The Role of Gibbons in Forest Regeneration: Seed Dispersal and Regeneration of *Nephelium melliferum* Gagnep. (Sapindaceae) on the Mo Singto Plot, Khao Yai National Park

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The Mo Singto Forest Dynamics Plot in Khao Yai Park, with its trees individually mapped and identified, is an ideal site for the study of the effects of gibbon foraging and seed dispersal on tree recruitment. Current studies focus on the effects on individual species consumed by gibbons as well as on the entire forest community. The fruiting tree N*ephelium melliferum* (Sapindaceae) is consumed by a variety of mammals but gibbons are the only dispersers that carry seeds far from the parent trees. Fruit consumption and seed fate were studied by sampling fruit-fall under the tree and by direct observation of frugivores in the trees. Squirrels dropped about 55% of the seeds of ripe fruit unharmed under the tree and pig-tailed macaques picked about 9% of the fruit, dropping most of it under the tree, whereas gibbons consumed about 20% of the fruits, swallowing the seeds. Gibbons disperse *Nephelium* seeds over virtually the entire home range, which occupies about ¾ of the plot. Nevertheless, examination of the distribution of *Nephelium* trees in the tree census indicates that while large trees (>10 cm in diameter) are distributed over the whole plot, smaller trees (1–9.9 cm) are mostly restricted to east and north-facing slopes. This suggests that very recent climate change may be restricting recruitment of the species to relatively moist areas. Further research is needed to test this idea.

Key words: Frugivores, gibbons, Khao Yai Park, *Nephelium melliferum*, seed dispersal, tree distribution

Introduction

Gibbons, being predominantly frugivorous, potentially play a major role in the dispersal of seeds of trees and lianas in the evergreen and moist deciduous forests of tropical Asia (Leighton and Leighton, 1983; McConkey, 2000; Whitington and Treesucon, 1991). Gibbons are able to remove the husks from relatively large kinds of fruits and they swallow the seeds, whereas other mammals such as squirrels and monkeys tend to chew up the seeds or drop them under the parent tree (Leighton and Leighton, 1983; McConkey et al., 2002; Kitamura et al., 2002). Movement of seeds from under the parent tree is potentially important to the recruitment of tree species, and may affect their persistence in the community (Chapman and Chapman, 1995).

The Mo Singto forest dynamics plot in Khao Yai Park was established primarily to study the diet and foraging behavior of gibbons and other frugivores in the forest, and was placed over the home range of a habituated group of white-handed gibbons (*Hylobates lar*) (Brockelman, 1998). Having a forest dynamics plot over a gibbon home range has greatly facilitated the study of diet, foraging behavior, seed dispersal, and its effects on tree recruitment—the detailed study of interactions between a fruiting tree and its dispersal agents.

The wild rambutan, *Nephelium melliferum* Gagnep. (Sapindaceae), was selected for detailed investigation because during its brief fruiting period during late April and May, it is the preferred fruit of gibbons and preliminary observations indicated that its seeds are swallowed and dispersed almost entirely by these primates. Here we report on observations on the fate of seeds and on dispersal agents of *Nephelium melliferum* made in 2004, which was a peak fruiting year for the species. We also report on an unexpected pattern in the distribution of *Nephelium* trees on the plot that has implications for dispersal and recruitment.

Methodology

1. *Study site*

The Mo Singto Forest Dynamics Plot is located about 1 km west of the park headquarters in the center of Khao Yai National Park, central Thailand, at 101° 22' E, 14° 26' N. It is located in seasonal evergreen forest at 725–815 m in altitude above sea level. This plot, 30-ha in area, was established using the same methodology as other plots in the Center for Tropical Forest Science (CTFS) network of the Smithsonian Institution, by being surveyed into 20 x 20 m quadrats with a theodolite and having every tree mapped, identified and tagged down to a size of 1 cm dbh (Condit, 1998; Manokaran et al., 1990). The plot has 200 species of trees ≥ 10 cm dbh, and approximately 120 species of lianas or woody climbers ≥ 3 cm dbh. Each tree has with an aluminum tag stamped with a number that can be looked up in the plot census database to determine its species, size and status. During the last census in 2005, all trees down to 1 cm dbh in size were mapped and tagged.

2. *Observation methods*

Just before the fruiting season of 2004, five trees were selected for detailed observations of feeding behavior of frugivores. Observations were made from dawn to dusk under or near each tree for a total of 100 h. Times of all animals entering and leaving the trees were noted, with observations on feeding behavior. Terrestrial animals visiting the tree at night were sampled by using 35-mm film camera traps with infrared beams that detect animal movement.

3. *Fruit and seed fall*

Early in 2004, 8 trees > 20 cm dbh that had fruit were randomly selected on the plot, and 10 fruit-traps, each 0.5 m in area, were placed in randomly selected positions under the canopy of each. The fruit-traps were made of plastic window screen sewn onto heavy wire circular frames, and were supported about 80 cm above the ground with pvc tubing. Fruit traps were checked every 2 days and all seeds and husks were removed to the laboratory. Since gibbons usually sever the husk cleanly into 2 equal halves before swallowing the pulp and seed, the numbers of seeds dispersed by gibbons could be estimated by counting husks. Monkeys (*Macaca nemestrina*), which visited some trees in large numbers but infrequently, dropped most of the seeds with most pulp attached on the ground under the tree. The relatively small amount of fruit carried away by monkeys could not be estimated from trap data. Squirrels (*Callosciurus finlaysoni*, *Ratufa bicolor* and *Tamiops mcclellendii*) always dropped seeds cleaned of pulp directly under the trees. Seeds dropped by squirrel species could be distinguished by the size of their tooth marks on the surface. They tended to cut the fruit husks into smaller and more irregular pieces than did gibbons.

4. *Gibbon foraging and seed dispersal*

Gibbons of group A, which occurred on the plot, were followed from the previous night's sleeping trees from dawn until entering the next sleeping trees. Each tree entered by the adult female or male was noted and behaviors observed in each tree including feeding and defecation were also noted in code form. Feces were collected and seeds of all fruit species were counted. These data were entered into a foraging data form in Microsoft Excel, and later combined with the tree census data table (with *x* and *y* coordinates of each tree) so that foraging paths from tree to tree could be mapped using ArcView GIS. Using ArcView, the distribution of food trees as well as defecation sites could be mapped.

Results

1. *Feeding by frugivores*

Five species of mammals, 2 primates and 3 squirrels, were seen feeding in the trees during the day, as listed in Table 1. In addition, both sambar and barking deer were camera-trapped under trees at night. Bears (species not known) were not seen but 230 seeds were found in one bear feces. Gibbons were clearly the most efficient dispersers because they swallowed a large amount of the fruit and carried it away from the trees. Squirrels consumed large numbers of fruits but dropped the seeds under the canopy; they were destroyed or removed by terrestrial animals. Monkeys sometimes dropped large numbers of partly consumed fruits, but these were eaten by deer the following night and morning. After feeding by monkeys, large numbers of partly eaten fruits littered the ground under the tree, but the next morning they were gone. Tracks of deer under the trees as well as camera trap data indicated that the dropped fruits were totally consumed by deer. The tame deer in the park always chewed up both whole fruits and seeds fed to them. Monkeys, rather than helping disperse the seeds, thus facilitated predation of large numbers of seeds by deer (and perhaps rodents).

Although gibbons tended to feed in all productive trees once or twice per day, monkeys were more sporadic and opportunistic feeders. It is possible that the observer prevented the nonhabituated monkeys from entering trees on some occasions.

Table 1. Summary of observational data on frugivores visiting *Nephelium melliferum* trees.

Species	Treatment	No. seeds removed	Seeds/ indiv/min	Dispersal?
Hylobates lar	swallow	3181	4.4	defecate in small clumps up to 500 m
Macaca nemestrina	suck pulp and drop seed	?	4.2	carry up to ca. 5 m
Ratufa bicolor	eat pulp and drop seed	581	1.5	under canopy
Callosciurus finlaysoni	eat pulp and drop seed	2245	1.6	under canopy
Tamiops mcclellandii	eat pulp and drop seed	few	?	under canopy
Bear	swallow fruit	?	?	defecate in large clump
Sambar deer	eat fruit and seed	?	?	seed predator
Muntjack	eat fruit and seed	hundreds per visit	?	seed predator

2. *Fruit trap collection*

The 80 fruit traps under the 8 sample trees caught a total of 92,000 fruits or remains of fruits. Gibbons dropped only husks, while squirrels and monkeys dropped fragments of husks and seeds. The 3 species of squirrels could be distinguished by the tooth-marks left on the seed coat. The total production of ripe fruit was used by the following species:

Gibbons	19 %
Monkeys	9 %
Variable squirrel (*Callosciurus*)	53 %
Giant squirrel (*Ratufa*)	1.4 %
Dropped or fallen unused	18 %

These percentages varied from tree to tree; gibbon consumption varied from 0 to 35 %, but was 0 in only 1 of the 8 sampled trees. For the 4 large gibbons in group A, the percentage consumption of fruits in the home range amounted to approximately 100 seeds per individual per day. The most surprising observation, however, was the large proportion of fruits taken by the variable squirrel, *Callosciurus finlaysoni*. It is assumed that most of the seeds dropped by these animals were consumed by rodents and deer, as they tended to disappear rapidly. Some seeds, however, could have been secondarily dispersed by rodents and insects.

3. *Gibbon foraging data*

Gibbons foraged regularly on *Nephelium* fruits, visiting 5 to 11 trees per day during the peak of the fruiting period, spending an average of 53 minutes feeding in *Nephelium* trees per day. An average of about 50 seeds were recovered from the feces of each adult per day (probably about 25–30 percent of the seeds were lost as they scattered while falling through the trees). This figure is somewhat smaller that the number estimated on the basis of fruit trap data (nearly 100 fruits per individual per day). The discrepancy may be explained by the facts that some husk halves assumed to be dropped by gibbons may have been dropped by other mammals, and that not all seeds dropped in feces were recovered after they scattered in the foliage. Thus, the 4 gibbons of group A probably dispersed a total of about 6000 seeds in their home range during the month-long *Nephelium* fruiting season. During this time, the group visited a total of at least 26 *Nephelium* trees.

4. Spatial distribution of trees

Nephelium melliferum is the third-most common species of tree on the Mo Singto plot, and adults are scattered throughout the plot with a preference for hills and ridges (Fig. 1). It is evident from the map that not all trees of this species fruit even in good years such as 2004. A separate map (Fig. 2) showing the distribution of saplings and pole-sized trees indicates that more recently-recruited trees have a markedly different distribution over the plot. Young trees are scarce in parts of the plot having west or south-facing slopes, but are abundant in areas with east and north-facing slopes. There are several possible causes of reduced recruitment of trees in some areas: lack of dispersal to these areas, lack of seed germination, or reduced survival of seedlings. Gibbon foraging and seed-fall data indicate that seeds are getting to all parts of the plot (data not shown). Therefore, there appears to be no dispersal limitation due to lack of a suitable dispersal agent. The other possible explanations cannot be excluded. Another possibility is that climate change has made some parts of the plot too dry and warm for germination and seedling survival.

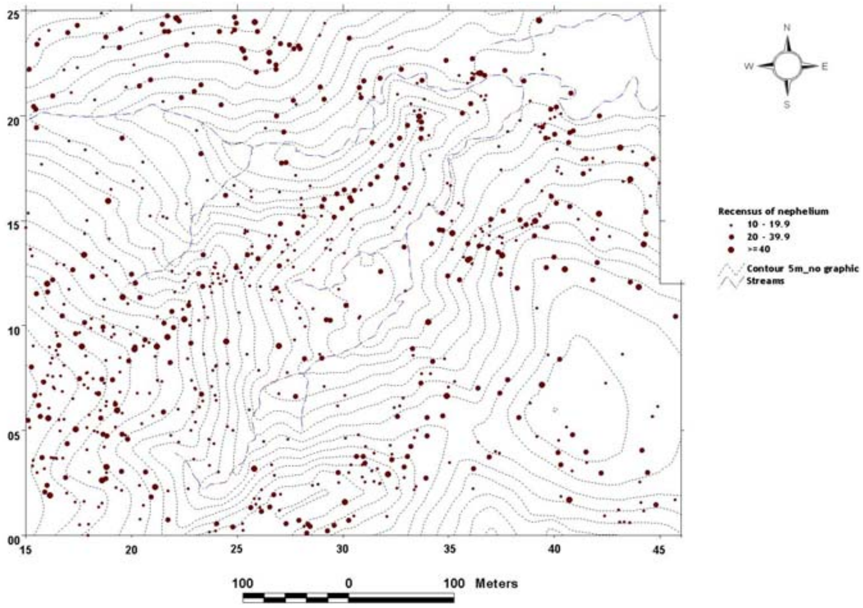

Figure 1. Map of the 30-ha Mo Singto plot showing the distribution of *Nephelium melliferum* trees > 10 cm in diameter. Contour interval is 5 m.

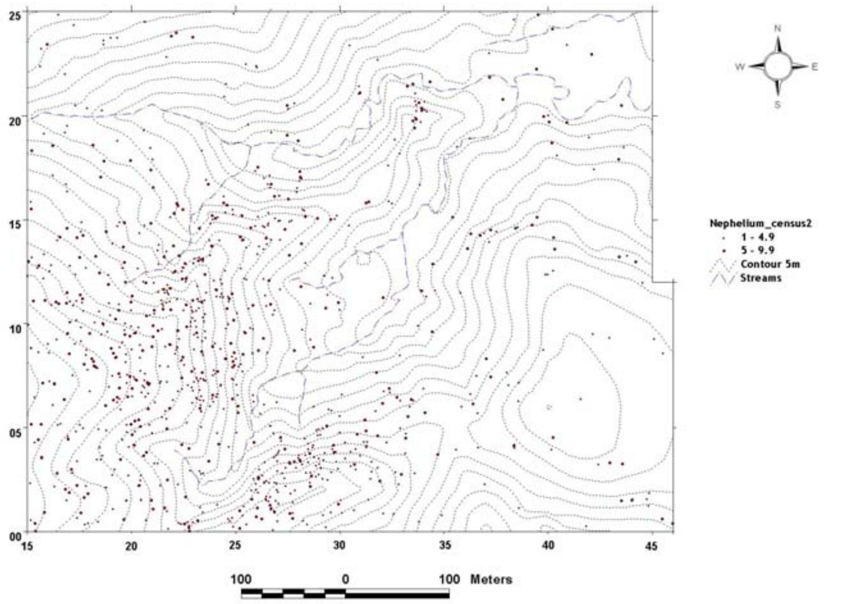

Figure 2. Map of the Mo Singto Forest Dynamics Plot showing the distribution of small trees of *Nephelium melliferum* 1–9.9 cm in diameter.

Discussion and Conclusions

Fruits of *Nephelium melliferum* are relatively large, have a cover that requires manipulation by hands and canines to remove, and have a relatively soft seed covered with a thick layer of very juicy, sour-sweet pulp. The fruit thus requires primates or other mammal hands to consume it; mammals such as deer do not remove the cover and merely chew up the fruit whole or the seed. Monkeys are able to remove the cover but do not swallow the seed. Somewhat surprisingly, all squirrels chew off the pulp but do not eat the seed; they drop all seeds under the canopy. Although gibbons clearly are efficient dispersers, they take only a relatively small proportion of the fruit crop. At all times during the day squirrels, primarily *Callosciurus finlaysoni*, are in the fruiting trees eating or just resting.

Although it appears that gibbons provide high quality dispersal of *Nephelium* seeds, an unknown number may be dispersed shorter distances by monkeys, rodents and dung beetles. Although deer appear to be rather efficient in scavenging fallen fruits, an unknown number of seeds probably escape predation by ground animals. Deer are primarily attracted by the bonanza of fruit left on the ground occasionally by feeding macaque troops.

Even though gibbons provide high quality dispersal of *Nephelium* fruits, they are able to consume on average about 20 % of the crop. Some trees they do not seem to visit at all; one such tree had rather sour fruit. The number of gibbons and their capacity for consuming fruits is somewhat limited; one adult cannot consume more that about a 100 fruits per day. It is possible that dispersal limitation by gibbons limits the number of recruits of *Nephelium* trees. They are, however, dispersed widely around the plot. It would be interesting to investigate how well the species is dispersed in forests without gibbons.

At present, *Nephelium melliferum* appears to be threatened by changes in the physical environment. This needs further investigation, to determine whether dispersal problems, germination, or seedling survival are the causes of the apparent change in distribution of trees. Seed dispersal needs to be studied in more detail to determine if there is any limitation. The number of gibbons on the plot has not changed in the past. Gibbons have maintained the same density of groups on the plot for as long as they have been observed, since 1980 (Brockelman et al., 1998). The census data will also be analyzed further to look for evidence that other species show signs of instability in wither size distributions or spatial distributions.

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