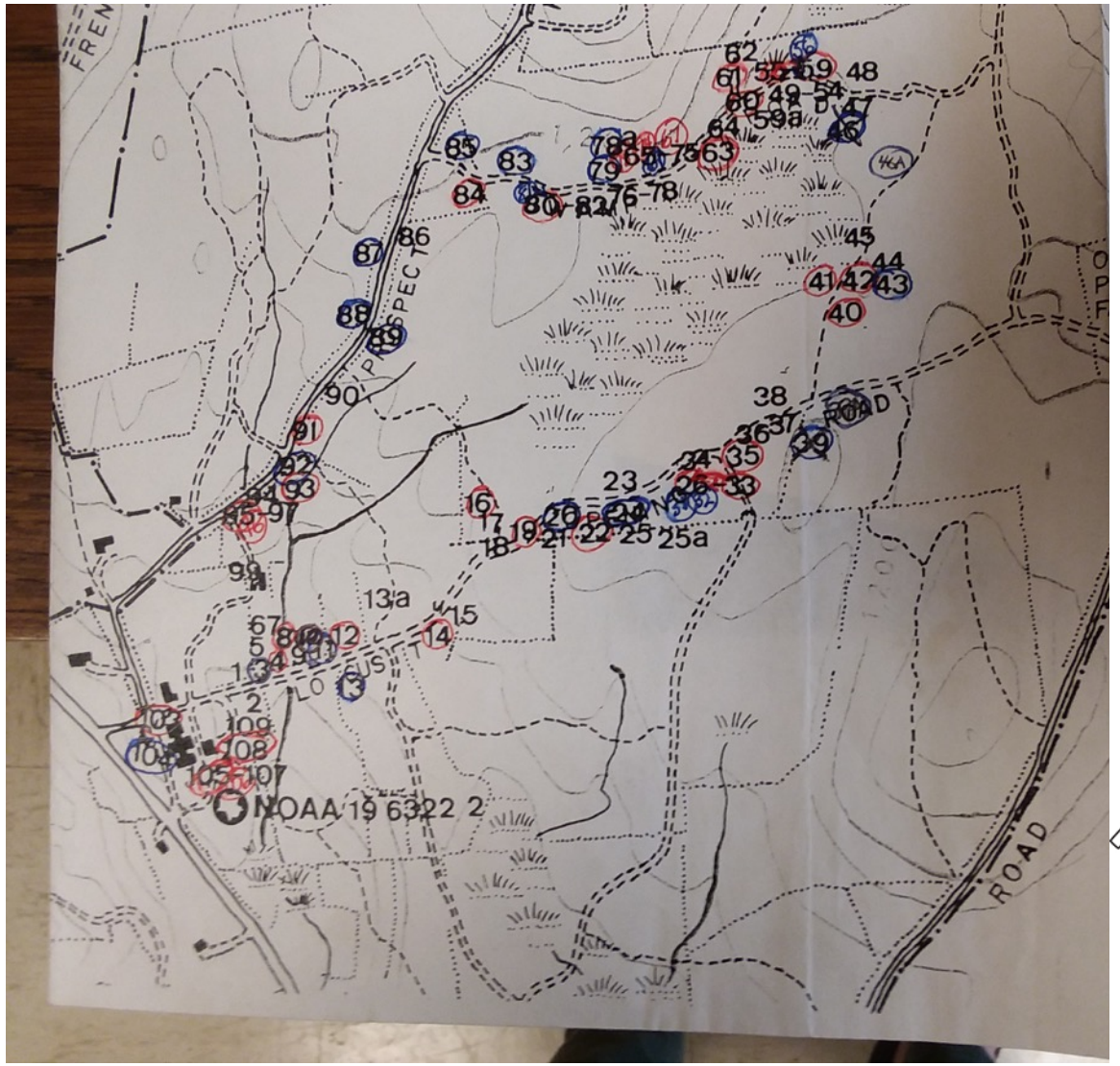
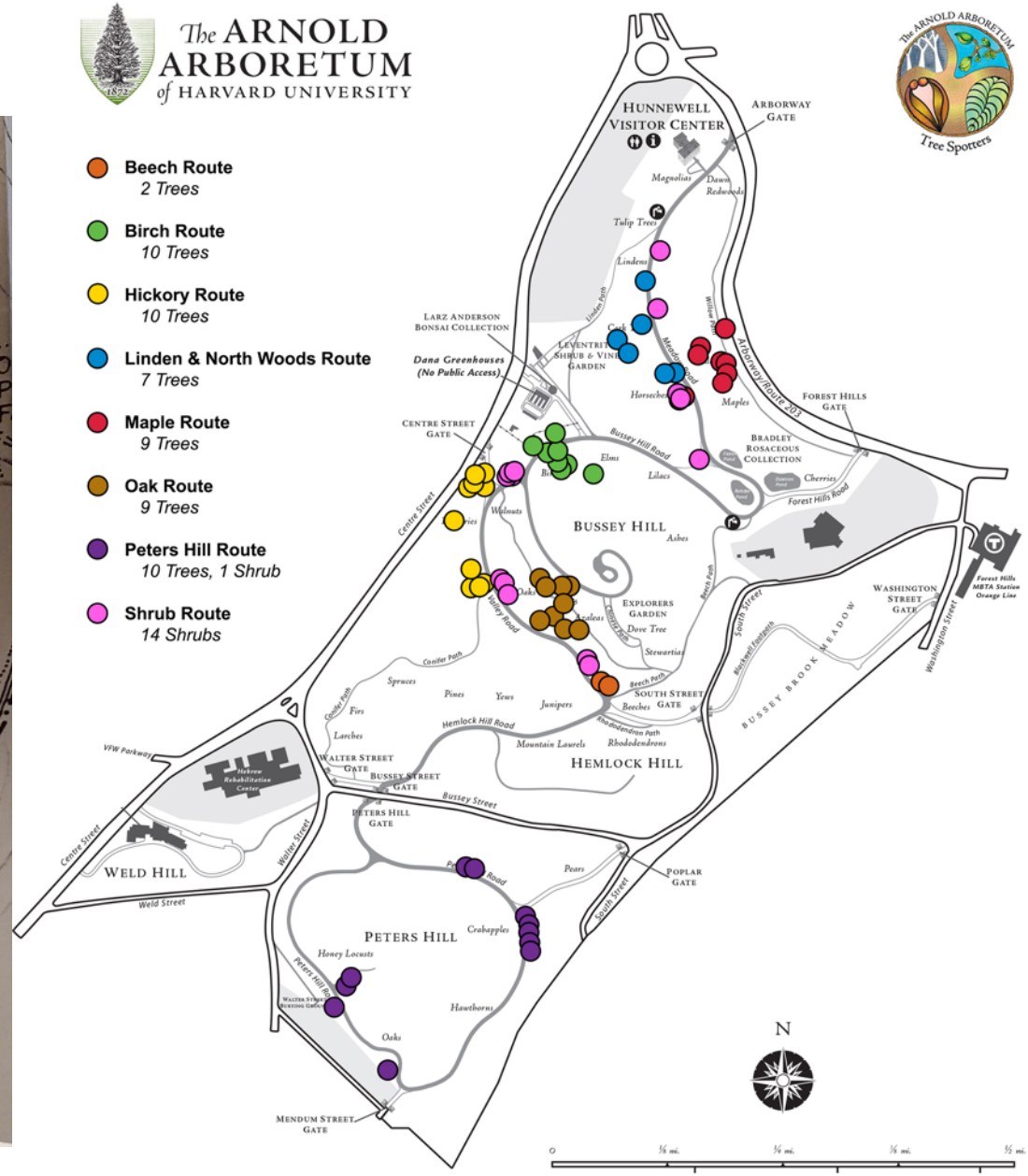
HARVARD FOREST

ARNOLD ARBORETUM



The ARNOLD ARBORETUM of HARVARD UNIVERSITY

- **Beech Route** *2 Trees*
- **Birch Route** *10 Trees*
- **Hickory Route** *10 Trees*
- **Linden & North Woods Route** *7 Trees*
- **Maple Route** *9 Trees*
- **Oak Route** *9 Trees*
- **Peters Hill Route** *10 Trees, 1 Shrub*
- **Shrub Route** *14 Shrubs*



APPROACH 2:

Let's try and see if there's an `urban' effect by combining sites into one model.

Again compare weather station data to hobo logger data in separate models

$$GDDlo \sim urban + (urban|species)$$

$$y_i \sim N(\mu_i, \sigma)$$

$$y_i = \alpha_l + \beta x_l + \sigma$$

$$\alpha_l \sim N(300, 100)$$

$$\beta_i \sim N(50, 20)$$

Model in Rstan

```
// Microclimates Analysis
// 30 Jan 2020 - Started by Cat
// Level: Species on INTERCEPTS and SLOPES

data {
  int<lower=1> N;
  int<lower=1> n_sp;
  int<lower=1, upper=n_sp> sp[N];
  vector[N] y;     // response
  vector[N] tx;    // urban predictor

  }

parameters {
  real mu_a_sp;
  real mu_b_tx_sp;
  real<lower=0> sigma_a_sp;
  real<lower=0> sigma_b_tx_sp;
  real<lower=0> sigma_y;

  real a_sp[n_sp]; // intercept for species
  real b_tx[n_sp]; // slope of urban effect

  }

transformed parameters {
  vector[N] yhat;

        for(i in 1:N){
            yhat[i] = a_sp[sp[i]] + // indexed with species
    b_tx[sp[i]] * tx[i];
  }
}
```

```
model {

  a_sp ~ normal(mu_a_sp, sigma_a_sp);
  b_tx ~ normal(mu_b_tx_sp, sigma_b_tx_sp);

        mu_a_sp ~ normal(300, 100);
        sigma_a_sp ~ normal(0, 100);

        mu_b_tx_sp ~ normal(50, 30);
        sigma_b_tx_sp ~ normal(0, 10);

  y ~ normal(yhat, sigma_y);

}

generated quantities{
   real y_ppc[N];
   for (n in 1:N)
      y_ppc[n] = a_sp[sp[n]] +
    b_tx[sp[n]] * tx[n];
    for (n in 1:N)
      y_ppc[n] = normal_rng(y_ppc[n], sigma_y);

}
```

Model in Rstan for Hobo loggers:

```
model {

  a_sp ~ normal(mu_a_sp, sigma_a_sp);
  b_tx ~ normal(mu_b_tx_sp, sigma_b_tx_sp);

        mu_a_sp ~ normal(250, 100);
        sigma_a_sp ~ normal(0, 100);

        mu_b_tx_sp ~ normal(50, 30);
        sigma_b_tx_sp ~ normal(0, 10);

  y ~ normal(yhat, sigma_y);

}

generated quantities{
   real y_ppc[N];
   for (n in 1:N)
      y_ppc[n] = a_sp[sp[n]] +
    b_tx[sp[n]] * tx[n];
    for (n in 1:N)
      y_ppc[n] = normal_rng(y_ppc[n], sigma_y);

}
```

Model Check:

```
> check_all_diagnostics(hl_urb_fake)
[1] "n_eff / iter looks reasonable for all parameters"
[1] "Rhat looks reasonable for all parameters"
[1] "0 of 12000 iterations ended with a divergence (0%)"
[1] "0 of 12000 iterations saturated the maximum tree depth of 10 (0%)"
[1] "E-FMI indicated no pathological behavior"
```

Fake Data:

GDD mean = 300
GDD sigma = 50
Urban effect mean = 50
Urban effect sigma = 20

	mean
mu_a_sp	292.10441
mu_b_tx_sp	48.47336

	mean
sigma_a_sp	62.71432
sigma_b_tx_sp	35.55321
sigma_y	20.75554

Model Check:

```
> check_all_diagnostics(hl_urb_fake)
[1] "n_eff / iter looks reasonable for all parameters"
[1] "Rhat looks reasonable for all parameters"
[1] "0 of 12000 iterations ended with a divergence (0%)"
[1] "0 of 12000 iterations saturated the maximum tree depth of 10 (0%)"
[1] "E-FMI indicated no pathological behavior"
```

Fake Data:

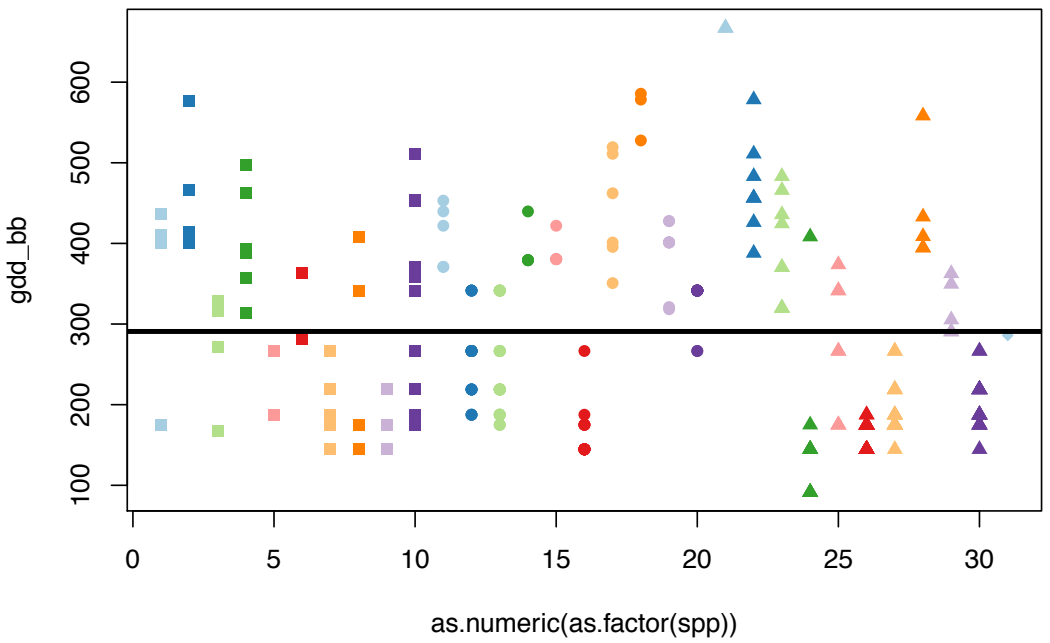
GDD mean = 250
GDD sd = 30
Urban effect mean = 40
Urban effect sd = 10

	mean
mu_a_sp	250.17243
mu_b_tx_sp	47.60886

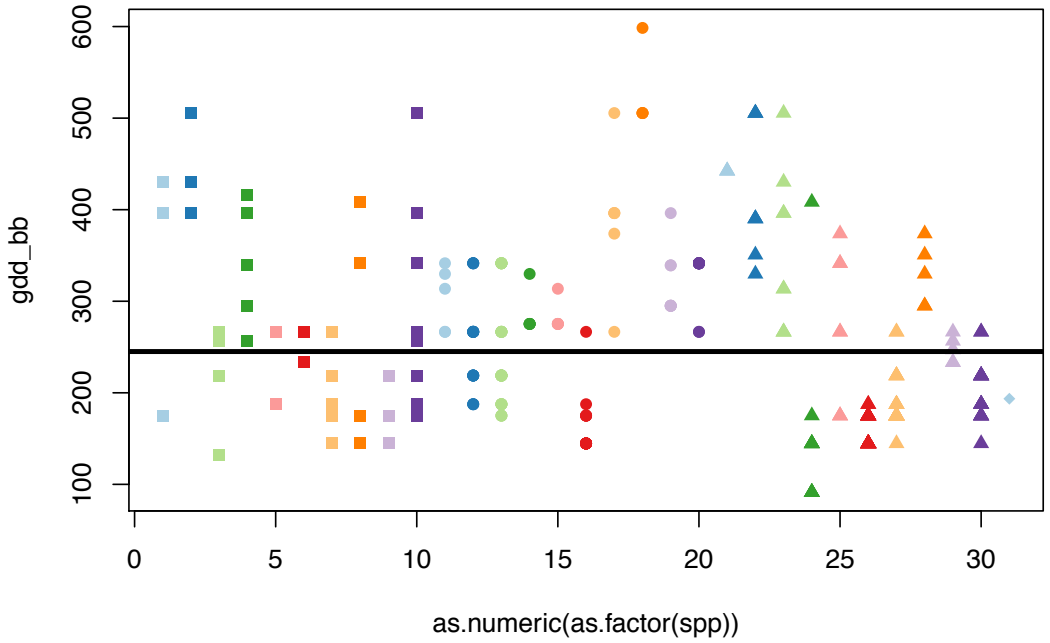
	mean
sigma_a_sp	34.53690
sigma_b_tx_sp	28.51673
sigma_y	10.08232

Raw Data

Weather Station



Hobo Logger



Model with Real Data

```
> check_all_diagnostics(hl_urb_fake)
[1] "n_eff / iter looks reasonable for all parameters"
[1] "Rhat looks reasonable for all parameters"
[1] "0 of 12000 iterations ended with a divergence (0%)"
[1] "0 of 12000 iterations saturated the maximum tree depth of 10 (0%)"
[1] "E-FMI indicated no pathological behavior"
```

Weather Station data:

	mean
mu_a_sp	404.4107
mu_b_tx_sp	-147.6127

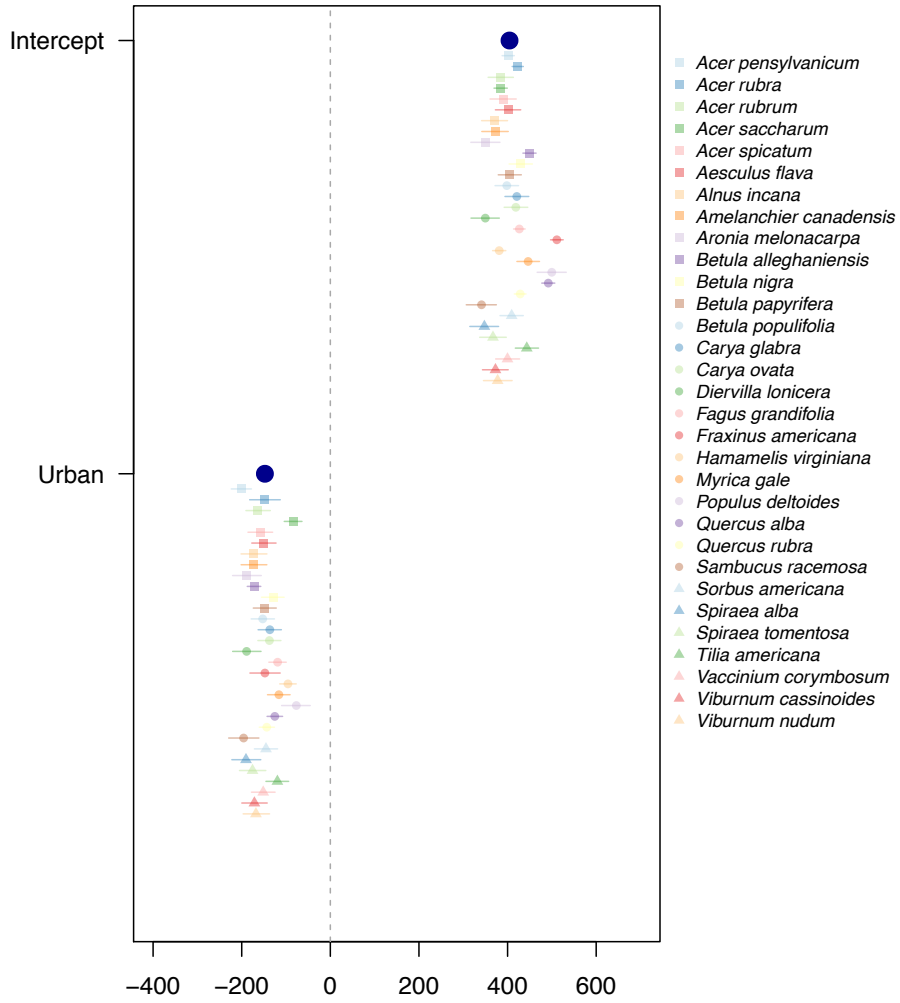
	mean
sigma_a_sp	56.86038
sigma_b_tx_sp	48.71077
sigma_y	44.22200

Hobo Logger data:

	mean
mu_a_sp	364.59661
mu_b_tx_sp	-54.77062

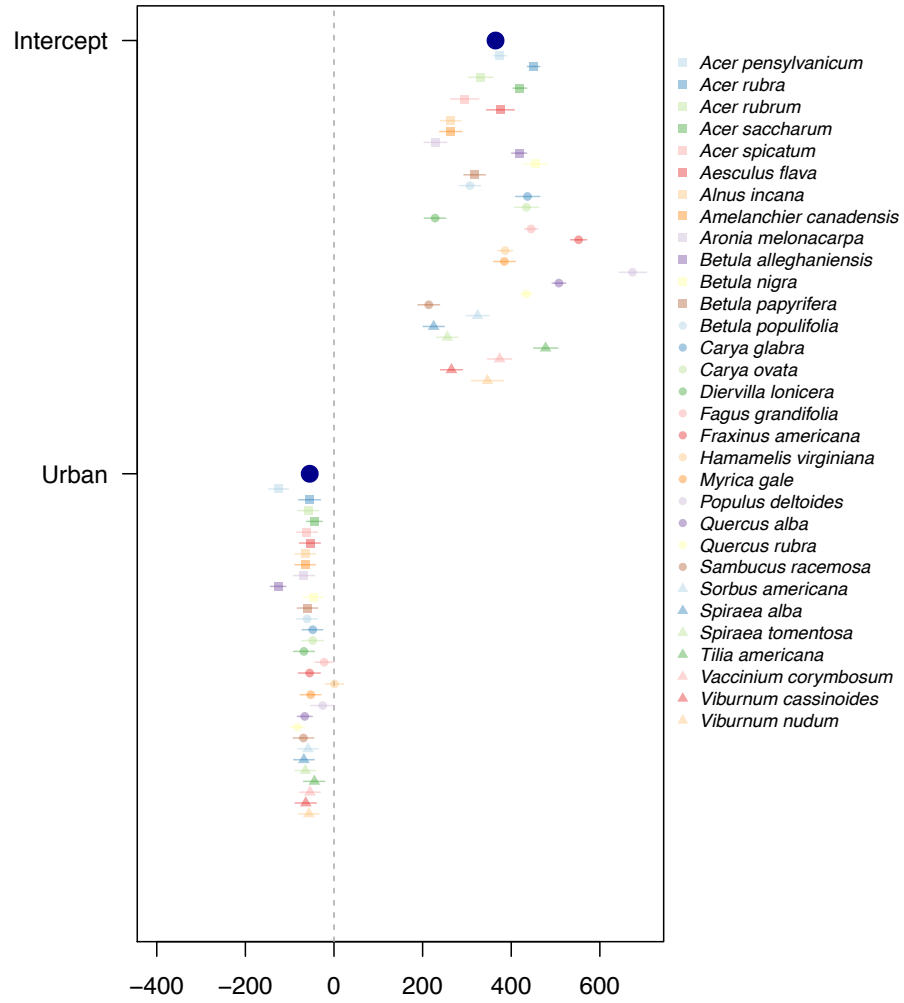
	mean
sigma_a_sp	114.20140
sigma_b_tx_sp	33.44762
sigma_y	48.16253

WEATHER STATION



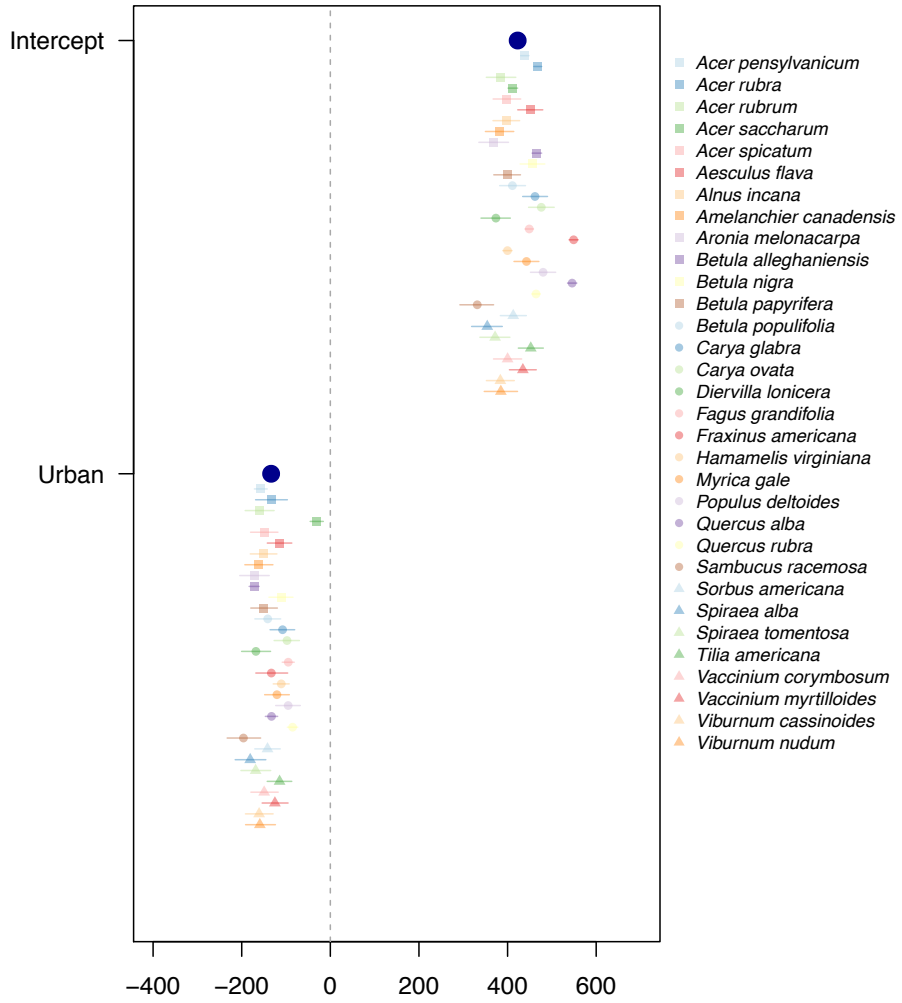
Model estimate change in growing degree days to budburst

HOBO LOGGER



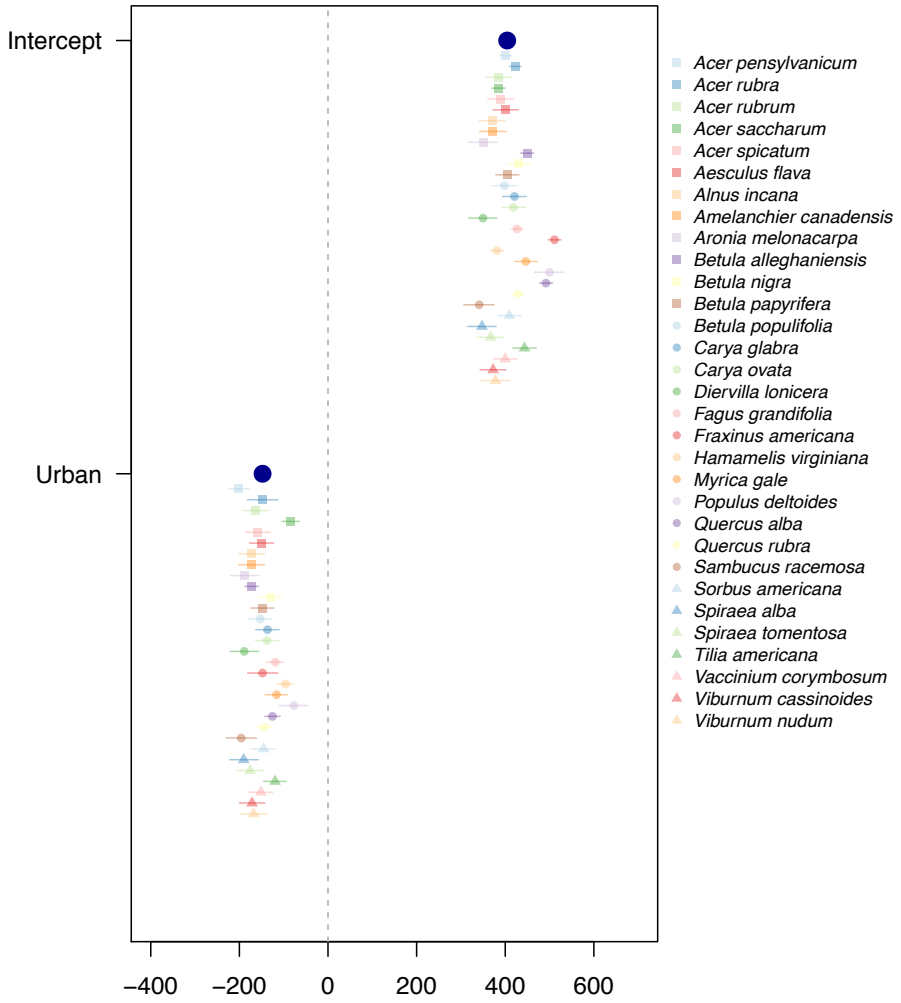
Model estimate change in growing degree days to budburst

WEATHER STATION: 2019



Model estimate change in growing degree days to budburst

WEATHER STATION: 2017-2019



Model estimate change in growing degree days to budburst