Environmental Limits to Species Distributions in Diverse Tropical Forests of Panama

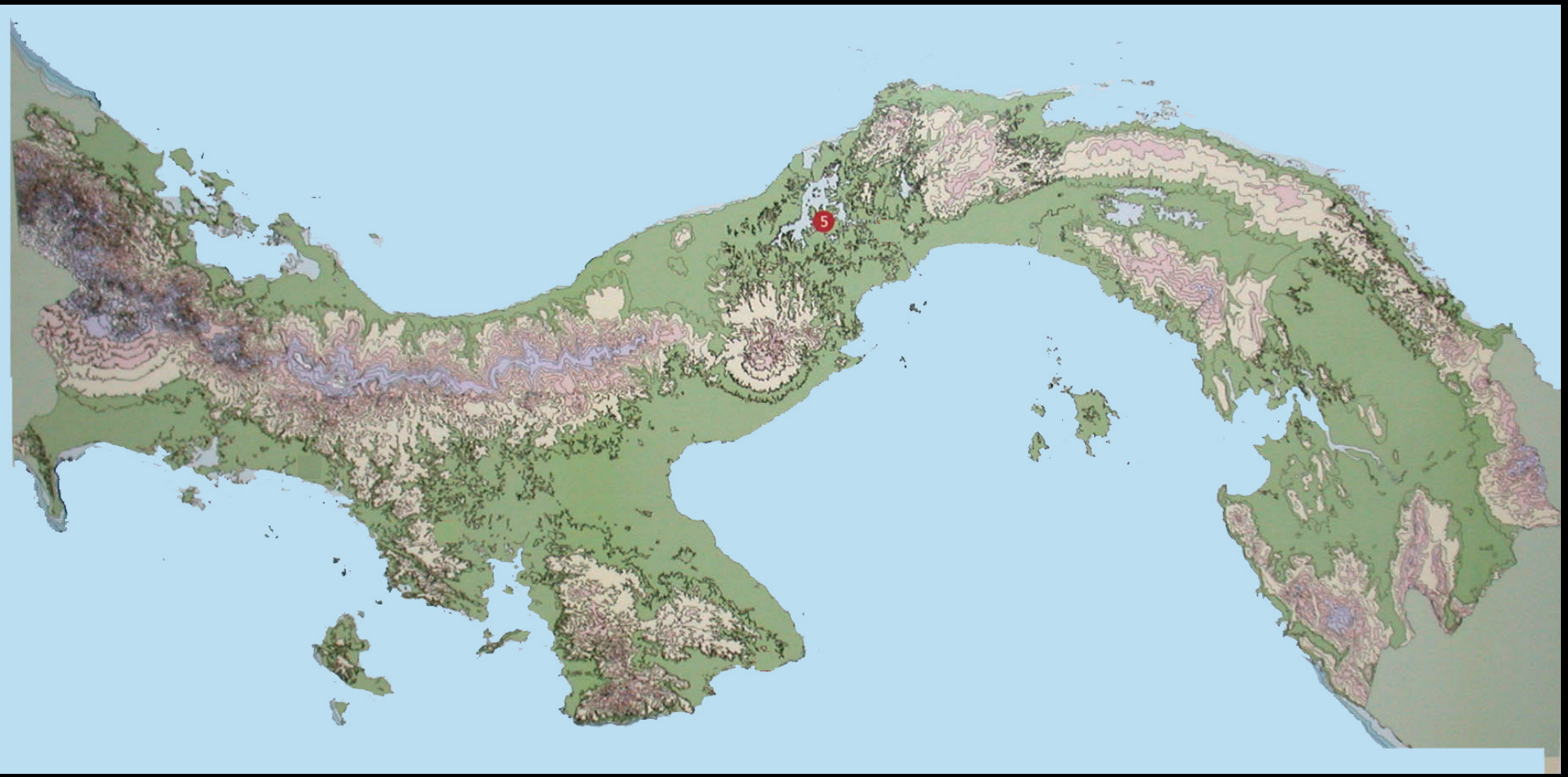
R. Condit, R. Pérez, S. Aguilar, S. Lao, B. Engelbrecht, B. Turner

Smithsonian Tropical Research Institute

Pontificia Universidad Católica de Chile, Santiago
19 October 2012

Panama's Setting

Panama's Terrain



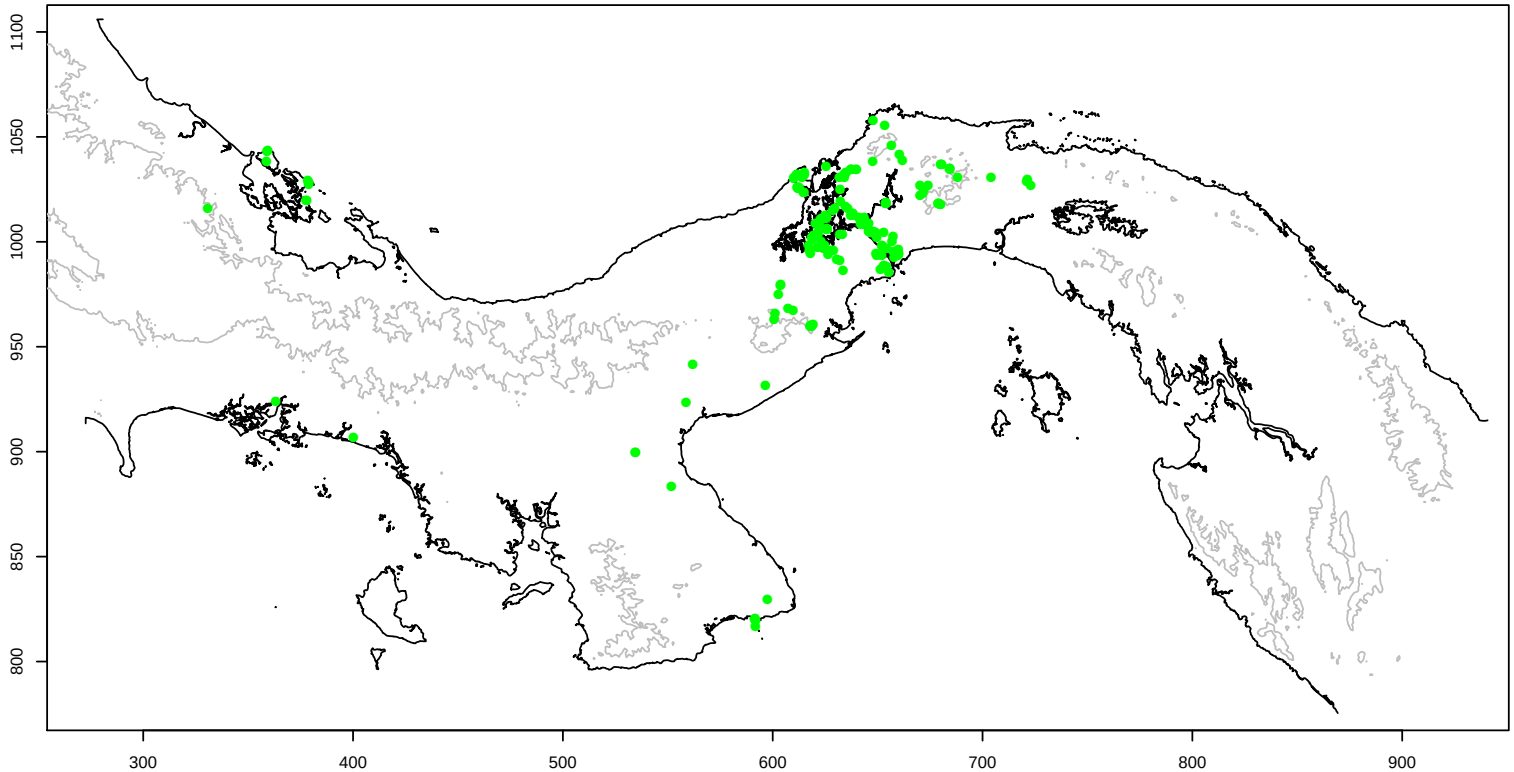
Climate and Deciduousness

Dry season intensity...

Astronium graveolens

Surveys of Tree Species

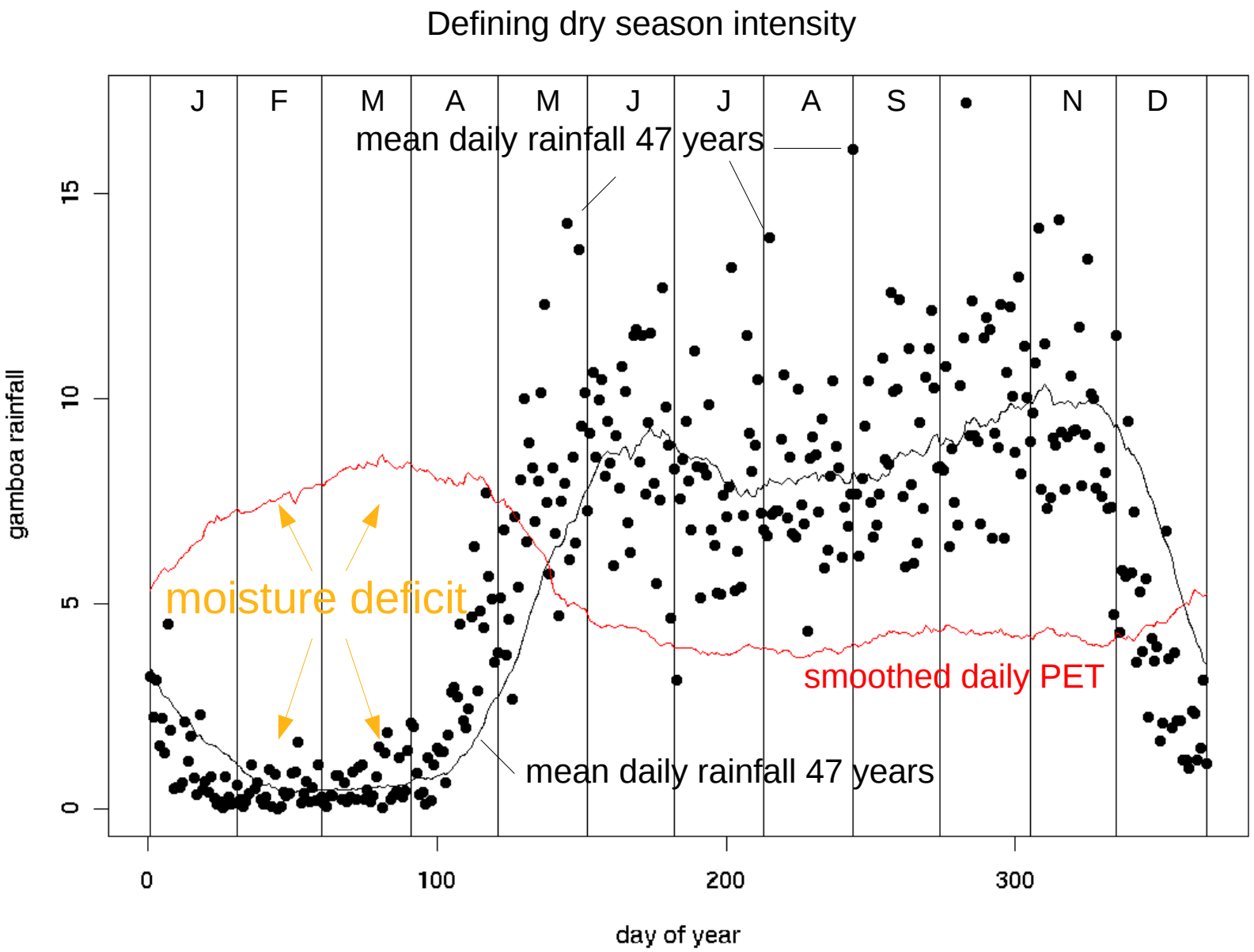
183 sites in Panama:
61 plots (full tree census) & 122 inventories (presence-absence)



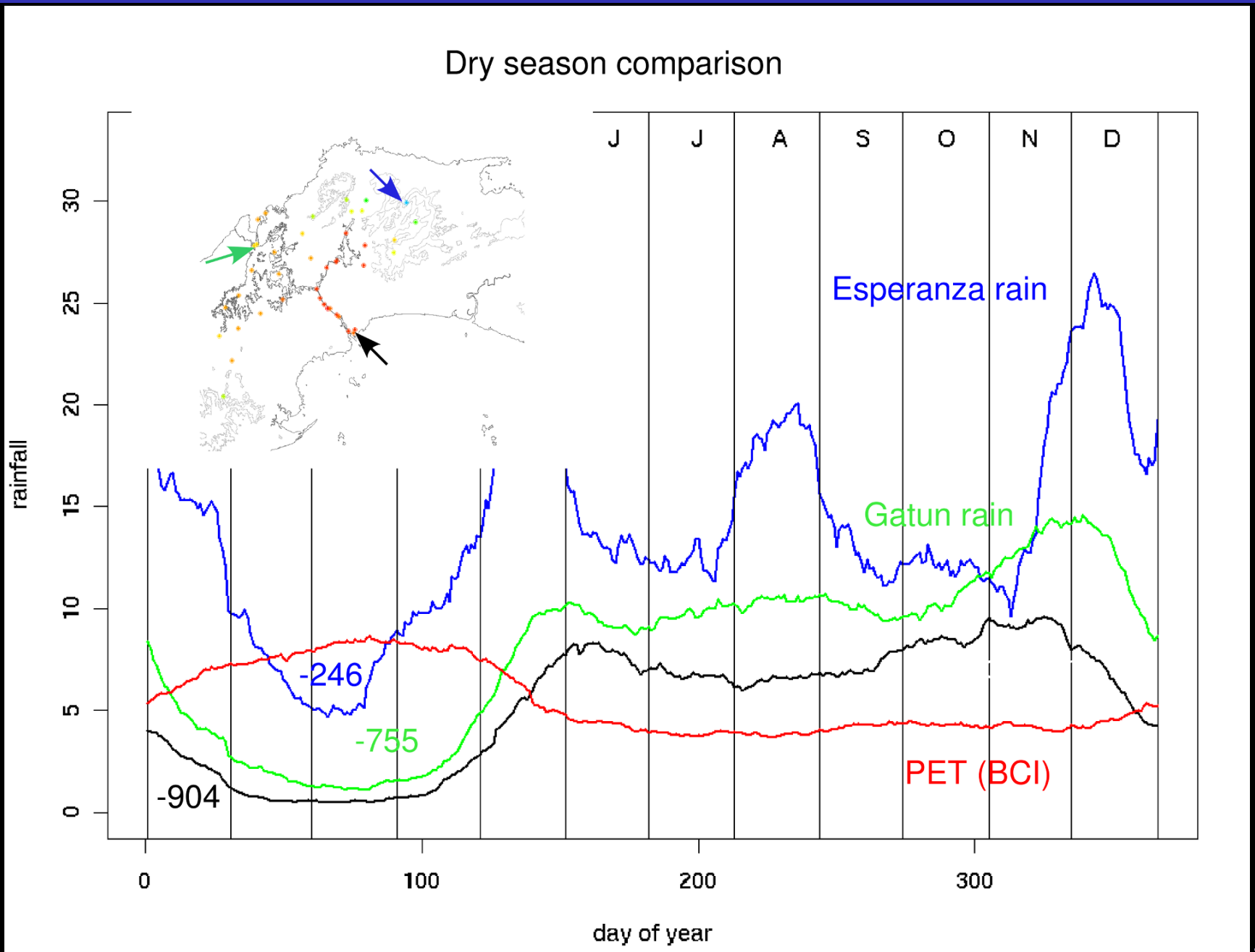
Limits to Tree Distributions

1. Tree Distribution Records
   - Tree plots
   - Tree inventories
2. Climate
   - Measuring the dry season
   - An Atlantic-Pacific shift in species
3. Geology
   - Limestone and deciduousness
   - A volcanic basement at Pipeline Road
4. Soil Chemistry
   - P and Ca extremely variable
   - Conspicuous local effects on tree species
   - Phosphorus favors and excludes species
5. Conclusions
   - Importance of dry season and phosphorus
   - Species favor wet and dry, rich and poor

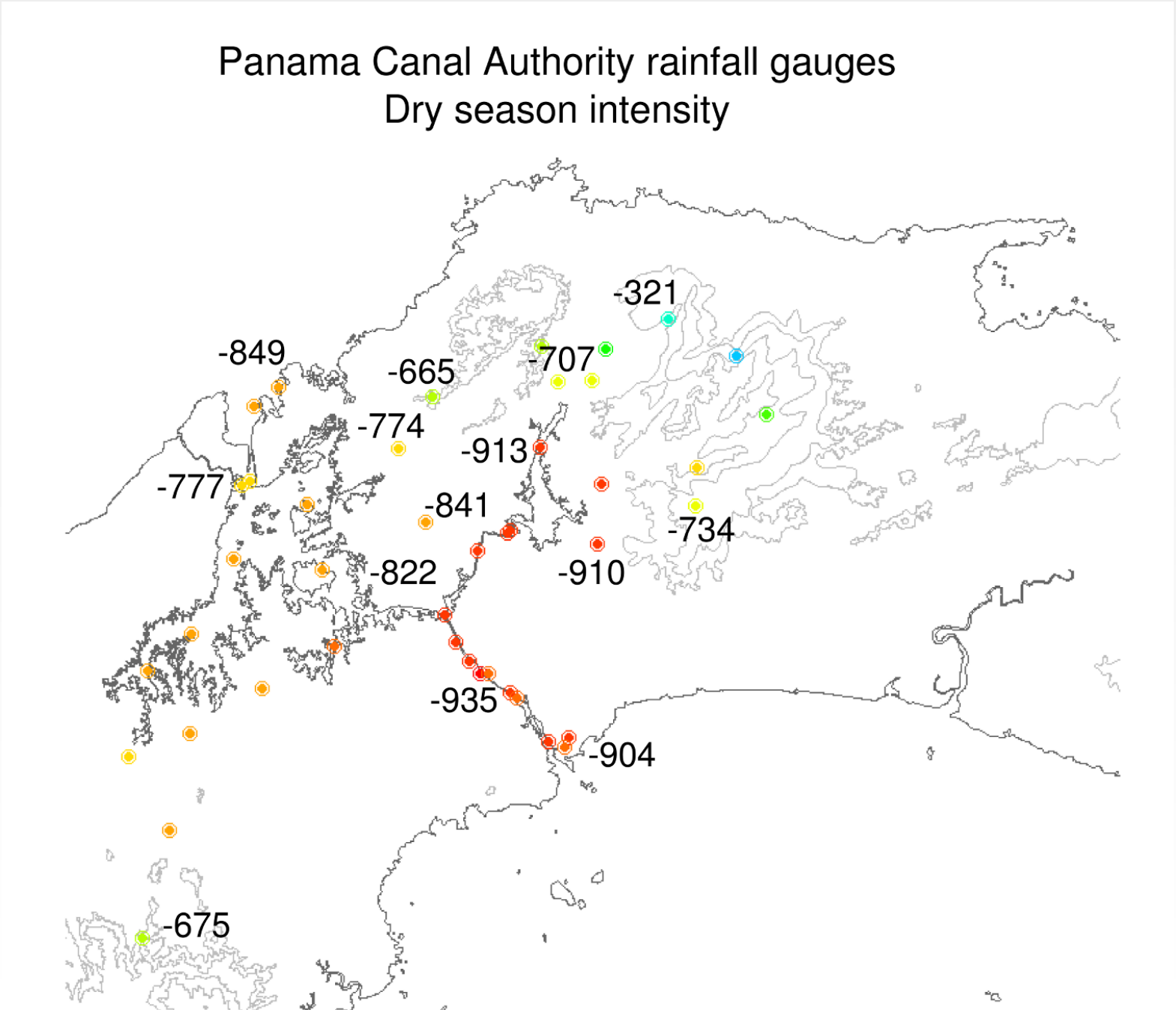
Rainfall and Evapotranspiration



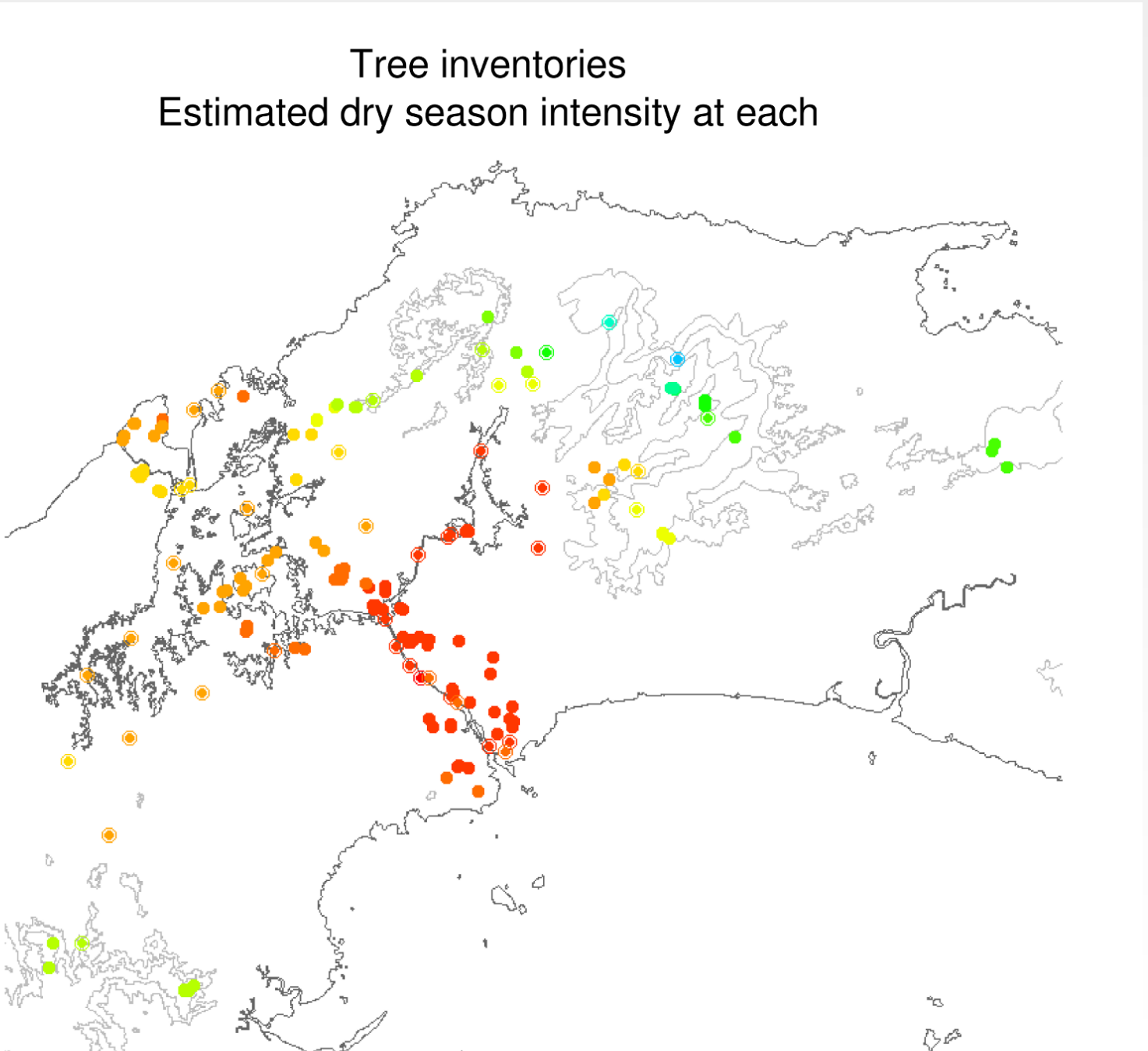
Dry Season Graph



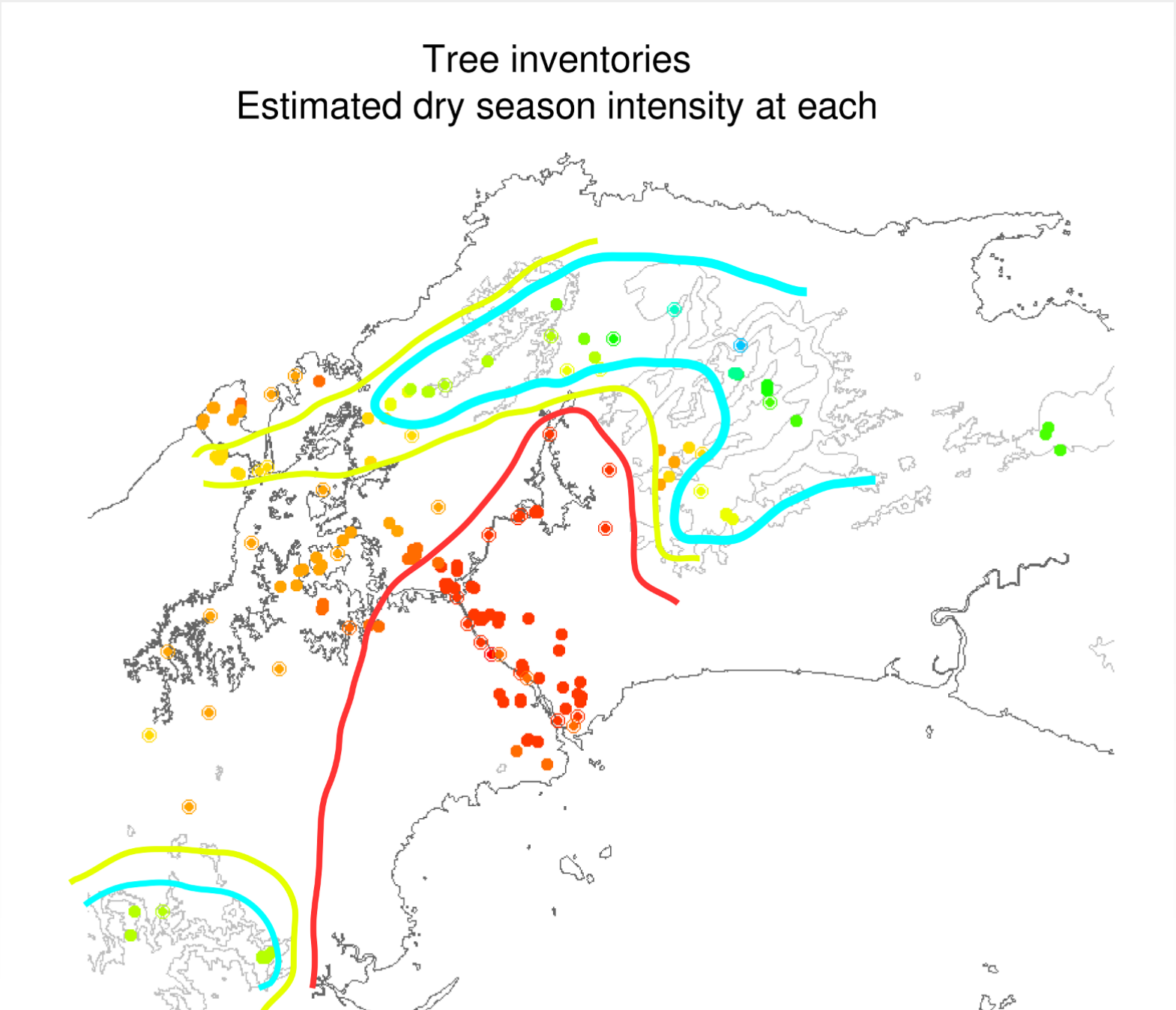
Climate Map


Panama Canal Authority rainfall gauges
Dry season intensity
-321
-849
-665
-707
-774
-913
-777
-841
-734
-822
-910
-935
-904
-675

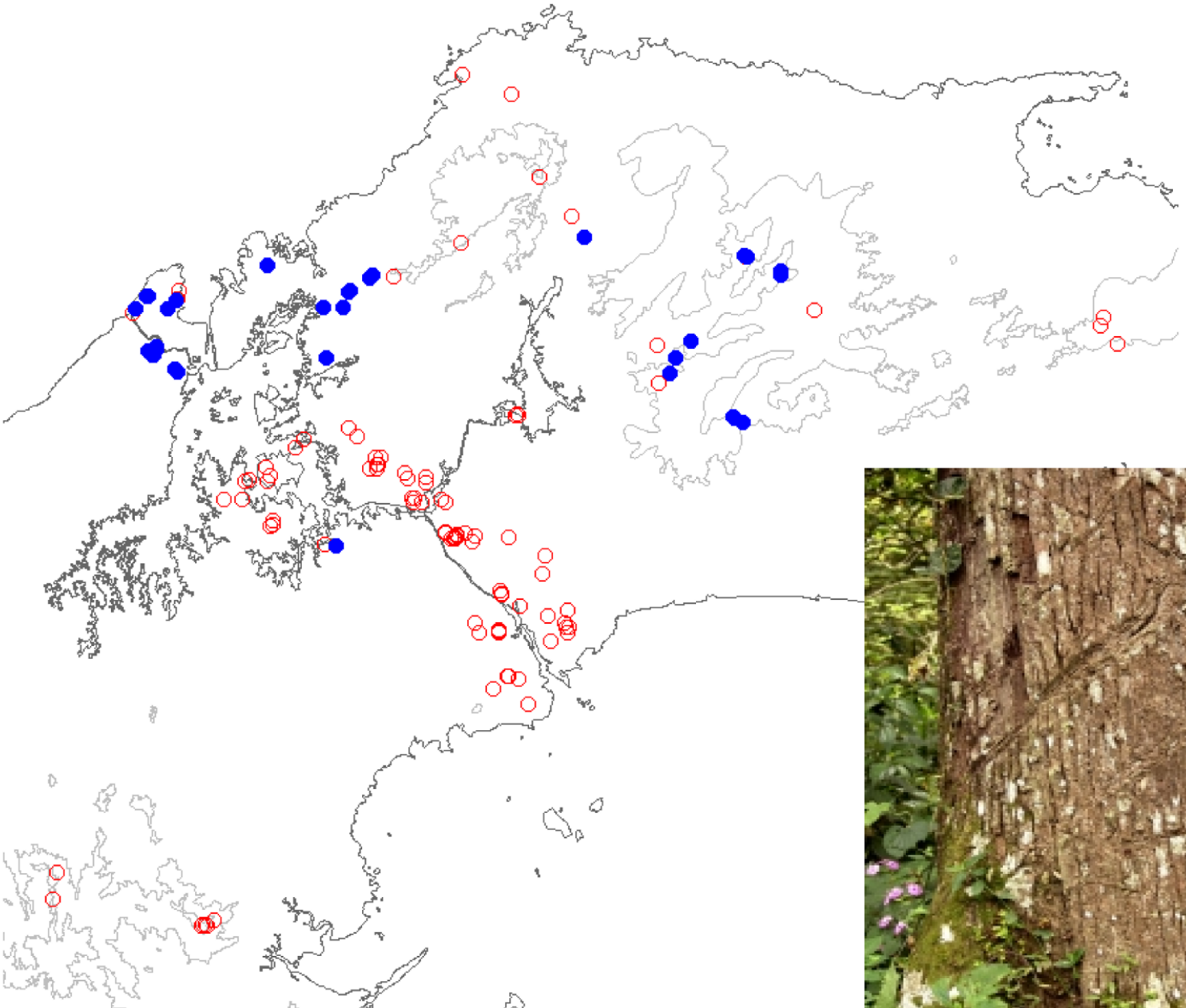
Climate Map



Climate Map

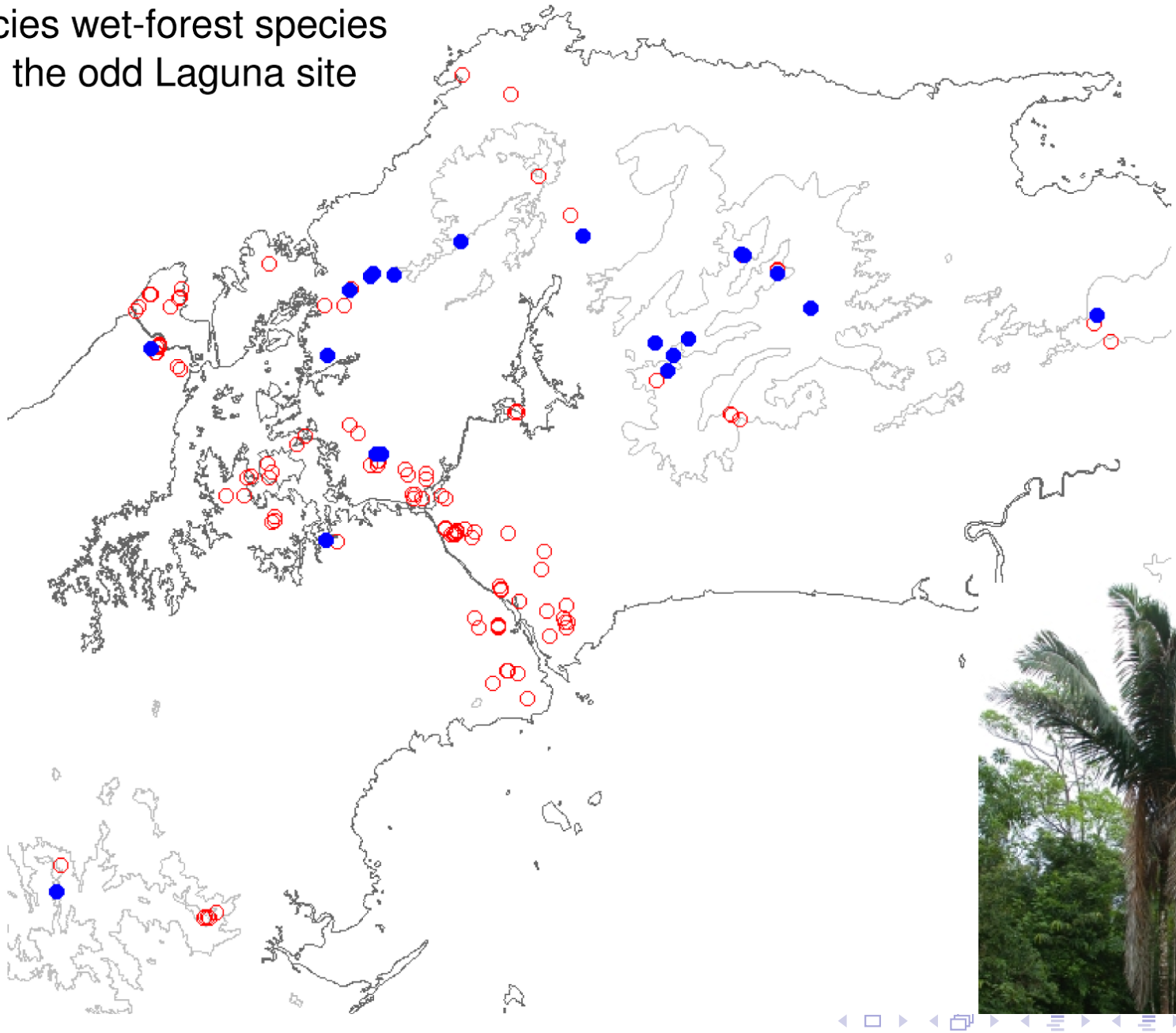


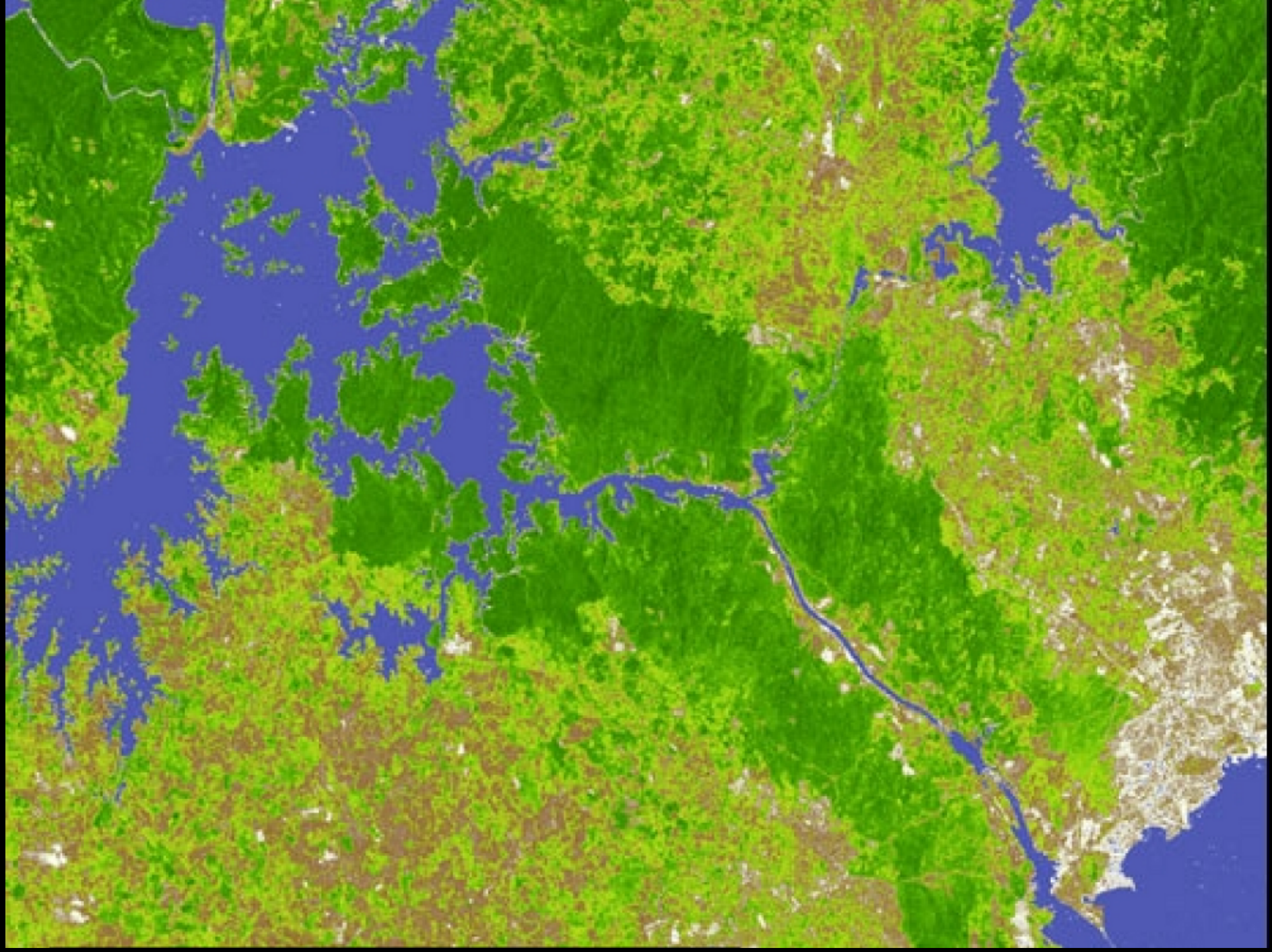
Manilkara bidentata plots and inventories

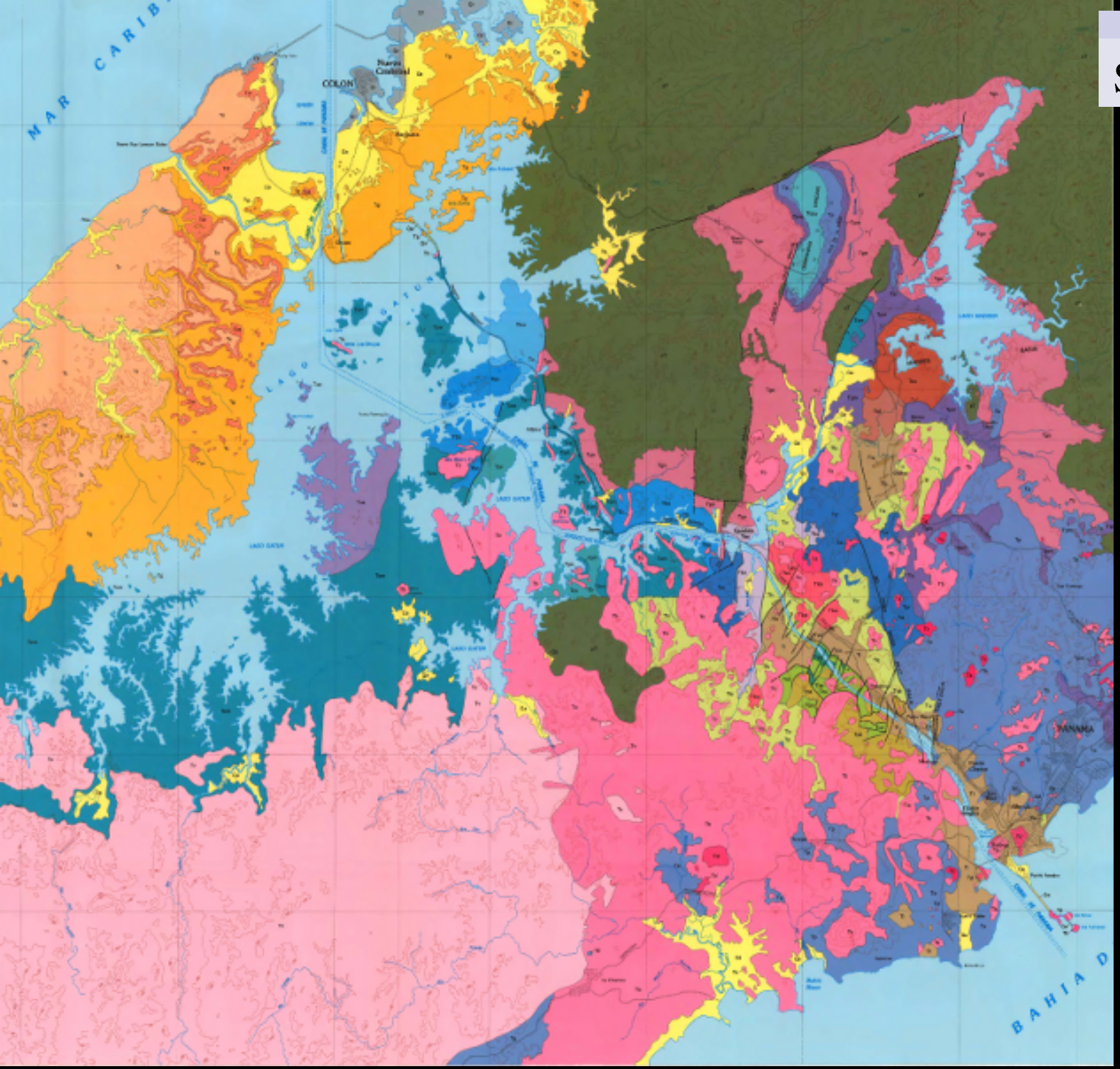


Welfia regia plots and inventories

32 species wet-forest species reach the odd Laguna site



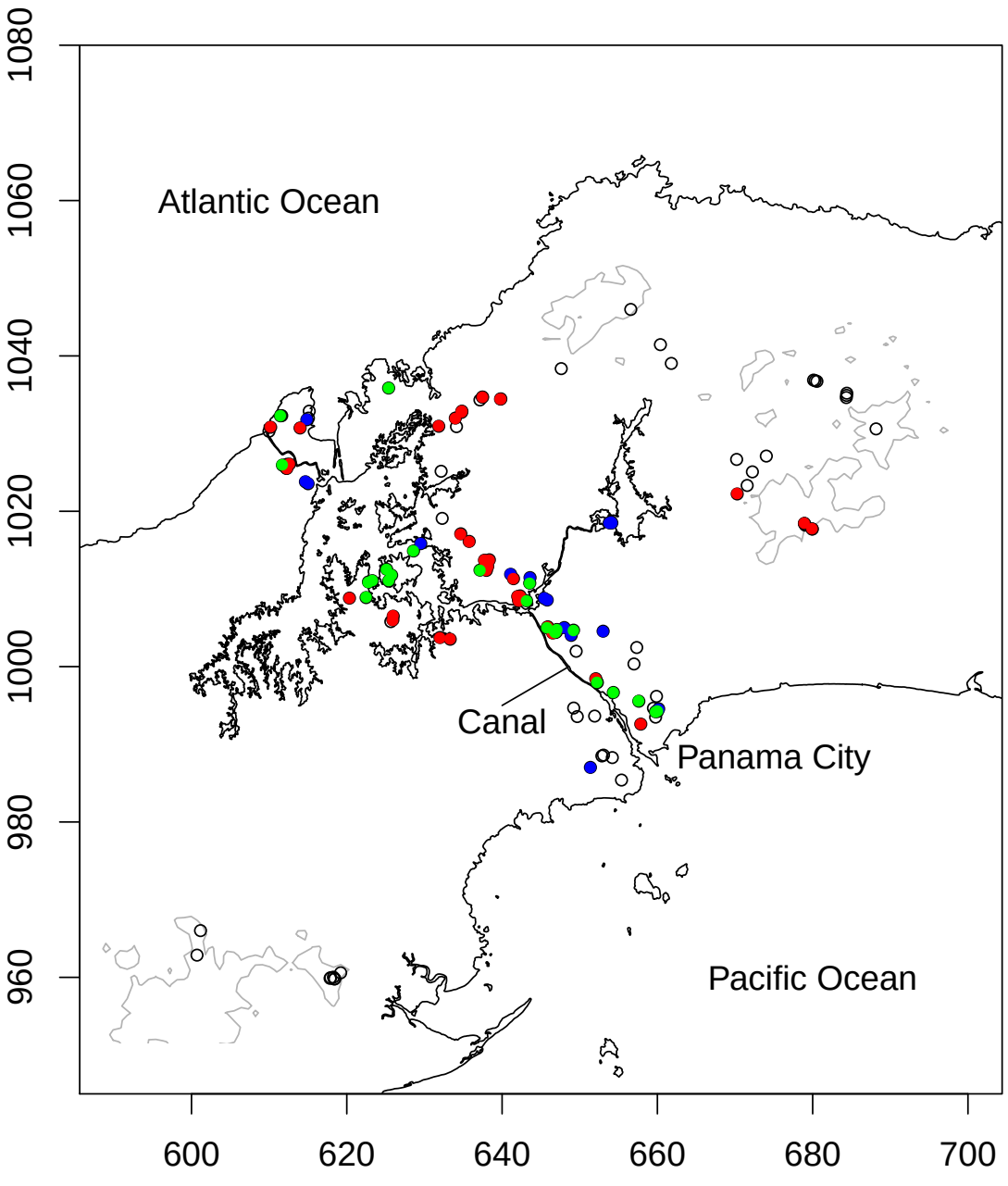




Stewart *et al.*

Deciduous Species and Limestone

Phosphorus Map



Low phosphorus

Medium phosphorus

High phosphorus

Turner's Soil Nutrient Summary (72 sites)

	Mean	Min	Max	Range
Al	942.11	323.30	1463.00	4.53
Ca	2058.96	25.00	9738.60	389.54
Fe	172.75	78.00	727.90	9.33
K	73.46	12.30	351.90	28.61
Mg	445.75	17.90	1410.70	78.81
Mn	107.70	1.90	322.60	169.79
P(resin)	2.99	0.07	22.80	325.71
P(Mehlich)	3.72	0.05	26.80	536.00
TotalP	462.18	72.20	1552.80	21.51
Zn	4.25	0.50	44.81	89.62
pH	5.62	3.34	7.33	2.19
N(Inorg)	3.65	0.57	6.44	11.30
N(Organic)	17.54	3.10	50.00	16.13

Soil Nutrient Comparison

	Panama		Amazon*	
	Min	Max	Min	Max
Ca	25.00	9738.60	2.90	3402.00
K	12.30	351.90	3.80	197.00
P(resin)	0.07	22.80	1.00	21.80
TotalP	72.20	1552.80	25.00	968.00

* Phillips *et al.* 2003, Quesada *et al.* 2011

Individual Species Biology

Individual Species Biology

Individual Species Biology

Individual Species Biology

Individual Species Biology

Individual Species Biology

Logistic Regression and Species Occurrence

- Multiple logistic regression
  – standard for occurrence modeling against many resources

Logistic Regression and Species Occurrence

- Multiple logistic regression
  – standard for occurrence modeling against many resources
- Gaussian logistic regression
  – adds second-order term allowing modal (humped) response

Logistic Regression and Species Occurrence

- Multiple logistic regression
  – standard for occurrence modeling against many resources
- Gaussian logistic regression
  – adds second-order term allowing modal (humped) response
- $\text{OccurrenceProb} \sim \text{InverseLogit}(\text{Climate} + \text{Soil} + \text{Climate}^2 + \text{Soil}^2)$

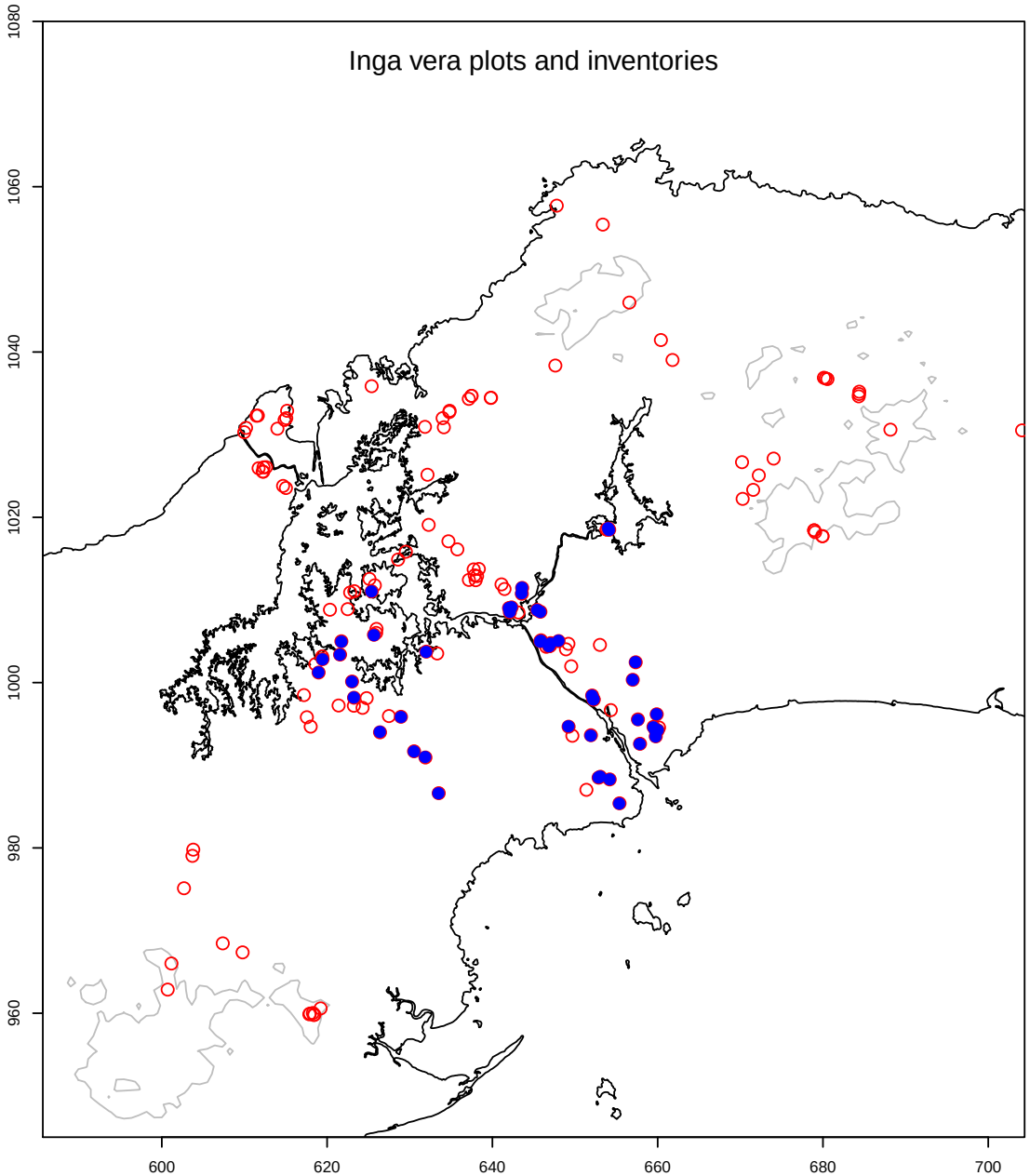
Logistic Regression and Species Occurrence

- Multiple logistic regression
  – standard for occurrence modeling against many resources
- Gaussian logistic regression
  – adds second-order term allowing modal (humped) response

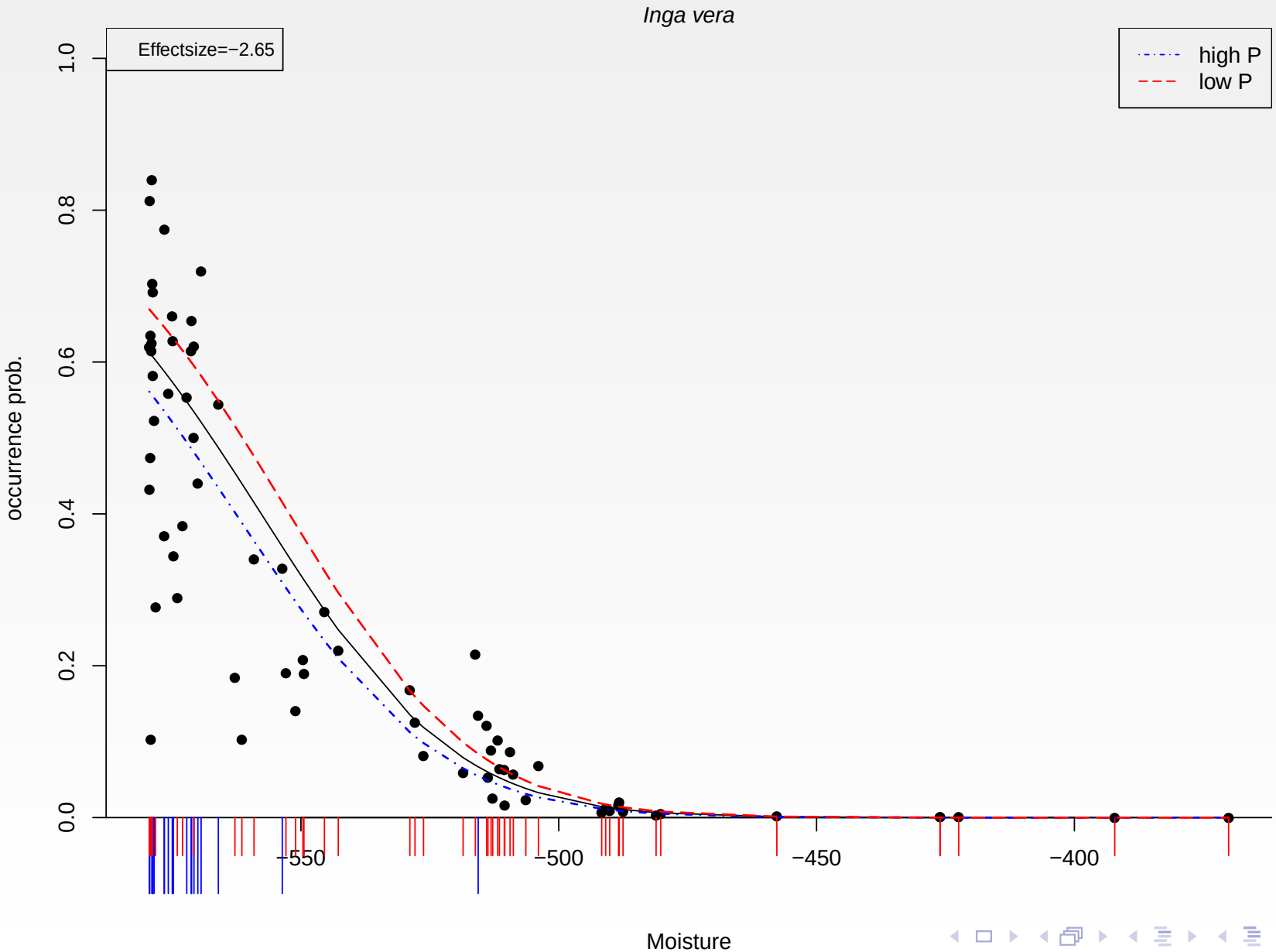
- Eight predictors in model:

  Dry season moisture
  Al
  Ca
  Fe
  K
  P (plant available)
  Zn
  N (inorganic)

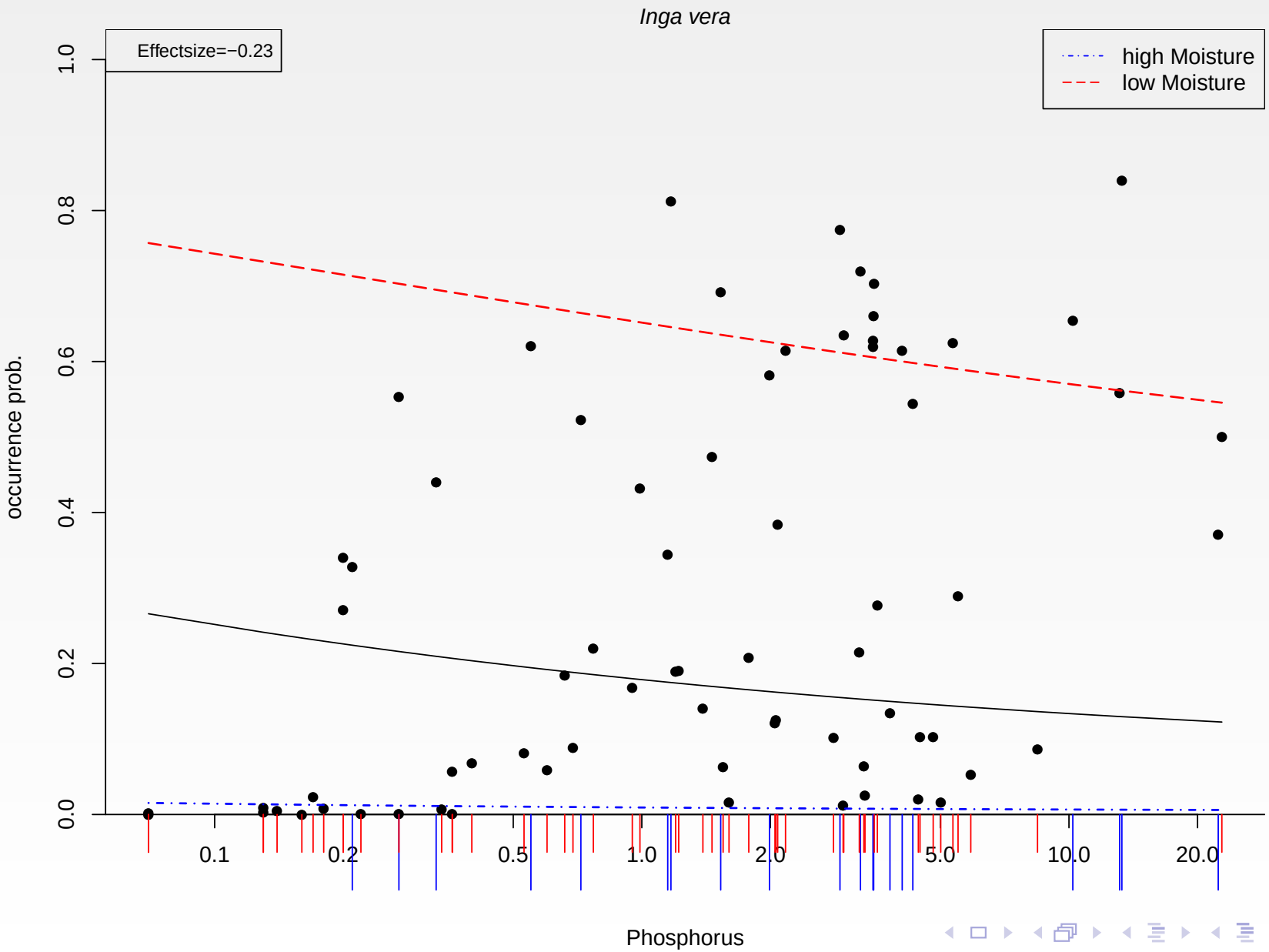
Species Distributions



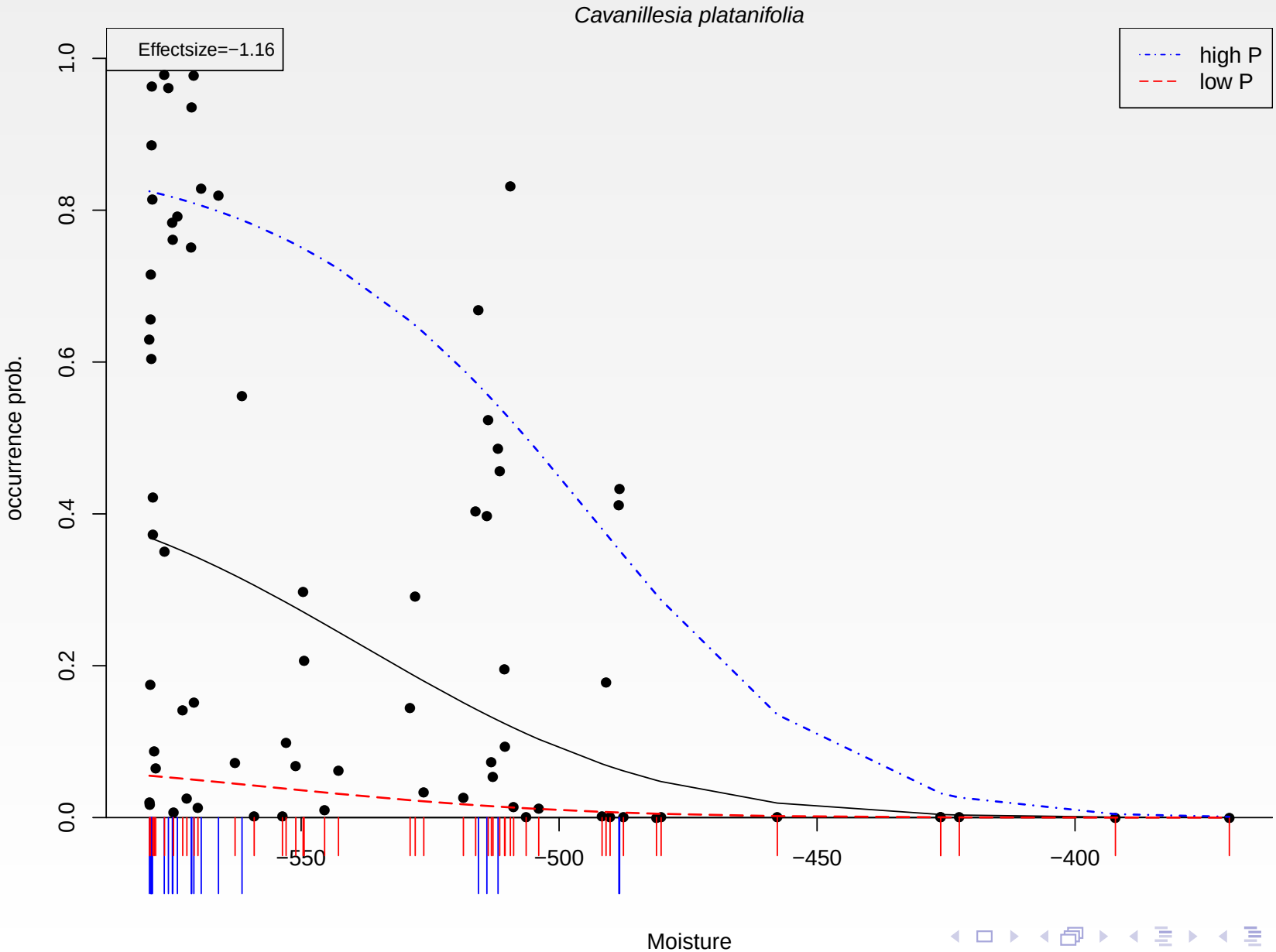
Logistic Model Isolating Drought (Phosphorus) Response



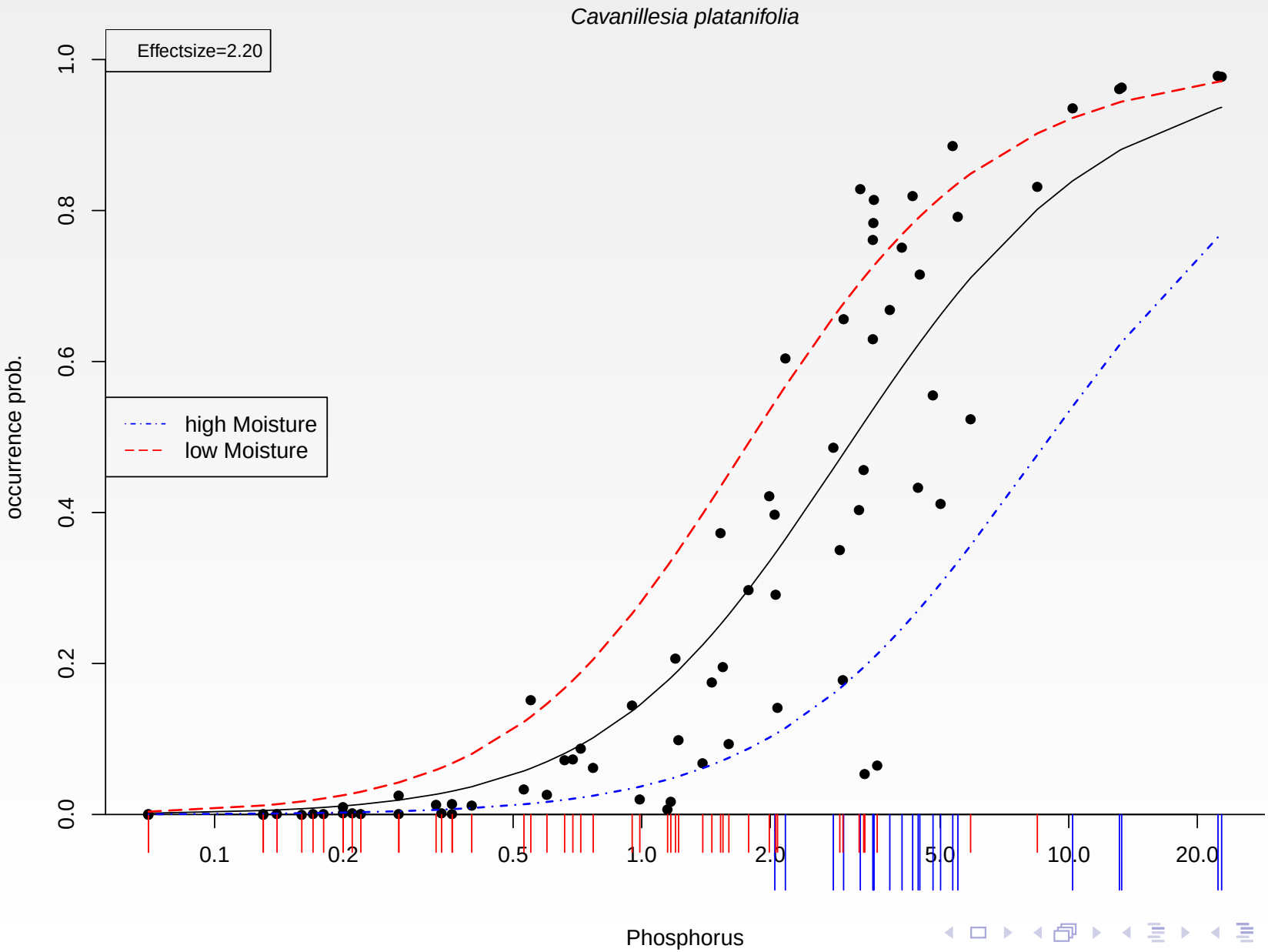
Logistic Model Isolating Drought (Phosphorus) Response



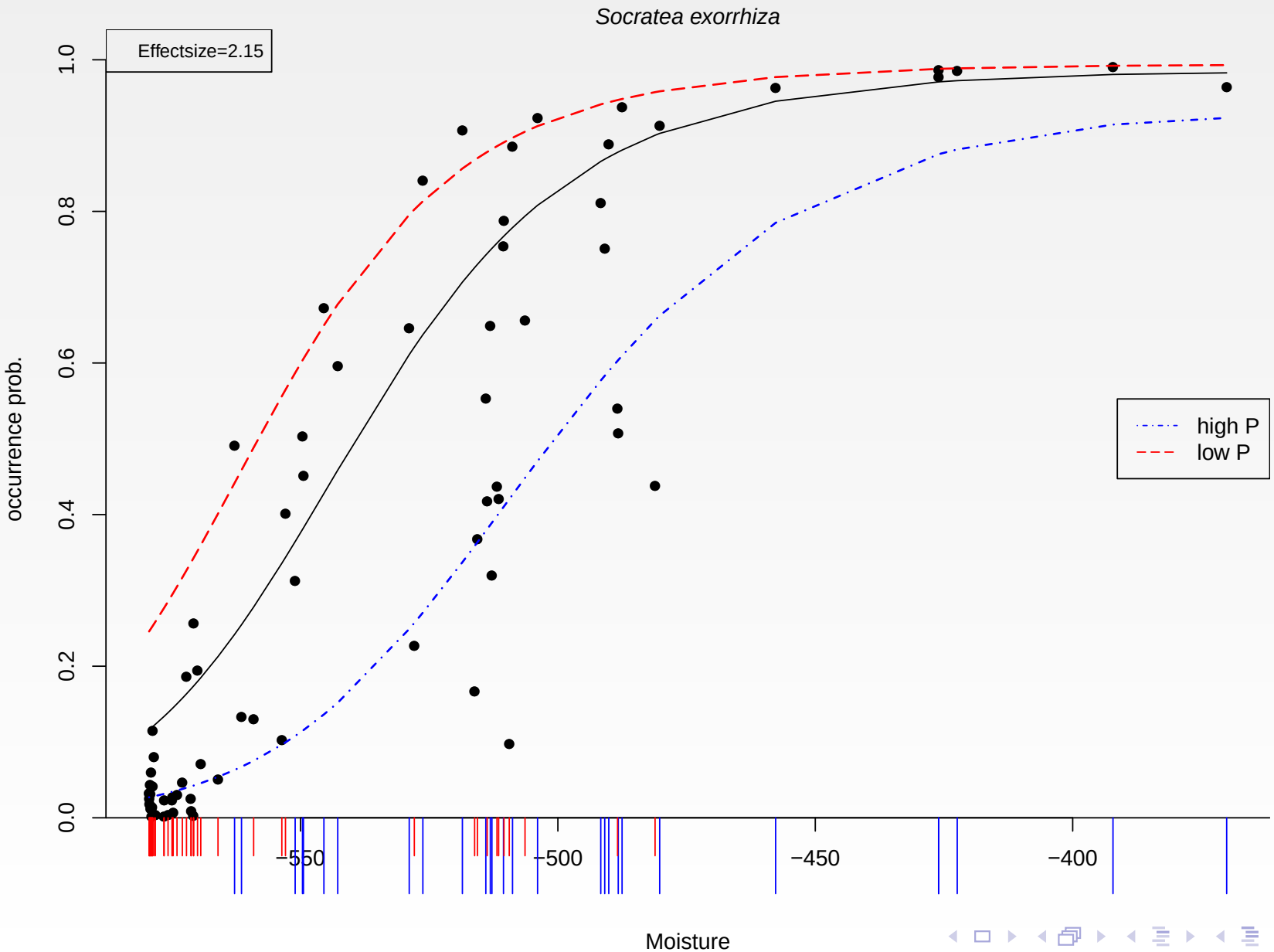
Logistic Model Isolating Drought (Phosphorus) Response



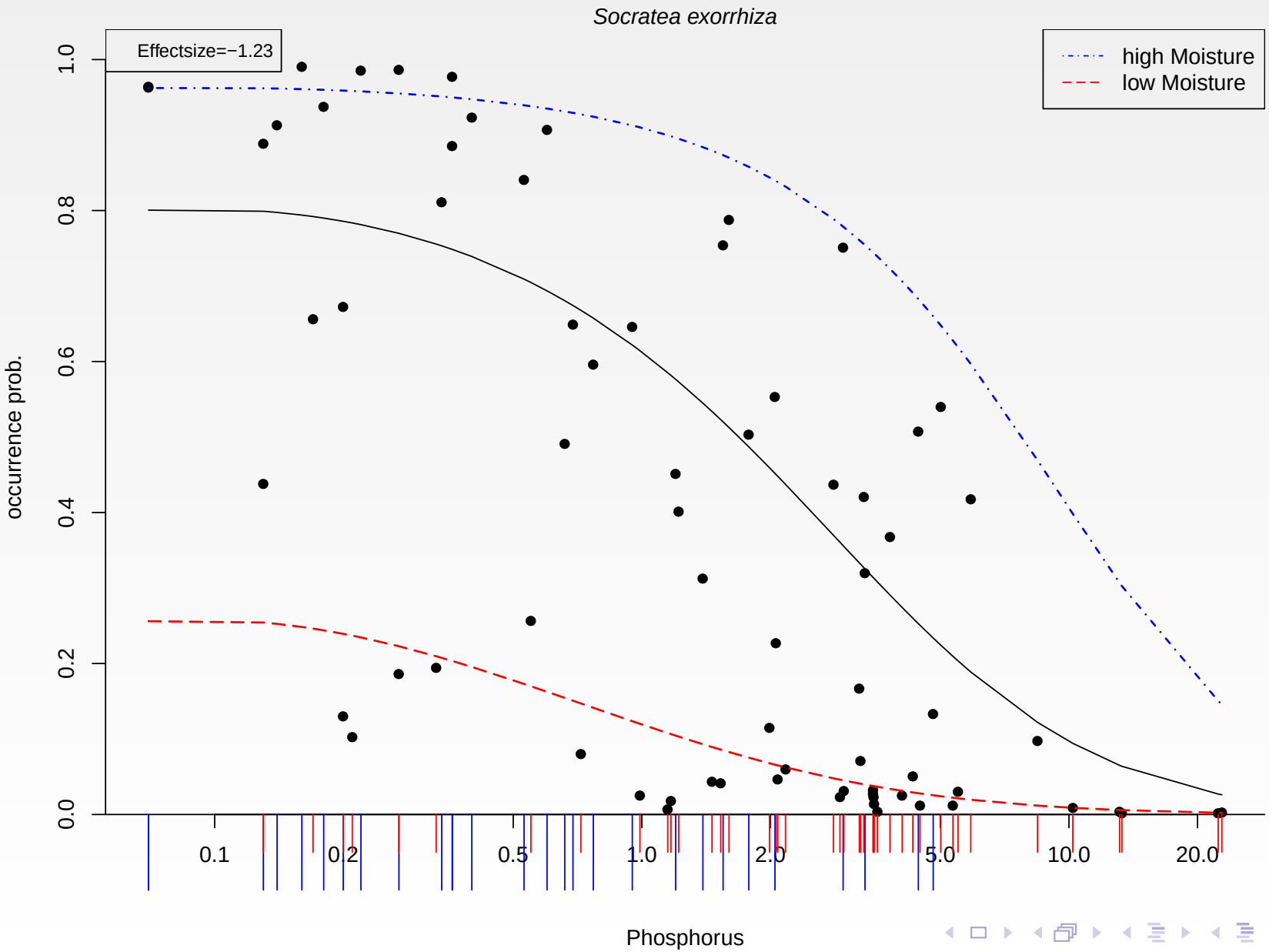
Logistic Model Isolating Drought (Phosphorus) Response



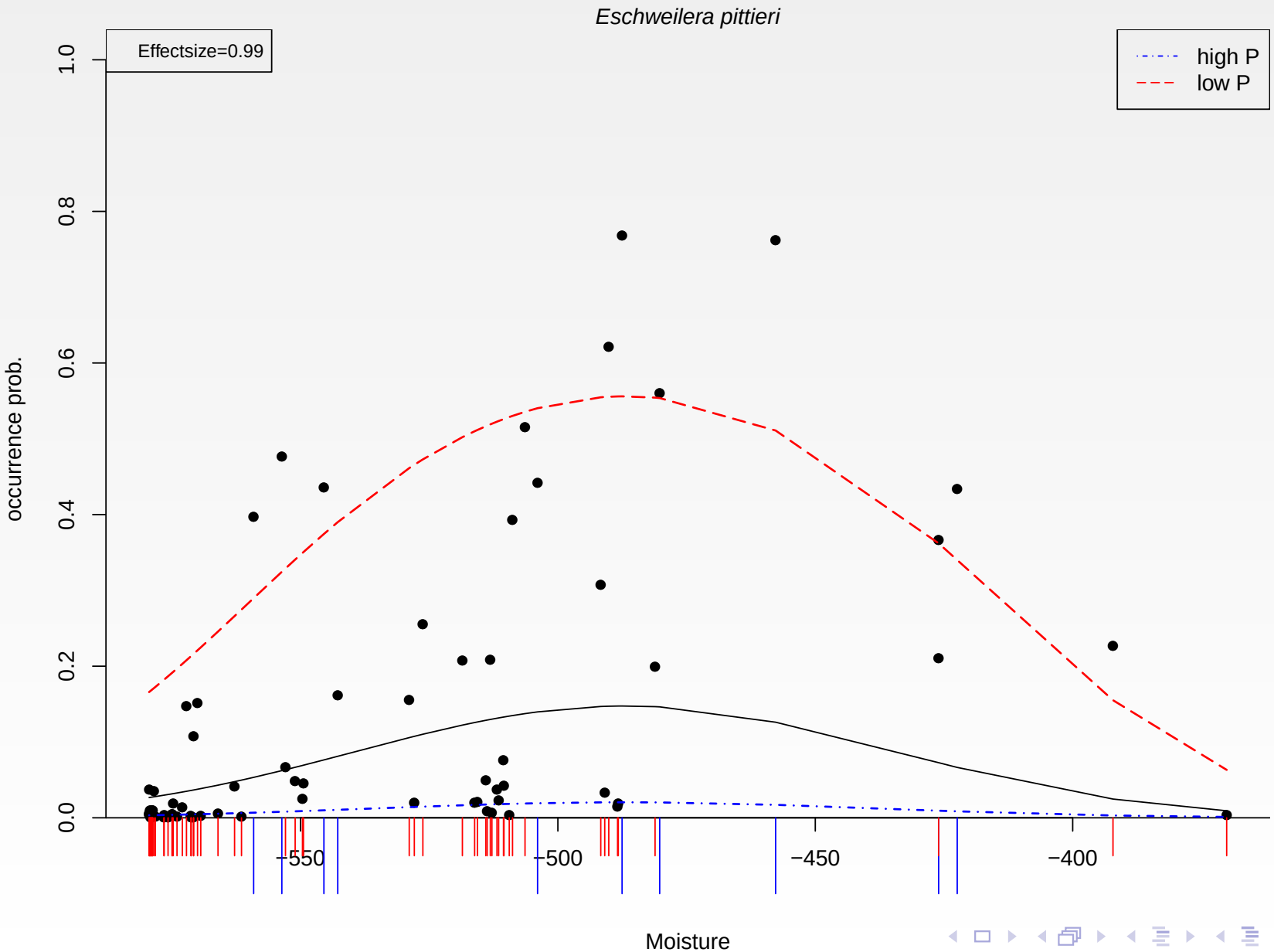
Logistic Model Isolating Drought (Phosphorus) Response



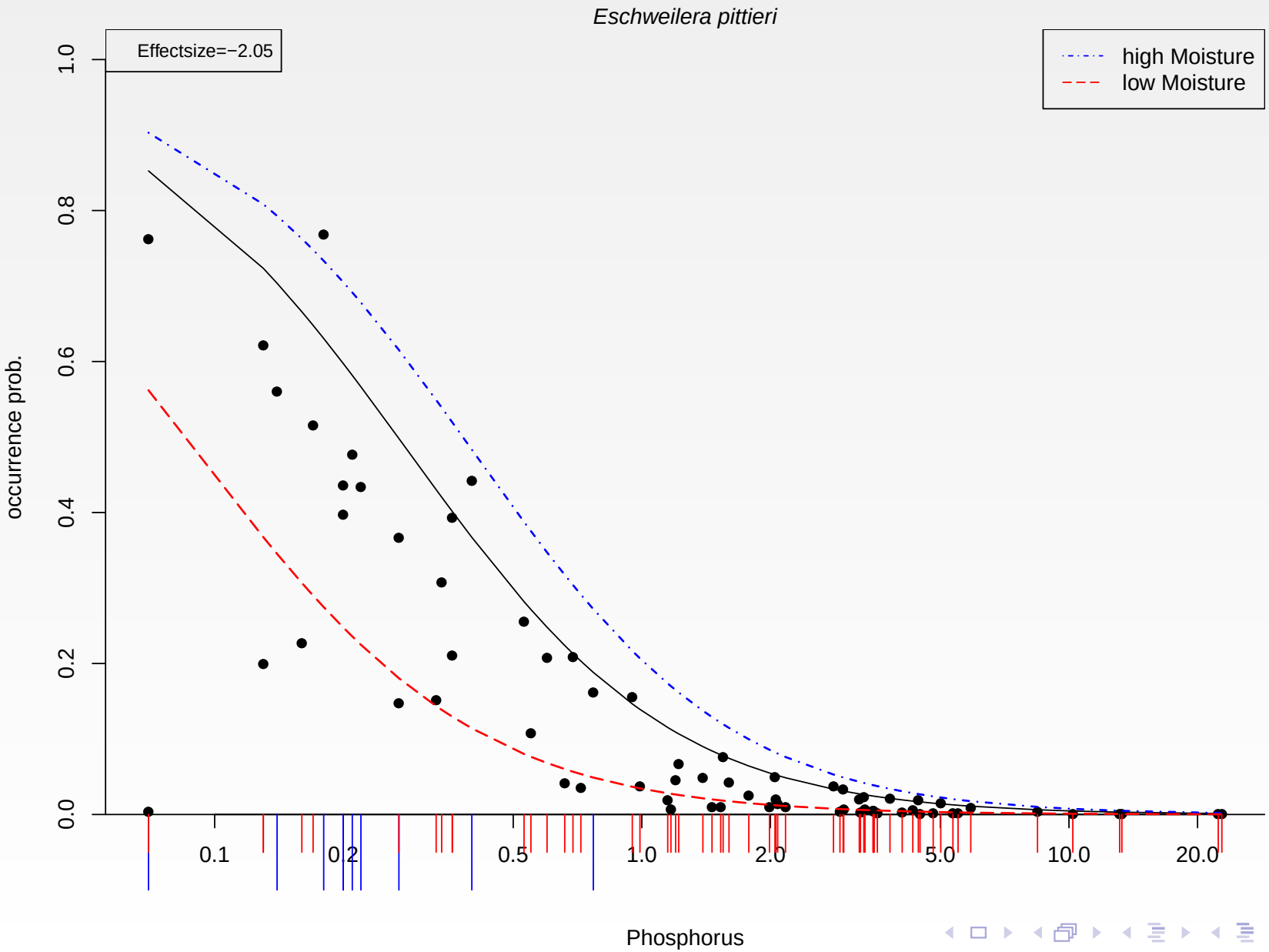
Logistic Model Isolating Drought (Phosphorus) Response



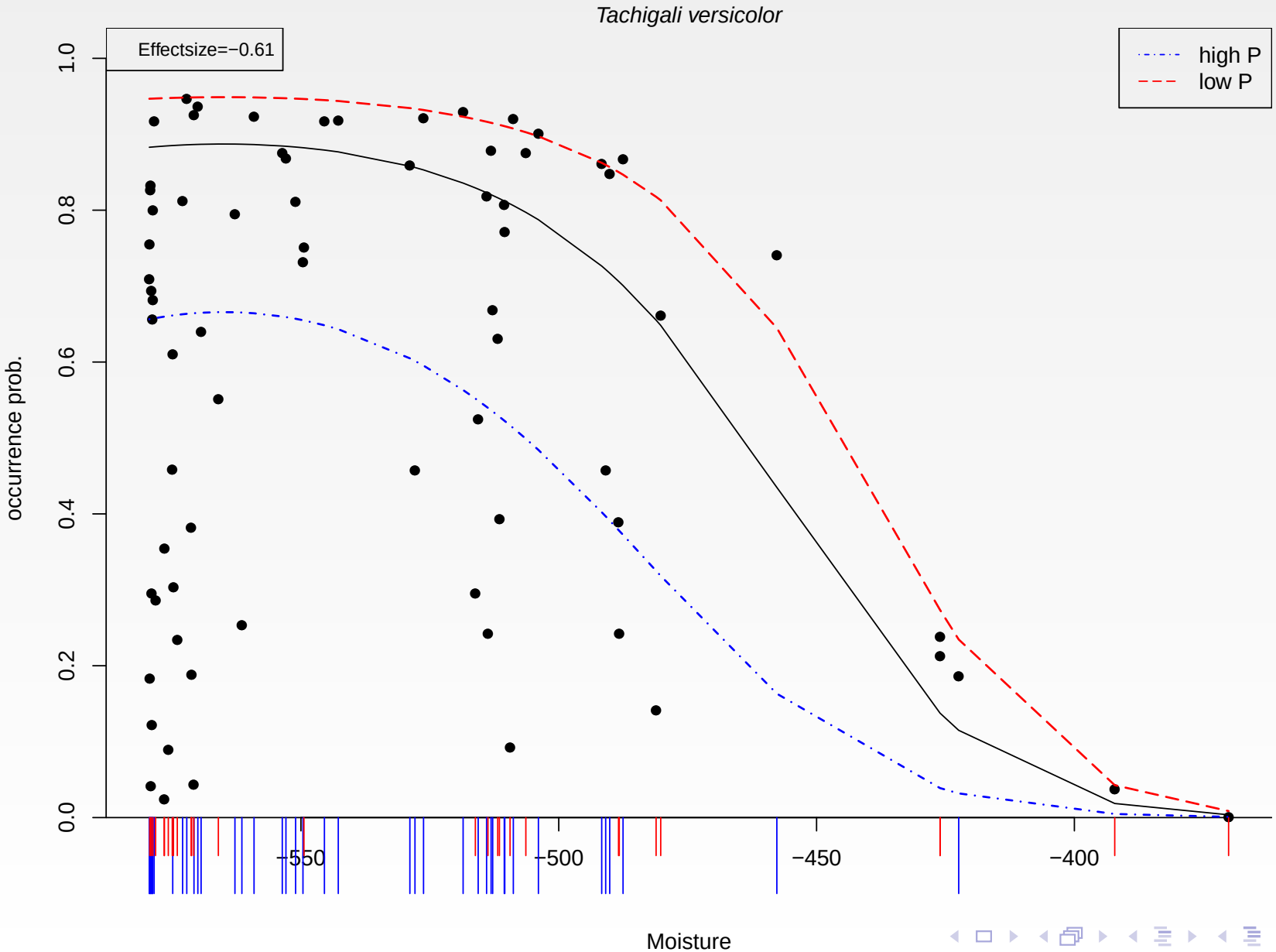
Logistic Model Isolating Drought (Phosphorus) Response



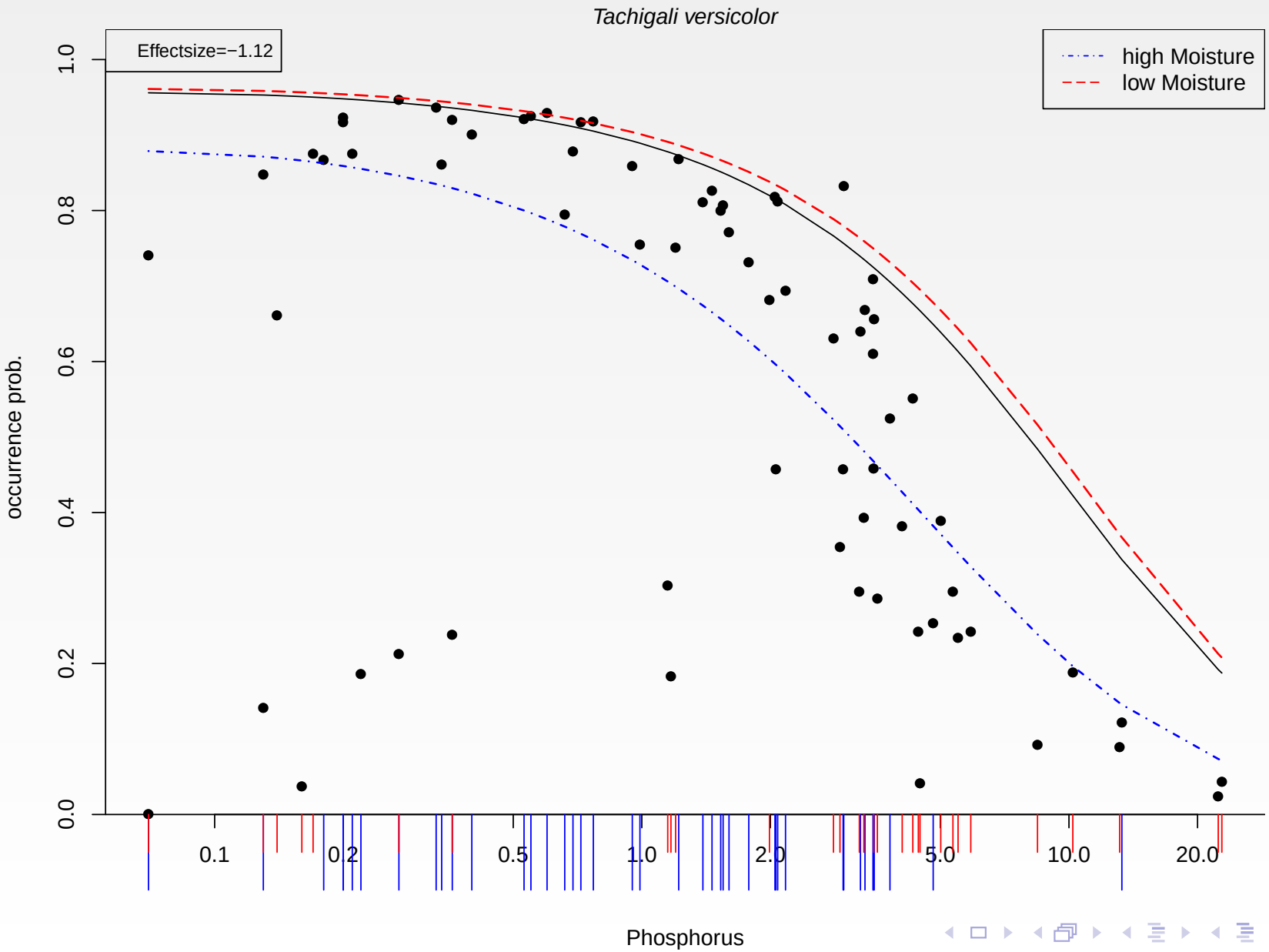
Logistic Model Isolating Drought (Phosphorus) Response



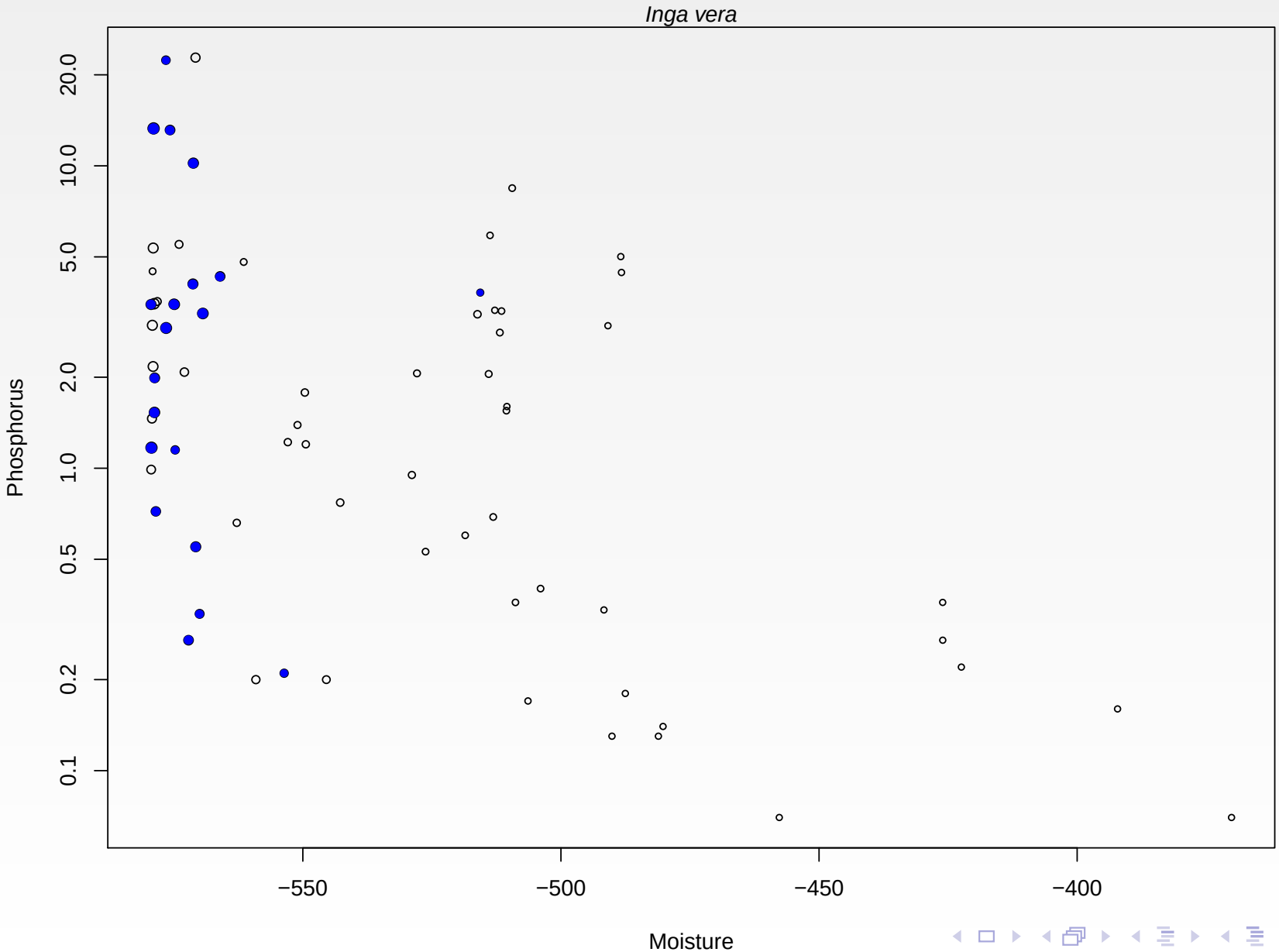
Logistic Model Isolating Drought (Phosphorus) Response



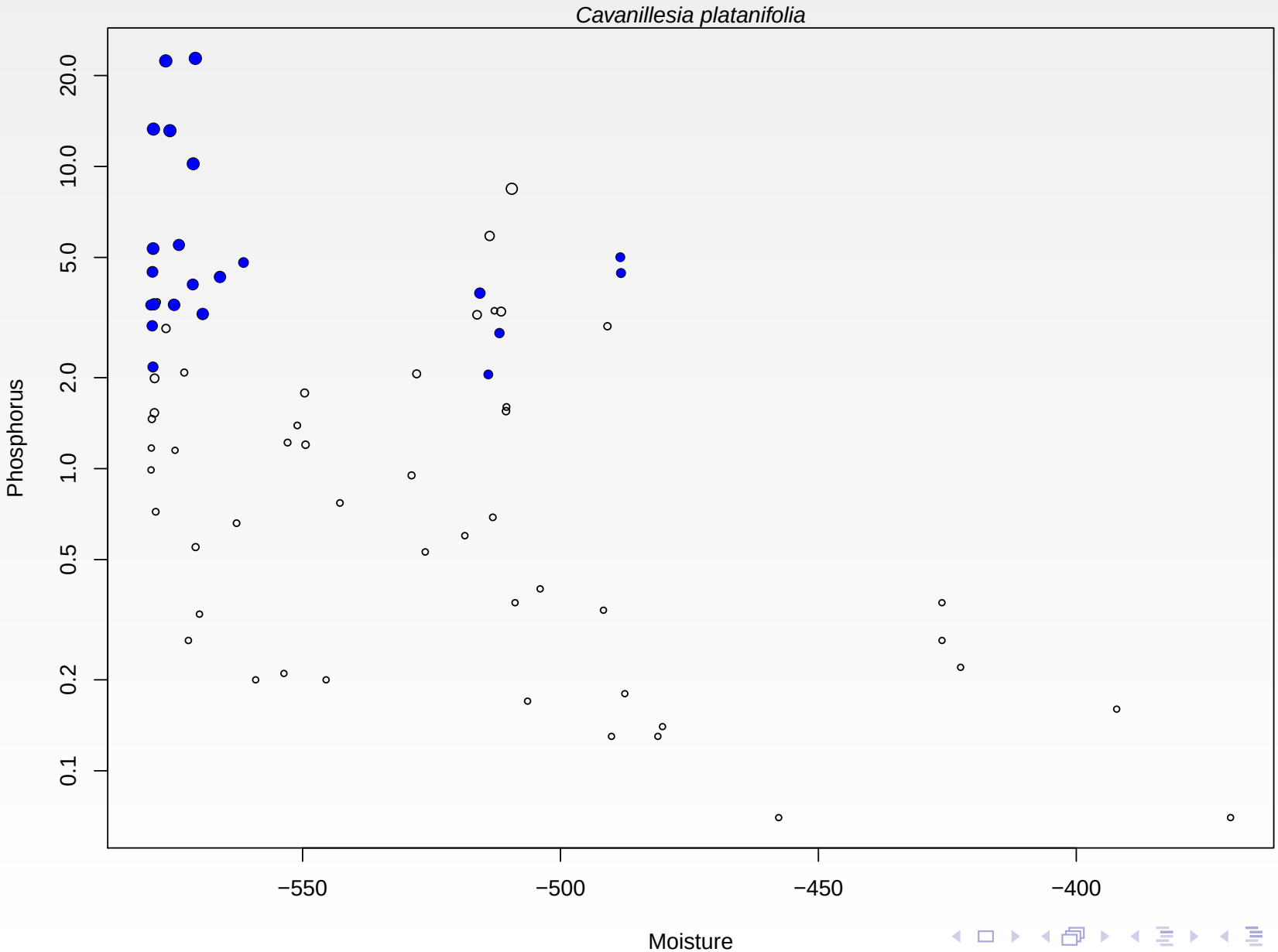
Logistic Model Isolating Drought (Phosphorus) Response



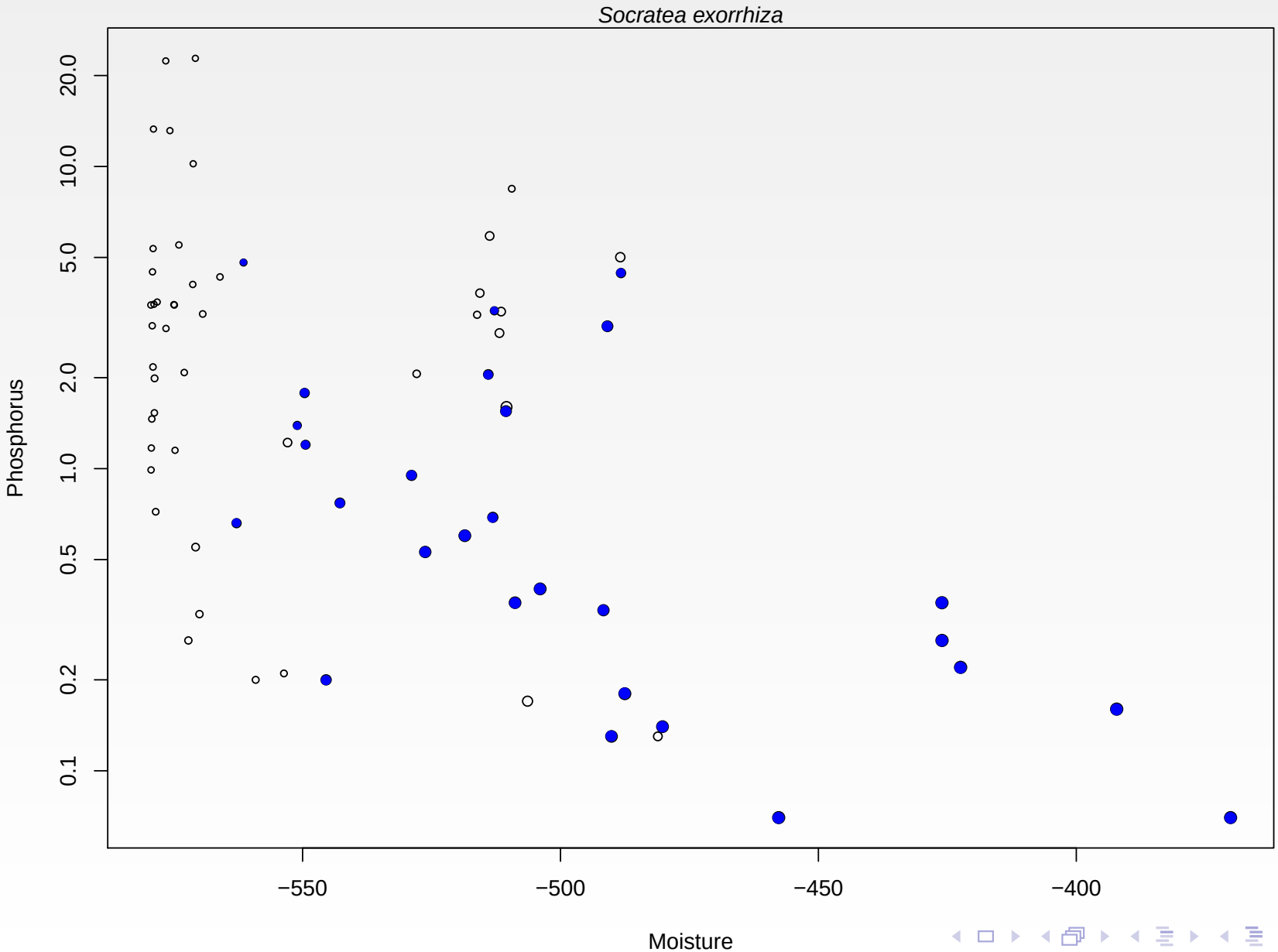
Phosphorus-Moisture Relation



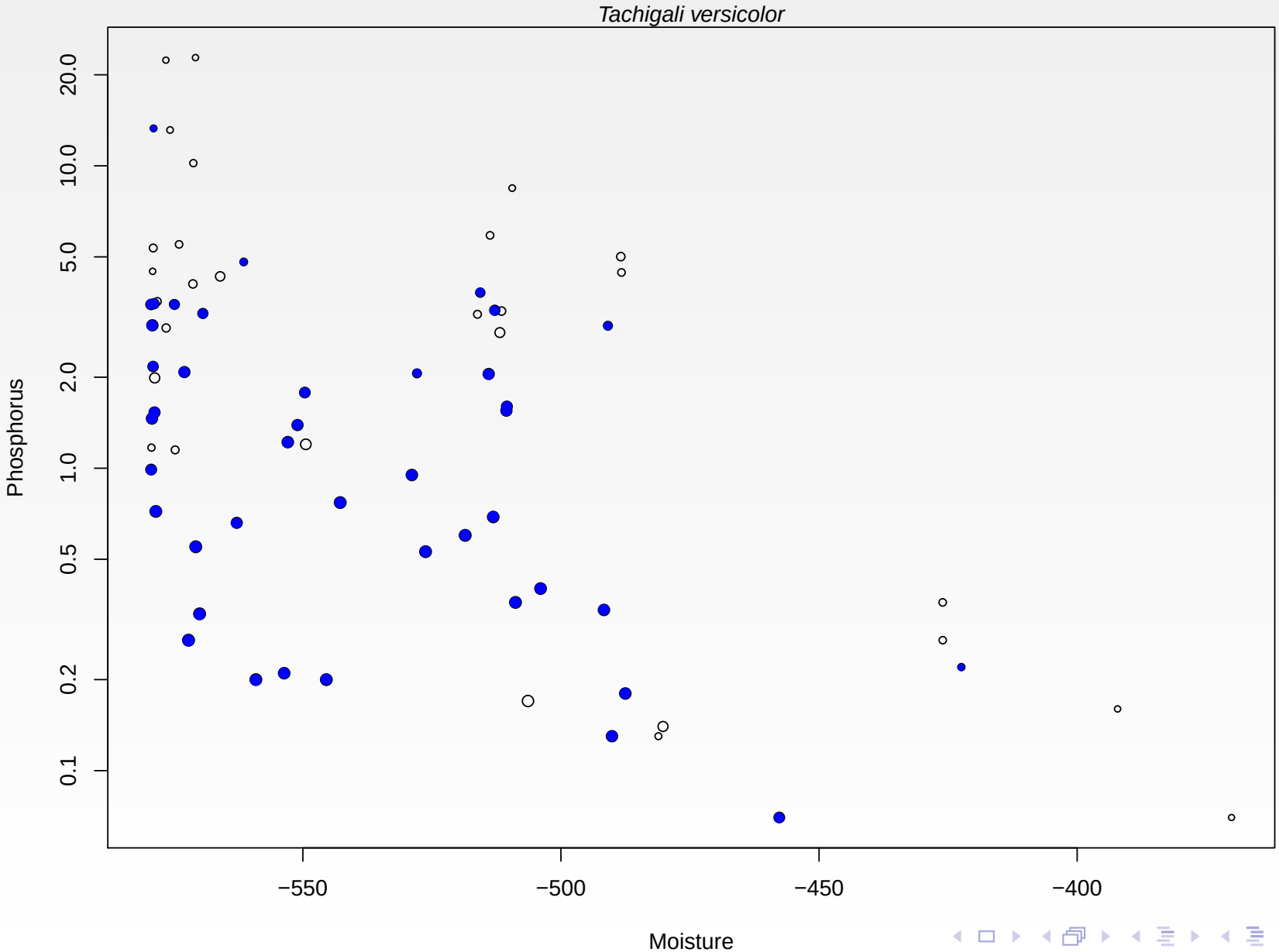
Phosphorus-Moisture Relation



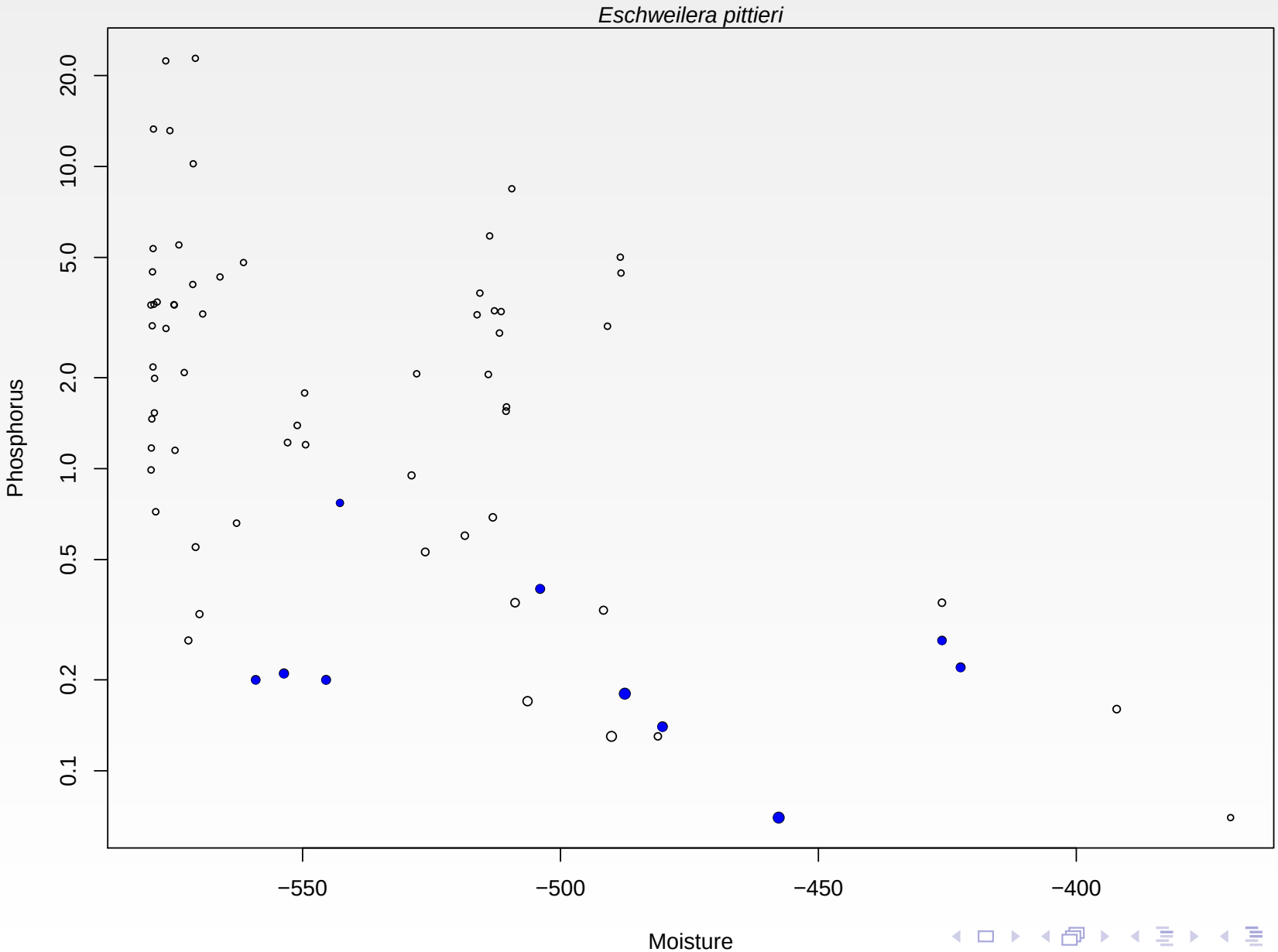
Phosphorus-Moisture Relation



Phosphorus-Moisture Relation



Phosphorus-Moisture Relation



Multi-level regression modeling

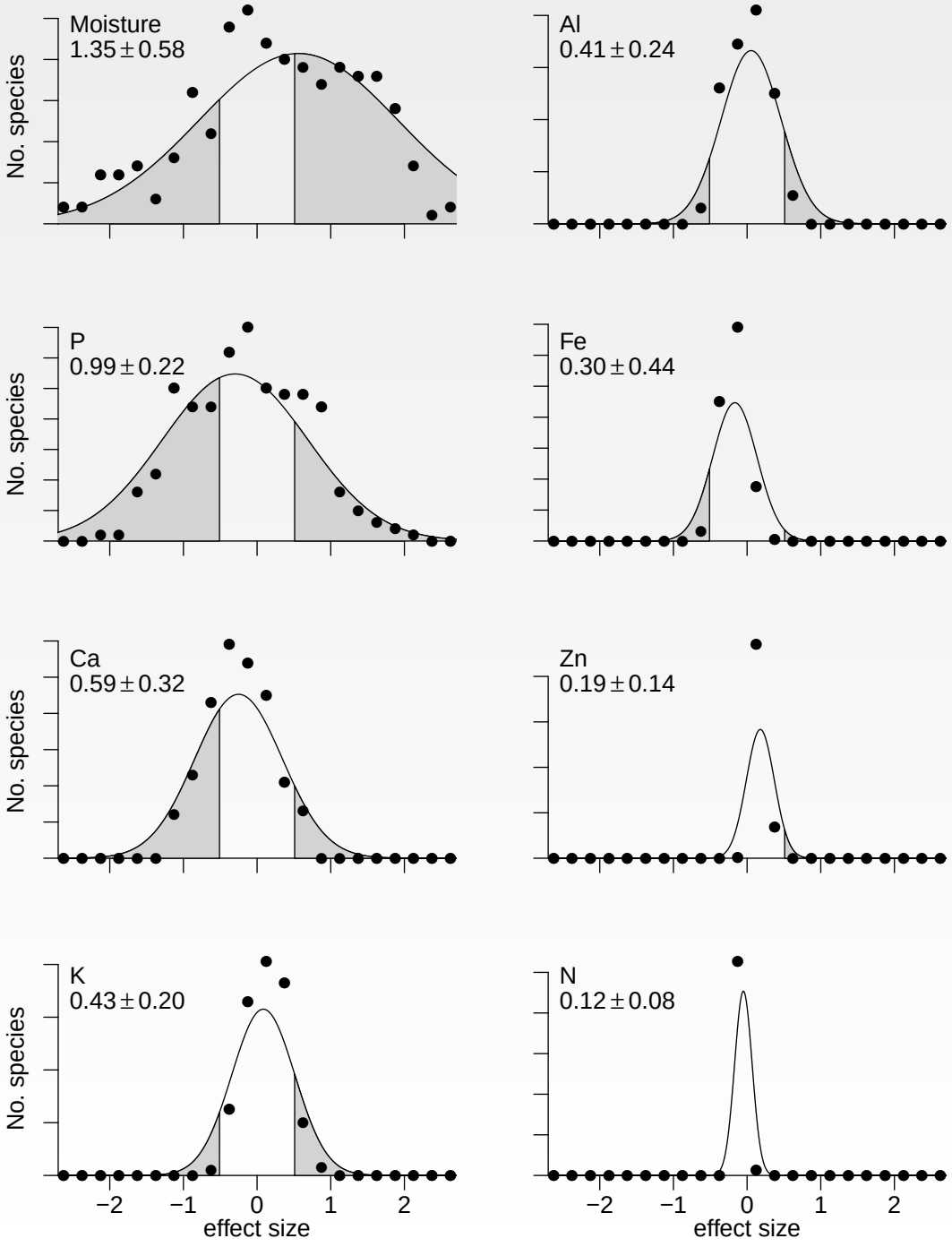
- 569 species' regressions fitted simultaneously
- An overarching Gaussian distribution describes the 569 response parameters (for each resource)
- (Bayesian terminology) The histogram of species responses is a prior for each species

Multi-level regression modeling

- 569 species' regressions fitted simultaneously
- An overarching Gaussian distribution describes the 569 response parameters (for each resource)
- (Bayesian terminology) The histogram of species responses is a prior for each species
- Crucial advantages

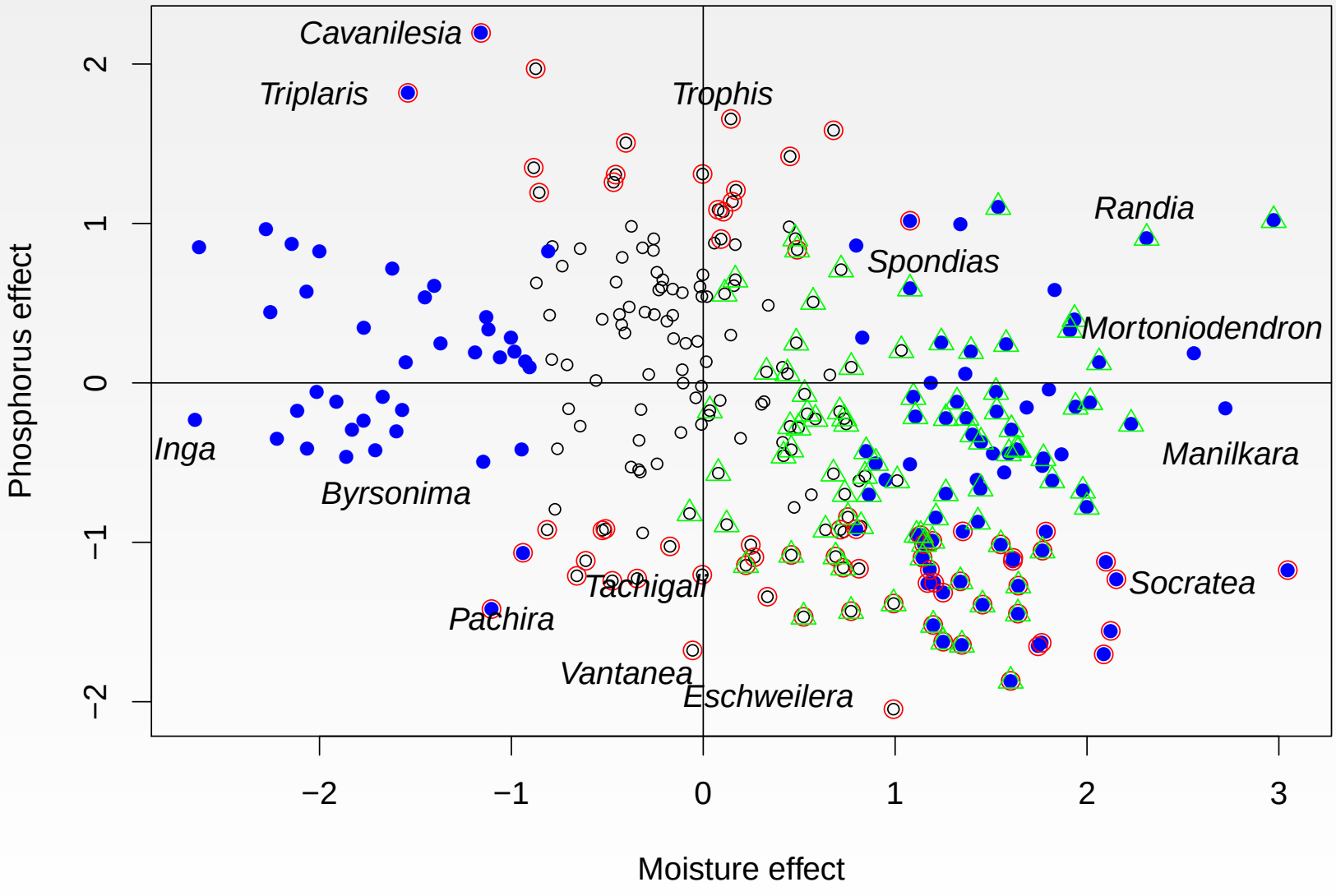
Multi-level regression modeling

- 569 species' regressions fitted simultaneously
- An overarching Gaussian distribution describes the 569 response parameters (for each resource)
- (Bayesian terminology) The histogram of species responses is a prior for each species
- Crucial advantages
  - Prevents overfitting of rare species (reins in outliers)
  - Produces results for species and entire community at once
  - Removes false positives
  - Independent regressions failed for many species
  - Removes need for artificial axes of species composition

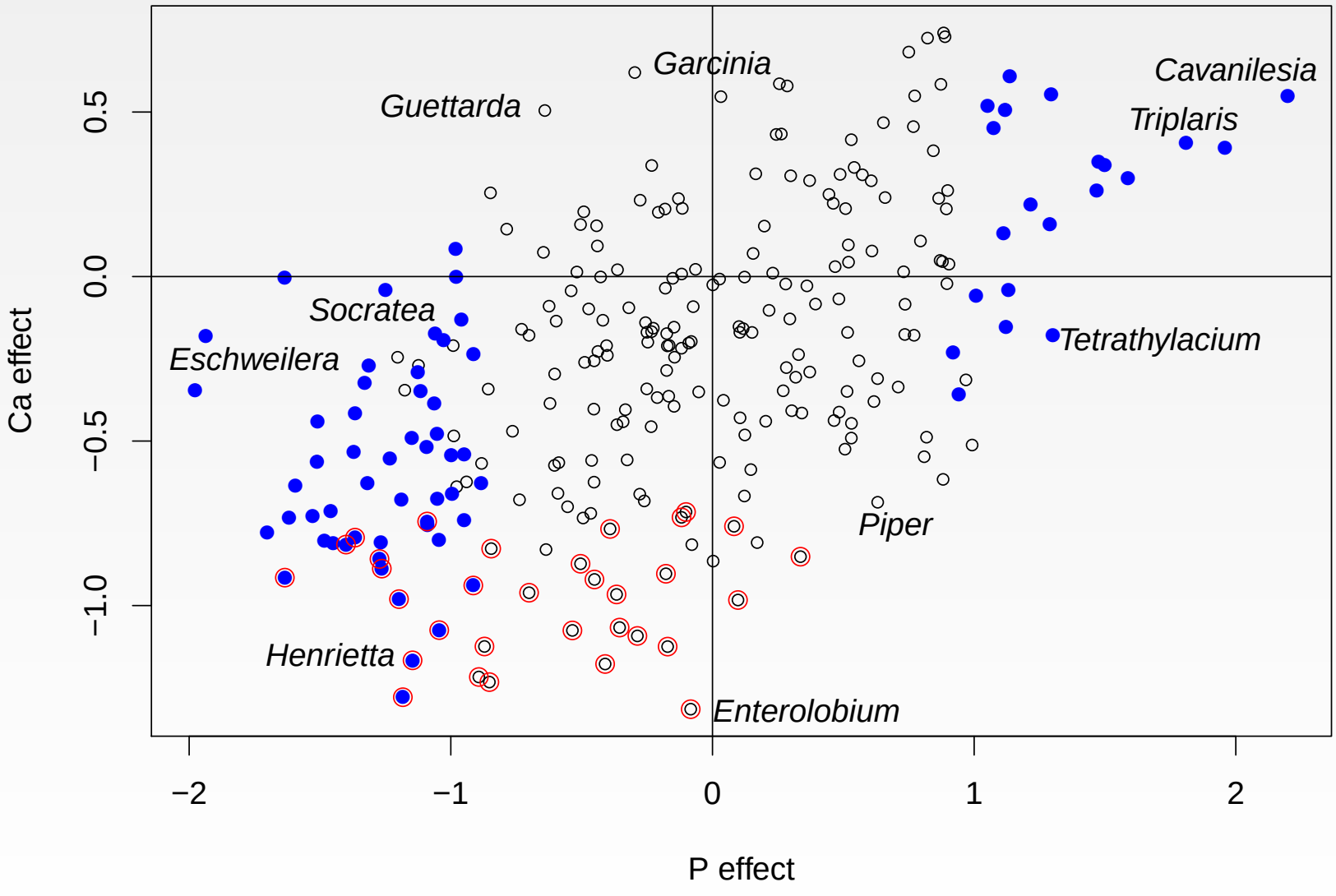


Community-wide response as histogram of 569 individual species' responses

Bivariate Responses, Moisture and P



Bivariate Responses, Ca and P



Conclusions

1. Dry season intensity is the strongest predictor of species occurrence

Conclusions

1. Dry season intensity is the strongest predictor of species occurrence
2. Phosphorus is nearly as important

Conclusions

1. Dry season intensity is the strongest predictor of species occurrence
2. Phosphorus is nearly as important
    - Both P avoiders and P demanders
    - Deciduous species require high P

Conclusions

1. Dry season intensity is the strongest predictor of species occurrence
2. Phosphorus is nearly as important
   - Both P avoiders and P demanders
   - Deciduous species require high P
3. Moisture and nutrients limit species, not the forest

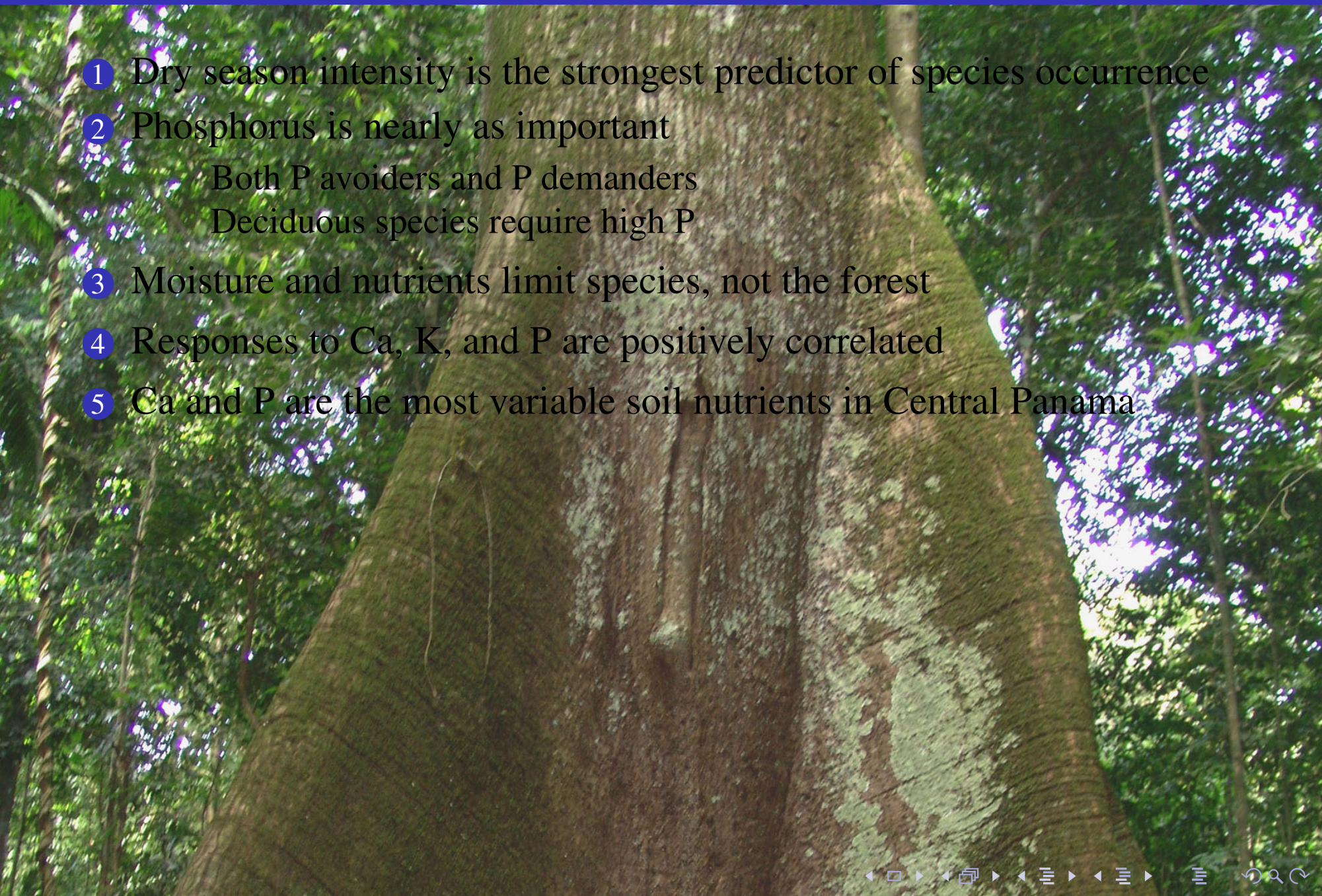
Conclusions

1. Dry season intensity is the strongest predictor of species occurrence
2. Phosphorus is nearly as important
   - Both P avoiders and P demanders
   - Deciduous species require high P
3. Moisture and nutrients limit species, not the forest
4. Responses to Ca, K, and P are positively correlated

Conclusions

1. Dry season intensity is the strongest predictor of species occurrence
2. Phosphorus is nearly as important
   - Both P avoiders and P demanders
   - Deciduous species require high P
3. Moisture and nutrients limit species, not the forest
4. Responses to Ca, K, and P are positively correlated
5. Ca and P are the most variable soil nutrients in Central Panama

Conclusions



1. Dry season intensity is the strongest predictor of species occurrence
2. Phosphorus is nearly as important
   - Both P avoiders and P demanders
     - Deciduous species require high P
3. Moisture and nutrients limit species, not the forest
4. Responses to Ca, K, and P are positively correlated
5. Ca and P are the most variable soil nutrients in Central Panama