The Rufford Foundation
Final Report

Congratulations on the completion of your project that was supported by The Rufford Foundation.

We ask all grant recipients to complete a Final Report Form that helps us to gauge the success of our grant giving. The Final Report must be sent in **word format** and not PDF format or any other format. We understand that projects often do not follow the predicted course but knowledge of your experiences is valuable to us and others who may be undertaking similar work. Please be as honest as you can in answering the questions – remember that negative experiences are just as valuable as positive ones if they help others to learn from them.

Please complete the form in English and be as clear and concise as you can. Please note that the information may be edited for clarity. We will ask for further information if required. If you have any other materials produced by the project, particularly a few relevant photographs, please send these to us separately.

Please submit your final report to jane@rufford.org.

Thank you for your help.

Josh Cole, Grants Director

Grant Recipient Details	
Your name	Rajeev Pillay
Project title	Assessing species richness and community composition of mammalian frugivores in Bornean twice-logged rainforests.
RSG reference	12984-2
Reporting period	February 2013 – August 2015
Amount of grant	£6000
Your email address	rajeev.pillay@ufl.edu, rajeev@conservation.in
Date of this report	31st August 2015

1. Please indicate the level of achievement of the project's original objectives and include any relevant comments on factors affecting this.

Objective	Not achieved	Partially achieved	Fully achieved	Comments
Assess the mammalian frugivore assemblage in twice-logged forests in Sabah, Malaysian Borneo				The initial objective of this project was to strategically place camera traps at fruiting trees to assess the mammalian frugivore community. This objective was not achieved because Southeast Asian rainforests follow mast-fruiting cycles in which the dominant dipterocarps (Family Dipterocarpaceae) fruit en masse once every 4-9 years. A large number of the animal-dispersed fruiting species also synchronise their fruiting with the dipterocarps. The first field season in 2013 was not a mast-fruiting year. Nevertheless, partial-fruiting events do occur at infrequent intervals and therefore, I tried to achieve this objective. I located 633 animal-dispersed fruiting trees along belt-transects at various sites of the SAFE Project in 2013. However, only eight of them actually fruited during February-June 2013 (Please refer to Preliminary Report for results from 2013). Camera trap and focal observation data that were obtained from these eight trees were too sparse to enable robust statistical analyses of mammalian frugivore community composition. Therefore, during the 2014 field season (a mast-fruiting year), I shifted the focus of this project to assessing the impact of logging on density- and distance-dependent predation of dipterocarp seeds and seedlings by mammalian frugivores and seed predators. Dipterocarps were chosen because they are the dominant trees in Bornean rainforests and are wind dispersed. However, mammalian frugivores and seed predators are known to play key roles in seedling mortality and survival. Since they are the most abundant of the trees in Borneo, obtaining adequate sample sizes was far easier

				for Dipterocarps than for animal-dispersed species. An Endangered dipterocarp (IUCN Red List), *Dryobalanops lanceolata*, was chosen as the focal species. The objectives of this research are outlined below:
Test whether the seed crops of *Dryobalanops lanceolata* are significantly different in logged and old growth forest				Selective logging tends to remove the largest and most reproductively active adult fruiting trees. The trees left behind are smaller and not as reproductively active as the large trees in old growth. The density of adult trees remaining is also low. After controlling for tree density by sampling an identical number of trees in both old growth and logged forest (n = 7 each), I predicted that trees in old growth forests would produce larger seed crops relative to those in selectively logged forests. I set up seedfall traps along four transects from the base of each tree. Seedfall traps were made of nylon mesh nets and suspended with the help of 1 m PVC pipes at each corner. Seedfall traps were set up at distances of 1, 2, 4, 8, 16 and 32 m along 4 transects each stretching from the base of the tree i.e. 20 traps per tree. Seven individuals of *D. lanceolata* were located in both logged and old growth forest (total 14 individuals). All seeds that fell into the traps were collected at durations of approximately 2 weeks and counted. The prediction for this objective was proved correct based on the observed data (Fig. 1).
Investigate the relationship between seed germination and seedling survival of *Dryobalanops lanceolata* and (1) Conspecific seed density and (2) Distance of seeds from maternal trees (Janzen-Connell effects)				During a mast-fruiting event, conditions in logged forests are expected to be similar to those in old growth forests during a partial fruiting episode (non-mast year). In these partial-fruiting episodes, only a few species fruit and therefore fruiting individuals can be isolated relative to each other. Seed predators could therefore be disproportionately attracted to these isolated fruiting trees, leading to an increased per-capita mortality of seeds dispersed close to parent trees relative to those far away. In contrast, predator satiation should be operating in old growth forest during a mast

				year since the massive influx of seeds in a short period of time is hypothesised to have evolved to satiate seed predators. Many seeds may escape predation during peak seedfall and subsequently establish. Predator satiation decreases mortality at the highest densities, directly opposing Janzen-Connell predictions. 1 m by 1 m seed plots were set up paired with each seedfall trap at a distance from 2 m from the traps along each of the four transects. Seeds that naturally fell into the plots were monitored over the duration of the mast event at the same time as the seedfall traps. Each seed was marked with a plastic tag stapled to the wings. Seeds that were alive at the time of monitoring were additionally marked with a number on the plastic tag to enable monitoring their fate at intervals of two-weeks. For each seed, data on the mortality agent (e.g. fungal pathogen, insect, rodent, bearded pigs) were obtained by careful examination (e.g. entry and exit holes for insect predation, gnaw marks for rodent predation, edible seed removed and only wings remaining for bearded pig predation). Camera traps were also set up at a subset of the plots to document the large vertebrates that fed on the seeds. Seed germination and seedling growth was monitored for 3 months from the initial seedfall. This is regarded as the most vulnerable phase in the life history of a plant. The results (Fig. 2) show that patterns of seedling mortality in old growth conform to the predator satiation hypothesis. However, patterns in the logged forest are contrary to the leptokurtic curve that is expected when predator satiation may not operate.
Investigate whether seedling recruitment in a mast-fruiting year is restricted to old growth forests				Prior studies have found that trees with large seed crops have been found to have higher seed and seedling survival. Old growth forests have more trees with large seed crops since the trees in general are much larger. I predicted that recruitment, even in a mast

				year, might be largely contained to old growth forests. The results show that there is no significant difference in recruitment rates between logged and old growth forest (Fig. 3a). However, careful examination shows that recruitment in logged forests is restricted to sites where the logging intensity was low (Fig. 3b).
Investigate the role of vertebrates relative to invertebrates and fungal pathogens in seed predation and seedling mortality				Host-specific pathogens and invertebrate pests have been found to be the primary agents driving rainforest plant diversity via NDD and Janzen-Connell effects. However, prior work shows that both native and invasive rodents have been found to increase in abundance in logged Bornean forests. These rodent species are known to be predators of dipterocarp seeds. I predicted that rodents may play a major role as seed predators in logged forests relative to invertebrate pests and fungal pathogens. Beside monitoring seed plots and collecting data on the mortality agent for every seed with observations and camera traps, I also set up paired exclosure experiments to test whether excluding rodents higher seed germination rates. The results show that this prediction bears out. Fig. 4 shows that invertebrates and fungal pathogens are the major mortality agents for seeds in old growth although bearded pigs depredated a large number of the remaining seeds in old growth forests at the tail-end of the mast-fruiting event. In Fig. 5, it is clear that despite the effect of pigs in old growth, invertebrates and fungi still dominate as mortality agents. This confirms studies from other tropical forests around the world. However, Fig. 5 shows that logging causes invertebrates and fungi to decrease in importance as seed predators while vertebrates (rodents) are playing a much bigger role. This is a critical and novel result showing that a key ecosystem function remains intact but the agents mediating the function change due to

				logging.

2. Please explain any unforeseen difficulties that arose during the project and how these were tackled (if relevant).

Funding was received from RSGF in January 2013. Fieldwork commenced in February 2013. The fact that South-East Asian rainforests operate on mast-fruiting cycles that occur at intervals ranging between 4-9 years, made it quite challenging to locate adequate numbers of fruiting trees that were actually in fruit and subsequently, start focal animal observation and camera trapping at these trees. Although 633 animal dispersed fruiting trees were located along belt-transects throughout the field sites of the SAFE Project, only eight individuals fruited during the period February-June 2013. Camera traps were set up at these trees to identify the mammalian frugivores that came to feed on fallen fruit. Early morning focal observations were also carried out at these trees to quantify the avian and arboreal mammal fruiting community. However, sample sizes obtained from these eight individual trees were too low to enable meaningful statistical analyses.

I therefore shifted the focus of my project slightly too wind-dispersed dipterocarps and the impact of logging on the Janzen-Connell mechanism, mediated by mammalian frugivores and seed predators. Dipterocarps (Family Dipterocarpaceae) are the dominant trees in South-East Asian rainforests. The Janzen-Connell mechanism postulates that specialized natural enemies maintain tree species diversity via two interacting mechanisms: (1) inhibiting regeneration near parent trees where seed and seedling density is high (density effect) and, (2) causing higher mortality of seeds and seedlings near the parent tree than far away (distance effect). This local negative density-dependence (NDD) confers an advantage to locally rare species and increases the probability of establishment of heterospecifics.

A mass-flowering event occurred between January-July 2014 and this was followed by a mast-fruiting event from July-November 2014. During the mass flowering event, I located various dipterocarp species in both twice-logged and old growth forest and identified a suitable species that would be sufficiently abundant at both logged and old growth sites to collect adequate samples. *Dryobalanops lanceolata*, an endangered dipterocarp endemic to the island of Borneo, was chosen as the focal species. Data collection on seed fall rates in both forest types, seedling emergence, seedling survival, the seed predators of this species and the importance of each type of seed predator was carried out from July-November 2014.

3. Briefly describe the three most important outcomes of your project.

a. Seedfall Rates

The results of this study indicate that trees in logged forest are producing significantly less seeds than those in old growth or primary forest (Fig. 2). There are several causal factors. Selective logging removes the largest and most economically valuable trees. *Dryobalanops lanceolata* is a prized timber species and has been classified as Endangered in the IUCN Red

List due to the fact that it is very rare now outside protected areas. The remaining trees in logged forest are therefore, small and not at peak reproductive maturity. They are also shorter than those in old growth forest and have smaller crown diameter. More importantly, since there is a very low density of conspecific adults in logged forest, cross-pollination is probably affected. The seeds produced in logged forest are therefore probably not as viable as those in old growth. The results indicate that very few seeds reach to a distance of 32 m in logged forest. The number of seeds produced is also significantly lower in logged forest.

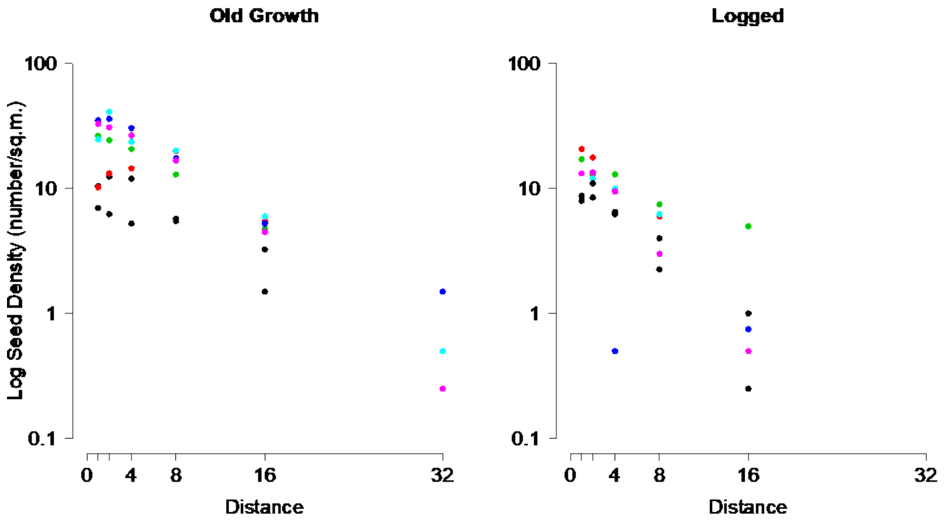

Fig. 1: Mean seedfall at each distance for each tree in old growth and twice-logged forest. The seed crop in logged forest is around half than in old growth for the same number of trees (n = 7 trees were sampled in each forest type). No seeds reach 32 m in logged forest. This is because trees in logged forest were significantly smaller, shorter and had significantly lower crown diameter than the trees in old growth forest.

b. Seedling Mortality Rates as a function of distance from the parent tree

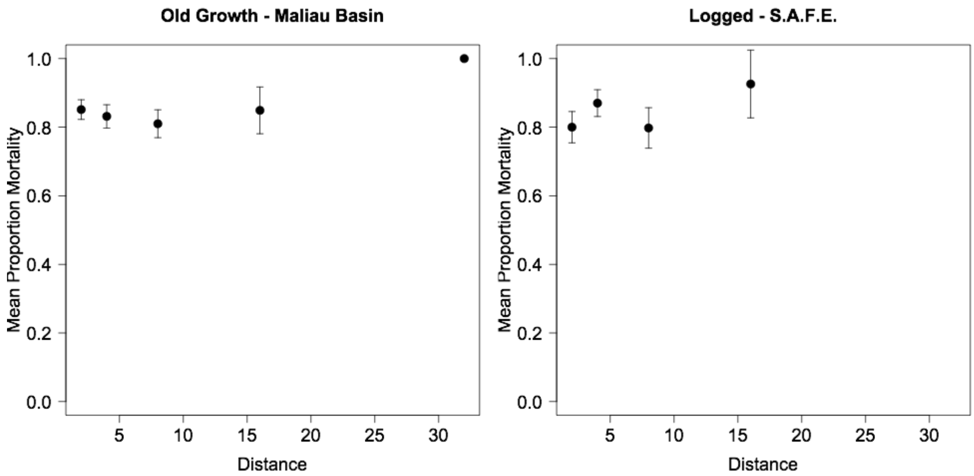

Fig. 2: The forest floor in old growth forest is swamped with so many seeds that the distance to the parent tree does not matter with respect to seed mortality. This matches the predator satiation hypothesis where a large number of seeds will satiate seed predators. However the pattern in logged forest is contrary to the leptokurtic curve that may be expected when predator satiation will not operate.

c. Seedling Survival Rates in Old-Growth and Logged

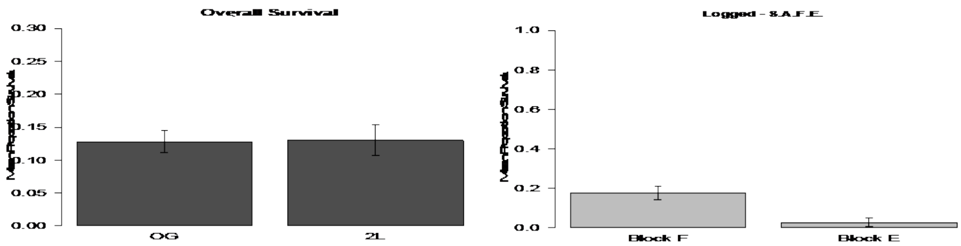

Fig 3a, b: At the end of 3 months, the seed-to-seedling transition period considered as the most vulnerable in the life cycle of a plant, there is no significant difference in survival rates between old growth and logged (Fig. 3a). However, a closer look at the underlying spatial distribution of seedlings reveals that most surviving seedlings are in forest Block F, than Block E, where only 7 seedlings survived at the end of three months (Fig. 3b). Block F has undergone low intensity logging in the past and is therefore much better in terms of forest quality and canopy cover than Block E, which has undergone high intensity logging.

d. Seed and seedling mortality by vertebrates relative to invertebrates and fungal pathogens

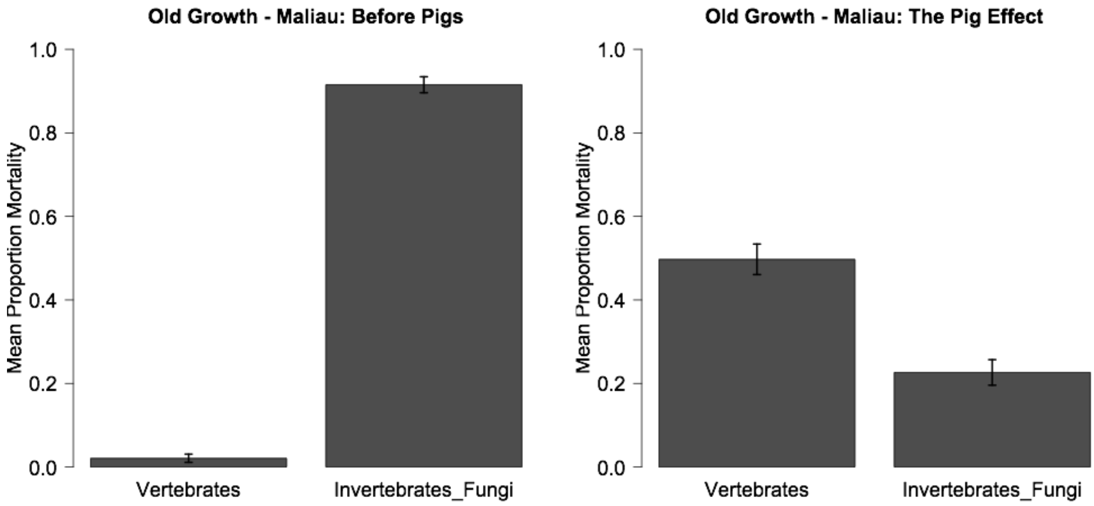

Fig. 4: From July 2014 up to the first week of Oct, the overwhelming majority of seed predation in old growth was by invertebrates and fungal pathogens. Around mid-Oct, at the tail end of the seedfall, bearded pigs depredated a major proportion of the remaining seeds and seedlings in OG.

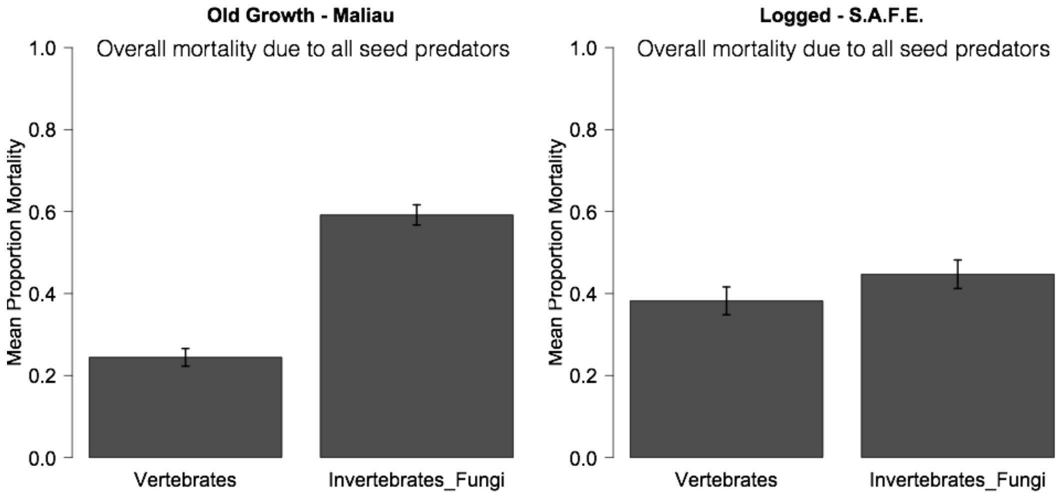

Fig. 5: Despite the depredation by bearded pigs, invertebrates and fungi remain the major agents driving negative density dependence in OG. In contrast, in logged forest, the role of invertebrates and fungi is significantly reduced, while that of rodents is significantly higher. Seed predation and seedling mortality by bearded pigs was negligible at SAFE.

4. Briefly describe the involvement of local communities and how they have benefitted from the project (if relevant).

During this study, local communities per se were not involved. However, data collection was carried out with the assistance of local field assistants. One of the assistants was skilled in the identification of plants and was therefore a great asset to the project. The second assistant was trained in plant identification and other aspects of data collection during the course of the fieldwork. Both assistants were trained in camera-trapping for seed predators that came to visit the fruiting trees.

5. Are there any plans to continue this work?

The SAFE Project currently has a few other ongoing projects that are examining dipterocarp seedling survival along a logging gradient. I expect my work to be the first study from this project that rigorously examines two critical ecological processes, the Janzen-Connell mechanism and the predator satiation hypothesis, and tests the impact of logging on these processes during a mast-fruiting year. During this study, I was able to focus on only one species due to manpower constraints. I plan to work on several more species during future mast-fruiting events and test whether the results of this study can be extrapolated to other species in the tree community.

6. How do you plan to share the results of your work with others?

This work is part of my PhD dissertation. I am in the process of writing up the results for publication in peer-reviewed journals. I will also submit reports to local and regional authorities in Sabah, such as the Sabah Biodiversity Council, Yayasan Sabah, Maliau Basin Management Committee and Sime Darby. After submission of the reports and journal article, I will also try to publish this in the popular media for wider dissemination to the general public. This can be in the form of a magazine article, newspaper article, a blog or a combination of all of these.

7. Timescale: Over what period was The Rufford Foundation grant used? How does this compare to the anticipated or actual length of the project?

The funds were used from February 2013 – November 2014. The timescale of the project was slightly longer than anticipated due to the fact that mast-fruiting occurred in mid 2014 and not 2013 as had been anticipated. The timetable in the original proposal was to complete the final report by December 2014. However, since I returned from fieldwork in December 2014, I requested an extension to submit my final report until August 2015.

8. Budget: Please provide a breakdown of budgeted versus actual expenditure and the reasons for any differences. All figures should be in £ sterling, indicating the local exchange rate used.

Item	Budgeted Amount	Actual Amount	Difference	Comments
Digital camera traps	3000	3538	+ 538	26 Bushnell Trophy Cam HD camera traps were purchased instead of 20 as originally budgeted to try to cover as many fruiting trees as possible.
Consumables (batteries, SD cards, etc. for camera traps)	0	1381	+1381	Batteries, SD cards and bungee cords were purchased to operate and secure the camera traps in the field.
Vehicle hiring charges (£9/day * 180 days)	1620	0	-1620	It was anticipated that the RSG would be used for vehicle hiring charges. However, another grant was received immediately after the RSG and covered vehicle hiring charges.
Per diem and wages for field assistants (£7.67/day * 180 days)	1380	781	-599	Part of field assistant wages were also covered by a grant from the University of Florida.
Hardware for constructing seedfall traps, steel mesh exclosures and marking seed plots (nylon mesh, PVC pipes, nails, steel wire mesh, paint, marking tape, etc.)	0	300	+300	The ability to cover expenses for vehicle and field assistant wages from another grant allowed covering unanticipated expenses for the dipterocarp seed predation experiments with the Rufford grant.
Total	6000	**6000**		

Exchange rate of £1 Sterling = 4.91 MYR (2013)

9. Looking ahead, what do you feel are the important next steps?

Southeast Asian forests are arguably among the most imperilled in the world due to selective logging and clear-felling of forests for oil palm agriculture. The results of this study appear to indicate that the intensity of logging can play a key role in determining the survival rate of seedlings of major tropical trees. The maintenance of tree species diversity in tropical forests is key to their conservation. Therefore, an important next step would be to try and determine whether the patterns observed in this study can be extended to other species as well.

Given that South-east Asian rainforests operate on intermittent mast-fruiting cycles, it would be of great ecological and conservation interest to determine dietary changes in mammalian and avian frugivores during mast-fruiting events and in the intervening lean (non-fruiting) years. Do frugivores move over large spatial scales to track fruit? Are frugivores truly obligate frugivores or do they supplement their diet with other sources of food and only feed on fruit opportunistically. Answering these kinds of questions will require the tracking of movements of frugivores and in-depth monitoring of their diets. These are exciting new frontiers with ample opportunities for research in the future.

10. Did you use The Rufford Foundation logo in any materials produced in relation to this project? Did the RSGF receive any publicity during the course of your work?

I have not yet used the RSGF logo on any materials. However, I intend to use the logo on my presentation for my PhD defence and on any future presentations on this project. All reports will also carry the RSGF logo and RSGF will be duly acknowledged in all publications and reports.