Hummingbird-pollination in the rainforest of Un poco del Chocó

Do artificial hummingbird feeders interfere with pollination?

Researcher
Ilse van Duuren
Supervisor
Nicole Büttner, Un poco del Chocó
Karin van Dueren den Hollander, HAS Den Bosch
Education
Applied Biology

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Institute
Un poco del Chocó

Researcher
Ilse van Duuren

Supervisor
Nicole Büttner
Un poco del Chocó
Ecuador
Email: unpocodelchoco@gmail.com
Website: www.unpocodelchoco.com

Karin van Dueren den Hollander
HAS Den Bosch
Postbus 90108
5200 MA ’s-Hertogenbosch
Website: www.hasdenbosch.nl

29th of August 2012

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This report is written during the internship of applied biology at Un poco del Chocó in Ecuador. During this internship the influence of feeders on hummingbird-pollinated plant species were studied through observing the visitations of hummingbirds on four different plants species and carry out a fruit and seed count on two different plant species. This research is important because there are a lot of feeders to attract hummingbirds without knowing what the effects of the feeders on the pollination of the hummingbird-pollinated plant species are.

I want to thank some people which supervised me during my intersnhip. Nicole Büttner thank you for your supervision during my internship. I learned a lot more about the hummingbirds and the hummingbird pollinated plant but I learned also new things about the rainforest in general. I am glad that I could do my internship at Un poco del Chocó. Karin van Dueren den Hollander thank you for your supervision of the HAS Den Bosch.

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Summary

Hummingbirds are the most important avian pollinators of Native American plants. It is important to investigate the influence of feeders on hummingbird-pollinated plants because the frequent use of hummingbird feeders might have an effect on the hummingbird-pollinated plant species, as well as it might have an influence on the hummingbird population. The pollination of flowers depends on visitors and especially rare plants or plants with a very specialized pollination system could suffer less visitations when a feeder is present and pollination might be insufficient. It is also important for Un poco del Chocó to investigate the influence of the feeders on the hummingbird-pollinated plants species. If more studies prove a negative effect of hummingbird feeders on pollination, then it might be easier to convince people to reduce the use of hummingbird feeders. For conservation in general, it is also important to investigate the influence of the feeders on hummingbird-pollinated plant species. Due to the various interactions in tropical forest, the conservation of plant species leads to a higher diversity of hummingbirds and other depending animals and plants.

For two and a half month hummingbird-pollinated plant species have been observed. The individuals of the same plant species were divided in two groups: one group with feeder present and the other group with feeder absent. In order to determine the nectar volume and sugar concentration of hummingbird-pollinated plant species nectar measurements were carried out. Further more a fruit and seed set was conducted in order to determine how many flowers were successfully fertilized by hummingbirds. The ratio of fruits to flowers gives a relative value for reproductive success. Seed set describes the ratio of the amount of developed seeds to the possible amount of seeds per fruit. In order to determine possible flower pollinators, morphology studies took place. The plant species were measured and hummingbirds were mist netted and measured as well.

The results of this research show that the feeders have a negative influence on the visitations of some of the investigated hummingbird-pollinated plants such as the *Heliconia sp*. and the *Pitcairnia nigra*. If the feeder was present there were less visits per hour, less flowers were visited and the hummingbirds spent less time visiting a flower *on the Heliconia sp*. In case of the *Pitcairnia nigra* there were less flowers visited with feeder present. On the other plant species there were no significant differences found in the visitations. Remarkable is that the visitations per hour compared to the open flowers of the *Palicoura demissa* were not as linear as expected. The expactation was the more open flowers the more hummingbirds would visited the *Palicourea demissa.* There is a significant difference between the fruit set of the *Heliconia sp.* with feeder present and absent. It is remarkable that the fruits of the *Heliconia sp.* with feeder present have more developed fruits than the ones without feeder. There is no significant difference between the seed sets of the *Pitcairna nigra* and the *Heliconia sp.* with feeder present and absent.

It is important to convince people that it is better to have more ornitophilous plants in their gardens to attract hummingbirds. This will help to preserve the hummingbird-pollinated plant species and it will attract also a lot of hummingbirds to the gardens. It important to carry out more research about the influence of feeders on the visitation and reproduction of hummingbird-pollinated plant species. There is still little known about the influence of feeders on other hummingbird-pollinated plant species. The position of the feeders is important. It is unknown at what kind of distance the feeders have an effect on the hummingbird-pollinated plant species. More research has to be carried out to find the relation between distance and visitations. This can be investigated by observing hummingbird-pollinated plant species with feeders on different distances of the plants.

1. Introduction

Hummingbirds are the most important avian pollinators of Native American plants (Coro et al, 2007). It is important to investigate the influence of feeders on hummingbird-pollinated plants because the frequent use of hummingbird feeders might have an effect on the hummingbird-pollinated plant species, as well as it might have an influence on the hummingbird population. A feeder contains a lot more energy than the hummingbird-pollinated plants in the vicinity of the feeder can produce. As hummingbirds prefer nectar sources with higher energy levels, they visit feeders more often than flowers. It has been calculated that for one hummingbird a single feeder represents the equivalent of visiting between 2000 and 5000 flowers in one day, depending on the amount of nectar and the sugar concentration (Coro et al, 2007). The pollination of flowers depends on visitors and especially rare plants or plants with a very specialized pollination system could suffer less visitations when a feeder is present and pollination might be insufficient (Lindenberg and Olesen, 2001). The fruit and seed production decreases and the hummingbird-pollinated plant species could go extinct (Coro et al, 2007). Furthermore the population of hummingbirds could increase and they would use the feeders more often than ornithophilous plants (McCaffrez and Wethington, 2008).

Approximately 300 feeders have been counted on the road of Quito to Mindo and in Mindo there are feeders present everywhere. Most people are not aware of the possible effect of the feeders on the hummingbird-pollinated plant species. They put the feeders up for tourism. For a little payment the tourists can observe these wonderful birds in the gardens (personal communication, Büttner). Even the authors of the field guide of Ecuadorian birds mention that they hope that there will be more feeders around to attract hummingbirds without considering the possible effect of the feeders on the hummingbird-pollinated plant species (Ridgeley and Greenfield, 2001).

The use of feeders in temperate climates could be justified because in autumn and winter, when there are not enough flowers hummingbirds can feed on, it is probably fine to put up a feeder and supply the hummingbirds with an extra source of food. In the tropical rainforest the situation is different. There is a rainy season and a dry season, but hummingbirds have a constant food source and pollinate the plants the whole year round (Ulmer, 1983).

It is important for Un poco del Chocó to investigate the influence of the feeders on the hummingbird-pollinated plants species. The more studies prove a negative effect of hummingbird feeders on pollination, the easier it might be to convince people to reduce the use of hummingbird feeders. The station could give advice to other people and could promote alternatives to attract hummingbirds, e.g. the use of ornitophilous plants in gardens.

For conservation in general, it is also important to investigate the influence of the feeders on hummingbird-pollinated plant species. Due to the various interactions in tropical forest, the conservation of plant species leads to a higher diversity of hummingbirds and other depending animals and plants.

During this study the influence of feeders on hummingbird-pollinated plants will be investigated. To answer this question the following problem and sub-questions are specified.

Problem: Which influence do feeders have on the visitation and reproduction of the plants hummingbirds naturally use as nutrition?

Sub-questions:

1. Which flowering plants do hummingbirds use as nutrition during the observation period?
2. Which species of hummingbirds use the feeders and/or plants?
3. Which species of hummingbirds possibly pollinates which plants?
4. How high is the nectar production and amount of sugar in the flowering plants hummingbirds feed on during the observation period?
5. Is there a difference between the plant use with a feeder present or absent?
6. Is there a difference between fruit and seed production of plants with a feeder present or absent?

2. Hummingbirds

The most important flower pollinating birds of South America are hummingbirds. Ecuador has a high diversity of hummingbird species. Hummingbirds are different to other birds because they are the only birds that can fly backwards. They have a high wing frequency which costs a lot of energy. Therefore they visit flowers. The nectar in flowers is their fuel to fly and catch small insects to obtain proteins (Büttner, 2005). Hummingbird pollinated flowers produce nectar with sugar concentrations between 8 and 28 percent. The plant visits depend on the nectar production and the sugar concentration of the plant. Hummingbirds prefer plants with higher sugar concentrations. When they visit flowers with a higher sugar concentration they have to visit less other flowers to obtain the same amount of energy (Hainsworth and Wolf, 1976). Nectar consists of various concentrations of different sugars such as sucrose, the monosaccharides fructose and glucose, as well as a small amount of amino acids and electrolytes. In America the nectars associated with plants pollinated by hummingbirds contain higher concentrations of the sugar sucrose than fructose and glucose taken together (Schmid, 2008). The hummingbird's bill is long and small and sometimes curved. The hummingbird tongue has two grooves running of their tip back towards their base. When the tongue tip is placed into the nectar the fluid is passively drawn through the grooves towards the mouth by capillary action (Gillis, 7th of March).

2.1 Different species of hummingbirds

During the observation period the following eleven different species of hummingbirds were seen.

White whiskered hermit *(Phaethornis yarugui).*

Figure 2.1 (Ridgeley 25th of February).

The white whiskered hermit is a large and dark hermit, common in undergrowth of humid forest, woodland and borders in lowlands and foothills west of the Andes. The bill is very long (45 mm), slightly curved and mostly red. The head is copper-bronze with metallic green below. Above the eye there is an orange stripe and underneath the eye there is a white stripe. The belly is grey with a white crissum and the tail is dark collared with a white tip on the end of the tale. The difference between male and female is minimal. The female has a longer white tip on the end of the tail (Ridgeley and Greenfield, 2001).

Stripe-throated hermit *(Phaethornis striigularis).*

Figure 2.2 (Montereybay, 25th of February).

The stripe-throated hermit is a small hermit that lives in the undergrowth and borders of humid deciduous forest and woodland in the lowlands. The bill is 23 mm long and somewhat curved. The head is copper-bronze with a white stripe above and underneath the eye. The throat and breast are greyish and the belly is brown/red and on the back the stripe-throated hermit is coloured metallic green. The wings and tail are dark collared with a white tip on the end of the tail. This species does not show sexual dimorphism (Ridgeley and Greenfield, 2001).

Wedge billed hummingbird *(Schistes geoffroyi).*

Figure 2.3 (Ridgeley 25th of February

The wedge billed hummingbird lives in the undergrowth and borders of the foothill and subtropical forest. The bill is short (15-18 mm) and sharply pointed. The head is green with a glittering green fore crown and a short white postocular spot. The gorget is glittering green with a patch of glittering blue and violet. The border below the patch is white. The lower under parts are bronzy green and the wings are dark collared. The rounded tail is bronzy green, bluer below with a broad blue-black band. The female has no glittering fore crown and the entire throat is white with smaller patches on the sides. The female has blue and violet patches on each side. The tail is blue with a dark blue band (Ridgeley and Greenfield, 2001).

Green thorntail *(Popelairia conversii).*

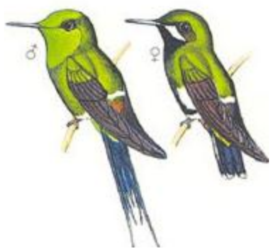


Figure 2.4 (Willifefocus 25th of February)

The green thorntail lives in the canopy and borders of humid forest in the lowlands and foothills west of the Andes. This is the only place in Ecuador where the thorntail is present. The head is shining green with a glittering green crown and a blue spot on the chest. There is a white band on the back and the tail is extremely long and deeply forked blue-black. The wings are dark collared. The female has a green head and back with a white band underneath the eye and a black throat. The under parts are mixed green and black with green and black with prominent white patch on the flank. The tail is much shorter than the males tail and is collared blue-black and the outer feathers are white tipped (Ridgely and Greenfield, 2001).

Booted Racket-tail *(Ocreatus underwoodii).*

The booted racket-tail is generally uncommon in lower growth and borders of foothills and subtropical forest and is more seen in the west of the Andes. The bill of the booted racket-tail is short (12 mm) and straight. The male has a bright shining green with glittering green throat and chest. The legs are white puffed. The tail is very long and deeply forked. The outer feathers are distally reduced to shafts and ending in large blue-black rackets. The female is shining green with a small white postocular spot. The belly is mostly white with green spots on the flanks. The legs are also white puffed but smaller compared to the male. The tail is also shorter compared to the male. The tail is mostly green and the outer feathers are blue-black with white tips (Ridgeley and Greenfield, 2001).

Figure 2.5 (Montereybay, 25th of February).

Purple throated woodstar *(Calliphlox mitchellii).*

Figure 2.6 (Ridgeley 25th of February)

The purple-throated woodstar lives in the canopy and borders of the foothill and the subtropical forest of the west Andes. The bill is straight and 13 mm long. The male is metallic green above with small white postocular spot. The gorget is glittering violet-purple bordered below by a broad white pectoral collar extending up onto the sides of the neck and it is almost connecting to the white postocular spot. The lower underparts are dusky green with red and white. The tail is a deeply forked dark bronzy and purple. The females throat is buffy whitish and reaches until the white postocular spot. The head and back are green and red and white on the belly. The tail is shorter compared to the male and is black (Ridgeley and Greenfield, 2001).

Purple crowned fairy *(Heliothryx barroti).*

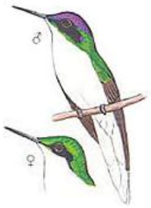


Figure 2.7 (Ridgeley 25th of February)

The purple crowned fairy lives in humid forest and woodland in the lowlands. The bill is short (18 mm) and straight. The head is shiny green with a purple fore crown above and black mask through the eyes ending in a violet tuft and bordered below by a green colour. Underneath the purple crowned fairy is white and has black wings. The tail is long and mostly white. The female looks like the male but has a green fore crown instead of a purple fore crown (Ridgeley and Greenfield, 2001).

Green crowned brilliant *(Heliodoxa jacula).*

The green crowned brilliant lives in the undergrowth and borders of foothill and lowers subtropical forest on the Westside of the Andes. The bill is nearly straight and 25 mm long. The green crowned brilliant has a green head with a small white postocular spot and is glittering green with a green fore crown. The throat and breast are also glittering green with a violet-blue patch on the lower throat. The belly is duller green. The green crowned brilliant has a long forked tail, which is blue-black as well as the wings.

The female has no glittering force crown and has a white postocular spot and a white stripe underneath the eye. The female has also a white belly with green dots. The tail is less deeply forked and is also blue-black with a white tip on the end of the tail (Ridgeley and Greenfield, 2001).

Figure 2.8 (Montereybay, 25th of February).

Rufous tailed hummingbird *(Amazilia tzacatl).*

Figure 2.9 (Ridgeley 25th of February)

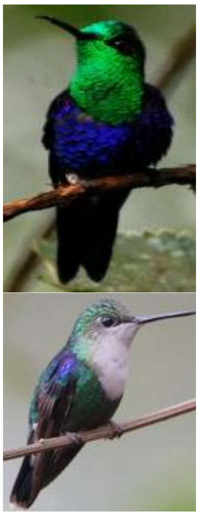
The rufous tailed hummingbird is common and widespread in clearings and gardens, secondary woodland and forest borders in more humid lowlands and semi-tropics and subtropics west of the Andes. The bill is essentially straight and 21 mm. The head is shining green and the throat and breast are glittering green. The belly is dingy greyish with some green flanks. The tail is red and the wings are brown. This species does not show sexual dimorphism (Ridgeley and Greenfield, 2001).

Andean emerald *(Amazilia franciae).*

The Andean emerald lives in the borders of humid and montane rainforest. The bill is essentially straight and 21 mm long. The Andean emerald has a shining green head with a glittering green crown. The breast and belly are white with some green on the sides. The tail is bronzy green and the outer feathers are tipped greyish. This species does not show sexual dimorphism (Ridgeley and Greenfield, 2001).

Figure 2.10 (Ridgeley 25th of February)

Green crowned woodnymph ***(Thalurania fannyi).***



The green crowned woodnymph lives generally in the lower growth and borders of humid forest and woodland in lowlands and foothills of northwest of the Andes. The bill is essentially straight and 19 mm. The green crowned woodnymph has a glittering green head throat and breast. The belly is violet-blue. The female is smaller than the male with shining green on the head. The throat and chest are pale grey with dark mixed green and grey lower under parts. The tail is somewhat forked and blue-black the outer feathers tipped whitish (Ridgeley and Greenfield, 2001).

Figure 2.11 (Montereybay, 25th of February).

3. Hummingbird-pollinated plants

Flowers are among the most complex objects in the plant kingdom. They vary in colour, size, morphology and in the type and amount of reward they offer to their animal pollinators. This diversity is believed to be the result of varied pollination strategies (Naterro and Cocucci, 2006). Birds in generally have a good colour vision. They have four or five different photo pigments to see colours while humans only have three (Jordan et al, 2010). That is why plants attract hummingbirds by their colour and not by their smell. Hummingbird-pollinated plants can be recognized by their red, orange or yellow colours and the flowers are often well exposed. (Ulmer, 1983). It is not always the flower itself attracting the hummingbird. Sometimes the flowers are green and inconspicuous but the leaves or other parts of the plant have red colours to attract the hummingbirds. Most hummingbird-pollinated flowers have a thick, waxy texture to avoid damage through the claws of a visiting bird (Zizka and Schneckenburger, 1999). Hummingbird-pollinated plant species have tubular flowers and a long stigma and stamen, which sometimes stick out of the flower (Kraemer, 1998). Not all of the hummingbirds are plant-pollinating species. There are species that drill a hole in the base of the flower and obtain their nectar that way. Not every hummingbird visit to a flower results in pollination. This depends on the morphology of the flower and the morphology of the bill of the hummingbirds. It has to fit precisely. The plant species with long flowers are associated with a lower diversity of hummingbird pollinators compared to the ones with shorter flowers (Fenster, 1991). Some of the most spectacular examples of co-evolution between flowers and their pollinators are reflected in their morphologies. Tongue length of insects and bill lengths of nectar-feeding birds are some of the most significant characters in pollination studies. While a plant species could go extinct if it is not sufficently visited, the pollinators might be more buffered against extinction due to their usage of several nectar plants (Lindenberg and Olesen, 2001). After the plants have been pollinated by hummingbirds they will produce fruits. The presence of a fruit is almost always an indication of successful pollination. The fruit set is a measurement for reproductive success of a plant. The presence of feeders may decrease the use of native plants and that could reduce the plant reproductive output by lowering fruit and seed production (McCaffrez and Wethington, 2008).

3.1 Hummingbird-pollinated plant species

The four different plant species which were studied during the observation period are described below.

Figure 3.1 (Duuren van, 2012)

Family name: *Bromeliacae*
Species: *Pitcairnia nigra*
The *Pitcairnia nigra* is a terrestrial plant in montane rainforest. The inflorescence is between 10 and 50 cm long and cylinder shaped. The inflorescence has triangle shaped leafs which are 10 cm long and red colored. The flowers grow between the triangles shaped leaves of the inflorescence and are black-purple colored. The fruits consist of three parts within each part around 1800 seeds (Reilly, 29th of August).

Figure 3.2 (Duuren van, 2012)

Family name: *Costaceae*
Species: *Costus pulverulentus*
The *Costus pulverulentus* is flowering the whole year round. The height of the plant can be up to one until two meters. The inflorescence is usually 3-7 cm long and red colored even as the flowers. The bracts on the inflorescence are oval shaped and spiral arranged. The leaves are dark green, spiral arranged and oval (Smithsonian tropical research institute, 29th of August).

Figure 3.3 (Duuren van, 2012)

Family name: *Heliconiaceae*
Species: Heliconia stilesii
The *Heliconia stilesii* is flowering the whole year round and can grow 4,5 untill 6 meters high. The inflorescence has 20 to 30 bracts which are red colored. The *Heliconia stilesii* has twelve yellow flowers per bract. (Berry and Kress, 1991). There are normally three seeds per fruit and on every bract there are twelve fruits if al the flowers are fertilized.

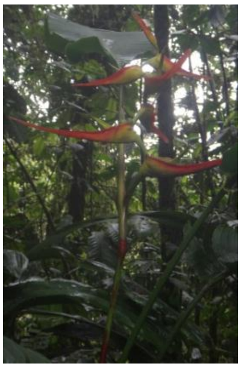


Figure 3.4 (Duuren van, 2012)

Species: *Heliconia latispatha.*
The *Heliconia latispatha* is flowering the whole year with a peak of April to September. The height of the plant is 45 cm to 1,5 meter. The inflorescence has three to seven bracts which are red, yellow and green coloured. The flowers are green. There are normally three seeds per fruit. (Berry and Kress, 1991). There are normally three seeds per fruit and at every bract there are twelve fruits if al the flowers are fertilized

Figure 3.5 (Duuren van, 2012)

Family name: Rubiacae
Species: *Palicourea demissa.*
Palicourea demissa is a common shrub in secondary cloud forests The Palidourea demissa can grow until a height of six meters. They flower of January until October with a peak in May and June. The inflorescences are red and yellow collared even as the flowers which are red or yellow. The fruits are green when they are unripe and dark blue when they are ripe. The fruits usually contain two seeds (Valois-Cuesta et al, 2010).

4. Materials and methods

In the first month the identification of the different species of hummingbirds were studied by hanging up the feeders and observing which species visited. For hummingbird identification the field guide “Birds of Ecuador” was used (Ridgeley and Greenfield, 2001). After a month the fieldwork started. The following plant species were observed: *Pitcairnia nigra, Costus pulverulentus, Palicourea demissa* and the *Heliconia sp*. The *Heliconia stilesii* and the *Heliconia lathispatha* were combined with the data analysis to get more individuals to compare. Table 4.1 how many individuals with and without feeder and how many observations per plant species were conducted during the observation period.

Table 4.1 the individuals and observation on the four different plant species

	Total individuals	Individuals		Observations
Pitcairnia nigra	9	Feeder present	6	9
		Feeder absent	3	7
Heliconia sp	14 *Heliconia stilesii* 2 *Heliconia lathispatha*	Feeder present	9	28
		Feeder absent	7	36
Costus pulverulentus	17	Feeder present	9	29
		Feeder absent	8	17
Palicourea demissa	11	Feeder present	4	24
		Feeder absent	7	15

4.1 Observation period

There was an observation period of two and a half month on hummingbird-pollinated plant species. Before each observation the number of open flowers was counted. Afterwards there was an observation period of one hour per plant in order to observe which hummingbird species visit the plant (if it was possible the gender of sexual dimorph species was identified as well). During each visitation the number of flowers visited and duration per visit was noted. It was not possible to observe the duration of visit per flower for the *Palicourea demissa* because the hummingbirds were too quick. Instead the overall duration for all visited flowers was noted and then divided by the number of flowers visited. Furthermore the plant species, the day, the time and the weather during the observation were noted (enclosure 1). The different spots were observed of 6:30 am until 7:30 am and of 8:00 am until 12:30 pm. On one day four different spots were observed. The different individuals were observed at different times.

4.2 Feeders

The feeders contained a sugar solution with a sugar concentration of 25 percent. The sugar concentration was measured with a refractometer (Bellingham and Stanley, Kent, UK ; range concentration 0-50% g sugar per 100 g nectar). The feeder was placed twenty meters away of the observed plant. The individuals of the same plant species were divided in two groups: one group with feeder present and the other group with feeder absent. Every three days the feeders had to be cleaned and filled again.

4.3 Nectar measurements

In order to determine the nectar volume and sugar concentration of hummingbird-pollinated plant species nectar measurements were carried out. First the whole inflorescence was bagged with mosquito nets to exclude floral visitors the day before the measurement took place (Büttner, 2005). The nectar volume was measured by using Hamilton Microliter syringes (Type 802, 805, 810). The sugar concentration was measured using a refractometer (Bellingham and Stanley, Kent, UK ; range concentration 0-50% g sugar per 100 g nectar). It is possible that the nectar production of a flower changes over the day. Therefore nectar was measured on the *Palicourea demissa* three times a day at 6:30 am, 10:30 pm and at 14:30 pm. It is more difficult to extract nectar of *Helcionia stilesii* and the *Costus pulverulentus*. On these plant species the nectar was measured once a day at 16:00 pm to get a daily production. A schedule for nectar measurement is attached which contains on which day and time which species of plant were observed and the number of measurements (enclosure 2).

4.4 Fruit and seed counting

The fruit counting is important to determine how many flowers were fertilized by hummingbirds. After two months the *Pitcairnia nigr*a and the *Heliconia sp*. began to produce fruit. The fruits were counted and the ratio of fruits to flowers gives a relative value for reproductive success. Furthermore the seeds of these flowers were counted. Seed set described the ratio of the amount of developed seeds to the possible amount of seeds per fruit. The fruit was opened in the laboratory and the seeds were counted. The seeds were divided in two groups: developed seeds and not-developed seeds. The possible amount of seeds per fruit was given by adding up the seeds of the two groups. The not-developed seeds were deformed and did not look like the developed seeds (Büttner, 2005). The shape of the seeds differs between different plants and were studied during the seed counting.

4.5 Energy calculations

With the measurements of the nectar and hummingbirds a calculation was made to determine the daily energy produce of the observed plant species, how much energy a feeder contains and what the required energy of a hummingbird per day is. The following formula was used to calculate the energy a hummingbird need per day in Kilojoule FMR (kJ/24h) = 7,895*body mass (gr) (Weathers and Stiles 1989). With the data of the nectar measurement the daily energy plant species produce was calculated in Kilojoule. A table in “Techniques for Pollination Biologists” was used to calculated how much µg sugar per µl nectar a flower contains. (Kearns and Inouye,1993). Thereafter the µg sugar was calculated by multiplying the amount of nectar with the µg sugar per µl. Then the µg sugar was multiplied with 0,01648 this is the factor to calculate the joules per day. This means that 1 µg sugar is as much as 0,01648 Joule. To calculate Kilojoule per day the joule per day was divided by thousand. An other calculation was made for the energy rate a feeder contains in Kilojoule per day. Whit this calculation was determined how many flowers of a specific plant species hummingbirds have to visit to get their required energy.

4.6 Morphology of the hummingbirds and flowers

Not every hummingbird visit to a flower results in pollination. This depends on the morphology of the flower and the morphology of the beak of the hummingbirds. It has to fit precisely (Fenster, 1991). In order to determine possible flower pollinators, morphology studies took place. Five flowers of the *Heliconia stilesii, Costus pulverulentus* and *Palicoura demissa* were taken and the following parts were measured: the total length of the flower, the width of flower opening, the length of the stigma and the length of the stamen. Hummingbirds were mistnetted and measured as well. The following parts were measured: the weight, the beak length, the length of the beak to the skull, the length of the beak and head and the width of the beak.

4.7 Processing the data

Excel was used for the data input of the observation period with the feeders present and absent. As well as the data of nectar measurements and the fruit and seed counting. Thereafter SPSS 17.0 was used for the statistic analyse. If there was a normal distribution the Independent sample T-test was used to determine if there was a significant difference in visitations per hour, the time of the visitations and the ratio of open flowers and flowers visited by hummingbirds with feeder present and absent even as the fruit and seed count with feeder present and absent. If data was not normally distributed and two different data sets were compared the levene test was used to check the homogeneity of variance first. If the variance between the two different groups was the same the Man-Whitney U test was used. If the variance between the two different groups was different the Kolmogorov-Smirnov test was used to determine if there was a significant difference in visitations per hour, the time of the visitations and the ratio of open flowers and flowers visited by hummingbirds with feeder present and absent as well as the fruit and seed count of the observed plants with feeder present and absent. Table 4.2 shows the different test that were used analysing the data of the observations. Table 4.3 shows which tests were used during the data analyse of the fruit and seedset.

Table 4.2 Statistical test used for analyzing the data of the observations

	Visitation per hour	**Time visits per flower**	**Ratio**
Pitcairnia nigra	Kolmogorov Smirnoff test	Independent sample t-test	Mann-Whitney U test
Heliconia sp.	Kolmogorov Smirnoff test	Mann-Whitney U test	Mann-Whitney U test
Costus pulverulentus	Mann-Whitney U test	Mann-Whitney U test	Mann-Whitney U test
Palicourea demissa	-	Mann-Whitney U test	Mann-Whitney U test

Table 4.3 Statistical test used for analyzing the data of the fruit- and seed set

	Fruit set	**Seed set**
Pitcairnia nigra	-	Kolmogorov Smirnoff test
Heliconia sp.	Kolmogorov Smirnoff test	Kolmogorov Smirnoff test

5. Results

5.1 Observations on the hummingbird pollinated plant species.

To conduct this research there was an observation period of two months on the visitation by hummingbirds on four different plant species. Per plant species is observed if there is a significant difference between the visitations of hummingbirds in an hour, the percentage of how many flowers the hummingbirds visited and the time hummingbirds visited a flower with feeder present and absent.

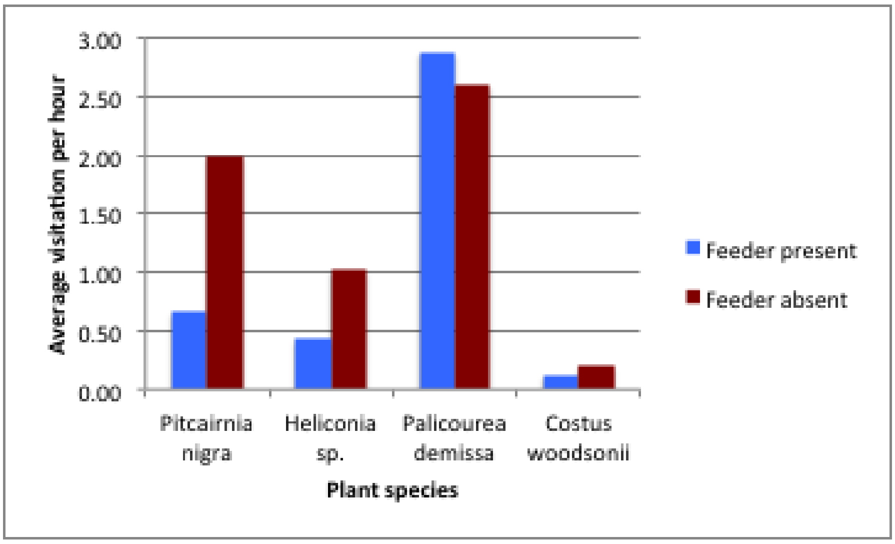


Figure 5.1 Average number of visitations per hour on four different plant species.

In figure 5.1 the average number of visitations in one hour by hummingbirds on the individuals of four different plant species with feeder absent and present are shown. The hummingbirds visited most at the *Palicoura demissa* and the less at the *Costus pulverulentus.* This also depends on the open flowers per individual. The *Pitcairnia nigra* has a mean of two open flowers per individual. *Heliconia sp*. has a mean of three open flowers per individual. *Palicourea demissa* has a mean of 32 open flowers per individual and *Costus pulverulentus* has a mean of 1 open flower per individual.

Hummingbirds visited a *Pitcairnia nigra* with a mean of 0,67 visits in one hour with feeder present and a mean of 1,63 visits in one hour with feeder absent. There is no significant difference between the visits per hour with feeder present and absent (Enclosure 6.1 Kolmogorov-Smirnoff test N_1=9, N_2=7, Z=1,134, P=0,153). Hummingbirds visited a *Heliconia sp*. with a mean of 0,43 visits in one hour with feeder present and a mean of 1,03 visits in one hour with feeder absent. The visit per hour was significantly lower at *Heliconia sp.* with feeders present (Enclosure 6.2 Kolmogorov-Smirnoff test N_1=28, N_2=36, Z=1,48, P=0,025). Hummingbirds visited a *Costus pulverulentus* with an average of 0,13 visits in one hour with a feeder present and an average of 0,2 visits in one hour with feeder absent. There is no significant difference between the visits per hour with feeder present and absent (Enclosure 6.3 Mann Whitney U-Test, N_1=24, N_2=15 U=165,5, P=0,533).

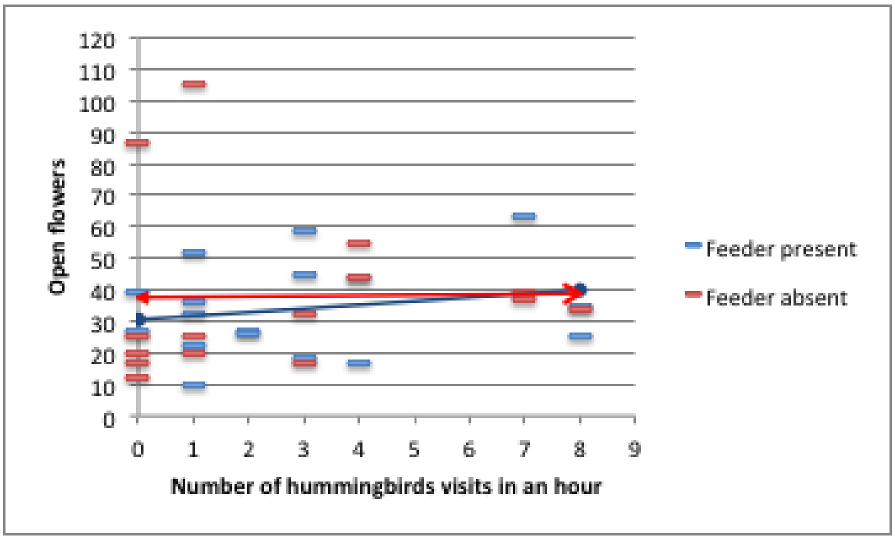


Figure 5.2 Number of hummingbirds visits in an hour compared to the open flowers of the *Palicourea demissa.*

Because the *Palicourea demissa* has between 12 and 105 open flowers per individual there is no comparison between feeder present and absent in visitations per hour because the open flowers can affect the number of visits in an hour on an individual. Figure 5.2 shows how many hummingbirds visited the *Palicourea demissa* in an hour compared to the open flowers. A trend line is added to determine if there is a linear effect at the number of hummingbirds visited the *Palicourea demissa* compared to the open flowers. The trend line shows a small linear effect with feeder present and is almost a straight line with feeder absent. With feeder present there is a small effect of the more open flower the more hummingbirds visit the flowers and with feeder absent is this less.

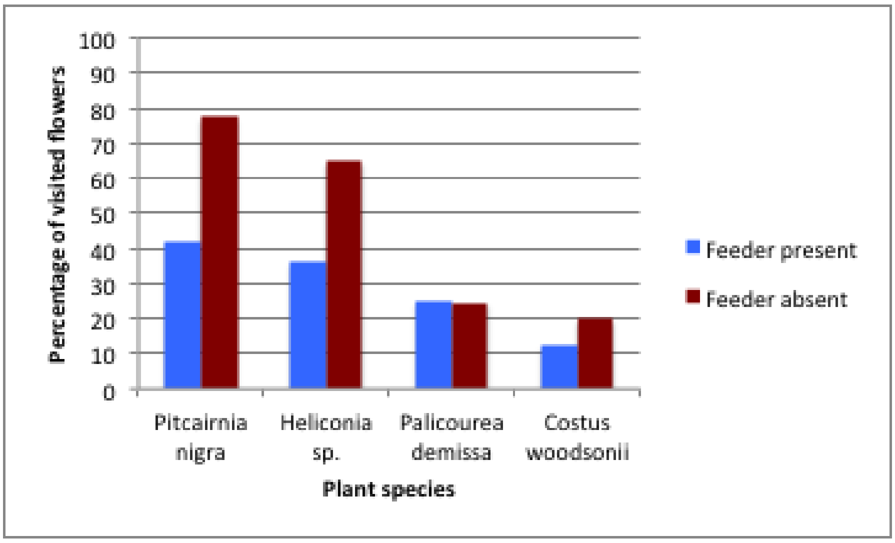


Figure 5.3 Mean percentage of visited flowers on four different plant species with feeder present and absent.

In figure 5.3 the mean percentage of visited flowers on four different plant species with feeder present and absent is shown. The *Pitcairnia nigra* has the highest percentage of flowers visited and the *Costus pulverulentus* has the lowest percentage of visited flowers. The graph shows a pattern that the percentages of flowers visited are higher with the feeder absent except for the *Palicourea demissa*. There are no significant difference in the percentage of visited flowers between the four different plant species with feeder present and absent (Enclosure 6.4 Univariate analysis of variance, F=2,099 P=0,101).

The hummingbirds visited *Pitcairnia nigra* with a mean of 41,7 percent of open flowers with feeder present and a mean of 77,3 percent of open flowers with feeder absent. The percentage of flowers visited was significantly lower at *Pitcairnia nigra* with feeders present (Enclosure 6.5 Mann Whitney U-Test, N_1=10, N_2=22, U=47, P=0,005). The hummingbirds visited the *Heliconia sp.* with a mean of 36,3 percent of open flowers with feeder present and with a mean of 64,9 percent of open flowers with feeder absent. The percentage of flowers visited was significantly lower at *Heliconia sp.* with feeder present (Enclosure 6.6 Mann Whitney U-Test, N_1=38, N_2=72, U=874, P=0,001). The hummingbirds visited the *Palicourea demissa* with a mean of 25 percent of open flowers with feeder present and a mean of 24,6 percent of open flowers with feeder absent. There is no significant difference between the percentage of flowers that were visited with feeder present and absent (Enclosure 6.7 Mann Whitney U-Test, N_1=52, N_2=46, U=1159, P=0,787). The hummingbirds visited the *Costus pulverulentus* with a mean of 12,5 percent of open flowers with feeder present and a mean of 20 percent of open flowers with feeder absent. There is no significant difference between the percentage of flowers that was visited with feeder present and absent (Enclosure 6.8 Mann Whitney U-Test, N_1=24, N_2=15, U=166,5, P=0,700).

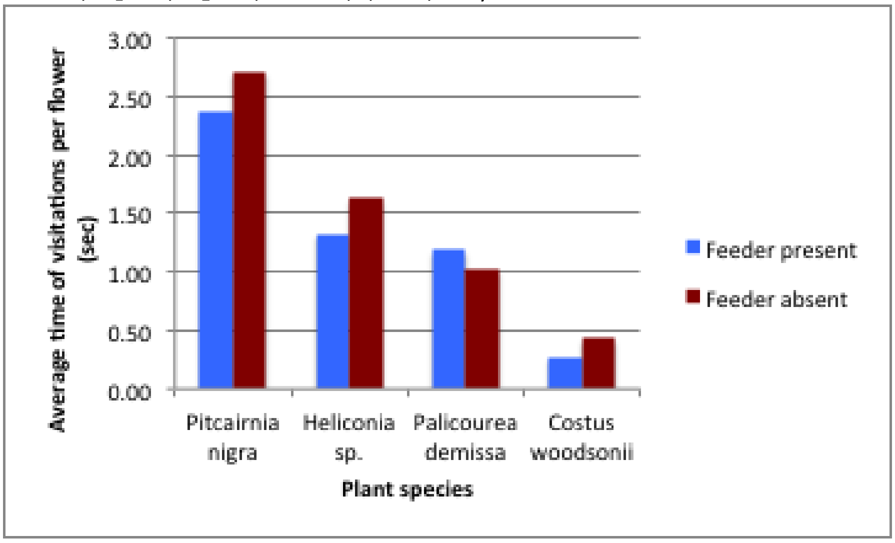


Figure 5.4 Average time of visitation per flower on the four different plant species

In Figure 5.4 the average time of visitations by hummingbirds on the four different plant species is shown. The *Pitcairnianigra* has the longest visit per flower and the *Costus pulverulentus* has the shortest visit per flower. The graph shows also pattern that the average time of visitations is higher with feeder absent except for the *Palicourea demissa.* There is no significant difference in the time that hummingbirds visited a flower between the four different plant species with feeder present and absent (Enclosure 6.9 Univariate analysis of variance, F=0,380 P=0,767).

Hummingbirds visited a flower of the *Pitcairnia nigra* with a mean of 2,36 seconds with feeder present and a mean of 2,71 seconds with feeder absent. There is no significant difference between the time hummingbirds visit a flower with feeder present or absent (Enclosure 6.10 Independent sample T-test, N_1=10, N_2=22, T=0,183 P=0,856). Hummingbirds visited a flower of *Heliconia sp.* with a mean 1,33 seconds with feeder present and a mean of 1,63 seconds with feeder absent. The time a hummingbird visited a flower was significantly lower at *Heliconia sp.* with feeders present (Enclosure 6.6 Mann Whitney U-Test, N_1=38, N_2=72, U=1006,5, P=0,022). Hummingbirds visited flowers of the *Palicourea demissa* with a mean of 1,18 seconds with feeder present and a mean of 1,02 seconds with feeder absent. There is no significant difference in the time that hummingbirds visited a flower with feeder present or absent. (Enclosure 6.7 Mann Whitney U-Test, N_1=52, N_2=46, U=1004,5, P=0,173). Hummingbirds visited a flower of *Costus pulverulentus* with a mean 0,27 seconds with feeder present and a mean of 0,43 seconds with feeder absent. There is no significant difference found in the time that hummingbirds visited a flower with feeder present or absent (Enclosure 6.8 Mann Whitney U-Test, N_1=25, N_2=15, U=167, P=0,721).

5.2 Fruit and seed set

To determine how many flowers were fertilized by hummingbirds a fruit and seed count was carried out for *Pitcairnia nigra* and for the *Heliconia sp.* The other plant species had not yet developed any fruits.

5.2.1 Pitcairnia nigra

In Figure 5.5 the fruit set of four individuals of *Pitcairnia nigra* without feeder present are shown. There is no fruit set of some individuals with feeder present because the fruits were rotten away. Individual one has one developed fruit of the 31 possible fruits, 3,23 percent of the fruits are developed. Individual two has 25 developed fruits of the 54 possible fruits, 46,30 percent of the fruits are developed. Individual three has 44 developed fruits of the 68 possible fruits, 64,71 percent of the fruits are developed and individual 4 has 19 developed fruits of the 27 possible fruits, 70,37 percent of the fruits are developed. The fruit set of *Pitcairnia nigra* shows a variable percentage of developed fruits per individual.

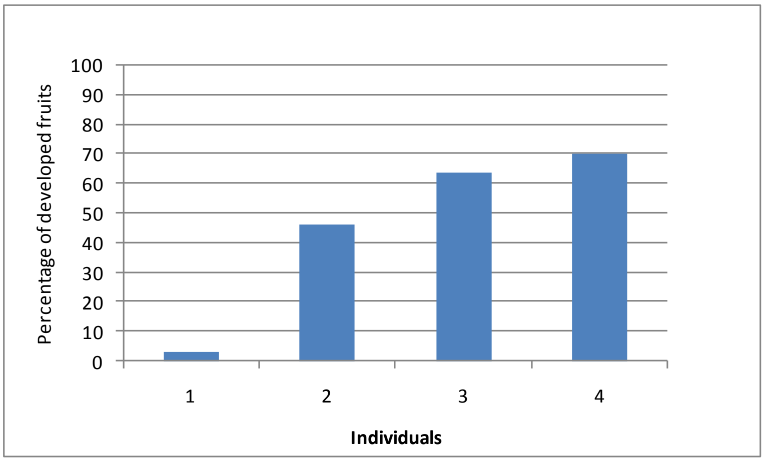


Figure 5.5 Fruit set of the Pitcairnia nigra without feeder

In figure 5.6 the mean percentage of the developed and undeveloped seeds with feeder present and absent of the *Pitcairnia nigra* is shown. One individual is used to determine the seed set of the *Pitcairnia nigra*. Every fruit has three chambers with seeds. Five fruits at the bottom with feeder absent and five compartments at the top with feeder present were used to determine the seed set. With feeder present 25,59 percent of the seeds are developed and 74,41 percent of the seeds are undeveloped. With feeder absent 37,42 percent of the seeds are developed and 62,58 percent of the seeds are undeveloped. There is no significant difference between the percentage of developed and undeveloped seeds with feeder present and absent (Enclosure 6.12Kolmogorov-Smirnoff test N_1=5, N_2=5, Z=0,949, P=0,329).

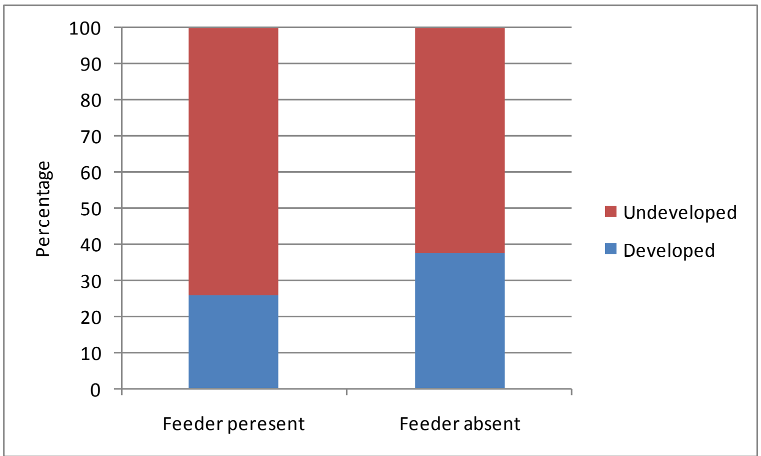


Figure 5.6 Seed set of the Pitcairnia nigra

5.2.2 Heliconia sp.

Figure 5.7 shows the fruit set of two individuals of the *Heliconia sp.* every individual had six inflorescences and on every inflorescence there were 12 possible fruits. The mean of the developed fruits with feeder present is 10,33 and with feeder absent 7,67. There were significantly more developed fruits with feeder present (Enclosure 6.13 Kolmogorov-Smirnoff test N_1=6, N_2=6, Z=1,443, P=0,031).

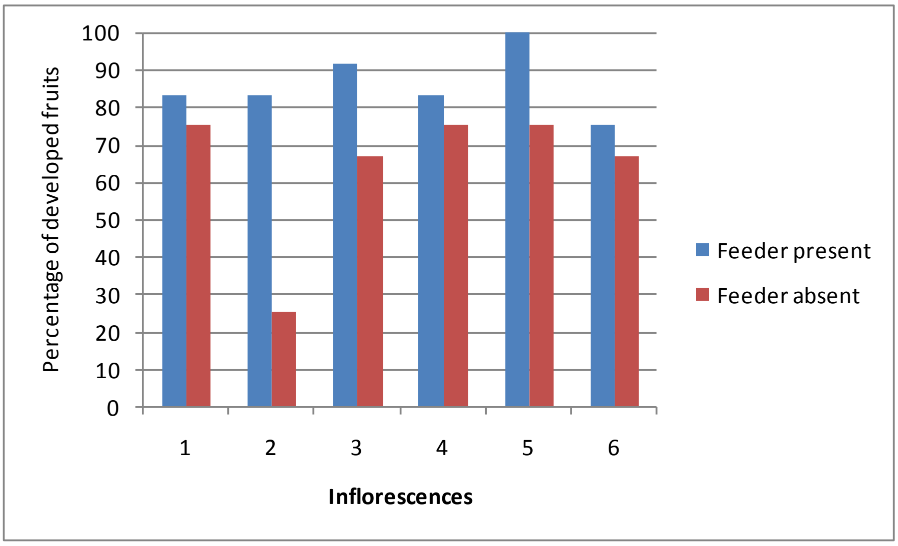


Figure 5.7 fruit set of the Heliconia sp. with feeder present and absent

In figure 5.8 the percentage of the developed and undeveloped seeds with feeder present and absent of *Heliconia sp.* is shown. Every fruit had three possible seeds. With feeder present 73,08 percent of the seeds are developed and 26,92 percent of the seeds are undeveloped. With feeder absent 90,32 percent of the seeds are developed and 9,68 percent of the seeds are undeveloped. There is no significant difference between the percentage of developed and undeveloped seeds with feeder present and absent (Enclosure 6.14 Kolmogorov-Smirnoff test N_1=12, N_2=12, Z=0,612, P=0,847).

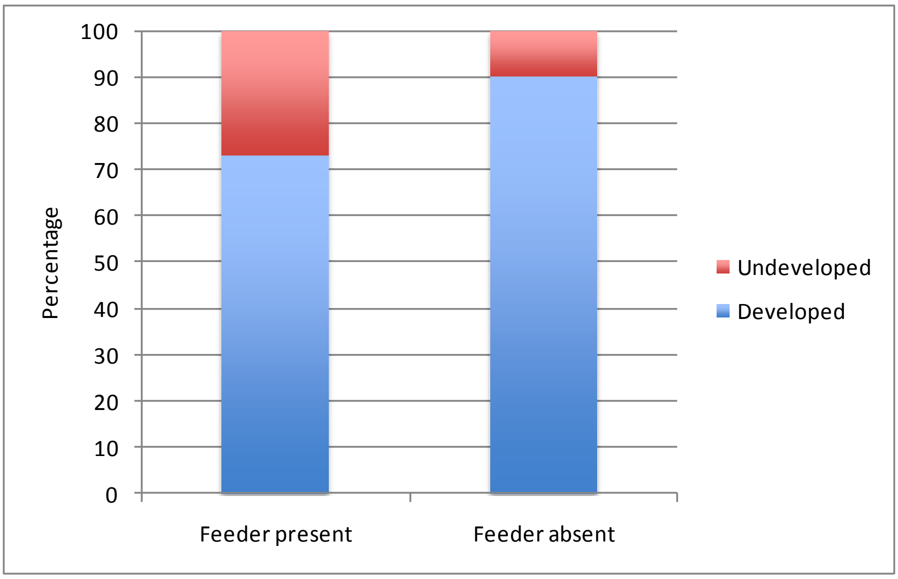


Figure 5.8 Seed set of the Heliconia sp.

5.3 Energy calculations

There is calculated how many energy four different species of hummingbirds need to get the required energy per day. As well as how much energy the flowers of the four observed plant species produce per day and what a feeder contains per day. This to compare the energy of a feeder with the energy individuals of a plant species produce and how many plants the hummingbirds have to visit to get their required energy per day. Table 5.1 shows four different species of hummingbirds and the average of the required energy they need per day. The table shows also the energy an individual plant species and a feeder produces per day. The feeder has a lot more energy per day than the plant can produce (Nectar measurements enclosure 3).

Table 5.1 Energy hummingbirds need and four different plant species produce per day

	Energy required per day (kJ)	Plant species	Energy an individual produce per day (kJ)
White wiskered hermit	49,34	*Palicourea demissa*	9,14
Green crowned brilliant (f)	67,90	*Pitcairnia nigra*	0,77
Green crowned brilliant (m)	75	*Heliconia stilesii*	0,08
Booted rackettail (f)	23,69	*Costus pulverulentus*	0,21
White necked jacobin	55,27	Feeder	1136,91

There is calculated how many individuals per plant species a hummingbird has to visit to get the required energy per day. Figure 5.9 shows per hummingbird species how many individuals of a plant species they have to visit to get the required energy per day.

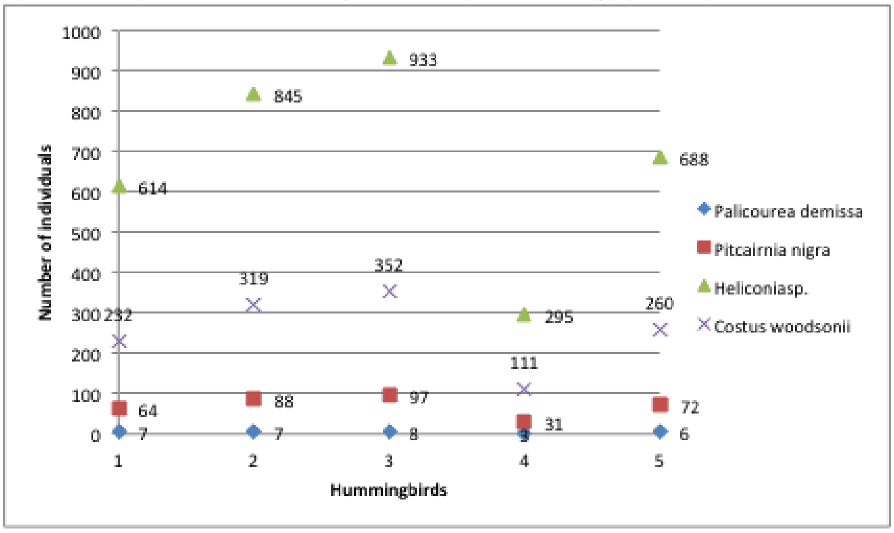


Figure 5.9 Number of individuals hummingbirds have to visit to get the required energy per day. 1= White whiskered hermit, 2 = Green crowned brilliant (f), 3= Green crowned brilliant (m), 4= Booted racket tail (f) and 5= White necked Jacobin.

The energy of the feeder is calculated as well. Figure 5.10 shows how many hummingbirds per species can get the required energy per day on the feeder. The feeder has a lot more energy per day than a plant species can produce. A feeder has enough energy to feed 23 white whiskered hermits per day whereas a white whiskered hermit has to visit 7 individuals of the *Palicourea demissa* or 64 individuals of the *Pitcairnia nigra* or 232 individuals of the *Costus pulverulentus* or 614 individuals of the *Heliconia sp.* per day to get the required energy.

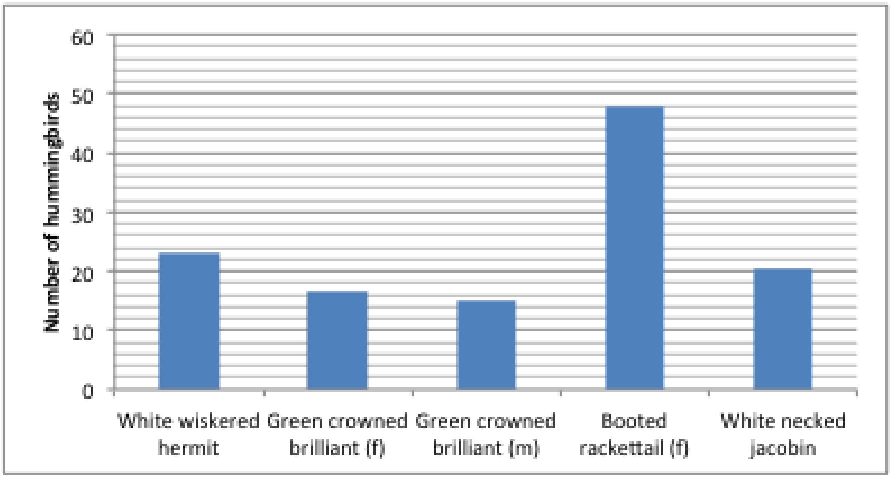


Figure 5.10 Number of hummingbirds that can visit a feeder to get the required energy per day

5.4 Morphology of the flowers and the hummingbirds

Not all the hummingbirds visited the feeder or all the four different plant species during the observation. Table 5.2 shows which hummingbird visited which plant species and which hummingbirds visited the feeder.

Table 5.2 Visitations by hummingbirds on the plant species and feeders. (HH = Heliconia stilesii and HL = Heliconia latispatha).

	Feeder	*Pitcairnia nigra*	*Heliconia sp.*	*Palicourea demissa*	*Costus pulverulentus*
White wiskered hermit	x	x	HH		x
Stripe throated hermit			HH	x	
Wedge billed hummingbird			HH		
Green thorntail				x	
Booted rackettail				x	
Purple throated woodstar				x	
Purple crowned fairy				x	
Green crowned brilliant	x	x	HL	x	
Rufous tailed hummingbird	x			x	
Andean amerald				x	
Green crowned woodnympf	x		HL	x	

In order to determine possible flower pollinators, morphology studies took place.Table 5.3 shows which hummingbirds were mistnetted and measured. The measured hummingbirds were compared with the measured flowers to look which hummingbirds are the possible pollinators of the *Heliconia stilesii, Palicourea demissa* and the *Costus pulverulentus* (Enclosure 4 and 5).

Table 5.3 Mean values of the measured hummingbirds

Species	Individuals	Weight (gr.)	Beak length (mm.)	Beak to skull (mm.)	Beak and head (mm.)	Width of the beak (mm.)
White wiskered hermit	4	6,25	39,5	44,9	56,14	4,44
Green crowned brilliant (f)	5	8,6	25,52	32,64	47,14	3,83
Green crowned brilliant (m)	5	9,5	23,65	30,27	44,88	3,67
Booted rackettail (f)	1	3	13,08	17,79	26,14	2,47
White necked jacobin	1	7	17,06	24,81	36,98	3,93

Figure 5.11 White wiskered hermit and the flower fof the Heliconia (Duuren van, 2012)

Figure 5.11 shows the actual size of the white whiskered hermit and the *Heliconia stilesii.* The measured White whiskered hermit (table 5.3) was compared with the measurements of the *Heliconia stilesii* (Table 5.4). The flower of the *Heliconia stilesii* has one stigma and five stamen. The stamen are sticking out the flower. Figure 5.11 shows that the shape of beak fits in the flower and the measurements confirm this. That is why the white whiskered hermit could be a possible pollinator of the *Heliconia stilesii*. The wedge billed hummingbird and the stripe throated hermit visited also the *Heliconia stilesii*. The wedge billed hummingbird is not a pollinator but a nectar robber. This species of hummingbirds drills a hole in the flower to contain the nectar. The stripe throated hermit could not be captured and measured but could also be a pollinator of the *Heliconia stilesii.*

Table 5.4 Mean values of the measured Heliconia stilesii

Straight part	Curve to the upper leave	Curve to the end	Flower opening	Stigma	Stamen	Upper stamen
24,04	22,52	24,58	3,89	39,05	44,73	11,82

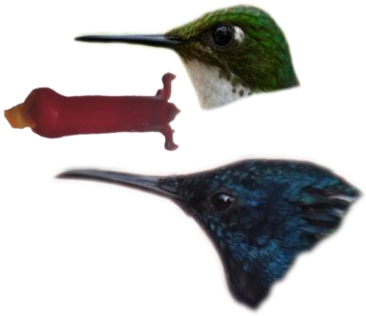


Figure 5.12 Booted racket tail (f), White necked jacobin and a flower of the Palicourea demissa (Duuren van, 2012).

Figure 5.12 and 5.13 shows the actual size of the booted rackettail female, the white necked jacobin, the green crowned brilliant female and male and the Palicourea demissa. The above mentioned hummingbirds were measured (table 5.3) and compared with the measurements of the *Palicourea demissa* (Table 5.4). The *Palicourea demissa* has one stigma and five stamen. The stigma is shorter than the stamen. Figure 5.12 shows that the shape of beak of the booted rackettail and the white necked jacobin. These beaks fit better in the flower than the beaks of the green crowned brilliants. The measurements of the hummingbirds and flowers confirm this. That is why you would say that the booted rackettail and the white necked jacobin have more chance to pollinate the *Palicourea demissa* instead of the green crowned brilliants. A lot of other hummingbirds that were not measured visited the *Palicourea demissa* (see table 5.2) these hummingbirds could also be a possible pollinator of the *Palicourea demissa*.

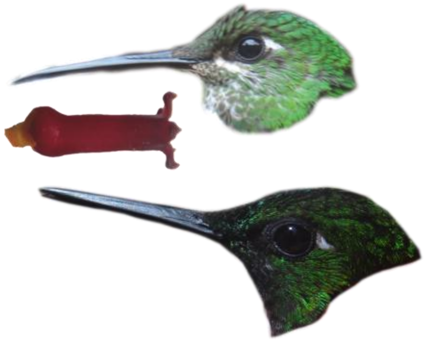


Figure 5.13 Green crowned brilliant female and male and the flower of the Palicourea demisaa (Duuren van, 2012).

Table 5.5 Mean values of the Palicourea demissa

Lenght	Flower opening	Stigma	Stamen	Upper stamen
19,13	3,37	10,77	16,31	4,49

Figure 5.14 White wiskered hermit and the flower of the Costus pulverulentus (Duuren van, 2012).

Figure 5.14 shows the actual size of the white whiskered hermit and the *Costus pulverulentus*. The measured White whiskered hermit (table 5.3) was compared with the measurements of the *Costus pulverulentus* (Table 5.6). The *Costus woodsonni* has one stigma and two stamen. Picture 5.14 shows that the shape of beak fits in the flower and the measurements confirm this. That is why the White whiskered hermit could be a possible pollinator of the *Costus pulverulentus*. The white whiskered hermit is the only hummingbird that visited the *Costus pulverulentus* during the observation period.

Table 5.6 Mean values of the measured Costus pulverulentus

Lenght	Flower opening	Stigma	Stamen	Upper stamen
49,98	4,32	47,07	38,72	5,38

5. Discussion

In this chapter the following research question will be discussed: *What is the influence of feeders on the visitation and reproduction of the plants hummingbirds naturally use as nutrition?*

Expected was that the feeders have an influence on the visitations form hummingbirds on hummingbird-pollinated plant species. Expected was that hummingbirds visit a plant less with feeder present and less plants are pollinated whereby the plants produce less fruits and seeds. For the Heliconia sp significant difference was found in visitations per hour, percentage of visited flowers and the average time that hummingbirds visit a flower on the *Heliconia sp.* When the feeder was present there were less visits per hour, less flowers were visited and the hummingbirds spent less time visiting a flower. The feeder has a negative influence on the visitation of hummingbirds on the *Heliconia sp.* For hummingbirds it is more efficient to visit flowers with the relatively highest concentrated nectar and the highest intake rates of nectar, such that these hummingbirds have to visit less other flowers (Hainsworth and Wolf, 1976). The feeders represent a higher energy source and a higher sugar concentration than the flowers of the *Heliconia sp.* Hummingbirds prefer an energy source with the highest amount of sugar and nectar (Hainsworth and Wolf, 1976). Therefore, they probably visit the feeder more often than the *Heliconia* flowers. If the intake rates of the feeder and the hummingbird-pollinated plant species are compared the feeders have much higher intake rates then the nectar that hummingbird-pollinated plant species can produce. The feeders have even a higher sugar percentage than the hummingbird-pollinated plant species can produce.

Also a significant difference was found in the percentage of visited flowers of the *Pitcairnia nigra* with feeder present and absent. There is no significant difference in the visitations per hour and the average time hummingbirds visited a flower on the *Pitcairnia nigra* with feeder present and absent. During the observation period, there were probably too less flowers flowering to get a good amount of individuals and observations. It is remarkable that there were no significant differences found during the observations of the *Palicourea demissa* and the *Costus pulverulentus* with feeder present and absent. On the *Costus pulverulentus* there was only one flower flowering per day. During the observations there were often no visits of hummingbirds but when the Costus pulverulentus was visited it was always by one species of hummingbird, the white whiskered hermit. Another reason for no significant difference in visitations on the *Palicourea demissa* and the *Costus pulverulentus* with feeder present and absent could be that the flowers were exposed to rain and contained more diluted nectar (Tadey and Aizen, 2001).

The visitations per hour compared to the open flowers of *Palicoura demissa.* were not as linear as expected. Expected was that hummingbirds visit more frequently when there are more flowers open. Also remarkable is that the visits on flowers with feeder present almost look the same compared to feeder absent. Expected was that with feeder present the hummingbirds would visit the flowers less. A reason for both expectations could be the rain. Hummingbirds can fly in heavy rain but the hummingbirds have to fly more horizontal and the frequency of the wing beat increases (Ortege-Jimenez and Dudley, 2012). This costs more energy and this could be a possible reason that the hummingbirds visit the flowers less when it is raining. More research has to be carried out to investigate whether hummingbirds fly less in rain. This can be done by observation of the visitation of hummingbirds on hummingbird-pollinated plant species in light, moderate and heavy rain and as control condition when it is not raining.

The position of the feeders is important. It is unknown at what kind of distance the feeders have an effect on the hummingbird-pollinated plant species. More research has to be carried out to find the relation between distance and visitations. This can be investigated by observing hummingbird-pollinated plant species with feeders on different distances of the plants.

There is a significant difference between the fruit set of the *heliconia sp.* with feeder present and feeder absent. It is remarkable that the fruits of the *Heliconia sp.* with feeder present have more developed fruits than the ones without feeder. There is no significant difference between the seed sets of the *Pitcairna nigra* and the *Heliconia sp.* with feeder present and absent. It was expected that the seed production would less with feeder present because the hummingbirds visited less flowers with feeder present but the seed set does not show a significant difference in seed lowering. The possible reason could be that there were not enough individuals to have a good amount of seeds. Maybe because of time constraints the seeds and fruits were not developed enough to get a realistic view. This could also be the reason that the fruits of the *Heliconia sp.* with feeder present have more developed fruits than the one without feeders. An other reason could be that the Heliconia sp. are self pollinated plants.

In general is it important to carry out more research to find the influence of feeders at the visitation and reproduction of hummingbird-pollinated plant species. This research shows that there is a negative influence of feeders on some plant species. There is still not much known about the influence of feeders on other hummingbird-pollinated plant species. Therefore more research has to be carried out. Observing the visitation of hummingbirds on hummingbird-pollinated plant species and investigate the fruit and the seeds set on developed and not-developed fruits and seeds. It is important to have enough time to do the observations and have enough individuals of a plant species to get enough data.

It is difficult to get nectar out of the *Heliconia sp.* and *Costus pulverulentus* because of the shape of the flowers. Only specialized hummingbirds can get the nectar easily out. To get a get a good overview of the nectar production of the *Heliconia sp.* and the *Costus pulverulentus* it is important to have enough flowers and work accurate because it is easy to stab the flowers and then only water comes out of the flower and the flower is unusable. It could be that the energy calculation of the *Heliconia sp.* and *Costus pulverulentus* slightly differs of the real nectar output because of the above mentioned reason.

During the research flowers of the *Heliconia sp., Costus pulverulentus* and *Palicourea demissa* are measured even as the hummingbirds that were mist netted. The morphology of the flowers and the hummingbirds tell something about the possibly pollinators of the observed flowers. To be sure which hummingbirds pollinate which flowers the flowers of the hummingbird-pollinated plant species have to be covered with mosquito nets. During the observations the plants are uncovered once a hummingbird has visited the flower it will be covered again and after a few months the seed and fruit set will be compared depending on the different hummingbirds species that have visited the flowers.

6. Conclusion and recommendations

During this research the *Pitcairna nigra*, *Heliconia sp. Palicourea demissa* and *Costus pulverulentus* were observed. The four different plant species are different in morphology and attract different species of hummingbirds. During the observation period the white wiskerd hermit, stripe-throated hermit, wedge billed hummingbird, green thorntail, booted racket tail, purple throated woodstar, purple crowned fairy, green crowned brilliant, rufous tailed hummingbird, andean emerald and the green crowned woodnymph were seen. The nectar production and concentrations are different on each plant species and each plant species produces a different amount of energy hummingbirds can use. The amount of energy depends on the open flowers, the daily production of nectar and the sugar percentage of the nectar. All above mentioned things have an influence on which particular plant species hummingbirds visit and which hummingbirds pollinate the flowers.

Based on this research there can be concluded that there is a negative influence of feeders on hummingbird-pollinated plant species in the visitations on the *Heliconia sp*. and the *Pitcairnia nigra* There is a significant difference between the visitations per hour, percentage of visited flowers and the average time that hummingbirds visited a flower on the *Heliconia sp*. When the feeder is present the *Heliconia sp.* are less visited compared to feeder absent. The same pattern is seen in the percentage of visited flowers of the *Pitcairnia nigra.* For hummingbirds it is more efficient to visit flowers with the relativity highest concentrated nectar and the highest intake rates. If you compare the feeder against hummingbird pollinated plant species the feeders have much higher intake rates and sugar concentrations then the hummingbird-pollinated plant species can produce. However there were no significant differences found between the visitations at the *Palicourea demissa* and *Costus pulverulentus* During the observation period there were probably to less flowers flowering to get a good amount of individuals and observations.

There is a significant difference between the fruit set of the *heliconia sp.* with feeder present and absent. It is remarkable that the fruits of the *Heliconia sp.* with feeder present have more developed fruits than the ones without feeder. There is no significant difference between the seed sets of the *Pitcaina nigra* and the seedset of the *Heliconia sp.* with feeder present and absent. During this research the hummingbirds visited the *Heliconia sp*. less with feeder present but the seed set does not show a significant difference in seed lowering. The possible reason could be that there were no enough individuals to have a good amount of seeds. Maybe because of time constraints the seeds and fruits were not developed enough to get a realistic view. This could also be the reason that the fruits of the *Heliconia sp.* with feeder present have more developed fruits than the one without feeders.

The results of this research show that the feeders have a negative influence on the visitations of the hummingbird-pollinated plants. Therefore it is important to convince people it is better to have more ornitophilous plants in there garden to attract hummingbirds. This will help to preserve the hummingbird-pollinated plant species and it will attract also a lot of hummingbirds to the gardens.

It is important to carry out more research on the influence of feeders at the visitation and reproduction of hummingbird-pollinated plant species. There is still not much known about the influence of feeders on other hummingbird-pollinated plant species. Therefore more research has to be carried out. In observing the visitation of hummingbirds on hummingbird-pollinated plant species and investigate the fruit and the seeds set on developed and not-developed fruits and seeds. It is important to have enough time to do the observations and have enough individuals of a plant species to get enough data.

The place of the feeders is important. It is unknown at what kind of distance the feeders have an effect on the hummingbird-pollinated plant species. More research has to be carried out to find out on which distance the feeders have an effect on the hummingbird-pollinated plant species. This can be investigated by observing hummingbird-pollinated plant species with feeders on different distances of the plants and in control conditions with feeder absent.

More research has to be carried out to investigate whether hummingbirds fly less in rain. This can be done by observation of the visitation of hummingbirds on hummingbird-pollinated plant species in light, moderate and heavy rain and as control condition when it is not raining.

Literature list

1. Berry, F. and Kress, W.J. (1991). Heliconia: an identification guide, Smithsonian books.
2. Coro, A.M. del, Monterrubio-Solis, C. Juarez, L. Flores-Moreno, I. Lopez-Saut, E. (2007). ' Effect of the presence of nectar feeders on the breeding success of Salvia Mexicana and Salvia fulgens in a suburban park near Mexico City' Elsevier 136, p. 155-158.
3. Büttner, N. (2005). Reproduktionserfolg, Nektar- und pollenproduktion verschieden häufiger, kolibribestäubter Bromelienarten im ecuadoorianischen Bergregenwald Universität zu Bonn
4. Büttner, N. (2012). *Personal communication*, 23th of February.
5. Duuren van, I. (2012). Pictures of hummingbirds and hummingbird-pollinated plant species, Un poco del Chocó Ecuador.
6. Fenster, C.B. (1991). Selection on floral morphology by ummingbirds 25(1) p. 98-101.
7. Hainsworht, F.R. and Wolf L.L. (1976). Nectar characteristics and food selection by hummingbirds. Oecologia 25, p. 101-113
8. Jordan, G. Deeb, S.S. Bosten, J.M. Mollon, J.D. (2010) 'The dimensionality of color vision in carriers of anomalous trichromacy' Journal of Vision 10, p. 1–19
9. KEARNS, C. A. & D. W. INOUYE (1993): Techniques for Pollination Biologists. University Press of Colorado, Colorado
10. Lindenberg, A.B. and Olesen, J.M. (2001). 'The fragility of extreme specialization Passiflora mixta and his pollinating hummingbird Ensifera ensifera' Journal of Ecologdicy 17 p. 323-329.
11. McCaffrez, R.E. and Wethington, S.M. (2008). 'How the presence of feeders affects the use of local floral resources by hummingbirds' A case study of Southern Arizona. The Condor 110(4) p. 786-791.
12. Nattero, J. and Cocucci, A. A. (2006). *Variations in floral traits of the tree tobacco in relation to its hummingbird pollinator fauna. Conicet-Universidad Nacional de Córdoba, Argentina*
13. Ortega-Jimenez, V.M. and Dudley, R. (2012). Flying in the rain: hovering performance of Anna's hummingbirds under varied precipitation. Utrecht: University of Utrecht.
    Ridgeley, R.S. and Greenfield, P.J. (2001). *The birds of Ecuador.* Cornell university, New york.
14. Schmid, R. (2008). *Sugar preferences of hummingbirds.*
15. Valouis-Cuesta, H. Soriano, P.J. Ornelas, G.F. (2011). Dimorphisms and self-incompatibility in the distylous species Palicourea demissa (Rubiaceae): possible implications
    for its reproductive output. The Botanical Society of Japan and Springer 2010
16. Weathers, W.W. and Stiles, F.G. (1989) Energetics and waterbalance in free-living tropical hummingbirds. Condor 91 p.324-331
17. Whitmore, T.C. (1998). *An Introduction to Tropical Rain Forests.* Second edition. Oxford: USA
18. Ziska, G. and Schneckenburger, S. (1999). *Blütenökologie, faszinierendes Miteinander von Pflanzen und Tieren.* Frankfurt: Germany

Internet

1. Gillis, G.B. (2011). Hummingbird tongue tips twist to trap nectar. <http://jeb.biologists.org/content/214/17/iv.1.full> Used: 7th of March
2. Montereybay (2012). Guatemalan Hummingbrids <http://www.monterey-bay.net/birds/guatemala/hummingbirds.htm> Used: 25th of February
3. Reilly, B. (unknown). Growing pitcairnias and pepinias http://www.bromsqueensland.com/GrowingPitcianiasPepinias.htm Used: 29th of August
4. Ridgeley, R.S. and Greenfield, P.J. (2001) Wildlifefocus Ecuadorin hummingbird guide <http://www.wildlifefocus.org/webcam/guide.htm> Used: 25th of February.
5. Smithsonian tropical research institute, Costus pulverulentus. <http://biogeodb.stri.si.edu/biodiversity/species/22159/> Used: 29th of August

Enclosure 1 Observation schedule

Day	Period	Weather	Plant species	Individu No.	Open flowers	Time	No. Flowers visited	Duration per flower	Hummingbird species

Enclosure 2 Schedule nectar measurements

Plant species	Date	Time	Number of measurements	µl nectar	Sugar concentration %

Enclosure 3 Nectar measurements

3.1 Nectar production of the *Palicourea demissa*

Datum	Time	Measurement	µl	Sugar percentage
27-04-2012	6:30	1	43	17
27-04-2012	6:30	2	39	17
27-04-2012	6:30	3	11	16.5
27-04-2012	6:30	4	4	11
27-04-2012	10:30	1	32	11
27-04-2012	10:30	2	8	13
27-04-2012	10:30	3	6	13
27-04-2012	14:30	1	24	8
27-04-2012	14:30	2	8	9
27-04-2012	14:30	3	2	11
27-04-2012	14:30	4	2	11
27-04-2012	14:30	5	5	7
Day production			184	12.04166667

3.2 Day production of the *Costus pulverulentus*

Datum	Time	Measurement	µl	Sugar percentage
05-06-2012	16:00	1	40	19
05-06-2012	16:15	1	100	3
05-06-2012	16:20	1	40	4.5
05-06-2012	16:20	2	20	11
05-06-2012	16:20	3	65	3
06-06-2012	16:00	1	11	23.5
06-06-2012	16:30	2	10	23.5
06-06-2012	16:30	3	50	14
06-06-2012	16:30	1	10	8
07-06-2012	16:00	1	36	7
07-06-2012	16:30	1	8	27
07-06-2012	16:30	2	7	26.5
07-06-2012	16:30	3	28	27

3.3 Day production of the *Heliconia ….*

Datum	Time	Measurement	µl	Sugar percentage
06-06-2012	16:10	1	8	10
06-06-2012	16:10	2	5	11
07-06-2012	16:15	1	8	20.5

Enclosure 4 Flower measurement

4.1 Flower measurements of the *Heliconia …*

	Flower 1	**Flower 2**	**Flower 3**	**Flower 4**	**Flower 5**
Straight part	24,23 mm.	23,18 mm.	25,60 mm.	21,99 mm.	25,22 mm.
Curve to the upper leave	18,03 mm.	23,05 mm.	23,35 mm.	25,02 mm.	23,15 mm.
Curve to the end	25,93 mm.	23,47 mm.	23,22 mm.	23,58 mm.	26,70 mm.
Flower opening	3,11 mm.	3,08 mm.	4,58 mm.	4,86 mm.	3,84 mm.
Stigma	40,18 mm.	37,52 mm.	37,43 mm.	37,72 mm.	42,38 mm.
Stamen 1	52,84 mm.	48,96 mm.	40,18 mm.	45,27 mm.	52,20 mm.
Stamen 2	52,81 mm.	47,22 mm.	48,45 mm.	41,14 mm.	42,20 mm.
Stamen 3	50,85 mm.	48,04 mm.	47,15 mm.	46,11 mm.	36,63 mm.
Stamen 4	45,75 mm.	42,14 mm.	42,11 mm.	39,78 mm.	42,08 mm.
Stamen 5	40,14 mm.	37,36 mm.	46,20 mm.	43,42 mm.	39,13 mm.
Upper stamen 1	13,80 mm.	14,32 mm.	13,22 mm.	13,80 mm.	3,72 mm.
Upper stamen 2	12,92 mm.	14,06 mm.	13,88 mm.	13,33 mm.	4,42 mm.
Upper stamen 3	13,41 mm.	13,72 mm.	13,09 mm.	14,45 mm.	6,03 mm.
Upper stamen 4	13,48 mm.	13,69 mm.	13,56 mm.	13,09 mm.	4,58 mm.
Upper stamen 5	13,67 mm.	13,02 mm.	13,43 mm.	13,52 mm.	5,21 mm.

4.2 Flower measurements of the *Palicourea demissa*

	Flower 1	Flower 2	Flower 3	Flower 4	Flower 5
Length	18,80 mm.	19,25 mm.	17,61 mm.	19,23 mm.	20,77 mm.
Flower opening	3,45 mm.	3,33 mm.	3,34 mm.	3,52 mm.	3,21 mm.
Stigma	11,87 mm.	11,56 mm.	10,15 mm.	9,84 mm.	10,41 mm.
Stamen 1	17,53 mm	17,10 mm.	14,85 mm.	17,42 mm.	15,45 mm.
Stamen 2	17,53 mm.	16,78 mm.	15,63 mm.	16,57 mm.	15,60 mm.
Stamen 3	15,94 mm.	16,01 mm.	16,17 mm.	16,57 mm.	16,36 mm.
Stamen 4	16,07 mm.	16,57 mm.	15,25 mm.	16,49 mm.	16,30 mm.
Upper stamen 1	4,73 mm.	4,30 mm.	3,60 mm.	4,84 mm.	4,70 mm.
Upper stamen 2	4,57 mm.	4,45 mm.	3,66 mm.	5,45 mm.	4,82 mm.
Upper stamen 3	4,52 mm.	4,37 mm.	4,57 mm.	4,45 mm.	4,50 mm.
Upper stamen 4	4,83 mm.	4,14 mm.	3,57 mm.	5,24 mm.	4,43 mm.

4.3 Flower measurements of the *Costus pulverulentus*

	Flower 1	Flower 2	Flower 3	Flower 4	Flower 5
Length	53,72 mm.	51,48 mm.	50,09 mm.	47,87 mm.	46,75 mm.
Flower opening	4,47 mm.	4,98 mm.	3,90 mm.	4,63 mm.	3,61 mm.
Stigma	49,93 mm.	50,63 mm.	44,49 mm.	49,19 mm.	41,13 mm.
Stamen 1	42,22 mm.	40,67 mm.	39,34 mm.	37,32 mm.	33,78 mm.
Stamen 2	40,13 mm.	39,93 mm.	38,26 mm.	38,96 mm.	36,61 mm.
Upper stamen 1	5,36 mm.	5,18 mm.	5,73 mm.	5,32 mm.	5,10 mm.
Upper stamen 2	6,18 mm.	4,78 mm.	5,14 mm.	5,20 mm.	5,81 mm.

Enclosure 5 Hummingbird measurements

Datum	Time	Species	Weight (gr).	Beaklenght	Beak to skull	Beak and head	Width
15-03-2012	12:00	Booted rackettail (f)	3	13.08	17.79	26.14	2.47
15-03-2012	11:40	White wiskered hermit (m)	6	38.6	45.87	54.88	4.42
26-03-2012	8:15	White wiskered hermit (f)	5	40.55	45.04	57.81	4.93
06-06-2012	8:30	White necked jacobin	7	17.06	24.81	36.98	3.93
06-06-2012	9:40	Green crowned brilliant (m)	10	24.44	32.44	44.53	3.58
06-06-2012	10:00	Green crowned brilliant (f)	9	25.06	32.29	46.43	3.87
06-06-2012	11:30	Green crowned brilliant (m)	10	21.7	28.11	44.52	3.79
06-06-2012	11:30	Green crowned brilliant (f)	8	26.22	31.67	64.17	3.71
06-06-2012	14:00	Green crowned brilliant (m)	9	25.86	30.51	47.23	3.84
06-06-2012	14:00	White Wiskered hermit (m)	6	39.71	43.87	56.42	4.21
06-06-2012	14:15	Green crowned brilliant (m)	10	23.17	30.42	44.43	3.93
06-06-2012	15:40	White Wiskered hermit (m)	8	39.17	44.48	55.43	4.2
07-06-2012	8:50	Green crowned brilliant (f)	8	25.67	33.88	47.03	3.96
07-06-2012	9:25	Green crowned billiant (m)	9	23.05	30.33	43.33	3.56
07-06-2012	9:25	Green crowned brilliant (f)	9	26.12	33.59	47.89	3.82
07-06-2012	9:45	Green crowned brilliant (m)	9	23.37	29.82	44.26	3.32
07-06-2012	14:30	Green crowned brilliant (f)	9	24.54	31.76	48.16	3.77

Enclosure 6 SPSS Output

6.1 Kolmogorov-Smirnov Test on visitations per hour on the *Pitcairnia nigra*

Frequencies

	Feeder	N
Visitation	feeder present	9
	feeder absent	7
	Total	16

Test Statistics

		Visitation
Most Extreme Differences	Absolute	.571
	Positive	.571
	Negative	.000
	Kolmogorov-Smirnov Z	1.134
	Asymp. Sig. (2-tailed)	.153

a. Grouping Variable: Feeder

6.2 Kolmogorov-Smirnov Test on visitations per hour on the Heliconia sp.

Frequencies

	Feeder	N
Visitations	Feeder present	28
	Feeder absent	36
	Total	64

Test Statistics[a]

		Visitations
Most Extreme Differences	Absolute	,373
	Positive	,008
	Negative	-,373
Kolmogorov-Smirnov Z		1,480
Asymp. Sig. (2-tailed)		,025

a. Grouping Variable: Feeder

6.3 Mann-Whitney U Test on visitations per hour of on the *Costus pulverulentus*

Test Statistics[b]

	visitations
Mann-Whitney U	166,500
Wilcoxon W	466,500
Z	-,623
Asymp. Sig. (2-tailed)	,533
Exact Sig. [2*(1-tailed Sig.)]	,700[a]

a. Not corrected for ties.

b. Grouping Variable: Feeder

Ranks

	Feeder	N	Mean Rank	Sum of Ranks
visitations	Feeder present	24	19,44	466,50
	Feeder absent	15	20,90	313,50
	Total	39		

6.4 Univariate Analysis of Variance on the percentage of visited flowers

Between-Subjects Factors

		Value Label	N
Feeder	1	Feeder present	106
	2	Feeder absent	155
Species	1	Pitcairnia Nigra	32
	2	Heliconia	92
	3	Palicoura	98
	4	Costus	39

Tests of Between-Subjects Effects

Dependent Variable:Ratio

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1.176E5	7	16806.925	14.955	.000
Intercept	278837.108	1	278837.108	248.116	.000
Feeder	7882.732	1	7882.732	7.014	.009
Species	70828.954	3	23609.651	21.008	.000
Feeder * Species	7077.188	3	2359.063	2.099	.101
Error	284325.824	253	1123.817		
Total	842337.935	261			
Corrected Total	401974.297	260			

a. R Squared = .293 (Adjusted R Squared = .273)

6.5 Mann-Whitney U Test on the percentage of visited flowers on the *Pitcairnia nigra*

Test Statistics

	Ratio
Mann-Whitney U	47.000
Wilcoxon W	102.000
Z	-2.780
Asymp. Sig. (2-tailed)	.005
Exact Sig. [2*(1-tailed...	.009

a. Not corrected for ties.

b. Grouping Variable: Feeder

Ranks

	Feeder	N	Mean Rank	Sum of Ranks
Ratio	Feeder present	10	10.20	102.00
	Feeder absent	22	19.36	426.00
	Total	32		

6.6 Mann-Whitney Test on the percentage of visited flowers and the time of visitation per flower on the *Heliconia sp.*

Ranks

	Feeder	N	Mean Rank	Sum of Ranks
Ratio	Feeder present	38	42,50	1615,00
	Feeder absent	72	62,36	4490,00
	Total	110		
Time_Visitation	Feeder present	38	45,99	1747,50
	Feeder absent	72	60,52	4357,50
	Total	110		

Test Statistics[a]

	Ratio	Time_ Visitation
Mann-Whitney U	874,000	1006,500
Wilcoxon W	1615,000	1747,500
Z	-3,240	-2,299
Asymp. Sig. (2-tailed)	,001	,022

a. Grouping Variable: Feeder

6.7 Mann-Whitney Test on the percentage of visited flowers and the time of visitation per flower on the *Palicourea demissa.*

Ranks

	Feeder	N	Mean Rank	Sum of Ranks
Timeperflower	Feeder present	52	53,18	2765,50
	Feeder absent	46	45,34	2085,50
	Total	98		
Ratio	Feeder present	52	50,23	2612,00
	Feeder absent	46	48,67	2239,00
	Total	98		

Test Statistics[a]

	Timeperflower	Ratio
Mann-Whitney U	1004,500	1158,000
Wilcoxon W	2085,500	2239,000
Z	-1,364	-,271
Asymp. Sig. (2-tailed)	,173	,787

a. Grouping Variable: Feeder

6.8 Mann-Whitney Test on the percentage of visited flowers and the time of visitation per flower on the *Costus pulverulentus*

Ranks

	Feeder	N	Mean Rank	Sum of Ranks
Ratio	Feeder present	24	19,44	466,50
	Feeder absent	15	20,90	313,50
	Total	39		
time_visitation	Feeder present	24	19,46	467,00
	Feeder absent	15	20,87	313,00
	Total	39		

Test Statistics[b]

	Ratio	time_ visitation
Mann-Whitney U	166,500	167,000
Wilcoxon W	466,500	467,000
Z	-,623	-,598
Asymp. Sig. (2-tailed)	,533	,550
Exact Sig. [2*(1-tailed Sig.)]	,700[a]	,721[a]

a. Not corrected for ties.

b. Grouping Variable: Feeder

6.9 Univariate Analysis of Variance on time of visitations per flower.

Between-Subjects Factors

		Value Label	N
Feeder	1	Feeder present	106
	2	Feeder absent	155
Plant_species	1	Pitcairnia Nigra	32
	2	Heliconia	110
	3	Palicourea	98
	4	Costus	21

Tests of Between-Subjects Effects

Dependent Variable:Time

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	68.425[a]	7	9.775	4.655	.000
Intercept	255.043	1	255.043	121.446	.000
Feeder	.148	1	.148	.071	.791
Plant_species	54.497	3	18.166	8.650	.000
Feeder * Plant_species	2.395	3	.798	.380	.767
Error	531.315	253	2.100		
Total	1099.325	261			
Corrected Total	599.740	260			

a. R Squared = .114 (Adjusted R Squared = .090)

6.10 Independent sample T-Test on time per hour of the *Pitcairnia nigra*

Group Statistics

	Feeder	N	Mean	Std. Deviation	Std. Error Mean
Time_visit	Feeder present	10	2,360	2,0972	,6632
	Feeder absent	22	2,509	2,1571	,4599

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means					95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Time_visit	Equal variances assumed	,122	,730	-,183	30	,856	-,1491	,8159	-1,8154	1,5172
	Equal variances not assumed			-,185	17,958	,856	-,1491	,8071	-1,8449	1,5467

6.11 Mann-Whitney Test on the fruit set of the *Heliconia sp.*

Ranks

	Feeder	N	Mean Rank	Sum of Ranks
Fruits	Feeder present	6	9.25	55.50
	Feeder absent	6	3.75	22.50
	Total	12		

Test Statistics[b]

	Fruits
Mann-Whitney U	1.500
Wilcoxon W	22.500
Z	-2.714
Asymp. Sig. (2-tailed)	.007
Exact Sig. [2*(1-tailed Sig.)]	.004[a]

a. Not corrected for ties.

b. Grouping Variable: Feeder

6.12 Independent sample T-Test on the seed set of the *Pitcairnia nigra*

Frequencies

	Feeder	N
Developed	Feeder present	5
	Feeder absent	5
	Total	10
undeveloped	Feeder present	5
	Feeder absent	5
	Total	10

Test Statistics[a]

		Developed	undeveloped
Most Extreme Differences	Absolute	,600	,600
	Positive	,200	,600
	Negative	-,600	-,200
Kolmogorov-Smirnov Z		,949	,949
Asymp. Sig. (2-tailed)		,329	,329

a. Grouping Variable: Feeder

6.13 Kolmogorov-Smirnov Test on the fruit set of the Heliconia sp.

Frequencies

	Feeder	N
Fruits	Feeder present	6
	Feeder absent	6
	Total	12

Test Statistics[a]

		Fruits
Most Extreme Differences	Absolute	,833
	Positive	,000
	Negative	-,833
Kolmogorov-Smirnov Z		1,443
Asymp. Sig. (2-tailed)		,031

a. Grouping Variable: Feeder

6.14 Kolmogorov-Smirnov Test on the seed set of the Heliconia sp.

Frequencies

	Feeder	N
Developed	Feeder present	12
	Feeder absent	12
	Total	24
Undeveloped	Feeder present	12
	Feeder absent	12
	Total	24
Total	Feeder present	12
	Feeder absent	12
	Total	24

Test Statistics[a]

		Developed	Undeveloped	Total
Most Extreme Differences	Absolute	,333	,333	,250
	Positive	,333	,250	,250
	Negative	,000	-,333	,000
Kolmogorov-Smirnov Z		,816	,816	,612
Asymp. Sig. (2-tailed)		,518	,518	,847

a. Grouping Variable: Feeder