The impact of the Mauritius Fruit Bat (*Pteropus niger*) on commercial fruit farms and possible mitigation measures.

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Background

The Mauritian Fruit Bat (*Pteropus niger*) is a medium size fruit bat with an average weight of adult female of 473g (Nyhagen*et al*., 2005). It is endemic to Mascarene Islands and was once found throughout the archipelago, however now found only on the island of Mauritius as the result of habitat destruction and hunting (Cheke and Dahl, 1981).

Mauritius has retained only 2% of its good quality native vegetation cover and lost 46% of its native vertebrate fauna (Safford, 2001). Remaining wildlife is strongly associated with native vegetation which is invaded by exotic species. At least 47 species are highly invasive and cause native habitat degradation. Additionally, numerous exotic animal species cause destruction to native plants, their fruits or seeds, and also spread invasive plant species (Safford, 2001).

Bats were the only mammals to naturally colonise the Mascarenes and as a consequence it is likely that the Mauritius Fruit Bat, as the only extant frugivorous mammal, plays an important role in the regeneration of the islands' native flora. A study on the foraging ecology of this bat recorded 22 food plant species in the diet (of which 32% were endemic). It suggests that these bats are important seed dispersers for several endemic/native plant species and are probably also involved in the pollination of some of them (Nyhagen, 2001, Nyhagen *et al*., 2005). For example the endemic forest canopy tree bois de natte (*Labourdonnaisia glauca)* shows adaptations to, and possibly a dependence on, seed dispersal by bats as these are the only native vertebrates feeding on this tree. There is a paucity of data on the habitat use and movement patterns of *P. niger*, so the ecosystem function of this species has not been adequately assessed.

The population of these bats has increased during the last decade and there are increasing claims that it is doing considerable damage to the commercial fruit crops and in particular to the litchi and mango crops. The fruit bats are estimated by the fruit growers to eat 50,000kg of litchis per annum and that this damage is increasing at a rate of 10% annually. The Mauritian Wildlife Foundation is involved in fruit bats studies and is uniquely placed to study and advice on this problem e.g. hosted and supervised an MSc study on the feeding ecology of the Mauritius Fruit Bat (Nyhagen, 2001), an MSc on the distribution and population size of the Mauritius Fruit Bat (Robin, 2007), and three MSc studies on the Rodrigues Fruit Bat (*Pteropus rodricensis)*, and have supervised and provided data for a PhD study on the population biology, feeding ecology and conservation of the Rodrigues fruit bat (Powell, 2004), and a BSc study on fruit bat predation in a litchi orchard (Ramlugun, 2013) and a proposed study on human perceptions of the fruit bat.

At present, the species is viewed as a common pest, having been implicated in crop damage by fruit farmers and back yard fruit growers. Fruit growers have been lobbying the Mauritian Government since 2002 (D. Sarjua, in litt. to Ministry of Agriculture, 18 Dec. 2002, copied to MWF) to remove *P. niger* from the protected species list so that the species may be legally controlled in orchards. The damage caused by these bats (and/or other animals) to exotic fruit crops needs to be assessed in order to mitigate conflict between fruit farmers and back yard fruit growers and the bats. Other potential commercial fruit crop predators include rats *Rattus rattus*, Common Mynah Birds *Acridotheres tristis*, Red-whiskered Bulbuls *Pycnonotus jocosus* and Ring-necked Parakeets *Psittacula eques*.

The commercial fruiting season in Mauritius runs mainly from October to December. This is the end of the dry season when there may be a lack of fruit in the forest forcing the bats to look elsewhere for food. In the study of the foraging ecology of the Mauritius Fruit Bat, Nyhagen (2001) suggested that damage to unripe fruit by introduced Long-tailed Crab-eating Macaques *Macaca fascicularis* may further limit the fruit available to bats and other endemic species, particularly during periods of shortage.

The effective long-term conservation of wildlife requires the support of the people who experience the direct impacts of the presence of the wildlife and its management (Gillingham and Lee, 2003). An understanding of the relationship between a species and the human population with which it comes into contact is therefore crucial to the design and implementation of projects seeking to promote conservation with development (Gillingham and Lee, 2003).

The species' sensitivity to habitat change, Red List conservation status (Vulnerable) and role in forest regeneration makes it important to consider the ecological and habitat requirements of *P. niger* when formulating management decisions (Granek, 2002). However, the species' status, diet, range, ecosystem function and habitat preferences must be identified in order for informed and sustainable conservation and management decisions about the species to be made (Kalko, 1997; Granek, 2002).

Aims

This project aimed to:

- Clarify the actual impact Mauritius fruit bats has on the commercial fruit plantations in Mauritius through detailed GPS tracking of the bats and monitoring of the orchards/fruit plantations in order to identifying other potential fruit pest.
- Provide valuable information about bats' habitat preferences (through compositional analysis), home ranges, seasonal movements and important feeding, breeding and roosting sites.
- Clarify the role *P. niger* plays in Mauritian ecosystem through faeces analysis for presence of seeds and pollen to indicate importance of bats in seed dispersal and plant pollination.

Results

Mango orchard

Between October 2014 and January 2015 Labourdonnaise mango orchards in the north of Mauritius was monitored. Twenty flowering trees were randomly selected and number of developing fruits on 20 panicles per tree was assessed weekly.

Since mango do not flower simultaneously, those trees which were already in fruits were assessed daily. Firstly height of the tree was estimated along with the number of fruits using tally counters, the tree was marked and then number of fallen fruits recorded daily. The fruits were divided into three categories: damaged by bats, damaged by birds and fallen due to natural causes i.e. over-fruiting, wind or overripe. The height of the trees were divided into two categories small tree (6m and below) and big trees (over 6m).

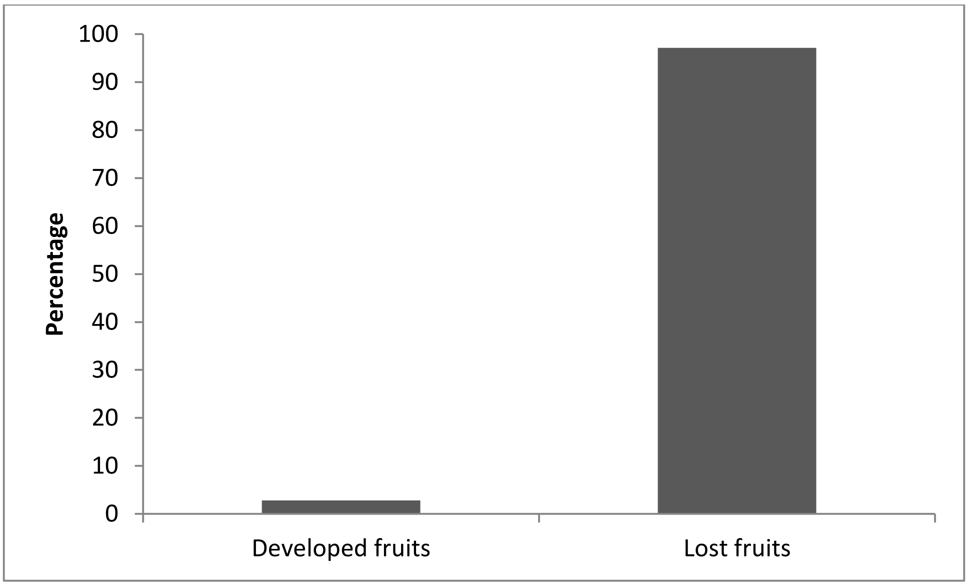

Figure 1. Percentage of developed and lost mango fruits

The results showed that on average 97% of developing fruits on a panicle are lost before they reach maturity (Fig.1). The remaining 3% of fruits accounts for around 510 (± 192 SD) mango fruits per tree.

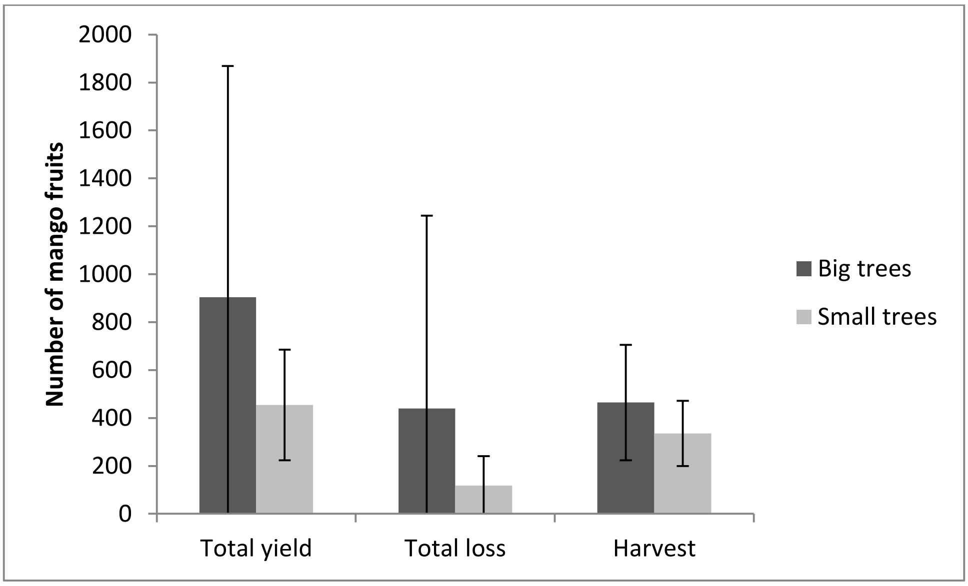

Figure 2. Average yield of mango fruits on small and large trees with total loss and harvestable fruits within the total yield. Bars indicate SD.

The total yield (Fig. 2)of big trees was around 904 fruits (± 964 SD) and small trees was of 453 fruits (±230 SD). From those fruits around 32% (± 21 SD) was lost on big trees and 23% (± 14 SD) on small trees due to animal and natural damage. The total number of fruits ready to harvest was 465 (±241 SD)on big trees and 335 (±136 SD)on small trees.

When looking at the damaged fruits (Fig. 3) bats account for around 11.39% (± 8.22 SD) of the damage on big trees and 2.65% (±3.71 SD) on small trees while birds are responsible for 0.84% (±1.11 SD) on big trees and 8.12% (±6.09 SD) on small trees. The majority of fruits on both big and small trees were lost due to natural causes (19.51% ± 20.72 SD and 12.65% ± 10.69 SD respectively).

To analyse the difference in fruit damage between big and small trees and each of the culprits, two-way ANOVA was performed. The data was *Ln* transformed to get equal error variances (Levene's Test F= 0.713; $P_{5,120}$= 0.615). The results reviled that there was no significant difference in total fruit damage between small and big trees (F= 1.703; df= 1; P= 0.194), however there was significant difference in the number of fruits damaged by bats and birds (F= 17.34; df= 2; P< 0.001). Furthermore, each of the culprits had significantly different effect on both small and big trees (F=25.552; df= 2; P< 0.001). The bats caused significantly more damage on the bigger trees (F=30.164; df= 40; P<0.001) while birds damaged significantly more fruits on small trees (F=30.646; df=37; P<0.001). The number fruits which fall down due to abiotical causes like wind, over-fruiting or over-ripening did not differ significantly between small and big trees (F= 4.054, df=43, P= 0.05).

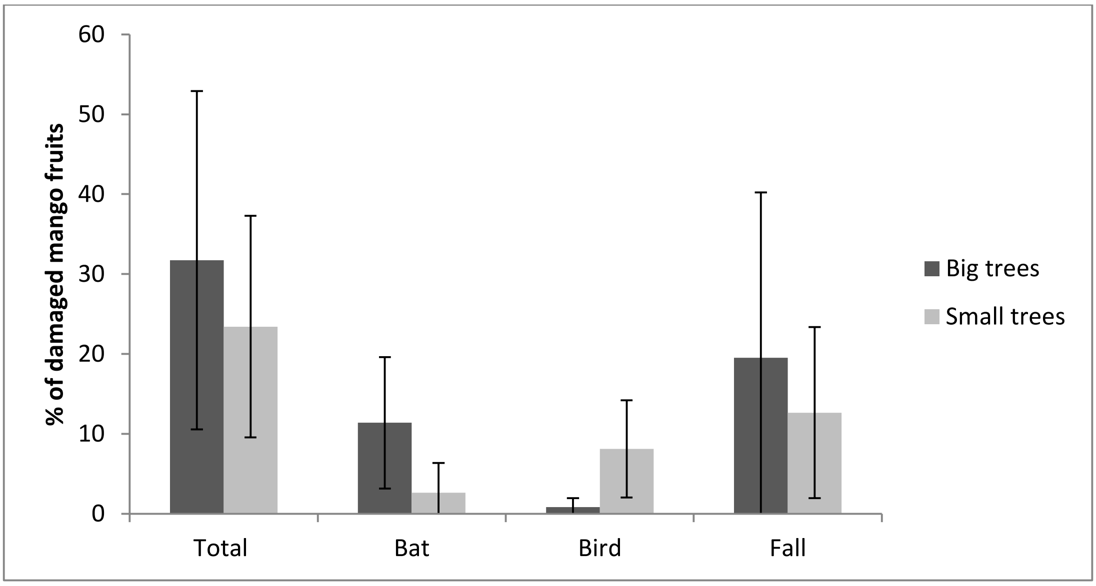

Figure 3. Percentage of the damage caused to mango fruits represented as a total loss and divided into loss caused by bats, birds and natural fall of the fruits. Bars represent SD.

Litchi Orchard

Between December 2014 and January 2015 Medine litchi orchard was visited and number of damaged fruits on 20 randomly selected trees was assessed. All the litchi trees at Medine were of similar size- 4-6m.

Similarly to the methods used to assess mango orchards, the selected litchi trees had number of panicles and average number of fruits per panicle estimated. Since all there trees were at the stage of harvest, the number of empty panicles at the top of the tree was counted. It was assumed that all the fruits from the upper panicles were eaten by bats. Thus, the average number of fruits per panicle was multiplied by number of empty panicles to estimate the damage bats made up to the date of orchard assessment. This calculation did not take into account the number of fruits damaged by birds.

Additionally, the number of intact fruits fallen down was counted, number of harvestable fruits on the trees (i.e. intact fruits with no discoloration or damage to the fruit skin) and number of fruits damaged on the tree (i.e. fruits which skin broke up sure to over-ripening or sun; fruits with discoloured skin).

On average, a litchi tree produce around 16.89 (± 3.42 SD) fruits per panicle and in total can support 4245 (± 1773 SD) fruits. At the time of assessment (Fig. 4), on average each tree lost 16.19% (± 5.3 SD) of fruits which fallen on the ground due to over-ripening while further 13.08% (± 7.84 SD) of fruits which were still on the tree were not suitable for the market due to discolouration or breaks in the skin. The bats contributed to around 9.25% (± 2.6 SD) of damage, given that all the empty panicles at the top of the tree were the cause of bat predation. Therefore, 61.49% (± 12.12 SD) of fruits produced by the tree was marketable and ready to harvest.

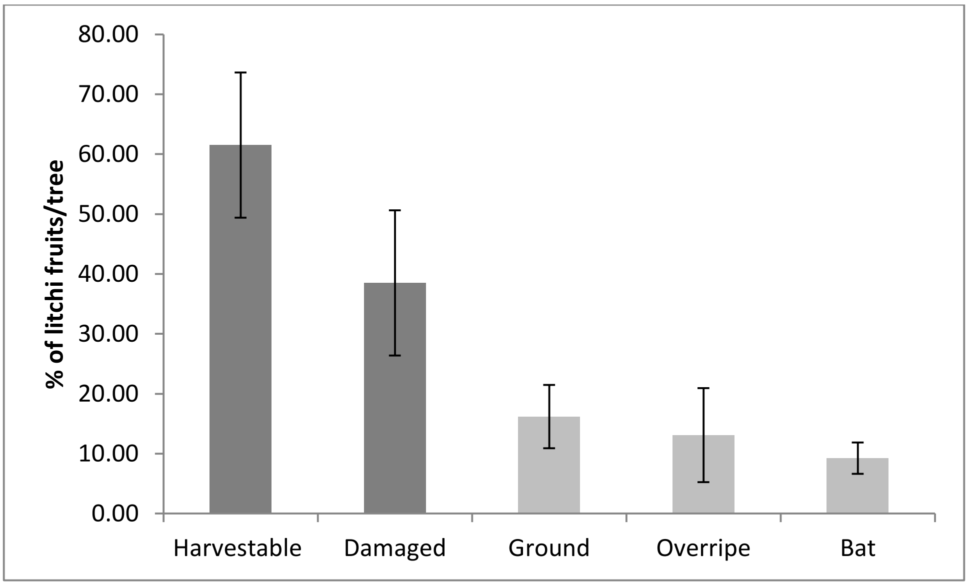

Figure 4. Percentage of harvestable and damaged litchi fruits. The damage is divided into fruits fallen on the ground, overripe on the tree and eaten by bats. Bars represent SD.

GPS data

Between December 2014 and April 2015 six bats (3 males and 3 females) were tagged with custom-made GPS/GSM devices (Microwave Telemetry, US). The devices were solar powered and able to record fixes every 30min-1h (depending on solar conditions during the day). The tags were equipped with Emtel mobile simcards and able to transfer the collected data every 24h directly to an email address using the mobile services. The data then could be viewed on Google Earth software which is freely available.

First bat (male) was caught in Medine litchi orchard, followed by two males caught in Pamplemousses area, the fourth bat (female) was caught in Blue Bay followed by females caught at Ferney and near Flacq.

The project is providing ground-breaking data about bat movements over a long period of time (Fig. 5). This is the first study to monitor fruit bats in such details and over long period of time. Three bats returned fixes over more than 4 months. The saturated mobile phone coverage in Mauritius, and the roosting of the bats in sunlit conditions means that data can be returned at high spatial and temporal resolution over long time periods; no other known studies where such long-term, high resolution data have been obtained for bats. So far it is clear that the bats are ranging over much of the island, roosting mainly in isolated forest fragments that suffer little disturbance, and feed in a range of sites including fruit trees in gardens, natural forest fragments and orchards. Bats occasionally move > 40 km in a night, and may revisit the same feeding site over several weeks. So far over 12 roost sites have been identified based on GPS data of 6 bats. Although the feeding site data have yet to be analysed, it is clear that the bats are spending a considerable amount of time foraging at sites other than fruit plantations, though repeated visits to specific orchards do sometimes occur. It is therefore essential to continue to monitor the movements of bats during the next commercial fruiting season and compare the results to none-fruiting season.

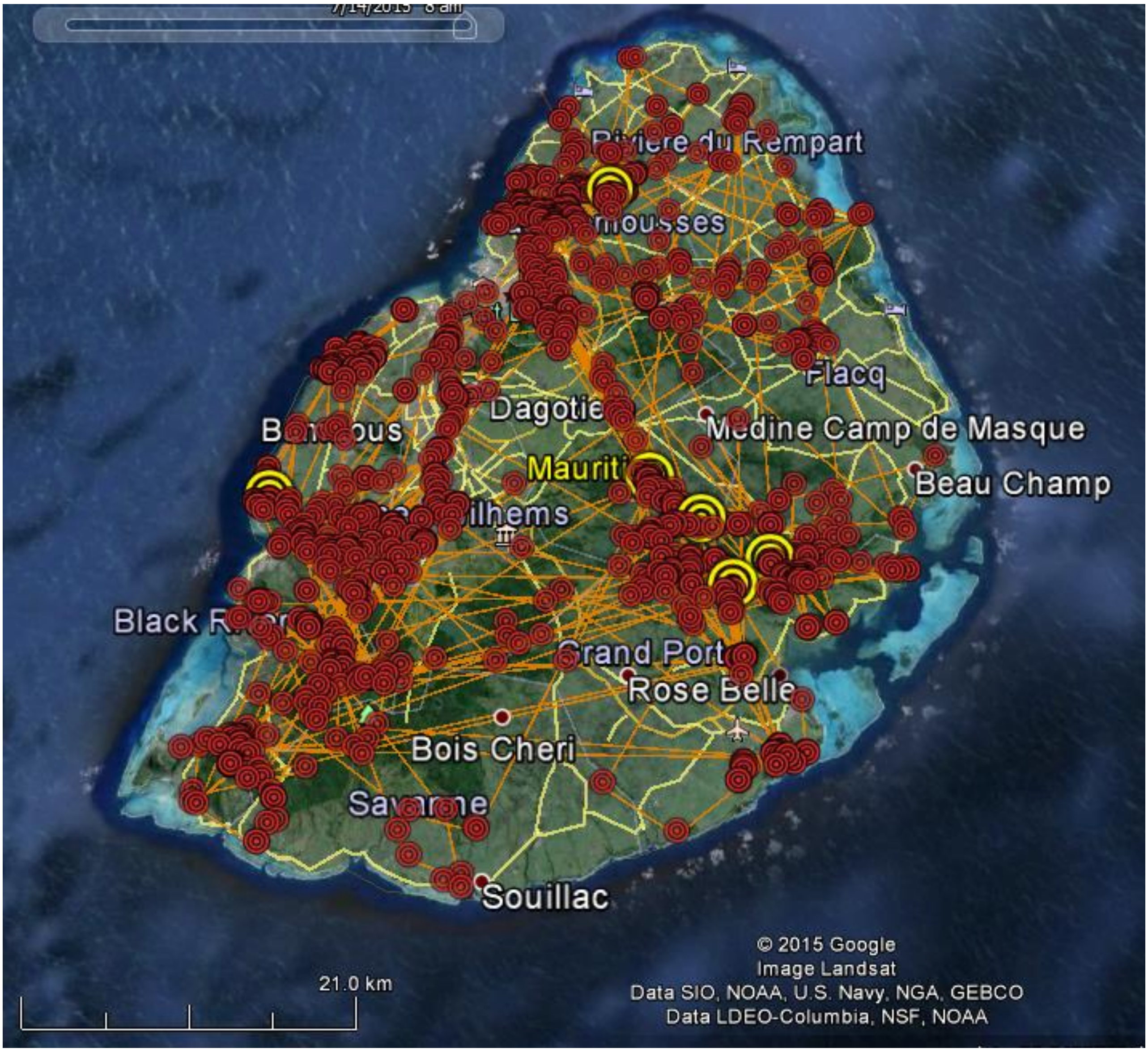

Figure 5. GPS tracks of 6 tagged bats between December 2014 and June 2015 projected in Google Earth software. The red dots represent fixes taken and yellow dots represent roosting place.

The movement data (Fig. 5) shows that only six bats can cover almost the whole island. Most of the time between December and March the bat movements were concentrated on the western coast of Mauritius while around March-April the bats moved towards eastern part of the island. The data clearly shows that the bats have no define home ranges and moves freely around the whole island. They change the roosts quite often, sometimes on a daily basis.

In terms of food availability so far, bats have been found to feed to a greater extent on Indian almond (*Terminalia catappa*) and tamarind fruits (*Tamarindus indica*) all over the year. Additionally, introduced *Ficus religiosa*, *F. microcarpa*, *F. elastica* and native *F. reflexa* are eaten when available. Since *Ficus* spp. do not fruit simultaneously and have no defined fruiting season (one tree may produce fruits several times over a year) these species are the major food source of bats during the winter.

Immediately after the main fruiting season of commercial fruits, in February and May bats were found to feed on *Syzygium* spp. (*S. jambos* and *S. cumini*), guava (*Psidium cattleianum* var. *littorale* and var. *lucidum*) and monkey apple (*Mimusops coriacea*). In June for the first time bats were observed to feed on fruits and leaves of endemic *Foetidia mauritiana* and *Ludia mauritiana* at Yemen, near Tamarin.

Seed germination experiments

To investigate the role of bats in forest regeneration, bat faces were collected from under the feeding trees of bats along with spat-out pellets (ejecta) and adequate fresh fruits. The seeds were extracted from the samples and dried. So far seeds of *F. elastica*, *F. microcarpa* and *F. reflexa* were collected. The seeds were sown in Petri dishes (90 mm) on a filter paper (90 mm). Each treatment (seeds extracted from faeces, seeds from spat-out pellets and seeds from fresh fruits) was replicated 15 times with 20 seeds in each Petri dish. All dishes were moisten with 5 ml of water and kept outside in a semi-shaded conditions to prevent overheating and excessive water evaporation. The seeds where checked weekly to monitor germination. Once no more seeds germinated within a week the experiment was thought to be finished.

F. microcarpa

Seed extracted from faeces had the highest germination success with a mean of 5.67 (± 3.6 SD) followed by seeds extracted from spat-out pellets (2.07 ± 1.28 SD) and seeds extracted from fresh fruits (0.47 ± 0.92 SD).

The data was analysed using one-way ANOVA. The data was *Sqrt* transformed to get normal distribution (Levene's Test F= 2.378; df= 2, 42; P= 0.105). The results showed that there was significant difference in germination between the seed types (F= 27.305; df= 2; P< 0.001).

***F. robusta* (*elastica*)**

Seed extracted from faeces achieved the highest germination with a mean of 7.87 (± 2.9 SD), while seeds from spat-out pellets and ripe fruits had lower germination susses (3.07 ± 1.49 SD and 3.67 ± 1.84 SD respectively).

The data was analysed using one-way ANOVA and was *Sqrt* transformed to achieve normal distribution (Levene's Test F= 0.809; df= 2, 42; P= 0.452). The results showed that there was a significant difference in germination success between seed types (F= 21.568; df= 2; P< 0.001).

F. reflexa

The data included germination of seeds from faeces and fresh fruits as insufficient number of pellets was collected. The highest germination was achieved by seeds extracted from bat faeces (8.13 ± 2.59 SD) while seed extracted from fresh fruits had germination success of 3.07 (± 2.07 SD).

The data was analysed using one sample T-test and showed that there was a significant difference in germination success between seed types (df= 14; P< 0.001).

Food preferences

The initial study of bat food preferences was done at the Black River aviaries. Three captive bats were placed in separate flying cages and exposed to different fruits. The cages were monitored using CCTV cameras. On the first night bats were offered guava (*Psidium cattleianum*), tamarind (*Tamarindus indica*) and monkey apples (*Mimusops coriacea*) while on the second night they were fed *F. elastica,* guava *Psidium guajava* and *Spondias dulcis*. The bat preferred guava on the first experiment and then moved to monkey apples. On the second night they ate figs and guava at first. Another set of experiment included mango (*Mangifera* spp.), Indian almond (*Terminalia catappa*) and *Foetidia mauritiana* fruits. One bat start feeding on *F. mauritiana* and moved to Indian almond. After eating two fruits it started to feed on mango. Another two bats started to eat Indian almonds and then mango. In all three cages all of 10 Indian almond fruits had removed flesh while mango was only partially eaten. *Foetidia mauritiana* was not eaten apart from a couple of fruits indicating that during winter (when fruits are scarce) the animals are forced to feed on the tree to survive, as found in Yemen. Thus the tree is an alternative food source if nothing else is available. The last experiment exposed bats to papaya, mango and Indian almond where papaya was the most preferred followed by Indian almond and mango.

The study indicates that Indian almond is an important non-commercial food source for Mauritian fruit bat and it seems to be selected over other fruits. Due to scarcity of mango at this time of the year it is difficult to conduct more experiments including the fruit however it is planned to conduct more extensive study in September 2015 where both ripe and unripe mango fruits will be present along with other bat-eaten fruits e.g. *Diospyros tesselaria* which is known to be eaten in the wild.

Discussion

Orchard data

The orchard data indicated that there is a clear difference between bat damage caused to large and smaller fruit trees. The bats are more likely to feed on trees over 6m tall while occasionally will attack trees under 6m. It is therefore essential to trim the trees in orchards and keep them relatively low. However, when looking at the damage caused by birds it has been shown that birds are more likely to feed on lower trees in orchards. The orchards provide a perfect breeding and feeding grounds for birds like introduces red-whiskered bulbuls (*Pycnonotus jocosus*) and common myna (*Acridotheres tristis*). Those animals commonly feed on variety of commercial fruits and the damage they cause to the fruits is associated with bats. The orchard surveys will be repeated in the coming 2015/2016 fruiting season where more orchards will be assessed and damage between bats and birds compared with more emphasis placed on litchi plantations. Additionally, mitigation methods will be tested to deter both bats and birds.

GPS data

The GPS data clearly show that *P. niger* have no natural boundaries in Mauritius and thus the whole island should be taken as its home range. The bats are able to move ca. 40 km during one night of feeding and can change roosting sites on a daily basis. Apart from permanent roosts which are often narrowed to the forested area and steep mountain slopes the bats roost in river valleys and forest remnants all over the island. The movement behaviour of the bats makes it very difficult to estimate the population number as it would be essential to count of the roosts at once which is logistically impossible.

Flying foxes are known to travel long distances, often within more than 10 km from their roost to the feeding sites (Corlett, 2009). However, the distances vary depending on species and their habitat. In the Northern Territory of Australia, *P. alecto* travelled between 15.5 km and 20 km a night (assuming straight line between hourly fixes) (Palmer and Woinarski, 1999) while in Queensland the distance was between 5 km and 15 km (Marcus and Hall, 2004). Similarly, *P. poliocephalus* had a feeding range of 25 km in Lismore while in Sydney it was 17 km (Spencer et al., 1991). In mainland Africa, *Eidolon helvum* foraged 59 km away from the roosting site in a single evening (Richter and Cumming, 2008). In American Samoa, *P. tonganus* flew between 5 km and 23 km during foraging, with the maximum recorded distance of 46.7 km (Banack and Grant, 2002), while in Malaysia the maximum foraging distance for *P. vampyrus* was over 87 km (Epstein et al., 2009).

The results of this study conform to the general view that pteropodids make long distance movements to feed.

The GPS study is ongoing with 4 more bats to be tagged in September 2015 and possibility to get additional 5 tags, thus the full analysis of this project will be available at the end of 2016.

Seed germination

The experiments showed that bat processed seeds achieved best germination success for all three fig species. A higher germination success for bat-processed seeds has been suggested previously by Picot et al., (2007) where *Ficus* seeds processed by *E. dupreanum* germinated better than the unprocessed seeds. They achieved germination rates of 20% for *F. brachyclada* and 40% for *F. pyrifolia* while no seeds germinated from ripe fruits. Also Entwistle and Corp (1997) recorded that the germination of *F. lutea* and *F. natalensis* seeds was higher after ingestion by *P. voeltzkowi* compared with germination rates of intact seeds. *Pteropus rufus* in Madagascar increased germination success of *F. polita*, *F. grevei* and *F. lutea* (Oleksy, 2014). A study on *A. jamaicensis* (Heer et al., 2010) on Barro Colorado Island, Panama, revealed that bats have positive effects on the germination of six native fig species (free-standing figs: *F. insipida*, *F. maxima* and *F. yoponensis*, and strangler figs: *F. nymphiifolia*, *F. obtusifolia* and *F. popenoei*). Although there was little difference in germination success of seeds removed from fruits manually and those extracted from bat faeces, the removal of seeds from the fruit pulp was a crucial step to facilitate germination. The control seeds left in the fruit pulp showed no germination and became infected by fungi and other microorganisms.

Fig trees are often describe as a ‘key stone’ species as they provide food sources for wide range of frugivores because individual trees produce fruits at different intervals several times a year (Lambert, 1991). Therefore, when other fruits are in short supply, figs are often in abundance, helping frugivores to survive times of food shortage (Kuaraksa et al., 2012). Fig trees are highly diverse and widespread in tropical ecosystems. From over 900 species described, many are endemic (Milton, 1991).

In their review, Shanahan et al., (2001) indicate that among mammals, Pteropodidae are among the major consumers of figs. They contribute to long-distance dispersal of fig seeds and the recruitment of new trees in the forest as well as in isolated areas. Bats can swallow between 60% and 80% of the seeds present in a fig fruit (Morrison, 1980; Nakamoto et al., 2009), which makes them very efficient fig consumers.

Because *Ficus* species are often described as ‘keystone’ species in tropical ecosystems (e.g. Lambert and Marshall, 1991), they have been promoted as framework species for tropical forest restoration (Goosem and Tucker, 1995). *Ficus* produce figs all year round, often when other fruits are scarce (Kuaraksa et al., 2012). They attract a wide range of frugivores and thus allow them to survive during times of food shortage (e.g. Shanahan et al., 2001). Many *Ficus* species are fire-resilient and drought - and pest-resistant, allowing them to survive under the harsh conditions found in many degraded areas (Condit, 1969). Additionally, their root systems can often penetrate even the hardest substrates (including rocks) improving its aeration and drainage, and making it suitable for the establishment of other plant species (Thornton et al., 2001).

Future Plans (August 2015-July 2016)

It is essential to continue the study and cover at least another fruiting and non-fruiting season. Up to date the study showed that more emphasis needs to be placed on litchi orchards and the damage birds cause to the fruits. Also, it will be crucial to test mitigation methods and bat deterrence. It is planned to focus on litchi orchards and test netting: nets placed over the trees vs. supported by a frame; water spraying: since most orchards are irrigated it would be interesting to test whether overhead irrigation at night will deter bats from the orchards. Another method to deter bats as well as birds would be use of reflective sound making ribbons. It is planned to test these mitigation methods between November 2015 and January 2016 when litchi is in fruits and animals are feeding on them.

Another four bats will be tagged as from September 2015 to follow them during the litchi fruiting season and it is planned to have five additional GPS tags to increase the sample size and time over which the bats are monitored.

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