SCIENTIFIC PAPERS

Tutorial #8

SHORT INTRODUCTION TO SCIENTIFIC PAPERS

- Scientists can submit their research as ***papers*** to journals
- ***Journals*** are run by some publisher
- Journals accept, reject or ask you to re-submit your paper with changes based on their own criteria. Papers are judged by independent ***reviewers*** (aka other scientists invited to review for that journal), that's why it's called 'peer-reviewed'
- Papers are the main way of scientists communicating (there is no other way really apart from conferences)

nature climate change | Volume 9

Example for journal…

…and its articles

Statistics Tutorial #8, Lisa Gotzian

Articles

Article | 22 April 2019

Asserting the climate benefits of the coal-to-gas shift across temporal and spatial scales

The benefits of using natural gas as a bridge fuel are often called into question. A coal-to-gas shift in China, Germany, India and the United States is broadly consistent with climate stabilization goals in the Paris Agreement, except when metrics emphasizing very short-term outcomes are used.

Katsumasa Tanaka, Otávio Cavalett […] & Francesco Cherubini

Article | 08 April 2019

Climate damages and adaptation potential across diverse sectors of the United States

In this Article, modelling results from a consistent set of sectoral climate change impact models, covering 22 impact sectors of the United States, are summarized. Findings are complex, but largely negative and expensive.

Jeremy Martinich & Allison Crimmins

Article | 01 April 2019

Reconciling opposing Walker circulation trends in observations and model projections

The Pacific Walker circulation is predicted to weaken, however, observations suggest a current strengthening. Satellite humidity observations show a weaker response than reanalyses; coupled with model simulations, this suggests that internal variability dominates recent strengthening.

Eui-Seok Chung, Axel Timmermann […] & Viju O. John

Article | 22 April 2019

Tropical influence on the North Pacific Oscillation drives winter extremes in North America

JOURNAL RANKINGS

- As a scientist, you try to get into higher ***ranked*** journals. A ranking is done based on how much papers published by that journal are cited. A ranking for environmental scientists can be found eg. here
- If you are in a higher ranked journal, chances are 1) the peer-reviewing process is better and your paper will receive even more improvements and 2) more people see you and might cite you 3) you are seen as 'a stronger researcher' and get into higher positions

7	Proceedings of the Royal Society B: Biological Sciences	journal	2.722 Q1	221	565	1819	30584	8538	1733	4.24	54.13	

a journal's ranking according to scimagojr.com

Source: https://www.scimagojr.com/journalrank.php?category=2301

HERE'S A LIST OF THE TOP-RANKED JOURNALS FOR ENVIRONMENTAL SCIENCES

	Title	Type	SJR	H index	Total Docs. (2018)	Total Docs. (3years)	Total Refs.	Total Cites (3years)	Citable Docs. (3years)	Cites / Doc. (2years)	Ref. / Doc.	
1	Nature Climate Change	journal	8.612 Q1	136	295	835	9380	10627	549	18.45	31.80	
2	Global Change Biology	journal	4.316 Q1	217	511	1157	38863	10538	1096	9.02	76.05	
3	Applied Catalysis B: Environmental	journal	3.753 Q1	205	1044	2510	59955	34657	2485	14.47	57.43	
4	Annual Review of Environment and Resources	book series	3.642 Q1	101	21	66	3439	640	65	9.74	163.76	
5	Global Biogeochemical Cycles	journal	3.509 Q1	164	108	339	8416	1988	333	5.76	77.93	
6	Environmental Innovation and Societal Transitions	journal	3.212 Q1	34	70	127	5201	1095	125	8.01	74.30	
7	Proceedings of the Royal Society B: Biological Sciences	journal	2.722 Q1	221	565	1819	30584	8538	1733	4.24	54.13	
8	Environmental Research Letters	journal	2.710 Q1	97	573	1215	33213	7391	1172	5.98	57.96	
9	Environment International	journal	2.693 Q1	157	595	872	36692	7467	825	8.17	61.67	

STRUCTURE OF PAPERS

- all papers follow the IMRaD structure:
  - Introduction
  - Methods
  - Results and
  - Discussion

LET'S LOOK AT ONE SPECIFIC STUDY: KLEIN ET AL., 2003

- We'll look at *Klein et al., 2004* and the effect of bee diversity on coffee fruit sets
- It's published in of the journals by "**The Royale Society**", which is ranked on #7 in the list (that's good!)
- **"Proceedings of The Royale Society B: Biological Sciences"** has the following requirements for each paper:

Main text

The main text of your article should be split into clearly-labelled sections. Usually these will be background, methods, results, discussion and conclusions, however please feel free to use whatever headings and subheadings best suit your article. Abbreviations should be written out in full on first use.

This means eg:

Introduction
Methods
Results and
Discussion

IMRaD!

Source: https://royalsociety.org/journals/authors/author-guidelines/

KLEIN ET AL., 2003: BEE DIVERSITY PREDICTS COFFEE FRUITS

- What's their research question?
- What's the study design?
- What statistical methods do you recognize?
- What are their results?

KLEIN ET AL., 2003: BEE DIVERSITY PREDICTS COFFEE FRUITS

Fruit set of highland coffee increases with the diversity of pollinating bees

Alexandra-Maria Klein*, Ingolf Steffan-Dewenter and Teja Tscharntke

Agroecology, University of Göttingen, Waldweg 26, D-37073 Göttingen, Germany

The worldwide decline of pollinators may negatively affect the fruit set of wild and cultivated plants. Here, we show that fruit set of the self-fertilizing highland coffee (*Coffea arabica*) is highly variable and related to bee pollination. In a comparison of 24 agroforestry systems in Indonesia, the fruit set of coffee could be predicted by the number of flower-visiting bee species, and it ranged from *ca.* 60% (three species) to 90% (20 species). Diversity, not abundance, explained variation in fruit set, so the collective role of a species-rich bee community was important for pollination success. Additional experiments showed that single flower visits from rare solitary species led to higher fruit set than with abundant social species. Pollinator diversity was affected by two habitat parameters indicating guild-specific nesting requirements: the diversity of social bees decreased with forest distance, whereas the diversity of solitary bees increased with light intensity of the agroforestry systems. These results give empirical evidence for a positive relationship between ecosystem functions such as pollination and biodiversity. Conservation of rainforest adjacent to adequately managed agroforestry systems could improve the yields of farmers.

KLEIN ET AL., 2003: BEE DIVERSITY PREDICTS COFFEE FRUITS

➤ There's **three hypothesises** and we'll go through them step by step.

We focused on the following questions.

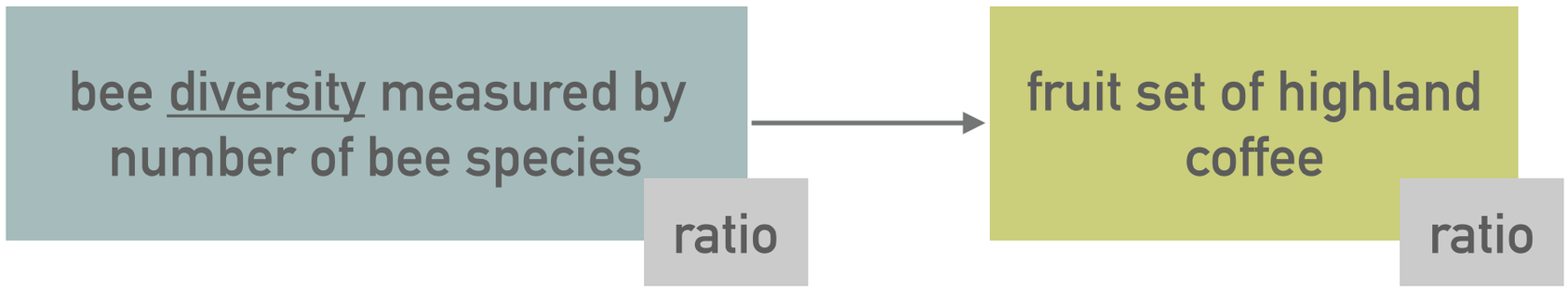
(i) Does the fruit set of highland coffee depend on pollinating bees, and is bee diversity or bee abundance more important?
(ii) Are social or solitary bees the more efficient pollinators of *C. arabica*?
(iii) Do distance to the nearest forest and shading of coffee influence the diversity of flower-visiting bees and the resulting fruit set?

THE STATISTICS OF THE PAPER

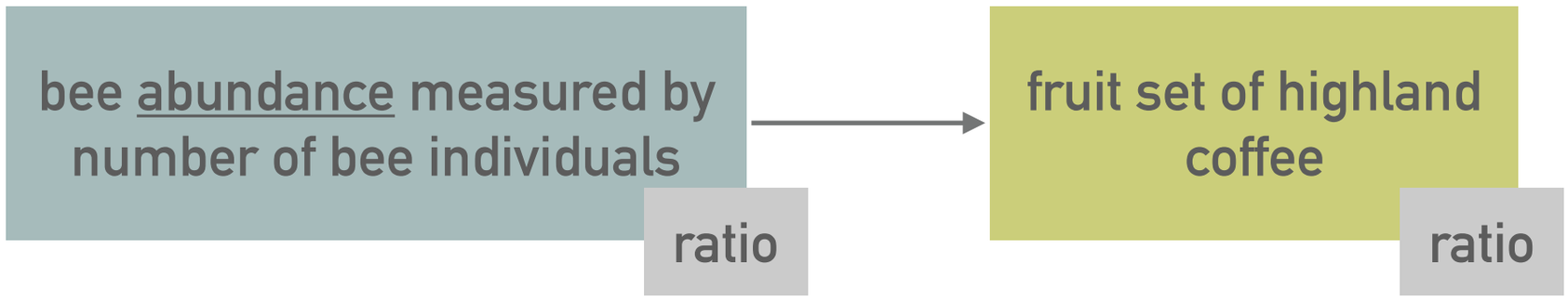
KLEIN ET AL., 2003: BEE DIVERSITY PREDICTS COFFEE FRUITS

- **Research question:** 1) Does the fruit set of highland coffee depend on pollinating bees, and is bee diversity or bee abundance more important?
- **Method:** each a **ratio** predictor, each a **ratio** response variable -> each is a **linear regression**

#1.1



#1.2



$$mx + b = y$$

Explanatory variable "Predictor" — *Response variable*

KLEIN ET AL., 2003: BEE DIVERSITY PREDICTS COFFEE FRUITS

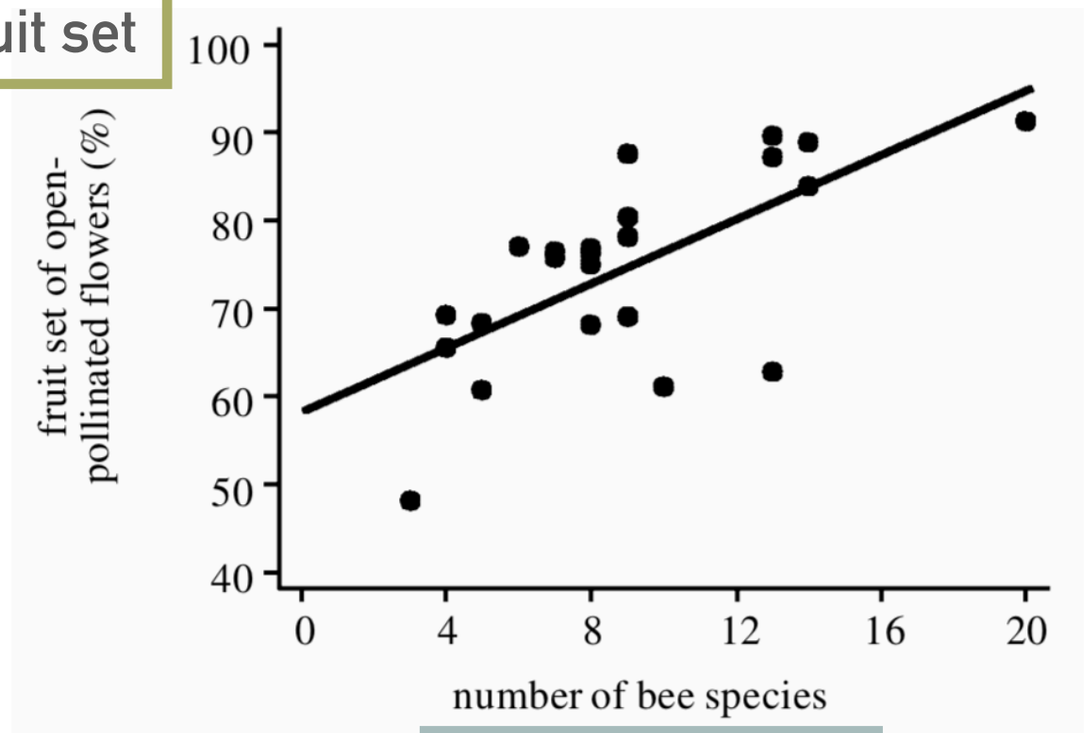
1

#1.1

bee <u>diversity</u> measured by number of bee species → fruit set of highland coffee

$$mx + b = y$$

fruit set



bee <u>diversity</u>

$$y = 58.56 + 1.81x$$

$F=17.90$, $\underline{r^2 = 0.449}$,
$n=24$, $p<0.001$

If I have 8 bees, how big would be my set of highland coffee according to this?

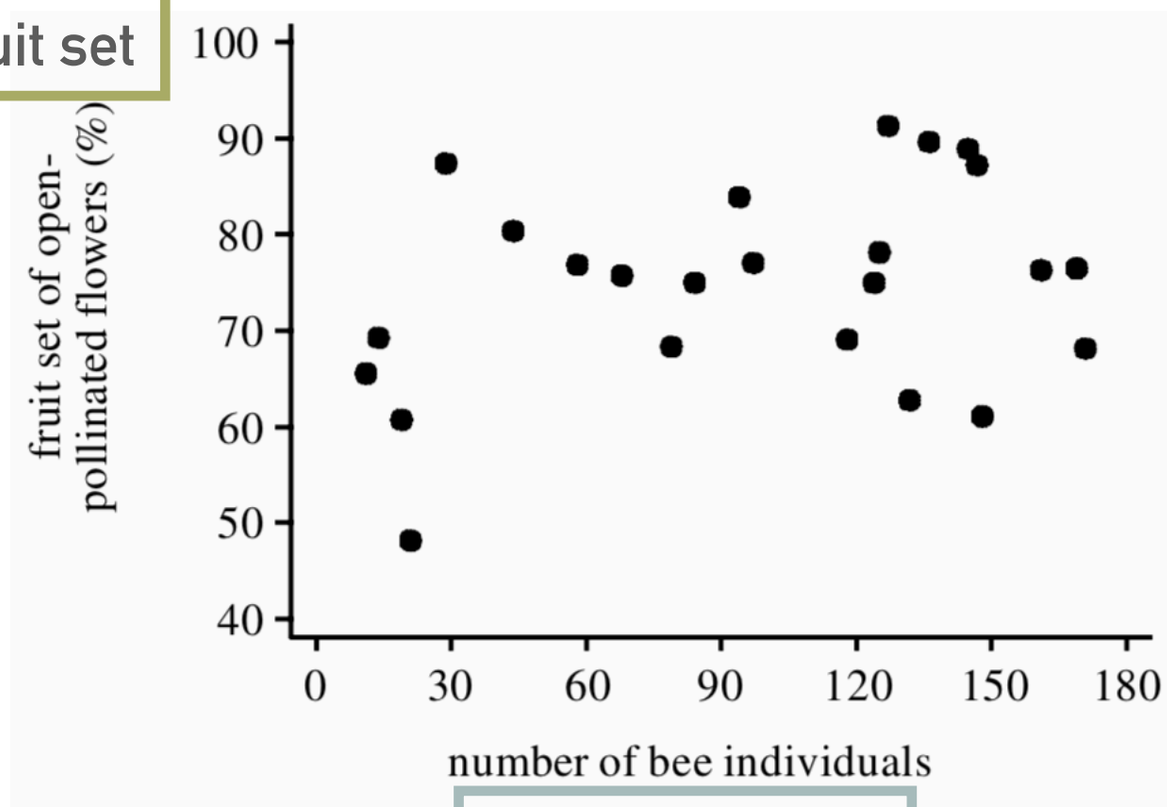
KLEIN ET AL., 2003: BEE ABUNDANCE?

#1.2

bee abundance measured by number of bee individuals → fruit set of highland coffee

$$mx + b = y$$

fruit set



bee abundance

$y = ?$

$F = 2.49, r2 = 0.102,$
$n = 24, p = 0.13$

not significant

KLEIN ET AL., 2003: BEE DIVERSITY PREDICTS COFFEE FRUITS

2

- **Research question:** 2) Are social or solitary bees the more efficient pollinators of *C. arabica*?
- **Method:** "We used ***t*-tests** to compare the means of fruit set between social and solitary bees."

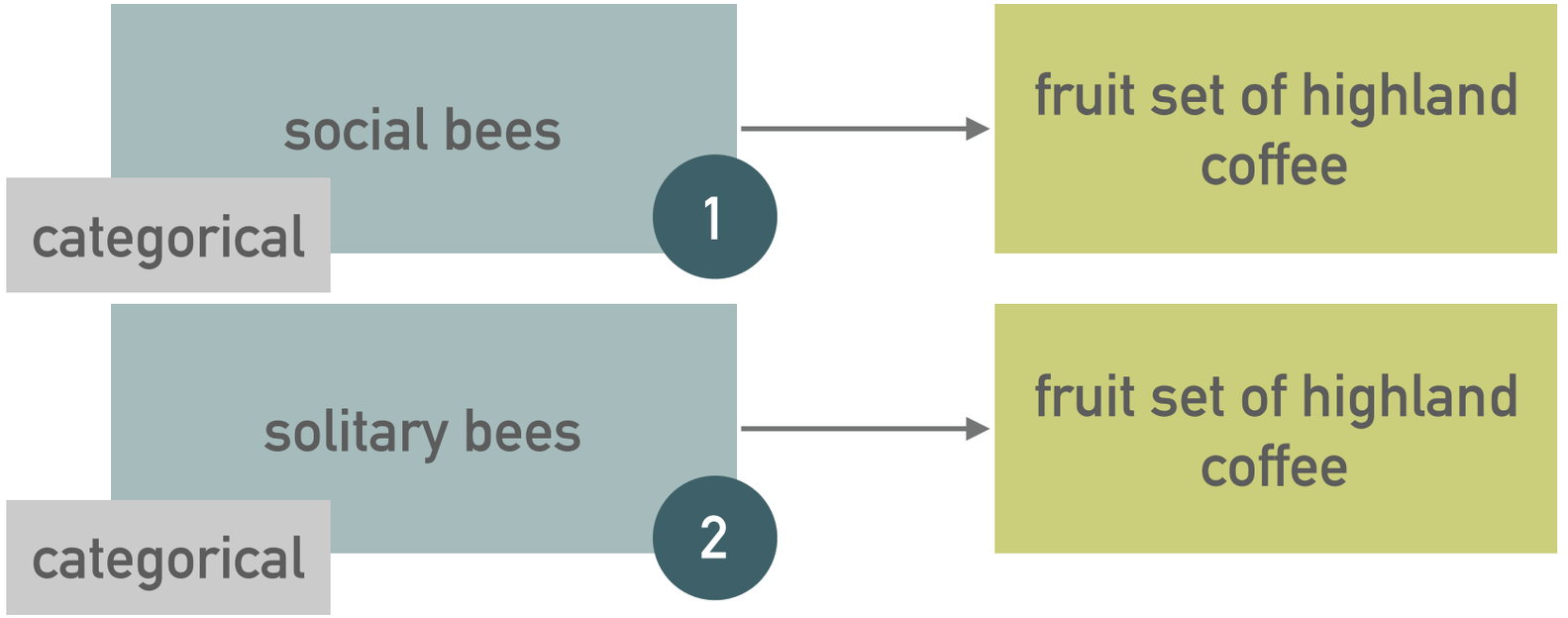


Table 1. Pollination efficiencies of social and solitary bees. Fruit set after a single visit of a specific bee species to a single virgi previously bagged coffee flower was analysed. The number of single visits for each species and the proportion of flowers t developed fruits are given. In addition, the frequency of flower visitation within the total of 75 min per study site is given for the 24 study sites.

bee species	number of replicates	fruit set (%)	frequency of flower-visitors
social bees			
Apis nigrocinta	51	76.5	343
Apis dorsata binghami	56	82.1	229
Apis cerana	13	84.6	269
Trigona (*Lepidotrigona*) *terminata*	20	80.0	106
Trigona sp. 3	12	75.0	23
Trigona (*Heterotrigona*) sp. 1	12	66.7	19
Trigona (*Heterotrigona*) sp. 2	12	58.3	154
	sum: 176	mean: 74.7 ± 3.51	sum: 1143
solitary bees			
Amegilla sp.	14	85.7	57
Chalicodoma (*Callome*	5	60.0	28
Ceratina sp.	10	90.0	26
Creightonella frontalis	20	90.0	101
Halictidae gen. sp.	11	90.9	146
Heriades sp.	28	92.9	113
Xylocopa (*Koptotorsoma*) *aestuans*	4	100	33
Xylocopa (*Zonohirsuta*) *dejeanii nigrocerulea*	9	88.9	53
	sum: 101	mean: 87.3 ± 4.16	sum: 557

social bees

1

solitary bees

2

fruit set

2

t-test: *Are the means of social and solitary bees different?*

$t = 22.31, p = 0.019$

$n = 7$ *social* $+ 8$ *solitary bees*

Before we get into **research question #3...**

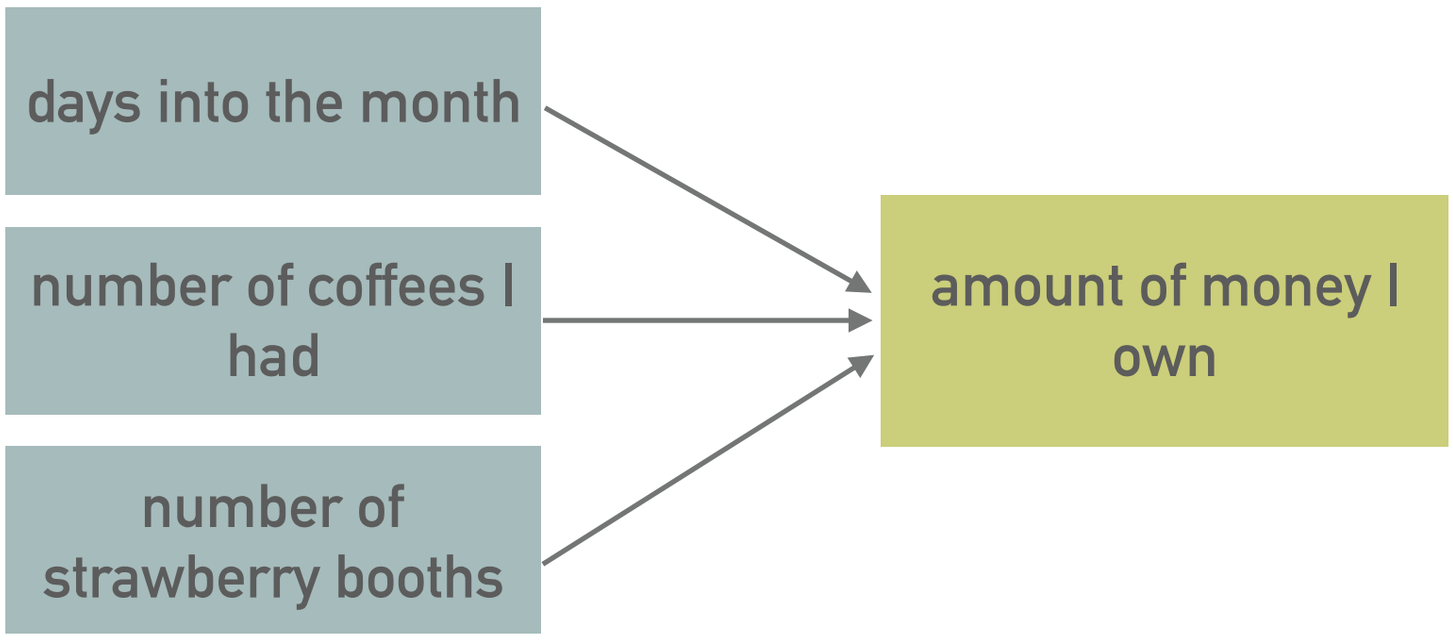
SHORT EXPLANATION: MULTIPLE LINEAR REGRESSION

Linear regression

$$mx + b = y$$

$$w_1 \cdot \#\ species + w_0 = fruit\ sets$$

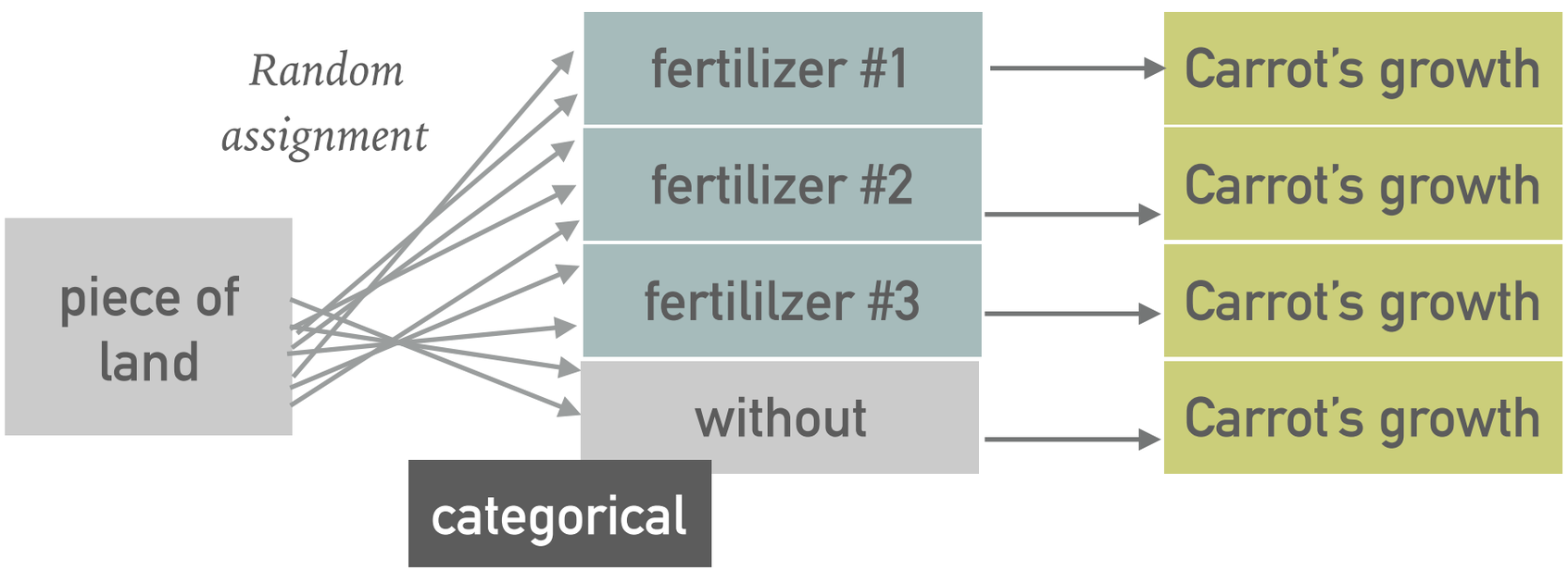
/ same thing, new names



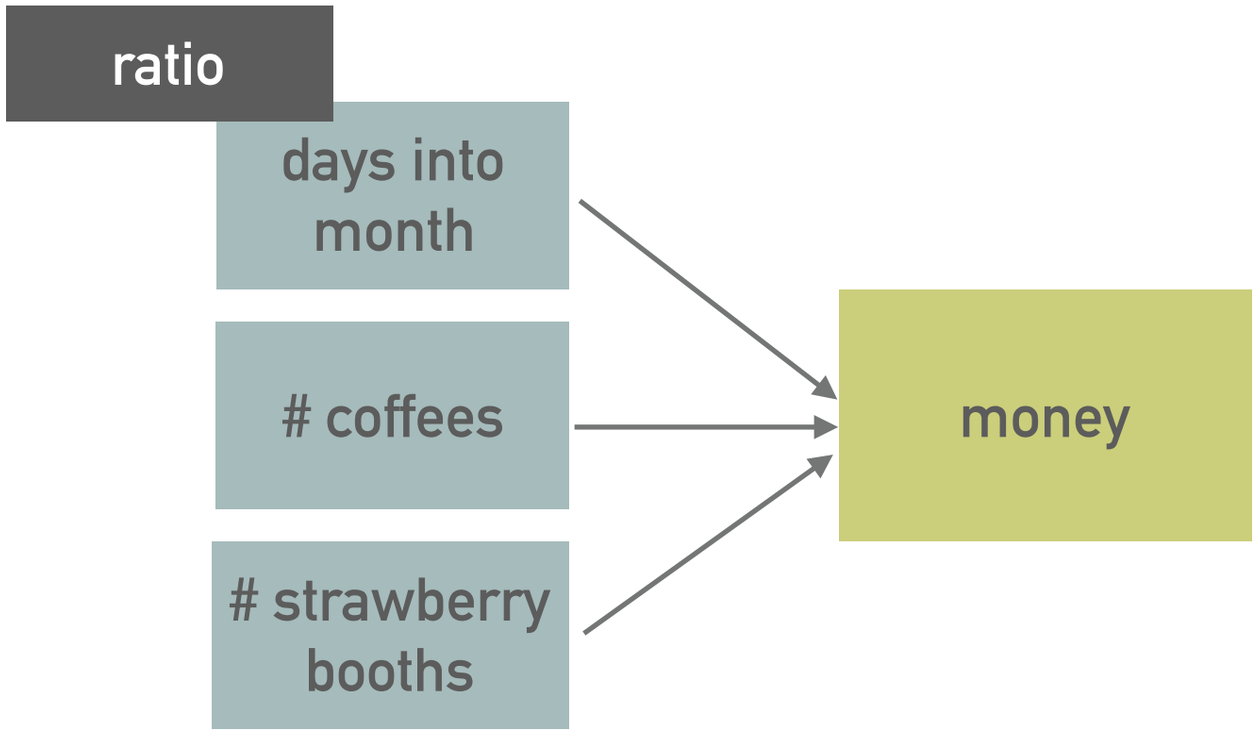
Multiple linear regression

$$w_0 + w_1 \cdot days\ into\ month + w_2 \cdot \#\ coffees + w_3 \cdot \#\ strawberry\ booths = money$$

WHY IS THIS NO ANOVA?



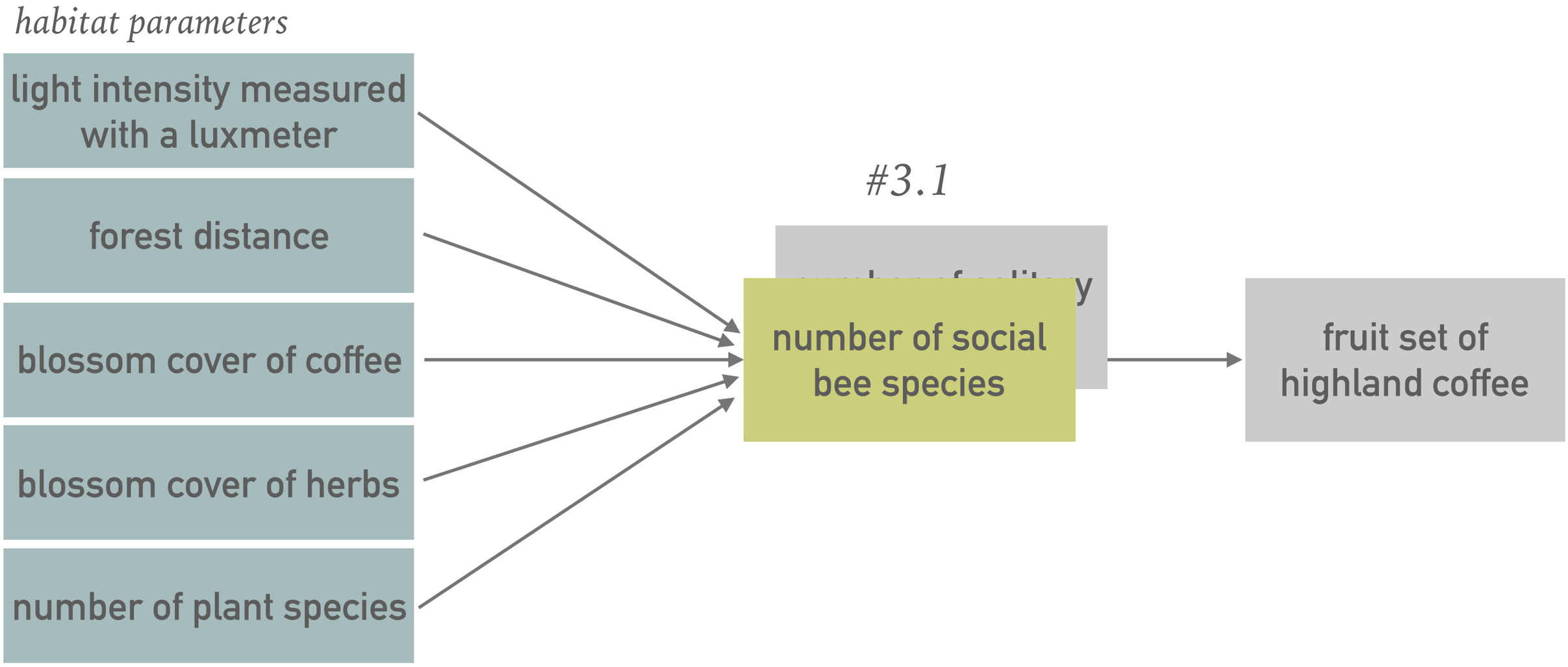
ANOVA



Multiple linear regression

KLEIN ET AL., 2003: HABITAT PARAMETERS

➤ **Research question:** 3) Do habitat parameters like distance to the nearest forest and shading of coffee influence the diversity of bees and the resulting fruit set?



KLEIN ET AL., 2003: HABITAT PARAMETERS

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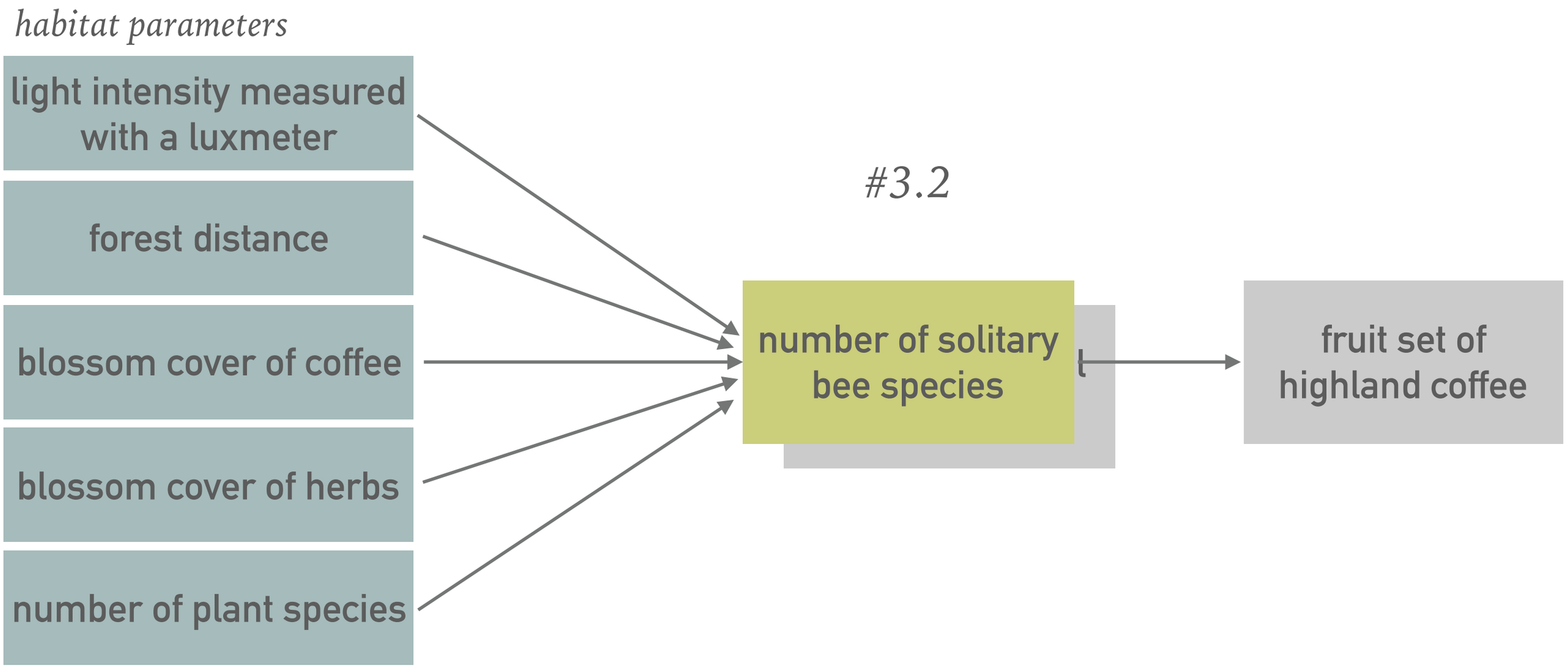
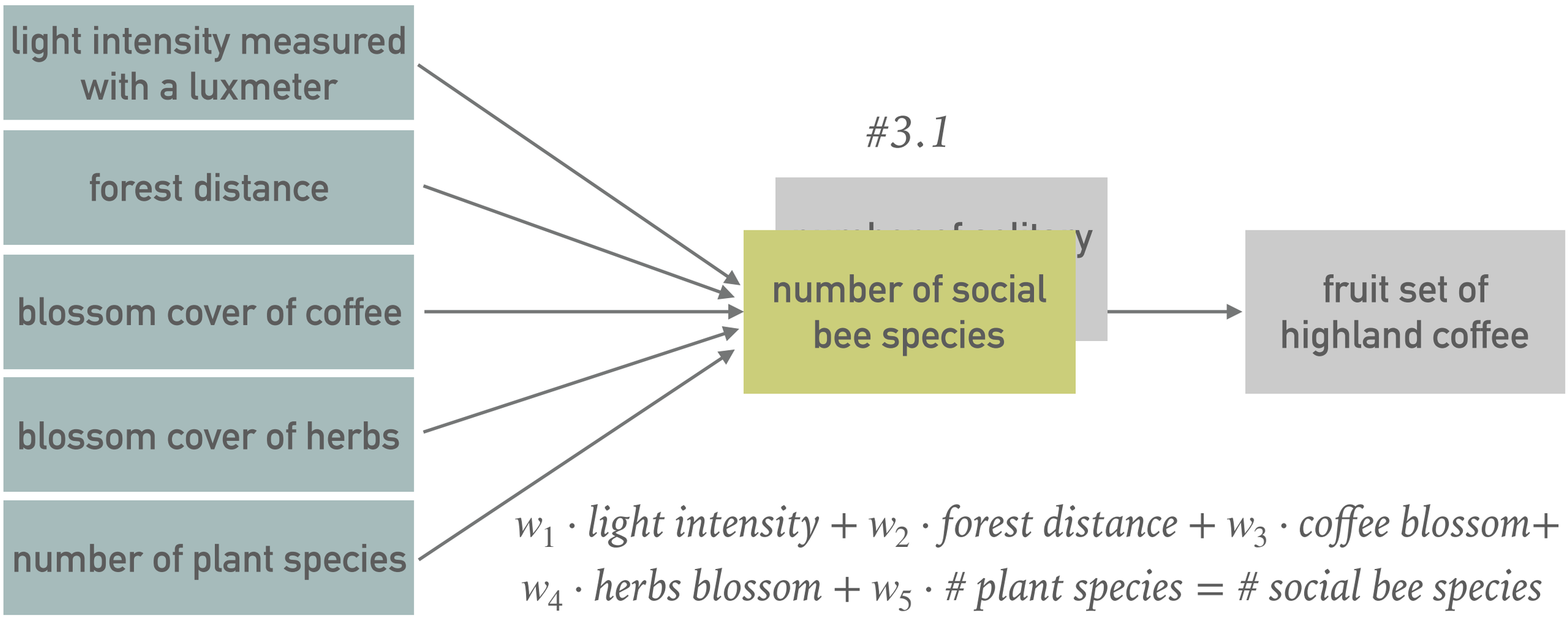


KLEIN ET AL., 2003: HABITAT PARAMETERS

- **Research question:** 3) Do habitat parameters like distance to the nearest forest and shading of coffee influence the diversity of bees and the resulting fruit set?
- **Method:** multiple **ratio** predictors, so **multiple linear regression** for each response variable aka dependent variable

habitat parameters



$$w_1 \cdot light\ intensity + w_2 \cdot forest\ distance + w_3 \cdot coffee\ blossom + w_4 \cdot herbs\ blossom + w_5 \cdot \#\ plant\ species = \#\ social\ bee\ species$$

KLEIN ET AL., 2003: HABITAT PARAMETERS

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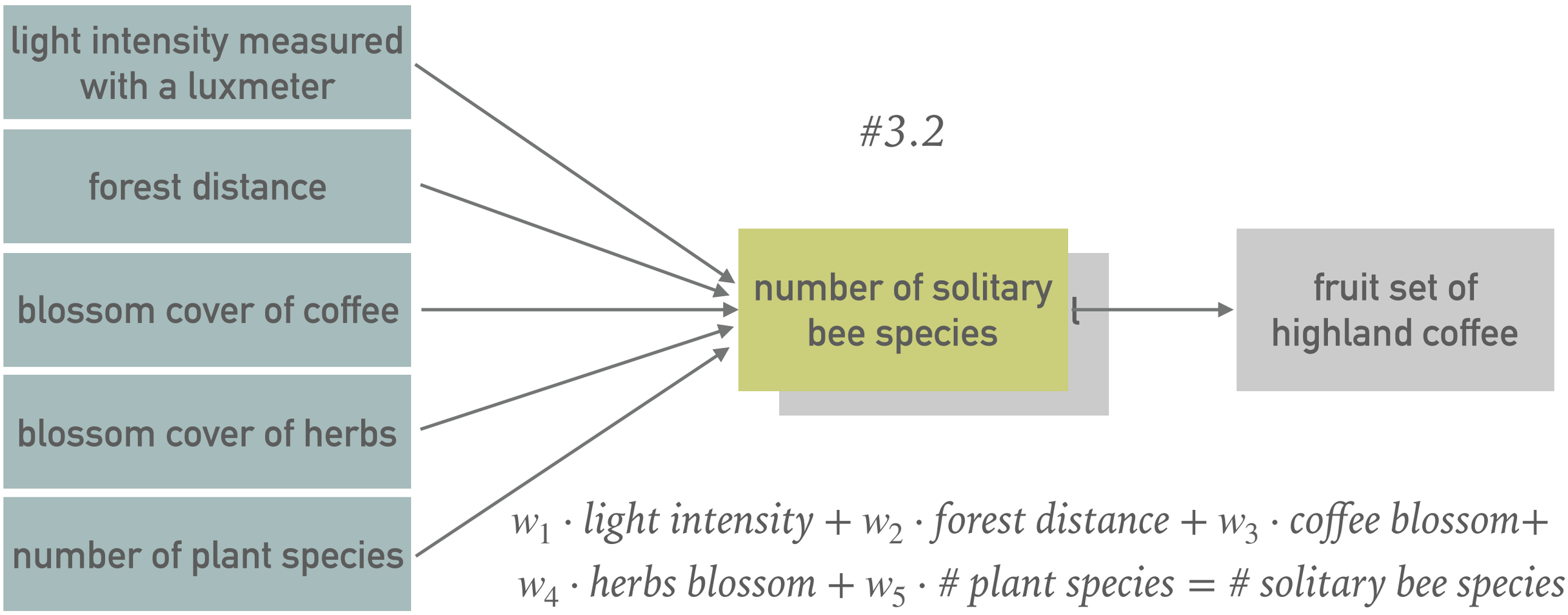
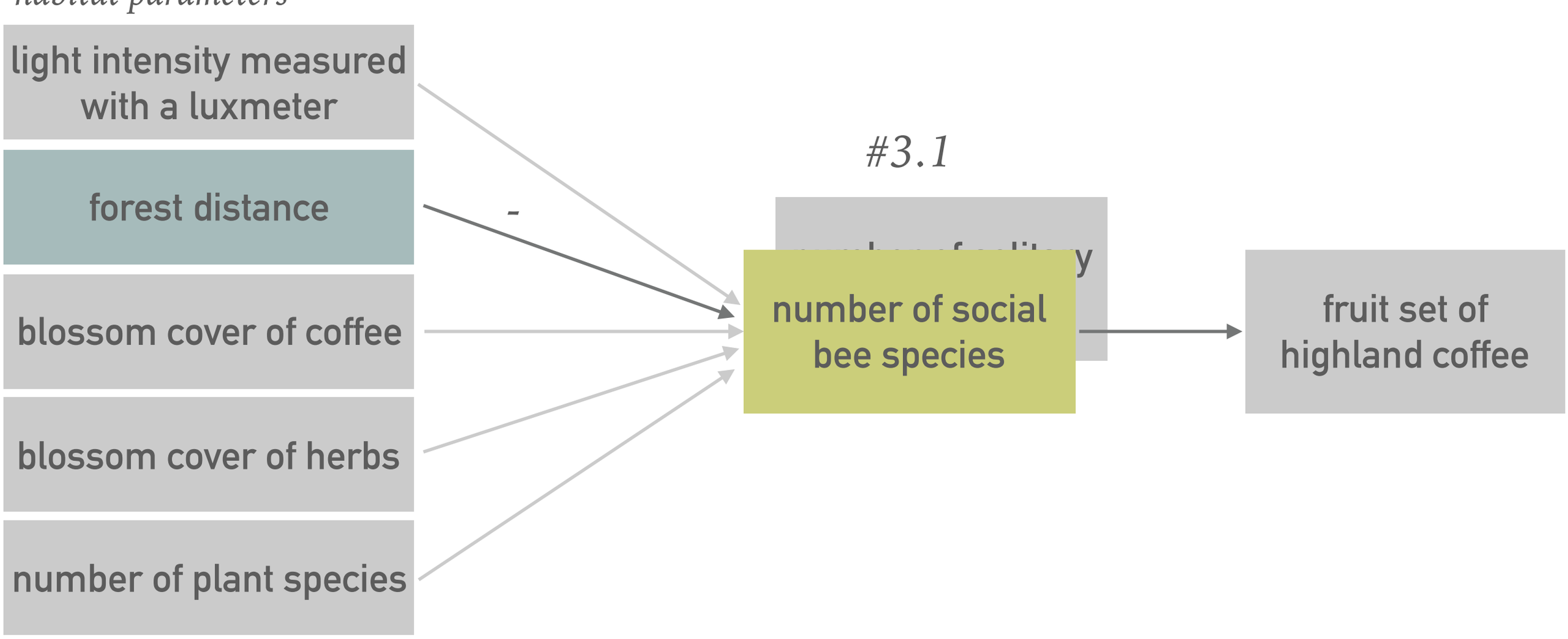


$$w_1 \cdot light\ intensity + w_2 \cdot forest\ distance + w_3 \cdot coffee\ blossom +$$
$$w_4 \cdot herbs\ blossom + w_5 \cdot \#\ plant\ species = \#\ solitary\ bee\ species$$

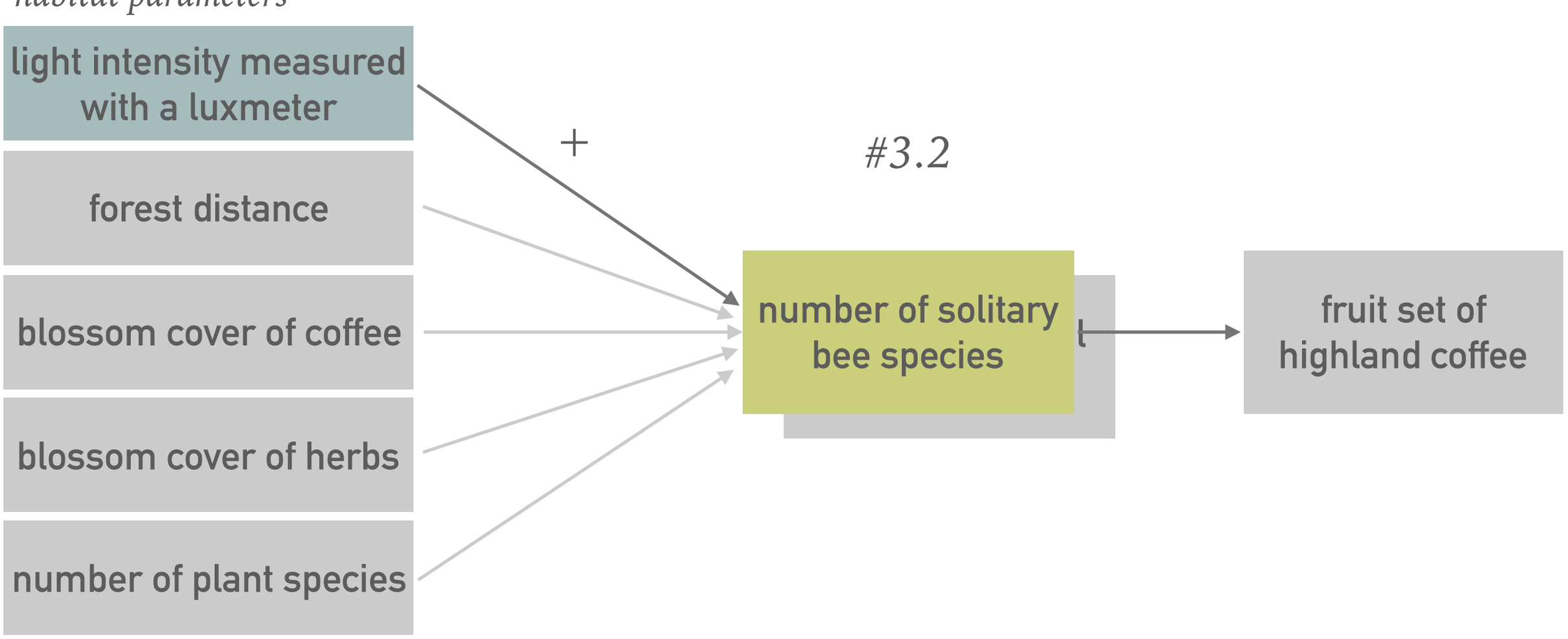
KLEIN ET AL., 2003: HABITAT PARAMETERS

- **Results:** only ***forest distance*** is significant, there's a negative relationship. The less forest distance, the more social bee species.
- $r^2 = 0.78$



KLEIN ET AL., 2003: HABITAT PARAMETERS

- **Results:** only ***light intensity*** is significant, there's a positive relationship. The more light intensity, the more solitary bee species
- $\underline{r^2 = 0.74}$



KLEIN ET AL., 2003: HABITAT PARAMETERS

Table 2. Results of stepwise multiple regression analyses of the effects of light intensity, forest distance, blossom cover of coffee, blossom cover of herbs and number of plant species on species richness and abundance of solitary and social bees and fruit set of open-pollinated, cross-pollinated and self-pollinated coffee. Only significant relationships are shown. Cross- and self-pollination did not show a relationship with any variable.

dependent variables	habitat factor (independent variables)	t	p	r^2
number of all bee species	light intensity (W m^{-2})	5.19	< 0.001	
	forest distance (m)		< 0.001	
	final model			77.79
number of all bee individuals	light intensity (W m^{-2})		< 0.001	52.98
number of solitary species	light intensity (W m^{-2})	5.29	< 0.001	
	number of plant species	2.75	0.012	
	final model			74.07
number of solitary individuals	light intensity (W m^{-2})	3.83	< 0.001	39.96
number of social species	forest distance (m)	−8.90	< 0.001	78.26
number of social individuals	light intensity (W m^{-2})	−5.71	< 0.001	59.67
fruit set of open-pollination	forest distance (m)	−2.83	0.010	
	light intensity (W m^{-2})	2.11	0.047	
	final model			46.35
fruit set of cross-pollination			n.s.	
fruit set of self-pollination			n.s.	

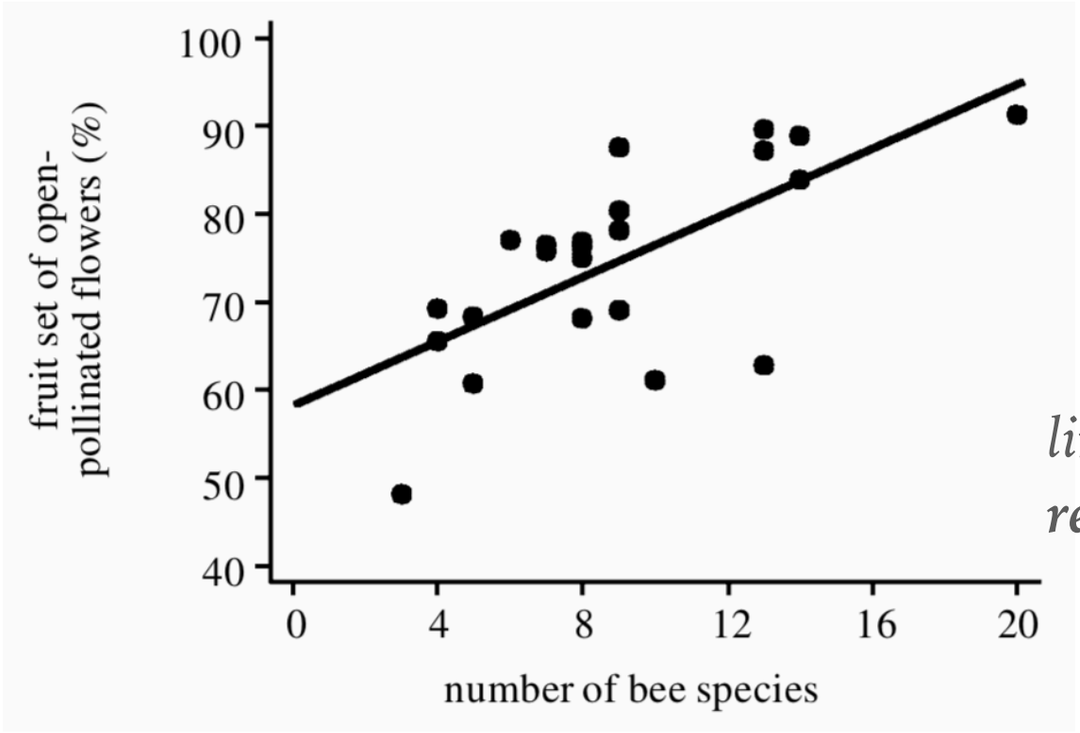
linear model results

more dependent variables for confirmation and to test other variables.

Each entry is a new model! #3.3, #3.4…

KLEIN ET AL., 2003: BEE DIVERSITY AND COFFEE FRUITS

- **Research Question 1**: bee diversity has a **linear** relationship with fruit set, not bee abundance
- **Research Question 2:** solitary bees have a significantly different mean for fruit set than social bees according to a **t-test**
- **Research Question 3:** forest distance negatively influences the social bee diversity, light intensity positively influences solitary bee diversity, all other habitat parameters are not significant, according to **multiple linear regression**



linear model for ***research question 1***

THE STRUCTURE OF THE PAPER

KLEIN ET AL., 2003: BEE DIVERSITY PREDICTS COFFEE FRUITS

Fruit set of highland coffee increases with the diversity of pollinating bees

Alexandra-Maria Klein*, Ingolf Steffan-Dewenter and Teja Tscharntke

Agroecology, University of Göttingen, Waldweg 26, D-37073 Göttingen, Germany

The worldwide decline of pollinators may negatively affect the fruit set of wild and cultivated plants. Here, we show that fruit set of the self-fertilizing highland coffee (*Coffea arabica*) is highly variable and related to bee pollination. In a comparison of 24 agroforestry systems in Indonesia, the fruit set of coffee could be predicted by the number of flower-visiting bee species, and it ranged from *ca.* 60% (three species) to 90% (20 species). Diversity, not abundance, explained variation in fruit set, so the collective role of a species-rich bee community was important for pollination success. Additional experiments showed that single flower visits from rare solitary species led to higher fruit set than with abundant social species. Pollinator diversity was affected by two habitat parameters indicating guild-specific nesting requirements: the diversity of social bees decreased with forest distance, whereas the diversity of solitary bees increased with light intensity of the agroforestry systems. These results give empirical evidence for a positive relationship between ecosystem functions such as pollination and biodiversity. Conservation of rainforest adjacent to adequately managed agroforestry systems could improve the yields of farmers.

1. INTRODUCTION

Almost all flowering plant species of tropical rainforests are pollinated by animals (Bawa 1990) and one-third of the human diet in tropical countries is derived from insect-pollinated plants (Crane & Walker 1983), so the worldwide decline of pollinators has potential consequences for the stability of crop yields (Allen-Wardell *et al.* 1998; Kevan & Phillips 2001). The highland coffee plant (*Coffea arabica* L.) is one of the major tropical cash crops and has been considered to be a self-fertilizing plant (Rehm & Espig 1991; Free 1993). It has only recently been shown that
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pollination services.

Fragmentation and destruction of natural or semi-natural habitats may result in the loss of bee diversity and disruption of plant–pollinator interactions (Rathcke & Jules 1993; Renner 1998; Cane 2001; Steffan-Dewenter *et al.* 2002), but experimental evidence is still extremely rare (Steffan-Dewenter & Tscharntke 1999; Cunningham 2000; Cane 2001; Steffan-Dewenter *et al.* 2002). The quality of the landscape matrix, with respect to the distance of crops from natural forest or other source habitats, may be important for many species (Perfecto & Vandermeer 2002). Fragmentation of tropical forest as part of the change to a mosaic of natural forest and agroforestry is known to affect pollinator communities greatly (Aizen & Feinsinger 1994). Coffee is traditionally grown under a canopy of shade trees. These traditional coffee agroforestry systems have relatively high biodiversity compared with unshaded monocultures (Perfecto & Vandermeer 1996; Moguel & Toledo 1999). One reason for the high biodiversity in shaded agroforestry systems is the structural and floristic complexity (Perfecto & Vandermeer 1996). Intermediate degrees of shade improve the coffee yield, but more than 50% shade causes high losses (Muschler & Bonnemaann 1997; Soto-Pinto *et al.* 2000). Microclimatic conditions of agroforestry systems affect flower visitation by bees (Klein *et al.* 2002), so the fruit set of coffee may also suffer.

In this study we analysed the effects of bee diversity and abundance on the fruit set of highland coffee in 24 agroforestry coffee fields, differing in shade and forest distance. We focused on the following questions.

Introduction

➤ *Background*

➤ *our three research questions*

(i) Does the fruit set of highland coffee depend on pollinating bees, and is bee diversity or bee abundance more important?
(ii) Are social or solitary bees the more efficient pollinators of *C. arabica*?
(iii) Do distance to the nearest forest and shading of coffee influence the diversity of flower-visiting bees and the resulting fruit set?

2. MATERIAL AND METHODS

(a) *Study area and experimental sites*

Coffee pollination was studied from November 2000 to March 2001 and from July 2001 to October 2001 at the margin of the Lore-Lindu National Park, Central Sulawesi (Indonesia),

2. MATERIAL AND METHODS

(a) *Study area and experimental sites*

Coffee pollination was studied from November 2000 to March 2001 and from July 2001 to October 2001 at the margin of the Lore-Lindu National Park, Central Sulawesi (Indonesia), 100 km south of the city of Palu, in the villages Wuasa, Watumaeta, Alitupu and Kaduwaa. The 24 study sites, i.e. agroforestry coffee fields, were characterized according to shade level and vegetation. Light intensity per study site was measured with a luxmeter (digital light gauge with four ranges from 0–1999 W m^{-2}) under standardized conditions (on the ground and

Material & Methods

➤ *Information on the* ***data*** *and* ***measured***

➤ *which statistical tests will be used*

(b)

Flower-visiting bees on *C. arabica* were observed from 28 December 2000 to 9 January 2001. The flowers generally open just before dawn and last for 2 days, but usually, depending on the weather conditions, a coffee flower is attractive to flower-visiting bees for only 1 day. At each study site we observed flower visitors for 25 minutes on each of three different days. Every day we observed a different full-blooming coffee plant from the one observed the day before and with about 100 flow-

(c) *Statistics*

Statistical analyses were performed using the software 'STATGRAPHICS PLUS for Windows 3.0' (Manugistics 1997). All data were tested for normality and transformed if necessary. The independent variables blossom cover of coffee and blossom cover of herbs were always $\log_{10}$-transformed and the independent variable forest distance was always square-root-transformed (Sokal & Rohlf 1995). After transformation to normality we tested correlations between five independent habitat factors. In stepwise multiple linear regression analyses with backward selection we examined which independent habitat factors were most important for the dependent variables: number of all bee species and individuals, and separately for social and solitary bee species and individuals. The best-fitting habitat factor was shown in simple linear regression with the dependent variable. We used *t*-tests to compare the means of fruit set between social and solitary bees. To analyse the effect of bee diversity on the spatial variability of fruit set, we calculated the coefficient of variation (CV) of fruit set resulting from open-pollination for three bushes per study site. We estimated the total species richness of flower-visiting bees per site with 100 randomizations at 5-minute intervals, using the estimator ACE (abundance-based coverage estimator of species richness) and the program ESTIMATES, v. 5 (Colwell 1997). The proportion of sampled and estimated species richness was calculated for each study site and a mean value for all sites is shown. Arithmetic means ± standard errors are given.

3. RESULTS

The number of flower-visiting bee species in each of the 24 agroforestry systems was closely related to fruit set and explained 45% of the variance (figure 1*a*), whereas the number of bee individuals was not related to fruit set (figure 1*b*). The number of bee species and the number of bee individuals were positively correlated ($F = 8.98$, $r^2 = 0.289$, $n = 24$, $p = 0.007$). Fruit set was correlated with both the number of social bee species ($F = 12.33$, $r^2 = 0.359$, $n = 24$, $p = 0.002$) and the number of solitary bee

Results

➤ *the results of the proposed statistics, mainly a lengthy description of numbers*

his patt ith mar set was ure 1*c*), bee dive ich as n al- cula lli- nati on.

This difference increased with increasing bee diversity ($F = 5.60$, $r^2 = 0.203$, $n = 24$, $p = 0.027$), thereby giving direct evidence of pollination limitation. The CV of fruit set for open-pollinated flowers was negatively related to bee diversity ($F = 6.76$, $r^2 = 0.235$, $n = 24$, $p = 0.016$), indicating that high bee diversity reduced the spatial variability of fruit set.

The mechanism of this relationship between diversity and ecological function was investigated using further pollination experiments. We observed 277 flower visits from 15 species on virginal (previously bagged) coffee flowers. The pollination efficiency of solitary bee species was significantly higher than that of social bee species. On aver-

We found 1143 individuals of seven social bee species (Hymenoptera: Apidae) and 895 individuals of 22 solitary bee species (Hymenoptera: Apidae, Megachilidae, Halictidae), which appeared to be a good estimate of bee diversity (on average $96.4 \pm 0.88\%$ species saturation; Colwell 1997). The diversity of flower-visiting bees was related to characteristics of the 24 agroforestry systems. The number of plant species, blossom cover of *C. arabica*, blossom cover of all plants, light intensity and distance to the forest were not significantly correlated with each other and were used as the five predictor variables. In stepwise multiple regression, the number of social bee species could be best explained by the distance to the forest margin (figure 2*a*), and the number of solitary bee species could be best explained by a combination of light intensity and plant diversity, the latter explaining a further 9.4% (out of a total of 74%) of the variance (figure 2*b*; table 2). The number of all flower-visiting bee species increased with light intensity and decreased with distance to the forest margin, the latter explaining a further 24.4% (out of a total of 78%) of the variation. Accordingly, fruit set of coffee significantly increased with increasing light intensity and decreased with increasing isolation distance from the forest margin, the latter explaining a further 9.2% (out of a total of 46%) of the variation (table 2). Fruit set of flowers that were manually cross-pollinated or self-pollinated was not related to forest distance or light intensity (table 2). The mean fruit set after self-pollination by hand has been observed to be 62.4% in all agroforestry systems (Klein *et al.* 2003).

4. DISCUSSION

Our results show that the fruit set of highland coffee could be predicted by the diversity, not abundance, of flower-visiting bees, so the collective role of a species-rich bee community was important for pollination success. The fruit set of open-pollinated flowers ranged from 60% to 90%, whereas cross-pollination by hand resulted on average in 75% fruit set and did not depend on pollinator diversity or habitat factors, indicating that pollination limitation played a major role. Both social and solitary bee species contributed to this diversity effect, but the underlyin[illegible]dy. In [illegible]st, com[illegible]ch poll[illegible]nd tem[illegible]ith one[illegible]ect cou[illegible]tor spe[illegible]

Discussion

➤ *so what? What's the significance?*

Comparing abundant social and rare solitary bee species, we showed that single flower visits of solitary bees resulted in fruit set with a higher probability than with social bee species. Hence, the contribution of each rare bee species may have been small, but the collective role of these rare species turned out to be of quantitative importance. Given the same number of flower visits, the species-rich solitary bees contributed more to fruit set than the abundant social bees, partly explaining the positive relationship between fruit set and bee diversity. Multiple flower visits providing a surplus of pollen appeared to be rare, as shown by (i) the low fruit set of many sites, and (ii) the short lifespan of each flower, because a coffee flower is attractive to bees for only 1 day. Flower visits are

Earlier studies have shown that, for several crops, solitary wild bees are more efficient pollinators than social honeybees (Corbet 1991). This could be explained by the following findings.

(i) Honeybees visit more flowers per unit time than other bees, and remain longer at branches with dense flowers, thereby consecutively visiting more flowers on the same plant (Heard 1994). Thus, there is a higher probability that honeybees transfer pollen of the same plant individual. Within-plant (geitonogamous) pollination has been shown to result in lower fruit set than cross-pollination for *C. arabica* (Klein *et al.* 2003).

(ii) Honeybees are known often to collect only nectar and to contact the stigma less often (Corbet 1987). A pollination experiment involving cashews in northeast Brazil showed that a solitary bee species was more efficient in depositing pollen on stigmas than the European honeybee (Freitas & Paxton 1998).

(iii) Long-tongued bees reach a hidden stigma more often than bees with a short tongue (Corbet 1996). In our study, most solitary bee species on coffee had longer tongues than the social bees (A.-M. Klein, personal observation). The corolla of coffee flowers is small and deep, so the long-tongued bees may have touched the stigma more often.

(iv) We observed that some social stingless bees often bite holes at the base of the flower to reach the nectar. Stingless bees are known to damage flowers, so fruit or seed set may be negatively influenced (McDade & Kinsman 1980; Maloof & Inouye 2000;

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➤ *who funded this research? Usually, equipment and people are expensive…*

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References

➤ *last but not least*

REFERENCES

Aizen, M. A. & Feinsinger, P. 1994 Habitat fragmentation, native insect pollinators, and feral honey bees in Argentine 'chaco Serrano'. *Ecol. Appl.* **4**, 378–392.

Allen-Wardell, G. (and 21 others) 1998 The potential consequences of pollinator declines on the conservation of biodiversity and stability of food crop yields. *Conserv. Biol.* **12**, 8–17.

Bawa, K. S. 1990 Plant–pollinator interactions in tropical rain forests. *A. Rev. Ecol. Syst.* **21**, 399–422.

Cambell, D. R. & Halama, K. J. 1993 Resource and pollen limitations to lifetime seed production in a natural plant population. *Ecology* **74**, 1043–1051.

Cane, J. H. 2001 Habitat fragmentation and native bees: a premature verdict? *Conserv. Ecol.* **5**, 3 [online] URL: http://www.consecol.org/vol5/iss1/art3.

Colwell, R. K. 1997 EstimateS: statistical estimation of species richness and shared species from samples. Version 5 User's Guide and application published at http://viceroy.eeb.uconn.edu/estimates

Corbet, S. A. 1987 More bees make better crops. *New Scient.* **115**, 40–43.

Corbet, S. A. 1991 Bees and the pollination of crops and wild flowers in the European community. *Bee World* **72**, 47–59.

Corbet, S. A. 1996 Which bees do plants need? In *The conservation of bees* (ed. A. Matheson, S. L. Buchmann, C.

EXERCISE

- Take the *Bullock et al., 2001* paper and write on a flipchart:
  - Research question
  - Study design (number of samples, location, time frame….) with sketch
  - Statistical analysis and Figures
  - Results
- One group will present their result in class.
- You have ~ 30 min.