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Animal-Plant Interaction: A Review On Terrestrial Vertebrate Seed Disperser Diversity And The Selectivity Pattern Based On The Size Of Fruits And Seeds

Daniel R. NDIZIHIWE
Assistant lecturer, Department of Agriculture and Agribusiness, Bishop Stuart University P.O BOX 9, Mbarara Uganda

Achille E. ASSOGBADJO
Professor, Laboratory of Applied Ecology, Faculty of Agronomic Sciences, University of Abomey Calavi, Benin

Sylvestre C. A. M. DJAGOUN
Lecturer, Laboratory of Applied Ecology, Faculty of Agronomic Sciences, University of Abomey Calavi, Benin

Barthélémy KASSA
Laboratory of Applied Ecology, Faculty of Agronomic Sciences, University of Abomey Calavi, Benin

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ABSTRACT

The study was based on 107 studies and data concerning disperser species, plant species and family, fruit type and size, seed size plant life form and the habitat, were presented in matrix form. Data from this matrix were used in determining the disperser species diversity considering large taxonomic groups (mammals, birds and reptiles) and selection pattern based on the fruit and seed size. The diversity of mammals was high followed by birds and then reptiles with 65%, 30% and 5% respectively. Mammal taxonomic group dominated and was sub divided into primates, ungulates, carnivores, rodents and bat sub-groups which accounted for 45%, 22%, 17%, 9% and 7% respectively confirming the dominance of primates. Simple correspondence analysis showed that ungulates dispersed very small fruits while carnivores, primates, bats and reptiles were categorized together for both small and medium sized fruits. Ungulates, birds and bats dispersed the smallest seeds while others dispersed both small and large sized seeds. The study revealed high diversity of mammals particularly primates therefore playing a huge role in structuring and restructuring terrestrial ecosystems, with a warning that the loss of ungulates may have catastrophic impacts on the structure and composition of small fruited and seeded plants.

Key words: Terrestrial vertebrates, seed dispersal, seed and fruit size

1. INTRODUCTION

Animal and plant traits were the products of coevolution according to the preliminary conceptual treatments of fruits and frugivores coevolution (Bongers et al. **2013**), thus, Zoochory accounts for the highest percentage (57%) of terrestrial seed dispersal (Diogo et al. **2016**) but less is known about how some characteristics mediate this relationship (McConkey et al. **2012**, Trolliet et al. **2013**, Kuhlmann and Ribeiro **2016**). The composition of seed banks in terms of species is strongly influenced by vertebrate seed dispersers (Jordano **2013**, Wandrag et al. **2015**) but there is a lack in understanding the diversity of these dispersers in terms of species. Loss of big and medium-sized frugivores reduces dispersal distance (Pérez-Méndez et al. **2016**) as well as massive loss of trees (Estrada and Fleming **2012**, Caughlin et al. **2015**), hence affecting plant species distribution across ecosystems and landscapes. Functional complementarity between species (Tilman and Snell-Rood **2014**) facilitates seed dispersal implying the importance of species richness (García and Martínez **2012**, Poisot et al. **2013**) where high disperser species diversity maintains stable ecosystem (Baur **2014**, Reid et al. **2015**). Fruit and seed characteristics also play an important role in determining the preferences of frugivorous animals (Aslan and Rejmanek **2012**, Valenta et al. **2013**) and the differences in these fruit and seed characteristics explains why some plants are more adapted to dispersal by some groups of animals but not others (Estrada and Fleming **2012**). Seed size is one of the factors that influence seed dispersal patterns in animal-dispersed plants (Lai et al. **2014**). Likewise, the size of the fruit may determine the animal groups adapted for its dispersal (Flörchinger et al. **2010**, Burns **2013**) but the relationship between the seed and fruit size and the disperser group

associated has not yet been elaborated. This study focused on collection, extracting and supplementing data from various published articles. In this case, the data looked almost primary (Alsheikh-Ali et al. **2011**) and aimed at elaborating on the diversity of terrestrial vertebrate seed dispersers, relationship between fruit and seed size characteristic and the type of animal dispersal agent involved.

2. METHODS

Only published studies were electronically searched and sorted to get the appropriate ones and a total of 441 articles was obtained and re-screened to get the more appropriate ones. 107 studies were retained and data was extracted based on the set parameters which included terrestrial vertebrate disperser taxonomic groups, sub taxonomic groups in case of mammals, plant species and families, plant life forms, fruit type and size (mm), the seed size (mm) and habitat type. All these parameters were extracted from all the articles and presented in matrix as well as indicating the authors and the year of publication. The final set up took a form of primary data (Alsheikh-Ali et al. **2011**) The missing information such as seed size, fruit size, plant life form and plant families were searched electronically. Blank spaces were left in case of failure to find the required data. (APPENDIX 1).

The number of species for each vertebrate taxonomic group (birds, mammals and reptiles), the number of plant families and plant species associated with each vertebrate taxonomic group was determined and presented in Microsoft excel spreadsheet. Mammals were thereafter sub-divided into different groups (primates, ungulates, bats, rodents, and carnivores) because they showed high dominance in the first instance. Likewise, the number of species for each mammalian group, the number of plant families and species associated with each mammalian group was determined and presented in Microsoft excel spread sheet.

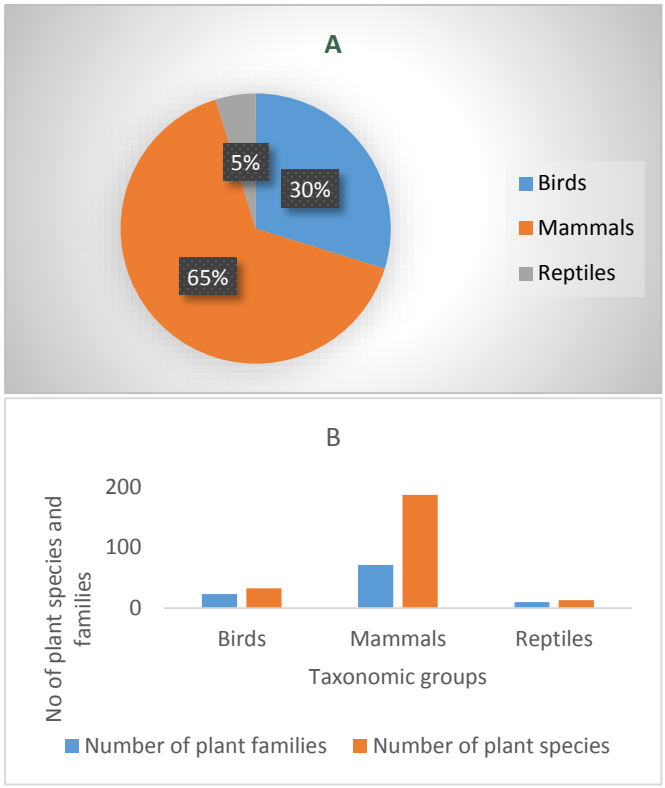
The size of the fruits and seeds were rarely presented in the studies reviewed. It therefore required direct internet search for this data to fulfil the set objective. To proceed with this, the frequency of interactions was used (Vázquez et al. **2015**) where the size (mm) of both fruits and seeds was organized in ranges/classes and the frequency of vertebrate groups that fell in each range/class was considered to determine the most frequent taxonomic group in each size range. For fruits, the size ranges considered were; <5, 5-10, 10.1-20, 20.1-30, 30.1-40, 40.1-50 and 50.1-100. For the case of seeds, the size ranges considered were; <1, 1-5, 5.1-10, 10.1-20, 20.1-30, >30. At this level, terrestrial vertebrate disperser categories considered were; birds, primates, rodents, bats, ungulates and reptiles. Data was arranged in Microsoft excel spreadsheet as size ranges (mm) with the frequency of each of the disperser group considered.

3. RESULTS

3.1 TAXONOMIC GROUP DIVERSITY

A total of 104 terrestrial vertebrate species was recorded, of which birds accounted for 30%, mammals 65% and lastly reptiles with only 5% *(figure1 part A)*. This showed a high species diversity in the group of mammals (68 species) followed by birds (31 species) and then reptiles (5 species).

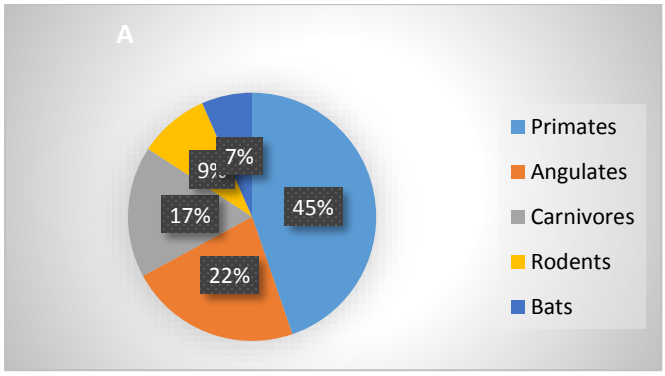
Figure 1: Large terrestrial vertebrate taxonomic groups and the associated plant species and families

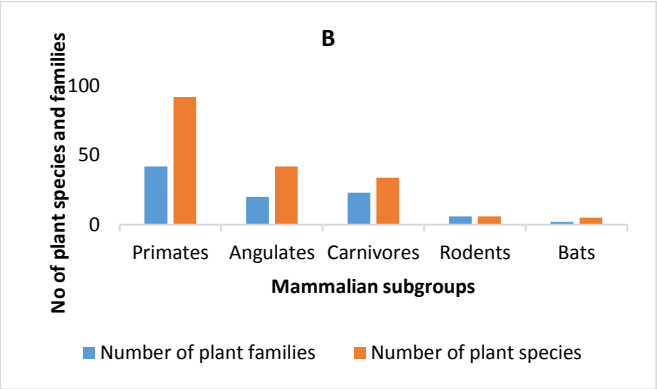


3.2 MAMMALIAN DIVERSITY

The species diversity in this case was high in primate subgroup which accounted for 45% (34) of the total number of species within the group. However, the dominance was not very high in comparison to the first instance where mammals over dominated birds and reptiles. Here, ungulates accounted for 22% and also carnivores with 17%, the least being rodents and bats with 9% and 7% respectively.

Figure 2: Mammalian sub groups and the associated plant species and families

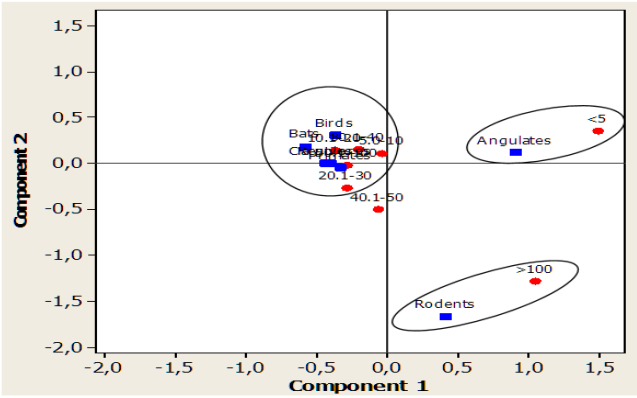




3.3 FRUIT SIZE AND ASSOCIATED DISPERSERS

Carnivores, primates, bats reptiles and to the small extent birds were associated with the fruit size ranges of 5-10, 10.1-20 and 20.1-30 while ungulates were classed in the <5 size range. Rodents dispersed fruits ranging from 40.1-50 and >100 but data was not sufficient enough to be relied on as opposed to ungulates that were accompanied by enough and reliable set of data. The size range of 50.1-100 was not associated to a specific vertebrate group. It can be noted that there was no clear difference in fruit sizes predated by different terrestrial vertebrate groups except a clear distinction in ungulates that predated small fruits of <5mm.

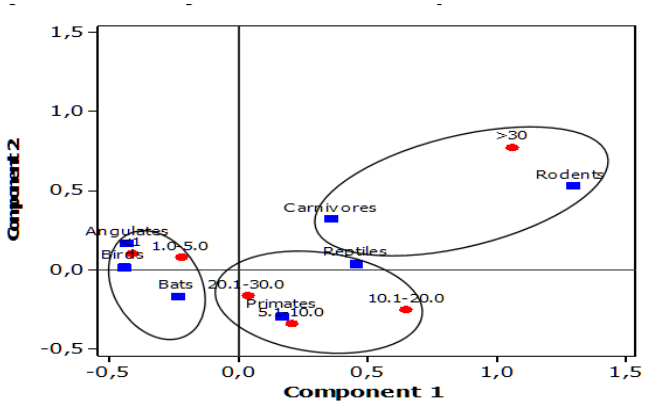
Figure 3: The fruit size ranges and the terrestrial vertebrate dispersers



3.4 SEED SIZE AND ASSOCIATED DISPERSERS

The ungulates, birds and to smaller extent bats dispersed small sized seeds (<5 and 1.0-5.0mm). Rodents, reptiles and carnivores dispersed seed sizes of 10.1-20.0 and >30mm, but rodents dispersed seeds of >30mm contrary to reptiles and carnivores that are much close to the dispersion of 10.1-20.0 mm sized seeds. Finally, the isolated vertebrate group of primates was found to be dispersing seeds of 5.1-10.0 and 20.1-30.0mm and this was the only vertebrate group to dispersed both small and large seeds in significant numbers. Briefly, ungulates and birds are observed as the dispersers of small seeded plants while the big seeded plants may be dispersed by rodents, primates and to the smaller extent by carnivores, other groups being intermediates

Figure 4: The seed size ranges and the terrestrial vertebrate dispersers



4. DISCUSSION

4.1 TAXONOMIC GROUP DIVERSITY

Vertebrate dispersal exerts a strong role in the identity of seeds and seed banks (Wandrag et al. **2015**). Species richness is the only factor for the frugivore assemblage that affects the probability of seed dispersal in degraded landscapes (García and Martínez **2012**). Findings showed that the vertebrate disperser species diversity is proportional to the plant species dispersed due to functional complementarity between these species (García and Martínez **2012**). Mammals play a great role in seed dispersal compared to others due to their high diversity (Matias et al. **2010**, McConkey et al. **2014**). Most plants produce fleshy fruits (Greenberg and Walter **2010**) that are preferred by mammals (Koike et al. **2008**) and this partly explains why mammalian species diversity was higher than birds and reptiles. Therefore extinction of mammals is disastrous to the structure and composition of plant communities in various ecosystems (Wang et al. **2007**). Birds are also greatly involved in seed dispersal (Garcia et al. **2010**, Heleno et al. **2011**). Ecosystem fluxes and mechanisms separated by times and distances are effectively linked by birds because of their ability to fly (Whelan et al. **2008**). The species diversity in reptile group was less possibly due to diet selectivity and less information available on the species that makes it up (Godinez-Alvarez **2004**), thus less number (13) of plant species. Galàpagos tortoises are important in ecosystem structuring due their ability to regularly move large quantities of seeds over reasonably long distances to places favorable for new plant establishment (Blake et al. **2012**).

4.2 MAMMALIAN DIVERSITY

The dominance of primates was because fruits are their favourite food (Chapman and Russo **2007**). Recent research has shown that primates provide unique seed dispersal services that cannot be compensated for by any other taxa (Clark et al. **2001**). Despite this indispensable role, half of the world's primates is threatened (Aslan **2013**) and this implies the need for adaptive conservation measures (Lambert **2011**). Ungulates can play a crucial role in dynamics of plant community (Albert et al. **2015**) and they do not primarily target fruits unlike most of the primates, they instead search for fleshy leaves and stem parts and end up dispersing seeds

accidentally by either endo-zoochory or epi-zoochory (Albert et al. **2015**). Carnivores not only disperse seeds (Koike et al. **2008**) from their parent plants but also enhance germinability (Aronne and Russo **1997**). The findings shows that carnivores accounted for 17% (13 species) of all mammal species recorded and effectively dispersed 34 plant species from 23 families, most of which were large seeded plants, thus they have a remarkable effect on forest dynamics (Nakashima et al. **2010**). Carnivorous low species diversity in comparison with primates and ungulates could be explained by their preferred diet which is dominated by meat (Pereira et al. **2014**). Rodents and bats were represented by the small number of species, 7 and 5 that dispersed 6 and 5 plant species respectively. This number looked low but it did not mean less participation in an ecosystem functionality (Mello et al. **2011**, Sunyer et al. **2013**). It may also be attributed to less attention given to these groups of animals in the domain of seed dispersal since data was obtained from published studies.

4.3 FRUIT SIZE AND ASSOCIATED DISPERSERS

The size of the fruit determines the animal groups adapted for its dispersal (Flörchinger et al. **2010**, Burns **2013**). Results obtained from this review showed that different seed categories were associated with different terrestrial vertebrate dispersers which is consistent with the results found by (Flörchinger et al. **2010).** However some vertebrate groups were found in the same size classes which meant no significant difference between them. According to the results obtained from simple correspondence analysis (SCA), carnivores and primates predated fruits of 20.1-30 and 10.1-20mm (medium sized to large fruits). Considering carnivores, the findings are consistent with the study by (Takahashi et al. **2008**) on the foraging behavior of the Japaneese Black Bear (*Ursus thibetanus japonicus).* A study conducted by (Flörchinger et al. 2010) confirmed that primates selected large fruits over the small ones that were preferred by birds, but in this review, the output from analysis was general in favor of medium sized class that dominated the large class, otherwise primates and carnivores dispersed more large seeds of 50.1-100mm than any other group.

Birds and bats were associated with size class of 5-10. Most of the bird species have small gapes that limit them from swallowing large fruits (Flörchinger et al. **2010**). The consumption of small fruits by birds may also be attributed to the reduction in number of large species due to different threats (Galetti and Pizo **2013**). Bats were found dispersing seeds that were too large to be dispersed by some bird species (Jordaan et al. **2012**) but the size of course remained small which can as well be explained by their size. Sometimes, bats and birds attack large fruits by spatting them and getting out seeds hence dispersal possibilities. Reptiles were as well associated to this medium sized fruit class because lizards and tortoises that dominate hence predating medium sized fruits (Jerozolimski **2003**). Rodents were associated to the size classes of large fruits but data retrieved were not sufficient enough to be globally generalized. Fruit size was considered among the minor factors that influence the removal of fruits and their seeds in rodents (Perea et al. **2011**). Ungulates were associated with the smallest fruit size class which is connected to domination of herbivores that prefer grazing on herbaceous species particularly of Poaceae family (Treydte et al. **2013**) which are characterised by small fruits. Due to their large

surface area, some small hooked fruits can adhere to their skin and be transported to distant places. Small seeds have a likelihood also to adhere to the hooves of large ungulates (hoof epizoochory) and be transported away from parent plants (Albert et al. **2015**).

4.4 SEED SIZE AND ASSOCIATED DISPERSERS

Fruit size factor may be different from seed size factor. This is primarily based on the type of the fruit such as a drupe or a berry. The size of the fruit is not directly proportional to seed size hence suitability differences to different dispersal agents. Small sized seeds were dispersed by ungulates, birds and bats. As discussed in the previous part, various species of birds possess small gape that limits them to swallowing large seeds (Flörchinger et al. **2010**, Gosper and Vivian-Smith **2010**), the same applies to bats (Seltzer et al. **2013**) while ungulates prefer small seeded species of Poaceae family (Treydte et al. **2013**) and the lightness (small size) characteristic of seeds to be attached to their hooves and fur (Albert et al. **2015**). Rodents, reptiles and carnivores were grouped together in the seed size classes of >30, and 10.1-20.0 mm. From figure 4, rodents dispersed large seeds though it was not reliable due to less data. Carnivores suit the category because of the large sized seeds they disperse of which some may be drupes and capsules with large seeds. In the previous section, reptiles dispersed medium sized fruits (Jerozolimski **2003**), which could be characterized by medium to large seeds. Primates are known for ingesting and dispersing smaller seeds more than larger seeds (Oliveira and Ferrari **2000**). The effect of seed and fruit attributes on the probability of being ingested is associated with seed shadow consequences because primate ingested seeds are usually dispersed to distant places than those dispersed by spitting (McConkey **2000**). Based on findings of this study, they fell in the seed size classes of 5.1-10.0 and 20.1-30.0 that evidently showed their clear participation in dispersal of both small and large seeds. This together with herbivory maintains the demography of plant communities hence regarded as ecosystem engineers (Chapman et al. **2013**).

5. CONCLUSION AND PERSPECTIVES

Ecosystem architecture is specially engineered by animals particularly vertebrates that are capable of clearly exhibiting a certain level of intelligence in fruit predation and consequently displacing seeds from their parents to more favorable conditions for establishment. The difference in the diversity of terrestrial vertebrates involved in seed dispersal signifies the most indispensable animal groups, on which their extinction may lead to eminent traumatic effect on the ecosystem structure. Therefore in first place, knowing these groups such as mammals and birds and moving further to distinguish the most active sub-groups within these major groups is important to appreciate the priority status and appropriate measures for adaptive conservation. The findings of the study clearly shows that some animals are completely outweighed in as far as plant seed dispersal is concerned as exemplified by reptiles, bats and amphibians that were not reported in this study which necessitates deep

research in these less frequent groups to find out the truth about their role in structuring the plant communities in terrestrial ecosystems.

Animal adaptation to seed dispersal is driven by different plant traits, one of which is seed and fruit size. Different terrestrial vertebrate groups can disperse different seed and fruit sizes, but still others disperse the same sized fruits and seeds despite being morphologically different. The uniqueness of some plant seed dispersal agents for example ungulates that disperse very small fruits and seeds, should be the field of great concern as loss in the diversity or even abundance may be followed by loss of the plant species that solely rely on this animal group. The findings thus, showed the expected seed dispersal agent given a seed and/or fruit size though it was not evident in some animal categories such as rodents and bats that were accompanied by less data. In the same way, other researches such as the relationship between plant life form and the dispersal agent, plant life form and the size of fruits and seeds, the habitat type and dispersal agents, life form and the type of the fruit and many other relationships can be conducted to clearly understand the whole interaction process. The method used in data extraction from various primary studies enabled collection of relevant data based on the set parameters but it was partly limited to the articles publicly accessed online.

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7. APPENDICES

APPENDIX I: Data Extracted From The Published Primary Studies On The Plant Seed Dispersal By Terrestrial Vertebrates

Animal species	Vertebrate taxonomic group	Mammal groups	Plant family	Plant species	Fruit fruit type/life form	Fruit size (mm)	Seed size (mm)	Habitat type	Reference
Ateles spp. (spider monkeys)	Mammal	Primate	Moraceae Cecropiaceae Myristicaceae	*Brosimum sp.* *Cecropia sp.* *Virola sp.*				Forest	Campbell et al. 2005
Nasalis larvatus (proboscis monkeys)	Mammal	Primate	Moraceae Phyllanthaceae Rubiaceae	*Ficus sp.* *Antidesma thwaitesianum* *Nauclea subdita*	Drupe/Shrub Berry/Shrub	8 18	5 1.5	Tropical forest	Matsuda et al. 2013
Dusicyon culpaeus (Fox)	Mammal	Carnivore	Lauraceae	*Cryptocarya alba*	Drupe/Tree	20	13	Savannah	Bustamante et al. 1992
Tapirus Indicus (Tapirs)	Mammal	Ungulate	Dilleniaceae Fabaceae Moraceae	*Dillenia indica* *Tamarindus indica* *Artocarpus integer*	Berry/Shrub Pod/Tree Syncarp/Tree	100 150 150	13 20 30	Forest	Campos-Arceiz et al. 2012
Turdinae *Catharus guttatus* *Turdus migratorius* *Mimus polyglottos* *Sturnus vulgaris* *Bombycilla cedrorum*	Bird		Caprifoliaceae	*Lonicera maackii*	Berry/Shrub	5	1	Shrub land	Bartuszevige and Gorchov 2006
Iguana iguana (Green iguanas)	Reptile		Anacardiaceae Araliaceae Smilacaceae	*Tapirira guianensis* *Didymopanax morototoni* *Smilax sp*	Drupe/Tree Berry/Tree	20 12	10 4	Forest	Moura et al.2014
Cattle	Mammal	Ungulate	Boraginaceae	*Cynoglossum officinale L*	Nut/Herb	5	2	Woodland	Clerck-Floate, 2007
Pan troglodytes (chimpanzees)	Mammal	Primate	Oleaceae Myrtaceae.	*Olea capensis* *Syzygium guineense*	Drupe/Shrub Drupe/Tree	20 30	13 23	Afromontane forest	Gross-Camp and Kaplin 2005
Alouatta. guariba (brown howler monkey)	Mammal	Primate	Cannabaceae Boraginaceae Myrtaceae	*Celtis spinosa* *Cordia sellowiana* *Eugenia pyriformis*	Drupe/Shrub Drupe/Shrub Drupe/Tree	7 15 28	3 9 13		Martins 2006
*Brachyteles arachnoides (*muriquis)	Mammal	Primate	Cannabaceae Myrtaceae Caricaceae	*Celtis spinosa* *Eugenia ligustrina* *Jacaratia spinosa*	Drupe/Shrub Berry/Tree Drupe/Tree	7 12	3 3	Forest	Martins 2006

			Rubiaceae	*Rudgea sp.*		10	6.3		
Ramphastos sulfuratus R. swainsinii	Bird		Flacourtiaceae	*Casearia nitida*	Capsule/Tree	15	6	Open plantation	Howe and Primack, 1975
Cercopithecus lhoesti, (l'Hoest's monkeys)	Mammal	Primate	Sapotaceae Rubiaceae Myrtaceae	*Chrysophyllum rwandense Sericanthe leonardii Syzygium guineense*	Berry/Tree Drupe/Tree Drupe/Tree	50 50 30	10 18 23	Sem-iidecidous forest	Gross-Camp and Kaplin, 2011
Pan troglodytes (chimpanzees)	Mammal	Primate	Meliaceae Malvaceae **Urticaceae** Oleaceae Penaeaceae Rosaceae Myrtaceae	*Ekebergia capensis D Grewia mildibraedii Myrianthus holstii D Olea capensis D Olinia rochetiana D Prunus africana D Syzygium guineense*	Berry/Tree Berry/Tree Nut/Shrub Drupe/Tree Berry/Shrub Berry/Tree Drupe/Tree	20 15 40 20 10 13 30	2 1.2 3 13 1.1 1.3 23	Sem-iidecidous forest	
Tamias senex (Shadow Chipmunk)	Mammal	Rodent	Pinaceae	*Pinus ponderosa*	Cone/tree	130	19	Thick forest	Fiehler, 2007
Nucifera Columbiana (Clark's nutcrackers)	Bird		Pinaceae	*Pinus albicaulis*	Cone/Tree	60	9	Open plantation	Tomback, 1982
Lagothrix cana (woolly monkeys)	Mammal	Primate	Sapotaceae	*Manilkara bidentata*	Berry/Tree	40	10	Thick forest	Levi and Peres
Bellbirds Bilvereyes.	Bird		Loranthaceae Loranthaceae Loranthaceae Loranthaceae Loranthaceae	*Alepis flavida, Peraxilla colensoi, P. tetrapetala, Ileostylus micranthus Tupeia antarctica*	Berry/Shrub	14	1	Clear forest	LADLEY and DAVE KELLY, 1996
Howler monkeys	Mammal	Primate	Melastomataceae Arecaceae Myrtaceae Fabaceae	*M. cinnamomifolia Syagrus oleraceae Myrcianthes pungens C. langsdorffii*	Berry/Tree Drupe/Tree Drupe/Tree Capsule/Tree	5 40 15 14	<1 32 9 6	Semi-decidous forest	FIGUEIREDO &LONGATII, 1997
Callithrix jacchus (Marmosets)	Mammal	Primate	Melastomataceae Moraceae	*M. cinnamomifolia Ficus sp.*	Berry/Tree Syconium/Tree	5 14	<1 1	Semi-decidous forest	
Pan paniscus (bonobo)	Mammal	Primate	Ebenaceae Meliaceae Clusiaceae Sapotaceae	*Diospyros sp. Guarea aurentii Garcinia sp. Manilkara yangambiensis*	Capsule/Tree Berry/Tree	20 55	14 10	Lowland tropical rain forest	Beaune et al.2013
Cattle and horse	Mammal	Ungulate	Urticaceae Caryophyllaceae	*Urtica dioica Juncus spp.*	Achene/Herb	1.5	1	Grassland	Cosyns et al. 2005
Goats	Mammal	Ungulate	Cistaceae Rhamnaceae	*Cistus albidus L. Rhamnus lycioides L.*	Capsules/Shrub Berry/Shrub	10 6	3 1	Shrub land	Grande et al 2013
Apodemus sylvaticus	Mammal	Rodent	Fagaceae	*Quercus ilex*	Arcon/Tree	10	<1		Gómez et al. 2007
Aceros cassidis (Sulawesi red-knobbed hornbill)	Bird		Myristiceae Annonaceae Myrtaceae	*Horsfelida brachiate Cananga odorata Syzygium sp.*	Berry/Tree	20	5	Lowland tropical rain forest	Kinnaird 1998
Sheep	Mammal	Ungulate	Fabaceae Apiaceae Poaceae Plantaginaceae	*Trifolium angustifolium Daucus carota Hordeum murinum Plantago lagopus*	Pod/Herb Umbel/Herb Caryopsis/Herb Capsule/Herb	8 4 80 2.5	4 1 3.5 1.7	Shrub land	Manzano and Malo, 2006
Artibeus jamaicensis (Jamaican fruit bat)	Mammal	Bat	Moraceae	*Ficus trigonata*	Syconium//Tree	10	1		August, 1981
Orioles, Tanagers, Trogons and Flycatchers	Bird		Moraceae	*Ficus continifolia*	Syconium//Tree	10	1	Tropical rain forest	Jordano, 1983
Pseudalopex culpaeus, (Native fox)	Mammal	Carnivore	Zygophylaceae Anacardiaceae	*Porlieria chilensis Schinus molle*	Nut/Shrub Berry/Tree	7.8 5	2 <1	Thornscrub	Silver et al. 2005
Tapirus terrestris (Lowland Tapir)	Mammal	Ungulate	Arecaceae Arecaceae Arecaceae Fabaceae Fabaceae Fabaceae Moraceae Myrtaceae Anacardiaceae	*Euterpe edulis Syagrus romanzoffiana S. oleracea Copaifera langsdorffii Enterolobium contortisiliquum Inga sp. Ficus sp. Psidium guajava Mangifera indica*	Drupe/Tree Drupe/Tree Drupe/Tree Capsule/Tree Pod/Tree Berry/Tree Drupe/Tree	13 30 50 14 35 40 60	7 21 32 6 8 3 26	Forest	Galetti et al, 2001
Oryctolagus cuniculus (Rabbit)	Mammal	Ungulate	Rubiaceae	*Plocama pendula*	Berry/Shrub	10	1	Shrub land	Nogales et al. 1995
Leontopithecus chrysomelas (golden-headed lion tamarins)	Mammal	Primate	Melastomataceae Celastraceae Urticaceae *Passifloraceae* Myrtaceae Fabaceae	*Henriettea succosa Cheiloclinium cognatum Pourouma acutiflora Passifloraceae sp. Myrcia fallax Inga subnuda*	Berry/Shrub	40	15	Tropical forest	Cardoso et al. 2011
Aouatta palliate (Howling monkeys)	Mammal	Primate	Moraceae	*Brosimum alicastrum*	Nut/Tree	15	9	Ever green rain forest	Estrada and Coates-Estrada 1984
Rhinoceros unicornis	Mammal	Ungulate	Euphorbiaceae	*Trewia nudiflora*	Berry/Tree	35	2	Riverine forest	Coates-Estrada and Estrada 1986
Platyrrhinus lineatus Geoffroy	Mammal	Bat	Moraceae	*Ficus sp.*				Smi-decidous fores	Figueiredo and Perin, 1995
Didelphis Virginiana (Opossums)	Mammal	Ungulate	Rosaceae	*Rubus rosifolius*	Berry/Herb	20	1	Forest gragment	Cáceres and Monteiro-Filho, 2007
Paradoxurus hermaphroditus (common palm civets)	Mammal	Carnivore	Sapindaceae	*Nepheliym lappaceum*				Rain forest	Nakashima and Sukor 2010
Felis catus	Mammal	Carnivore	Cupressaceae Rutaceae Solanaceae	*Juniperus phoenicea Neochamaelea pulverulenta Withania aristana*	Cone/Tree	14	5	Open forest	Nogales, 1996
Eulemur fulvus rufus (Brown lemur)	Mammal	Primate	Malvaceae	*Grewia grandulosa*	Drupe/shrub	28	19	Dry deciduous forest	Spehn and Ganzhorn
Alouatta spp (Howler monkeys)	Mammal	Primate	Moraceae	*Ficus enormis*	Syconium/Tree	13	3		de Figueiredo 1993
Tapirus terrestris (Lowland Tapir)	Mammal	Ungulate	Arecaceae	*Maximiliana maripa.*	Nut/Tree	60	40	Riverine forest	Fragoso et al. 2003
Anas crecca (teal/duck)	Bird		Characeae Cyperaceae	*Chara oogonia*					Brochet et al. 2010

			Juncaceae Potamogetonaceae	*Eleocharis palustris* *Juncus spp.* *Potamogeton pusillus*					
Cercopithecus nictitans (putty-nosed monkey)	Mammal	Primate	Annonaceae Burseraceae Cannabaceae Fabaceae Sapindaceae Rubiaceae	*Isolona pleurocarpa* *Santiria trimera* *Celtis gomophylla* *Parkia filiciodea* *Deinbollia pinnata* *Rytigynia umbellulata*	Pod/Tree Drupe//Tree Drupe/Tree Berry/Shrub Berry/Shrub	45 25 10 15 9	8 17 6 1.1 <1	Montane Forest	Chapman et al. 2009
Didelphis aurita (the common opossum)	Mammal	Ungulate	Urticaceae	*Cecropia hololeuca*	Achene/Tree	160	3	Tropical semi-deciduous forest	de Viveiros and Garcia 1999
Sheep	Mammal	Ungulate	Urticaceae	*Urtica dioica*	Achene/Herb	1.5	1	Grassland	Kuiters & Huiskes, 2010
Didelphis albiventris (White-eared opossum)	Mammal	Ungulate	Piperaceae Urticaceae Solanaceae Cannabaceae Urticaceae	*Piper L.* *Cecropia Loefl.* *Solanum L.,* *Trema Lour.* *Urera Gaudich*	 Achene/Tree Drupe/Tree Achene/Liana	 150 5 3.5	 2.3 3.8 3	Seasonal semideciduous forest.	Cantor et al. 2010
Cacajao melanocephalus ouakary, Chiropotes chiropotes and *Chiropotes albinasus*	Mammal	Primate	Rubiaceae Lecythidaceae Fabaceae Fabaceae	*Duroia velutina* *Eschweilera tenuifolia* *Inga rhynchocalyx* *Macrolobium acaciifolium*				Dense forest	Barnett, 2012
Vulpes vulpes L (Red fox.)	Mammal	Carnivore	Cannabaceae	*Celtis australis L.*	Berry/Tree	10	1	Shrub land	Juan et al. 2006
Gorilla gorilla gorilla (Low land gorilla)	Mammal	Primate	Sapindaceae Euphorbiaceae	*Ganophyllum giganteum* *Uapaca guineensis*	Drupe/Tree Berrylike/Tree	20 25	15 7	Tropical forest	Petre et al. 2013
Dasyprocta ssp. (common agouti)	Mammal	Rodent	Arecaceae	*Astrocaryum aculeatissimum*	Drupe/Tree	50	33	Rainforest	Donatti et al. 2009
Papio Anubis (Baboon)	Mammal	Primate	Euphorbiaceae Meliaceae Rubiaceae	*Securinega virosa* *Azadirachta indica* *Nauclea latifolia*	Berrylike/Shrub Drupe/Tree Drupe/Shrub	5 25 80	<1 10 30	Savannah woodland	Lieberman & Swaine, 1979
Leontopithecus chrysopygus (black lion tamarin)	Mammal	Primate	Burseraceae Cannabaceae Acanthaceae Boraginaceae	*Protium sp* *Celtis pubescens* *Mendoncia sp.* *Cordia sp*	Berrylike/Tree	5	<1	Semideciduous mesophytic forest	Passos, 1997
Ursus arctos (Brown Bears)	Mammal	Carnivore	Ericaceae Grossulariaceae Araliaceae Rosaceae Liliaceae Adoxaceae	*Vaccinium spp.* *Ribes spp.* *Oplopanax spp.* *Rubus spp.* *Streptopus spp.* *Sambucus spp.*				Rainforest	Willson1 and gende, 2004
Pan troglodytes (chimpanzees)	Mammal	Primate	Moraceae Myristicaceae Anacardiaceae	*Myriallfhus holstii* *PycnanthusAngolensis* *Pseudospondias microcarpa*	 Drupe/Tree Berry/Tree	 35 25	 10 6	Woodland	Takasaki, 1983
Corvus corax	Bird		Solanaceae Cactaceae Rubiaceae Rubiaceae Cupressaceae Arecaceae Liliaceae Myristicaceae	*Lycium intricatum* *Opuntia ficus-indica* *Rubia fruticosa* *Plocama pendula* *Juniperus sp* *Phoenix canariensis* *Asparagus pastorianus* *Myrica faya*	Berry/Shrub Tuna/Herb Berry/Shrub Berry/Shrub Drupe/Tree Berry/Shrub Drupe/Shrub	14 50 5 5 11 5 5	1 2 <1 <1 5 <1 <1	Shrub land	Nogales et al. 1999
Domestic goats	Mammal	Ungulate	Cactaceae	*Cactus spp.*				Thornscrub	Baraza and Valiente-Banuet, 2008
Macaca fuscata (Japanese macaques)	Mammal	Primate	Actinidiaceace Aquifoliaceae	*Actinidia arguta* *Ilex macropoda* *Akebia sp.*	Berry/Liana Berry/Tree	40 6.5	2.5 1	Coniferous fores	Tsuji, 2011
Hemiphaga novaeseelandiae (Kereru)	Bird		Lauraceae	*Beilschmiedia tawa*	Berry/Tree	33	1.5	Forest	Bell, 1995
Trachemys scripta elegans (red-eared sliders)	Reptile		Moraceae Poaceae Polygonaceae	*Morus spp.* *Echinochloa crus-galli* *Rumex crispus*	 Achene	 5	 1		Kimmons and Moll
Macaca mulatta (rhesus macaques)	Mammal	Primate	Moraceae Phyllanthaceae	*Ficus sp.* *Baccaurea sp*				Secondary forest	Tsuji et al. 2013
Chlorocebus tantalus tantalus (tantalus monkeys)	Mammal	Primate	Zingiberaceae Guttiferaceae Apocynaceae Vitaceae Euphorbiaceae Fabaceae	*Aframomum angustifolium.* *Harungana madagascariensis* *Landolphia sp.* *Leea guineensis* *Bridelia speciosa* *Albizia gummifera*	Berry/Herb Berrylike/Shrub Berry/Shrub Drupe/Shrub Pod/Tree	60 4 6 5 25	5 <1 <1 4 6	Montane forest	Agme et al. 2009
Terrapene carolina bauri (Florida box turtle)	Reptile		Arecaceae	*Serenoa repens*	Drupe/Tree	20	12	Pine rockland forest	Liu et al. 2004
Melursus ursinus (Sloth Bear)	Mammal	Carnivore	Myrtaceae Anacardiaceae	*Syzigium cumini* *Mangiifera indica*	Berry/Tree Drupr/Tree	50 60	40 26	Rain forest	Tobler, 2002
Helarctos malayanus (sun bear)	Mammal	Carnivore	Convolvulaceae Moraceae Burseraceae	*Erycibe maingayi* *Ficus consociata* *Canarium pilosum*	 Syconium/Tree Drupe/Tree	 11 45	 1 27	Ever green rain forest	McCONKEY and Galetti 1999
Odocoileus virginianus Zimm (white-tailed deer)	Mammal	Ungulate	Amaranthaceae Lythraceae Rosaceae Amaranthaceae Caprifoliaceae	*Chenopodium glaucum* *Lythrum salicaria* *Potentilla norvegica* *C. album* *Lonicera sp.*	Achene/Herb Capsule/Herb Achene/Herb Achene/Herb	3 4 2 2	<1 <1 <1 <1	Deciduous forest	Myers et al. 2004
Lagothrix lagothricha (Woolly Monkeys)	Mammal	Primate	Urticaceae Moraceae Melastomataceae Urticaceae Urticaceae Fabaceae Lecythidaceae	*Cecropia spp,* *Ficus spp.* *Henriettella spp.* *Coussapoa spp.* *Pourouma bicolor* *Inga bonplandiana* *Gustavia hexapetala*	 Drupe/Tree Berry/Tree	 20 50	 15 10	Tropical rain forest	Stevenson, 2000
Odocoileus virginianus (White-tailed deer)	Mammal	Ungulate	Caprifloriaceae	*Lonicera maackii*	Berry/Shrub	5	1	Agricultural-forest matrix	Guiden et al 2015
Caracara plancus (Crested caracaras)	Bird		Arecaceae	*Attalea phalerata*	Berry/Tree	52	10		Galetti and Guimarães, 2004
Macaca fuscata (Japanese macaques)	Mammal	Primate	Actinidiaceace Rosaceae	*Actinidia arguta* *Rabus phoenicolasius*	Berry/Liana Berrylike/Shrub	40 10	2.5 1	Warm temperate forest	Otani, 2003

Sus scrofa (feral pigs)	Mammal	Ungulate	Prumnopityaceae	*Prumnopitys taxifolia*	Berrylike/Tree	13	1		O'Connor* and Dave Kelly, 2012
Scatter-hoarding rodents	Mammal	Rodent	Lecythidaceae	*Bertholletia excelsa*	Capsule/Tree	150	50	Flooded forest	Haugaasen et al. 2010
Ptilogonys cinereus (Gray Silky-flycatchers) *Myiozetetes similis* (Social Flycatchers);	Bird		Loranthaceae	*Psittacanthus schiedeanus*	Berry/Shrub	20	1.3	Cloud forest remnant	Buen and Ornelas 2001
Civets (Viverridae)	Mammal	Carnivore	Lamiaceae Rosaceae	*Vitex glabrata* *Prunus ceylanica*	Berry/Tree Drupe/Tree	15 30	1 10	Tropical forest	Chakravarthy and Ratnam 2015
Geochelone denticulata (Amazonian tortoise)	Reptile		Apocynaceae, Fabaceae Annonaceae Moraceae Moraceae Moraceae	*Rauvolfia micrantha* *Lecointea amazonica* *Rollinia sp.* *Helicostylis tomentosa, Ficus spp.* *Brosimum lactescens*	Capsule/Shrub Capsule/Tree Drupe/Tree Drupe/Tree	7 50 30 20	3 35 24 15	Rainforest	Guzmán and Stevenson
Propithecus diaderna edwardsi, Eulemur fuluus rufus, Eulemur rubriventer)	Mammal	Primate	Anacardiaceae Sapotaceae Myrtaceae	*Protorhrrs sp.* *Chrysophyllum madagascariensis* *Eugenia sp.*	Berry/Tree	60	10	Montane rain forest	Overdorff and Strait 1998
*Lemur catta (*Ring-tailed Lemurs)	Mammal	Primate	Fabaceae	*Tamarindus indica*	Pod/Tree	150	20	Gallery forests	Mertl-Millhollen et al. 2011
Nucifera Columbiana (Clark's nutcrackers)	Bird		Pinaceae	*Pinus albicaulis*	Cone/Tree	60	9	Open plantation	Hutchins and Lanner 1982
Cerdocyon thous (Crab-eating Fox)	Mammal	Carnivore	Myrtaceae	*Eugenia umbelliflora*	Berry/Tree	13	2	Rainforest	Cazetta and Galetti 2009
Saguinus mystax Saguinus fuscicollis	Mammal	Primate	Vitaceae	*Leonia glycycarpa Pourouma sp.,*	Dupe/Tree	30	23	Rainforest	Garber 1986
Papio cynocephalus Cercopithecus albogularis	Mammal	Primate	Fabaceae	*Afzelia quanzensis*	Pod/Tree	100	10	Rainforest	Gathua, 2000
Heliosciurus rufobrachium Paraxerus palliatus	Mammal	Rodent							
Alouatta caraya (black and gold howlers)	Mammal	Primate	Myrtaceae Lauraceae Lauraceae	*Eugenia punicifolia* *Ocotea diospyrifolia* *Nectandra megapotamica*	Drupe/Shrub Drupe/Tree Drupe/Tree	26 15 6	14 8 4	Flooded forest	Bravo 2011
Podarcis lilfordi (lizard)	Reptile		Solanaceae	*Lycopersicon esculentum*	Berry/Liana	60	1.2		Castilla, 2009
Cerradomys subflavus	Mammal	Rodent	Arecaceae	*Allagoptera arenaria*	Drupe/Tree	25	18	Semi deciduous forest	Grenha et al. 2010
Pan paniscus (bonobo)	Mammal	Primate	Fabaceae	*Dialium spp.*				Rain forest	Beaune et al. 2013
Macaca fuscata (Japanese macaques)	Mammal	Primate	Myricaceae Lauraceae Lauraceae Lauraceae	*Myrica rubra* *Persea thunbergii* *Neolitsea sericea* *Litsea acuminata*	Berry/Tree Drupe/Tree Drupe/Tree Drupe/Tree	20 22 25 25	4 18 18 18	Rain forest	Tsujino and Yumoto, 2009
Sus scrofa (Wild boar)	Mammal	Ungulate	Moraceae Amaranthaceae Moraceae	*Morus sp.* *Amaranthus blitum* *Ficus religiosa*	 Achene/Herb Syconium/Tree	 2 15	 <1 1	Shrub land	Dovrat et al. 2012
Sylivia atricapilla Erithacus rebecula S. borin S. melanocephala Turdus merula	Bird		Rosaceae	*Rubus ulmifolius*	Berry/Herb	19	1		Jordano 1982
Chiroderma doriae C. villosum	Mammal	Bat	Moraceae	*Ficus sp.*				Humid forest	Nogueira and Peracchi
Lepus Capensis L (Hares)	Mammal	Ungulate	Poaceae Amaranthaceae Amaranthaceae Nyctaginaceae Poaceae Poaceae	*Tragus berteronianus* *Achyranthes aspera* *Pupalia lappacea* *Boerhavia repense* *Harpachne schimperi* *Themeda triandra*	Caryopsis/Herb Achene/Herb Achene/Herb Berrylike/Shrub Caryopsis/Herb Caryopsis/Herb	2 3 3 4 1.3 2	<1 <1 <1 <1 <1 <1	Grassland	Agnew and Flux 1970
Rabbit	Mammal	Ungulate	Caryophyllaceae Asteraceae Urticaceae Plantaginaceae	*Sagina apetala* *Senecio jacobaea* *Urtica dioica* *Veronica arvensis*	Capsule/Herb Achene/Herb Achene/Herb Capsule/Herb	5 4 1.5 5	<1 <1 1 <1	Grassland	Pakeman et al. 1999
Sheep	Mammal	Ungulate	Fabaceae Fabaceae Fabaceae	*Trifolium stellatum L.* *T. tomentosum L.* *T. campestre Schreb*	Pod/Herb Pod/Herb Pod/Herb	5 5 5	1 1 1	Grassland	Russi et al. 1992
Dromiciops australis	Mammal	Marsupial	Santalaceae	*Viscum album*	Berry/Tree	25	10	Temperate forest	Amico and Aizen 2000
Vulpes vulpes L. (red fox)	Mammal	Carnivore	Myrtaceae	*Myrtus communi*	Berry/Shrub	8	1		Aronne and Russo 1997
Ursus americanus (black bears)	Mammal	Carnivore	Rosaceae Rosaceae Berberidaceae Anacardiaceae Caprifoliaceae	*Amelanchier alnifolia* *Prunus virginiana* *Mahonia repens* *Rhus trilobata* *Symphoricarpos oreophilus*	Berry/Shrub Drupe/Shrub Berry/Shrub Berry/Shrub Drupe/Shrub	13 10 12 7 25	1 7 1 1 16		Auger et al. 2002
Loxodonta africana africana	Mammal	Ungulate	Fabaceae	*Acacia erioloba*	Pod/Tree	28	5	Forest	Dudley 1999
Tapirus indicus (Tapirs)	Mammal	Ungulate	Arecaceae	*Syagrus romanzoffiana*	Drupe/Tree	30	21	Atlantic forest	Giombini et al. 2009
Cyanocitta cristata (blue jays)	Bird		Fagaceae	*Fagus grandifolia*	Nut/Tree	15	4	Woodlot	Johnson and Adkisson 1985
Nucifera Columbiana (Clark's nutcrackers)	Bird		Pinaceae	*Pinus flexilis*	Cone/Tree	40	10	Open plantation	Lanner and Vander Wall 1980
Cattle	Mammal	Ungulate	Fabaceae	*Biserrula pelecinus*	Pod/Shrub	20	2		Malo and Suarez 1995
Cervus elaphus (Red deer)	Mammal	Ungulate	Cistaceae	*Cistus ladanifer*	Capsules/Shrub	10	<1	Mediteranean ecosystem	Malo and Suárez 1998
Pteropus dasymallus (Orii's flying fox)	Bat		Combretaceae Moraceae	*Terminaria catapa* *Ficus sp.*	Drupe/Tree	60	30		Nakamoto et al. 2009
Macaca fuscata yakui (Yakushima macaque)	Mammal	Primate	Moraceae Pentaphylacaceae Ericaceae	*Ficus thunbergii* *Eurya japonica* Euphorbiaceae	Syconium/Tree Berrylike/Shrub Berry/Shrub	20 5 6	1 <1 <1	Warm temperate forest	Otani and Shibata 2000
Civettictis civetta (African civet)	Mammal	Carnivore	Burseraceae Myristicaceae Arecaceae Myristicaceae	*Dacryodes edulis* *Pycnanthus angolensis* *Elaeis guineensis* *Staudtia stipitata* *Trilepisium sp.*	Drupe/Tree Drupe/Tree Drupe/Tree Drupe/Tree	90 30 70 60	70 20 32 40	Rain forest	Pendje 1994

			Moraceae						
Canis latrans (Coyote)	Mammal	Carnivore	Ebenaceae	*Diospyros virginiana*	Berry/Tree	60	10		Roehm and Moran 2013
Alouatta palliata mexicana (Mexican howler monkeys)	Mammal	Primate	Moraceae	*Ficus* spp				Tropical rain forest	Serio-Silva and Rico-Gray 2003
Eulemur fulvus fulvus (common brown lemur)	Mammal	Primate	Lamiaceae Malvaceae	*Vitex sp.* *Grewia triflora*	Drupe/Shrub	10	7	Tropical dry forest	Sato 2012
Martes foina (Pine martens)	Mammal	Carnivore	Ericaceae Rosaceae	*Vaccinium myrtillus* *Rubus idaeus*	Berry/Shrub Berry/Herb	7 15	1 1	Temperate woodland	Schaumann and Heinken 2002
Cebus apella *Ateles aniscus*	Mammal	Primate	Rhamnaceae	*Ziziphus sp.*					Zhang and Wang 1995
Macaca fuscata yakui (Japanese monkeys)	Mammal	Primate	Lauraceae	*Persea thunbergii*	Drupe/Tree	22	18	warm temperate evergreen forest	Yumoto et al. 1998
Mitu salvini (Salvin's curassows)	Bird		Rubiaceae Moraceae	*Geophila repens* *Ficus sphenophylla*	Drupe/Herb Syconium/Tree	5 10	3 1	Lowland tropical forest	Yumoto 1999
Dicaeurn hirundinaceurn *Acanthaqenys rufogularis*	Bird		Loranthaceae	*Lysiana exocarpi*	Berry/Shrub	10	1		Yan 1993

APPENDIX II: The Frequency Of Different Vertebrate Groups Per Fruit Size Range

	Animal group						
Fruit size (mm)	Birds	Primates	Ungulates	Carnivores	Reptiles	Bats	Rodents
<5	0	1	18	0	0	0	0
5.0-10	9	19	13	7	2	1	1
10.1-20.0	7	21	6	8	4	0	0
20.1-30.0	0	16	3	3	1	0	1
30.1-40	2	7	2	0	0	1	0
40.1-50	0	4	2	2	1	0	1
50.1-100	4	6	3	5	1	0	1
>100	0	1	4	0	0	0	2

APPENDIX III: The frequency of different vertebrate groups per seed size range

	Animal group						
Seed size (mm)	Birds	Primates	Ungulates	Carnivores	Reptiles	Bats	Rodents
<1	4	9	15	1	0	0	1
1.0-5.0	13	23	26	12	4	1	0
5.1-10.0	4	15	3	3	1	0	1
10.1-20.0	0	13	2	3	2	0	2
20.1-30.0	0	6	4	2	1	1	0
>30	0	2	1	4	1	0	2