LESSONS AND REFLECTIONS ON NATURE RESTORATION

ORANGUTANS AND FIGS IN AN OIL PALM LANDSCAPE

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BORNEO RHINO ALLIANCE (BORA)

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December 2025

BRINGING BACK OUR RARE ANIMALS

BORNEO RHINO ALLIANCE

Front cover

Ficus annulata, shown here at 3 years 1 month old, grown from a marcot, planted on to a riparian zone and fruiting prolifically, with BORA staff Norashimah Janih, Ronald Jummy and Mohamad Soprih Amdan

(Photo: Mellinda Jenuit)

Back cover

The BORA team at Sabah Ficus Germplasm Centre (standing), Hassan Sani, James Sandiang, Maslin Mohiddin and (squatting) Mohamad Soprih Amdan, Ronald Jummy and Mellinda Jenuit

Published by Borneo Rhino Alliance, Faculty of Science and Technology,
Universiti Malaysia Sabah, Jalan UMS, 88400 Kota Kinabalu, Sabah

LESSONS AND REFLECTIONS ON NATURE RESTORATION - ORANGUTANS AND FIGS IN AN OIL PALM LANDSCAPE

by John Payne, Mellinda Jenuit, Ronald Jummy, Hassan Sani, Mohd. Soprih Amdan and Zainal Zahari Zainuddin, BORNEO RHINO ALLIANCE (BORA)

Produced as a part of the 'Experimental Habitat Restoration for Orangutans in Kinabatangan Landscape', a project of WWF-Malaysia, funded by Unilever, with additional information from work conducted under 'Berembang (Sonneratia caseolaris) as a possible freshwater wetland restoration tree species' funded by The Habitat Foundation

e ISBN 978-629-94462-2-4

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Glossary

ha	hectare(s)
m	metre(s)
cm	centimetres

The conceptual background

If one draws a simple graph of the relationship between size of an area of natural habitat and the number of species that it can sustain (species-area curve), it turns out that the smaller the area, the fewer species that the area can support (Figure 1). This has been known to biologists for at least one hundred years (Arrhenius, 1921) and has been researched intensively and verified thereafter, especially through research conducted in the 1960s-90s. The knowledge is usually framed as 'island biogeography theory', one of the major theories in ecology, and its applicability to natural systems is well documented.

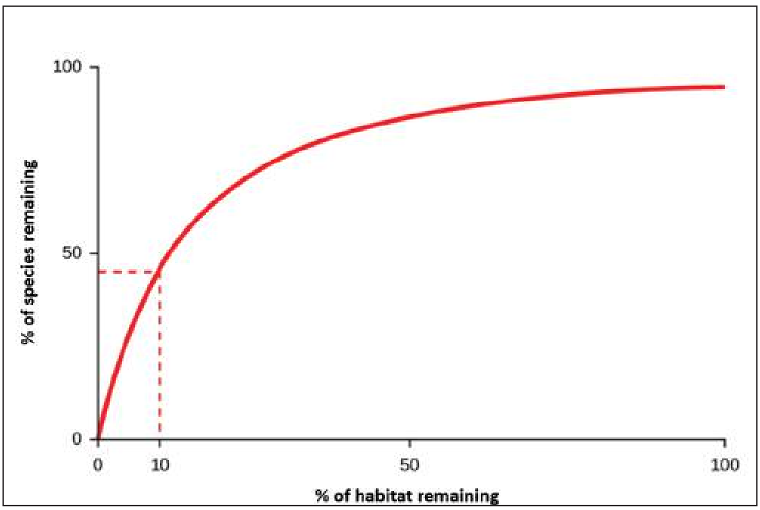


Figure 1. Species Area Curve

As a rule of thumb from the species-area curve graph, if ninety percent of the original habitat is eventually lost, leaving only ten percent of the land still covered in forest, then fifty percent of all species originally there will go extinct. This is the situation now in the lower Kinabatangan region (roughly 500,000 hectares), some forty years after the beginning of a major conversion there of forests to oil palm plantations. But extinctions resulting from decreasing habitat are not sudden. They happen very, very slowly. The process plays out over many decades or even centuries as sources of nutrition for each species decline and births decline in tandem. Big-sized species, whether trees or mammals, will be the first to go, because their populations require lots of space and resources to survive and reproduce.

All the forest patches in the Kinabatangan landscape are small and, individually, they will each lose a lot more than 90% of species that were originally present. 10% of the landscape is 50,000 hectares but 10 hectares, for example – representing a relatively large 'small patch' - is just 0.002% of the landscape.

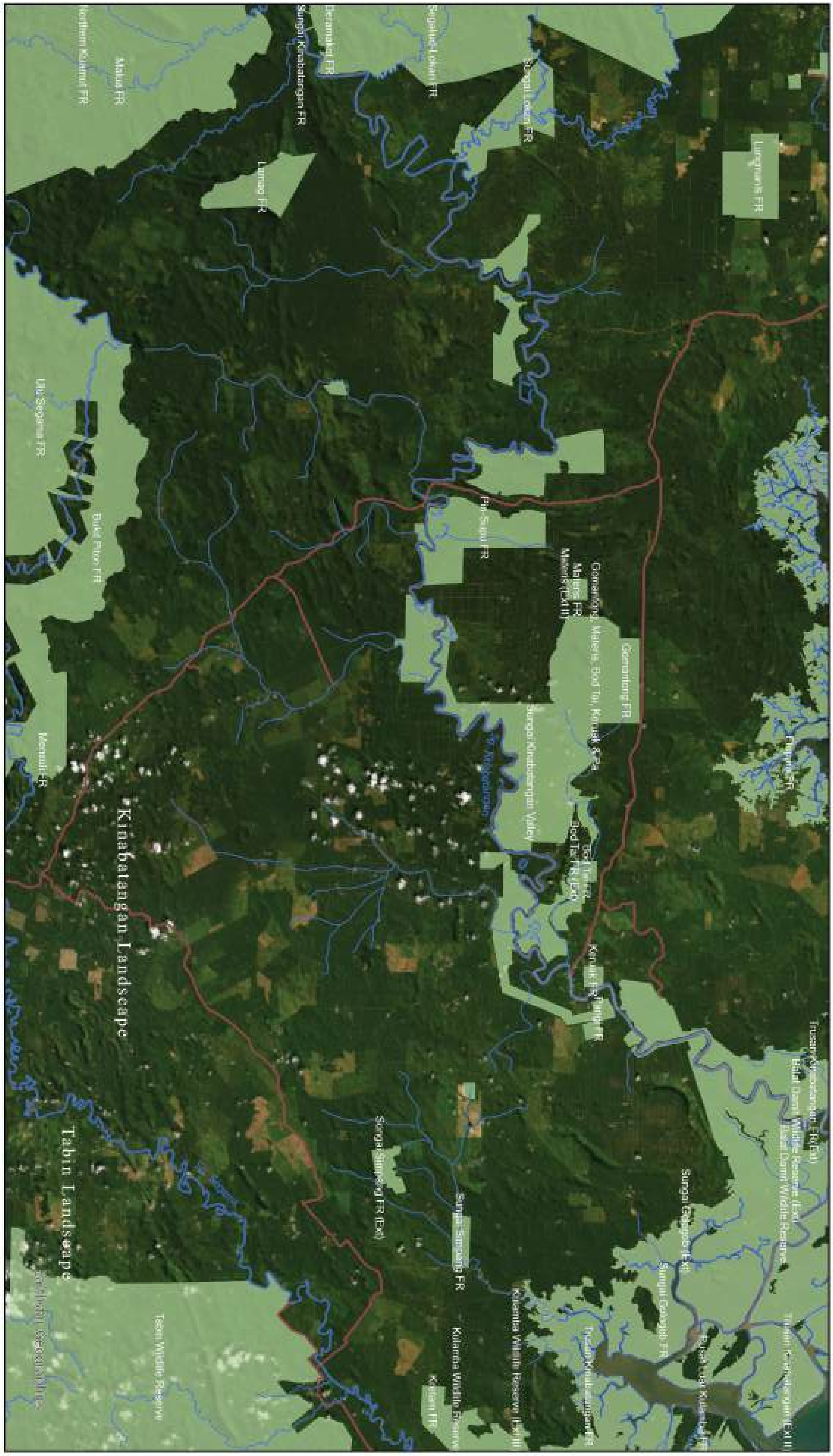
The only way to fight the tyranny of the species-area curve is for the implementation of targeted interventions, that do not leave everything to nature, but aim to ensure that reproduction amongst the rarest and most susceptible species is sustained. For many sensitive species, the challenge to sustain them will be either too great or impossible. But for a few, it will be possible and worthwhile.

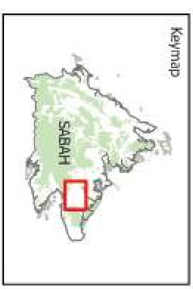
'Interventions' in the context of this book means doing things to help sustain survival and reproduction of those species most at risk of being lost - such as the Bornean banteng, Bornean orangutan and trees that grow to large size. The programme reported by Borneo Rhino Alliance (BORA; www.bringingbackourrareanimals.org) in this book aims to show that an entire landscape can be modified to favour selected species (in this case with a focus on the Bornean orangutan) by enriching the landscape with the most favoured food plants on areas of land that are not under oil palm production. The food plants themselves are also an integral part of overall biodiversity enrichment.

Why restore habitat for orangutans?

This book represents a report on and analysis of a programme named 'Experimental Habitat Restoration for Orangutans in Kinabatangan Landscape', which BORA operated from 2020-2025, with the specific objective 'To develop methods for enriching, restoring and maintaining lands within the oil palm landscape in favour of sustaining an orangutan meta-population in the long term.'

In the 1980s, the largest population of wild orangutans in Malaysia existed in the catchment of the lower Kinabatangan river in eastern Sabah, with unbroken tracts of natural forests (but logged, with all the former big trees missing) on flat lowland terrain interspersed with freshwater and peat swamp forests, that together supported the highest known natural population densities of this species in Borneo (Payne, 1988). By year 2000, 90% of the land area of about 500,000 hectares had been converted to oil palm plantations, with only 9% still under forest and 1% human settlements (Map 1).





Map 1. Approximate extent of the Kinabatangan Landscape, as defined in this book

N

1:400,000

0 4 8 16 Km

Legend

Main Road

Major River

Forest Reserve (FR) and Wildlife Scantuary

Total area, excluding major Forest Reserves on the eastern, southern and western sides of the map, is about 500,000 hectares (5,000 square kilometres)

From around year 2000 to now, the Kinabatangan orangutan population in this mixed oil palm and forest landscape has been well-studied and reported by Dr Felicity Oram and the NGO Hutan (Oram et al, 2022). The most startling conclusion is that, although orangutan numbers have declined drastically since the 1980s, some 800 orangutans are still living and reproducing in a landscape which is now primarily oil palm plantation, with many small, scattered blocks of forest. Female orangutans that are refuging in (mostly very degraded) residual forest patches continue to give birth and raise young, while mature male orangutans not only refuge in forest patches but move distances of many kilometres through the plantations to mate with females (Ancrenaz et al, 2014; Ancrenaz et al, 2015; Sherman et al, 2020; Ancrenaz et al 2021; Oram et al, 2022).

These observations come some thirty to forty years after the loss of the bulk of the former forest habitat, and as the oldest oil palm plantations have been replanted with new palms. All orangutans living in this landscape require some forest as a place to refuge and to stay cool, and non-palm trees as places to build their nightly nest. Their other and perhaps most vital requirement, however, is access to varied and nutritious food, predominantly fruits and young leaves. These observations have not only been documented but a contributory solution has been proposed, in the form of large-scale boosting of orangutan food plants in the oil palm landscape (Payne & Oram, 2020; Payne & Zainal, 2023a).

In summary, orangutans can live and reproduce in a predominantly non-forest landscape, but an underlying limiting factor is the amount of food available, especially to the females who are restricted largely to life in residual forest patches. Oil palms do not provide much food for orangutans. Neither, seasonally, do small forest patches.

Significant amounts of high-quality orangutan habitats could potentially be recreated in the Kinabatangan landscape on sites that are not under productive oil palm trees. If implemented at scale, the currently scattered Kinabatangan orangutan population could be secured for the longer term. Riparian (riverside) zones, wetlands, buffer zones, 'High Conservation Value' sites and steep slopes offer space for creating numerous potential orangutan food centres, along with enrichment of government-controlled conservation areas such as protection forests and wildlife sanctuary.


Figure 2. *Ficus kerkhovenii*, a large strangling *Ficus*

Why are figs special?

Ficus (family Moraceae) is a genus of woody plants containing large, medium-sized and small trees, shrubs, climbers, epiphytes and (most famously) hemi-epiphytes, the latter commonly known as strangling figs (Figure 2). About 150 *Ficus* species occur in Borneo (Kochumen, 1995; Berg & Corner, 2005). New Borneo species are described from time to time (for example, Gardner et al, 2025). *Ficus* is often quoted as a keystone genus, referring to a type of plant or animal that has a disproportionately large positive impact on its ecosystem, linking many other species together and supporting overall biodiversity. *Ficus* fruits (actually an inflorescence in an enclosed receptacle, known technically as a syconium) are eaten by fish (if they fall into streams and rivers), terrestrial mammals (such as mousedeer), terrestrial birds (such as pheasants) and, in the branches, stems and canopies, by multiple species ranging from squirrels, primates, civets, elephants, hornbills and pigeons. Orangutans feed on the fruits of most *Ficus* species and on the leaves and bark of some.

Examination of the literature on the diet of wild orangutans since the 1960s indicates that one plant genus – *Ficus* – features very heavily in all study areas. Some studies (but not all) suggest that orangutan population density may be linked to amounts of *Ficus* plants in the forest (Wich et al, 2004; Milne et al, 2021). In its published observations since 2015, Hutan (https://wwMilnew.hutan.org.my/) has shown that over 20% of feeding observations of wild orangutans are on the genus *Ficus*. Although in some months, other types of plants may become more important, no other food plant genus approaches this level of sustained use by orangutans. Payne & Zainal (2023b) illustrated more than one hundred favourite Bornean orangutan food plants, where more than two thirds are *Ficus* species.

In addition to the sheer number of *Ficus* species and variety of physical life forms, another important element in the story is that different *Ficus* plants have different times of fruiting, and much of the fruiting tends to occur outside the peak of fruiting of other native trees (Appendix 1). The general trend is that *Ficus* species which grow to relatively small size bear fruits throughout the year. The pattern in larger trees and in stranglers is very different. Some plants bear fruits once or twice or three times per year, with a similar pattern every year. In many *Ficus* species which grow to large size, however, different individual plants have different fruiting times and there is no consistent annual pattern. Appendix 1 shows just a few examples of individual *Ficus* trees and stranglers that have been monitored in Kinabatangan and in Tabin, where fruiting occurs at odd intervals. These observations show that *Ficus* provides food to wildlife throughout every year, most importantly when there is very little alternative food available. One can imagine that the more *Ficus* plants in any locality, and the greater the diversity of *Ficus* species present, the lower the chance that wildlife will come into plantations and gardens to seek food.

Some oil palm growers have expressed concern that by adding strangling figs into an area, as the plants grow and produce fruits eaten by birds, there will be more strangling fig seedlings sprouting and growing in the future on the palm trunks. In our experience this is a not a significant concern. Most fig seeds deposited on to palms will have been brought in from forests by birds, and most of the seeds and seedlings will die and, in any case, space available on oil palm trunks will be invaded by the more abundant ferns and other epiphytes. All of them will either need to be tolerated or removed.

Enrichment of land for orangutans and other wildlife should not focus exclusively on *Ficus*. For sites which are rarely or never flooded, other genera of favourite food plants of orangutans and other wildlife species include *Spatholobus* and *Gnetum* (both lianas, with leaves and fruits eaten by many mammal species), and *Endospermum* and *Diospyros* (both trees whose fruits are relished by orangutans and other wildlife). These genera were tried in the programme reported here, and are described and depicted in Payne & Zainal (2023b). Special mention also goes to laran (*Neolamarkia cadamba*) a fast-growing native tree that provides structure and shade, and has been shown as a favoured orangutan nest tree, as well as providing foods (fruits & bark) outside the main fruiting periods. For permanent freshwater wetlands and some sites subject to flood waters, *Sonneratia caseolaris* represents a possible tree species to provide food to orangutans and other frugivores (Figure 3).

Figure 3. Orangutan feeding in a *Sonneratia caseolaris* tree
(Photo: Charles Ryan/ Sticky Rice Travel)

Sabah Ficus Germplasm Centre

Production by BORA of all planting materials for creation or enrichment of orangutan habitat is done in a combined arboretum and nursery known as Sabah Ficus Germplasm Centre (SFGC) in Tabin Wildlife Reserve, Lahad Datu District (GPS coordinates: N5°11’59.70”; E118°30’244”).

The origin of the SFGC was as a ‘rhino food garden’ initiated in 2011. The intention then was to provide fresh browse to feed captive Sumatran rhinoceros in the Reserve, to be harvested from planted, fast-growing preferred food plant species. The number of plantings and species of *Ficus* at Tabin, using primarily vegetative propagation from wild plants in the Tabin region, was gradually increased from 2012 onwards, planting strangling fig cuttings and marcots as well as tree fig species into soil (Figure 4) and, more experimentally, on to tree trunks, and focusing on the species that the rhinos were found to prefer. Initially, wildings (wild seedlings taken from old oil palms or from the soil or old buildings) were used to increase the number and variety of *Ficus* plants maintained in the garden. Methods of propagation were guided initially by Hartmann et al (1997). The BORA staff at Tabin developed the details of techniques to propagate *Ficus* plants through formal training and, mainly, on-the-job experimentation.

A starting point in 2018 was to try wildings of strangling figs planted on to the trunks of old oil palms scheduled for retention in set-aside lands (Figure 5). That meant removing the seedlings of strangling figs from old oil palms that are to be cut down and replaced with young palms, and replanting the seedlings on to the trunks of palms that are to be retained within ‘set-aside’ areas such as riparian zones and steep slopes, in accordance with MSPO (Malaysian Sustainable Palm Oil) and RSPO (Roundtable on Sustainable Palm Oil) guidelines to restore non-oil palm natural vegetation on those zones.

Figure 4. Former Deputy Prime Minister of Malaysia Tun Musa Hitam plants a seedling of *Ficus francisi*, a small riverside tree endemic to northern Borneo, in Sabah Ficus Germplasm Centre, December 2016

Figure 5. Masri Pudin, former Group General Manager of Sawit Kinabalu, planting a *Ficus* wildling into an old oil palm in Sungai Pin estate conservation area in an early experiment in 2018

We quickly found that at most sites, wild macaque monkeys of one or two species would find and pull off the planted wildings, however clever we might be at disguising the wildlings. The early trials also drew attention to the fact that almost every patch of residual forest in the oil palm landscape of eastern Sabah holds at least one group of macaques, either *Macaca nemestrina* or *M. fascicularis*, or both, and hybrids are seen in some localities.

With the death of the last native Malaysian rhinoceros at Tabin in November 2019, the propagation of rhino food plants was halted. But BORA decided to reformulate the garden as a component of a nursery to mass-produce *Ficus* planting material for restoration and enrichment in oil palm plantations and in Forest Reserves. In tandem, it was decided to actively boost the number of *Ficus* species present. From 2019, other genera of favourite food plants of orangutans have been sought and brought into the nursery.

Subsequently, also starting in 2019 and funded by WWF-Malaysia/ Unilever under the WWF Malaysia 'living landscapes approach' to landscape management in Sabah, BORA started to focus on production of planting materials and then planting and maintaining them in an array of sites and conditions in oil palm plantations and also Forest Reserve. The coming of the Covid19 pandemic in early 2020 and ensuing movement controls meant that most initial work had to be done in and near the BORA field site in Tabin Wildlife Reserve, both inside the forest and in nearby oil palm estates owned by Tradewinds Plantations and KLK. From 2021 onwards, this work was focused in the Kinabatangan landscape.

At time of writing (2025), in excess of 1,000 living plants representing about 90 native *Ficus* species are held in SFGC (Appendix 2). They are maintained as a genetic resource and to supply planting materials for habitat restoration and enrichment. Equally important as the production of materials for planting out into oil palm plantations is the fact that the SFGC provides an opportunity to conduct ad hoc small-scale experiments, with daily observation of results and trends. Trial-and-error led to the development of standard procedures. SFGC is operated by four full time staff (who also participate in planting, weeding and monitoring of plantings in oil palm plantations), continuously supervised on a part-time basis by a programme director.

Propagation methods

Propagation methods used for this programme are described by Zainal & Payne (2023). The term ‘seedling’ is often used to describe the young plants that are planted on set-aside sites. But not all planting materials are seedlings.

Seedling – here means a plant that is grown from a seed in a nursery. Seeds are removed from fruits, cleaned with water and put into a soil-based mixture in a poly bag, and raised to a height and size that is considered sufficient to plant into soil at the site where it will grow to maturity. If the seeds of the species to be grown are less than 2 mm diameter and numerous, a feature which applies to almost all *Ficus* species, then the seeds are usually first germinated ‘en masse’ in a ‘bed’ of fine soil.
No experiments were performed to compare performance of seeds that had been passed through animal digestive tracts with seeds prepared by manual separation, washing and drying, as the latter method was found to be satisfactory in terms of germination and survival, and much easier to manage.

Wilding – refers to a seedling which has grown naturally in the wild from a seed dropped or dispersed from the parent plant by an animal or the wind or flood waters. Small wildings can be collected and brought into a nursery, and raised to larger size as a seedling.

Cuttings – this refers to vegetative propagation, whereby lengths of large, leafy twigs are cut from living mother plants of the desired species and treated in a nursery to create materials that look like seedlings (Figure 6). Only a few native plant species are amenable to this method. Rate of survival of the resulting ‘seedlings’ is unpredictable and often low.

Marcot - this is another vegetative method for propagation of planting materials, and derives from the term ‘marcottage’ or air-layering in English. It involves getting healthy growing twigs of the mother plant to produce roots while the twig is still on the mother plant (Figure 7). Once the roots are visible, the stem with these roots are cut from the mother plant and put into soil in poly bags, to be grown to large size before planting out in the target planting site. A big potential advantage of this method is that the marcotted twig is from an adult plant, and it can potentially start producing fruits within a year or two. The advantage of marcots over cuttings is that survival rate both in the nursery and after planting out is usually much higher (often 100%) with marcots.

Stakes - (also known as poles, and called ‘truncheons’ by Kuaraksa & Elliott, 2013, in order to distinguish them from use of the word ‘stake’ and ‘pole’ to mean a dead wooden pole used to support flimsy live plants). In an attempt to seek solutions to planting into sites where there is vigorous herbaceous and shrub ground cover, which quickly overgrows and often causes the death of planted materials that are less than 1 m tall, experiments were conducted by cutting branches 5-10 cm in diameter and about 2 m long, with a handsaw, from parent strangler *Ficus*. Bark was removed from the lower 3 cm of the live stake, twigs and shoots trimmed, rooting hormone dusted on to the lower end, exposed cuts dusted with the insecticide cypermethrin and sealed with paint (Figure 8). In a few experiments, the stake was kept in the nursery in pots with moist soil for several months to stimulate and see sufficient root growth prior to planting out.

Hardening – means the process of introducing planting materials that have been nurtured under the optimum conditions of moisture, light and nutrients in a nursery to the harsher conditions that they will experience in the real world of the out-planting site (Figure (9). Without the hardening phase, seedlings usually exhibit signs of shock soon after they have been planted out, with leaves curling or falling off, cessation of growth and sometimes death. At SFGC, seedlings are typically hardened once they reach a height of around 30 centimetres. In the case of restoration planting in Sabah, the hardening process typically means putting the seedlings in a site near the nursery where exposure to light is greater and there is less consistent provision of moisture

Figure 6. *Ficus* cuttings planted into coconut husk clumps in plastic rooting trays, a method abandoned after it was found that mortality is often high with no obvious reason

Figure 7. A typical marcot (bottom centre) on the mother plant, demonstrated by Ronald Jummy

Figure 8. Ronald Jummy brings *Ficus* stakes to SD Guthrie Segaliud estate, early 2021

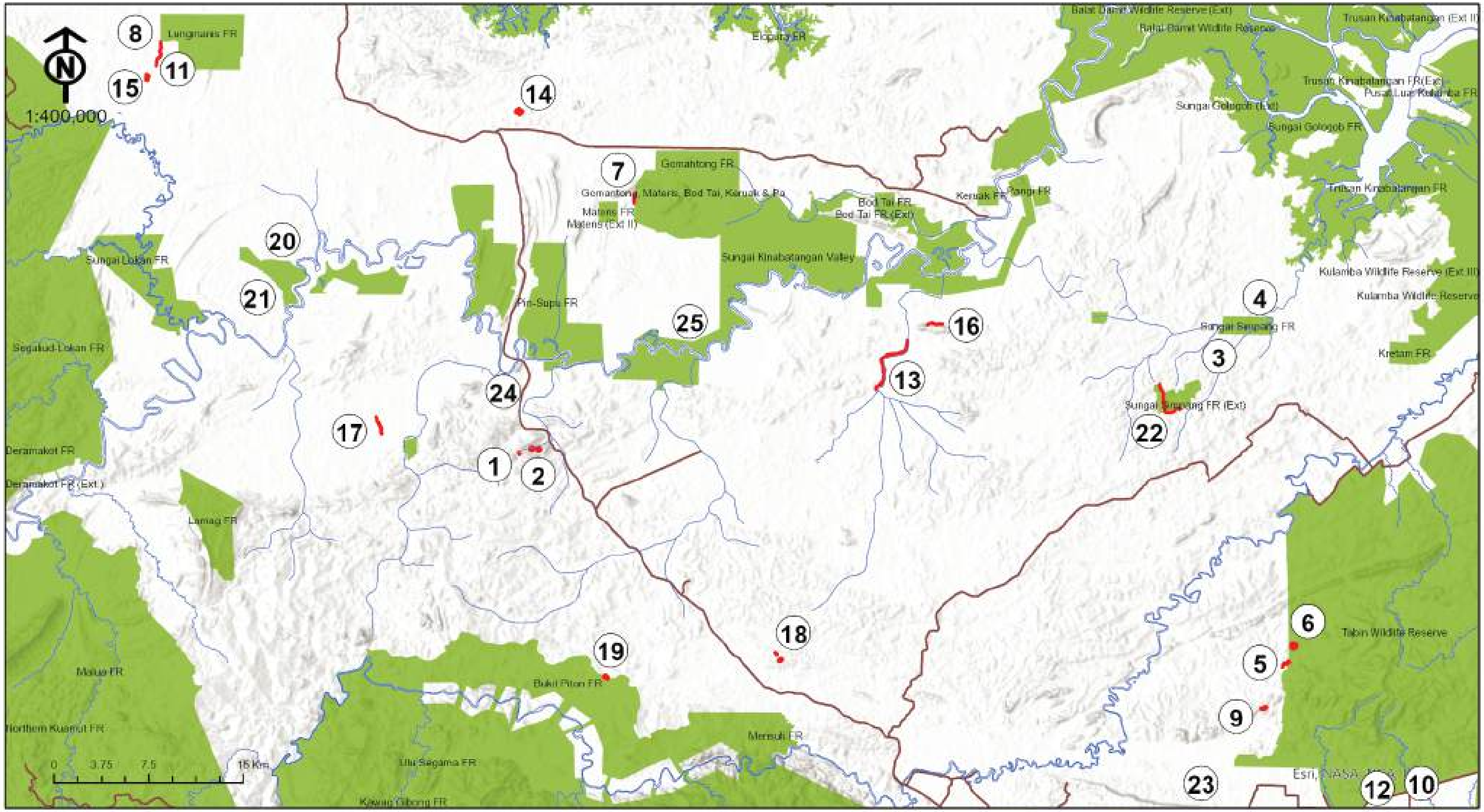
Figure 9. The seedling hardening area in SFGC, visited by WWF-Malaysia head Dr Robecca Jumin and H.E. Michalis Rokas, Head of the EU Delegation to Malaysia in 2022

The restoration and enrichment sites

The work reported here was not part of a governmental or palm oil industry endorsed programme. Everything that was done in oil palm plantations depended on the interest and support of individual estate or regional managers. Making contact with those managers was in itself a challenge, proceeding on an ad hoc basis of lucky contacts. A total of eight major oil palm growers in Kinabatangan engaged with BORA. Several others - whose total land area in Kinabatangan is in the order of 100,000 hectares - were asked and declined.

The intention from the beginning of this work was to experiment not only with various plant species (predominantly but not only *Ficus*) using vegetative and seed production of materials, but also with different types of substrates, not only in terms of soil but also existing vegetation cover. Due to the inevitably haphazard way in which experimental sites were located and allocated, and the fact that set-aside lands in oil palm plantations are largely in riparian (riverside) zones, swampy areas and on marginal soils, it was not possible to develop a structured planting plan. Apart from being able to do planting only on sites allocated by oil palm growers, with most sites already designated as 'set-asides', the details of much of the initial planting was done based on a combination of experience and hunches of the BORA staff involved.

As of 2025, planting out of orangutan food plants has been done on twenty-five sites (Map 2), 20 allocated by managers of oil palm management units and 5 inside Forest Reserve. Nineteen sites are in the Kinabatangan landscape (on the north side of the Segama river), while six sites are in the Tabin landscape (south side of Segama river). The sites in the Tabin landscape were chosen largely because governmental-mandated movement controls in 2020 and 2021 made access to Kinabatangan difficult or impossible. A summary of the sites by vegetation type and set-aside type (forest edge buffer zone, HCV area, large riparian, medium-size riparian, small riparian, permanent wetland, hillside terrace and sandstone hilltop) is shown in Table 1. A detailed description of the sites, arranged in chronological order of start date, is provided in Appendix 3.



Map 2. The restoration and enrichment planting sites in Kinabatangan and Tabin landscapes.

Legend

- Main road
- Major river
- Restoration and enrichment planting sites
- Forest Reserve (FR) and Wildlife Sanctuary

No	Site name	Ha planted	No. of plants	No	Site name	Ha planted	No. of plants	No	Site name	Ha planted	No. of plants
1	KHB Abedon Tanaki riparian	30	1025	10	KLK Ladang Tungku	3.12	1044	19	Bukit Piton Forest Reserve	0.89	120
2	KHB Abedon Tanaki hill top	0.88	115	11	SD Guthrie Segaliud estate (north riparian)	0.74	203	20	Genting Lokan estate	1.12	192
3	Sungai Simpang Forest Reserve west	6	337	12	Malambabula Wildlife site	1.95	1417	21	Genting Lokan Ladang 8	0.19	30
4	Sungai Simpang Forest Reserve east	4.72	630	13	Genting Layang & Tenegang estate	46 & 0.65	174 & 18	22	Glenealy AKB estate	8.72	1300
5	Estate P, Lipad River	3.82	849	14	Estate BP	22	361	23	MPOB Lahad Datu	0.74	287
6	Borneo Rhino Sanctuary	2.65	412	15	KLK Segar Usaha estate	9.66	235	24	Sawit Kinabalu Sungai Pin estate	0.14	50
7	Estate T	3.1	291	16	Genting Tanjung estate	3.66	400	25	FGV Hillco estate	37.67	136
8	SD Guthrie Segaliud estate (riparian south)	4.16	658	17	Koh Koh Estate	3.98	188				
9	Hill in Estate P	5.62	135	18	Sawit Kinabalu Sandau estate	3.64	985				

	Set aside type / Vegetation	Forest edge buffer zone	HCV Area	Large riparian	Medium size riparian	Small riparian	Permanent wetland	Hillside terrace	Sand-stone hilltop
1	Regenerating logged forest		✓						
2	Heavily degraded forest		✓						
3	Secondary forest		✓		✓✓		✓		
4	Regenerating forest / old cocoa plantation surrounding a lake		✓						
5	Mixed forest and old oil palms		✓						
6	Non-woody plants on old logging road		✓						
7	Old oil palms	✓		✓	✓	✓✓			
8	Old oil palms & *Mucuna* surrounding a lake		✓						
9	Low vegetation, many creeping plants					✓			
10	Low vegetation, few creeping plants	✓				✓✓		✓	✓
11	No plants at all	✓					✓✓		

Table 1. Summary of the sites enriched under this programme by vegetation type and substrate type (✓= one site)

In addition, 10 x 1 m tall healthy *Ficus* seedlings were planted to the east of Lahad Datu town on very sandy soil between the beach on the south side of Dent Peninsula and oil palm. Species chosen were those seen growing as large adult plants on Tanjung Aru beach, Kota Kinabalu. Only one each of *F. microcarps, F. drupacea* and *F. crassiramea* survived after a few months.

Planting, maintenance and monitoring

Only healthy, nursery-produced seedlings and marcots were planted in set-aside lands. Height at time of planting averaged 60 cm, to about 1 metre tall for challenging sites, meaning seasonally flooded sites and sites with abundant and aggressive weed growth. A small handful of rock phosphate was scattered into the planting hole at time of planting. No other form of fertilization was done at any site. Normally, no watering was done, and water supply depended on rainfall, although in a very few specific circumstances one round of watering was done (plants with road access during a dry period at one site, plus marcots planted on to tree forks at time of planting).

Maintenance of planted materials was done according to a combination of observed need and human resources available. By far the major maintenance requirement was removal of weeds. All was done manually with parangs, and brush-cutters used where weed growth was prolific. No herbicides were used.

Of the 10,690 seedlings and marcots planted by BORA between 2020-2025, the growth rates of a sample of 538 were measured for a period of two years after planting, with some monitored for a further one or two years. Parameters measured were height, stem width and number of leaves or crown area (estimated from at least two diameter measurements of the outer-most leaves) (examples are shown in Appendix 4).

An additional 13,011 planting materials were provided to 25 other parties over years 2022-2025. Of those, about 2,397 were planted in the Kinabatangan landscape. Survival cannot be reported as comprehensive checking has not been done.

Results and observations - technical

Overview

At the beginning of the work reported here, comments were made by a senior project adviser that oil palm growers will know the best methods to plant orangutan food plants. But that belief turned out to be incorrect. The domesticated, mass-produced oil palm is an extraordinarily robust plant that has been bred over many generations to tolerate almost all soil types, periodic dry and wet weather, rough handling and planting, as well as competition with weeds and legume cover crops. The work involved in planting and tending oil palms is undoubtedly tough and requires discipline and wise management. But the implementation follows well-honed standard operating procedures. Wild, native plants are a different matter.

The results of the programme have yielded a wealth of technical information and added to our knowledge of *Ficus* and several other wildlife food plant genera, greatly supplementing existing knowledge which is confined largely to dipterocarps, fast-growing native trees that are suitable for carbon sequestration but less so for wildlife, domestic fruit trees and exotic species.

One of the key issues of interest to all stakeholders in habitat restoration is how many of the planted seedlings and marcots survive, often summarized as % mortality. This is quite a complex issue. In the programme reported here, we tried to reduce potential mortality that could be attributed to avoidable factors. Thus, all seedlings and marcots planted were of high quality, planting holes were adequate for the size of the planting materials, and standard operating procedures included adding rock phosphate to every planting hole, and filling residual space gently but firmly with topsoil.

Observed mortality was due to several factors (Table 2), most notably two: competition with aggressive weeds (in many sites, especially those that were flood-free) and flood waters (in low-lying sites). Other causes of seedling and marcot death were macaque monkeys (which damaged many plantings, but in some cases the damage was severe enough to kill the plant), dry periods with no little or no rain in the weeks soon after planting, elephants (two sites), sambar deer (one site) and inadvertent damage by contractors involved in water and drainage who had not been informed of the restoration planting (two sites).

Sites with mortality observed in the year or so after first planting are not always replaced with new seedlings or marcots, depending largely on the site-specific causes of mortality. Evaluation of whether to replant is ultimately subjective, but based on consideration of the estimated risk of recurrence (for example, it is usually not worth replanting at sites with very aggressive growth of *Mucuna bracteata* or *Merremia peltata* or high risk of recurrent floods). Decisions on replanting are largely based on biotic factors, but two other factors were also considered: degree of observed interest and support from the estate management, and distance from BORA's nursery (some sites were more than four hours' drive from base). Table 2 summarises mortality at sixteen sites in this programme. It can be seen that for some sites, all dead plantings were replaced, while at others, some dead plantings were replaced but not all, and a few sites were abandoned after the first planting.

Of the 10,690 seedlings and marcots planted by BORA, 1,206 (11.3%) died or were severely damaged within months after planting, and the majority were replaced with fresh seedlings or marcots. At time of writing (late-2025) the precise number of surviving plants (both originals and replacements) is not known, but is expected to be similar to that 1,206:10,690 ratio, meaning around 90% survival of original and replacement plantings.

Any mortality in years 2024-2025 would be due primarily to inability to sustain adequate maintenance, plus some flood water and macaque damage.

No	Iniitial number planted	Area (ha)	% mortality in first planting	Main causes of mortality	Replacement (% of original) with reasons
1	630	4.72	96	Full shade under secondary forest	0 (excessive shade)
2	330	6	98.5	Weeds and no maintenance	0 (too far from base to repeat at this site)
3	849	3.82	17.3	Macaques & miscellaneous	100 (model riparian zone with old palms)
4	412	2.65	23.7	Shade under logged forest and overland waterflow	100 (model site under regenerating logged forest)
5	291	3.1	8.3	Shade under old palms and flood waters	100 (model buffer zone of old palms adjacent to forest)
6	861	4.9	22.9	*Merremia* and other weeds, also desiccation of stakes	75 (at some places, weeds too aggressive to manage realistically)
7	135	5.62	21.5	Inadvertent herbicide use by estate works and sambar deer	51 (continued sambar deer browsing and/or herbicide use anticipated at edge of site)
8	274	46	45.9	Mainly flood waters and macaques, also elephants and collapsed palm trunk support of marcots	100 (desired to persist with riparian enrichment without old palms present; estate management well-engaged)
9	361	22	57.6	Combination of shade and aggressive weeds at forest edge	0 (difficult to cope with both shade and weeds, surviving plants deemed sufficient; estate management not interested)

10	235	9.66	31.9	Mainly *Mucucna* cover crop, also buffoloes and inadvertent damage by pond edge clearing by contractor	100 (estate management well-engaged; but the site later abandoned due to inability to cope with *Mucuna*)
11	400	3.66	20.6	Weeds and macaque, also mismatch of species planted on wet clay soil at hill base	100 (unusual forested hill adjacent, with resident reproducing orang utans; estate management well-engaged)
12	188	3.98	27.4	Significant inadvertent damage by stream-widening contractor	100 (replacement and new plantings done by the estate management)
13	115	0.88	7.7	Dessication in dry weather	100 (mortality due to bad luck)
14	985	3.64	14.9	Weeds, including *Mucuna*, also elpehants and macaques	83 (*Mucuna* growth cannot be adequantely managed at edge of site)
15	1540	8.72	38.6	Combination of weeds and dry weather	62 (remaining live plants growing well, with no significant gaps))
16	28	0.65	100	Flood waters	0 (very low-lying site, and future floods anticipated)

Table 2. Seedling and marcot mortality and replacement at sixteen sites

ABC of plant growth

Water (air in Bahasa Malaysia), minerals (nutrient, but baja in the case of fertilizers applied to oil palms) and light (cahaya) are all essential ingredients for plant growth.

Even in the absence of macaques, planting of wildings, cuttings or marcots of strangling fig species on to the trunks of old oil palms or forks in small trees and on to wooden stumps turned out not to be a good way to do enrichment with orangutan food plants at any worthwhile scale. In an example illustrating this, Laman (1995) planted and monitored 6,720 *Ficus stupenda* seeds at 336 sites on upper branches (30 metres above ground) of 45 diptercocarp trees in West Kalimantan forest, choosing what he thought were optimal sites for growth. Only 1.3% of seeds had survived after one year and, of those, only 0.04 % showed vigorous growth. He concluded that 'water stress appeared to be the critical factor limiting seedling growth'. Our observations mirror those findings, with *Ficus* seedlings planted on to trees and old either dying from lack of water and minerals or, at best, surviving with very slow growth rates (Figure 10 and Figure 11).

Figure 10. Ronald Jummy planting a *Ficus* cutting on to an old oil palm in Sungai Pin estate, 2018

Figure 11. The same cutting on the same oil palm in 2023, showing extremely slow growth rate

The reality is that only a very small percentage of fig seeds dispersed naturally grow into mature plants. We confirmed over the period 2018-2022 by multiple observations in Sabah Ficus Germplasm Centre and in planting sites in oil palm plantations that availability of minerals and water are key factors very significantly limiting growth rate of *Ficus* on substrates other than soil. It was observed by BORA at Tabin that if a strangler *Ficus* seedling (or marcot or cutting) planted on to a tree trunk cannot grow at least one root to the soil, in order to obtain water before the next non-rainy period, it will die (Figure 12).

In addition, the blockage of sunlight by oil palm fronds contributed to extremely slow *Ficus* growth rates. The observations put paid to any idea that strangling figs are unique in being able to survive and grow on the inhospitable substrate of large tree branches. Rather, the observations demonstrate that enormous numbers of strangling fig seeds must be dispersed by frugivores to allow a tiny percentage to germinate into fully-fledged stranglers. It was clear that there must be sufficient water, minerals and light to allow survival, and that this occurs at only a very few specific and essentially random sites, and that growth will be very slow until roots have reached the ground.

That process will normally take years. The main implication for restoring or enriching habitat with stranglers is that the marcot or cutting is best planted into soil (Figure 13), or low down on the host tree. The higher it is placed in the tree, the lower its chances of survival. Soil as a substrate is best – even for stranglers – because water and minerals are not such limiting factors there, and sunlight-trapping fronds and branches can be cut away.

Figure 12. A *Ficus* marcot planted experimentally on to a tree trunk, showing that a root needs to grow down in to the soil below before further growth can start

Figure 13. Rauf Prasodjo of Unilever planting a *Ficus* marcot into soil between oil palms in KHB Abedon estate

Water

The seeds, seedlings and marcots of all *Ficus* species require plentiful water daily for most rapid growth, but the soil or other substrate must be well-drained. Waterlogged substrates result in poor, slow growth (even with those species which tolerate and survive waterlogging) and, potentially, harmful fungal growth. The primary harm from fungi is in the form of moulds, which can cover the soil surface and prevent adequate oxygenation. A general rule of thumb for the nursery is to water twice per day on days with no rain, once per day on rainy days, and no watering to be done late afternoon or after dark.

Minerals

The experiments with planting wildings or marcots on to old oil palm trunks and the same types of planting materials planted into soil demonstrated that minerals are a prerequisite for growth from the earliest stages. Planting out into field conditions showed that a small quantity of rock phosphate placed into the planting hole is sufficient to stimulate growth after the shock of removal from a nursery and the act of planting. The rock phosphate should be scattered into the hole, and not dumped in as a single clump. Apart from that, fertilizer is optional, and we find that growth of all species is adequate without any fertilizer as long as water and sunlight are not limiting.

Light

One of the most prominent results of the work done under this programme is that shade severely stunts growth of all *Ficus* species, and probably all the other orangutan food plant genera included in the trials. For *Ficus*, all other factors being equal (good quality planting materials, adequate weed removal, no macaque damage and addressing the issue of waterlogging and flooding), it is clear from all the planting done to date that the more light that the planted seedling or marcot receives, the quicker it grows in leaf production, diameter and height. The observations were stark. Plants that are exposed from above to several hours of sunlight in the middle hours of the day, but receive little sunlight in the earlier and later hours, due to shade from adjacent vegetation, fare significantly less well than plants that are exposed to sunlight throughout the daylight hours. Plants that are exposed from above to several hours of sunlight in the middle hours of the day, but receive little sunlight in the earlier and later hours, due to shade from adjacent vegetation (Chart 1), fare significantly less well than plants that are exposed to sunlight throughout the daylight hours.

There is little point in analysing and reporting in detail on observed growth rates of *Ficus* planted by BORA. The wide range of factors such as heights at time of planting, patterns of sunlight and rainfall after planting and inherent soil fertility, as well as intensity of weed competition and effort put into weed removal at different sites, is just too complex to be able to generate meaningful conclusions by assessing the actual growth rate data. However, a general look at the growth rate data accumulated on the various plants in various situations since 2020 (Appendix 4) would not surprise a gardener. The more sunlight and water (but not waterlogging) and ample nutrients, the faster and more robust and healthier is the growth of all *Ficus* species, without exception. We found that even the species that is the most adapted of all to life on exposed upper tree branches and rocky outcrops, *Ficus deltoidea*, performs best on moist, mineral-rich sites.

'Optimum conditions' means a healthy seedling or marcot planted into well-drained fertile soil, with no restriction on amount of light, water and minerals, and adequate removal of competing weeds. 'Very poor conditions' means a weak seedling or wilding or marcot, planted into soil that is either waterlogged or subject to flooding, or rocky or very infertile sites, with no removal of competing weeds. The former will flourish. The latter will almost certainly die. Working always towards the former situation should be the aim, using high quality planting materials, improving the quality of sub-optimum substrates if possible and putting as much effort as possible into weed removal.

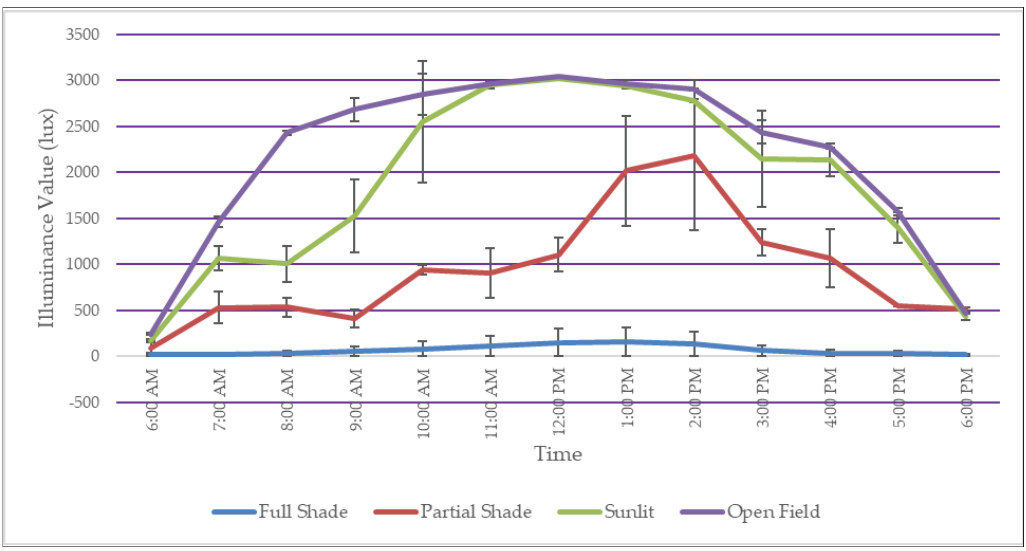


Chart 1: Actual sunlight (illuminance values) recorded at four sites in and near Sabah Ficus Germplasm Centre with a Proskit MT-4617LED Light Intensity Meter

Seed and vegetative propagation methods

There are pros and cons in choosing whether to grow *Ficus* from seed or marcots.

We found that the fruits of different *Ficus* species contain differing average numbers of seeds, varying from just a few to over 100,000 but typically more than a few tens per fruit (Table 3). If we take a rough average of several thousands of fruits per tree per season, with 100 seeds per fruit, then a single 'average' *Ficus* tree or strangler may produce hundreds of thousands of seeds per season. In nature, a half a million seeds dispersed by birds may yield anything from zero to a few plants that grow to maturity.

No.	*Species*	Average number of seeds per fruit	Average seeds per ml (as dried & stored in 1.8ml vials)
1	*Ficus punctata*	100,000 +	5890
2	*Ficus variegata*	539 - 1300	2000
3	*Ficus trichocarpa*	142 - 973	2680
4	*Ficus racemosa*	215 - 897	3874
5	*Ficus rosulata*	607 - 634	n/c
6	*Ficus treubii*	288	n/c
7	*Ficus villosa*	134 - 278	n/c
8	*Ficus fulva*	274	2836
9	*Ficus sagittata*	123 - 226	
10	*Ficus tinctoria*	147	2190
11	*Ficus parietalis*	121	786
12	*Ficus minahassae*	99 - 119	7748
13	*Ficus albipila*	98	6457
14	*Ficus stupenda*	91	193

15	*Ficus drupacea*	73	585
16	*Ficus forstenii*	71	384
17	*Ficus annulata*	31 - 60	423
18	*Ficus pisocarpa*	38 - 44	928
19	*Ficus recurva*	43	2550
20	*Ficus pellucidopunctata*	38	1074
21	*Ficus deltoidea*	3-5	18
22	*Ficus stolonifera*	n/c	6678
23	*Ficus leptogramma*	n/c	4638
24	*Ficus benjamina*	n/c	2697
25	*Ficus stricta*	n/c	1709
26	*Ficus brunneoaurata*	n/c	1540
27	*Ficus callosa*	n/c	926
28	*Ficus lindsayana*	n/c	840
29	*Ficus crassiramea*	n/c	762
30	*Ficus depressa*	n/c	375
31	*Ficus subcordata*	n/c	209
32	*Ficus cucurbitina*	n/c	115

Table 3. Variation in numbers of seeds per *Ficus* syconium (fruit) by species (n/c = not counted)

Cuttings (Figure 6) were found to be less effective than either seedlings or marcots because survival rate was much less predictable and usually much lower than survival of seedlings and marcots, both in the nursery and in the field.

A very significant bonus of using seedlings is that *Ficus* seeds of all species are not 'recalcitrant', meaning that they can be stored dried or in refrigerators or freezers without significant loss of viability. In contrast, the seeds of most other humid tropical woody plant genera are recalcitrant, meaning that drying and / or freezing results in 100% mortality, and such seeds have to be planted into soil as soon as possible after fruits have been collected. Many humid tropical woody plant species bear fruit at unpredictable periods of between 2 and 10 years. The constraint is obvious for 'recalcitrant' plant species: nurseries have to await fruiting seasons in order to obtain seeds and produce seedlings.

Although the seeds of all *Ficus* species are non-recalcitrant, differences between species in details were seen. For example, unlike *F. racemosa*, the seeds of *F. variegata* did not perform well if they had been kept in a freezer before planting, but if the fresh fruits of the latter species were deliberately chilled before removing the seeds, the seeds showed very high germination rate.

Ficus seedlings in the nursery are susceptible to a common tree seedling nursery problem: roots growing out of the bottom of the 'pot' (black plastic bag filled with soil) in which they are growing, and twisting in circles because they are unable to grow downwards. We found that planting such seedlings did not adversely affect growth in the early years after planting. As *Ficus* is a generally robust genus with variable life forms in many of the species, we do not believe that use of such seedlings will adversely affected long-term growth and stability.

A disadvantage of marcots over seeds is that while tens of thousands of *Ficus* seeds can be obtained from one mother plant and planted at any one time, typically only a few tens of marcots can be obtained from a mother plant at any one time. However, there are three main advantages of marcots. One advantage is that marcotting can be done at any time, including in the absence of any fruits. A second advantage is that they can be planted in shallow soil and on to rocky sites, as they lack tap roots, and their emerging roots can spread laterally over the soil or rock surface. The third potential advantage is that marcots taken from mature mother plants that have already born fruits can start to bear fruit within two or three years of planting out into soil, whereas plants grown from seed will typically take five years or more before first fruiting. In SFGC, it was found that *F. annulata, F. parietalis* and *F. pisocarpa* grown from marcots bear fruits within 2.5 years after planting. These are general observations, but exceptions may occur. We have seen fruiting of some planted seedlings bear fruits within three years. Finally, there is an issue of distance of source materials from work base. For tree *Ficus* and for stranglers where there was no mother plant within two or three hours' drive from the nursery, seeds yielded more planting materials than marcots for the amount of effort expended.

Some guidance on transportation and planting

The leaves of seedlings of *Ficus* tree species, and some other species such as *Endospermum peltatum*, are relatively thin and sensitive to wind and potentially to desiccation under sunlight when in nursery pots, while the leaves of strangler species are thick and more robust. To minimize observed adverse impacts of wind and desiccation on planting materials during the typically 2-6 hour journey between nursery and planting site, all plants and most especially the sensitive ones, should be surrounded on all sides and top by a frame of black netting or plywood (Figure 14).

Figure 14. *Ficus* seedlings from SFGC brought to SD Guthrie Segaliud estate, surrounded by a frame of black netting to minimise desiccation en route

Even with such protection, the leaves of sensitive species wilt during the journey. Most will survive this, but the shock will result in slow recovery and slow early growth. The leaves of one of the most impressive *Ficus* species, *F. albipila*, a tree which grows to 45 m tall, seem to be the most sensitive of all, so sensitive that leaves of seedlings are scorched by bright sunlight, to the extent that this is perhaps the only *Ficus* species that breaks the general rule of maximum sunlight for fastest growth.

If the plants are not immediately planted out and are instead kept in a nursery in the receiving plantation, steps need to be taken to ensure that care there is adequate. Although variation was seen in the approach of different estates, in some cases planting materials supplied by BORA were placed at a site with no shade (even though specifically requested in advance), with no or insufficient watering, no partitioning of smaller and taller plants to allow water and sunlight to get to the smaller plants, plants allowed to lean over at an angle for long periods, and little advance planning for the date, labour and tools necessary for planting out. Effort had to be devoted to building rapport and 'teaching' experienced planters how to care for plants other than oil palms. This includes ensuring that watering will be done at least once or twice daily, carefully arranging polybags with the planting materials so that different planting material heights are not mixed together and so that they do not lean or fall over, and that light intensity is neither overly strong nor overly low.

In the nursery, some strangler species (notably *F. benjamina, F. caulocarpa, F. subcordata, F. virens and F. stricta*) show flimsy growth in the absence of support, and initially appear to be unsuitable for planting unless there are trees or old oil palms or adjacent planted wooden poles that can provide that support. However, as these species grow, by 2 m tall or 2 years old, they readily become free-standing trees.

At sites which are shaded, either from retained old oil palms or under secondary forest, any species of *Ficus* or other orangutan food plant can be planted, at any size, with a fair expectation of survival after one year. The issue of concern is the slow growth rate. Why plant at a spot where growth will be slower instead of a similar spot where it will be faster? For this reason, at shaded sites, it is best to select planting points that enjoy the most sunlight, and to not use regular spacing along lines. By choosing sunlit sites in shady planting areas, however, there comes a need for more frequent weed removal.

The biggest management problem - weeds

The key requirement in allowing and facilitating growth of *Ficus* of all species is to provide adequate weed removal. In this context, 'weeds' refers to any and all plants that compete with the planted materials for space, nutrients and light. Generally, and not surprisingly, the more shade, the less weed growth. In well-lit conditions, where weed growth is vigorous, two somewhat problematic and two very serious scenarios were observed. Grasses are the least serious problem as in general they do not over-top one metre tall. Two exceptions may be the highly invasive vasey grass (*Paspalum urvillei*) which grows prolifically and fast throughout eastern Sabah from wind-dispersed seeds and can reach 2 metres in height within a few months (Figure 15). Rumput Riong (*Themeda vilossa*), also reaching more than 2 metres tall within a few months, is currently very rare and scattered in Sabah but may spread in the future especially on poor, sandy soils. Secondly, there are miscellaneous ferns, mainly *Nephrolepis biserrata* on fertile and damp sites (Figure 16) and *Dicranopteris linearis* on dry, sandy sites. They do not smother or strangle woody plants but are locally much more abundant than any planted *Ficus*, and may spread vegetatively, and so compete for light and nutrients.

The first serious problem consists of leguminous ground cover crops (particularly *Mucuna bracteata*, also *Pueraria, Calopogonium* and *Centrosema*) which are planted routinely in oil palm plantations, that rapidly spread vegetatively and may envelope sites allocated for planting of *Ficus*, smothering and strangling them (Figure 17). Twice-monthly cutting back of *Mucuna* is insufficient to prevent its spread, so for restoration work such sites may need to be abandoned.

The other serious creeping plants are of the genera *Merremia* (native to Borneo and also known as *Decalobanthus*, with three species noted at sites planted in this programme) and *Mikania micrantha* (from Central America). In open sites, both genera grow faster than any *Ficus* species (potentially several centimetres of stem per day, according to some unreferenced estimates) and quickly smother and strangle planted *Ficus* with tendrils (Figure 16 and 18).

For other, similar programmes funded by WWF-Malaysia and contracted to contractors, the usual specified weed removal is 4, 4, 2, 2, 1 times / year over 5 years. This was based to a large extent on experience in Bukit Piton Forest Reserve (Mansourian et al, 2020), immediately south of the Kinabatangan landscape reported here. That site was mainly heavily degraded forest with patches of low vegetation, and very little, localised *Mucuna* or *Merremia*.

In BORA's experience, that frequency is a good generic prescription, but actual need varies greatly from site to site. For most sites, we found that four rounds of weeding in year 1 after planting and two rounds in year 2 were adequate. Weeding was done only infrequently and ad hoc thereafter, due primarily to insufficient funding and reliable manpower, as well as to the logistical problems involved in the wide scatter of many small restoration sites.

But some sites with little or no shade from trees or old palms required frequent weeding in order to survive. In one site, although there were scattered old palms, ground cover was largely *Mucuna bracteata*, and twice-monthly removal was found to be insufficient (Figure 17). At another site (Figure 16 and 18), a small riparian zone with no tree cover dominated by *Merremia peltata, Mikania micrantha* and *Nephrolepis biserrata,* during the first year after planting of *Ficus*, initially with Covid19-related movement controls and impassable roads at the end of the year, almost no weeding was done. There, the growth rate of planted *Ficus* was greatly inhibited and the main stems of many plantings were bent and kinked, although no plantings died as a result of weed growth. A programme of twice-monthly intensive weed removal was instituted in February 2022, which continued until April 2023 (except during periods of heavy rainfall that prevented access). After April 2023, weeding was done every three months until BORA staff were unable to cope with the sheer number of sites requiring weeding. This regime proved to be sufficient (Figure 19).

In summary, the implications of weed cutting on funding, human resources, logistics, time and choice of restoration sites needs to be evaluated for all programmes and all potential sites. There might be a case to not embark on restoration for sites where *Mucuna* or *Merremia* are dominant.

Figure 15. Vasey grass (*Paspalum urvillei)* can quickly grow to 2 metres tall, even on infertile, dry soils

Figure 16. Riparian zone in SD Guthrie Segaliud Estate, 2021

Figure 17. *Mucuna bracteata* surrounding a water supply pond in a KLK estate

Figure 18. *Merremia peltata* & *Mikania* on a planted *Ficus racemosa* tree in SD Guthrie Segaliud estate

Figure 19. The same tree shown in Figure 18, at age 4 years 8 months, with Soprih Amdan

Pests and diseases

Pig-tailed macaques (*Macaca nemestrina*; Figure 20) and long-tailed macaques (*M. fascicularis*; Figure 21) have clearly adapted well to the oil palm – forest edge in eastern Sabah. Overall, they represent the most serious animal pest in restoration and enrichment work. IUCN categorization of both species as endangered is blatantly wrong in the case of Sabah and Malaysia. Oft-repeated statements that they are threatened by habitat loss are equally non-sensical. They are clearly now forest edge species that thrive on food provided by human-made habitats, where productivity of their main foods (oil palm fruits, other fruits, leaf shoots, grasses, large insects, small birds and their eggs and hatchlings, lizards and foods actively provided by humans) is higher than in natural closed-canopy rainforest. Existing knowledge that various zoonotic infections are transmitted by free-ranging macaques to humans, especially malaria in Sabah, seems to hardly impact government policy on managing macaques.

It was observed during work reported here that most residual forest patches in the oil palm - forest landscape contain groups of one or both species. It can be surmised that they compete for food with orangutans where the individuals of the latter species persist, and cause constant stress to orangutans in the smaller forest patches. More relevant to the results presented here, they can potentially be the single major cause of damage to restoration planting. Macaques detect any new item within their home range, and investigate it. ‘Investigation’ includes pulling, snapping, ripping, biting and uprooting. Damage by macaques can also be expected at the very early marcotting stage, when the marcotted growth is still on the mother tree. At SFGC outside the area protected by well-maintained electric fence, up to 50% of marcots are destroyed on the branch of the mother plant before they can be harvested. Preliminary trials adding chilly powder to the marcotting medium saw some reduction in such damage.

Figure 20. Part of a troop of pig-tailed macaques on the edge of an oil palm estate

Figure 21. Long-tailed macaques on the road to Sabah Ficus Germplasm Centre

When seedlings or marcots are planted out on to set-aside areas in oil palm plantations where macaques occur, it can be expected that about 20% (range 0 -100%) will be significantly damaged by macaques. This damage leads to the death of some plantings, while the growth rate of many is slowed, or trees grow misshapen (Figure 22). At sites 5, 13, 14 and 16 in Appendix 3, more than 25% of plantings were damaged by macaques, including plantings of 1 metre height. Damage by other mammal species is rare and localised.

Both macaque species are categorised by IUCN as Vulnerable and declining in numbers. This is not the case in eastern Sabah, where observations by the senior authors since 1980s indicate that numbers of pig-tailed macaques in the mixed oil palm forest landscape are higher than in the former dipterocarp forest, and their reproduction rate now seems to be maximal. Unlike Holzner et al (2019), no BORA staff has seen a macaque eat a rat in oil palm plantations, based on daily observations by several people between 2010 and 2025. In the mixed oil palm landscape, we see the main food of macaques to be oil palm fruits, together with invertebrates, eggs and chicks of all wild bird species, and grasses. Both macaque species are 'protected animals' under the Sabah Wildlife Conservation Enactment 1997, so culling is not permitted.

The only possible effective mitigation measures appear to be avoidance of restoration where macaques occur (but they are present in about 90% of sites in Kinabatangan where restoration planting has been or could be done), and making plantings as inconspicuous as possible. Of course, even where macaques are present, they miss some plantings, which do grow and thrive (Figure 23), but the likely 'costs and benefits' need to be guessed and weighed. Is it worth planting in a site when, based on experience to date it may be anticipated that, say, a quarter of plantings might be damaged by macaques? Depending on such factors as how far the site is from base, and risks that the plantings might equally die from drought or flood, the answer might be yes or no. At one site where strangling *Ficus*

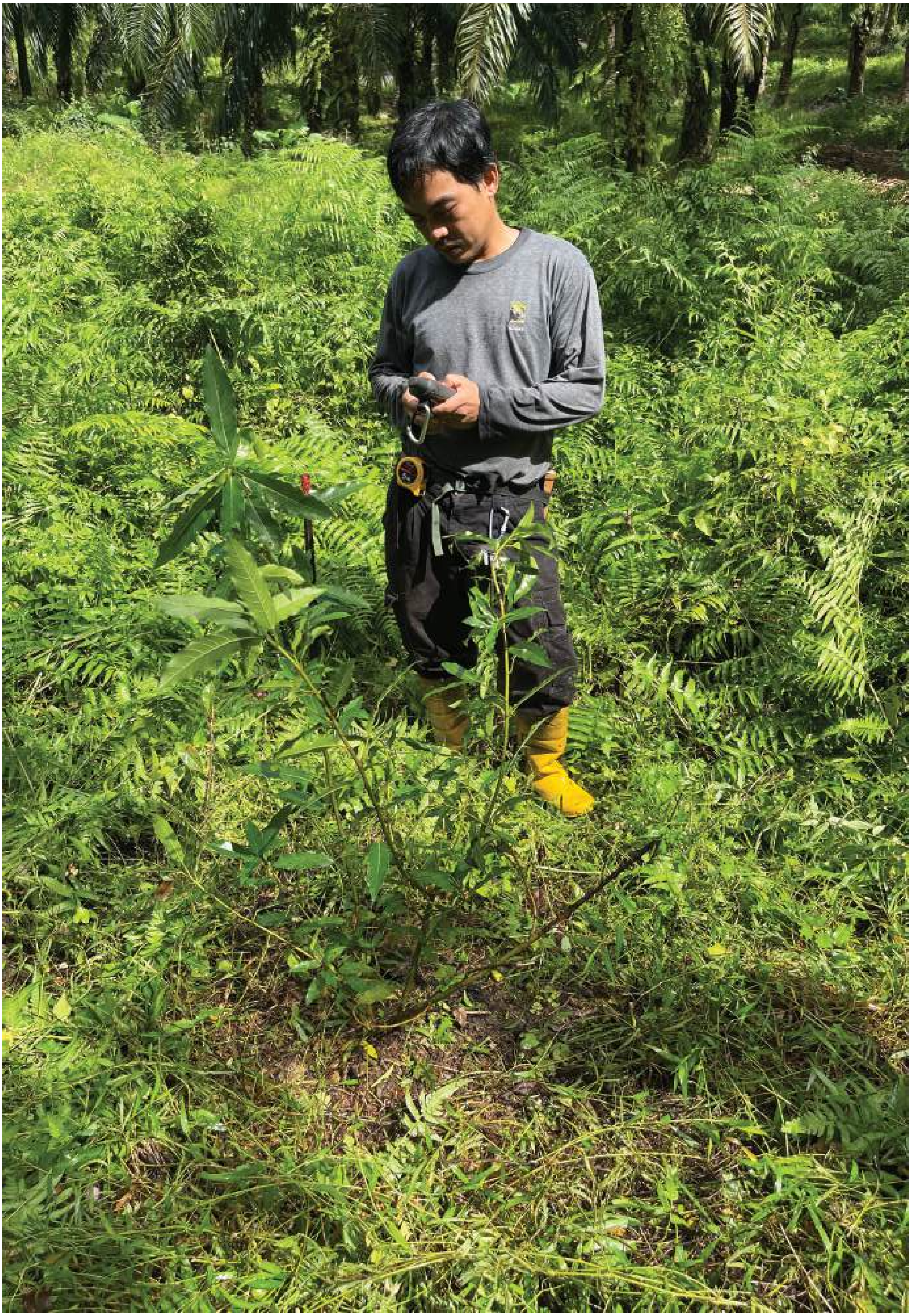


Figure 22. A *Ficus racemosa* seedling repeatedly damaged by macaques in a Genting Plantations estate, monitored by Alvin Erut

Figure 23. This two-year old *Ficus* marcot planted on to a tree fork survived macaques and floods in a riparian zone in a Genting Plantations estate

Figure 24. A *Ficus* marcot planted on to a tree in a wetland set-aside site in a FGV estate with protective wire mesh to protect it from macaque damage

plants were planted into forks in native trees in a permanent wetland in year 2025, wire mesh was put in place around the plantings as a means to minimise macaque damage (Figure 24). The effectiveness has yet to be assessed.

Insect damage in restoration planting done to date has been slight. In the nursery, very small (1-2 mm long) bugs (Hemiptera), known as hoppers, suck sap from very young seedlings (with 2-4 leaves) in seed trays and at first potting of seedlings. The only way to prevent this is to keep all very small seedlings within areas covered on all sides by fine netting. In planted sites, the most serious insect damage appears to be by larvae of a moth (*Phauda flammans*) which can defoliate entire *Ficus* plantings, and some stem borers (larvae of various insects, usually longhorn beetles or moths) that can significantly damage the stems of large planted *Ficus* stakes. Leaf galls (growths that develop in reaction to the feeding stimulus of insects and mites) were observed on some larger plantings after one or two years are unsightly but do not kill the plant. They were observed most commonly on *Ficus caulocarpa* and *F. racemosa*. Crickets and grasshoppers fed on shoots and young leaves, but to date this has been very localized and did not cause mortality. *Crematogaster* species ants (known as semut tongek) were observed to construct nests that encircle the stems of plantings, particularly *F. racemosa*, causing significant damage to the bark, which then opens the stem to pathogens. It seems that this risk can be minimised by ensuring that all traces of weeds, including dried remnants of cut weeds, are removed from the plantings.

In summary, diseases and pests other than macaques seem unlikely to be issues of concern in planning or implementing a restoration programme. In some localities, sambar deer (which browse repeatedly on saplings) and wild pigs (now depleted as a result of African swine fever) may cause significant damage. But this is uncommon in small forest patches in oil palm areas, where there are rarely breeding populations of either ungulate species. Where macaques are present at proposed restoration sites, they will damage and kill at least some plantings. Assessment of the potential loss of plantings, time and money needs to be done. One approach is to try, see what happens within one year, and then make decisions. For macaques, translocation is not a solution, as there will be some remaining individuals that will reproduce and utilize space and resources left vacant by the translocated individuals. A contraception programme will take too long to show any significant impact in macaque numbers before restoration work can commence.

Climbing plants in habitat restoration

All the climbing *Ficus* species observed under the programme reported here are ‘root climbers’, whereby adventitious roots emerge from the growing stem and attach to and climb tree trunks over many years. About ten kinds are in SFGC and several, notably *Ficus trichocarpa* and *F. allutacea*, were planted out in Kinabatangan. One of the most spectacular is *Ficus punctata*, where female fruits are about 7 cm in diameter, and contain over 100,000 seeds per fruit, and one or two fruits ripen daily over many months, providing one of the orangutan’s favourite foods (Figure 25).

Much of a wild orangutan’s diet comes from feeding on small quantities of leaves and fruits from numerous non-*Ficus* climbing plants, often known as lianas, with a special fondness for legumes. None of the non-*Ficus* lianas planted in this study are root climbers but, instead, are the more common type of climber, whereby tendrils emerge from the growing points of seedlings, seeking, latching on to and twining around trunks, stems or branches of nearby trees.

When planting climbing plants as a form of habitat enrichment, selection of the nearest ‘nurse’ tree(s) is crucial. Root climbers rely on the bark texture. A rough surface enables their roots to grip securely. They cannot anchor to a smooth surface. In contrast, non-*Ficus* species with twining stems, such *Spatholobus* and *Gnetum*, rely on the size of the ‘nurse’ trees, not on the texture of the bark. Successful climbing was usually observed in seedlings planted next to trees with diameter less than 10 centimetres (Figure 26). Addition of a trellis can aid initial climbing growth by the seedling, but was considered too time-consuming in this programme.

All climbers and root climbers planted in this programme, on all soil types, grew very slowly (Figure 26), much slower than *Merremia*. Inevitably, planting sites are shaded to a greater or lesser degree because

Figure 25. A female *Ficus punctata* climber on a binuang tree

climbing plants need trees in order to grow. It is believed that light is the main factor limiting their growth. In addition, however, all three non-*Ficus* genera – *Spatholobus* species, *Bauhinia diptera* (= *Bracteolanthus dipterus*, a Borneo endemic) and *Gnetum* species - were found to be intolerant of waterlogging and flood waters, and either died or remained stunted in these conditions.

Two other problems were experienced in attempting to produce large quantities of lianas as orangutan food plants. Firstly, unlike most *Ficus*, they tend to flower and fruit rarely. *Spatholobus*, for example, was seen to produce significant quantities of flowers and fruits in 2019 (Figure 27) but not in any of the following six years. Secondly, attempts to marcot the above three non-*Ficus* genera of lianas were unsuccessful.

In summary, when deciding on a habitat restoration or enrichment programme, it may be wise to omit climbing plants, or perhaps to incorporate them as a special element for enrichment of secondary forests. Given that orangutans feed on a very wide array of liana leaves and fruits, a more plausible approach might be to conduct targeted silviculture at sites where there is existing tree cover. Silviculture means actively controlling the growth, composition and structure of forests to meet an objective – in this case, to promote growth of orangutan food plants. This would entail cutting bunches of liana stems where there are many stems of the same species in competition for host trees, but leaving some of the larger liana stems, trying to retain all liana species present, and cutting away branches to allow more light to enter the site.

Figure 26. A *Gnetum liana* seedling planted June 2022 in a secondary forest set-aside land, seen here 2024 with Alvin Erut

Figure 27. *Spatholobus macropterus* fallen fruits in 2019

Planting *Ficus* stakes

This method (Figure 8) initially seemed promising for two reasons in combination. Firstly, noting that aggressive weed growth kills almost all plantings at some sites (especially on moist, fertile alluvial sites with no tree cover, where weedy stems and tendrils grow too rapidly for adequate manual removal to cope) it is best to make the planting material as tall as possible. Secondly, it is fortuitous that this method can work for at least some *Ficus* species which produce fruits favoured by wildlife. A major problems with use of stakes, however, is that not many can be sourced at any one time, and the logistics of transporting them from base to planting site are more problematic than seedlings and marcots. Based on our general observations, it appears that this method can be successful in only a very few species, notably *Ficus caulocarpa, F. microcarpa* and *F. benjamina,* which are locally common and robust to repeated cutting of branches. In total only 82 stakes were planted. On a hill slope terrace, only two have survived out of ten planted, while on streamside alluvium, only 11 have survived out of 62 planted. This low rate of survival is believed to be due primarly to a combination of insufficient root growth leading to desiccation of the entire plant during dry periods. Some planted stakes were also damaged by wood-boring beetles and their larvae. However, those that did survive after one year have thrived (Figure 28).

In summary, stakes may have a role to play in moist sites where there is abundant weed growth. After being cut from the mother plant, they should be retained in a nursery, with the bottom embedded in moist soil for several months, to allow growth of plentiful adventitious roots, before planting out. Number of stakes available will always be small.

Figure 28. One of the *Ficus microcarpa* stakes shown in Figure 8 at age 4 years 8 months, with Norashimah Janih

Fertigation

A trial on fertigation treatment applied to seedlings of four *Ficus* species starting at the four-leaf stage resulted in more uniform and vigorous growth, thereby shortening the time required for the seedlings to reach the hardening phase (Figure 29). The fertigated seedlings received water and nutrients through irrigation four times daily. In contrast, conventionally treated seedlings received nutrients via solid fertilizer application and were watered only twice a day. With fertigation, seedlings reached 30 cm tall (the height preferred by BORA for transfer of seedlings out of the nursery for hardening) in as little as two months. Under the conventional method, however, seedlings required at least two additional months to achieve the same height. In this trial, the response of seedlings to different substrate types over three months was evaluated (Figure 30). Seedlings grown in cocopeat with fertigation proved to have the quickest growth rate. Measurements of ranges of heights are in Appendix 5.

Figure 29. Three-month old *Ficus kerkhovenii* seedlings of the same age, on the right site with fertigation, on the left side without fertigation

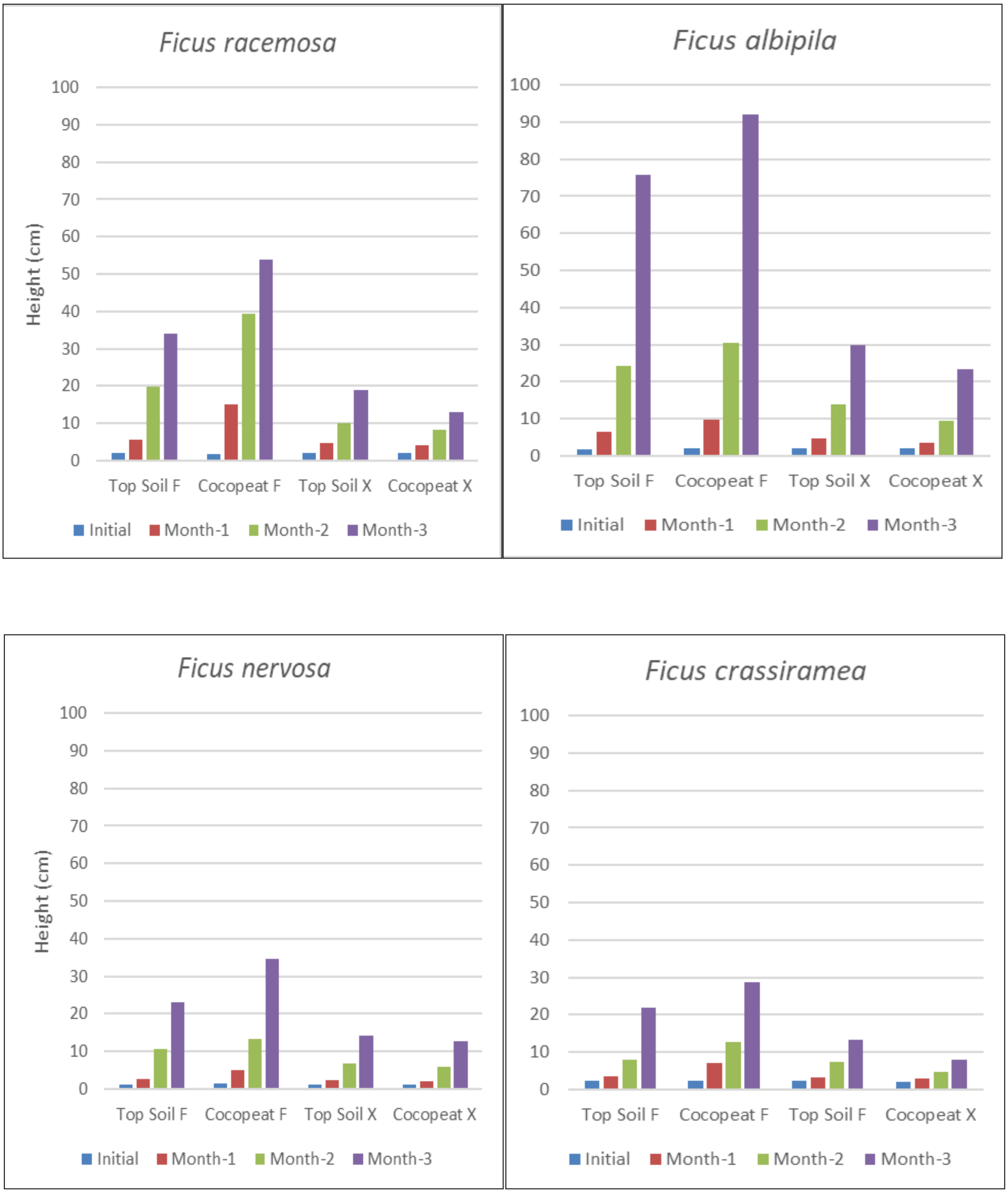


Figure 30. Growth response over three months to treatments with and without fertigation in four *Ficus* species

In summary, for any serious restoration or enrichment programme, meaning programmes that will be adequately funded over at least several years, it will be worthwhile to choose a few plant species and to implement fertigation from the earliest stages. The number and quality of planting materials will be greatly improved, with turnover twice as fast as with a nursery that lacks fertigation.

Substrate characteristics

Some strangling *Ficus* species thrive by growing from a seed that starts life in a crack on an old building. At least one, *Ficus tinctoria*, possibly evolved as a specialist of bare rocks, enabling it to flourish in any substrate (Figure 31). In February 2020, 10 large *Ficus benjamina* cuttings were planted with topsoil into bare roadside decaying sandstone in an oil palm estate (Figure 32). Initially, they thrived (Figure 33), but were inadvertently later removed during palm replanting. Probably this approach could be used successfully to grow *F. benjamina* and *F. tinctoria* on rocky sites. However, we decided not to pursue the idea, as the great majority of set-aside lands in the oil palm landscape are soil, not rock. Instead, to promote interest in our work from a wider range of stakeholders, BORA and the Fire and Rescue Department collaborated with Lahad Datu town and district authorities on World Environment Day (5 June) in 2022 and 2023 by removing hundreds of wildings of those species from urban buildings (Figure 34 & 35) and translocating them for planting into soil in Sawit Kinabalu oil palm estates (Figure 36).

Figure 31. *Ficus tinctoria*, a climbing fig that possibly evolved as a specialist of bare rocks

Figure 32. A *Ficus benjamina* large cutting, planted on a roadside sandstone cutting in KHB Abdedon estate in February 2022

Figure 33. The same cutting four months later

Figure 34. Fire and Rescue Department Malaysia remove *Ficus* wildings from buildings in Lahad Datu town, World Environment Day 2022

Figure 35. Lahad Datu local government staff and NGOs assemble hundreds of 'rescued' *Ficus* wildlings for replanting into an oil palm plantation set-aside land

Figure 36. Wildings from Lahad Datu buildings planted in Sawit Kinabalu's Sandau estate, 20 months later

None of the restoration sites made available by participating oil palm growers were of nutrient-depleted, podzolized soils. In general, however, all the plant species investigated in this programme exhibited a wide range of tolerance to different soil types. For any poor or shallow soil conditions, the generally preferred planting material would be marcots of the robust and fast-growing *Ficus microcarpa*. For swampy sites, *F. crassiramea* and *F. caulocarpa* grown from either marcots or seeds can be added as well as *F. microcarpa*. For riparian sites of all widths which are rarely subject to flooding and which are rarely waterlogged, *F. racemosa* seedlings (Figure 37) are the best choice. Species that perform well on and are suitable for planting in well-drained open sites, including hill slopes, are (trees) *F. variegata* (Figure 38; usually the fastest-growing tree fig), *F. melinocarpa* (Figure 39) and *F. magnoliifolia*, and all stranglers. Fastest growth on terraced slopes was seen in marcots of *F. microcarpa* (again) and *F. annulata* (Figure 40), with *F. benjamina* less so.

Figure 37. *Ficus racemosa* seedlings nurtured in a nursery in KHB Abedon estate prior to planting out

Figure 38. *Ficus variegata* at 33 months old in a riparian zone

Figure 39. A grove of mature *Ficus melinocarpa* trees on a hill top in an oil palm plantation

Figure 40. A 4-years 8-months old *Ficus annulata* in a riparian zone in SD Guthrie Segaliud estate

As a guide for further planting, some general results may be useful (Table 4). Due to the occurrence of confounding factors (inadequate weeding at some sites, damage by macaques, browsing by deer, shade, etc) these results reflect general observations by BORA staff rather than quantitative data analysis.

Substrate	Best performing species	Moderately performing spcies	Least suitable species
Sites that are constantly waterlogged and affected by frequent severe flooding	None found to date	*F. microcarpa, F. crassiramea, F. caulocarpa, Sonneratia caseolaris*	All other species
Riparian zones with gleysols	*F. variegata, F. racemosa, F. microcarpa, F. parietalis, F. drupacea, F. melinocarpa, F. magnoliifolia*	-	*Endospermum peltatum*
Riparian zones with infrequent flooding	*F. racemosa, F. albipila, F. lindsayana, F. forstenii, F. francisci, F. variegata, F. annulata*	All other species	-
Valley bottoms	-	-	*Endospermum peltatum*

Hill slopes	*F. microcarpa, F. annulata, F. variegata, Endospermum peltatum, F. melinocarpa,*	-	All other species
Sandstone hill tops	*F. microcarpa, F. pisocarpa, (marcots only)*	-	-

Table 4. Performance of plantings under six common set-aside substrates

Twenty best species for enrichment and restoration

All the species that we have grown and planted – *Ficus* and non-*Ficus* - are worthy of consideration for restoration work. But some can be regarded as favourites. The main criterion is a measured fast growth rate under moderate conditions of moisture, light and minerals. But there are several other, more subjective criteria. These include: good growth even under sub-optimal conditions; easy to find mother plants (because they are relatively common and prominent) to obtain planting materials; easy to propagate (either because they bear fruit often or can be propagated vegetatively); are seemingly preferred as food by mammals and birds. This list outlines twenty that we currently prefer – bearing in mind that many others are also good. We regretfully omit all lianas because of their rare fruiting, slow growth rates and resistance to vegetative propagation.

Ficus microcarpa (Banyan, Jejawi, Ara Nunuk or Bonja; Figures 28 and 36) is a strangler than can grow to large size on most substrates including freshwater wetlands, old oil palms and hill slopes. Barring macaque damage, marcotting is 100% successful. It produces young leaves and fruits often and abundantly.

Ficus racemosa (Tangkol or Nunuk Ragang) is a tree, a specialist of the banks of large and medium sized rivers (Figure 41), that can grow to large size, even if planted away from any river. Unlike most tree *Ficus*, it is monoecious (both male and female flowers occur within the same syconium). Once mature, it fruits prolifically (Figure 42), the large fruits being relished by all frugivorous mammals and birds as well as freshwater fish, and the leaves by primates, colugos and flying foxes. It is easy to grow in large quantities from seed. Unlike many other *Ficus* species, saplings survive heavy browsing by deer and other herbivores.

Figure 41. A stand of wild *Ficus racemosa* trees in their natural habitat – a riparian zone – in an oil palm estate

Figure 42. Bunches of *Ficus racemosa* fruits, a mix of unripe and ripe

Ficus variegata (Tandiran or Nyawai) is a very fast-growing, straight-trunked dioecious (separate male and female) tree (Figure 38) that grows on all well-drained soil types and usually starts to bear its large fruits when only 3 years old. It is easy to grow in large quantities from seed.

Ficus parietalis (Ara Kertas) is a robust climbing plant that can also exist as a small tree, and is sometimes seen locally abundant on old oil palms. It is dioecious, with female figs being orange-red in colour when ripe and relished by many wildlife species, while male figs are yellow when ripe. Female figs are probably the tastiest of all species (Figure 43).

Ficus tinctoria gibbosa (Ara Diamond) A robust epiphytic climber with rhombic leaves, now locally common on old buildings, and which grows well as a tree on all well-drained soils (Figure 31). Orangutans eat the leaf shoots and fruits.

Figure 43. A wild orangutan feeding on fruits of a *Ficus parietalis* planted about ten years ago in Sabah Ficus Germplasm Centre

Ficus crassiramea (Ara Manggis) A large strangler with distinctively long leaves and long petioles, most common in wetlands and on peat (Figure 44).

Ficus callosa (Paw-paw) A handsome tree, with large, thick, glossy leaves resembling those of *Artocarpus* in mature trees, but long and lobed in immature trees (Figure 45). The leaves are relished by large browsing mammals. First fruiting when grown from seed occurs after five years.

Ficus melinocarpa (Ara Kuning) A handsome dioecious tree that grows rapidly to large size (Figure 39) and can bear fruit by age two years when grown from seed (Figure 46). Gibbons favour the female fruits.

Ficus magnoliifolia (Ara Hitam) A handsome monoecious tree that also grows rapidly to large size (Figure 47).

Ficus annulata (Ara Susu or Tetikar) A robust plant that can grow rapidly to large size as a strangler or tree on any well-drained including hard slopes (Figure 40).

Ficus benjamina (Beringin or Waringin) A strangler that can grow free-standing to large size, even on rocky substrates, with distinctive small, downward pointing laves, and with prolific small fruits (Figure 48).

Ficus pisocarpa (Ara Puncak) A strangler that can be grown on poor soils on hill tops as well as fertile lands to become free-standing (Figure 49).

Ficus subcordata (Ara Berhabuk) A strangler that can grow to large size. Its large fruits (5 cm long when ripe) attract many frugivorous mammal and bird species (Figure 50)

Ficus drupacea (Ara Titingan) A strangler of coastal areas that can grow to large size, tolerating sandy soils near the sea (Figure 51 & 52).

Ficus stricta (Ara Tebiatu) A strangler that can grow into a large free standing tree (Figure 53).

Ficus fistulosa and *F. nota* (Nangka Air Paya) Two closely-related and similar common small trees of secondary forests, often near streams, that fruit prolifically from the trunk and larger branches Figure 54).

Ficus francisci (Gatal Berbulu) A rare small tree, endemic to Borneo along small watercourses (Figures 4 and 67). Leaves are relished by herbivorous mammals.

Endospermum peltatum (Sesenduk) A fast-growing tree, to 40 metre tall, grown from seed (Figure 55). The fruits are relished by orangutans and other wildlife. Most plantings are damaged repeatedly by macaques (Figure 56) and this can often be seen in the odd, asymmetrical shape of mature tree crowns.

Sonneratia caseolaris (Berembang or gasing) The only mangrove tree that can thrive in freshwater wetlands that are seasonally or permanently under water. Grown from seed. Fruits are relished by orangutans and other wildlife species (Figure 3 and 57).

Litsea garciae (Pengolaban) A fast-growing tree of the *Lauraceae* (avocado) family (Figure 58) that produces copious fruits attractive to large frugivorous mammals and birds.

Figure 44. A *Ficus crassiramea* marcot planted in a Gigantochloa bamboo stem in a flood-prone riparian zone in a Genting Plantations estate

Figure 45. A *Ficus callosa* seedling with its distinctive long, lobed leaves

Figure 46. The first fruits seen on a two-year old *Ficus melinocarpa* planted tree in Sabah Ficus Germplasm Centre

Figure 47. A seventeen-month old *Ficus magnoliifolia* grown from seed

Figure 48. (Above) Bornean giant squirrel feeding on unripe *Ficus benjamina* fruits in Sabah Ficus Germplasm Centre
Figure 49. (Below) Lesse green leafbird feeding on the fruits of a planted *Ficus pisocarpa*

Figure 50. A wild infant orangutan feeding on fruits of a planted Ficus subcordata in Sabah Ficus Germplasm Centre

Figure 51. A *Ficus drupacea* wilding growing on a roadside tree

Figure 52. A mature *Ficus drupacea* strangling fig

Figure 53. Three two-year-old *Ficus stricta* trees in Glenealy estate

Figure 54. A wild *Ficus fistulosa* tree in a secondary forest set-aside in an oil palm estate

Figure 55. Three-year old *Endospermum peltatum* tree planted in Genting Plantation Tanjung estate

Figure 56. Zainal Z Zainuddin points out the macaque damage on a planted *Endospermum peltatum* seedling in the same estate; the crowns of mature trees of this species are usually misshapen due to early macaque damage

Figure 57. Semi-ripe fruits of *Sonneratia caseolaris*

Figure 58. A *Litsea garciae* tree with young fruits

The flood-prone abandoned land conundrum

'The problem is not to find the answer. It is to face the answer' Terence McKenna

Aerial photographs taken in 1971 show that there were scattered patches of land in the Kinabatangan landscape that were devoid of tree cover, although the great majority of the landscape at that time was under forest cover. Examples were around the Butong and Labaung rivers, downstream and upstream respectively of Bukit Garam on the north bank of Kinabatangan river. These areas are at some of the lowest elevations in the floodplain. Possibly, they had been covered in forest on peat that might have been destroyed in the massive El Nino fires of 1878 or 1916. One of us drew a map in 1989 (Figure 59) showing the larger areas of predominantly swampy and flood-prone lands, which at that time clearly would not be able to sustain agriculture. A few parts of the flood-prone lands shown on this map have successfully been converted to oil palm planation with the construction of adequate drainage ditches and canals, but most cannot be cultivated due to periodic high flood waters. Previously, those lands were covered in natural freshwater swamp forest.

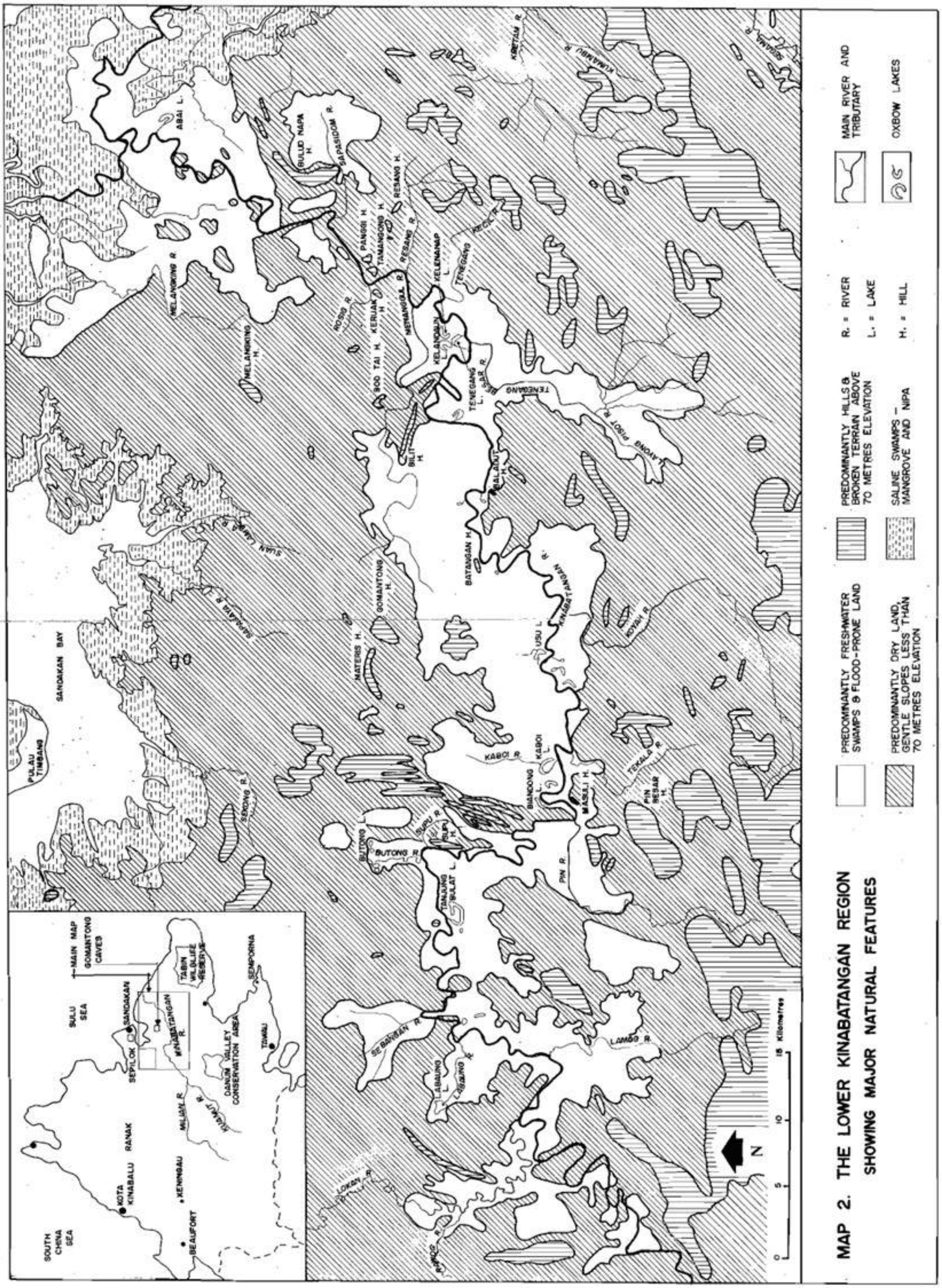


Figure 59. Freshwater wetlands in Kinabatangan, mapped in 1989

The 1992 Cabinet view of a proposal for the establishment of Kinabatangan Wildlife Sanctuary was that legislating sufficient land for sustaining wildlife populations would take up ‘too much’ land, especially ‘native land’. That decision did not stem a flow that had been initiated in the 1970s for enthusiastic land applicants to obtain land titles and the planting of oil palms throughout the Kinabatangan floodplain, irrespective of soil type or flood risk.

In 1992, the oxbow lake to the south-west of Masuli Hill was covered largely in pure stands of *Mallotus muticus* that were removed in 1997-98 for oil palm plantation, which could not be sustained due to repeated flooding. Since abandonment of the oil palms around 2003, attempts to actively reforest this site have had limited success, with the only surviving planted seedlings being of *Mitragyne speciosa* with scattered *Nauclea orientalis* successfully self-seeding and growing thereafter. Planted *Mallotus muticus* and *Terminalia copelandii* seedlings were killed by flood waters (Figures 60, 61 and 62).

Abram et al (2014) calculated that 15,810 ha of land planted with oil palms in the Kinabatangan landscape is commercially redundant, because repeated flood inundation has killed all or most palms, despite the presence of drainage channels (Figure 63). Subject to interest of and policy decisions by the owners of lands that cannot sustain oil palm, currently unproductive wetlands in the oil palm landscape offer a possible opportunity to create a habitat that could be used by orangutans. If those swamps could also be planted with flood-tolerant trees with known commercial potential (for example, *Nauclea orientalis, Terminalia copelandii*; Wong, 2002; Figure 64), then commercial wood production could potentially be developed on some of that land.

Figure 60. Masuli oxbox lake, 2007

Figure 61. Masuli oxbox lake, 2014

Figure 62. Masuli oxbox lake, 2019

Figure 63. Satellite view of abandoned oil palm plantations in a Kinabatangan wetland

Figure 64. A natural stand of *Nauclea orientalis*

Flood waters that last a day or two usually do not result in the death of existing woody plants (Figure 65). But there is a very major impediment to enriching abandoned wetlands with orangutan food plants. Periodic flood waters that last many days or weeks, and that are incurred at least once annually will kill the great majority of plant species (Figure 66), both oil palms and key orangutan food species. There are three elements to the problem. One is that the great majority of plant species, even when mature, cannot tolerate the usual waterlogging that characterises much of the Kinabatangan floodplain. There is no point to plant species which will die as they mature because of inability to tolerate chronic waterlogged soil. The few trees species that grow naturally in periodically flooded lands in Kinabatangan include those named above plus *Excoecaria indica* and *Colona serratifolia*. The second part of the problem is that none of these flood-adapted species can provide significant amounts of food for orangutans. Their fibrous fruits and leaves contain very little nutritional value. Amongst non-tree orangutan food plants, only the flood-tolerant woody scrambler *Bridelia stipularis* appears to thrive in these conditions. The third part of the problem – and the most difficult to resolve - is that flood waters will likely over-top any seedlings (including those of flood tolerant species) planted in the ground before they have grown tall enough for the crown (leafy twigs) to escape being under water. For all seedlings, including those of wetland-adapted species, more than two or three days under water will result in death of the seedling.

Figure 65. A two-year old *Ficus francisci* tree in a flooded riparian zone

Figure 66. A frequently flooded part of an oil palm plantation

There are three main possible approaches to restoring open freshwater wetlands to forest cover with orangutan conservation as an objective. The first is to plant strangling figs (marcots or seedlings) on to raised objects implanted into the wetland, so that the young plant is above usual flood levels, but can grow its roots downwards. Necessary minerals for growth must be added with the seedling or marcot on to the raised object. Planting strangling figs onto hardwood posts or frames is expensive and time-consuming.

Experiments were conducted by BORA in 2021, planting *Ficus* on to 1.2 metre-tall portions of dead oil palm trunks embedded into waterlogged, seasonally- flooded soil (Figures 67 and 68). Thirty portions of trunks were tried, about 100 kg each in weight. All the trunks rotted and collapsed within a year, before much growth had been achieved by the *Ficus* (Figure 69). In 2022 and 2023, large bamboo posts were tried at the same site (Figure 44). The results indicated that bamboo is preferable, being not only much lighter in weight and easier to prepare, but also longer-lasting. However, unusually high and long-lasting flood waters in 2025 killed all the planted *Ficus* (Figure 70). The conclusion is that either option (oil palm trunk or bamboo as a base to keep plantings above flood levels) may collapse as a result of decay by fungus and bacteria, or by strong flood waters, before the *Ficus* is sufficiently large to survive independently. An even cheaper, easier way to plant tall seedlings in wetland sites was also tried: cutting off the bottom of the polybag container, and placing the seedlings plus polybag sheath on to the soil. But with this, the main problem of subsequent flood waters going over the top of the seedling remained unsolved.

Figure 67. Preparing stumps from dead oil palm trunks in an experiment to plant *Ficus* marcots above flood levels in a wetland set-aside

Figure 68. Moving the oil palm trunk stumps into a riparian wetland set-aside

Figure 69. The stumps rotted within a year, even after wrapping them in tough plastic sheets

Figure 70. A *Ficus crassiramea* marcot planted into a bamboo stem died 20 months later due to unusually high and long-lasting flood waters

Another option is to keep on planting tall seedlings year after year until at least two whole years occur successively with no major flooding. That might occur perhaps once in a decade or less often. Cost and effort are increased significantly, yet the actual risk of flooding remains unchanged.

Only one tree species was identified that grows in freshwater (Figure 71) and which yields fruits that are relished by orangutans (Figures 3 and 57) and other frugivorous animals: *Sonneratia caseolaris*, known locally as berembang or gasing (see Box). This tree is not related to *Ficus*. Fruits are produced year-round.

Figure 71. A clump of *Sonneratia caseolaris* trees

Sonneratia caseolaris, known locally as berembang or gasing. Seeds obtained from ripe fruits (Figures 72, 73 and 74) grew best when planted into wet clay soil. Like other tree species tried under this programme, the seedlings cannot tolerate being over-topped by water. But once the height of the seedling is above water level (whatever that may be), and strong currents have not dislodged the seedling, and some leaves remain above water, growth is robust. Trial plantings of berembang were carried out on three types of substrate: in a small pond in the Sabah Ficus Germplasm Centre where water level is constant; in open (treeless) wetlands in four oil palm estates, where water level varies in tandem with heavy rainfall and height of flood waters from the Kinabatangan river (Figure 75); and on the lower Tungku river (southeast side of Tabin Wildlife Reserve; Figure 76). All 45 berembang plantings in the SFGC pond survived and are thriving. In the open treeless wetlands, all 58 berembang died at two of the sites, where water levels vary from 0 to 2 metres above ground level and flooding can last for weeks, while most of those planted in the two other wetland sites, where water levels rise to about one metre for short periods, survived. At Sandau 32 out of 35 survived while at Sungai Pin, only 9 out of 50 survived following an unusually massive and long-lasting flood in year 2025. 100 more were planted at this site after the flood subsided. At the Tungku river site, three methods of planting were tried at the river edge: (1) direct planting into the ground (30 seedlings), (2) planting into soil mounds about 30 cm high (10 seedlings; Figure 74), and (3) planting into soil mounds about 30 cm high, with the polybags intact except that the bottom of the bags were cut off (10 seedlings; Figure 77). The mounded soil was intended to keep the seedlings above water level during flooding and to reduce potential competition with weeds. The treatment with polybags planted into the mounds was intended to minimize the effects of anticipated erosion by river flow. During flooding, seedlings planted directly into the ground were severely affected and all died (Figure 78). This was due to the combination of factors including the seedlings being submerged under water for many days, washed away by strong currents, and/or damaged by the debris carried by the flood water. Seedlings on mounded soil were minimally to moderately damaged, with some erosion of the mounds caused by the river current. During a dry period, however, all seedlings on mounded soil were adversely affected by desiccation and died. Pneumatophores (roots naturally growing upwards into the air to exchange oxygen and carbon dioxide) appeared as early as five months after planting, not solely based on age, but more on sustained soil wetness (Figure 79). The overall lesson is that survival of berembang seedlings, like other freshwater-adapted wetland tree species, depends on fortuitous rainfall and flood water patterns in the first two or three years after planting.

Figure 72. Dried *Sonneratia caseolaris* seeds ready for planting

Figure 73. Collecting wetland clay soil for planting *Sonneratia caseolaris* seeds

Figure 74. *Sonneratia caseolaris* seedlings germinated best in wet clay soil

Figure 75. Planting a *Sonneratia caseolaris* seedling in a wetland site in Sandau estate

Figure 76. Planting *Sonneratia caseolaris* seedlings on mounds next to Tungku river

Figure 77. Planting a *Sonneratia caseolaris* seedling in the polybag with the bottom cut off

Figure 78. The after-effects of prolonged high flooding along the Tungku river, early 2025

Figure 79. Base of a 15-month-old *Sonneratia caseolaris* planted in the Sandau estate wetland

A third option is to not plant anything and hope that nature will bring in seeds of woody plants. This latter option is clearly the cheaper and, in many cases, the most rational one. Sometimes, seeds of wetland-adapted tree species that are already abundant in the soil will germinate immediately after flood waters have receded (Figure 80), but typically, sedges and other coarse herbaceous plant species take over freshwater wetlands before seeds of trees, dispersed by wind or water, can enter and germinate (Figure 81). In that sense, planting trees in saline water is easier because mangrove trees are adapted to grow in tidal saline water, while sedges and herbaceous plants cannot withstand the salinity.

Finally, an alternative possible approach to making abandoned freshwater wetlands biologically useful would be to create mounds or bunds, rendering some of the land lower and permanently under water, but providing sites above normal water levels that can be planted with preferred trees or stranglers. Such a method is used successfully in some plantations for oil palm cultivation (Figure 82), but could potentially be replicated on abandoned estate lands with larger earth mounds and deeper intervening channels.

Figure 80. Naturally-emerging *Nauclea* seedlings soon after flood waters subsided

Figure 81. A wetland that has filled naturally with sedges, ferns and other non-woody plants, now difficult to convert to alternative vegetation

Figure 82. Mounds created for planting oil palms in a wetland could be similarly created for planting native trees

Is restoration and enrichment planting in an oil palm landscape truly worthwhile?

'Those who cannot change their mind cannot change anything' George Bernard Shaw.

Bartholemew et al (2024) found that 'active restoration of logged (dipterocarp) forests recovers initial seedling production, but elevated mortality (compared to survival of seedlings monitored in logged forests without any enrichment planting) lowers the efficacy of active restoration to enhance recruitment or diversity of seedling communities'. This seems to imply that for all the cost and effort that is put into planting seedlings in logged forests, the high mortality of seedlings (both natural and planted) means that the cost and effort is probably not worthwhile. However, this is a very different situation from restoration using *Ficus* in oil palm plantations, where the only possible natural source of native woody plant species will be seeds dispersed by frugivorous birds and mammals. The actual rate of dispersal of seeds into the oil palm landscape is likely to be very low, with none at all for most *Ficus* species, and the process involved will be spread over decades. The point here is to raise questions on whether active planting of native woody plants on set-aside lands in in oil palm plantations is cost-effective or not, and whether the cheapest strategy is to do nothing, and await natural takeover of set-asides by woody plants. Apart from money cost, the key factors here are: (i) time, and (ii) whether natural, passive enrichment by natural seed dispersers will result in biodiverse set-asides. Observations made by BORA show that strangling *Ficus* are dispersed into old oil palm plantations by pigeons and other bird and mammal dispersers. However, the further from a large forest block, the fewer the dispersing birds and the fewer the *Ficus*. Also, the array of *Ficus* species is small, typically with only one or a few species in any one area. It is clear that active enrichment of multiple *Ficus* species and adequate tending can not only speed up a natural process by many years, even decades, but also ensure that multiple species are used.

This study does not point to a preference – whether in terms of ecology, cost or convenience - either for restoring wildlife habitat under abandoned old oil palms or for planting on to land cleared of the old oil palms. Restoration work will follow whatever locations and land cover are made available by the estate manager. The stark difference is that old palms (and secondary forest) are convenient in providing a variety of microhabitats, with prevailing low light intensity resulting in slow growth of any planted materials. Costs are much greater if planting is done into herbaceous vegetation, due to the necessary high frequency of weed removal, but with the benefit that fast grow rate of plantings can be guaranteed, if weeding is performed adequately and if there is no long dry period during the first year or so.

Results and observations – the socio-economic ecosystem

The current situation

The biggest problem to be addressed that has been exposed through the 2019-2025 programme reported here is not technical but related to policy and to the framework and supply chain that currently exists in relation to financing and the production and growing of native woody plants for habitat restoration and enrichment.

The pressure from some parties involved in habitat restoration programmes is to maximise rate of planting and minimise cost. If the objectives are to either meet committee or donor-generated KPIs, or to sequester carbon, then this way of viewing restoration is acceptable. If the point is to restore or create habitat for specific wild species – in this case Bornean orangutan – or for a general enhancement of biological diversity in a particular area, the pressure is misplaced. Fortunately, there was no such influence on the programme reported here.

There is a general problem to address and two specific ones.

The general problem is that the entire field of restoration and enrichment of natural habitat, both in damaged protection forests and conservation areas, and in non-forest production landscapes is currently in a state of disorder. This is not to say that the system is chaotic, but that the various players are not functioning in an integrated, effective and efficient way. Consider the following elements in the current Malaysian ecosystem of human endeavours in restoration and enrichment:

Government policy level Conservation of biodiversity (including but not limited to large vertebrates) at Malaysian national level is subsumed into just a single one out of about 27 Ministries, and even within that one natural resource Ministry, there is competition for attention with other weighty issues relating to climate change, carbon, land, minerals and mapping. At Sabah level, terrestrial biodiversity is split between forestry, environment and tourism. By default, within the government ecosystem, forestry departments are left to deal with terrestrial restoration and enrichment. In the current era, governmental departments are widely viewed as implementers, not policy makers. Decisions that in the past might have been made by departmental directors are now often diverted to Ministers or to Cabinet level, and necessary supporting decisions might not come for many years, if ever.

Forestry Departments Forestry Departments are struggling with recasting their role as the single largest land manager now at the end of the cash-rich era of significant production of wood from natural forests and the beginning of a new cash-poor era where responsibilities have shifted to an uncomfortable combination of terrestrial biodiversity management and wood production from plantations. Forestry Departments are under some pressure to 'restore' of 'reforest' forests that have been damaged by past logging operations. The areas involved are very large. Yet there is a prevailing lack of clarity on the key purpose of such restoration or reforestation. Is it to 'restore' biodiversity or to plant trees for future wood production?

A 12 year long, USD13 million programme in Bukit Piton Forest Reserve, Sabah, specifically billed as for restoration of orangutan habitat involved planting over 600,000 seedlings but almost none of them was a key orangutan food plant, presumably because no nursery was producing orangutan food plants. The only publicly-available analysis of this programme (Mansourian et al, 2020) stated that 10% of trees planted were 'fruit trees' (all tree bear fruit) but did not state what species were planted.

Two big problems with so-called 'fruit trees' are, firstly, that they might not be native species and, secondly, they will all bear fruit in the annual fruiting peak, a time when orangutan food is already super-abundant and of little value to orangutans. The balance of 70% dipterocarps and 20% pioneer species planted in the Bukit Piton case are not orangutan food plants. More recently, (after 2020) there seems to be an unstated aim that the main purpose of restoration in forest reserves is to accelerate sequestration of carbon, with unspecified 'biodiversity' elements added into explanatory texts as a sop to donors and the public.

Palm oil industry After forests, the next most extensive land use in Malaysia is oil palm plantation. To be clear, there is no historical background requiring oil palm land-owners to be involved in biodiversity of any sort or in any way other than biological control of pests, and this book is not criticizing any aspect of oil palm. Despite the advent of RSPO (since 2004) and MSPO (2015, mandatory since 2020), over the period 2019-2025 operating with eight oil palm grower companies, we did not see any sign of interest either in informing RSPO or MSPO auditors of local orangutan presence or of making orangutan conservation as a sustainability gambit. There seem to be four main reasons for this observation. Firstly, (at estate level) admitting the presence of orangutans locally implicitly brings a potentially burdensome responsibility of ensuring they will still be there in the future. Secondly, (at corporate level) mere mention of the name orangutan brings concern of potential attack by NGOs. Thirdly, people in sustainability, whether auditors or staff of the oil palm growers, may lack one or both of experience or stature within the company to propose specific programmes (such as orangutan conservation), and they may already be overwhelmed by the numerous demands placed by RSPO and MSPO standards. Fourthly, like the rest of us, very few people in the palm oil industry will think of or conceptualise something that they have never seen before. Most things that are new are either unknown to most people are ignored, or even resisted.

Donors for restoration In the absence of pre-existing and established norms, policies and directives from government or industry, donors tend to be a double-edge sword in the restoration world. The positive side is that they provide the funds for the restoration to be done. The negative side is that the funds, being donor-driven, may tend to prioritise perception and glamour over reality and effectiveness. Many donors wish to measure performance by the number of seedlings planted for the lowest cost. Put bluntly but not too unfairly, in a not atypical scenario, that means that low quality seedlings obtained cheaply in large quantities may be planted quickly by people who are either on a low income or inexperienced. Fortunately for the programme reported here, the metric agreed by the donors was extent of area restored (in hectares), thereby avoiding the risks associated with number of seedlings. In many areas where habitat restoration work has been agreed, the best method to prioritise is repeated cutting of weeds (plants that are not wanted), leaving space and light for any existing desired plants to flourish. A major problem is ensuring all team members know which plants to cut and which to leave alive. Moreover, the success of this approach is difficult or impossible to measure quantitatively, and so generally not wanted by donors.

Local communities Local human communities may be involved through one of three perspectives: initiators (whoever they might be) who want to integrate restoration and local community benefit from the outset; initiators whose prime concern is to get high quality restoration done by whatever means possible and where local communities present an obvious choice for the workforce; and donors who provide the funds. Two prime examples of programmes in Sabah that were formulated from the beginning to be work done by the indigenous community near to where the restoration is to be done are KOPEL/MESCOT (https://www.kopelkinabatangan.com/) and HUTAN (https://www.hutan.org.my/). BORA is different in that while all field staff are from several indigenous communities, there was no specific attempt to prioritise people from communities nearest to the work sites. In large part, that was due to the fact that BORA wanted staff who would work full-time over many years, a requirement which is independent of distance from family. Donors often require that local communities be involved in the restoration work. That requirement may be well-intended but does not necessarily guarantee high-quality work by motivated people. If a restoration project is linked to involvement of local communities, there is a tendency to choose tree species where seedlings are abundant so that local people can collect and sell wildings to the project. Few or none of those tree species provide significant foods to orangutans. Thus, much time, effort and funds have been spent on 'restoring forests' that provide little or no more food for wild orangutans than does an oil palm plantation.

Project implementation method There are three main sorts of implementation, although a hybrid of more than one is possible. The first and most effective was pioneered in Sabah by the INFAPRO programme in Sabah (https://facethefuture.com/projects/sabah-maleisie-boshersel-en-bescherming) starting in 1993. The INFAPRO method was to establish a full-time team, composed of paid, dedicated staff who work together over many years. The team manages the nursery, plants the plants, and conducts weeding and maintenance work thereafter, until no more maintenance is required. They operate as a team of gardeners rather than plantation contractors. This is the model adopted by BORA and HUTAN. KOPEL/MESCOT has a similar model but with the inclusion of volunteers from outside the area. The only major problem with this model is that someone has to raise funds year after year to sustain the team. The lessons learned through INFAPRO were not taken up by either the forestry authority or donors, who tend to favour contractors, who in turn require supervision and management. Contractors are normally identified and chosen by a tendering system, and they implement all or some of the jobs of seedling supply, planting and maintenance. There may be an element of selecting a cheap but not necessarily best tenderers. Monitoring is done very quantitatively, based on number of seedlings planted and surviving after a certain period. Trust must be high that the monitoring team will do a professional job. This model seems to be preferred by institutions that expect to have access to significant funds over many years, such as government departments and major donors and mainstream NGOs. Our observations of other habitat restoration projects in Sabah over three decades indicates that the prime objective of contractors performing such work is to minimise costs and maximise profits, while the objective of contractor workers may be to implement measures to prevent thorough monitoring. On the positive side, a system will be put in place to quantitatively monitor and verify progress, thereby enabling smooth monitoring and reporting. On the negative side, overall quality of work may be lower than is seen with the long-term professional team model. Also, with contracting arrangements, people doing the work on the ground are given no leeway to try new approaches and develop their experience and motivation. The third implementer model is a mix of one-off donors, clubs, associations, volunteers and students. These projects tend to be short term, and may be done primarily for glamour or advertising a particular company, institution or product. Mortality of planted seedlings may be high and there might be no quantifiable biological value.

The first of the two specific problems is that the species of plants involved in restoration and enrichment work are currently those obtainable in existing nurseries, while the species that should be used (for whatever objective) are typically not available. To date, most restoration programmes have simply gone for tree species for which there are existing suppliers. Suppliers of planting materials and all planting contractors tend to choose tree species that are the cheapest to produce or purchase, yet only one of those species in the Borneo context (*Neolamarkia cadamba*) is of any value to orangutans, for nesting and food outside the main overall forest fruiting periods. Even this species is sensitive to soil parameters, and will not thrive (or may die) in wet sites and on slopes and ridge tops. Seemingly to date, BORA alone has decided what plant species are needed and then built capacity and expertise to provide them.

The second specific problem to address now is that unless and until the work done under the programme reported here is given clear policy support by at least one prominent and influential stakeholder, then the work will not be scaled up to a level that will have the intended effect of sustaining a wild orangutan population (excluding those orangutan populations that already exist within large forest conservation areas). Any one or more of five stakeholders could take up the challenge to introduce and enunciate a policy of oil palm orangutan coexistence that must include boosting the productivity of orangutan food plants in the oil palm forest landscape, namely: 1. National government of Malaysia. 2. State government of Sabah. 3. A leading national palm oil-related governmental authority. 4. One or more major oil palm growers (if one were to take it up and market the idea as a contribution to sustainability, others will likely follow, if the first one does not run into problems). 5. A major mainstream conservation NGO that has influence on government policy and on palm oil – only WWF fits that description.

Finally, there is a further potential problem to be addressed. In the human ecosystem of players involved in habitat restoration, the term ‘protect’ (or ‘protection’) and ‘conservation’ appear to have become more prominent in recent years, seemingly at the expense of ‘restoration’ and ‘enrichment’. A moment’s reflection on the basic tenets of conservation biology will reveal that simply ‘protecting’ something will result in a slow deterioration in number of species present (e.g. Arrhenius, 1921, and vast amounts of theoretical and field research thereafter). Loss of species will be slow and indetectable if viewed year on year or even decade on decade (Preston, 1962). The phenomenon can be described as Sorities Paradox, or Paradox of the Heap (Williamson, 1994), and is nowadays often described as Boiling Frog Syndrome. The only hope of sustaining biological diversity and to prevent extinction of the rare species is to either set aside vast areas (millions of hectares) of natural habitat (no longer an option, other than retaining large areas already set aside) and / or actively manage and enrich an array of small areas. The push to prioritise protection over restoration (for habitats) and recovery (for species) represents a subtle threat to preventing extinctions. Why is this happening? The most likely explanation is the most usual one: money. The costs of 'protection' are significantly lower than the costs of restoration. A small team of men paid modest salaries can 'protect' a very large area of habitat. But, as shown by the programme reported here, a skilled team required several years to restore just 100 hectares of wildlife habitat.

Costs

One independent published analysis (Kuaraksa & Elliott, 2013) provides a starting point on how tree seedling production costs might be assessed. They calculated an actual production cost of USD1.14 per tropical *Ficus* seedling, grown from seed, in the nursery, and ready for planting out in Thailand. It must be noted that this Thailand study used USD6.53 per 8 hour day for labour cost, and labour cost was about 70% of overall production cost. BORA staff daily rate (paid within the context of a monthly salary) varies largely according to length of service but now averages USD20 per day, three times greater than the Thai study. In Peninsular Malaysia now (2025), daily paid workers recruited by mainstream NGOs can expect a rate of between USD25 to 35 per day. Also, in the Thailand study, seedlings were reckoned ready for planting out at 20 cm height, much smaller than the minimum of 60 cm reckoned by BORA to be suitable. That extra seedling maintenance time would add 10-20% on to the cost. Thus, if the Thailand study is taken as an independent benchmark, a production cost for BORA seedlings should be of the order of US$1.14 x 0.7 (cost of labour as a percentage of all costs) x 3 (2025 Sabah cost compared to 2012 Thailand cost) x 1.15 (extra time in nursery for seedlings to grow bigger) = US$2.70 or RM11.50. In addition, and very importantly, the Thailand study omitted costs of the institutional arrangements (supervision, administration etc) for operating the programme, which could easily add 20% or more to costs, bringing a rough cost of production to about RM15 per seedling. Thus, using the Thailand study as an independent reference point, and scaling up production numbers (thereby benefitting from a lower marginal cost per seedling), a production cost per seedling of RM10 is not unreasonable. But to provide an element of profit to sustain the nursery in Sabah in year 2025, a minimum sale price of RM20 per seedling seems reasonable. Nevertheless, Sabah Forestry Department proposed RM5 per *Ficus* seedling as appropriate, with RM10 regarded as too high, although RM10 is accepted by some other local NGOs.

How does that independently-derived calculation compare with BORA's actual experience? Detailed calculation of the actual costs of running the BORA programme reported here is fraught with problems. The long preparatory phase, before the idea of developing the programme, cannot now be estimated. Costs of building a nursery and its associated hardware is easier, but there are wide margins of variance, depending on what materials can be obtained cheaply (e.g. hardwood) and what can be created by staff who are handymen. Even cost of manpower cannot be calculated precisely, because BORA was involved in multiple work streams throughout the period reported to date, including development of an assisted reproductive technology programmme for wildlife with government, establishment of pastures for wild cattle and elephants, production of books, engagement with the palm oil industry and government at various levels, seeking new income sources and trying out various wildlife-related ideas. Some staff involved in the work reported here were essentially full-time, but most were part-time in relation to raising and growing *Ficus*, the latter including the senior management and administration staff of BORA. Rather than attempting to itemize every component cost, and likely derive an under-estimate because management and overall NGO administration time is under-represented, a much simpler but reasonably accurate approach is to start with the observation that monthly operational costs of BORA averaged about RM100,000 per month. Roughly 40% of that cost went to the programme reported here, including a miscellany of peripheral and optional costs, such as travel and time spent maintenance and monitoring as well as on meetings and on seeking new plant sources, addressing bureaucracy, reporting, contributions to sustaining BORA's leadership and administration staff, trials with vegetative propagation methods, trials with freezing seeds etc.

Thus, the cost of running the programme to produce, plant and manage *Ficus* planting materials can be stated as RM40,000 per month. Cost of successfully growing one seedling includes not only production of the planting material but also the costs of bringing to planting sites, planting, and maintenance for two to three years. It is tempting, and ultimately necessary for potential future programmes and their donors, to translate that figure to number of planting materials produced. Once the programme was underway, the number of planting materials produced was between about 500 – 1,000. In fact, significantly more could be produced for essentially the same cost, but the demand was rarely present from oil palm growers or from other NGOs, and was absent from government. If, say, 1,000 seedlings are produced and ready for sale monthly, a fair price per seedling plus basic maintenance for three years would be RM40 per plant, excluding an element of profit.

Cost per seedling is just the beginning. Cost of successfully growing one seedling includes not only production of the planting material but also the costs of bringing to planting sites, planting, and maintenance for two to three years. One can provide a rough breakdown of BORA costs (with no profit element) from two angles. Firstly, taking the cost of operating the programme reported here as RM40,000 per month, with a potential to produce 2,500 seedlings per month, that works out as RM16 per seedling. This amount includes producing, transporting, planting and maintenance for two to three years. Having said that, the actual human resources time put into maintenance was significantly less than optimum, as human and financial resources were always limiting. The second angle is a more generous assumption of RM10 per planting material supplied based on actual production cost, plus RM10 for cost and transporting and planting each one, and RM20 for maintenance of each plant for two-three years (although that cost varies greatly from site to site). This breakdown is very rough, but as a 'ballpark' implies that the minimum cost of successfully growing one high-quality, desirable planting material for restoration or enrichment for wildlife should be of the order of RM40. The cost would be higher for materials which are rare (e.g. those that fruit rarely and need greater care in preparation) or of large size (e.g. more than one year of care in the nursery and more than 60 cm tall).

It is actually impossible to put a precise number on the cost of 'growing one seedling and leaving it on the safe assumption that it will continue to grow', as each situation will be different. Often, donors are not so interested in how many planted seedlings will reach a stage where they can be safely abandoned, but want to know cost of producing or buying a seedling. The authors of this book have seen the pressure put on projects to minimize 'cost per seedling', and we have seen the results. They include: taking wildlings of common and robust tree species (not *Ficus*) and putting them into small polybags (some of those tree species could be regarded as invasive, as they can be observed now dominating parts of the Kinabatangan landscape at the expense of other tree species); pretending that those species are 'wildlife food species' even if they are not; poor quality and marginally healthy seedlings; no vegetative propagation of planting materials where that might be preferable (for example, marcots for planting on rocky sites, and living stakes for sites with thick weed growth or flood risk); no attempts to produce and store high quality seeds for future use; ignoring plant species which fruit rarely or are difficult to propagate but are significant as frugivorous vertebrate food plants; and most significantly of all, not paying sufficient attention to maintenance after planting out, with concomitant high and unreported mortality.

As restoration work is still in large part donor-driven, a case may still be made for a quantity over quality approach, in terms of project costs, if numbers go to tens of thousands of plantings. The fundamental problem, however, is that the resulting productivity of food edible for wildlife (in this case, orangutans) per hectare per year will be extremely low (because the planted plants are not major food plants and many will die anyway), and potentially insufficient to sustain those orangutans.

Currently, price suppression may be limiting the quality of restoration work. This is particularly evident in Sabah, where even the Sabah Forestry Department advocates for seedlings to be sold at a maximum of about RM6 per seedling, and less for common species. NGOs involved in restoration seem to tolerate this situation. This may be through one or more of a desire to fall in line with government advice, or donor pressure, or out of fear that higher prices would mean other NGOs with lower quotations would get the job. At the village nursery level, the ‘local community’ goes along with low prices, just as they accept – but are not necessarily aware of - subsidized prices for petrol, rice and cooking oil. Quality of seedlings produced in village nurseries is seen to be variable but often low, with only very common, robust tree species involved. It is difficult to identify if that situation occurs primarily because rural residents actually prefer to produce cheap, low-quality seedlings that involves very little effort, or because they see that there is no market for better, higher priced seedlings that would require more effort.

Until and unless there is a move towards paying higher prices for good quality planting materials such as those produced by BORA, there is one alternative approach to tolerating the current low price scenario for plants that will produce fruits edible to mammals and birds: use only seeds from common, robust plant species (no rare or sensitive species and no marcots); use fertigation to maximise early growth rate; and sell the seedlings at small size (say, less than 20 cm tall). The onus will then be on the buyer / planter to be responsible to increase the seedling size to a greater height and to harden them.

Future approaches to enrichment and restoration

Technical

In some sites (but not all) the aim to improve habitat for orangutans could be achieved in part by silviculture, that is, by cutting away non-orangutan food plants and leaving those that are eaten by orangutans. This is difficult to promote, optimize and report on, in part because it requires experience and skill in the workforce, and because donors cannot measure the effort made. BORA did not apply this method much, as the workload imposed by maintaining planted seedlings and marcots was already high.

Some progress towards increasing number of orangutan food plants planted and reducing costs could be made in the future, by choosing the most easily propagated and most robust, fast-growing orangutan food plant species. These comments should not be taken, however, as a recommendation to plant only these species. In general, the more species, the better, in terms of enhancing biodiversity and of ensuring that at least some plants are fruiting at any one time.

To some extent, the choice of *Ficus* planted to date and highlighted in this paper is linked to the availability of those species within the orbit of SFGC, and also to the limited ability to seek other species elsewhere during the early years, which coincided with movement control periods spanning April 2020 to late 2021. Several strangling fig species that bear large fruits (e.g. *F. cucurbitina, F. dubia, F. stupenda, F. subcordata* and *F. xylophylla*), attractive to orangutans and other large-bodied frugivores, merit attention, especially *F. xylophylla*, very rare in Sabah, which has a big advantage for restoration work in that it thrives on nutrient-deficient soils such as white sand and peat.

Choice of whether to plant seedlings and marcots at allocated sites with regular spacing along regular-spaced lines, or subjectively, where the planting supervisor feels that there are the best chances of survival and good growth, is in itself subjective. Use of planting lines is easier in planning, administration and monitoring. Simple string or rope with tape measure and compass can be managed by any team with minimal supervision, as can siting of planting holes, and subsequent monitoring is easy. After some growth has occurred, line planting is visually more impressive to donors and other visitors. But there are several reasons why subjective choice of planting sites is superior in some circumstances. Sites which are relatively small in area, or narrow or oddly shaped, or with broken topography, are more amenable to subjective choice. Crucially, an experienced and confident supervisor needs to be on site. Most importantly, the supervisor can gauge and choose the best sites in terms of soil quality, drainage, amount of shade, aspect (in relation to sunlight) and relative threat of aggressive weed growth. In some circumstances, subjective choice is essential, such as in swampy areas where there might be no point in planting anything except on the highest points in the local landscape.

Socio-economic

The main donor for this study, WWF-Malaysia/Unilever took a practical approach, with the metric for progress being number of hectares planted with favoured orangutan food plants, and the species chosen and their spacing left up to BORA. This turned out to be a workable model satisfactory to all parties involved.

In addition to that, much leeway was given to experiment in ways that are too minor and numerous to be outlined here. Examples include: (1) experiments in vegetative propagation of liana species (none of the early small-scale trials were successful, and they were therefore abandoned),

(2) experiments with *Ficus* cuttings (none of the early small-scale trials were successful in terms of satisfactory survival rate in the nursery), (3) travels in and outside Tabin Wildlife Reserve to seek, collect and propagate species that had not previously been found or tried, (4) trials with various planting media, fertilizers and fertigation in the nursery, (5) experiments with cryopreservation of seeds and post-thaw viability.

Concluding Remarks and Recommendations

In order to prevent extinction of rare and endangered species, the prevailing focus on ‘protecting’ and ‘conserving’ wildlife must be shifted towards targeted interventions that serve to sustain and recover wild clusters of declining species, so that they can become viable populations. Proponents and implementers of programmes that involve protection or restoration or both must be aware of the implications of island biogeography theory on their work. They must also learn to recognize and accept two fundamental elements of carbon-based life: it has evolved to maximise its reproduction and all individuals will die. If simply ‘protected’, species that are rare in an area now will likely become rarer and go extinct. If an existing remnant habitat patche is simply protected, species that are common there now will tend to become commoner. It does not make much sense to actively plant more tree species that are already common and reproducing. One might even be helping an ‘invasive species’ to become more invasive. No species – whether plant or animal - that is already common needs to be helped to become more common. In fact, species – whether plant or animal - that are robust and tending to outcompete rarer species may need to be reduced in numbers to free up space and food for the rare and declining species. In prevailing circumstances, the need for discussion and decision-making becomes muted because emotions may enter the discussion. This is particularly prominent with animal species (such as macaques and feral dogs), where individual animal welfare gets conflated with population management.

Slowing death rate (anti-poaching and illegal trade) should be viewed as a supplement to the more necessary and sustainable goal of enhancing birth rate (better nutrition) as a means to recover clusters of endangered species. For the same amount of funding, a few targeted restoration programmes will pay greater dividends than many ‘blanket’ protection programmes. (Attention: governmental forestry and wildlife authorities, nature conservation NGOs and providers of funds, including donors and financial institutions).

The bulk of those interventions must seek to boost productivity of the natural foods of those targeted species, because sustained daily nutrition is vital to reproduction and healthy demography. This applies not only to Bornean orangutans but to most endangered wild species. This understanding must apply to all who are working in the technical side of wildlife management (Attention: researchers and academics, governmental forestry and wildlife authorities, nature conservation NGOs and donors).

Almost all natural foods are plants (including for the prey of predators). Thus, boosting productivity of natural foods in free-ranging situations means selecting sites and growing and managing those sites for enhanced plant biomass production, with an emphasis on leaves and fruits (Attention: researchers and academics, oil palm plantation owners, directors and managers, governmental forestry and wildlife authorities, nature conservation NGOs and donors).

The land-owners or delegated land-managers in the case of orangutans are the governmental forestry and wildlife authorities and the major oil palm growers. Their support is vital but currently muted or lacking. This book calls for explicit policy support for the idea of targeted habitat enrichment by growing and maintaining selected plant species, from (a) Government of Sabah, (b) governmental forestry and wildlife authorities, and (c) the major oil palm growers. (Attention: Government of Sabah, governmental forestry and wildlife authorities, and oil palm plantation owners, shareholders, directors and managers).

Generating an overall, agreed strategy and detailed implementation plan is almost impossible, as multiple investors, land-owners and managers with differing worldviews and priorities are involved. Certification of oil palm management units by MSPO and RSPO is currently done at individual management unit level. However, both MSPO and RSPO are urged to seek ways to provide support to the vision outlined in this book, which must involve landscape level guidelines and, perhaps, incentives. (Attention: MSPO and RSPO).

Just as everything looks like a nail for those whose only tool is a hammer, enriching landscapes with food plants (in this case, intended for orangutans but in a place where many other, more abundant fruit-eating animals exist) may have unintended negative consequences. In the programme reported here, macaque monkeys were not only the single biggest animal destroyer of planted *Ficus* plants, but will also be a major beneficiary in the future from those plants that they failed to destroy. Macaques, living in large groups, already stress orangutans where both species exist, and consume the bulk of potential orangutans foods. BORA has received several reports from specialist tour guides and ecologists of macaques wiping out local bird populations by targeting nests and consuming eggs and chicks. Put bluntly, macaques can cause a slow process of local extinctions of orangutans and many bird species. Macaques are also reservoirs of human malaria. The solution is not to stop growing orangutan food plants. The solution is that Sabah must consider to introduce a programme to reduce macaque numbers in plantations and in small forest set-aside lands. Vasectomies under sedation of temporarily-captured male macaques probably offers the most humane and least-controversial option. This is not difficult if a full-time professional team is tasked for the job over many years and arguably more useful than teams fielded to protect forest habitats from poaching (Attention: wildlife authority).

The technical lessons learned in the programme reported here could be useful to various stakeholders. Some of the most significant lessons are:

- *Ficus* is a unique and readily adopted genus of plants for habitat enrichment and restoration.
- Other tree genera can be added, but propagation and growing lianas at scale is probably too challenging to be worthwhile.
- A serious nursery for restoration and enrichment work should use fertigation to maximise rate of production and turnover of good quality planting materials.
- A long-term restoration team with a gardener's approach (the same people involved in seed acquisition to nursery management to final maintenance work) will likely do a better job than use of contractors. Apart from the problem of securing long-term funding for professional teams, the main constraint to pursuing this method is that measuring the outputs of contractors is easily quantified with numbers, while measuring the outputs of a team of gardeners is difficult because they are subjective and may differ (positively) from pre-set work plans. Providers of funding are requested to abandon number of seedlings as a metric, to shift to number of hectares treated, and pay more attention to outcomes rather than to outputs. (Attention: providers of funds, including donors and financial institutions.)
- Clear thought needs to be given in advance to the pros and cons of operating in a seasonally-flooded or permanent freshwater wetlands. The cost of inputs and the time frame needed are high and long respectively. The risks of both early phase set-backs and of ultimate failure are high. Despite possible hesitancy and high initial costs, creation of soil mounds or bunds in such sites, and planting on to those mounds or bunds, is likely to result in long term successful enrichment with productive wildlife food plants. Cost represents the only constraint to be resolved. (Attention: governmental forestry and wildlife authorities, oil palm plantation owners, shareholders, direc-

tors and managers, nature conservation NGOs and donors).

In addition to low awareness of the points made in the recommendations above, there seems to be laissez-faire approach by government - which is not in itself a problem – but which allows for competition between NGOs for funds from donors to implement an array of projects that lack a coherent vision. Generating and forcing everyone to accept a single vision may be unwise and impossible, but the current human socio-economic and administrative 'ecosystem' can be improved in order to better support effective nature restoration work.

It is well-known and oft-repeated, yet frequently-ignored, that a project must define its objectives. In Kinabatangan, treeless habitat ideal for enrichment with elephant food plants has been planted with trees that are not food plants for either elephants or orangutans. Some programmes to restore orangutan habitat, reported in public domain, have grown tens of thousands of trees that are not orangutan food plants. Either the objective of the project or the types of planting materials should have been amended. In the absence of a single ecosystem restoration vision that is silent on specifics, the objective of every restoration and enrichment project needs not only to be defined, but the objective needs to be cognizant of the bigger picture and the needs of other rare species and of other projects. (Attention: governmental forestry and wildlife authorities, nature conservation NGOs and donors).

Habitat restoration in Sabah seems to bear a resemblance to being in a 'low-income trap' whereby a cycle of low input of money, income insecurity and limited opportunities have resulted in a persistent inability to upscale to effective biodiversity management. This is not to be critical of the programmes that have been initiated by civil society efforts and donors, and sustained by them over many years. Rather, the fact that they have not been replicated or placed within a governance infrastructure demonstrates the 'low-income trap' metaphor, whereby voluntary organisations are plugging gaps that governments, the palm oil industry, banks and big businesses are not stepping up to fill. We should not worry about a future 'middle-income trap' in the nature restoration world because once specific areas have been enriched and once the concepts that are involved are widely accepted, that 'middle-income trap' will be just what is needed. (Attention: governmental forestry and wildlife authorities, palm oil industry and providers of funds, including donors and financial institutions).

Little published literature exists on the technical and quantitative aspects of restoring habitat with the dual purpose of biodiversity recovery and carbon sequestration. Hamdan (2021) showed that fast-growing Malaysian tree species with intermediate wood density (around 50 gm / cm^3, *Acacia* and *Hevea* rubber) yielded the fastest rate of carbon sequestration. In contrast, fast-growing trees with low wood density (0.29 gm / cm^3, *Macaranga* spp) and slow-growing tree species with high wood density (above 0.70 gm / cm^3, some dipterocarp species) yielded an intermediate rate of carbon sequestration. Slow-growing tree species with medium wood density (0.40 to 0.70 gm / cm^3, many dipterocarp species) yielded the lowest rate of carbon sequestration. Published wood density of Malaysian *Ficus* species varies between 0.28 to 0.62 gm /cm^3, while growth rates recorded in the work described here are as fast as *Acacia*, rubber and *Neolamarkia cadamba* (wood density of the latter reported as 0.29-0.56 gm / cm^3). In terms of carbon sequestration during early years of growth (around 0 – 10 years) *Ficus* will therefore sequester more carbon than dipterocarps and be similar to *Acacia,* rubber and *Neolamarkia*. We suggest the following ten *Ficus* species as ideal for programmes where carbon sequestration and biodiversity restoration are joint goals: *Ficus microcarpa, Ficus racemosa, Ficus variegata, Ficus crassiramea, Ficus callosa, Ficus melinocarpa, Ficus magnoliifolia, Ficus annulata, Ficus benjamina and Ficus stricta*. As with most human endeavours, improvements are led by small groups of passionate and competent people, who arrange themselves by self-selection. Too much governmental policy and regulation may be as harmful as submission to donor demands. The following recommendations, arranged by stakeholder type, follow that precept:

Wildlife authority

With limited resources, prioritise a few species and a few geographical areas for attention and action.

Treat each wildlife species as a management issue (either to reduce, or sustain or increase numbers) and give increased attention to habitat and population management, and less to individual animals.

Prioritise a policy to sustain Bornean orangutans in the landscapes in which they occur with an emphasis on habitat enrichment in both governmental and corporate-owned lands.

Forestry authority

Ensure that all programmes in Forest Reserves have a clear objective and that implementation adheres to the objective. ‘Biodiversity’ is too vague. Replace that with either targeted wild species, or wood or carbon, or a combination.

Work towards mass production of planting materials for wood production and wild species management, but do not strive to keep seedling prices low.

Move away from historical ways of treating occupation of land within Forest Reserves, and away from imposition of fees on non-profit occupiers, towards encouragement of non-profit organisations to do restoration within Forest Reserves, where possible through professional teams and profit-sharing on sales.

Legal authority

Change the prevailing legalistic view of wildlife management that predates year 2000 towards a view that is based on biological reality and pragmatic solutions to wildlife management issues.

Governmental palm oil institutions

Realise that populist projects dating from decades ago, which tend to prioritise unnecessary 'rescue' and 'saving' of individual wild animals, and animals in captivity, are no longer appropriate. Oil palm is the second biggest land use in Malaysia after forests. Move both policy and funding towards treating each wildlife species as a management issue (either to reduce, or sustain, or increase numbers) and give increased attention to habitat and population management.

Financial institutions and donors

Critically analyse and decide upon projects proposed by external parties for nature conservation. Usually, no research is necessary. Usually 'The problem is not to find the answer. It is to face the answer'.

Forgo glamour projects. Do not choose 'protection' projects primarily because they are cheaper or easier than restoration and enrichment projects. Make commitments of at least five years to every project, if necessary choosing just one programme instead of several. Make sure implementers have a credible project objective and methods and resources to implement the programme. Understand that projects must be operated by competent people who need decent salaries over years. Some programmes are operated by academic staff who are paid by the university, and who have administrative support. They can employ students, 'interns', recent graduates and volunteers, thereby offering artificially low costs to donors and, potentially, sub-standard work. Also, academic staff may priorities publications over actual beneficial outcomes.

Prioritise provision of decent staff salaries and related costs for chosen programme implementers – that is the single biggest funding need for small, specialist NGOs. Do not overly-focus on costs other than NGO staff costs (salaries, EPF and insurance), including administration and finance staff as well as project leaders and field teams. Normally, about 75% of programme costs should be staff costs. A habit of minimizing staff costs has led to short-lived and ineffective restoration programmes.

Researchers and academics

Try to avoid seduction by prevailing fashions in biology, and to reduce number of peer-reviewed papers for publication in scientific journals.

Recognise that in nature conservation, experience counts higher than any statistical tests.

Pay more attention to the implications of species-area curve and extinction debt, and to the importance of nutrition and demography in endangered species recovery.

Oil palm plantation owners, shareholders, directors and managers

Critically analyse and decide upon projects proposed by external parties for research or conservation in oil palm plantations to ensure that they are credible and useful.

Potentially make available the various set-aside lands within plantations for wildlife management or nature restoration purposes.

Nature conservation NGOs

Review the Concluding Remarks and Recommendations in this book and make use of those you deem useful.

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Acknowledgements

Thanks go to BORA staff Alvin Erut, Davidson Kuntil, James Sandiang, Juspin Balungking, Maslin Mohiddin, Norashimh Janih, Roland Ruslin, Saadia Rappe, Shakila Ibnoh, Lonia Adam, Bridget Yong Stephens, Maryanne Mathew and all other BORA staff who have contributed to work that has led to the insights and guidelines presented here.

The work reported here was authorized under Sabah Biodiversity Council Access Licence reference number JKM/MBS.1000-2/2JLD.16(75) and funded by Unilever / WWF-Malaysia as part of WWF Malaysia's 'living landscapes approach' to landscape management in Sabah. Some of the initial work was also funded by Sime Darby Foundation. The Habitat Foundation supported the work on *Sonneratia caseolaris* as a potential tree species to enrich permanent wetland sites. Sabah Forestry Department allowed BORA to base our activities in Tabin Wildlife Reserve and to develop the Sabah Ficus Germplasm Centre there, and provided miscellaneous support including plant and insect identification. Sabah Wildlife Department provided policy-related support. Universiti Malaysia Sabah provided office space in the Faculty of Science and Technology. BORA has been greatly aided by the existence of the blogsite https://borneoficus.info/, created and maintained by Mr Quentin Phillipps. Oil palm growers including Genting Plantations, Glenealy Plantations, KLK, Kretam Holdings Berhad, MPOB, Sawit Kinabalu, Sime Darby Plantations, Tian Siang and Tradewinds Plantation granted permission to plant orangutan food plants on their estates, and KLK provided significant in-kind assistance.

The text and arrangement of this book benefitted from comments by Glyn Davies. The views expressed in this book do not necessarily reflect the views of persons or institutions other than the authors.

Mark Iven of WWF-Malaysia prepared the map. Darrysie S J and 1StopBorneo provided valuable support in production of this book.

Appendices

Appendix 1. Fruiting patterns of 35 *Ficus* species observed by BORA over at least three years

A. Species with consistent or fairly consistent patterns

No.	Species	Month											
		J	F	M	A	M	J	J	A	S	O	N	D
1	*Ficus aureopilosa*	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
2	*Ficus geocharis*	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
3	*Ficus megaleia*	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
4	*Ficus pseudobeccarii*	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
5	*Ficus rubrostellata*	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
6	*Ficus stolonifera*	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
7	*Ficus treubii*	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
8	*Ficus uncinata*	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
9	*Ficus fistulosa*	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
10	*Ficus lepicarpa*	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
11	*Ficus leptogramma*	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
12	*Ficus nota*	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
13	*Ficus rosulata*	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
14	*Ficus cereicarpa*	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
15	*Ficus francisci*	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
16	*Ficus deltoidea*	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
17	*Ficus minahassae*	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
18	*Ficus sinuata*	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
19	*Ficus racemosa*	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
20	*Ficus albipila (2)*	✓	✓			✓	✓	✓					✓
21	*Ficus annulata (3)*	✓	✓	✓		✓	✓	✓	✓				✓
22	*Ficus benjamina (1)*	✓	✓			✓	✓	✓					✓
23	*Ficus pisocarpa (4)*	✓	✓	✓			✓	✓	✓				✓
24	*Ficus punctata (2)*	✓	✓				✓	✓	✓				✓
25	*Ficus pellucidopunctata (2)*	✓	✓			✓	✓			✓	✓		
26	*Ficus depressa (2)*	✓	✓	✓				✓	✓	✓			
27	*Ficus heteropleura (2)*	✓	✓	✓				✓	✓				

28	*Ficus parietalis (3)*		✓	✓	✓			✓	✓		✓		
29	*Ficus virens (2)*		✓	✓				✓	✓				
30	*Ficus microcarpa (5)*		✓	✓	✓				✓	✓	✓		
31	*Ficus crassiramea (4)*			✓	✓	✓				✓	✓	✓	
32	*Ficus subgelderi (3)*			✓			✓				✓		
33	*Ficus consociata (1)*			✓							✓		
34	*Ficus xylophylla (1)*										✓		

Notes:

✓ refers to ripe and near-ripe fruits observed in that month

For numbers 1-18, at least three plants for each species have been monitored over at least three years

For number 19, fruiting is nearly continuous, as new figs develop while ripe ones fall

Ficus variegata has a similar pattern to *F. racemosa*, whereby most trees bear ripe fruits in most months, but the occurrence of ripe fruits differs between different trees in the same area

For numbers 20-34, numbers in parentheses refer to the number of plants monitored over at least three years

B. Examples of *Ficus* species with varying fruiting patterns

Species	Pattern
F. callosa	One tree January-March 2021, then December 2021-January 2022, another tree June 2023, another September-October 2023; other trees August 2025
F. cucurbitina	One plant observed over four years fruiting every November-February and June-August. Two other plants fruiting September-October 2024.
F. drupacea	One individual, February 2024
F. inaequipetiolata	One plant in July, several in September 2024
F. kerkhovenii	One individual, May-June, another in October 2023
F. lindsayana	Several trees in one area fruiting asynchronously over the months August-October 2024
F.melinocarpa	Three mature trees January-March 2021 and the same trees at the same time in 2023; two in May 2021, the same two June-August 2022
F.magnoliifolia	One mature tree August 2021, same tree in August-September 2024, but not in 2022-2023
F. pallescens	One individual December 2023-March 2024
F. rubrocuspidata	One individual July 2023 and March 2024
F. sagittata	One plant observed fruiting continuously all year round; another in March-April 2024 only; two others in October-November 2023 only.
F. scaberrima	One plant, January-February 2024, another plant March 2024, another October-November 2024
F. stricta	One plant, June 2021, same plant November-December 2022 and again December 2023-January 2024
F. subcordata	One plant each at Tabin and Tawau Hills, July-September over 2 or 3 consecutive years
F. subulata	One plant, September-November 2021

F. sundaica	One plant, June 2021, one January-February 2024, another plant April, another May, 2024, two others September-October 2024
F. tinctoria	One plant observed fruiting September to February 2024; one plant in March-April 2024; one in June 2024; one in July 2024, all near Tabin HQ
F. trichocarpa	One plant observed over three years fruiting every December-February and June-August. Another plant fruiting May-June, another August-September 2024
F. villosa	One plant fruiting all year round but amounts vary between months

Appendix 2. List of *Ficus* species in Sabah Ficus Germplasm Centre 2025

(E) = species endemic to Borneo (all other species are widespread in Southeast Asia and/or eastwards to Sahul and/or in the Philippines))

D = dioecious, there are male trees and female trees, with male trees producing figs that contain only male flowers and female trees producing figs with only female flowers; M = monoecious, male and female flowers are present within the same fig (syconium)

No.	Scientific Name	Name Used in SFGC	Notes	Sex
1	*Ficus albipila*	Ara Lebah	Large tree (45 m)	M
2	*Ficus allutacea*	Ara Selaput	Root climber	D
3	*Ficus annulata*	Ara Tetikar or Ara Susu	Large hemi-epiphyte	M
4	*Ficus aurata*	Gatal Piring	Shrub or small tree	D
5	*Ficus aureopilosa*	Bendera Besar	Earth fig; Large shrub or small tree	D
6	*Ficus barba-jovis (E)*	Ara Barba	Root climber	D
7	*Ficus benjamina*	Ara Beringin	Large strangler	M
8	*Ficus brunneoaurata (E)*	Gatal Kinasaraban	Small tree	D
9	*Ficus callophylla*	Ara Daun Tebal	Medium hemi-epiphyte	D
10	*Ficus callosa*	Paw-paw	Large tree (40 m)	M
11	*Ficus caulocarpa*	Ara Belimbing	Large strangler	M
12	*Ficus cavernicola (E)*	Ara Mesilau	Root climber	D
13	*Ficus cereicarpa (E)*	Gatal Basah	Large shrub or small tree	D

14	*Ficus consociata*	Ara Abu	Hemi-epiphyte	M
15	*Ficus crassiramea*	Ara Manggis	Large strangler	M
16	*Ficus cucurbitina*	Ara Berbulu	Very large hemi-epiphyte	M
17	*Ficus cumingii*	Ara Kapal Kayu	Shrub or small tree	D
18	*Ficus deltoidea*	Mas Cotek	Epiphyte or shrub	D
19	*Ficus densechini (E)*	Ara Deduit Sayap	Root climber	D
20	*Ficus depressa*	Ara Jantung	Medium liana	M
21	*Ficus drupacea*	Ara Titingan	Large strangler	M
22	*Ficus eumorpha (E)*	Ara Mar-mar	Shrub or small tree	D
23	*Ficus fistulosa*	Nangka Air Paya	Large shrub or small tree	D
24	*Ficus forstenii*	Ara Sultan	Medium strangler	M
25	*Ficus francisci (E)*	Gatal Berbulu	Small tree	D
26	*Ficus fulva*	Gatal Ranau	Shrub or small tree	D
27	*Ficus geocharis*	Bendera Garib	Earth fig; Small tree	D
28	*Ficus globosa*	Ara Ungu	Climber or hemi-epiphytic shrub	M
29	*Ficus gul*	Gatal Gul	Medium tree (25 m)	D
30	*Ficus hemsleyana*	Ara Kertas Berbulu or Ara Muru Turu	Small tree or climber	D
31	*Ficus heteropleura*	Ara Kertas Kecil	Medium shrub or epiphyte	D
32	*Ficus inaequipetiolata (E)*	Gatal Silam	Shrub or small tree	D
33	*Ficus kerkhovenii*	Ara Kerkhoven	Large strangler	M
34	*Ficus lawesii*	Ara Mangga	Large strangler	M

35	*Ficus lepicarpa*	Nangka Air Maragang	Large shrub or small tree	D
36	*Ficus leptocalama*	Ara Mogong	Shrub or treelet	D
37	*Ficus leptogramma (E)*	Nangka Air Rangup	Small to medium tree (20 m)	D
38	*Ficus lindsayana*	Ara Batang Merah	Large hemi-epiphyte	M
39	*Ficus magnoliifolia*	Ara Hitam	Large tree (45 m)	M
40	*Ficus megaleia*	Bendera Berbulu	Earth Fig; Small tree	D
41	*Ficus melinocarpa*	Ara Kuning	Large tree (35 m)	D
42	*Ficus microcarpa*	Ara Nunuk or Bonja	Very large banyan strangler	M
43	*Ficus midotis*	Ara Selungkoi	Small shrub or climber	D
44	*Ficus minahassae*	Ara Ajinomoto	Small tree (25 m)	D
45	*Ficus montana*	Ara Kapal	Small shrub	D
46	*Ficus nervosa*	Ara Obah	Large tree (40 m)	M
47	*Ficus nota*	Nangka Air Bukit	Small tree	D
48	*Ficus oleifolia*	Ara Silam	Small montane fig	D
49	*Ficus pallescens*	Ara Panji or Ara Nunuk Merah	Small to medium strangler	M
50	*Ficus parietalis*	Ara Kertas	Small tree or climber	D
51	*Ficus pellucidopunctata*	Ara Mud	Large strangler	M
52	*Ficus pisocarpa*	Ara Puncak or Ara Tudan	Medium hemi-epiphyte	M
53	*Ficus pseudobeccarii*	Bendera Bujur	Earth fig; small tree	D
54	*Ficus punctata*	Ara Deduit	Root climber	D
55	*Ficus punctata var callicarpa*	Ara Deduit Kesiladan	Root climber	D

56	*Ficus racemosa*	Tangkol	Large tree (30 m)	M
57	*Ficus recurva*	Ara Kertas Halus	Root climber	D
58	*Ficus recurva var or Ficus sabahana*	Ara Lipan Kecil	Root climber	D
59	*Ficus rosulata*	Nangka Air Pasir	Small tree	D
60	*Ficus rubrocuspidata*	Ara Menitis	Small climber	D
61	*Ficus rubrostellata*	Bendera Halus	Earth fig; Small tree	D
62	*Ficus sagittata*	Ara Gam	Large root climber	D
63	*Ficus satterthwaitei*	Nangka Air Pinausok	Small tree	D
64	*Ficus scaberrima*	Ara Babag or Nuratas	Small shrub or epiphyte	D
65	*Ficus septica*	Lintotobou	Large shrub or small tree	D
66	*Ficus sinuata*	Ara Diya	Small climber	D
67	*Ficus stolonifera*	Bendera Rash	Earth Fig; Small shrub or large tree	D
68	*Ficus stricta*	Ara Tebiatu	Large strangler	M
69	*Ficus stupenda (E)*	Ara Giant	Large strangler	M
70	*Ficus subcordata*	Ara Berhabuk	Large hemi-epiphyte	M
71	*Ficus subgelderi*	Ara Tenegang	Large hemi-epiphyte	M
72	*Ficus subsidens (E)*	Ara Kinabalu	Small creeping shrub	D
73	*Ficus subulata*	Ara Mata Ikan	Small tree or climber	D
74	*Ficus sumatrana*	Ara Buah Lubang	Large strangler	M
75	*Ficus sundaica (Form A)*	Ara Urit	Large hemi-epiphyte	M
76	*Ficus sundaica (Form B)*	Ara Tingkah	Large hemi-epiphyte	M

77	*Ficus tarennifolia (E)*	Nangka Air Unduk	Small tree	D
78	*Ficus tengerensis*	Nangka Air Kesiladan	Small tree	D
79	*Ficus tinctoria var gibbosa*	Ara Diamond	Epiphytic climber or small tree	D
80	*Ficus tinctoria var hutan*	Ara Diamond (daun kecil)	Epiphytic climber or small tree	D
81	*Ficus treubii (E)*	Ara Tupai	Earth fig; Small to medium tree	D
82	*Ficus trichocarpa*	Ara Epal	Root climber	D
83	*Ficus uncinata*	Bendera Lebar	Earth fig; small tree	D
84	*Ficus uncinulata*	Velcro Fig	Root climber	D
85	*Ficus uniglandulosa*	Ara Kelenjar	Epiphyte or shrub or small tree	D
86	*Ficus variegata*	Tandiran	Large tree (40 m)	D
87	*Ficus villosa*	Ara Lipan	Root climber	D
88	*Ficus virens*	Ara Fesada	Large strangler	M
89	*Ficus xylophylla*	Ara Garib	Large strangler	M
90	*Ficus sp*	Ara Core Area	Small tree	D
91	*Ficus sp*	Ara Getah Kuning	Large strangler	M

Appendix 3. Summary of the restoration and enrichment sites

No	Site name	Start Date	Substrate and planting treatment	Planting pattern	Ha planted	No. of plants	Purpose and main features
1	KHB Abedon estate Tanaki riparian, Kinabatangan Landscape	17/02/20	Riparian zone, river 2m wide, with old palms in place, at the bottom of a steep valley. Well-drained sandy soils, but very wet during rainy periods. Planting of *Ficus* and *Spatholobus* done subjectively.	Approx. 10m	30.00	1,025	To explore restoration on a typical riparian zone (small river) with 2-3 rows of old palms retained at replanting. Male and breeding female orangutans reliably reported in the vicinity. Due to denied access (COVID lockdowns) for maintenance work throughout year 2020 up to mid-2021, no monitoring or maintenance work of the initial plantings was done. Many plants did not survive and only few have been located subsequently.

2	KHB Abedon estate Tanaki hill top, Kinabatangan Landscape	17/02/20 and new site 24/09/22	Top of a sandstone hill, formerly deforested and covered with widely-spaced old oil palms, resam fern (Dicranopteris linearis) and scrub. Little or no topsoil. Planting of *Ficus* and *Spatholobus* done subjectively.	Selected sites where survival potential thought to be best	0.88	115	To explore restoration on infertile sandstone hill slopes. Male and breeding female orangutans reliably reported in the vicinity. Due to denied access (COVID lockdowns) for maintenance work throughout year 2020 up to mid-2021, no monitoring or maintenance work of the initial plantings was done. Some plants did survive but not all have been located subsequently. The 2022- 2025 plantings are maintained and monitored by the estate management. Planting of *Ficus* marcots by the estate management continues.
3	Sungai Simpang Forest Reserve west, Kinabatangan Landscape	18/09/20	An old major logging road used in the 1960s-70s inside a 555 ha Forest Reserve and now covered in grasses and herbaceous plants. Line planting, mainly *Ficus*.	10m grid	6.00	337	To explore restoration on an abandoned old logging road with dense herbaceous weeds. Orangutan present. Due to denied access for maintenance work from October 2020 until November 2021, all except 5 of the plantings had died by November 2021. The site was abandoned. Main cause of mortality due to competition with grass and other weeds.

4	Sungai Simpang Forest Reserve east, Kinabatangan Landscape	18/09/20	Closed-canopy regenerated secondary forest on riparian land inside a 555 ha Forest Reserve that had been heavily logged in the 1960s-70s. Line planting, mainly *Ficus*.	10m grid	4.72	630	To explore restoration under dense regenerating logged forest. Orangutan present. Due to denied access for maintenance work from October 2020 until November 2021, all except 25 of the plantings had died by November 2021. The site was abandoned. Main cause of mortality probably due to excessive shade plus competition with existing woody seedlings.
5	Estate P, Lipad river, Tabin landscape	07/10/20	Riparian zone, river about 10m wide. Soil is deep, fertile well-drained, rarely flooded, with two to four rows of old oil palms along the banks. Line planting, mainly *Ficus*.	10m	3.82	849	To explore restoration under rows of 4 or 5 old palms retained on a fertile riparian zone (medium-sized river). Planting was initiated at this area, near to SFGC when no movement out of the area was allowed. It has become a showcase site. To date, orangutans have not been seen at this site, although several individuals periodically seen in SFGC, 800 m away.

6	Borneo Rhino Sanctuary, inside Tabin Wildlife Reserve, Tabin landscape	09/11/20	Gentle slopes, regenerating dipterocarp forest, heavy shade, inside Tabin Wildlife Reserve, the site total protected from browsing mammals by electric and physical fence. Line planting, mainly *Ficus*.	10m	2.65	412	To explore restoration under regenerating logged dipterocarp forest with protection from browsing mammals. Sparse resident orangutan population. Developed near to SFGC when governmental movement restrictions out of Tabin were in place. The site was monitored up to December 2021 but abandoned thereafter when it became clear that excessive shade and overland flow during rainstorms was severely inhibiting growth of plantings and led to 24% mortality over one year.
7	Estate T, Kinabatangan Landscape	28/01/21	Buffer zone of five rows of old palms bordering the largest tract of forest remaining in the region (11,800 ha), mixed topography including frequently waterlogged areas. Line planting, *Ficus* and *Spatholobus*.	10m	3.10	291	To explore restoration under old palms retained as a buffer zone adjacent to a Gomantong Forest Reserve. Orangutans present. Main interest is response to planting under old palms which is not a riparian zone, with both dry and waterlogged sites. About 10% mortality was recorded due mainly to occasional flood waters.

8	S D Guthrie Segaliud estate (riparian south), Kinabatangan Landscape	29/01/21	Riparian zone, a 1m wide stream straightened in late 1980s, with old palms removed and regenerated naturally by tall herbaceous vegetation dominated by *Nephrolepis biserrata, Merremia peltata* and *Mikania micrantha*. 560m from the 2,455 ha Lung Manis Forest Reserve. Line planting, *Ficus*.	10m	4.16	658	How to address weed control in a completely exposed riparian site with dense, fast-growing herbaceous weeds. Orangutans including female with young present within 560 m. After one year, a contractor had to be employed to conduct twice-monthly weeding for the following 15 months. With that, survival and *Ficus* growth rate was outstanding.
9	Hill in Estate P, Tabin landscape	24/02/21	A steep hill slope, formerly deforested and terraced, now covered with secondary forest and scrub. 1,200 m from Tabin Wildlife Reserve, through oil palm. Planting of *Ficus* and *Spatholobus* done subjectively.	Approx. 10m	5.62	135	To identify orangutan food plants species that will thrive on steep slopes. No orangutans seen nearby. 34% mortality after one year, mainly due to repeated herbicide use by estate workers, also some grazing by wild sambar deer.

10	KLK Ladang Tungku Buffer Zone, Tabin land-scape	30/04/21	Gentle topography, flood-free fertile soil, under old oil palms. Line planting, mainly *Ficus*.	Approx. 10m	3.12	1,044	Enrichment of oil palm forest edge buffer zone - currently old oil palms with no treatment
11	S D Guthrie Segaliud estate (north riparian), Kinabatangan Landscape	30/05/21	Riparian zone, a 1m wide stream straightened in late 1980s, with two rows of old palms along the wa-tercourse. Adjacent to the 2,455 ha Lung Manis Forest Reserve. Line planting, *Spatholobus* and other lianas.	Approx. 10m	0.74	203	To compare with identical soil type in Pertama estate south (number 8 above), and how to address con-straints imposed by shade. Orangutan mother and infant seen in this riparian zone in 2021. Same treatment as site 8, although lower frequency of weed-ing sufficient. Low mortality, all due to waterlogging at some sites.
12	Malambabula Wildlife site, Tabin land-scape	30/08/21	Flat, fertile land. Edge of an experimental elephant feeding ground, mainly grasses with sparse tree cover. Planting of *Ficus* done subjectively.	Approx. 10m	1.95	1,417	To explore if growing *Ficus* is compat-ible with elephant use of the habitat. Almost all *Ficus* were destroyed by elephants within one year.

13	Genting Layang estate and Tenegang estate, inabatangan Landscape	14/09/21	Riparian zone, river more than 10m wide, gleysol soil always waterlogged and seasonally heavily flooded, formerly cleared, but abandoned and now covered in secondary forest, enriched with planting of non-orangutan swamp forest tree species. Planting of *Ficus* done subjectively on higher points.	On selected highest points lacking tree cover	46.0 & 0.65	274 & 28	To explore ways to enrich the most difficult substrate (permanently waterlogged soil with periodic massive flooding) with orangutan food plants (all previous work in this zone used tree species not used by orangutans as food sources). Male orangutan(s) enter the northern part of this restoration zone from a 1,400 ha forest block to the north. 26% mortality within year 1, mostly to severe damage by resident long-tailed macaques. Many remaining planted *Ficus* trees stunted and mis-shapen due to macaque damage. Year 2025 floods caused additional mortality of younger plantings. Some initial planting of berembang done in Tengang estate, but plans for planting in the entire estate were abandoned when it became clear that flood waters there will kill all planted trees (only Nauclea species thrive).

14	Estate BP, Kinabatangan Landscape	21/01/22	Buffer zone of secondary forest and old cocoa plants, on sloping land around a water supply lake within a plantation. Planting of *Ficus* and *Gnetum* done subjectively.	Selected sites where survival potential thought to be best	22.0	361	To explore options for enrichment of lakeside catchments in oil palm estates (some estates retain secondary forest around their water supply lake, but enrichment options are restricted by excessive shade). Work at this site focused on the edge of the forest patch, where sunlight penetration is greatest. No records of orangutans nearby.
15	KLK Segar Usaha estate, Kinabatangan Landscape	24/02/22	Buffer zone of sparse old oil palms and legume cover crop around a water supply lake within a plantation. Fertile soil. 900 m from the Pertama estate restoration sites and 4.2 km from the nearest forest to the south. Part of an imaginary corridor. Planting of *Ficus* done subjectively.	Selected sites where survival potential thought to be best	9.66	235	To explore options for treatment of a lakeside catchment in oil palm where there is aggressive weed growth. This estate has abandoned old oil palms and dense, aggressive *Mucuna* cover crop around a shallow lake. No records of orangutans nearby. About half of the enrichment work was destroyed by inadvertent damage by machinery used in lakeside maintenance work. The *Mucuna* cover crop was so aggressive that maintenance was abandoned after 2 years.

16	Genting Tanjung estate, Kinabatangan Landscape	10/03/22	Buffer zone of sparse old palms and thick herbaceous vegetation at the bottom of a 154 ha forested hill within a plantation. Planting of *Ficus*, *Endospermum* and *Litsea* done subjectively.	Selected sites where survival potential thought to be best	3.66	400	To explore enrichment options on a large set-aside hill mainly covered in good quality forest. A few orangutans survive here, including at least one female and infant (the latter observed in 2022). The hill has been isolated by oil palm plantation since 1990s with hill dipterocarp forest habitat and very few naturally-occurring orangutan food plants. Planted *Endospermum* thrived on slopes (despite repeated damage by resident pig-tailed macaques) but less so on flat land due to periodic waterlogging at base of the hill.
17	Koh Koh estate, Kinabatangan Landscape	31/03/22	Riparian zone, fertile soil, infrequent flooding, river 2m wide, with old palms removed and young, tall herbaceous vegetation, but very few aggressive creeping plant species. Line planting of mixed *Ficus* species along the course of the river.	Approx. 10m	3.98	188	How to enrich an exposed riparian zone with *Ficus*. 350 m from nearest 140 ha forest patch which contains orangutans. Some plantings were inadvertently destroyed by heavy machinery used in riparian maintenance.

18	Sawit Kinabalu Sandau estate, Kinabatangan Landscape	09/12/22	Buffer zone of dense *Mucuna* cover crop and grassland in a 55 ha forest patch surrounding a water supply lake within a plantation. Planting of *Ficus* (on hill slope and wetland) and berembang (on wetland) done subjectively.	Approx. 10m	3.64	985	To explore enrichment methods where aggressive *Mucuna* cover crop and grassland are present. A resident female orangutan here gives birth periodically, although stressed by resident pig-tailed macaques. With maintenance work from the land-maanger, this proved to be one of the most successful enrichment sites.
19	Bukit Piton Forest Reserve, Kinabatangan Landscape	08/12/22	Heavily logged dipterocarp forest on gentle slopes with sparse tree cover and much herbaceous growth and no protection from elephants. 11,655 ha of this Reserve were planted with 1,820,000 tree seedlings over the period 2007-2022 at a cost of some RM60 million. However, the very great majority were not favourite orangutan food plants. Line planting, *Ficus*.	Approx. 10m	0.89	120	To explore enrichment methods in sparse logged forest with many open patches, and high risk of elephant damage. Large wild orangutan population present.

20	Genting Lo-kan estate, Kinabatangan Landscape	18/03/23	Riparian zone, river (Kinabatangan), 120 m wide, occasionally flooded but not waterlogged, with old oil palms and patches of scrub. Line planting, *Ficus*.	Approx. 10m	1.12	192	To reconnect two large blocks of freshwater swamp forest along the Kinabatangan river. Local orangutan presence unknown, but about 220 ha of suitable contiguous forest habitat exists to the north and 770 ha of forest to the south.
21	Genting Lo-kan Ladang 8, Kinabatan-gan Land-scape	21/11/23	Permanently waterlogged site, usually understanding freshwater, planted with *Sonneratia caseolaris*	Approx. 10m	0.19	30	Investigation of how to grow orangutan food trees in permanently waterlogged site subject to flooding. Orangutans present locally in Lot 10 of Kinabatan-gan Wildlife Sanctuary. All seedlings died due to periodic flooding and desiccation. The experiment here is terminated.
22	Glenealy AKB estate, Kinabatangan Landscape	28/04/23	Buffer zone of about 12 metres width, bare soil and scrub bordering a 430 ha Forest Reserve. Line planting along the Forest Reserve boundary.	Approx. 3m	8.72	1,300	To improve the quality of a buffer zone currently consisting of open soil with no shade. Orangutans in the Forest Reserve.

23	MPOB Lahad Datu, Tabin landscape	19/06/24	Buffer zone on the upper Sapagaya river, 2 m wide, fertile, seasonally flooded, mostly under grasses and non-aggressive herbaceous weeds, about 10 metres each side.	Approx. 10m	0.74	287	To enrich tree growth along a riparian zone. Sparse orangutan population in Tabin Wildlife Reserve, 2.5 km away. Old male orangutan sometimes seen in oil palm estates about 3 km away.
24	Sawit Kinabalu Sungai Pin estate, Kinabatangan Landscape	02/12/24	*Sonneratia caseolaris* planted in an open wetland periodically under flood waters for many days	Selected sites where survival potential thought to be best	0.14	50	Investigation of how to grow orangutan food trees in permanently waterlogged site subject to flooding. Orangutan present locally on Masuli hill, 300 m away.
25	FGV Hill-co estate, Kinabatangan Landscape	04/07/25	'HCV' area in a permanently wet part of Kinabatangan floodplain with tree cover (mainly naturally-regener-ated *Nauclea* and *Mallotus muticus*)	Selected sites where survival potential thought to be best	37.67	136	Further investigation of how to grow strangling *Ficus* on standing live trees in a permanently waterlogged site subject to flooding. Plantings are protected by wire mesh sheath. 98 strangler seedlings planted on to hol-lows in trees; 22 seedlings planted into mounds in soil; 16 x 2m long stakes planted into soil. Orangutans present nearby in Lot 5 of Kinabatangan Wild-life Sanctuary

	All Kinabatan-gan sites	-	-	-	187.92	7,551	
	All Tabin landscape sites	-	-	-	17.90	4,144	

Appendix 4. Examples of *Ficus* growth monitoring

A. Growth of large fig trees and stranglers within two years.

Plant Age (month)	Growth Forms (n)	Plant Height (m)			Diameter (mm)			Crown Area (m^2)		
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
0	Large trees (26)	0.74	1.60	1.12 ±0.24	4.22	13.10	7.98 ±2.44	0.01	0.36	0.11 ± 0.08
	Stranglers (12)	0.46	1.37	0.87 ±0.28	5.14	23.84	8.73 ±4.95	0.07	0.36	0.20 ±0.10
1-5	Large trees (26)	0.21	2.13	1.25 ±0.38	5.10	26.30	11.31 ±5.52	0.02	1.83	0.49 ± 0.46
	Stranglers (12)	0.55	1.78	1.14 ±0.38	7.20	27.50	14.42 ±6.56	0.01	1.55	0.48 ± 0.48
6-10	Large trees (20)	0.64	3.31	1.95 ±0.70	8.40	52.10	23.18 ±11.95	0.15	6.54	1.75 ± 1.58
	Stranglers (8)	1.10	2.21	1.53 ±0.36	10.05	37.53	18.12 ±8.97	0.29	3.04	1.14 ± 0.89
11-15	Large trees (12)	2.01	4.50	3.02 ±0.70	17.00	79.88	42.36 ±18.21	1.53	11.46	4.65 ± 3.03
	Stranglers (6)	1.35	2.96	2.12 ±0.69	16.60	55.72	33.12 ±15.81	0.94	4.39	2.70 ± 1.61
16-20	Large trees (7)	3.90	5.00	4.52 ±0.50	63.49	116.8	91.00 ±17.74	7.80	22.50	15.40 ± 4.81
	Stranglers (2)	1.85	4.60	3.23 ±1.94	23.13	101.8	62.45 ±55.61	1.75	21	11.38 ±13.61
21-25	Large trees (7)	5.00	5.00	5.00 ±0.00	101.0	165.5	130.3 ±25.52	25.00	25.00	25.00 ± 0.00
	Stranglers (2)	2.20	5.00	3.60 ±1.98	32.40	130.7	81.55 ±69.51	2.69	25	13.85 ±15.78

B. Growth of stranglers with different propagation methods within two years.

Plant Age (month)	Method	Plant Height (m)			Diameter (mm)			Crown Area (m^2)		
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
0	Seeds (5)	0.72	1.37	0.96 ± 0.29	6.42	23.84	11.04 ± 7.33	0.09	0.36	0.19 ± 0.12
	Marcots (7)	0.46	1.21	0.81 ± 0.28	5.14	8.72	7.08 ± 1.20	0.08	0.28	0.17 ± 0.08
	Posts (4)	1.63	2.08	1.93 ± 0.20	27.50	57.82	46.58 ±13.54	N/A	N/A	N/A
1-5	Seeds (5)	1.03	1.78	1.43 ± 0.27	12.4	24.4	19.70 ± 6.50	0.14	1.55	0.74 ± 0.61
	Marcots (7)	0.55	1.49	0.93 ± 0.31	6.84	15.54	10.65 ± 3.29	0.01	0.28	0.19 ± 0.10
	Posts (4)	1.63	2.08	1.93 ± 0.20	27.50	57.82	46.58 ±13.54	0.11	0.93	0.40 ± 0.46
6-10	Seeds (1)	1.73	1.73	1.73	30.41	30.41	30.41	0.98	0.98	0.98
	Marcots (7)	1.10	1.69	1.37 ± 0.25	11.45	24.37	15.55 ± 4.47	0.29	1.60	0.81 ± 0.51
	Posts (4)	1.68	2.24	1.97 ± 0.23	26.92	59.90	48.57 ±15.09	0.40	1.60	0.92 ± 0.56
11-15	Seeds (1)	2.93	2.93	2.93	55.72	55.72	55.72	4.11	4.11	4.11
	Marcots (5)	1.35	2.96	1.95 ± 0.63	16.3	49.00	28.54 ±12.67	0.86	3.92	1.71 ± 1.28
	Posts (4)	2.06	2.90	2.45 ± 0.34	32.19	64.90	55.61 ±15.65	0.47	5.56	3.95 ± 3.28

16-20	Seeds (1)	4.60	4.60	4.60	101.8	101.8	101.80	21	21	21
	Marcots (1)	1.85	1.85	1.85	23.13	23.13	23.13	1.75	1.75	1.75
	Posts (4)	2.50	4.10	3.13 ± 0.68	36.45	94.37	73.76 ±25.92	4.4	14.57	10.18 ± 4.23
21-25	Seeds (1)	5.00	5.00	5.00	180.7	180.7	180.70	25	25	25
	Marcots (1)	2.20	2.20	2.20	32.40	32.40	32.40	2.69	2.69	2.69
	Posts (4)	3.23	5.00	4.56 ± 0.89	46.20	141.2	105.65 ±41.26	6.70	25	20.43 ± 9.15

C. Individual evaluations after 25 months in S D Guthrie Segaliud estate (riparian, 1m wide stream, rarely flooded, rarely visited by no macaques, non-woody weeds only, with aggressive *Merremia*)

No.	Species	Age (month)	Height (m)	Diameter (mm)	Crown Area (m)	Health Score
1	*F. variegata*	25	5.++	131.30	25.++	0
2	*F. variegata*	15	2.99	54.50	3.13	0
3	*F. variegata*	15	2.01	17.00	1.53	0
4	*F. variegata*	8	3.31	52.10	6.54	0
5	*F. variegata*	8	1.91	28.60	2.39	0
6	*F. variegata*	6	1.19	16.00	0.47	0
7	*F. racemosa*	25	5.++	165.50	25.++	0
8	*F. racemosa*	25	5.++	120.30	25.++	0
9	*F. racemosa*	25	5.++	160.60	25.++	0
10	*F. racemosa*	25	5.++	130.90	25.++	0
11	*F. racemosa*	25	5.++	102.20	25.++	0
12	*F. racemosa*	25	5.++	101.00	25.++	0
13	*F. racemosa*	15	3.04	24.70	1.83	0

14	*F. racemosa*	15	2.53	21.70	2.01	0
15	*F.racemosa*	15	2.44	48.00	8.24	0
16	*F. racemosa*	8	1.71	17.00	0.55	0
17	*F. racemosa*	8	1.63	28.10	2.128	0
18	*F. racemosa*	6	1.64	25.00	1.83	0
19	*F. racemosa*	6	1.36	16.00	1.22	0
20	*F. racemosa*	6	1.32	26.30	1.36	0
21	*F. annulata*	25	5.++	180.70	25.++	0
22	*F. annulata*	6	1.78	27.50	1.55	0
23	*F. microcarpa cutting*	25	5.++	114.20	25.++	0
24	*F. microcarpa cutting*	25	5.++	141.20	25.++	0
25	*F. microcarpa cutting*	25	5.++	121.00	25.++	0
26	*F. microcarpa*	15	2.08	24.70	1.11	0
27	*F. microcarpa*	8	1.69	14.20	0.52	0
28	*F. microcarpa*	8	1.38	13.20	1.60	0
29	*F. microcarpa*	8	1.24	14.50	0.73	0

30	*F. benjamina*	25	2.20	32.40	2.69	0
31	*F. benjamina cutting*	22	3.23	46.20	6.78	0
32	*F. pisocarpa*	15	2.96	49.00	3.92	0
33	*F. melinocarpa*	8	2.82	29.60	2.03	0
34	*F. magnoliifolia*	8	2.05	18.40	1.03	0
35	*F. magnoliifolia*	8	0.64	9.80	0.22	macaque damage
36	*F. magnoliifolia*	6	1.34	19.60	1.24	0
37	*F. magnoliifolia*	6	0.21	N/A	0.03	macaque damage
38	*F. crassiramea*	15	1.57	31.40	1.74	0
39	*F. crassiramea*	15	1.35	21.30	0.94	0
40	*F. subcordata*	6	1.53	20.20	1.20	0
41	*F. drupacea*	6	1.37	14.00	0.15	0
42	*F. drupacea*	6	1.03	12.40	0.43	0

0 health score = good condition

D. Best performing species in Estate P (riparian, 8m wide river, rarely flooded, under old oil palms)

Species	Age	Plant Height (m)			Diameter (mm)			Crown Area (m^2)		
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
F. benjamina	5 years	6.45	10.7	8.99 ± 1.97	133.5	200.9	169.8 ± 25.8	22.7	94.1	66.1 ± 28.0
F. microcarpa	5 years	8.00	9.98	8.94 ± 0.84	133.6	229.9	180.8 ± 34.7	30.8	61.3	50.9 ± 11.6
F. annulata	5 years	6.73	9.10	7.88 ± 1.01	139.8	236.4	201.9 ± 36.8	30.5	82.3	60.4 ±23.7
F. lindsayana	5 years	6.16	8.47	7.32 ± 1.63	121.4	142.3	131.9 ± 14.8	23.3	28.0	25.6 ± 3.36
F. forstenii	5 years	6.66	8.15	7.16 ± 0.85	114.7	158.8	138.2 ± 22.2	25.1	34.0	29.5 ± 4.49
F. pisocarpa	5 years	5.41	7.18	6.24 ± 0.73	128.5	145.9	137.6 ± 7.51	32.6	58.2	44.4 ± 9.57
F. tinctoria	5 years	5.35	6.08	5.80 ±0.40	112.9	149.4	133.9 ± 16.8	28.6	38.7	36.5 ±8.58
F. fistulosa	5 years	4.80	6.69	5.63 ± 0.96	110.0	118.9	114.9 ± 4.54	13.5	26.4	21.5 ± 7.03
F. francisci	5 years	3.15	3.69	3.48 ± 0.21	66.0	115.0	89.3 ± 19.6	28.1	59.3	41.7 ± 11.2
F. crassiramea	5 years	-	4.65	-	-	94.0	-	-	18.9	-
F. cucurbitina	4 years 4 months	6.70	9.55	8.41 ± 1.23	116.1	159.0	143.4 ± 17.2	17.3	69.0	42.7 ± 21.7
F. drupacea	4 years 4 months	6.42	8.22	7.23 ± 0.70	135.5	266.4	174.4 ± 52.8	29.1	75.2	50.7 ± 22.2

F. depressa	4 years 4 months	3.93	7.00	5.32 ± 1.21	90.18	120.1	111.0 ± 12.2	4.45	18.0	12.5 ± 5.34
F. magnolii-folia	3 years 4 months	5.51	8.44	6.69 ± 1.12	122.0	165.5	155.8 ± 25.4	11.3	34.2	24.2 ± 9.43

E. Best performing species in S D Guthrie Segaliud estate after 4 years 8 months (riparian, 1m wide stream, rarely flooded, rarely visited by no macaques, non-woody weeds only, with aggressive Merremia)

Species	Age	Plant Height (m)			Diameter (mm)			Crown Area (m²)		
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
F. variegata	4 years 8 months	11.6	20.0	15.9 ± 3.03	229.2	444.4	321.7 ± 91.6	44.9	158.8	91.5 ± 3.1
F. racemosa	4 years 8 months	13.5	16.4	14.8 ± 1.22	309.2	369.7	342.1 ± 24.5	97.3	169.7	118.4 ±29.3
F. annulata	4 years 8 months	13.3	9.78	11.5 ± 1.25	183.4	353.5	279.9 ±67.9	39.2	134.2	104.2 ±37.9
F. microcarpa	4 years 8 months	7.04	11.9	10.2 ± 1.98	181.3	280.4	238.0 ±38.7	17.5	99.1	63.7 ±33.6
F. benjamina	4 years 5 months	7.65	12.4	9.61 ± 2.29	86.3	269.9	189.7 ±85.3	21.8	183.9	106.8 ±66.9
F. caulocarpa	4 years 5 months	8.46	9.60	9.03 ± 0.81	211.5	235.2	223.4 ±16.8	68.2	87.7	77.9 ±13.8
F. depressa	4 years 2 months	-	8.34	-	-	179.7	-	-	62.8	-
F. tinctoria	4 years 2 months	-	4.32	-	-	163.2	-	-	61.5	-
F. lindsayana	3 years 10 months	9.09	10.9	9.99 ± 1.27	176.6	202.0	189.3 ± 17.9	42.6	76.5	59.5 ±24.0
F. crassiramea	3 years 10 months	7.70	9.32	8.86 ±0.78	137.3	215.1	172.4 ± 34.4	17.9	60.4	46.5 ±24.6
F. pisocarpa	3 years 10 months	4.62	9.10	7.45 ± 2.01	122.9	164.6	147.4 ± 18.0	27.14	69.4	54.2 ±18.8
F. cucurbitina	3 years 10 months	4.79	8.84	7.17 ± 1.51	117.5	184.3	148.1 ± 26.3	34.5	53.7	44.2 ±7.52
F. melinocarpa	3 years 3 months	8.80	13.6	11.4 ± 2.43	136.1	219.6	168.4 ± 44.8	18.4	33.6	27.0 ±7.78

F. magnolii-folia	3 years 3 months	6.20	11.2	8.15 ± 1.85	102.3	214.4	161.3 ± 40.7	3.54	26.6	18.6 ±9.00
F. drupacea	3 years 3 months	5.92	9.80	7.65 ± 2.01	122.9	164.6	147.4 ± 18.0	22.2	62.4	42.7 ±17.1
F. subcordata	3 years 1 month	-	7.44	-	-	115.2	-	-	30.5	-
F. callosa	2 years 1 month	6.52	7.50	7.01 ± 0.41	72.9	119.2	94.2 ± 18.7	5.30	12.8	9.20 ±3.06

F. Best performing species in Genting Layang Estate riparian (riparian, 12m wide river, wetland zone, periodic severe floods, long-tailed macaque damage, under secondary forest)

Species	**Age**	**Plant Height (m)**			**Diameter (mm)**			**Crown Area (m^2)**		
		Min	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
F. racemosa	4 years	8.53	11.3	10.6 ±1.29	187.7	303	241.2 ± 45.9	5.06	11.0	7.32 ±1.86

G. Best performing species in Genting Tanjung Estate (base of steep hill, mixed slopes and waterlogged, under sparse old oil palms & secondary forest, significant macaque damage)

Species	Age	Plant Height (m)			Diameter (mm)			Crown Area (m^2)		
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
Endosper-mum peltatum	3 years 6 months	5.18	11.6	8.61 ±1.98	123.8	264.6	169.0 ± 54.2	12.3	101.1	46.4 ± 34.5
F. variegata	3 years 3 months	5.18	9.14	6.55 ±1.77	116.7	277	176.3 ± 74.8	7.03	24.0	15.0 ± 8.21
F. magnolii-folia	3 years 3 months	3.05	4.88	4.30 ±0.84	58.7	130.4	100.3 ± 33.3	10.1	13.3	11.4 ± 1.48
F. racemosa	3 years	2.29	5.49	4.46 ±1.31	34.0	86.0	63.8 ± 20.1	1.98	18.1	8.84 ± 7.85
Litsea garciae	3 years	2.49	4.18	3.12 ±0.93	55.7	96.9	72.2 ± 21.8	8.07	26.9	16.0 ±9.76
F. melino-carpa	2 years 4 months	-	4.71	-	-	71.8	-	-	10.9	-

H. Best performing species in Sandau Estate (moist, fertile part of land surrounding water supply pond, under sparse secondary forest, significant macaque damage to *F. variegata*)

Species	Age	Plant Height (m)			Diameter (mm)			Crown Area (m^2)		
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
F. racemosa	2 years 9 months	6.10	12.35	8.99 ± 1.21	90.6	251.8	145.8 ± 39.7	9.69	88.3	35.6 ± 16.8
F. variegata		1.61	7.70	4.14 ± 1.58	26.9	212.7	79.3 ± 37.5	3.36	38.7	8.85 ± 9.02
F. benjamina		3.61	4.52	3.91 ± 0.53	58.9	110.7	82.7 ± 26.1	5.66	15.9	9.76 ± 5.41
F. magnolii-folia		1.42	6.13	3.83 ± 2.15	42.9	134.4	79.8 ± 45.8	1.42	23.6	9.47 ± 9.79
F. microcarpa		1.10	5.07	3.77 ± 1.68	33.9	119.6	75.0 ± 37.3	2.79	35.7	17.5 ± 14.9
F. stricta		2.18	4.82	3.28 ± 1.26	46.0	70.7	58.0 ± 12.8	1.82	12.0	5.70 ± 4.45
F. annulata		-	4.66	-	-	125.0	-	-	21.4	-

I. Best performing species in Glenealy estate (well-lit forest edge, well-drained soil)

Species	Age	Plant Height (m)			Diameter (mm)			Crown Area (m^2)		
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
F. drupacea	2 years 5 months	5.18	7.92	6.64 ± 1.17	92.4	191.6	136.5 ± 37.0	20.8	83.5	38.4 ± 25.6
Endospermum peltatum		4.88	10.1	6.59 ± 2.15	65.7	118.9	100.9 ± 21.2	11.8	48.9	28.3 ± 15.9
F. variegata		5.16	7.32	6.52 ± 0.83	102.0	203.4	150.9 ± 41.8	9.75	41.1	27.3 ± 13.6
F. stricta		4.88	6.71	5.73 ± 0.69	81.2	98.7	89.2 ± 6.39	9.77	22.6	13.8 ± 5.15
F. cucurbitina		3.60	7.62	5.39 ± 1.93	62.4	135.3	94.6 ± 34.3	8.66	38.4	21.4 ± 13.6
F. callosa		3.62	6.18	5.19 ± 0.96	48.6	107.7	85.5 ± 22.1	4.17	8.76	6.60 ± 1.68
F. microcarpa		3.62	5.60	4.93 ± 78.7	51.62	97.0	79.6 ± 17.0	8.79	22.9	13.4 ± 5.79
F. benjamina		3.06	6.05	4.82 ± 1.39	65.5	131.4	92.4 ± 26.6	8.22	34.3	16.8 ± 10.8
F. melinocarpa		3.05	5.64	4.39 ± 0.95	73.6	145	120.1 ± 29.7	4.15	24.1	13.7 ± 7.94
F. annulata		3.04	5.20	4.29 ± 0.83	84.2	142.0	107.6 ± 21.3	14.4	17.9	16.1 ± 1.39
F. pisocarpa		2.21	4.88	3.80 ± 0.99	61.6	183.0	105.2 ± 50.6	9.24	19.3	14.0 ± 4.66
F. magnoliifolia		3.43	4.67	3.76 ± 52.7	61.56	152.6	110.6 ± 33.5	5.49	17.8	10.5 ± 5.58
F. lindsayana		2.33	3.22	2.75 ± 0.45	51.2	72.6	60.8 ± 10.8	3.97	8.22	6.77 ± 2.43

Appendix 5. Seedlings height measurements of four *Ficus* species with and without fertigation from planting date to three months

Species	Treatment	Substrate	Height (cm)			
			Initial	Month-1	Month-2	Month-3
F. racemosa	Fertigation	Top Soil (15)	2.0 ± 0.3	5.6 ± 2.3	19.7 ± 3.1**	33.9 ± 9.5**
		Cocopeat (15)	1.8 ± 0.5	15 ± 3.2**	39.2 ± 7.9**	53.9 ± 8.1**
	Conventional	Top Soil (15)	1.9 ± 0.4	4.8 ± 1.7	10.0 ± 2.2	19.0 ± 6.1
		Cocopeat (15)	1.9 ± 0.7	4.2 ± 1.2	8.3 ± 1.9	13.1 ± 4.0
F. albipila	Fertigation	Top Soil (15)	1.7 ± 0.5	6.6 ± 1.9**	24.2 ± 5.8**	75.8 ± 20.3**
		Cocopeat (15)	1.9 ± 0.6	9.75 ± 2.7**	30.6 ± 4.3**	92.2 ± 15.8**
	Conventional	Top Soil (15)	1.9 ± 0.5	4.8 ± 1.9	13.8 ± 5.4	30.0 ± 5.0
		Cocopeat (15)	1.9 ± 0.5	3.6 ± 1.6	9.54 ± 2.0	23.5 ± 5.7
F. nervosa	Fertigation	Top Soil (15)	1.2 ± 0.2	2.7 ± 0.6*	10.6 ± 2.4**	23.1 ± 8.7**
		Cocopeat (15)	1.3 ± 0.3	4.9 ± 1.0**	13.2 ± 4.1**	34.7 ± 9.6**
	Conventional	Top Soil (15)	1.1 ± 0.1	2.3 ± 0.6	6.7 ± 2.2	14.3 ± 3.2
		Cocopeat (15)	1.1 ± 0.3	2.0 ± 0.5	5.8 ± 1.9	12.6 ± 2.6
F. crassir-amea	Fertigation	Top Soil (15)	2.2 ± 0.6	3.6 ± 1.1	8.1 ± 2.7*	21.9 ± 7.3**
		Cocopeat (15)	2.3 ± 0.6	7.1 ± 1.3**	12.6 ± 2.7**	28.6 ± 8.5**
	Conventional	Top Soil (15)	2.2 ± 0.8	3.1 ± 1.1	7.3 ± 1.8	13.3 ± 4.2
		Cocopeat (15)	2.1 ± 0.7	3.0 ± 1.2	4.8 ± 1.3	8.1 ± 2.7

Following well-established findings that wild orangutans are living and reproducing in the mixed oil palm and forest landscape of eastern Sabah, and that a major problem the orangutans face is insufficient food availability, BORA conducted a programme from 2018-2025 to initiate boosting of natural production of orangutan foods on 'set-aside' lands in that landscape. The single most important orangutan food plant genus is the genus *Ficus*, of which there are 150 species in Sabah, ranging from strangling figs and large trees to small trees, climbing plants, epiphytes and bushes. *Ficus* proved to be an ideal plant for nature restoration, with fast growth rates and constant fruit production if several species are planted together. Most technical issues are now resolved, the only major problem being that of how to restore habitat in flood-prone freshwater wetlands. The programme revealed significant supply chain problems in the whole arena of human efforts in nature restoration which, if not addressed, will mean that ongoing nature restoration efforts remain fragmented and of low biological significance. This book describes the technical results of the work, and ends with an analysis of ways in which the various participants can help to boost the effectiveness of nature restoration programmes.

e ISBN 978-629-94462-2-4

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