Demographic data from 13 populations of the understory herb *Heliconia acuminata* (Heliconiaceae) in an experimentally fragmented tropical landscape (1997-2013)

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METADATA

I. CLASS I. Data Set Descriptors

A. Data set identity: Demographic data from populations of the understory herb *Heliconia acuminata* (Heliconiaceae) in an experimentally fragmented tropical landscape (1997-2013).

B. Data set identification code:

1. Dataset File 1: `HDP_plots.csv`
2. Dataset File 2: `HDP_1997_2009.csv`

C. Data set description:

1. **Originators:** Emilio M. Bruna, Department of Wildlife Ecology and Conservation, University of Florida, PO Box 110430, Gainesville, FL 32611-0430, USA and Center for Latin American Studies, University of Florida, PO Box 115530, Gainesville, FL 32611, USA.

2. **Abstract:** Habitat fragmentation is thought to be a leading cause of extinction, but the demography of species in fragmented landscapes remains poorly understood. This is particularly true in tropical ecosystems, where studies monitoring populations of species in both fragments and areas of continuous habitat across all life-history stages are virtually nonexistent. Here we report 12 years (1997-2009) of annual censuses of 13 populations of the Amazonian understory herb *Heliconia acuminata* (LC Rich.). These surveys were conducted in plots established in 1997 in the experimentally fragmented landscape of the Biological Dynamics of Forest Fragments Project, located north of Manaus, Brazil. The plots, each 50 x 100 m, are located in forest fragments of different sizes (N = 4 plots in 1-ha fragments and N = 3 plots in 10-ha fragments) as well as continuous forest (N = 6 plots). The population in each plot was censused annually, at

which time we recorded identified, marked, and measured new seedlings, identified any previously marked plants that had died, and recorded the size of individuals that survived. During the flowering season we conducted regular surveys to recorded the identity of flowering plants and the number of inflorescences each produced. The resulting dataset comprises >67000 plant x year records of N = 8586 plants, including N = 3464 seedlings that became established after the initial census. These data have been used in publications on topics ranging from how fragmentation-related reductions in germination influence population growth rates to tests of statistical methods for analyzing reproductive rates.

D. Key words: Amazon, Brazil, deforestation, demography, edge effects, flowering, forest fragments, habitat fragmentation, integral projection models, matrix models, population dynamics, vital rates.

CLASS II. RESEARCH ORIGIN DESCRIPTORS

A. Overall project description:

1. **Identity:** The *Heliconia* Demography Project

2. **Originators:** Emilio M. Bruna, W. John Kress, and María Uriarte

3. **Period of study:** 1997-2009

4. **Objectives:** Habitat fragmentation continues to be a major focus of research by ecologists (Didham et al. 2012, Haddad et al. 2015, Brudvig et al. 2017, Resasco et al. 2017, Fletcher et al. 2018) decades after it was first identified as a threat to the integrity of ecosystems (Harris 1984, Wilcove et al. 1986). A large body of empirical research has documented myriad biotic changes associated with fragmentation, including the local extinction of plant species from fragments (Harrison and Bruna 1999, Laurance et al. 2011). Although the demographic mechanisms underlying these

extinctions are rarely known (Bruna et al. 2009), they are often hypothesized to result from reduced rates of individual growth, reproduction, or survivorship in fragments (Laurance et al. 1998, Zartman et al. 2015). This is especially true tropical forest fragments, where abiotic conditions can be dramatically different from those in primary forest (reviewed in Broadbent et al. 2008). Tests of this hypothesis remain limited, however, by the paucity of long-term demographic data collected in both fragments and continuous forests (Bruna et al. 2009).

The *Heliconia* Demography Project (HDP) seeks to fill this

The core of the HDP is annual censuses of thirteen *H. acuminata* populations located in either continuous forest or one of the BDFFP's experimentally isolated forest fragments. The primary purpose behind their initial collection was to parameterize size-structured demographic models (Caswell 2000, Ellner and Rees 2006) with which to compare the demography and population dynamics of *H. acuminata* populations in fragments and continuous forest and determine if reductions in seedling establishment in forest fragments could lead to negative population growth rates.

5. **Abstract:** Here we report 12 years (1997-2009) of annual censuses of 13 populations of the Amazonian understory herb *Heliconia acuminata* (LC Rich.). These surveys were conducted in plots established in 1997 in the experimentally fragmented landscape of the Biological Dynamics of Forest Fragments Project, located north of Manaus, Brazil. The plots, each 50 x 100 m, are located in forest fragments of different sizes (N = 4 plots in 1-ha fragments and N = 3 plots in 10-ha fragments) as well as continuous forest (N = 6 plots). The population in each plot was censused annually, at which time we recorded identified, marked, and measured new seedlings, identified any previously marked plants that had died, and recorded the size of individuals that survived. During the flowering season we conducted regular surveys to recorded the

identity of flowering plants and the number of inflorescences each produced. The resulting dataset comprises >67000 plant x year records of N = 8586 plants, including N = 3464 seedlings that became established after the initial census. These data have been used in publications on topics ranging from how fragmentation-related reductions in germination influence population growth rates to tests of statistical methods for analyzing reproductive rates.

6. **Sources of funding:** The initial establishment of plots and the 1998-2002 surveys were supported by grants to E. M. Bruna from the Smithsonian Institution (Graduate Student Research Award), the University of California, Davis (Center for Population Biology Graduate Research Grant, M. E. Mathias Graduate Research Grant), the Biological Dynamics of Forest Fragments Project (Graduate Student Logistics Grant), the National Science Foundation (Dissertation Improvement Grant INT 98-06351), and the Ford Foundation (Dissertation Year Fellowship). The 2001-2005 surveys were supported a grant from the National Science Foundation to E. M. Bruna (Research Starter Grant DEB-0309819). The 2006-2009 surveys were supported by grants from the National Science Foundation to E. M. Bruna (DEB-0614149) and María Uriarte (DEB-0614339). Subsequent analyses and the preparation of these data for archiving were supported by the National Science Foundation (DEB-1948607).

B. Subproject description

1. **Site description**

   a. **Site type:** Lowland Tropical Forest

   b. **Geography:** The data were collected at the Biological Dynamics of Forest Fragments Project (BDFFP, 2°30'S, 60°W), a 1000-km mosaic of lowland forest, forest fragments, secondary forests, and pastures located approximately 70 km north of Manaus, Amazonas, Brazil (Fig. 1).

c. **Habitat:** The habitat at the BDFFP is tropical evergreen lowland forest ('tropical moist forest', *sensu* Holdridge (1967)). The forest canopy at the sites is ~35–40 m tall, with emergent trees of up to ~45 m (Rankin-de-Mérona et al. 1992). The tree community at the BDFFP is highly diverse: ~1300 species total (Laurance 2001), with as many as 280 tree species ha^{-1} (Oliveira and Mori 1999). The understory is dominated by stemless palms (Scariot 1999). All HDP plots are located in *terra-firme* (i.e., non-flooded) forest and none are bisected by streams.

d. **Geology:** Soils in the sites are nutrient-poor xanthic ferralsols, known as yellow latosols in the Brazilian soil classification system. Despite their high clay content they have poor water-retention capacity (Fearnside and Leal-Filho 2001). The often rugged topography at the BDFFP ranges in elevation from 50-150 m elevation (Gascon and Bierregaard 2001).

e. **Watersheds:** The BDFFP landscape includes catchments of the Urubu, Cuieiras, and Preto da Eva rivers (Nessimian et al. 2008).

f. **Site history:** A complete history of the BDFFP can be found in Gascon and Bierregaard (2001) and Bierregaard et al. (2002). Briefly, the BDFFP reserves were established on three cattle ranches. Fragments were isolated between 1980-1984 by felling the trees surrounding the patch of forest to be isolated (Lovejoy et al. 1986). Fragment reserves were fenced to prevent the incursion of cattle from the surrounding pastures. To ensure fragments remain isolated, a 100m strip around each fragment is regularly cleared of the secondary growth (Gascon and Bierregaard 2001). The structure and species composition of the secondary growth that surrounds a fragment, which is strongly dependent on whether fire was used to clear land prior to planting pasture grasses (Mesquita et al. 2001), can have large effects on

the species composition, ecological processes, and abiotic conditions in fragments (reviewed in Laurance et al. 2002, 2011). The BDFFP is currently administered collaboratively by the Smithsonian Tropical Research Institute and Brazil's Instituto Nacional de Pesquisas da Amazônia (INPA).

g. **Climate:** Mean annual temperature at the site is 26°C (range 19-39°C). Annual rainfall ranges from 1900-2300 mm (Scott et al. 2021), with a pronounced dry season from June-December in which there is <100 mm rain per month.

2. Sampling Design & Research Methods

a. **Focal species:** *Heliconia acuminata* (Heliconiaceae) is a perennial, self-incompatible monocot native to Amazonia (Kress 1990) and widely distributed throughout the Amazon basin (Kress 1990). Although many species of *Heliconia* grow in large aggregations on roadsides, gaps, and in other disturbed habitats, others, including *H. acuminata*, grow primarily in the shaded forest understory (Kress 1983). *Heliconia acuminata* is the most abundant understory herb throughout much of the BDFFP (Ribeiro et al. 2010); the other two *Heliconia* species found in the BDFFP reserves are either very rare (*H. latispatha*) and restricted saturated soils adjacent to streams (*H. tarumaensis*).

Each *Heliconia acuminata* has a basal rhizome from which emerge erect vegetative shoots with broad leaves, as well as one or more flowering shoots if the plant is reproductive. Plants grow slowly (Bruna and Ribeiro 2005) and the proportion of plants that flower is low (Gagnon et al. 2011). The primary herbivores of *Heliconia* species are Hispine beetles, whose larvae and adults scrape the surface of

unrolled immamture leaves (Strong 1977). The beetle species associated with *H. acuminata* is *Cephaloleia nigriceps* Baly (Staines and Garcia-Robledo 2014); it actually does little damage to leaves but can cause extensive damage to bracts, flowers, and developing ovaries.

Heliconia can be propagated by segmenting the rhizome (Berry and Kress 1991, Bruna and Andrade 2011), and clonal spread is common in the *Heliconia* species found in open or disturbed habitats (Schleuning et al. 2008). However, recruitment in *H. acuminata* and other understory species is primarily via seeds (Bruna 1999, 2002). Plants that flower do so during the rainy season, with the propbability of flowering increasing with plant size (Bruna and Kress 2002). The overwhelming majority of plants that flower (75%) produce just one infloresence (range = 1-7), each of which has on average 22.28 $\pm$ 1.17 SE flowers (range 4-62) that remain open for one day before falling from the plant. Pollen transfer experiments indicate self-compatibility is extremely low (Bruna and Darrigo, *unpubl. data*); succesfully pollinated flowers can produce 1-3 seeds, with an average of 2 seeds per fruit (Bruna and Kress 2002).

Heliconia acuminata is pollinated by the 'traplining' hummingbirds *Phaeothornis superciliosus* and *P. bourcieri*. Visitation rates to flowers are extremely low (<1 visit hour^{-1}, Bruna et al. 2004), as are rates of fruit production (Bruna and Kress 2002). The fleshy blue fruits are consumed by birds (Uriarte et al. 2011); in our study sites the primary dispersers are the White-necked Thrush (*Turdus albicollis*), the Thrush-like-Manakin (*Schiffornis turdinus*), and several species of manakin (*Pipra erythrocephala*, *P. pipra*, *Lepidothrix serena*, and

Corapipo gutturalis). The seeds germinate 6-7 months after dispersal, which coincides with the onset of the rainy season (Bruna 1999, 2002). Post-dispersal seed predation is negligible. Experiments revealed that few *H. acuminata* seeds germinate after one year unless protected from burial under leaf-litter (Bruna 1999, 2002), which is consistent with the generalization that few plant species in lowland tropical forests have seed banks .

b. **Taxonomy, systematics, and voucher specimens:** *Heliconia* is the only genus in the family Heliconiaceae. This family is distinguished from the others in the order Zingiberales by inverted flowers, having a single staminode, and fruits that are drupes. It is estimated that there are 200-250 species of *Heliconia*, almost all of which are native to the Neotropics. *Heliconia acuminata* L. C. (Rich.) (Richard 1831) is one of the approximately 20 *Heliconia* species found in the Brazilian Amazon (Kress 1990). We deposited voucher specimens of *H. acuminata* collected in areas adjacent to demographic plots at the herbaria of the Instituto Nacional de Pesquisas da Amazônia (Accession Numbers INPA 189569-189573) and the University of California, Davis (Accession Numbers DAV 69391-69396).

c. **Permanent Plots:** Surveys of *Heliconia acuminata* demography were carried out in 13 permanent demographic plots distributed across the BDFFP landscape (Bruna and Kress 2002). Six plots are in continuous forest, four are in 1-ha fragments, and three are in 10-ha fragments (Fig. 1). Each demographic plot is 50m x 100m and is subdivided into 50 contiguous subplots of 10 x 10 m to facilitate the surveys. Plots in 1-ha fragments were established in a randomly selected half of the fragment, plots in 10-ha fragments are located in the center of the fragment, and plots in continuous

forest are located 500-4000 m from any borders with cattle pastures or secondary forest (Fig. 2). The plots furthest apart are from each other are separated by ~70 km.

Plots 1-ha fragments, 10-ha fragments, and three of the continuous forest sites were established from January-April 1997, the remaining three plots in continuous forest were established in January 1998. To mark the plants, a team of 2-3 people slowly walked through each subplot and located all *Heliconia acuminata* and marked them with a wooden stake to which was attached an individually numbered aluminum tag. The size of each plant was measured in two ways: (1) by counting its number of vegetative shoots and (2) by measuring the height of the plant from the ground to the top of its highest leaf (rounded to the nearest cm). Three additional plots were established in continuous forest sites in 1998 (CF 4-6); all plants in these plots were tagged and measuring in the same way as in other plots.

d. **Frequency of Data Collection** Plots were censused annually at the onset of the rainy season to coincide with seedling establishment (generally late January to February). The exception to this was the three continuous forest plots established in August 1998, which were censused in August 1999. During each census team members recorded which plants died, the size (i.e., height and number of shoots) of all surviving plants, and the size of all new seedlings, which were also marked with a numbered tag. Regular visits were made to all 13 plots throughout the rainy season to identify reproductive individuals, at which time we recorded the number of inflorescences.

3. **Project personnel:** In addition to the Originators, other key personnel include the Project Managers that were responsible for coordinating the annual censuses and other

field activities, BDFFP Technicians (*"Mateiros"*) that assisted with data collection and provided logistical support in the field, and undergraduate and postgraduate field assistants hired to assist with the surveys.

a. **Project Managers:** Paulo Rubim (2007-2012), Maria Beatriz Nogueira (2002), Maria Rosa Darrigo (2002-2003), Cris Follman Jurinitz (2003), Simone Benedet (2004).

b. **BDFFP Technicians:** Osmaildo Ferreira da Silva, Francisco Marques, Alaercio Marajó dos Reis, João de Deus Fragata, Romeu Cardoso.

c. **Undergraduate & Postgraduate Field Assistants:** Olavo Nardy (2000), Obed Garcia (2001), Sylvia Heredia (2001-2002), Maria Beatriz Nogueira (2002), Cris Follman Jurinitz (2003), David M. Lapola (2003), Denise Cruz (2003), Cristina Escate (2004), Bruno Turbiani (2005), Elisabete Marques da Costa (2006), Wesley Dáttilo da Cruz (2007), Jefferson José Valsko da Silva (2007).

CLASS III. DATA SET STATUS AND ACCESSIBILITY

A. Status

1. **Latest update:** 2022-05-24

2. **Latest archive date:** 2022-05-24 *(to replace with date of archiving at Dryad)*

3. **Metadata status:** Complete (last update: 2022-05-25)

4. **Data verification & quality control procedures:** An extensive review of the data was conducted prior to the dataset's archiving. We began by generating a list of potential anomalies that could indicate errors (e.g. extremely large changes in size from one year to the next, plants marked as dead that had subsequent measurments), and

then wrote code to search for these anomalies using the R statistical programming language (Team 2014). We also used the `pointblank` library (**iannonePointblankDataValidation2022?**), which similarly identifies cases in a dataset for review and validation. All records flagged were evaluated by E. M. Bruna by checking the values in the electronic records against the original data sheets. Any necessary corrections to the dataset were also made using R scripts; the code for these changes and for preparing the datasets for archiving is archived at Zenodo [link]. Questions from future users of the database should be referred to E. M. Bruna, who will investigate and update the database as needed. Code for any post-archiving updates is maintained at Github (https://github.com/BrunaLab).

B. Accessibility

1. **Storage location and medium:** Ecological Society of America Data Archives [URL] and the Dryad Digital Repository [URL].

2. **Location of original data forms, electronic files, and archived copies:** Original data sheets and electronic data files are stored at the University of Florida. Original data files and paper copies are stored in separate locations, with electronic copies of data sheets (.pdf format) and electronic data files (.csv and .xlsx format) are stored on a desktop computer, a synced institutional cloud storage account, and a portable hard drive. The integrity of digital files is verified semi-annually.

3. **Contact person(s):** Emilio M. Bruna, Department of Wildlife Ecology and Conservation, Box 110430, Gainesville, FL 32611 USA. Phone: (352) 846-0634. Email: embruna@ufl.edu

4. **Copyright restrictions:** None

5. **Proprietary Restrictions:**

a. **Proprietary restrictions:** None.

b. **Conditions of Reuse:** Any publication using data collected at the BDFFP must include a BDFFP Technical Series Number in the Acknowledgments. Authors can request a series number upon the acceptance of their article by contacting the BDFFP's Scientific Coordinator or E. M. Bruna.

c. **Citation:** Authors of any publications or products using these data cite should the data paper and data archive as per *Ecological Archives* and *Dryad* policy. We also request that they provide E.M. Bruna a copy of their article upon acceptance, which allows us to track the dataset's usage, inform users of any corrections or updates, report articles using the data to the funding agencies that provided support, and document that different ways in which the scientific community uses the data.

d. **Disclaimers:** While the data are provided in good faith and are accurrate to the best of our knowledge, they are provided "as is". We do not assume any legal liability or responsibility for their accuracy, completeness, or utility. The responsibility for use and analysis of these data lies completely with the user.

CLASS IV. DATA STRUCTURAL DESCRIPTORS

A. Dataset File 1: Descriptors of demographic plots

1. **Identity:** `HDP_plot_descriptors.csv`

2. **Size:** 14 rows (including header), NA bytes.

3. **Format and storage mode:** ASCII text, comma delimited. No compression scheme used.

4. **Header information:** The first row of the file contains the variable names.

5. **Alphanumeric attributes:** Mixed

6. **Special Characters:** Missing values are represented with NA.

7. **Authentication Procedures**: checksum (MD5:2d3ec96006667abab1ecc14e72055850)

8. **Start & End Columns:** Start: `plot`, End: `yr_isolated`

9. **Variable Information:** Each row is one plot, with the columns providing plot-specific values for each variable.

[**INSERT TABLE 1 HERE**]

B. Dataset File 2: *Heliconia* Demographic Data

1. **Identity:** `HDP_data_1997-2009.csv`

2. **Size:** 66785 rows (including header), 3.79 kilobytes.

3. **Format and storage mode:** ASCII text, comma delimited. No compression scheme used.

4. **Header information:** The first row of the file contains the variable names.

5. **Alphanumeric attributes:** Mixed.

6. **Special Characters:** Missing values are represented with NA. **NOTE: What about true blanks? They are NA as well**

7. **Authentication Procedures**: Checksum (MD5:15bbb4869fe192649e93d3474d3145d1)

8. **Start & End Columns:** Start: `plot`, End: `tag_number`

9. **Data anomalies:** Following each survey, the measurements of plant height and stem number were compared with those from the previous year to identify potential errors in either plant measurement or entry (e.g., a plant with 1 shoot in year t and 11 shoots in year t+1 is likely an error in data entry). Discrepancies were investigated by referring to the original data sheets and, on occasion, returning to the field to remeasure plants. Following data entry the original data sheets were copied and stored in a secure location.

No surey in cabo frio in 2003, some missing in 2000?

Plants that could not be found during a survey were recorded as 'missing' but maintained on the survey list to be searched for in subsequent years. The same is true of plants under branches or the crowns of fallen trees (they might not be measured for several years, e.g., until the leaves dried and dropped or the area under the crown could be safely searched). The codes used to denote such cases are defined in Table 2.

The stakes and numbered tags used to mark plants were sometimes displaced, broken, or buried under leaf litter as a result of tree falls or other disturbances. If a tag couldn't be found after an extensive search, the plant would be marked with a new tag number. In some cases, determining such a plant's original number was straightforward (e.g., all plants in a low-density subplot were found except one, which in the prior year was similar in size as the plant found without a tag). In those cases, the plant's prior measurements were transferred to the new number and we logged the details of the tag number transfer (e.g., old number, new number, year; the latest version of the log is archived at [zenodo]. In other cases, however, it was impossible to definitively determine a plant's original number (e.g., when two adjacent and similarly sized plants were both missing their tags). In these cases the original number was maintained in the database

with the plant's status noted as 'missing' in subsequent surveys. The record for the new number indicates the plant with which it is associated is an established plant that was found without a tag (and not a new seedling; see Section IV and Table 2). There were also cases in which established plants were found without tags in subplots where all previously tagged plants had already been located and measured (i.e., previous survey teams failed to find and mark the plants). These plants were also marked, measured, and added to the database as an established but unmarked plant. Of the N = 947 plants in the dataset, 11% were found without tags after the plot had been established. Almost half of these (49%) were in the three plots where *H. acuminata* density was highest (CF-1, FF-7, CF-3).

8. **Variable information:** Each row in the data set is a demographic plot, with columns of data describing that plot. Blanks do not denote missing information, but rather nothing relevant to report.

[INSERT TABLE 2 HERE]

CLASS V. SUPPLEMENTAL DESCRIPTORS

A. **Computer programs and data-processing algorithms:** The code used to process the data and prepare it for archiving is archived at Zenodo [link] and available for continuous improvement at Github (https://github.com/BrunaLab). The Github repository also includes the up-to-date list of tag changes and any corrections to the dataset made after its archiving.

B. **Publications and results:** The following articles have included analyses of part or all of the dataset. An update list can be found in the HDP's Github repository (https://github.com/BrunaLab).

1. Bruna, E. M. and W. J. Kress. 2002. Habitat fragmentation and the demographic

structure of an Amazonian understory herb (*Heliconia acuminata*). *Conservation Biology*, 16(5): 1256-1266.

2. Bruna, E. M., O. Nardy, S. Y. Strauss, and S. P. Harrison. 2002. Experimental assessment of *Heliconia acuminata* growth in a fragmented Amazonian landscape. *Journal of Ecology*, 90(4): 639-649.

3. Bruna, E. M. 2002. Effects of forest fragmentation on *Heliconia acuminata* seedling recruitment in the central Amazon. *Oecologia*, 132:235-243.

4. Bruna, E. M. 2003. Are plant populations in fragmented habitats recruitment limited? Tests with an Amazonian herb. *Ecology*, 84(4): 932-947.

5. Bruna, E. M. 2004. Biological impacts of deforestation and fragmentation. Pages 85-90 in *The Encyclopaedia of Forest Sciences*. J. Burley, J Evans, and J Youngquist, (eds.). Elsevier Press, London.

6. Morris, W. F., C. A. Pfister, S. Tuljapurkar, C. V. Haridas, C. Boggs, M. S. Boyce, E. M. Bruna, D. R. Church, T. Coulson, D. F. Doak,, S. Forsyth, J-M. Gaillard, C. C. Horvitz, S. Kalisz, B. E. Kendall, T. M. Knight, C. T. Lee, and E. S. Menges. 2008. Longevity can buffer plant and animal populations against changing climatic variability. *Ecology* 89(1): 19-25.

7. Fiske, I., E. M. Bruna, and B. M. Bolker. 2008. Effect of sample size on estimates of population growth rates calculated with matrix models. *PLoS ONE* 3(8): e3080.

8. Fiske, I. and E. M. Bruna. 2010. Alternative spatial sampling in studies of plant demography: consequences for estimates of population growth rate. *Plant Ecology* 207(2) 213-225.

9. Uriarte, M., E. M. Bruna, P. Rubim, M. Anciaes, and I. Jonckeeere. 2010. Effects of

forest fragmentation on seedling recruitment of an understory herb: assessing seed vs. safe-site limitation. *Ecology* 91(5):1317-1328.

10. Gagnon, P. R., E. M. Bruna, P. Rubim, M. R. Darrigo, R. C. Littlel, M. Uriarte, and W. J. Kress. 2011. The growth of an understory herb is chronically reduced in Amazonian forest fragments. *Biological Conservation* 144: 830-835.

11. Uriarte, M. Anciães, M. T.B. da Silva, P. Rubim, E. Johnson, and E. M. Bruna. 2011. Disentangling the drivers of reduced long-distance seed dispersal by birds in an experimentally fragmented landscape. *Ecology* 92(4): 924-93.

12. Côrtes, M., M. Uriarte, M. Lemes, R. Gribel, W. J. Kress, P. Smouse, E. M. Bruna. 2013. Low plant density enhances gene flow in the Amazonian understory herb *Heliconia acuminata*. *Molecular Ecology* 22: 5716-5729.

13. Brooks, M. E., K. Kristensen, M. R. Darrigo, P. Rubim, M. Uriarte, E. M. Bruna, and B. M Bolker. 2019. Statistical modeling of patterns in annual reproductive rates. *Ecology* 100(7): e02706.

14. Scott, E. R., M. Uriarte, and E. M. Bruna. 2022. Delayed effects of climate on vital rates lead to demographic divergence in Amazonian forest fragments. *Global Change Biology*. 28(2):463-479.

C. **Other relevant publications and datasets:** The following articles and archives include data that can be used in concert with the census data to conduct demographic modeling and other analyses (e.g., seeds per fruit, seed germination rates, seedling survival rates, plant growth rates following damage, etc). An updated list can be found in the HDP's Github repository (https://github.com/BrunaLab).

1. Emilio M. Bruna and Ana Segalin Andrade. 2011. Edge effects on growth and biomass partitioning of an Amazonian understory herb (*Heliconia acuminata*; Heliconiaceae).

American Journal of Botany. 98(10):1727–1734.

2. M. C. Cortes, V. Gowda, W. J. Kress, E. M. Bruna, and M. Uriarte. 2009. Characterization of 10 microsatellite markers for the understorey Amazonian herb *Heliconia acuminata*. *Molecular Ecology Resources* 9(4):1261–1264.

3. Emilio M. Bruna and Maria Beatriz Nogueira Ribeiro. 2005. Regeneration and population structure of extitHeliconia acuminata in Amazonian secondary forests with contrasting land-use histories. *Journal of Tropical Ecology*. 21(1):127–131.

4. Emilio M. Bruna, W. John Kress, Francisco Marques, and Osmaildo Ferreira da Silva. 2004. *Heliconia acuminata* reproductive success is independent of local floral density. *Acta Amazonica* 34(3):467–471.

5. Emilio M. Bruna (1999). Seed germination in rainforest fragments. *Nature* 402(6758):139–139.

6. Maria Beatriz N. Ribeiro, Emilio M. Bruna, and Waldir Mantovani. 2010. Influence of post-clearing treatment on the recovery of herbaceous plant communities in Amazonian secondary forests. *Restoration Ecology* 18: 50–58.

7. Emilio M. Bruna and Maria Beatriz Nogueira Ribeiro. 2005. The compensatory responses of an understory herb to experimental damage are habitat-dependent. *American Journal of Botany* 92(12):2101–2106.

8. Emilio M. Bruna and Maria Beatriz Nogueira Ribeiro. 2005. Regeneration and population structure of *Heliconia acuminata* in Amazonian secondary forests with contrasting land-use histories. *Journal of Tropical Ecology* 21(1):127–131.

9. Bruna, Emilio M. 2014. *Heliconia acuminata* seed set (seeds per fruit), 2008. Figshare. Dataset. https://doi.org/10.6084/m9.figshare.1273926.v2

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460 **References**

461 Berry, F., and W. J. Kress. 1991. Heliconia: An identification guide. Smithsonian
462 Institution Press, Washington D.C., USA.

463 Bierregaard, R. O., C. Gascon, T. E. Lovejoy, and R. Mesquita, editors. 2002. Lessons from
464 Amazonia: The ecology and conservation of a fragmented forest. Yale University Press,
465 New Haven.

466 Broadbent, E. N., G. P. Asner, M. Keller, D. E. Knapp, P. J. C. Oliveira, and J. N. Silva.
467 2008. Forest fragmentation and edge effects from deforestation and selective logging in
468 the Brazilian Amazon. *Biological Conservation* 141: 1745–1757.

469 Brudvig, L. A., S. J. Leroux, C. H. Albert, E. M. Bruna, K. F. Davies, R. M. Ewers, D. J.
470 Levey, R. Pardini, and J. Resasco. 2017. Evaluating conceptual models of landscape
471 change. *Ecography* 40: 74–84.

472 Bruna, E. M. 1999. Seed germination in rainforest fragments. *Nature* 402: 139–139.

473 Bruna, E. M. 2002. Effects of forest fragmentation on *Heliconia acuminata* seedling
474 recruitment in central Amazonia. *Oecologia* 132: 235–243.

475 Bruna, E. M., and A. S. de Andrade. 2011. Edge effects on growth and biomass partitioning
476 of an Amazonian understory herb (*Heliconia acuminata*; Heliconiaceae). *American*
477 *Journal of Botany* 98: 1727–1734.

478 Bruna, E. M., I. J. Fiske, and M. D. Trager. 2009. Habitat fragmentation and plant
479 populations: Is what we know demographically irrelevant? *Journal of Vegetation Science*
480 20: 569–576.

481 Bruna, E. M., and W. J. Kress. 2002. Habitat fragmentation and the demographic structure
482 of an Amazonian understory herb (*Heliconia acuminata*). *Conservation Biology* 16:
483 1256–1266.

484 Bruna, E. M., W. J. Kress, O. F. da Silva, and F. Marques. 2004. Heliconia acuminata
485 reproductive succeess is independent of local flowering plant density. *Acta Amazonica* 34:
486 467–471.

Bruna, E. M., and M. B. N. Ribeiro. 2005. The compensatory responses of an understory herb to experimental damage are habitat-dependent. *American Journal of Botany* 92: 2101–210.

Caswell, H. 2000. Matrix population models. Sinauer, Sunderland, MA.

Didham, R. K., V. Kapos, and R. M. Ewers. 2012. Rethinking the conceptual foundations of habitat fragmentation research. *Oikos* 121: 161–170.

Ellner, S. P., and M. Rees. 2006. Integral projection models for species with complex demography. *The American Naturalist* 167: 410–428.

Fearnside, P. M., and N. Leal-Filho. 2001. Soil and development in Amazonia: Lessons from the Biological Dynamics of Forest Fragments Project. Yale University Press, New Haven, Connecticut, U.S.A.

Fletcher, R. J., R. K. Didham, C. Banks-Leite, J. Barlow, R. M. Ewers, J. Rosindell, R. D. Holt, A. Gonzalez, R. Pardini, E. I. Damschen, F. P. L. Melo, L. Ries, J. A. Prevedello, T. Tscharntke, W. F. Laurance, T. Lovejoy, and N. M. Haddad. 2018. Is habitat fragmentation good for biodiversity? *Biological Conservation* 226: 9–15.

Gagnon, P. R., E. M. Bruna, P. Rubim, M. R. Darrigo, R. C. Littell, M. Uriarte, and W. J. Kress. 2011. Growth of an understory herb is chronically reduced in Amazonian forest fragments. *Biological Conservation* 144: 830–835.

Gascon, C., and Jr. Bierregaard Richard O. 2001. The Biological Dynamics of Forest Fragments Project: The study site, experimental design, and research activity. Pages 31–42 Lessons from Amazonia: The ecology and conservation of a fragmented forest. Yale University Press, New Haven.

Haddad, N. M., L. A. Brudvig, J. Clobert, K. F. Davies, A. Gonzalez, R. D. Holt, T. E. Lovejoy, J. O. Sexton, M. P. Austin, C. D. Collins, W. M. Cook, E. I. Damschen, R. M. Ewers, B. L. Foster, C. N. Jenkins, A. J. King, W. F. Laurance, D. J. Levey, C. R. Margules, B. A. Melbourne, A. O. Nicholls, J. L. Orrock, D.-X. Song, and J. R. Townshend. 2015. Habitat fragmentation and its lasting impact on Earth's ecosystems.

514 *Science Advances* 1: e1500052.

515 Harris, L. D. 1984. The fragmented forest: Island Biogeography Theory and the preservation
516 of biotic diversity. University of Chicago Press, Chicago.

517 Harrison, S., and E. Bruna. 1999. Habitat fragmentation and large-scale conservation: What
518 do we know for sure? *Ecography* 22: 225–232.

519 Holdridge, L. R. 1967. Life zone ecology. Tropical Science Center, San Jose, Costa Rica.

520 Kress, J. 1990. The diversity and distribution of *heliconia* (Heliconiaceae) in Brazil. *Acta*
521 *Botanica Brasileira* 4: 159–167.

522 Kress, W. J. 1983. Self-incompatibility in central American *heliconia*. *Evolution*: 735–744.

523 Laurance, W. F. 2001. The hyper-diverse flora of the central Amazon. Pages 47–53 *in* R. O.
524 Bierregaard Jr., C. Gascon, T. E. Lovejoy, and R. Mesquita, editors. Lessons from
525 Amazonia: The ecology conservation of a fragmented forest. Yale University Press, New
526 Haven.

527 Laurance, W. F., J. L. C. Camargo, R. C. C. Luizão, S. G. Laurance, S. L. Pimm, E. M.
528 Bruna, P. C. Stouffer, G. Bruce Williamson, J. Benítez-Malvido, H. L. Vasconcelos, K. S.
529 Van Houtan, C. E. Zartman, S. A. Boyle, R. K. Didham, A. Andrade, and T. E. Lovejoy.
530 2011. The fate of Amazonian forest fragments: A 32-year investigation. *Biological*
531 *Conservation* 144: 56–67.

532 Laurance, W. F., L. V. Ferreira, J. M. Rankin de Merona, and S. G. Laurance. 1998. Rain
533 forest fragmentation and the dynamics of Amazonian tree communities. *Ecology* 79:
534 2032–2040.

535 Laurance, W. F., T. E. Lovejoy, H. L. Vasconcelos, E. M. Bruna, R. K. Didham, P. C.
536 Stouffer, C. Gascon, R. O. Bierregaard, S. G. Laurance, and E. Sampaio. 2002.
537 Ecosystem Decay of Amazonian Forest Fragments: A 22-Year Investigation.
538 *Conservation Biology* 16: 605–618.

539 Lovejoy, T. E., R. O. Bierregaard, A. B. Rylands, J. R. Malcolm, C. E. Quintela, L. H.
540 Harper, K. S. Brown, A. H. Powell, C. V. N. Powell, H. O. R. Schubart, and M. B. Hays.

1986. Edge and other effects of isolation on Amazon forest fragments. Pages 257–285 *in* M. Soulé, editor. Conservation Biology: The science of scarcity and diversity. Sinauer; Associates, Sunderland, MA, USA.

Mesquita, R. C. G., K. Ickes, G. Ganade, and G. B. Williamson. 2001. Alternative successional pathways in the Amazon Basin. *Journal of Ecology* 89: 528–537.

Nessimian, J. L., E. M. Venticinque, J. Zuanon, P. De Marco, M. Gordo, L. Fidelis, J. D. Batista, and L. Juen. 2008. Land use, habitat integrity, and aquatic insect assemblages in Central Amazonian streams. *Hydrobiologia* 614: 117–131.

Oliveira, A. A. de, and S. A. Mori. 1999. A central Amazonian terra firme forest. I. High tree species richness on poor soils. *Biodiversity and Conservation* 8: 1219–1244.

Rankin-de-Mérona, J. M., G. T. Prance, R. W. Hutchings, M. F. da Silva, W. A. Rodrigues, and M. E. Uehling. 1992. Preliminary results of a large-scale tree inventory of upland rain forest in the central Amazon. *Acta Amazonica* 22: 493–534.

Resasco, J., E. M. Bruna, N. M. Haddad, C. Banks-Leite, and C. R. Margules. 2017. The contribution of theory and experiments to conservation in fragmented landscapes. *Ecography* 40: 109–118.

Ribeiro, M. B. N., E. M. Bruna, and W. Mantovani. 2010. Influence of post-clearing treatment on the recovery of herbaceous plant communities in Amazonian secondary forests. *Restoration Ecology* 18: 50–58.

Scariot, A. 1999. Forest fragmentation effects on palm diversity in central Amazonia. *Journal of Ecology* 87: 66–76.

Schleuning, M., V. Huamán, and D. Matthies. 2008. Flooding and canopy dynamics shape the demography of a clonal Amazon understorey herb. *Journal of Ecology* 96: 1045–1055.

Scott, E. R., M. Uriarte, and E. M. Bruna. 2021. Delayed effects of climate on vital rates lead to demographic divergence in Amazonian forest fragments. *Global Change Biology*.

Staines, C. L., and C. Garcia-Robledo. 2014. The genus *cephaloleia* Chevrolat, 1836 (Coleoptera, Chrysomelidae, Cassidinae). *ZooKeys* 436: 1–355.

568 Strong, D. R. 1977. Rolled-Leaf Hispine Beetles (Chrysomelidae) and their Zingiberales host
569 plants in Middle America. *Biotropica* 9: 156–169.
570 Team, R. C. D. 2014. R: A language and environment for statistical computing. R
571 Foundation for Statistical Computing, Vienna, Austria.
572 Uriarte, M., M. Anciães, M. T. B. da Silva, P. Rubim, E. Johnson, and E. M. Bruna. 2011.
573 Disentangling the drivers of reduced long-distance seed dispersal by birds in an
574 experimentally fragmented landscape. *Ecology* 92: 924–937.
575 Wilcove, D. S., C. H. McLellan, and A. P. Dobson. 1986. Habitat fragmentation in the
576 temperate zone. Pages 237–256. *in* M. E. Soulé, editor. Conservation biology: The
577 science of scarcity and diversity. Sinauer Associates, Sunderland.
578 Zartman, C. E., J. A. Amaral, J. N. Figueiredo, and C. D. Dambros. 2015. Drought impacts
579 survivorship and reproductive strategies of an epiphyllous leafy liverwort in central
580 Amazonia. *Biotropica* 47: 172–178.

Variable	Definition	Codes	Storage
plot	Code used to identify a plot	FF1-7: plots in fragments CF1-6: plots in continuous forest	string
habitat	Habitat type in which a plot is located	one: 1-ha fragment ten: 10-ha fragment forest: continuous forest	string
ranch	Ranch in which a plot is located	Porto Alegre, Esteio, Dimona	string
bdffp_no	BDFFP ID Number for the reserve in which plot is located	2017, 2018, 1104, 1301, 2206, 1202, 3209, 1501, or 'NA' (for plots outside BDFFP reserve boundaries)	string
yr_isolated	Year in which a fragment was initially isolated	1980, 1983, 1984	integer

Variable	Definition	Codes	Range	Storage
plot	Plot in which plant is located (See Table 1)	FF1-7, CF1-6	-	string
subplot	Subplot in which plant is located	A1-E10, A6-J10	-	string
plant_id	Unique ID number assigned to each plant	-	1-8660	integer
year	Calendar year in which survey was conducted	-	1998-2009	integer
shts	No. of vegetative shoots a plant has	-	0-24	integer
ht	Distance from ground to height of plant's tallest leaf (in cm)	-	0-226	integer
infl	If reproductive, the number of inflorescences observed during flowering season	-	1-7	integer
recorded_sdlg	If plant was newly established seedling in survey year	TRUE = seedling FALSE = not a seedling)	-	logical
found_without_tag	If plant was found without a tag in survey	TRUE = established plant with no tag FALSE = seedling or previously marked plant	-	logical
census_status	Status in a census	measured = plant alive, measured dead = plant died between this and prior census missing = plant not found in census	-	string

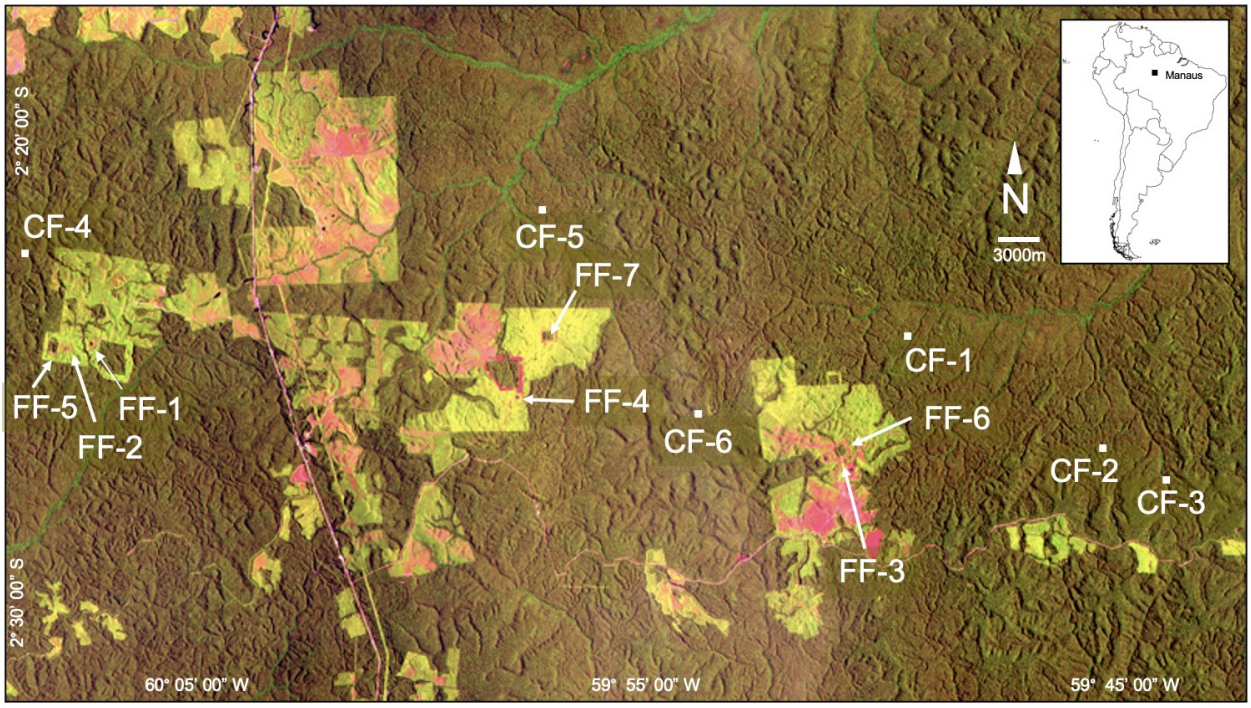

Figure 1. Satellite image of the Biological Dynamics of Forest Fragments Project showing the location of the *Heliconia* Demographic Plots. Plots are located in Continuous Forest (CF) or Forest Fragments (FF). Dark green is primary forest, light green is regenerating forest, and red indicates pasture and recently cleared areas. For additional details on each plot see Table 1.

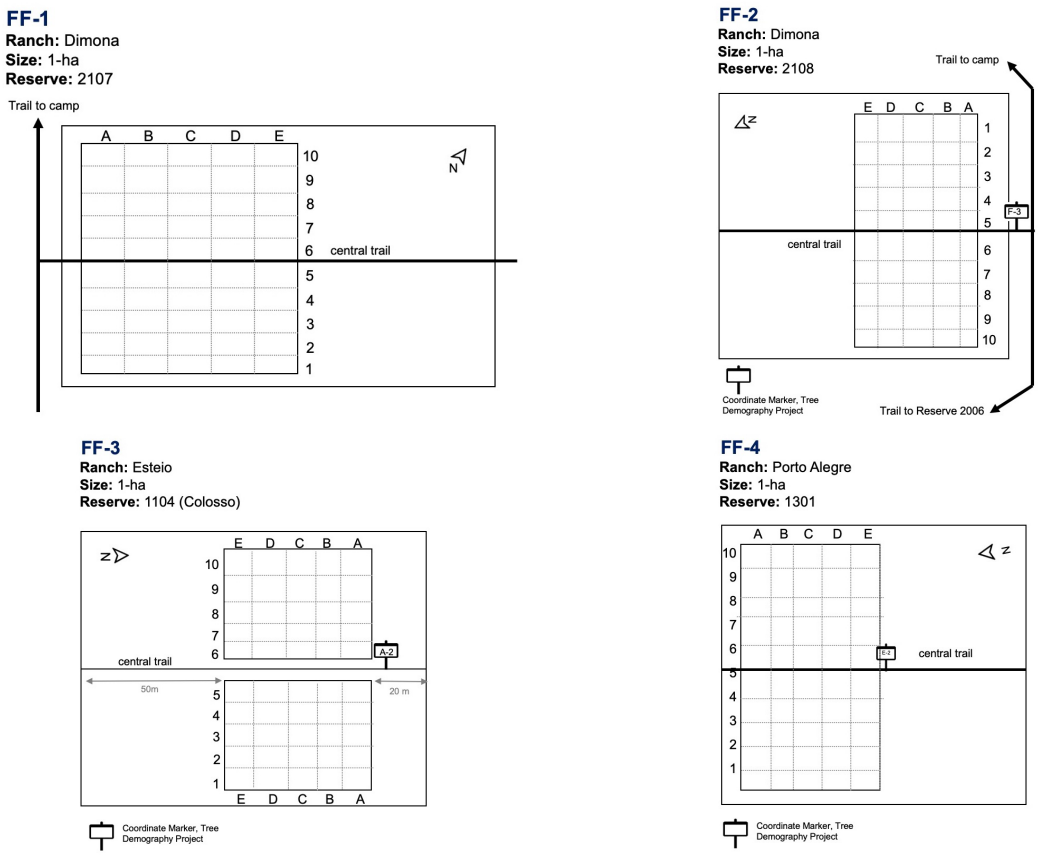
FF-1
Ranch: Dimona
Size: 1-ha
Reserve: 2107
Trail to camp
A B C D E
10 9 8 7 6 central trail 5 4 3 2 1
N
FF-2
Ranch: Dimona
Size: 1-ha
Reserve: 2108
Trail to camp
E D C B A
1 2 3 4 5 F-3 central trail 6 7 8 9 10
Coordinate Marker, Tree Demography Project
Trail to Reserve 2006
FF-3
Ranch: Esteio
Size: 1-ha
Reserve: 1104 (Colosso)
E D C B A
10 9 8 7 6 A-2 central trail
50m
20 m
5 4 3 2 1
E D C B A
Coordinate Marker, Tree Demography Project
FF-4
Ranch: Porto Alegre
Size: 1-ha
Reserve: 1301
A B C D E
10 9 8 7 6 central trail 5 4 3 2 1
Coordinate Marker, Tree Demography Project

Figure 2

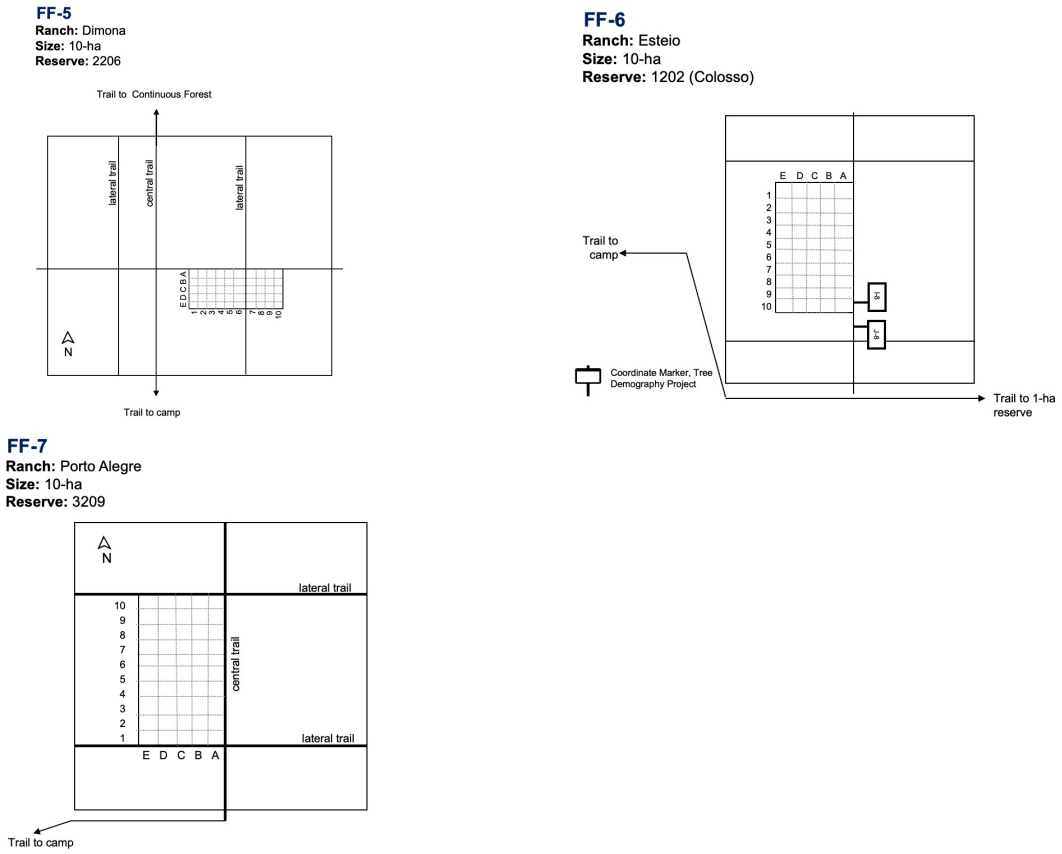

Figure 3. Schematic of the location, orientation, and layout of each *Heliconia* Demographic Plots. The plots are located in Forest Fragments (A-G) or Continuous Forest (H-M).

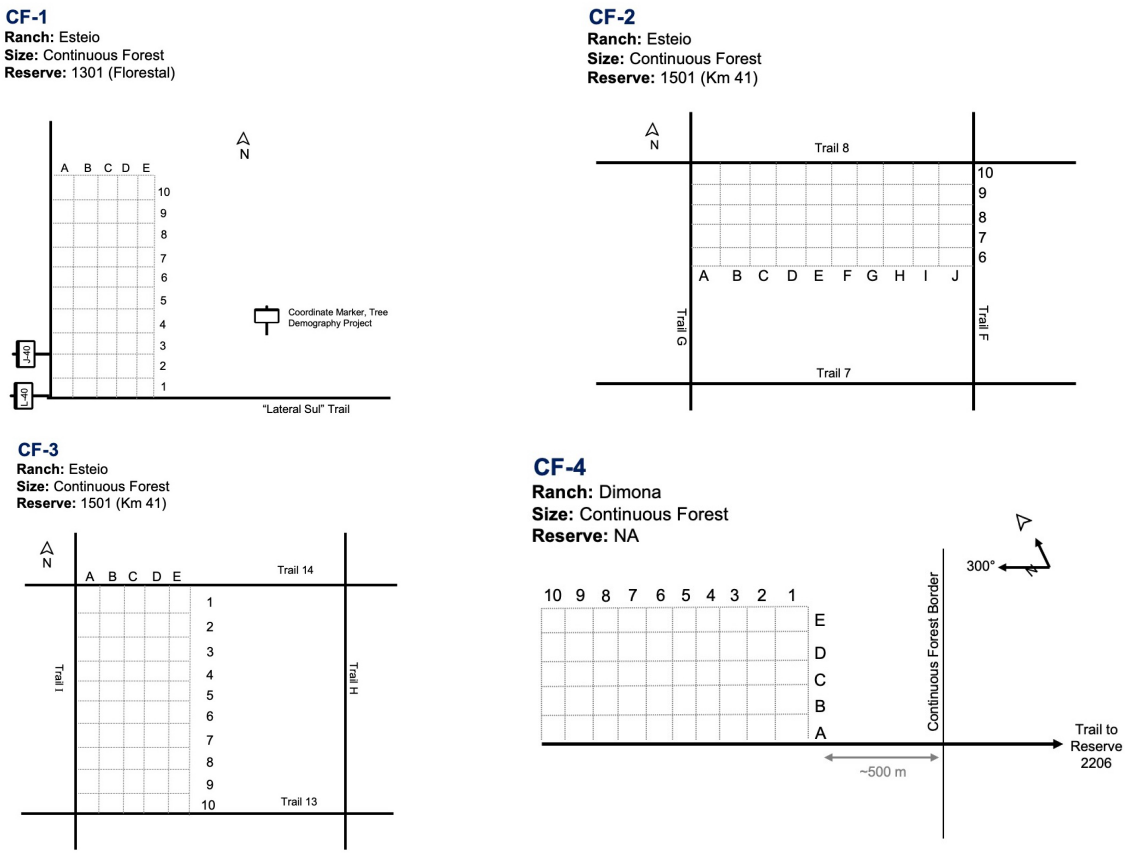
CF-1
Ranch: Esteio
Size: Continuous Forest
Reserve: 1301 (Florestal)
N
A B C D E
10
9
8
7
6
5
4
3
2
1
Coordinate Marker, Tree Demography Project
-40
-40
"Lateral Sul" Trail
CF-2
Ranch: Esteio
Size: Continuous Forest
Reserve: 1501 (Km 41)
N
Trail 8
10
9
8
7
6
A B C D E F G H I J
Trail G
Trail F
Trail 7
CF-3
Ranch: Esteio
Size: Continuous Forest
Reserve: 1501 (Km 41)
N
A B C D E
Trail 14
1
2
3
4
5
6
7
8
9
10
Trail I
Trail H
Trail 13
CF-4
Ranch: Dimona
Size: Continuous Forest
Reserve: NA
300°
10 9 8 7 6 5 4 3 2 1
E
D
C
B
A
Continuous Forest Border
Trail to Reserve 2206
~500 m

Figure 4

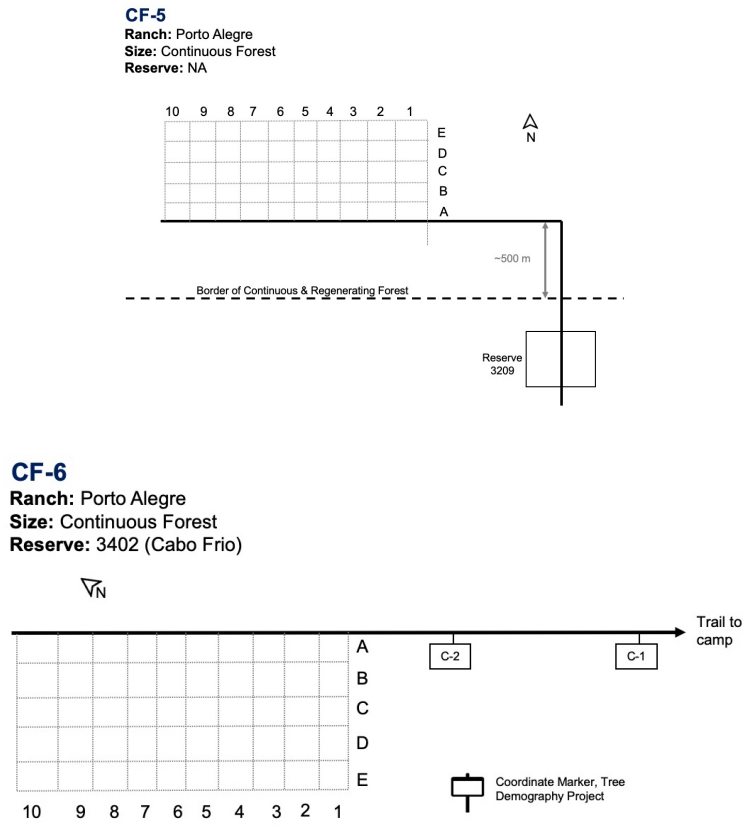

Figure 5. Schematic of the location, orientation, and layout of each *Heliconia* Demographic Plots. The plots are located in Forest Fragments (A-G) or Continuous Forest (H-M).