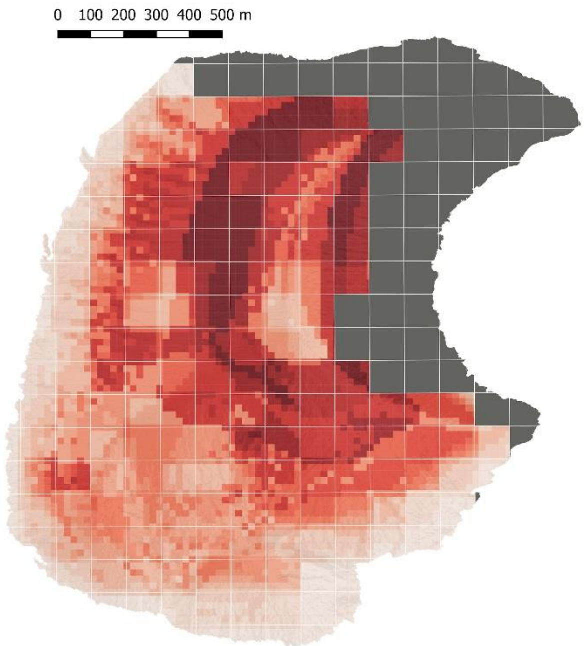
Appendix 1A Maps showing the predicted spatial distribution of plant success, based on a 20 × 20 m grid. Success, as measured by lifetime growth rate, has been graded on a scale of 1 – 100. Areas shaded grey were excluded from the habitat survey and thus cannot be fully parameterized.



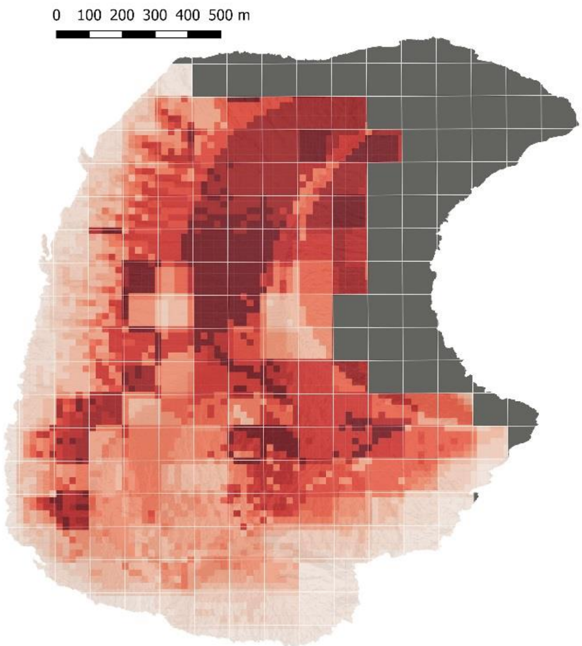
Cassine orientalis



Coptosperma borbonicum

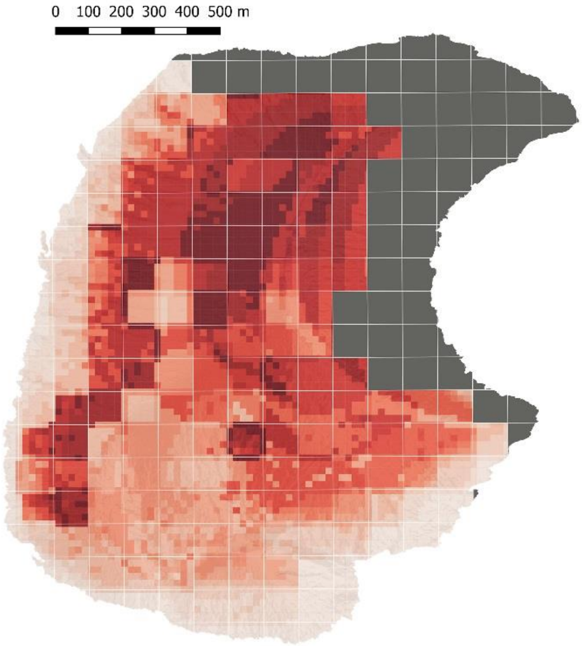


Diospyros egrettarum

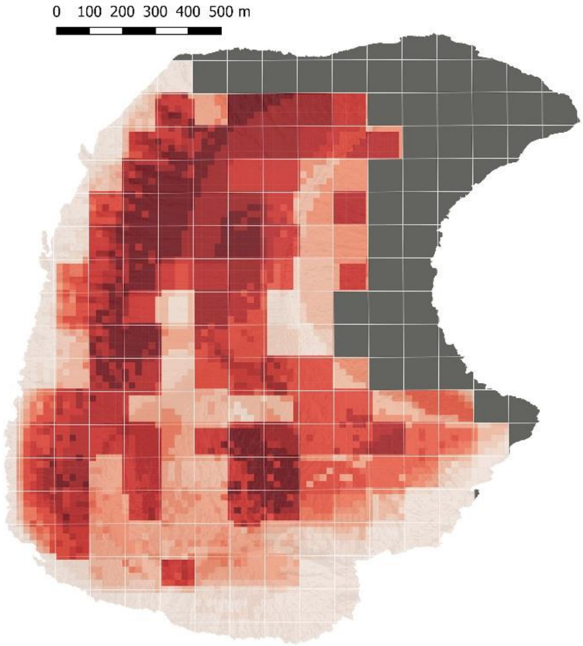


Dodonaea viscosa

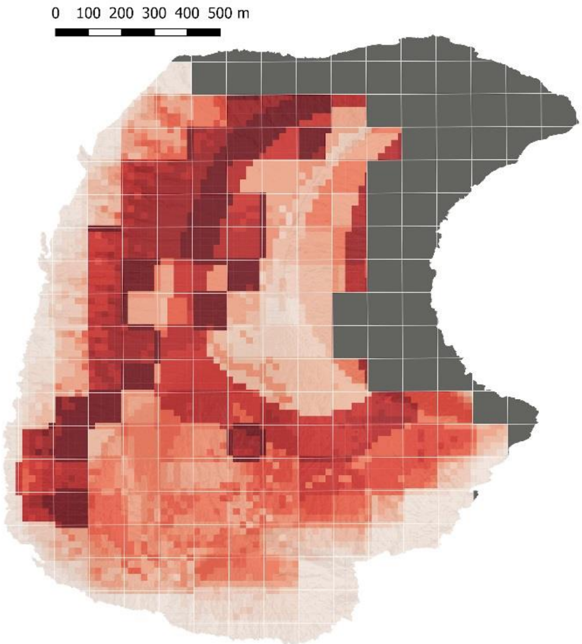
Appendix 1A (cont.) Maps showing the predicted spatial distribution of plant success, based on a 20 × 20 m grid. Success, as measured by lifetime growth rate, has been graded on a scale of 1 – 100. Areas shaded grey were excluded from the habitat survey and thus cannot be fully parameterized.



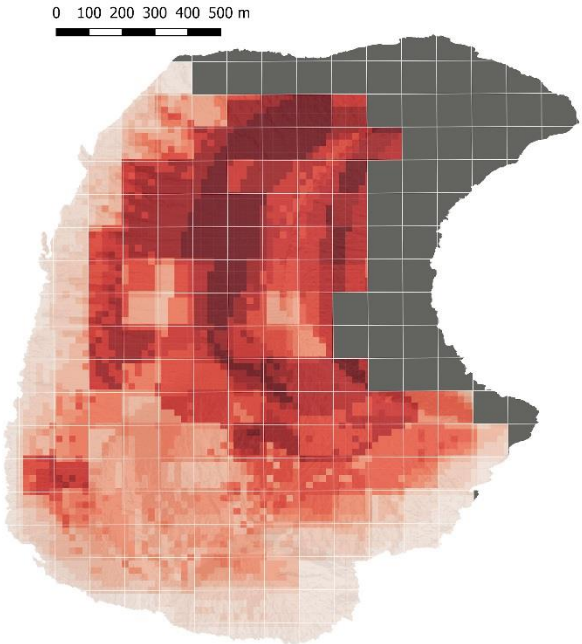
Eugenia lucida



Fernelia buxifolia



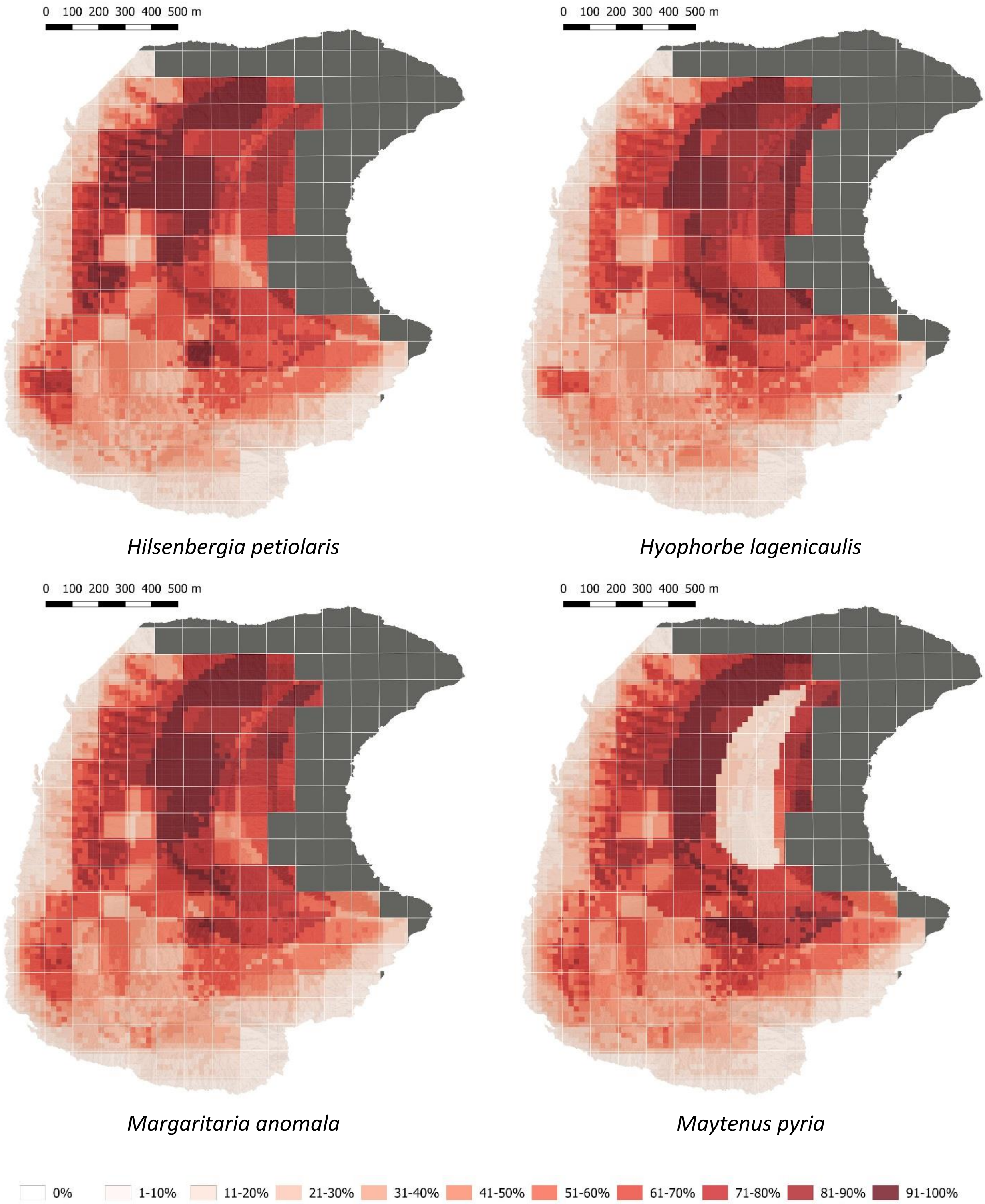
Foetidia mauritiana



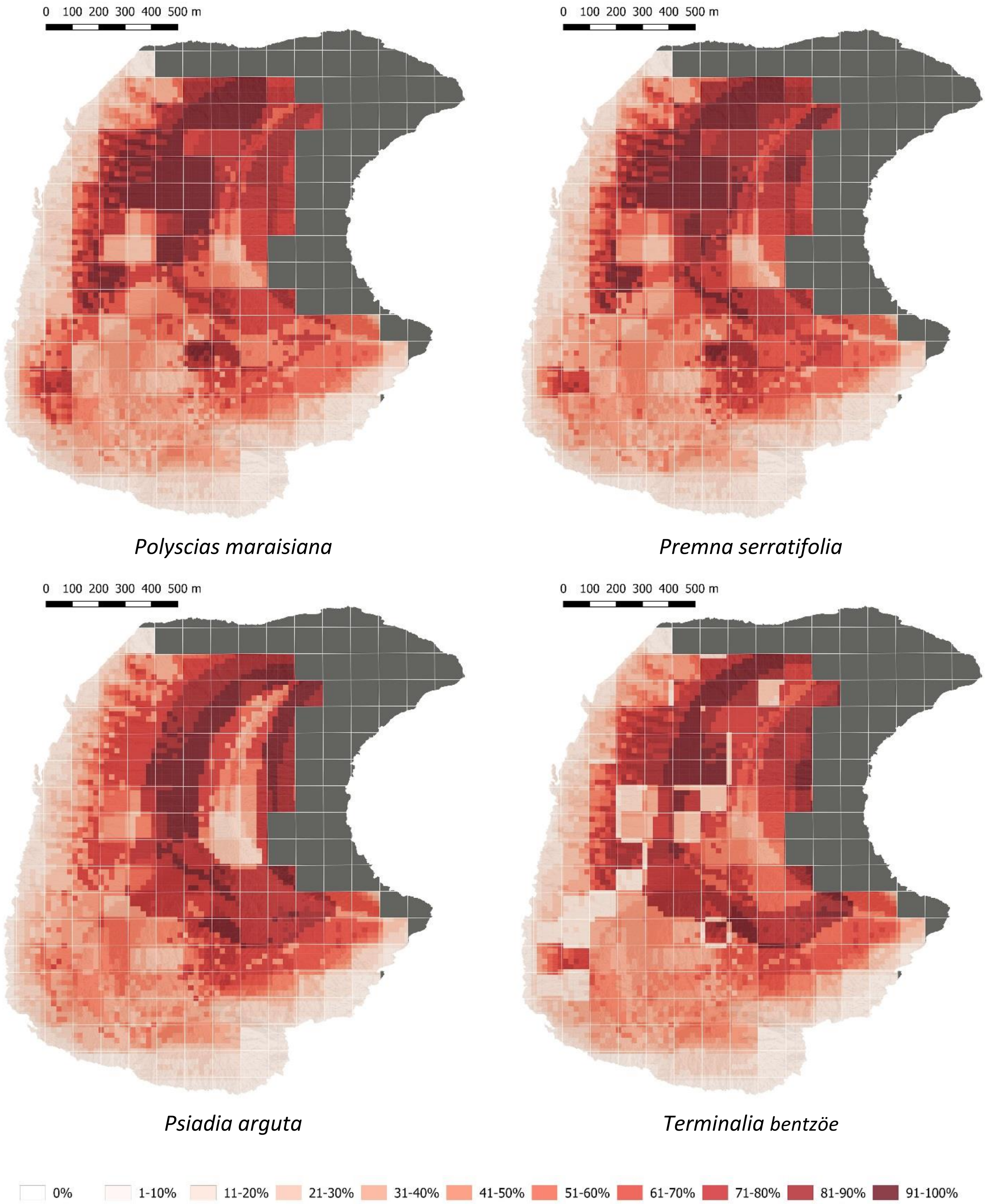
Gagnebina pterocarpa

0% 1-10% 11-20% 21-30% 31-40% 41-50% 51-60% 61-70% 71-80% 81-90% 91-100%

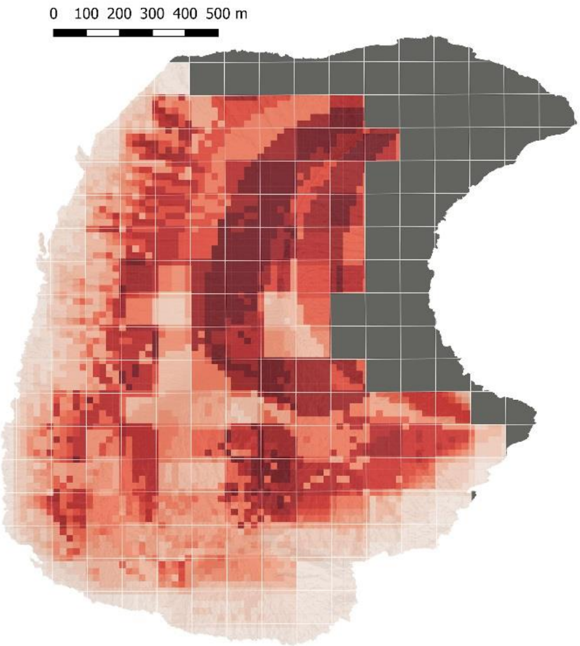
Appendix 1A (cont.) Maps showing the predicted spatial distribution of plant success, based on a 20 × 20 m grid. Success, as measured by lifetime growth rate, has been graded on a scale of 1 – 100. Areas shaded grey were excluded from the habitat survey and thus cannot be fully parameterized.



Appendix 1A (cont.) Maps showing the predicted spatial distribution of plant success, based on a 20 × 20 m grid. Success, as measured by lifetime growth rate, has been graded on a scale of 1 – 100. Areas shaded grey were excluded from the habitat survey and thus cannot be fully parameterized.

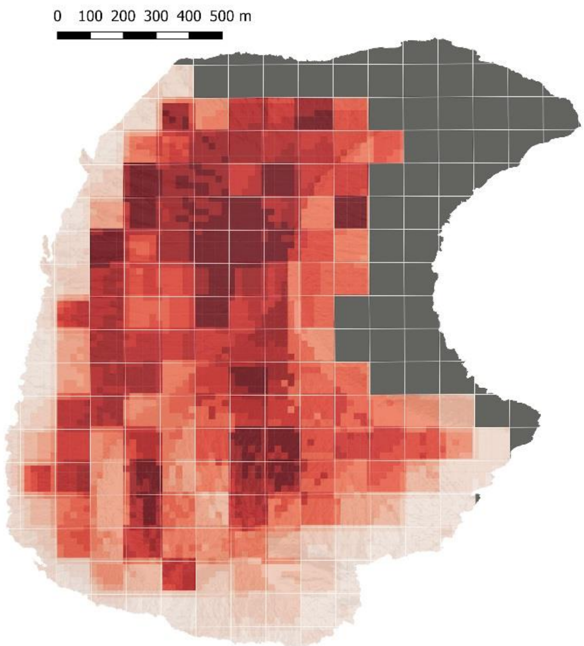


Appendix 1A (cont.) Maps showing the predicted spatial distribution of plant vigour, based on a 20 × 20 m grid. Vigour has been graded on a scale of 1 – 100. Areas shaded grey were excluded from the habitat survey and thus cannot be fully parameterized.

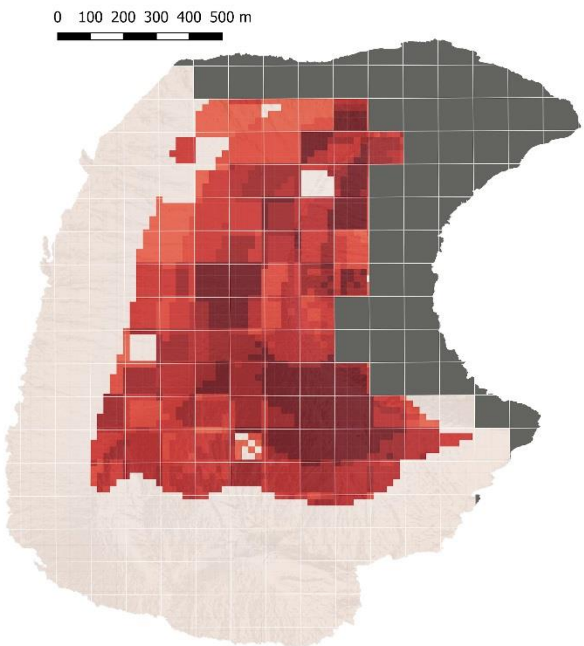


Volkameria heterophylla

Appendix 1B Maps showing the predicted spatial distribution of regeneration frequency, based on a 20 × 20 m grid. The probability of obtaining a regen has been graded on a scale of 1 – 100. Areas shaded grey were excluded from the habitat survey and thus cannot be fully parameterized.

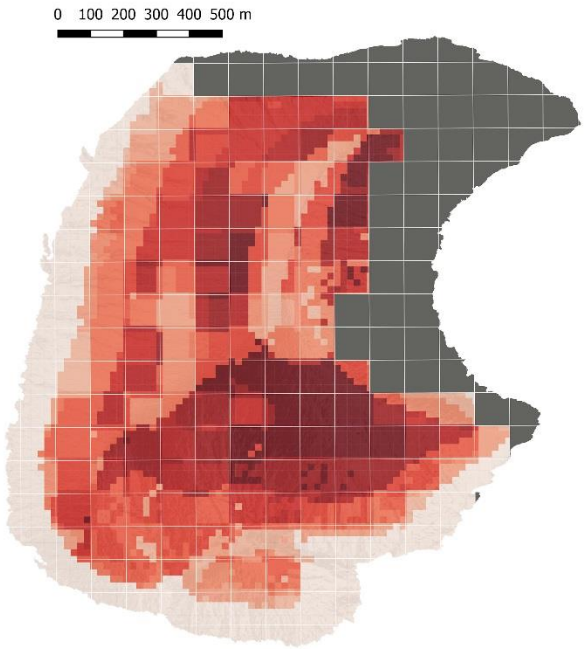


Asparagus umbellulatus

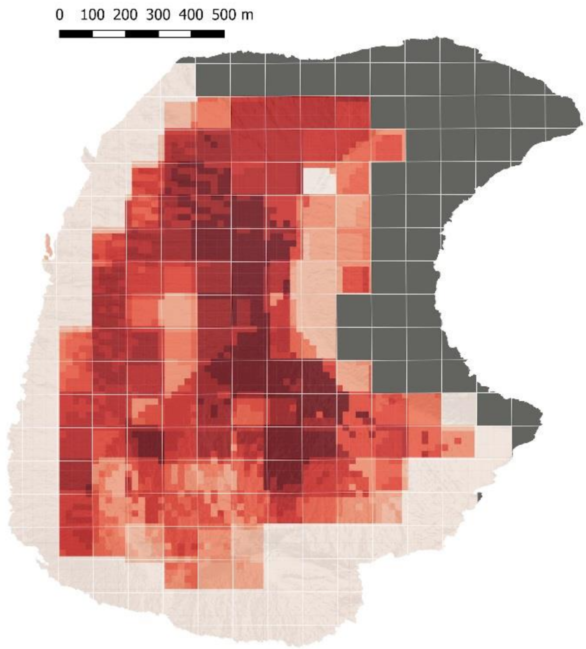


Dodonaea viscosa

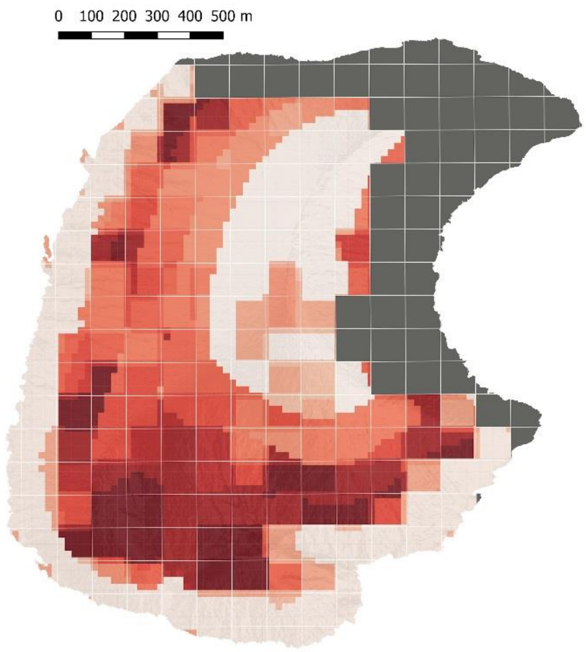
Appendix 1B (cont.) Maps showing the predicted spatial distribution of regeneration frequency, based on a 20 × 20 m grid. The probability of obtaining a regen has been graded on a scale of 1 – 100. Areas shaded grey were excluded from the habitat survey and thus cannot be fully parameterized.



Gagnebina pterocarpa



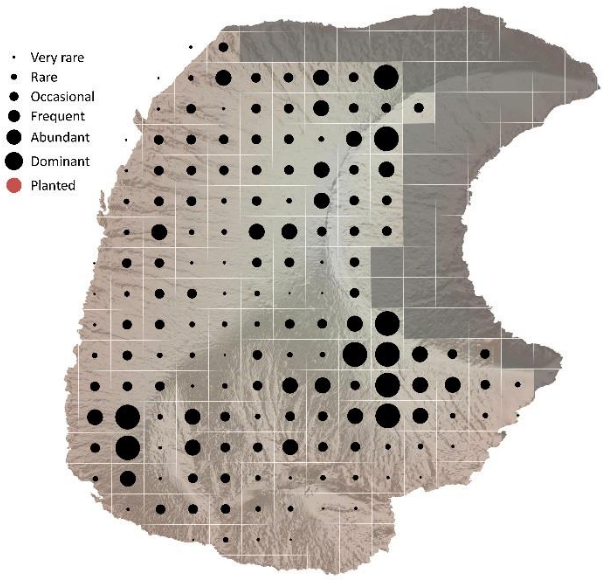
Hyophorbe lagenicaulis



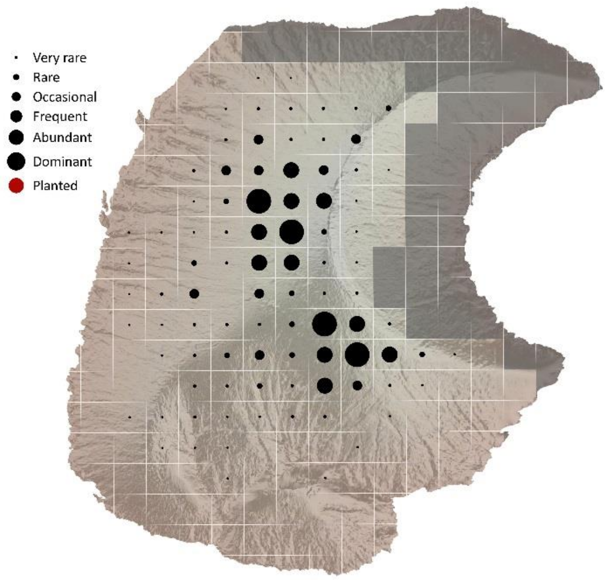
Psiadia arguta

0% 1-10% 11-20% 21-30% 31-40% 41-50% 51-60% 61-70% 71-80% 81-90% 91-100%

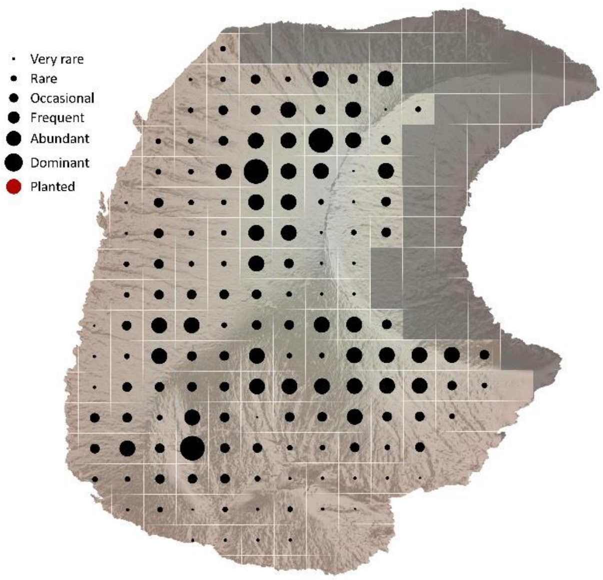
Appendix 2A Example maps showing the distribution of four common alien species. Abundance scores are represented by size-graded circles. Areas shaded grey were excluded from the habitat survey.



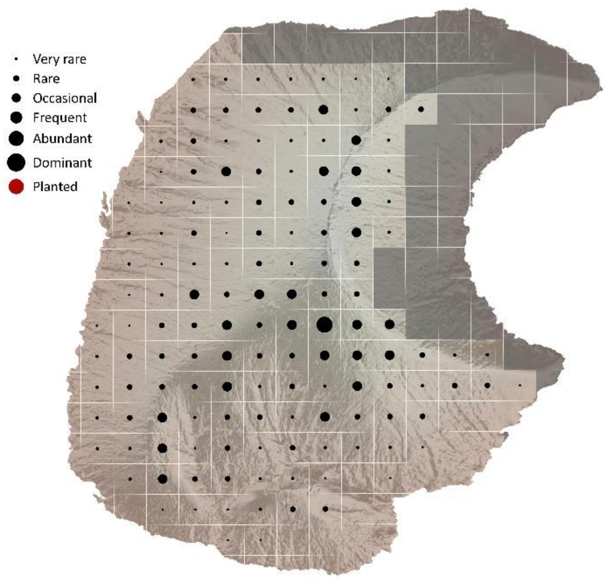
Achyranthes aspera



Bidens pilosa

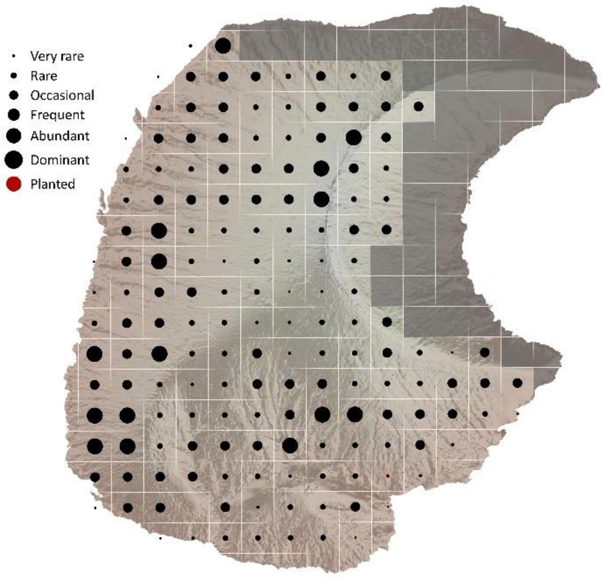


Cenchrus echinatus

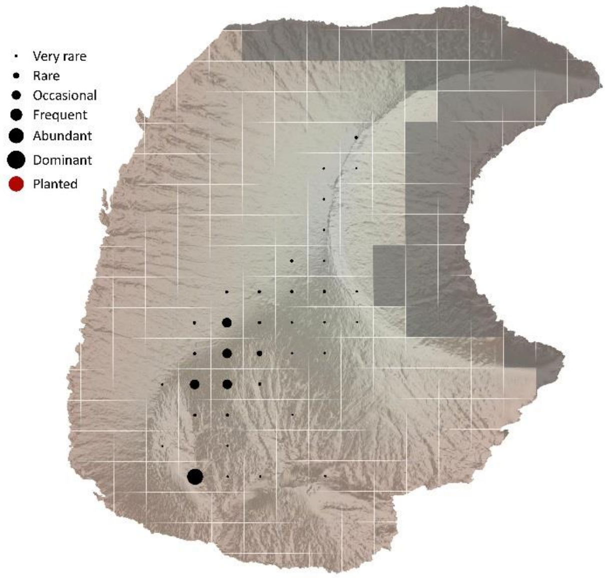


Desmodium incanum

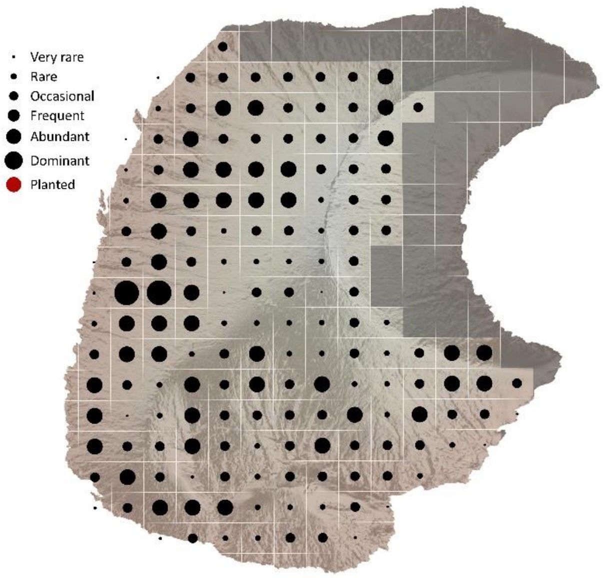
Appendix 2B Example maps showing the distribution of four common Mauritian native species. Abundance scores are represented by size-graded circles. Areas shaded grey were excluded from the habitat survey.



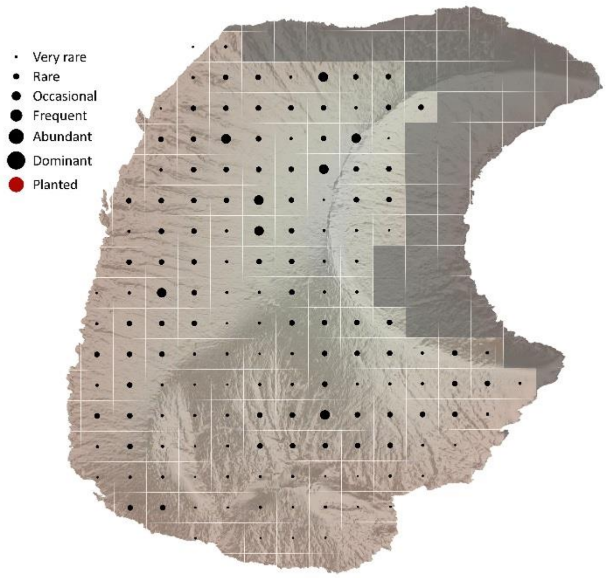
Boerhavia coccinea



Cyperus compressus

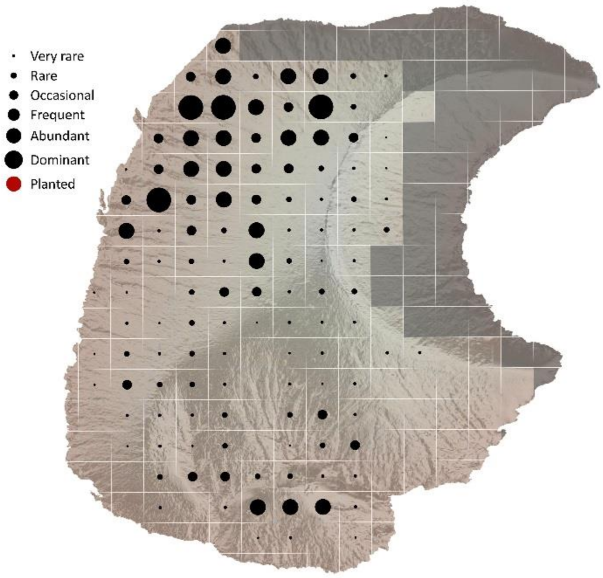


Dactyloctenium ctenoides

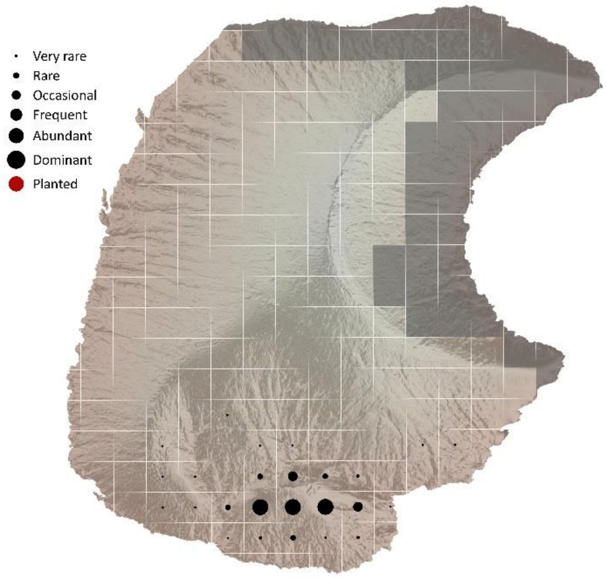


Passiflora suberosa

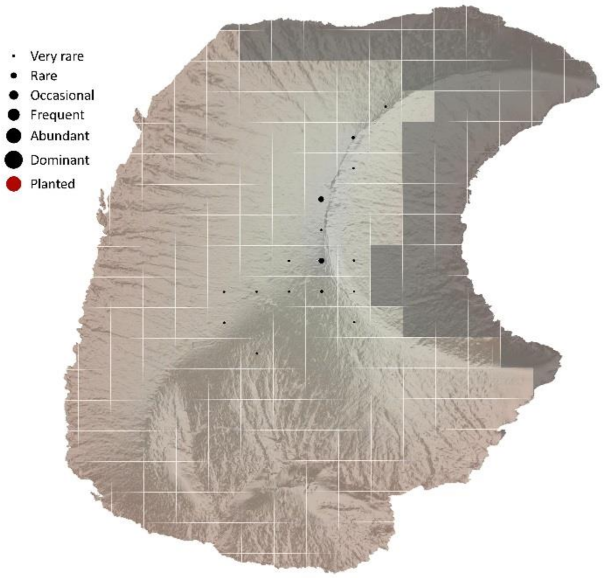
Appendix 2C Example maps showing the distribution of four native species. Abundance scores are represented by size-graded circles. Areas shaded grey were excluded from the habitat survey.



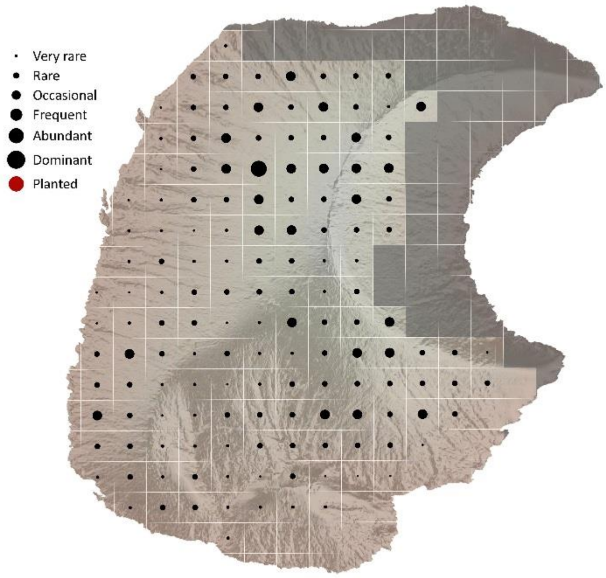
Cymbopogon caesius



Fimbristylis cymosa

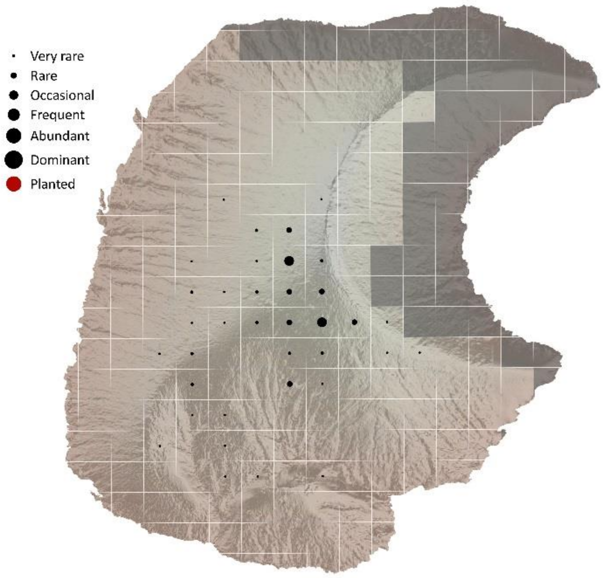


Phyllanthus mauritianus

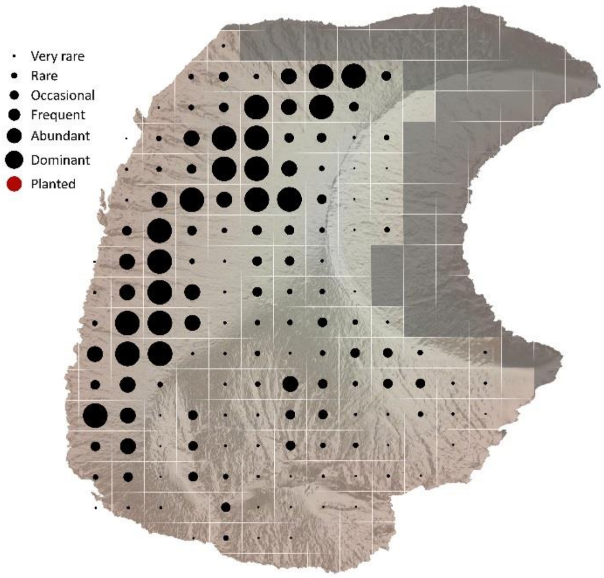


Tylophora coriacea

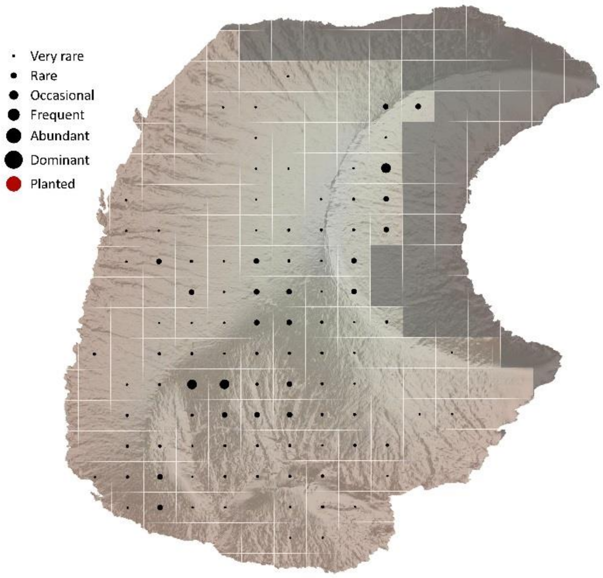
Appendix 2D Example maps showing the distribution of the four woody species excluded from the habitat survey. Abundance scores are represented by size-graded circles. Areas shaded grey were omitted.



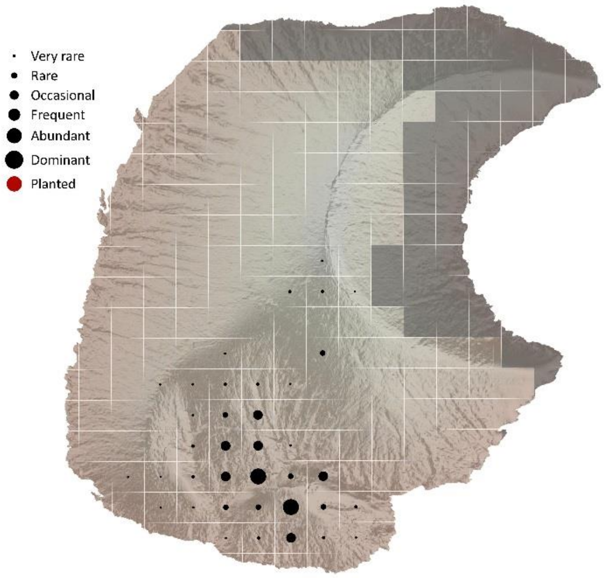
Dracaena concinna



Latania loddigesii



Pandanus vandermeeschii



Scaevola taccada