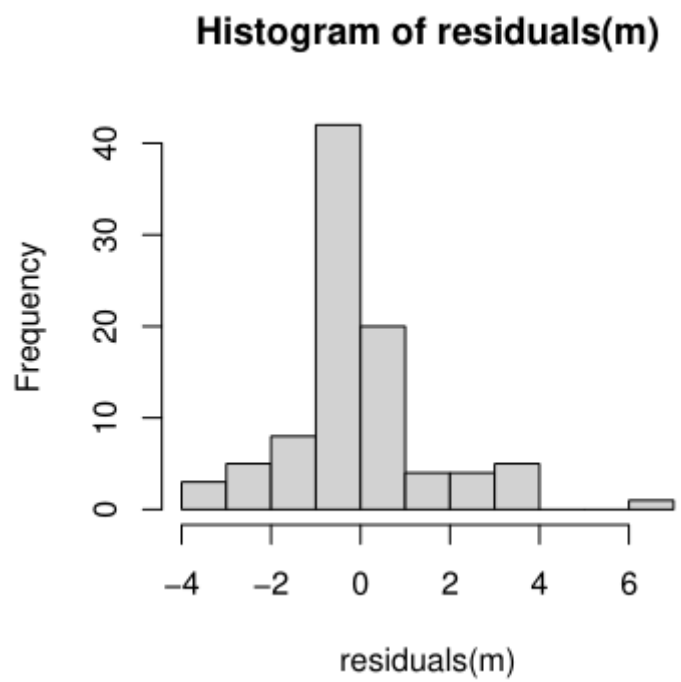
Discussion of exercise 4

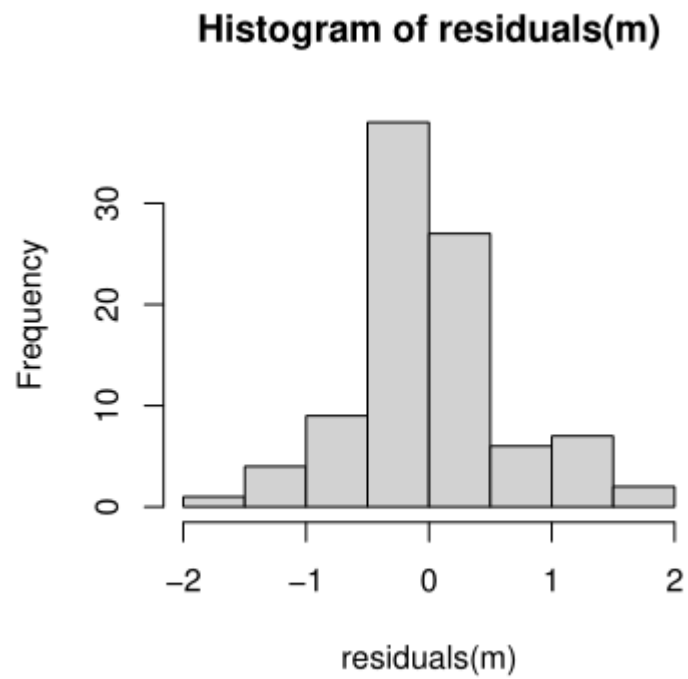
- The importance of data exploration
- Backward selection vs. biologically justified models


mean_T_winter
max_T_winter
min_T_winter
mean_T_summ
max_T_summe
min_T_summer
light
snow
soil_moist
altitude

Untransformed



Sqrt-transformed



Backward selection

```
##
## Call:
## lm(formula = sqrt(Thalictrum.alpinum) ~ mean_T_winter + max_T_winter +
##     min_T_winter + mean_T_summer + max_T_summer + min_T_summer +
##     light + snow + +altitude, data = plants, na.action = na.exclude)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -1.64774 -0.32645 -0.09373  0.32101  1.60726
##
## Coefficients:
##                Estimate Std. Error t value Pr(>|t|)
## (Intercept)    2.262390   8.600678   0.263  0.79316
## mean_T_winter  0.534162   0.561831   0.951  0.34446
## max_T_winter  -0.031941   0.424243  -0.075  0.94016
## min_T_winter  -0.111548   0.238945  -0.467  0.64182
## mean_T_summer  0.766547   0.275480   2.783  0.00666 **
## max_T_summer  -0.129458   0.065572  -1.974  0.05163 .
## min_T_summer  -0.179251   0.126460  -1.417  0.16005
## light          0.007020   0.003649   1.924  0.05779 .
## snow           0.012631   0.005140   2.457  0.01605 *
## altitude      -0.005797   0.005905  -0.982  0.32903
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.6468 on 84 degrees of freedom
##   (1 observation deleted due to missingness)
## Multiple R-squared:  0.546,  Adjusted R-squared:  0.4973
## F-statistic: 11.22 on 9 and 84 DF,  p-value: 2.528e-11
```

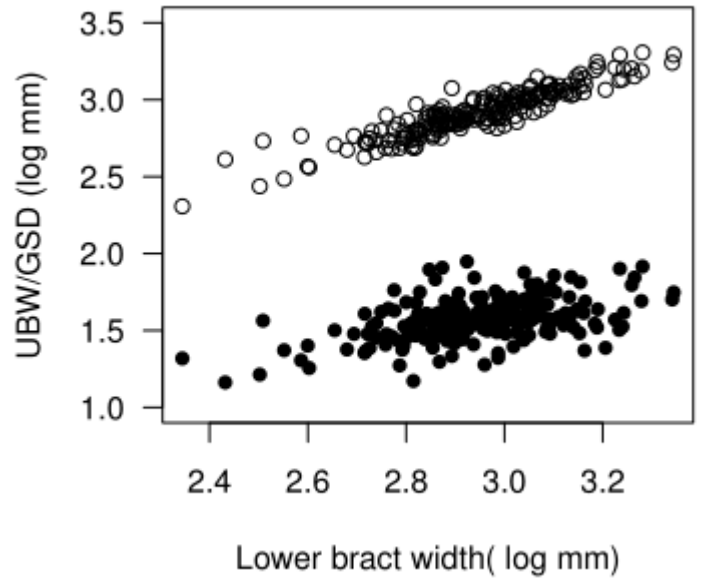
```
##
## Call:
## lm(formula = sqrt(Thalictrum.alpinum) ~ mean_T_winter + min_T_winter +
##     mean_T_summer + max_T_summer + min_T_summer + light + snow +
##     soil_moist + altitude, data = plants, na.action = na.exclude)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -1.62694 -0.32380 -0.07332  0.29264  1.62183
##
## Coefficients:
##                Estimate Std. Error t value Pr(>|t|)
## (Intercept)    2.411671   8.576529   0.281  0.77927
## mean_T_winter  0.569210   0.446838   1.274  0.20631
## min_T_winter  -0.143767   0.218489  -0.658  0.51238
## mean_T_summer  0.768061   0.275298   2.790  0.00655 **
## max_T_summer  -0.132171   0.066057  -2.001  0.04871 *
## min_T_summer  -0.205011   0.126349  -1.623  0.10852
## light          0.007255   0.003712   1.954  0.05408 .
## snow           0.013162   0.005162   2.550  0.01263 *
## soil_moist    -0.005695   0.016416  -0.347  0.72953
## altitude      -0.005748   0.005857  -0.981  0.32929
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.6415 on 82 degrees of freedom
##   (3 observations deleted due to missingness)
## Multiple R-squared:  0.5455, Adjusted R-squared:  0.4956
## F-statistic: 10.94 on 9 and 82 DF,  p-value: 5.347e-11
```

Minimal adequate model

```
##
## Call:
## lm(formula = sqrt(Thalictrum.alpinum) ~ mean_T_winter + mean_T_summer +
##     max_T_summer + light + snow, data = plants, na.action = na.exclude)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -1.50452 -0.40421 -0.04351  0.27470  1.60612
##
## Coefficients:
##                Estimate Std. Error t value Pr(>|t|)
## (Intercept)   -6.437373   1.316222  -4.891 4.49e-06 ***
## mean_T_winter  0.360464   0.121818   2.959  0.00396 **
## mean_T_summer  0.794341   0.174225   4.559 1.65e-05 ***
## max_T_summer  -0.080261   0.045387  -1.768  0.08046 .
## light          0.006737   0.003594   1.874  0.06419 .
## snow           0.012148   0.004627   2.625  0.01021 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.6445 on 88 degrees of freedom
##   (1 observation deleted due to missingness)
## Multiple R-squared:  0.5277, Adjusted R-squared:  0.5008
## F-statistic: 19.66 on 5 and 88 DF,  p-value: 4.199e-13
```

- Note that r^2 is very high (for ecological analyses), and dropped just a tiny bit from the full (saturated) model.

ANCOVA/Floral integration/allometry




```
mUBW = lm(log(UBW)~log(LBW), data=blossoms)
mGSD = lm(log(GSD)~log(LBW), data=blossoms)
summary(mUBW)$coef
```

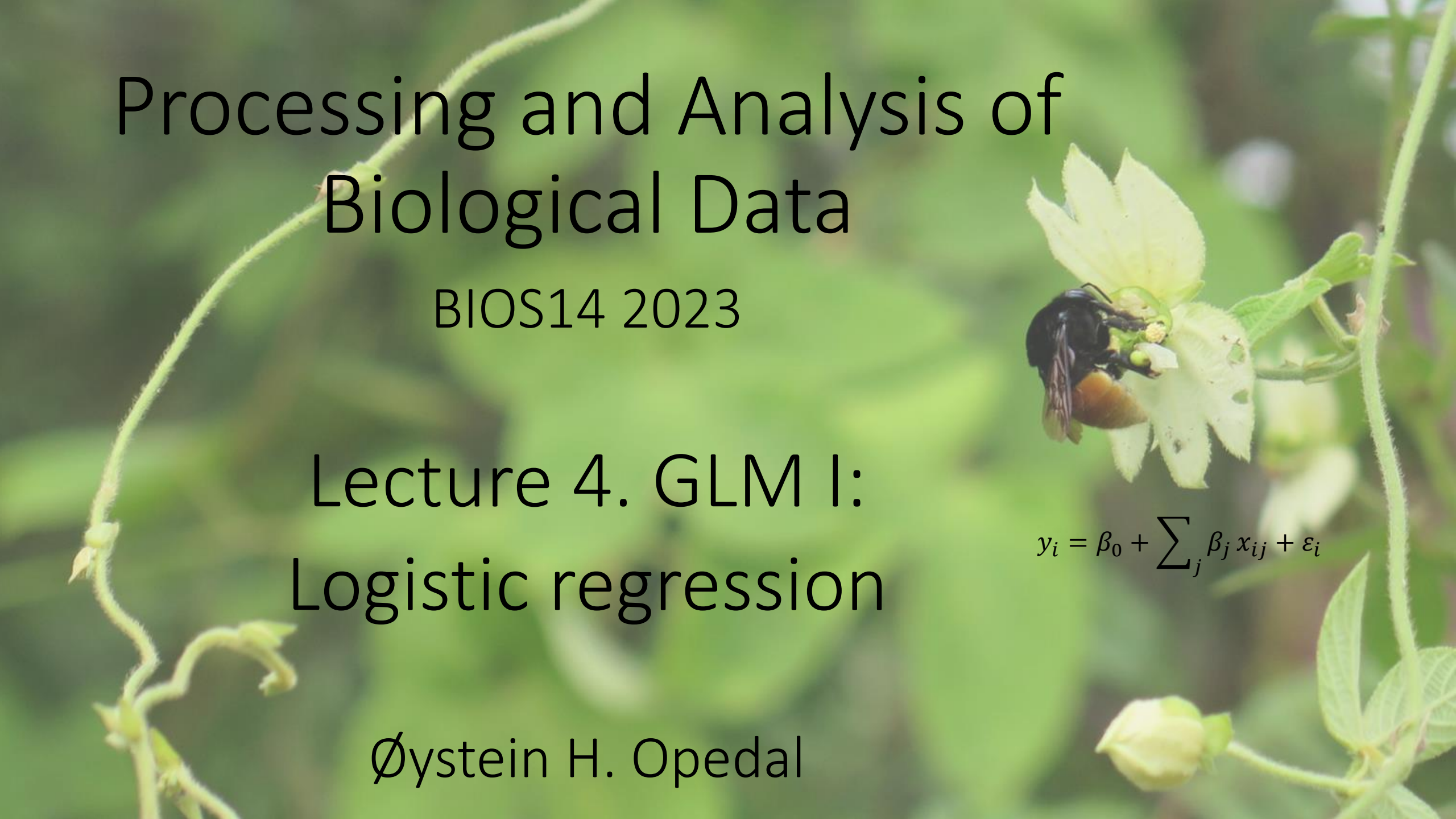
```
##               Estimate Std. Error   t value     Pr(>|t|)
## (Intercept) 0.3193964 0.07851616  4.067907 6.822632e-05
## log(LBW)    0.8819832 0.02662027 33.132018 3.727171e-83
```

```
summary(mGSD)$coef
```

```
##               Estimate Std. Error  t value     Pr(>|t|)
## (Intercept) 0.3782970 0.15788784 2.395986 1.749721e-02
## log(LBW)    0.4047488 0.05353059 7.561073 1.416389e-12
```

Processing and Analysis of Biological Data

BIOS14 2023



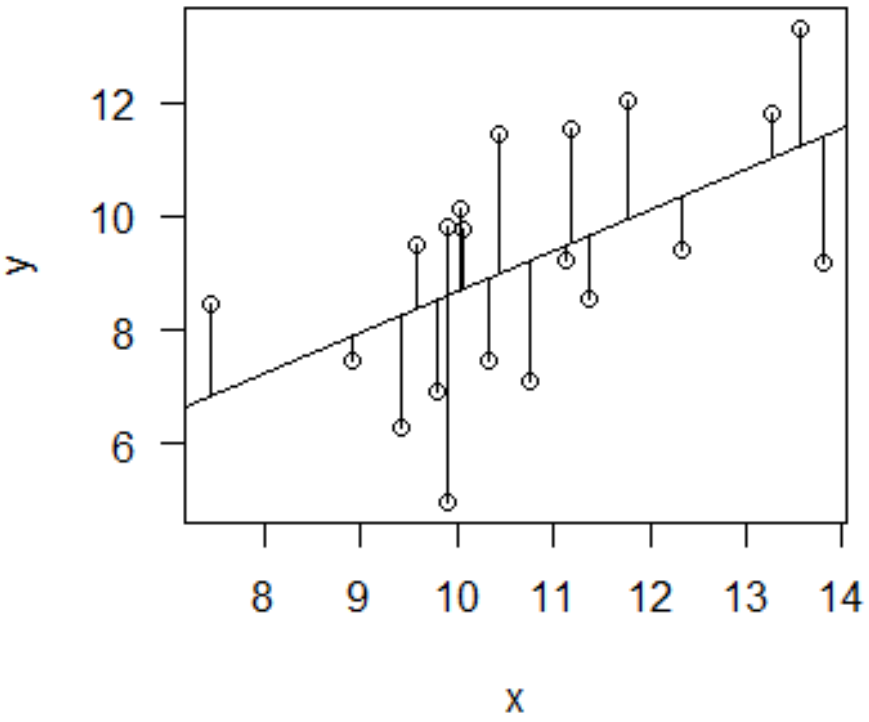
Lecture 4. GLM I: Logistic regression

$$y_i = \beta_0 + \sum_j \beta_j x_{ij} + \varepsilon_i$$

Øystein H. Opedal

The linear model

- Most of the models we will work with in this course are linear models, that describe how a linear set of predictors relate to a response variable
- A key element of the model is the so-called linear predictor:
- $y_i = \beta_0 + \sum_j \beta_j x_{ij} + \varepsilon_i$, $\varepsilon \sim N(0, \sigma^2)$
- The term $\varepsilon \sim N(0, \sigma^2)$ means that the residuals (epsilon) are assumed to follow a normal distribution



Generalized linear models

- Generalized linear models extend the linear model by relaxing the assumption of normally distributed residuals
- The model connects a response variable to the familiar linear predictor (η) through a **link function** (g)
- The link functions are specific to different **error distributions**, the most common are **Binomial** and **Poisson** errors

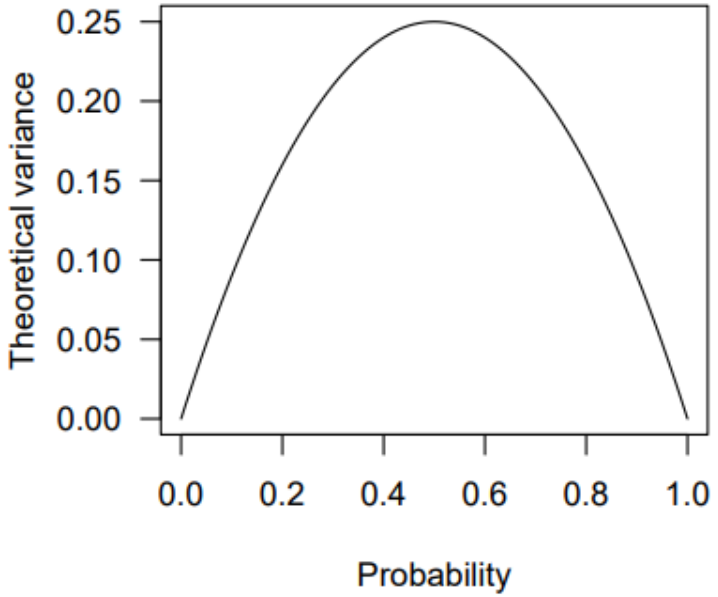
$$\eta = \beta_0 + \sum_j \beta_j x_{ij} + \varepsilon_i,\ \varepsilon \sim N(0, \sigma^2)$$

$$y = g^{-1}(\eta)$$

Analysis of binary (0/1) data

- Binary data can be analysed with a binomial error distribution
- The binomial distribution summarizes a set of Bernouli trials yielding 0/1 responses, where 1 is “success” and 0 is “failure”.
- The distribution is defined by two parameters, the number of trials *n* and the probability *p*.

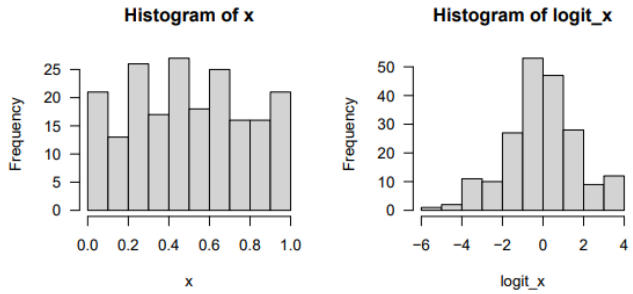
$$\sigma^2 = np(1-p)$$

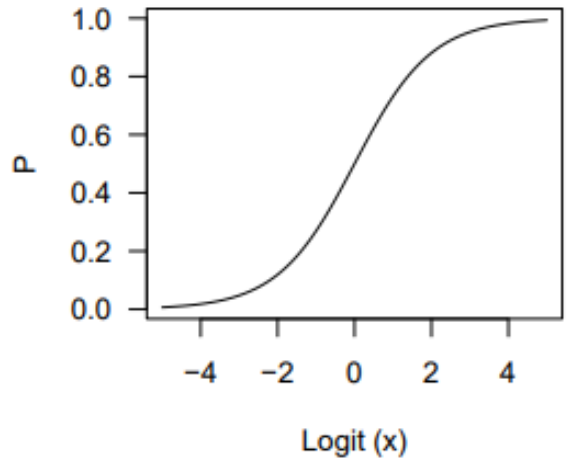


Logistic regression

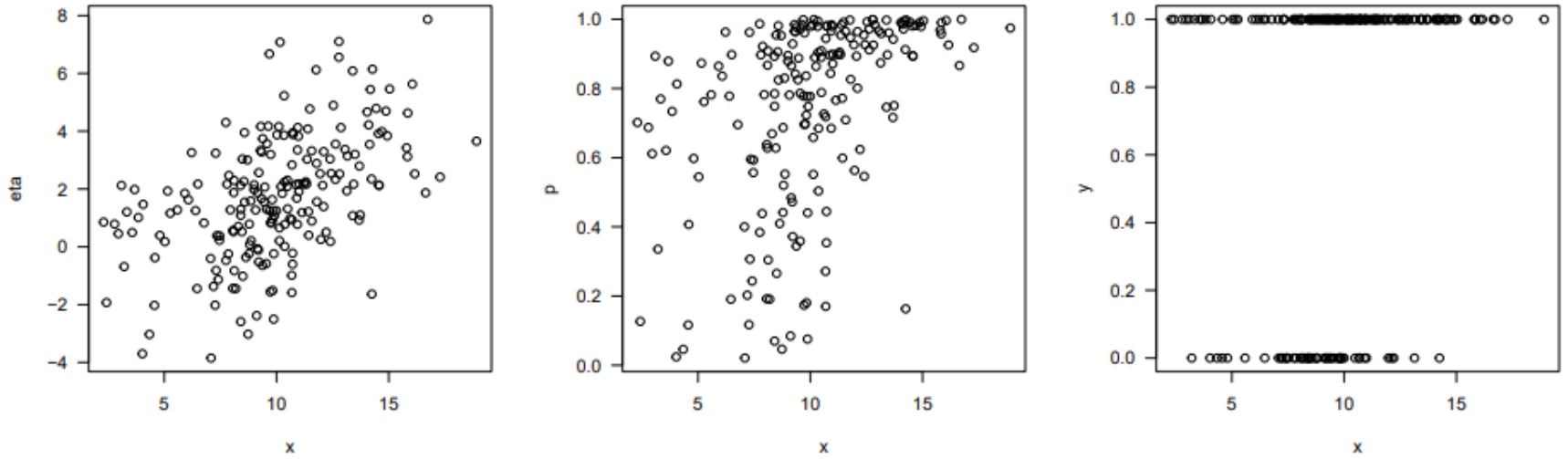
- A GLM with binomial errors is called a logistic regression
- The most common link function is the logit (log odds) link
- The data can be binary (0/1), sets of binary variables (number of successes and failures), or proportions

$$logit(x) = log(\frac{x}{1-x})$$

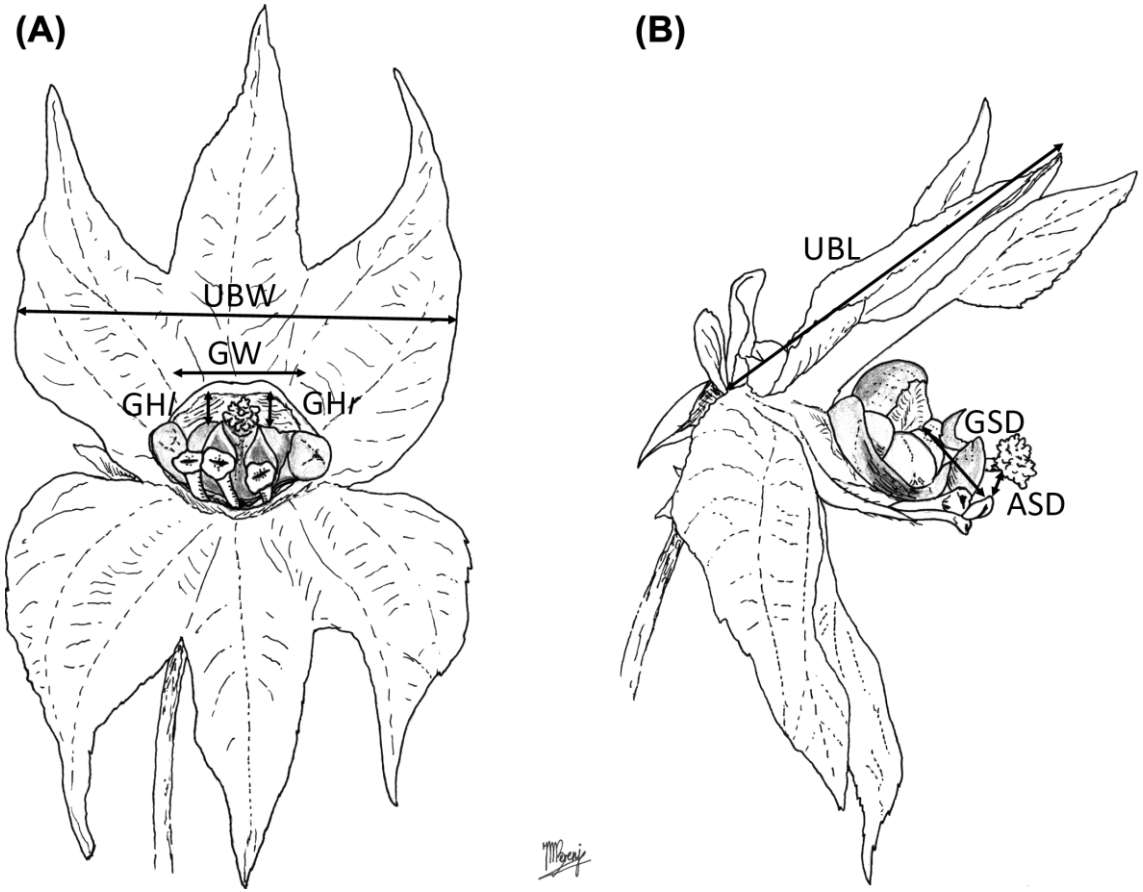


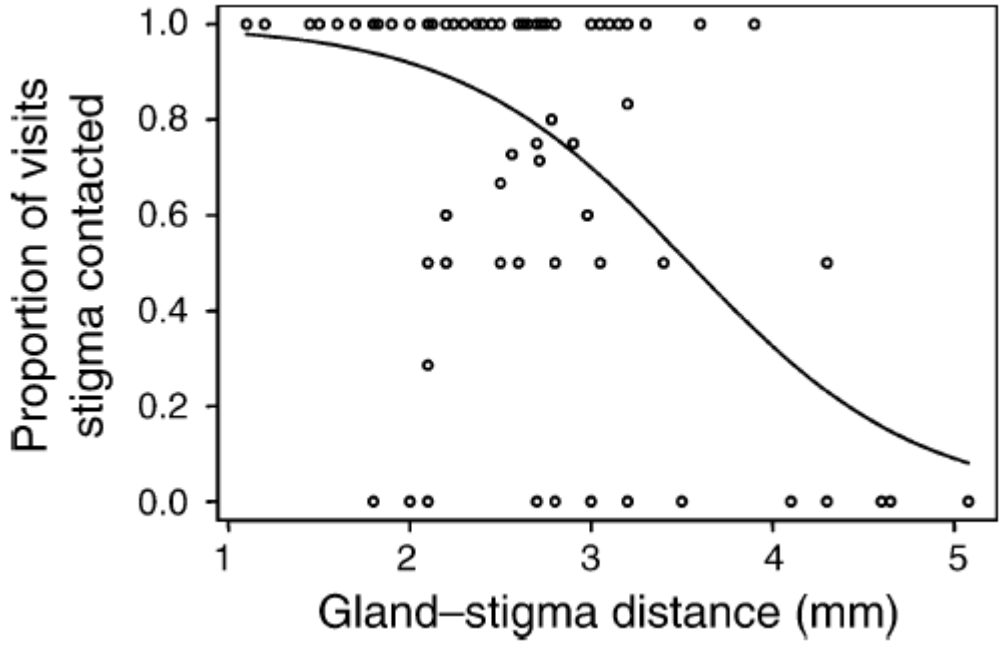


Logistic regression



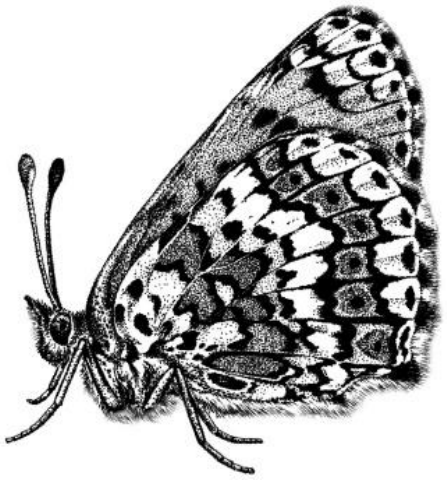
Example: functional pollination studies





Example: plant-animal interactions

- The Glanville Fritillary butterfly (*Melitaea cinxia*) and the powdery mildew *Podosphaera plantaginis* share *Plantago lanceolata* as a host plant
- A tripartite interaction between a plant, a herbivore, and a plant pathogen



A tripartite interaction between a plant, a herbivore, and a plant pathogen

- The Glanville Fritillary butterfly (*Melitaea cinxia*) and the powdery mildew *Podosphaera plantaginis* share *Plantago lanceolata* as a host plant
- Butterfly survival tends to be lower on mildew-infected host plants

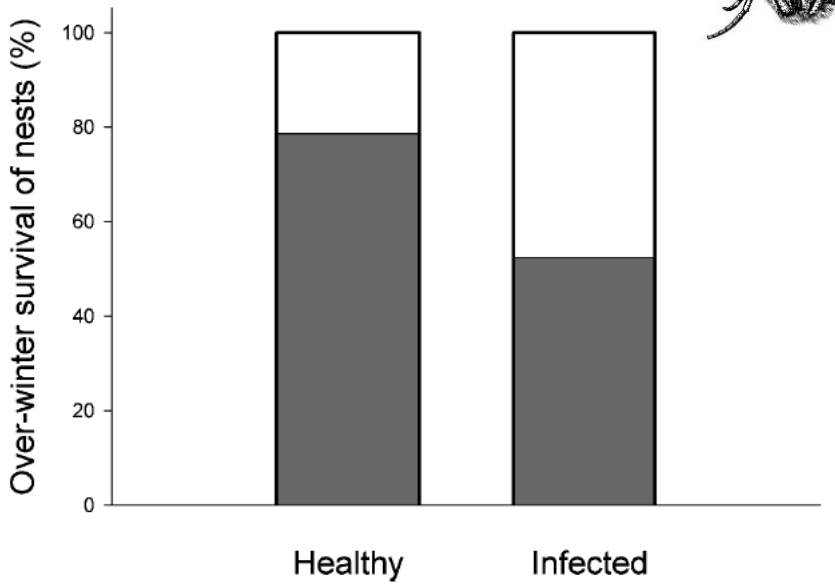
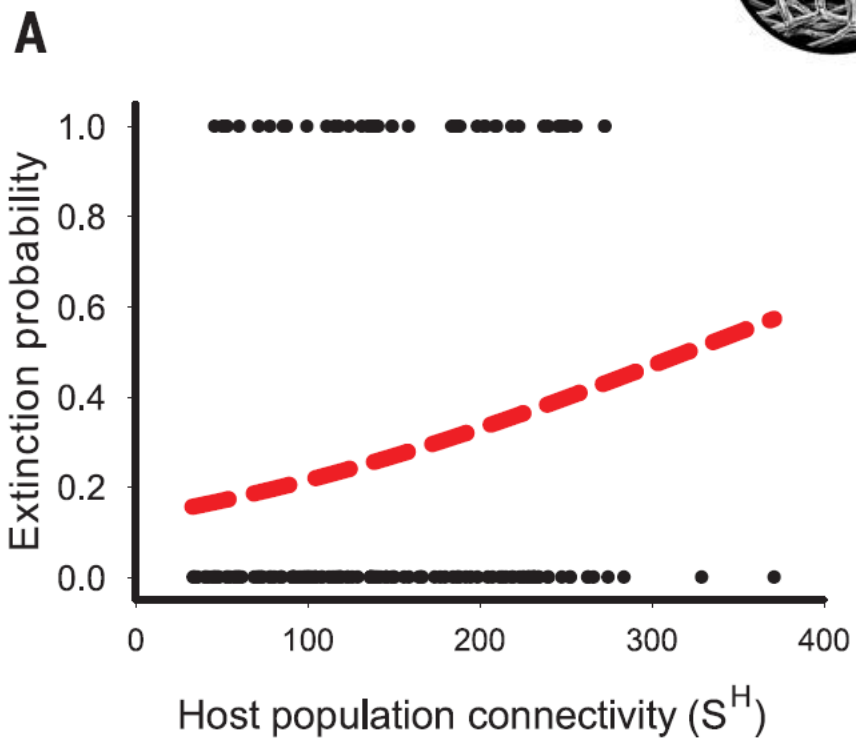


Fig. 4. Over-winter survival of *M. cinxia* larval groups was 26% higher in non-infected than in infected host populations.

Laine 2004 Oikos

Host plants can evolve pathogen resistance

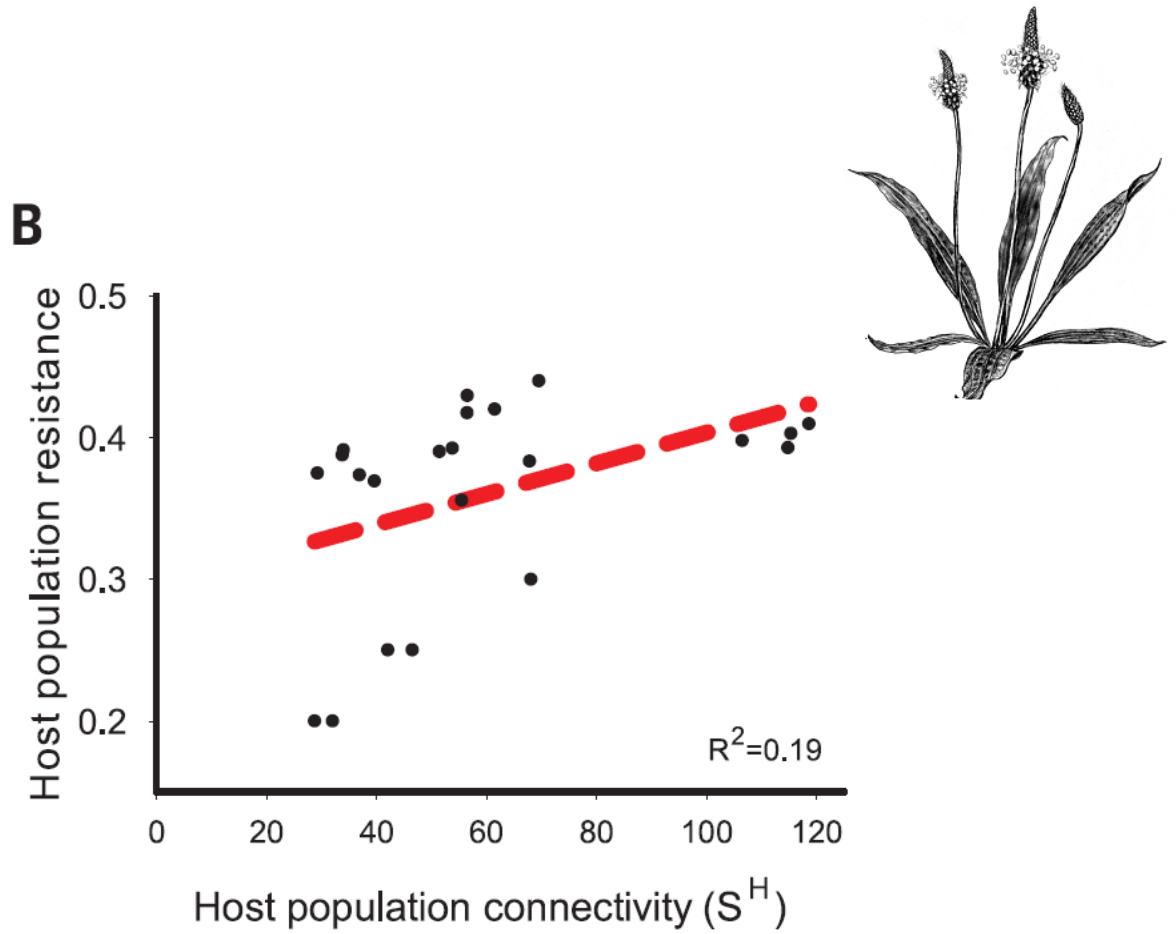
- The mildew is more likely to go locally extinct when infecting well-connected *Plantago* populations



Jousimo et al 2014 Science

Host plants can evolve pathogen resistance

- The mildew is more likely to go locally extinct when infecting well-connected *Plantago* populations
- These host populations have evolved greater resistance towards the pathogen



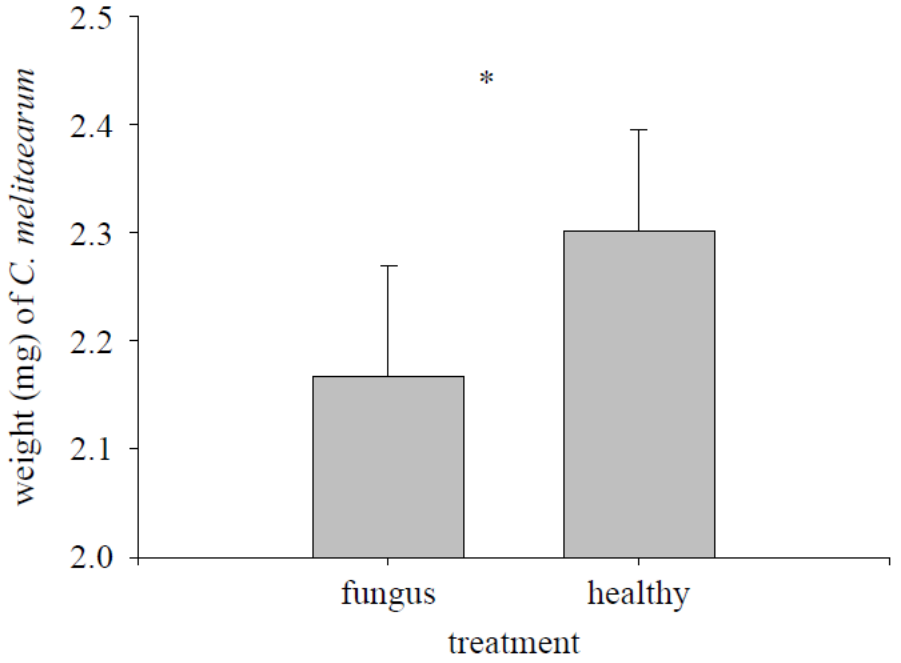
Jousimo et al 2014 Science

A tritrophic interaction between a plant, a herbivore, and a parasitoid

- The wasp *Cotesia melitaearum* is a parasitoid of the Glanville Fritillary

A tritrophic interaction between a plant, a herbivore, and a parasitoid – mediated by a pathogen

- The wasp *Cotesia melitaearum* is a parasitoid of the Glanville Fritillary
- The wasp grows better when host larvae feed on healthy host plants

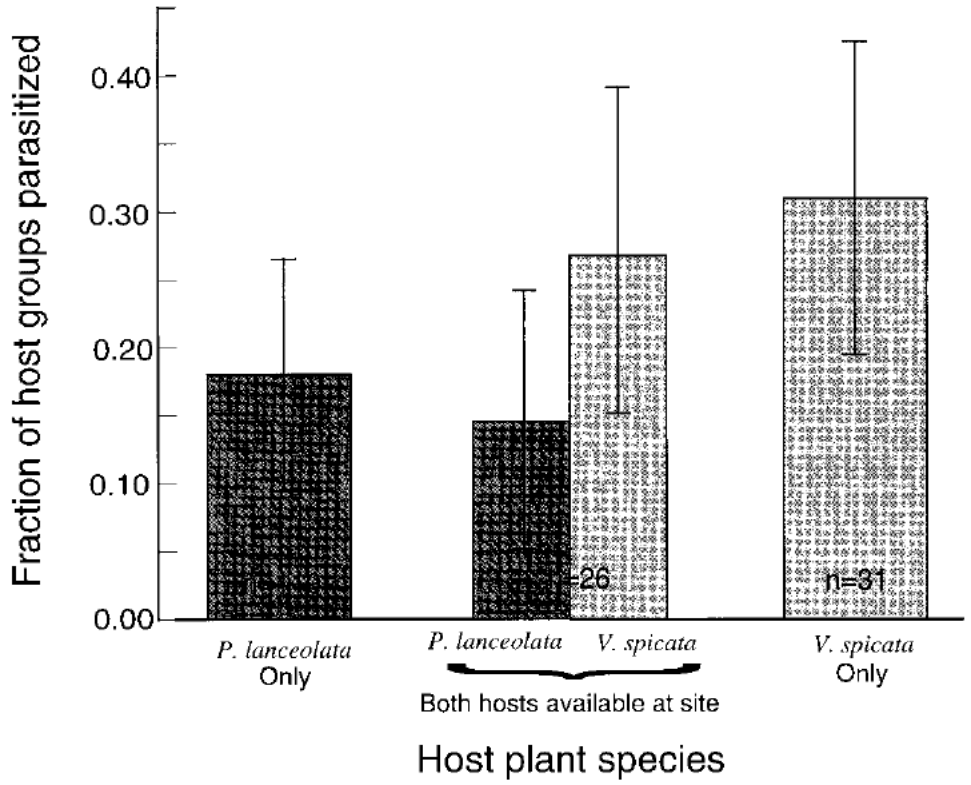


van Nouhuys & Laine 2008 PRS

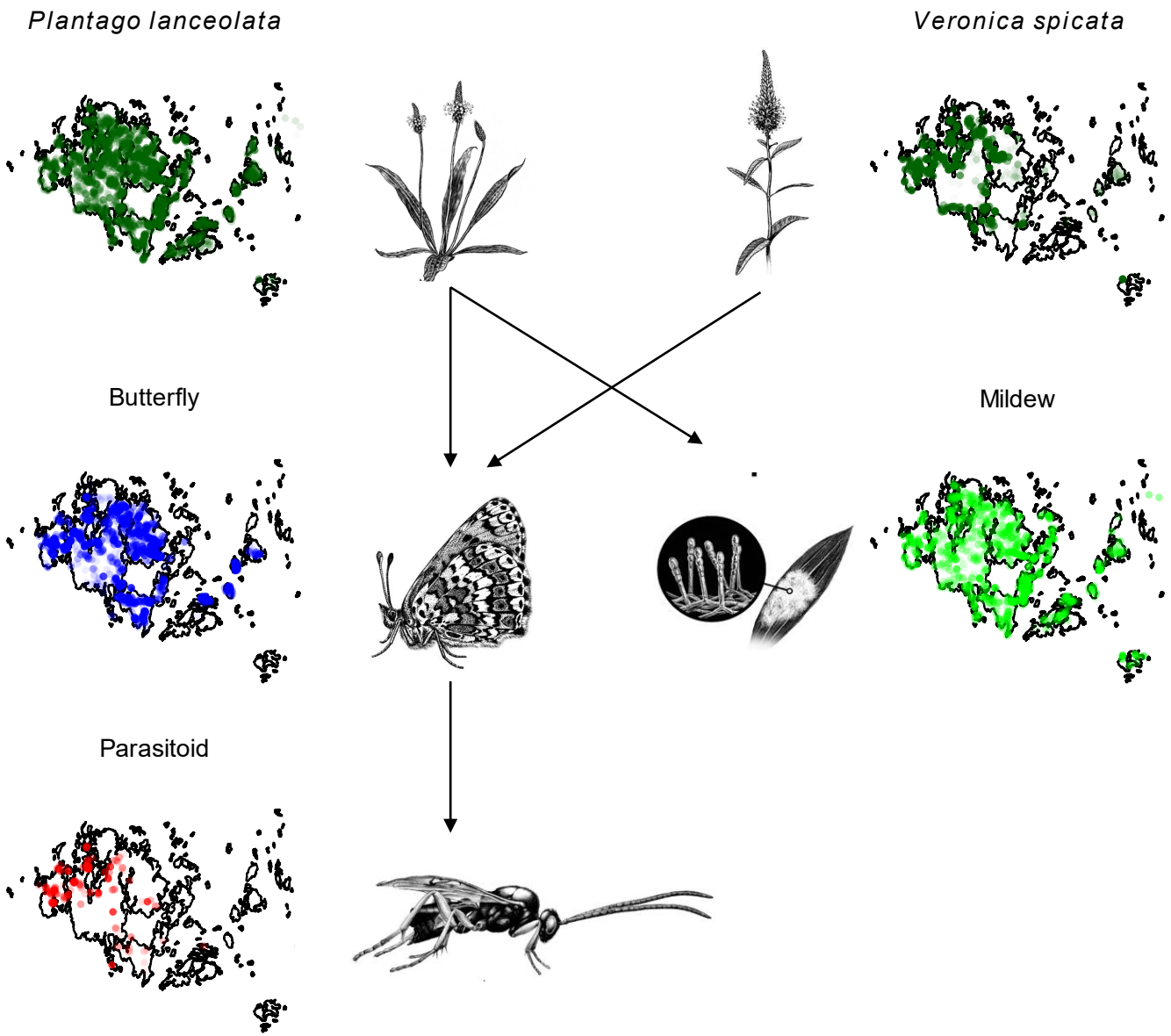
Butterfly host plant choices

- The Glanville Fritillary uses two different host plants in the Åland Islands: *Plantago lanceolata* and *Veronica spicata*

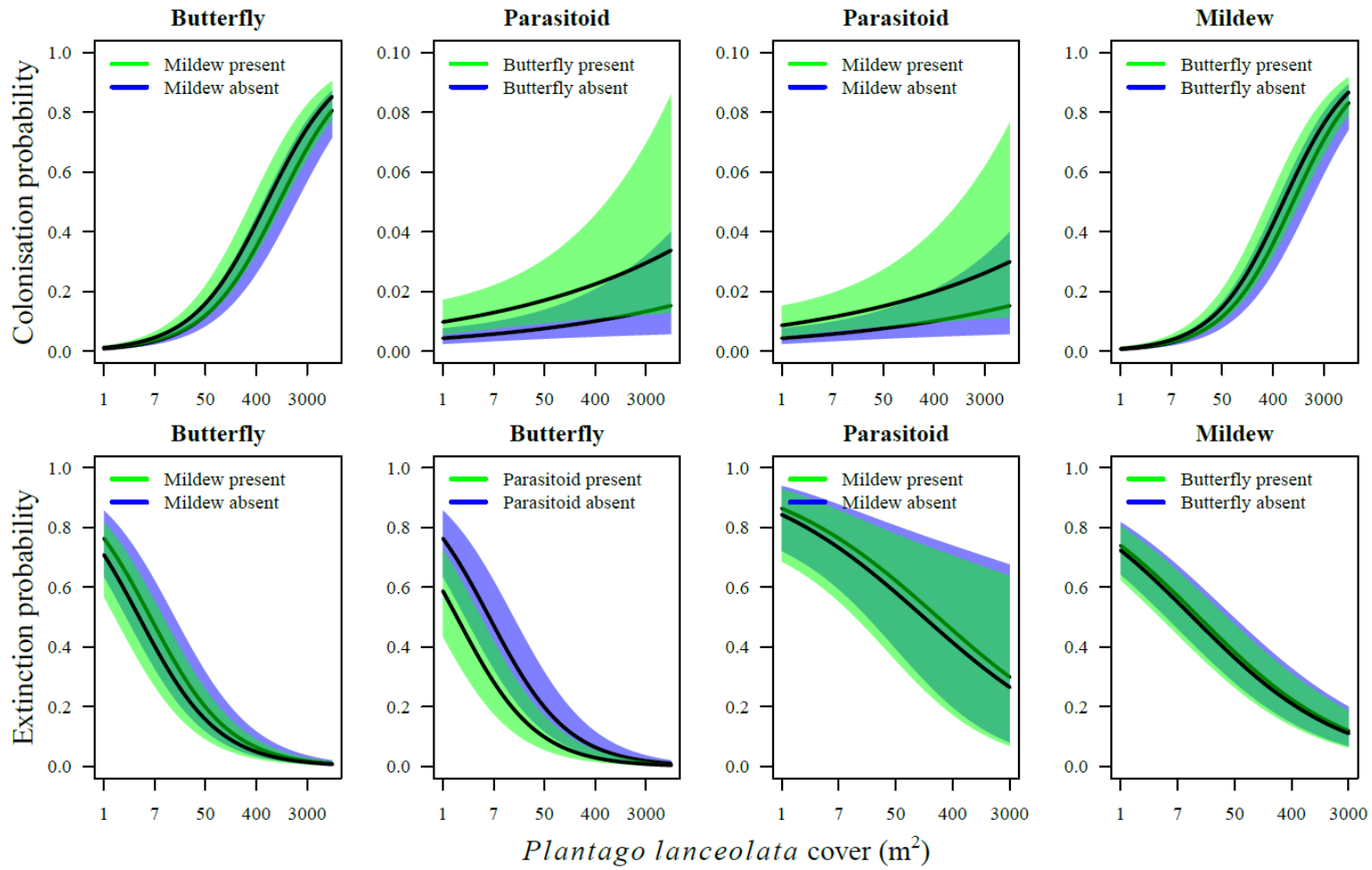
Butterfly host plant choices have consequences



Does this affect metacommunity dynamics?



Weak and unexpected effects of the presence of interacting species within patches



Logistic regression model in R

- The parameter estimates from a GLM are on the link scale, i.e. they describe in this case the change in the log odds of y per unit change in x
- The deviance measures the deviation of the model from a "perfect" model
- The normal r^2 is not valid, though there are options

```
##
## Call:
## glm(formula = y ~ x, family = binomial(link = "logit"))
##
## Deviance Residuals:
##     Min       1Q   Median       3Q      Max
## -2.0156  -1.1761   0.6573   0.7813   1.2629
##
## Coefficients:
##             Estimate Std. Error z value Pr(>|z|)
## (Intercept) -0.60084    0.53714  -1.119   0.2633
## x            0.17488    0.05543   3.155   0.0016 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## (Dispersion parameter for binomial family taken to be 1)
##
##     Null deviance: 227.10  on 199  degrees of freedom
## Residual deviance: 216.37  on 198  degrees of freedom
## AIC: 220.37
##
## Number of Fisher Scoring iterations: 4
```

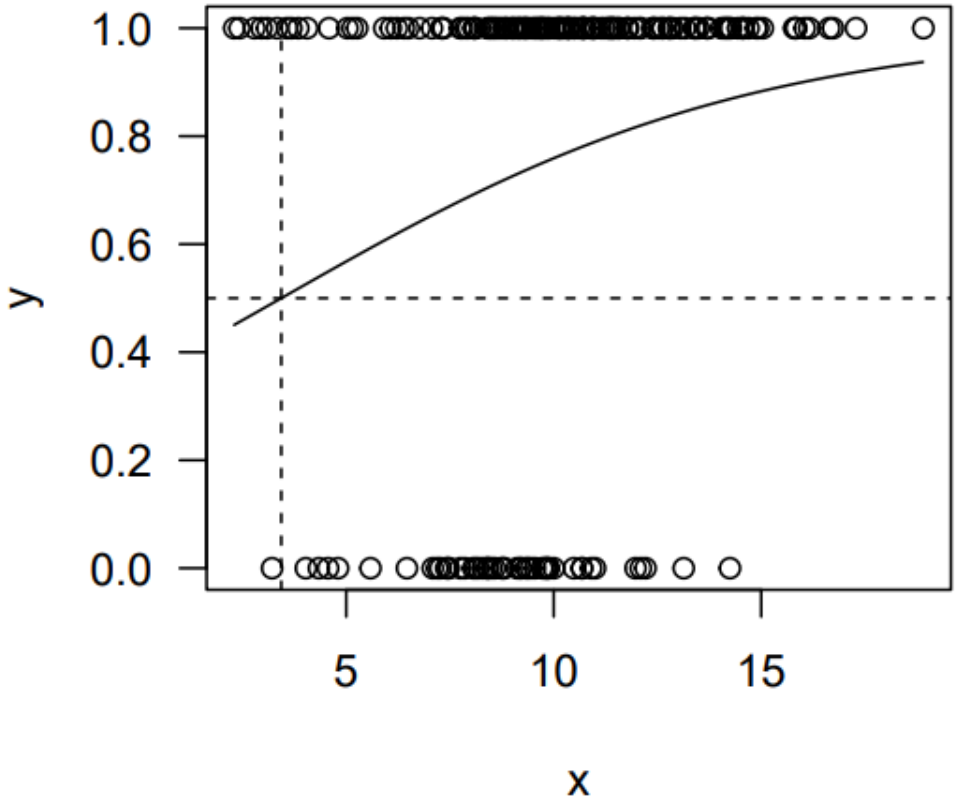
The r^2 in logistic regression

- We can quantify model fit through various "Pseudo r^2" metrics (see lecture notes)
- Another important measure is the coefficient of discrimination D, or Tjur´s r^2. This measures the difference in the model-predicted probabilities between observed 1´s and observed 0´s.

$$D = \bar{\hat{\pi}}_1 - \bar{\hat{\pi}}_0,$$

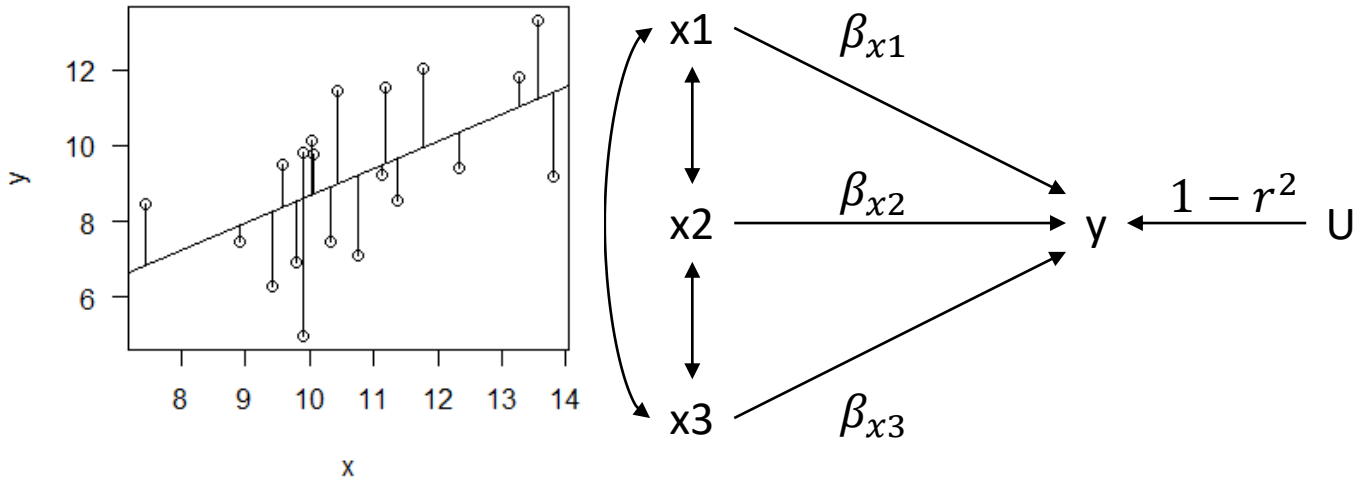
Logistic regression

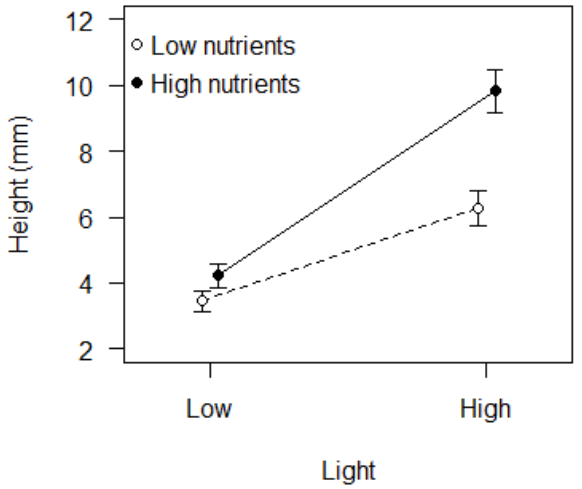
- To quantify effects, we can backtransform the parameter estimates to the probability scale to illustrate effects in e.g. a graph

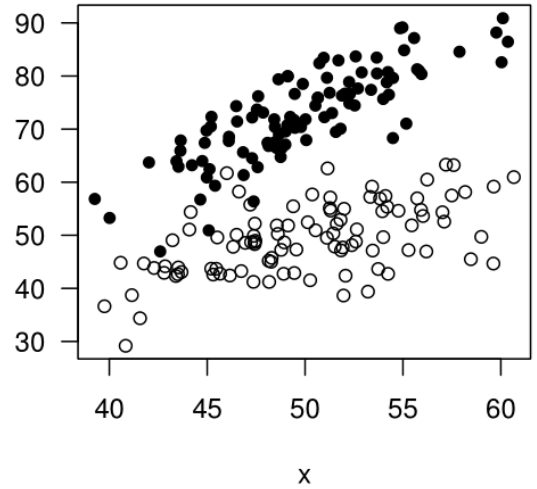


Overview of (generalized) linear models

- Continuous covariates: (multiple) regression
- Categorical covariates: N-way ANOVA
- Continuous and categorical covariates: ANCOVA







Overview of (generalized) linear models

- Binary/proportional data: Logistic regression