Dear Author,

Please, note that changes made to the HTML content will be added to the article before publication, but are not reflected in this PDF.

Note also that this file should not be used for submitting corrections.
Fruit gardens enhance mammal diversity and biomass in a Southeast Asian rainforest

Jonathan Harry Moore a,b,⁎, Saifon Sittimongkol a,b,c, Ahimsa Campos-Arceiz b, Tok Sumpah d, Markus Peter Eichhorn a

a School of Life Sciences, The University of Nottingham, University Park, Nottingham NG7 2RD, United Kingdom
b School of Geography, The University of Nottingham Malaysia Campus, Jalan Broga, 43500 Semenyih, Kajang, Selangor, Malaysia
c Department of Science, Biology Section, Faculty of Science and Technology, Prince of Songkla University, Pattani 94000, Thailand
d Krau Wildlife Reserve, Pahang, Malaysia

ABSTRACT

Protected areas are frequently inhabited by people and conservation must be integrated with traditional management systems. Cultivation of fruit gardens is a low-impact agroforestry technique which alters the structure and composition of forest stands and has the potential to thereby influence animal communities. This is of particular interest in the rainforests of Southeast Asia, where limited fruit availability between intermittent mast fruiting events results in low mammal densities. We assessed how agroforestry practises of an indigenous community affected terrestrial mammal abundance, diversity and assemblage composition within Krau Wildlife Reserve, Pahang, Malaysia. We used baited camera traps to compare mammal abundance and diversity between seven fruit gardens and eight control sites. Fruit gardens contained similar species richness and abundance levels but higher diversity and almost threefold higher mammal biomass. Fruit gardens contained five times as many fruit-producing trees and a positive correlation was found between the number of fruit trees and total mammal biomass. Mammal community composition differed between the two habitats, with fruit gardens attracting nine species of conservation concern. These results suggest that traditional agroforestry systems may provide additional resources for mammals and therefore their net effects should be considered in conservation policy.

Please cite this article as: Moore, J.H., et al., Fruit gardens enhance mammal diversity and biomass in a Southeast Asian rainforest, Biological Conservation (2015), http://dx.doi.org/10.1016/j.biocon.2015.12.015

© 2015 Published by Elsevier B.V.
within the reserve boundaries. The Chewong continue to practise traditional cultivation, hunting, fishing and gathering of wild fruits, herbs and plants for medicines (Howell, 1984). Their cultivation techniques include clearings for planted crops alongside fruit gardens which are enhanced with favoured fruiting trees. Fruit garden cultivation involves the selection of suitable patches of forest, removal of certain tree species within these areas (used for building materials or otherwise unwanted), then the planting of fruiting tree species such as durian Durio spp., kepayang Pangium edule and rambutan Nephelium lappaceum. Fruit gardens are lightly tended and fruit is collected annually during the months of June, July and August for up to 50 years. Fruit gardens are contiguous with old growth forest and involve limited forest clearance, maintaining much of the original vegetation composition and structure (Wiersum, 2004). Since favoured species of fruiting trees are planted among the existing vegetation, it is likely that the long-term effect will be to increase fruit resources through higher densities and seasonal availability of annually fruiting tree species.

Our study aimed to investigate how fruit gardens influence the abundance, diversity and composition of terrestrial mammalian frugivore assemblages at this site. We anticipated that (a) fruit gardens would leave a legacy of greater abundance of fruiting trees than natural forest areas, and (b) this would act as a resource drawing in greater abundance and diversity of frugivores.

2. Methods

2.1. Study area

Krau Wildlife Reserve, Pahang, (3°33’N 102°30’E; Fig. 1) is approximately 600 km² in size, with a range in altitude from 45 to 2108 m above sea level. Vegetation within the reserve predominantly consists of lowland dipterocarp forest (61%), hill dipterocarp forest (22.5%) and upper dipterocarp forest (9%) with minor components of secondary forest (1.1%) and cultivated/cleared land (0.6%) (Chou and Saw, 2006). Contiguous forests in the mountainous North and lowland South-West combine to a total area of 1100 km²; however forests outside the reserve are highly fragmented by rubber tree and oil palm plantations.

Contiguous forests in the mountainous North and lowland South-West combine to a total area of 1100 km²; however forests outside the reserve are highly fragmented by rubber tree and oil palm plantations. Over the past 50 years defaunation of many large-bodied mammal species has occurred in this reserve, with the total loss of the Asian elephant Elephas maximus, gaur Bos gaurus, Sumatran rhino Dicerorhinus sumatrensis and Javan rhino Rhinoceros sondaicus, alongside a reduction in numbers of Malayan Tiger Panthera tigris jacksoni, Malayan tapir Tapirus indicus, sambar deer Rusa unicolor and barking deer Muntiacus muntjak.

2.2. Sampling strategy

We surveyed two types of plots: fruit gardens and controls (natural forest). Fruit gardens were identified by local guides as areas currently or previously cultivated for growing fruiting tree species for local consumption. Time since establishment varied from 6 to 55 years according to estimates from local elders (30 ± 8, mean ± SE). Fruit gardens are often situated in close proximity to current or abandoned villages within the forest; those selected for study were 1015 ± 446 m from the nearest active village (mean ± SE). Control plots were chosen based on local knowledge as being natural unmodified forest (no known previous management) with potential for conversion into a fruit garden based on Chewong impressions of suitability. This depends upon existing plant species (trees and understory) along with the suitability of the site for growing fruiting species and accessibility (882 ± 202 m from nearest active village).

A minimum distance of 0.5 km between fruit garden and control plots was used to ensure independent sampling of locations. While a distance of 1–2 km is preferred for terrestrial mammal species (Brodie and Giordano, 2013), we were constrained by the positions of fruit gardens, and aimed to maximise survey effort in line with recommendations by Tobler et al. (2008).

The boundaries of fruit gardens were marked out by local guides and measured in straight line segments. The distance from a central point to each corner was measured and Heron’s formula used to calculate area (Çokakolu et al., 2013). A circular plot was placed randomly within each site. Diameter at breast height (dbh, measured at 1.3 m) was measured for all saplings (1–10 cm dbh) within a 9 m radius and trees (>10 cm dbh) within an 18 m radius (~1000 m²). Specimens were collected for fruit tree identification as determined by local guidance.

2.3. Camera trapping

Seven fruit garden and eight control plots were surveyed over a two-month period using 24 HD Bushnell camera traps. Our aim was to obtain

Please cite this article as: Moore, J.H., et al., Fruit gardens enhance mammal diversity and biomass in a Southeast Asian rainforest, Biological Conservation (2015), http://dx.doi.org/10.1016/j.biocon.2015.12.015

Fig. 1. Map showing locations of fruit garden and control study plots within Krau Wildlife Reserve, Pahang, Malaysia.
the equivalent of eight weeks of camera trapping per plot (56 days).

Each survey consisted of two camera trapping phases per plot with a
duration of 7–10 days per phase and four camera traps deployed per
phase. Cameras were placed along active animal trails to maximise
chance of detecting species and locations changed for the second
phase to increase coverage. LED sensitivity was low, one minute video
duration, one second trigger delay, highest resolution and date-time
stamp enabled. Cameras were 40 cm above the ground with a slight
downward angle to ensure consistent capture rates of both small and
large mammal species.

Fruit baits were deployed to increase capture rates and designed to
emulate small-scale fruiting events. Bait was placed 220 cm from the
camera to reduce glare from infrared detection and for consistent
identification. Some fruits were split to increase scent and attract
more frugivores. The type and individual weights of fruit bait were
dependent on local market availability. Baits included a combination
of langsat (Lansium domesticum), mango (Mangifera spp.), campedak
(Artocarpus integer) and kepayang. 1.5 kg of fruit bait was used per
camera trap per phase, totalling 31 kg of fruit bait for 20 cameras over
each 7–10 day period. Longer durations could not be achieved due to
degradation and consumption of fruit. The fruits were chosen for their
varied characteristics to appeal to a wide range of frugivore species,
though may not have attracted all species present.

Mammals were identified using Francis (2008). Due to limitations of
camera trap images, reliable identification to species level was not
possible for smaller mammals. Two mouse deer species (Tragus kanchil
and Tragulus napu), three squirrel species (Callosciurus notatus, Lariscus
insignis and Rhinosciurus laticaudatus) and four rat species (Leopoldamys
sabanus, Maxomys surifer, Rattus tiomanicus and Maxomys whiteheadii)
were grouped into three functional taxa for diversity analysis. Foraging
guilds of animal species were determined based on recommendations
from Pineda-Munoz and Alroy (2014) and obtained from a range of
sources (Appendix A).

2.4. Data analysis

Numbers of individuals were based upon independent captures. All
triggers of the same species were considered to be the same individual
until a period greater than one hour had elapsed between triggers after
which a new individual was counted (Silveira et al., 2003). Average
body mass for mammal species was taken from Francis (2008) apart
from sambar deer from Dahlan and Dawend (2013). These were multi-
plied by the number of individuals to estimate total mammal biomass.
To ensure that inconsistent detection did not confound assessments of
community structure we calculated per-species detectability using
PRESENCE and compared values obtained from gardens and control
plots (Hines, 2006).

Coverage was calculated to assess completeness of sampling, defined as the proportion of the total number of individuals in a com-

munity that belong to the species represented in the sample (Chao
and Jost, 2012). Hill’s numbers (Hill, 1973) were calculated in line
with current consensus on quantifying species diversity (Tuomisto,
2010). Hill’s numbers are defined to the order of $q (D)$, with estimated
species richness of $(D)$ weighted towards rare species due to its insensi-
tivity to relative frequencies, exponential of Shannon’s entropy $(D)$
weighted towards common species, and inverse of Simpson’s diversity
$(D)$ weighted towards highly abundant species. These therefore
provide complementary information on the richness and evenness of
assemblages.

Additional covariates were analysed to evaluate potential biases in
the data. Spatial autocorrelation of abundance and diversity indices
was assessed using Moran’s $I$. No evidence of spatial autocorrela-
tion was found (see Appendix B) and subsequent analyses therefore omitted
spatial covariates. Further potential confounding effects of age of fruit
garden and distance to closest active village on the abundance and
diversity of mammals were assessed; no significant relationships were
found (Appendix B).

An analysis of similarity (ANOSIM) assessed whether species com-
position varied between samples. This grouped samples according to
the a priori hypothesis that they would differ among habitat types
(fruit garden or control). Significance was assessed by comparison of
the observed value of $R$ (ANOSIM statistic) against 1000 values generat-
ed via random permutations of the group assignment. All statistics were
computed using R version 3.0.2 and package vegan 2.0-10 (Oksanen
et al., 2013; R Development Core Team, 2014). Sørensen’s Index of dis-
similarity was calculated for every pair of sites then averaged to deter-
mine levels of turnover among assemblages (fruit garden and control).

3. Results

3.1. Vegetation

A total of 15 plots were sampled; seven fruit gardens and eight con-
trol plots. The average area of a fruit garden was 320.0 ± 759 m$^2$. Sam-
ping plots within fruit gardens did not differ significantly from controls
in number of saplings (fruit gardens: 52.7 ± 41.8, controls: 79.6 ± 29.1,
mean ± SE; $t$ = 1.349, df = 8.5, $P = 0.212$) or basal area (m$^2$/ha) (fruit
gardens: 3.03 ± 0.71, controls: 3.66 ± 0.40; t = 0.840, df = 12, $P = 0.420$)
but they contained half as many trees per 1000 m$^2$ (fruit gar-
dens: 28.8 ± 3.9, controls: 60.4 ± 1.9; $r = 8.214$, df = 6.4, $P = 0.001$)
which there were approximately five times more fruiting trees than
control plots (fruit garden: 12.80 ± 3.13, control: 2.63 ± 0.65; $r = 42$
3.620, df = 12, $P = 0.004$). 45% of tree stems within fruit gardens
were fruit-bearing compared with 4% in control forest plots.

3.2. Frugivore diversity

3.2.1. Vertebrate community

We recorded 1678 individuals of 21 vertebrate species (16 mammal,
four bird and one reptile) (Table 1) from 1024 camera trap nights. Of
the 21 species nine were of notable IUCN status with one endangered
(Malayan tapir Tapiro iris), six vulnerable (large spotted civet Vivera
megaspila, Asian small-clawed otter Aonyx cinerea, southern pig-tailed
macaque Macaca nemestrina, sun bear Helarctos malayanus, sambar
deer, Malayan Peacock Pheasant Polyplectron malacense), and
two near threatened (Crested Fireback Lophura ignita and the Great
Argus Argus argus). Birds (52 individuals) were excluded from sub-
sequent analyses.

All species were recorded within fruit gardens, though five were not
found in control plots (Asian small-clawed otter, small-toothed-palm
civet Arctogalidia trivirgata, masked-palm civet Paguma larvata, long-
tailed macaque Macaca fascicularis and the Malayan tapir). Of all
individuals detected within fruit gardens 44% were omnivorous, 38% her-
bivorous, 16.5% exclusively frugivorous and 0.5% carnivorous compared
to controls with 74% omnivorous, 21% herbivorous and 5% frugivorous.
There was therefore a higher proportion of frugivores in fruit gardens,
contributed predominantly by southern pig-tailed macaques.

Coverage was 0.996 and 0.999 for fruit garden and control plots
respectively, indicating that sampling was close to completion and
estimates of diversity within habitats are reasonable. No significant
difference in per-species detectability was found between areas
($t = -0.1746$, $P = 0.864$).

3.2.2. Mammal community

Fruit gardens did not differ significantly from control plots in mean
abundance of mammal individuals (fruit gardens: 101 ± 22, controls:
$114 ± 16$, $t = 0.53$, df = 13, $P = 0.606$). When total body mass (kg)
of mammal species was taken into account, however, fruit gardens
were found to have significantly higher body mass of mammals than
control areas ($t = 3.60$, df = 12, $P = 0.004$). Fruit gardens contained
almost three times the total biomass of mammals with an average of
Table 1

<table>
<thead>
<tr>
<th>Order</th>
<th>Family</th>
<th>Genus</th>
<th>Species</th>
<th>Common name</th>
<th>BM (kg)</th>
<th>TA (F)</th>
<th>TA (C)</th>
<th>Foraging guild</th>
<th>IUCN</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>Artiodactyla</td>
<td>Cervidae</td>
<td>Muntiacus</td>
<td>muntjak</td>
<td>21</td>
<td>6</td>
<td>3</td>
<td>Herbivore</td>
<td>LC</td>
</tr>
<tr>
<td>1.2</td>
<td>Artiodactyla</td>
<td>Cervidae</td>
<td>Rusa</td>
<td>unicolor</td>
<td>134</td>
<td>14</td>
<td>12</td>
<td>Herbivore</td>
<td>LC</td>
</tr>
<tr>
<td>1.3</td>
<td>Artiodactyla</td>
<td>Susidae</td>
<td>Sus</td>
<td>scrofa</td>
<td>32</td>
<td>16</td>
<td>7</td>
<td>Omnivore</td>
<td>LC</td>
</tr>
<tr>
<td>1.4</td>
<td>Artiodactyla</td>
<td>Tragulidae</td>
<td>Tragulus spp</td>
<td>Mouse deer</td>
<td>4</td>
<td>4.2</td>
<td>20</td>
<td>Herbivore</td>
<td>LC</td>
</tr>
<tr>
<td>1.5</td>
<td>Carnivora</td>
<td>Mustelidae</td>
<td>Aonyx</td>
<td>cinerea</td>
<td>3.5</td>
<td>5</td>
<td>0</td>
<td>Carnivore</td>
<td>VU</td>
</tr>
<tr>
<td>1.6</td>
<td>Carnivora</td>
<td>Ursidae</td>
<td>Helarctos</td>
<td>malayanus</td>
<td>45</td>
<td>7</td>
<td>3</td>
<td>Omnivore</td>
<td>VU</td>
</tr>
<tr>
<td>1.7</td>
<td>Carnivora</td>
<td>Viverididae</td>
<td>Vivera</td>
<td>megalapia</td>
<td>8</td>
<td>56</td>
<td>57</td>
<td>Omnivore</td>
<td>VU</td>
</tr>
<tr>
<td>1.8</td>
<td>Carnivora</td>
<td>Viverididae</td>
<td>Paguma</td>
<td>larvata</td>
<td>4</td>
<td>6</td>
<td>0</td>
<td>Omnivore</td>
<td>LC</td>
</tr>
<tr>
<td>1.9</td>
<td>Carnivora</td>
<td>Viverididae</td>
<td>Actogalidia</td>
<td>trivirgata</td>
<td>2</td>
<td>9</td>
<td>0</td>
<td>Omnivore</td>
<td>LC</td>
</tr>
<tr>
<td>1.10</td>
<td>Columbiformes</td>
<td>Columbidae</td>
<td>Chalcophaps</td>
<td>indicus</td>
<td>–</td>
<td>6</td>
<td>3</td>
<td>Frugivore</td>
<td>LC</td>
</tr>
<tr>
<td>1.11</td>
<td>Galliformes</td>
<td>Phasianidae</td>
<td>Argusinus</td>
<td>argus</td>
<td>–</td>
<td>4</td>
<td>8</td>
<td>Frugivore</td>
<td>NT</td>
</tr>
<tr>
<td>1.12</td>
<td>Galliformes</td>
<td>Phasianidae</td>
<td>Lophura</td>
<td>ignita</td>
<td>–</td>
<td>1</td>
<td>5</td>
<td>Omnivore</td>
<td>NT</td>
</tr>
<tr>
<td>1.13</td>
<td>Galliformes</td>
<td>Phasianidae</td>
<td>Polyleptodon</td>
<td>malacense</td>
<td>–</td>
<td>3</td>
<td>9</td>
<td>Omnivore</td>
<td>VU</td>
</tr>
<tr>
<td>1.14</td>
<td>Primates</td>
<td>Cercopithecida</td>
<td>Macaca</td>
<td>fascicularis</td>
<td>5</td>
<td>1</td>
<td>0</td>
<td>Omnivore</td>
<td>LC</td>
</tr>
<tr>
<td>1.15</td>
<td>Primates</td>
<td>Cercopithecida</td>
<td>Macaca</td>
<td>nemestrina</td>
<td>6</td>
<td>111</td>
<td>40</td>
<td>Frugivore</td>
<td>VU</td>
</tr>
<tr>
<td>1.16</td>
<td>Rodentia</td>
<td>Hystricidae</td>
<td>Atherurus</td>
<td>macrorurus</td>
<td>2</td>
<td>124</td>
<td>61</td>
<td>Herbivore</td>
<td>LC</td>
</tr>
<tr>
<td>1.17</td>
<td>Rodentia</td>
<td>Hystricidae</td>
<td>Hystrix</td>
<td>brachyura</td>
<td>8</td>
<td>115</td>
<td>112</td>
<td>Herbivore</td>
<td>LC</td>
</tr>
<tr>
<td>1.18</td>
<td>Rodentia</td>
<td>Muridae</td>
<td>N/A</td>
<td>N/A</td>
<td>0.5</td>
<td>330</td>
<td>498</td>
<td>Omnivore</td>
<td>N/A</td>
</tr>
<tr>
<td>1.19</td>
<td>Rodentia</td>
<td>Sciuridae</td>
<td>Squirrel</td>
<td>species</td>
<td>0.25</td>
<td>91</td>
<td>116</td>
<td>Omnivore</td>
<td>N/A</td>
</tr>
<tr>
<td>1.20</td>
<td>Squamata</td>
<td>Varanidae</td>
<td>Varamus</td>
<td>salvator</td>
<td>–</td>
<td>1</td>
<td>2</td>
<td>Insectivore</td>
<td>LC</td>
</tr>
</tbody>
</table>

Fig. 2. Kernel density estimate of frugivore relative frequencies by body mass (kg) for both fruit garden and control plots with illustrative mammal species. Mammals depicted relative to body mass size (from left to right; squirrel sp., rat sp., brush-tailed porcupine, large spotted civet, southern pig-tailed macaque, Malayan porcupine, barking deer, Eurasian wild pig, sun bear and sambar deer).

Fig. 3. Correlation between number of fruit trees and total mammal biomass (kg) within fruit garden and control plots.

Please cite this article as: Moore, J.H., et al., Fruit gardens enhance mammal diversity and biomass in a Southeast Asian rainforest, Biological Conservation (2015), http://dx.doi.org/10.1016/j.biocon.2015.12.015
trees; a positive correlation was found between number of fruiting trees and mammal biomass. Although mammal species richness and overall abundance did not differ between fruit gardens and control areas, the evenness of communities was greater in fruit gardens, average body size was larger, and a distinct species composition was present, including a number of species of conservation importance. This demonstrates that fruit gardens are playing an important role in attracting and supporting terrestrial mammals.

Fruit gardens contained an increased density of fleshy-fruit-producing tree species such as durian, mango, rambutan, cempedak and kepayang. These fruit annually over the months of June, July and August, when fruits are also collected by the Chewong. Mammal communities within fruit gardens contained a higher proportion of primarily frugivorous species, contributed mainly by southern pig-tailed macaques, which are known to favour areas with high fruit availability (Laska, 2001). Pyke et al. (1977) showed that many mammal species directly move towards areas where encounter rates of desirable food types are increased. Many mammal species are known to shift their diets in relation to spatial and temporal fruit availability, including masked-palm civets, which switch their diet from rodents and birds in primary forests to a predominantly fruit-based diet during the fruiting season in logged forest and farmland (Zhou et al., 2008). Sun bears have been documented switching from a predominantly insectivorous diet during inter-mast periods to almost entirely fruit-based during mast fruiting events (Fredriksen et al., 2006). Densities of mouse deer have been found to correlate with the abundance of small fruits due to their requirements for a highly nutritious and readily digestible diet (Heydon and Bulloh, 1997).

Fruiting events in gardens occur annually, much higher frequency and distinct from the mast fruting events exhibited by the dominant dipterocarp trees of Southeast Asian rainforests, which occur at intervals of up to 7 years with limited fruit availability in between (Corlett and Primack, 2011; Curran and Leighton, 2000; Numata et al., 2003).

The relative scarcity of fruit within Southeast Asian forests is more pronounced than is typical for rainforest regions, and therefore the effects of supplementary fruit are expected to be particularly strong in this region. Rainforests with comparable fruit scarcity exist in both Africa (Newbery et al., 2006) and South America (Norden et al., 2007) and we predict that similar phenomena will occur in these areas. There are also similar agricultural practises to the Chewong, with the potential to enhance mammal communities, which occur elsewhere in Southeast Asia, such as the fruit gardens of the Orang Rimba in Indonesia (Cairns, 2014), the Dusun of Sarapua island, Central Maluku, Indonesia (Kaya et al., 2002) and the forest gardens of the Dayak people in East Kalimantan, Indonesia (Mulyoutami et al., 2009). Elsewhere analogous systems of forest gardens are found in the Uvan Uplands of Sri Lanka (Nuber et al., 1994), the forest gardens of the Kayapo Indians of the Brazilian Amazon (Posey, 1985) and Maya forest gardens in Mexico (Gómez-Pompa Arturo, 1990). The phenomenon of terrestrial mammal enhancement resulting from anthropogenically enhanced fruit availability is therefore potentially widespread throughout the tropics.

Chewong gardens are located within an intact forest landscape, which is an important factor in interpreting these patterns. Duelli and Obrist (2003) found that agroforestry systems connected with natural forest remnants facilitated dispersal, increasing diversity of animal species. The Chewong gardens differ from the majority of tropical agroforestry systems studied to date which are typically located on the edge of forests (Bhagwat et al., 2008; Scales and Marsden, 2008). Bali et al. (2007) demonstrated that agroforests and plantations which are distant from natural forest have reduced mammal species richness.

Chewong fruit gardens have similar basal area to natural forest, are relatively small in scale and involve limited forest clearance, maintaining much of the original vegetation composition and canopy structure. This is crucial in sustaining greater diversity of faunal species both old growth forest specialists and generalists (Chazdon et al., 2009; Tscharntke et al., 2011; Wiersum, 2004). In particular, intensively managed agroforests with reduced canopy connectivity have negative influences on large mammal distributions (Cassano et al., 2014), especially for arboreal mammals which rely on canopy pathways for movement across landscapes (Estrada et al., 2012).

Nine species of conservation concern (43% of species recorded in this study), classified as endangered, vulnerable and near threatened (IUCN, 2014), were found actively foraging within fruit garden areas, compared with just seven species of conservation concern in control plots. This emphasises that the habitat provided by fruit gardens supports vulnerable populations. Most studies of tropical agroforestry have focused on trees, plants, insects or birds, and at sites with a single or limited mixture of fruiting tree species. These differ from the diverse Chewong fruit gardens. The complexity, composition and tree species type incorporated in agroforests, along with the surrounding forest mosaics, are all important factors determining how animal communities respond to them (Bali et al., 2007; Gallina et al., 1996; Harvey et al., 2006; Oliveira et al., 2011).

Estrada et al. (2012) reviewed the importance for primate conservation of tropical agro-ecosystems ranging from simplified pasturelands to more complex polycultures and agroforestry. Across four regions they found 49% of the 57 primate taxa recorded were classified as critically endangered, endangered, vulnerable or near threatened. While our camera trapping was restricted to terrestrial vertebrates, we anticipate that similar patterns might be found in Krau Wildlife Reserve for arboreal and volant frugivores. Agro-ecosystems can therefore play an important role in conservation.

Since many indigenous tribes inhabit what have now been designated as protected areas, balancing conservation while respecting indigenous peoples’ rights and practises is difficult (Aziz et al., 2013). The Chewong are largely forest-dwelling and have limited integration into the wider society. They rely predominantly on forest resources. Activities include hunting of small to medium-sized mammals, birds and fish, which provide essential dietary protein. In addition, they gather

---

Table 2

<table>
<thead>
<tr>
<th>Quadrant</th>
<th>Metric</th>
<th>Fruit garden</th>
<th>Control</th>
<th>F1,15</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>4D</td>
<td>SChao</td>
<td>9 ± 0.9</td>
<td>7 ± 0.6</td>
<td>3.7</td>
<td>0.075</td>
</tr>
<tr>
<td>4D</td>
<td>SDChao</td>
<td>9.8 ± 1</td>
<td>8.7 ± 1.6</td>
<td>0.3</td>
<td>0.583</td>
</tr>
<tr>
<td>4D</td>
<td>S2</td>
<td>5.4 ± 0.5</td>
<td>3.5 ± 0.4</td>
<td>8.9</td>
<td>0.011</td>
</tr>
<tr>
<td>4D</td>
<td>1/D</td>
<td>4.4 ± 0.5</td>
<td>2.6 ± 0.3</td>
<td>9.4</td>
<td>0.009</td>
</tr>
</tbody>
</table>

Fig. 4. Hill series plot (order “D”) indicating diversity of terrestrial mammalian frugivores for fruit garden and control plots. Effective species S with shaded standard error.
forest products such as rattan for building, herbs for medicinal purposes, honey for consumption and plant poisons for hunting. Crops such as rice and cassava are grown in agricultural clearings to provide a sustained carbohydrate source. These practices all have potential impacts on the surrounding forest and animal communities. While fruit gardens were found in our study to enhance the diversity and biomass of terrestrial frugivores, these effects should be seen as part of a wider portfolio of activities within the forest. Decisions on the impacts of indigenous prac-
tices should be made on a case-by-case basis, taking into account the 
conservation objectives of a given protected area and considering the overall sustainability of the indigenous community (Robinson et al., 2011). Integration of conservation management schemes alongside indig-
igenous peoples is essential, and certain aspects of traditional practises 
can have net benefits for conservation (Dressler et al., 2010).

High densities of small-bodied rats and squirrels were present in 
control plots (Fig. 2). Lower densities in fruit gardens may be attributed 

to a shift in habitat usage to avoid predators such as civets and other car-
nivorous species (Dickman, 1992). The abundance of small-bodied 
mammals is an indicator of a partially defaunated system. Many large-
bodyed frugivores such as elephants and rhino are absent from Krau or 
greatly reduced in number. Larger frugivores are capable of feeding on 
and consuming a greater size range of large-seeded plant species 
(Levey, 1987). A greater gut capacity with a longer seed retention time 
(Nathan et al., 2008), larger home ranges, and travelling at higher speeds 
means that large frugivores are capable of providing long-distance and 
high-quality seed dispersal (Harestad and Bunnell, 1979). Their loss has 
implications for future plant recruitment (Harrison et al., 2013). To 
some extent the Chewong, through creation of fruit gardens, may be 
providing a partial replacement for these ecological services.

5. Conclusion

Traditional fruit gardens within this forest reserve attracted a greater 
diversity and biomass of terrestrial mammalian frugivores than were 
found in control plots, including a number of species of conservation 
concern. Fruit gardens are likely to play an important role in maintain-
ning vulnerable species through increased abundance of annual-fruiting 
tree species. The mast fruiting nature of dipterocarp forests is likely to 
enhance this effect, but similar patterns are expected in regions where 
agroforestry practises supplement available fruit, particularly during seasons of relative scarcity. Agroforestry practises vary widely between 
indigenous communities in terms of their clearance techniques, tree 
species incorporated, management and landscape context. Their poten-
tial role in conservation should therefore be assessed on a case-by-case 
basis. The maintenance of traditional land-use systems can in some 
cases have positive outcomes for conservation and should therefore be 
considered when developing management plans for inhabited reserves.

Acknowledgements

We are very grateful to the Department of Wildlife and National Parks (DWNP) Peninsula Malaysia for research permits, and for the support of A. Abdul and K. N. Kamaruddin in Krau Wildlife Reserve headquaters and the Institute of Biodiversity (IBD). A research permit 
was granted to SS by Malaysia’s Economic Planning Unit (UPE: 40/ 
200/19/2986). Lah and Tok provided invaluable help in the field, and 
N. Azuwa provided logistical support. 

Map. KML file containing the Google map of the most important areas 
described in this article.

Appendix A. Supplementary data

Supplementary data associated with this article can be found in the 
These data include Google map of the most important areas described 
in this article.
Please cite this article as: Moore, J.H., et al., Fruit gardens enhance mammal diversity and biomass in a Southeast Asian rainforest, Biological Conservation (2015), http://dx.doi.org/10.1016/j.biocon.2015.12.015