# ANALYZING REFORESTATION STRATEGIES

By Zachary Stein

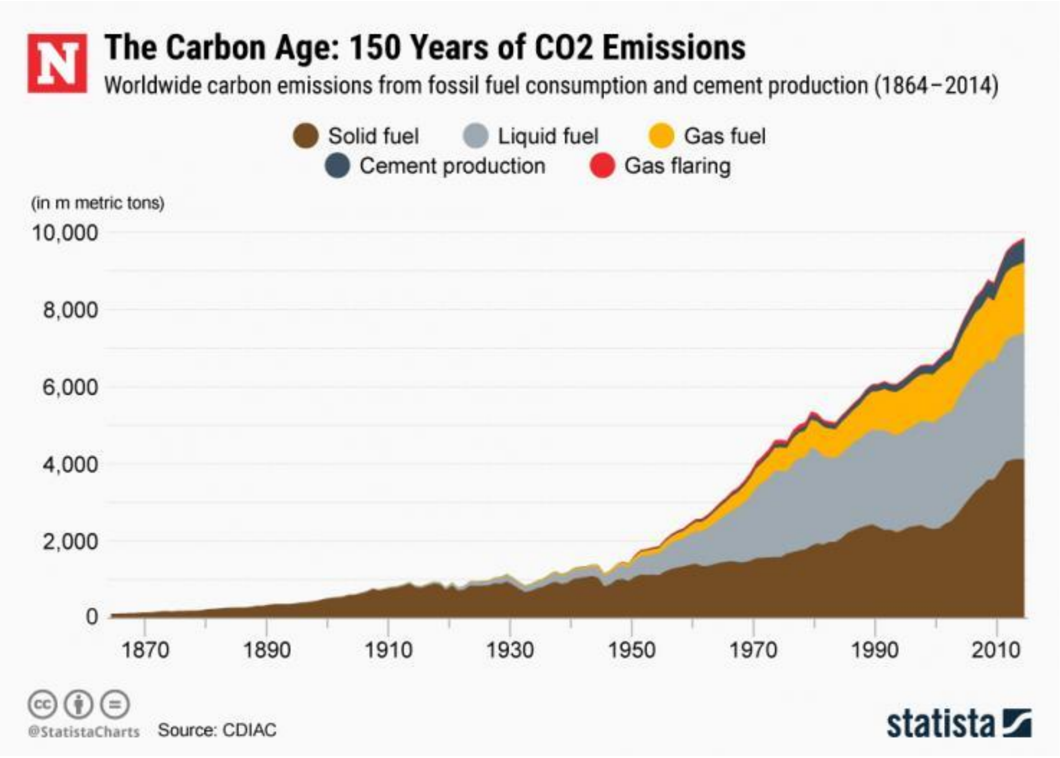
# DEALING WITH CLIMATE CHANGE

- As the amount of greenhouse gases increase in the atmosphere, we are dealing with changing weather.
- This creates economic hardship for people.
- Most of the greenhouse gases are carbon dioxide (Others are methane, nitrous oxide, and water).
- Carbon dioxide is released into the atmosphere from burning fossil fuels.
  - Coal, gasoline, diesel, kerosene, LPG.
- What can we do?

# OBVIOUS SOLUTIONS

- The amount of $CO_2$ released into the atmosphere is exponential.
- We need to reduce the amount of $CO_2$ released into the atmosphere.
- However, this is not easy.
- What can we do?

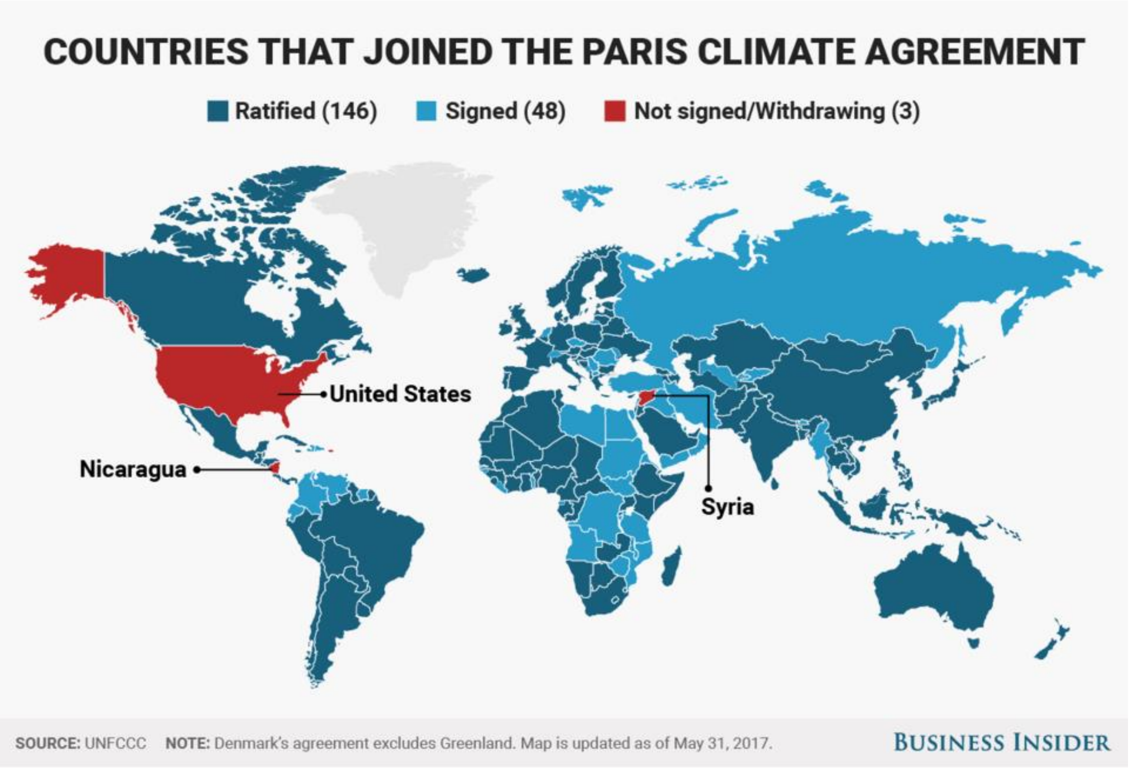
[1]



# CLIMATE AGREEMENTS

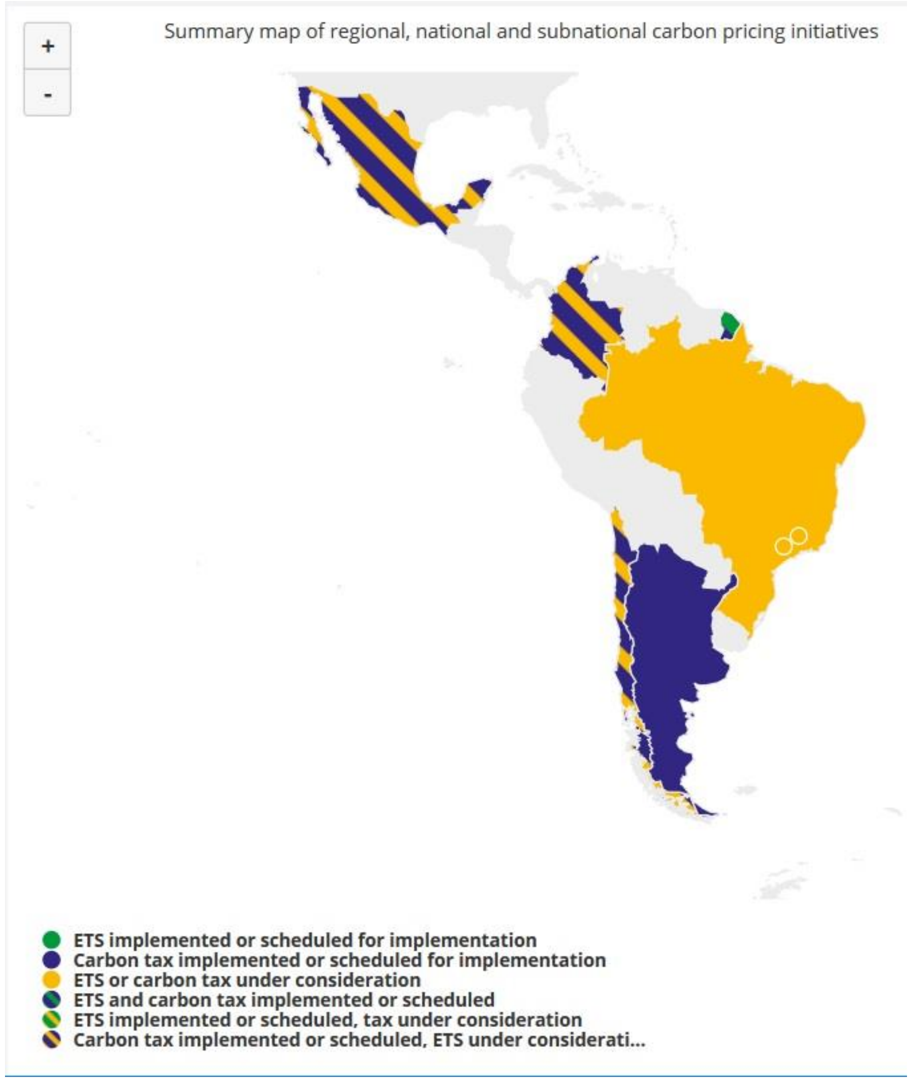
- Multiple international agreements have been signed in order to reduce greenhouse gas emissions.
- Some examples:
  - Kyoto Protocol (1997)
  - Paris Agreement (2016)

[2]



# CARBON TAXES

- One way to reduce carbon taxes is to tax the sources of emissions.
- In my work at the WRI and Climate institute, I have been looking at carbon taxes in Latin America.
- Many of them tax various sources of $CO_2$.
  - This way, greenhouse gas emissions are decreased, or increase at a slower rate.
  - Also, some want to promote renewable sources of energy.



# REFORESTATION

- An alternative to reducing carbon emissions is capturing carbon from the atmosphere.
- One of the best ways to do this is through reforestation.
- Besides capturing $CO_2$, there are other environmental benefits to reforestation.
  - Reduced flooding and soil erosion.
- So, what is the best reforestation strategy?

# GOALS

- What mix of species is best for creating a mixed ecosystem? Is there a range for each species that works well?
- We have to keep in mind that with an initial seeding or planting, some species might end up dying while others will thrive. This will result in a change to the mix of the ecosystems. If this happens, will the reforested area become a problem area?
- Can we also determine which species are important for the success of a reforestation effort?

# INITIAL DATA

| PLANTATIONS & WOODLOTS (0-20y rate, tC/ha/y) | | | | | | NATURAL REGENERATION | | MANGROVE TREE RESTORATION | | MANGROVE SHRUB RESTORATION | | AGROFORESTRY | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| teak | eucalyptus | other broadleaf | oak | pine | other conifer | 0-20y rate, tC/ha/y | 20-60y rate, tC/ha/y | 0-20y rate, tC/ha/y | 20-60y rate, tC/ha/y | 0-20y rate, tC/ha/y | 20-60y rate, tC/ha/y | 0-20y rate, tC/ha/y | 20-60y rate, tC/ha/y |
| 8.4 | 11.1 | 6.9 | 5 | 5.7 | 5.9 | 5.1 | 1.4 | 2 | 2.9 | 0.3 | 0.5 | 4.2 | 0.2 |
| 8.4 | 11.1 | 6.9 | 5 | 5.7 | 5.9 | 5.1 | 1.4 | N/A | N/A | N/A | N/A | 4.2 | 0.2 |
| 8.4 | 11.1 | 6.9 | 5 | 5.7 | 5.9 | 5.1 | 1.4 | 2 | 2.9 | 0.3 | 0.5 | 4.2 | 0.2 |
| 8.4 | 11.1 | 6.9 | 5 | 5.7 | 5.9 | 5.1 | 1.4 | N/A | N/A | N/A | N/A | 4.2 | 0.2 |
| 8.4 | 11.1 | 6.9 | 5 | 5.7 | 5.9 | 5.1 | 1.4 | N/A | N/A | N/A | N/A | 4.2 | 0.2 |
| 8.4 | 11.1 | 6.9 | 5 | 5.7 | 5.9 | 5.1 | 1.4 | N/A | N/A | N/A | N/A | 4.2 | 0.2 |
| 8.4 | 11.1 | 6.9 | 5 | 5.7 | 5.9 | 5.1 | 1.4 | 2 | 2.9 | 0.3 | 0.5 | 4.2 | 0.2 |
| N/A | 10.3 | 3.2 | 2.6 | 5.8 | 3.2 | 5.1 | 1.4 | N/A | N/A | N/A | N/A | 4.2 | 0.2 |
| 8.4 | 11.1 | 6.9 | 5 | 5.7 | 5.9 | 5.1 | 1.4 | 2 | 2.9 | 0.3 | 0.5 | 4.2 | 0.2 |
| 8.4 | 11.1 | 6.9 | 5 | 5.7 | 5.9 | 5.1 | 1.4 | N/A | N/A | N/A | N/A | 4.2 | 0.2 |
| 8.4 | 11.1 | 6.9 | 5 | 5.7 | 5.9 | 5.1 | 1.4 | N/A | N/A | N/A | N/A | 4.2 | 0.2 |
| 8.4 | 11.1 | 6.9 | 5 | 5.7 | 5.9 | 5.1 | 1.4 | N/A | N/A | N/A | N/A | 4.2 | 0.2 |
| N/A | 10.3 | 3.2 | 2.6 | 5.8 | 3.2 | 5.1 | 1.4 | N/A | N/A | N/A | N/A | 4.2 | 0.2 |
| N/A | 10.3 | 3.2 | 2.6 | 5.8 | 3.2 | 5.1 | 1.4 | N/A | N/A | N/A | N/A | 4.2 | 0.2 |
| 8.4 | 11.1 | 6.9 | 5 | 5.7 | 5.9 | 5.1 | 1.4 | 2 | 2.9 | 0.3 | 0.5 | 4.2 | 0.2 |
| 8.4 | 11.1 | 6.9 | 5 | 5.7 | 5.9 | 5.1 | 1.4 | 2 | 2.9 | 0.3 | 0.5 | 4.2 | 0.2 |
| 8.4 | 11.1 | 6.9 | 5 | 5.7 | 5.9 | 5.1 | 1.4 | N/A | N/A | N/A | N/A | 4.2 | 0.2 |

# TEST DATA

| | A | B | C | D | E | F | G | H | I | J | K | L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | Teak | Eucalyptus | Oak | Pine | Other_Conifers | Mangrove_Tree | Mangrove_Shrub | ha | SWater | FWater | Years |
| 2 | Carbon_Absorption | 8.4 | 11.1 | 5 | 5 | 5.9 | 2 | 0.3 | 5000 | 0.11 | 0.05 | 20 |
| 3 | Min_Per | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | | | | | | |
| 4 | Max_Per | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | | | | | | |
| 5 | Low_Cutoff | 0.02 | 0.05 | 0.03 | 0.07 | 0.07 | | | | | | |
| 6 | High_Cutoff | 0.19 | 0.11 | 0.12 | 0.18 | 0.18 | | | | | | |
| 7 | | | | | | | | | | | | |

# CHOOSE AND CALCULATE

| | Teak | Eucalyptus | Oak | Pine | Other_Conifers | Mangrove_Tree | Mangrove_Shrub | ha | SWater | FWater | Years |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Carbon_Absorption | 8.4 | 11.1 | 5 | 5 | 5.9 | 2 | 0.3 | 5000 | 0.11 | 0.05 | 20 |
| Min_Per | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | | | | | | |
| Max_Per | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | | | | | | |
| Low_Cutoff | 0.02 | 0.05 | 0.03 | 0.07 | 0.07 | | | | | | |
| High_Cutoff | 0.19 | 0.11 | 0.12 | 0.18 | 0.18 | | | | | | |

Use Min_Per and Max_Per to randomly Choose values. → Use Cutoff to check If it will be viable (0 or 1). → Check if the forest will be viable (Also 0 or 1).

↓

Repeat multiple times and analyze.

# METHODS

- I used R and Bayesian.
- I used MCMC and JAGS for analyzing the data. This produced intercept graphs and ROC curves.
- Also, output is generated for the area covered by each species of tree and whether or not it will be viable.

# R CODE

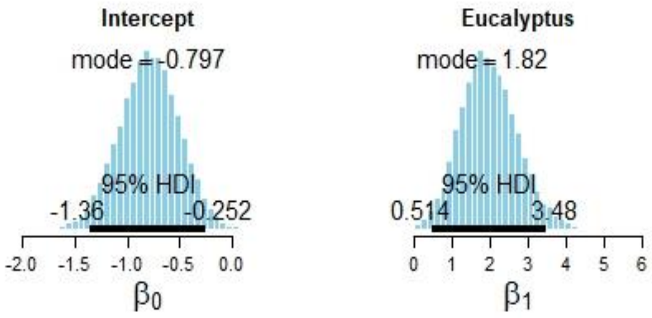
```r
OCArea <- runif(1,treedata$Other_Conifers[2],treedata$Other_Conifers[3])

five_ran <- TArea+EArea+OArea+PArea+OCArea

TArea <- (TArea/five_ran)*Left
EArea <- (EArea/five_ran)*Left
OArea <- (OArea/five_ran)*Left
PArea <- (PArea/five_ran)*Left
OCArea <- (OCArea/five_ran)*Left

    #Calculate if the species is out of the ideal range.
    if (TArea>treedata$Teak[5]){
      TAreacalc = 0
    } else if (TArea<treedata$Teak[4]){
      TAreacalc = 0
    } else {
      TAreacalc = 1
    }

    if (EArea>treedata$Eucalyptus[5]){
      EAreacalc = 0
    } else if (EArea<treedata$Eucalyptus[4]){
      EAreacalc = 0
    } else {
      EAreacalc = 1
    }

    if (OArea>treedata$Oak[5]){
      OAreacalc = 0
    } else if (TArea<treedata$Oak[4]){
      OAreacalc = 0
    } else {
      OAreacalc = 1
    }

    if (PArea>treedata$Pine[5]){
      PAreacalc = 0
    } else if (TArea<treedata$Pine[4]){
      PAreacalc = 0
    } else {
```

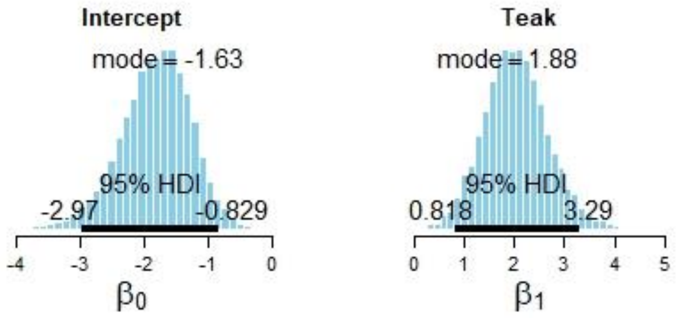
```r
  return(hitRate)
}

for(i in varList){

  yName = "Viable" ; xName = c(i)
  fileNameRoot = "output"
  numSavedSteps=15000 ; thinSteps=2

  mcmcCoda = genMCMC( data=trainData , xName=xName , yName=yName ,
                      numSavedSteps=numSavedSteps , thinSteps=thinSteps ,
                      saveName=fileNameRoot )
  #-------------------------------------------------------------------------------
  # Display diagnostics of chain, for specified parameters:
  parameterNames = varnames(mcmcCoda) # get all parameter names
  for ( parName in parameterNames ) {
    diagMCMC( codaObject=mcmcCoda , parName=parName ,
              saveName=fileNameRoot , saveType=graphFileType )
  }
  #-------------------------------------------------------------------------------
  # Get summary statistics of chain:
  summaryInfo = smryMCMC( mcmcCoda ,
                          saveName=fileNameRoot )
  show(summaryInfo)
  # Display posterior information:
  plotMCMC( mcmcCoda , data=trainData , xName=xName , yName=yName ,
            pairsPlot=TRUE , showCurve=FALSE ,
            saveName=fileNameRoot , saveType=graphFileType )
  #-------------------------------------------------------------------------------

  parameter_file = read.csv(paste0(fileNameRoot,"SummaryInfo.csv"),row.names = 1)

  parameter = parameter_file[1:2,"Mode"]

  hitRates[i] = bayesLog(trainData, testData[[xName]], testData[[yName]], parameter, xName)

}

print(hitRates)
```

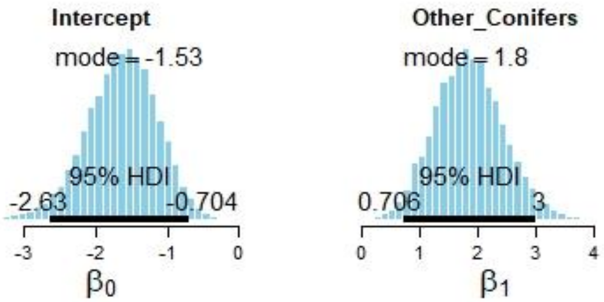
# FIRST TEST DATA SET

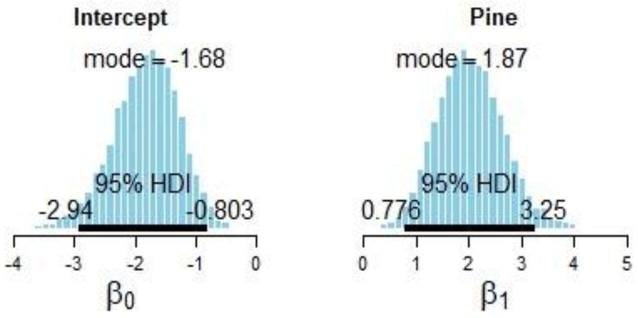
| Input | Teak | Eucalyptus | Oak | Pine | Other_Conifers | SWater | FWater |
|---|---|---|---|---|---|---|---|
| Carbon_Absorption | 8.4 | 11.1 | 5 | 5 | 5.9 | 0.11 | 0.05 |
| Min_Per | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | | |
| Max_Per | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | | |
| Low_Cutoff | 0.02 | 0.05 | 0.03 | 0.07 | 0.07 | | |
| High_Cutoff | 0.19 | 0.11 | 0.12 | 0.18 | 0.18 | | |

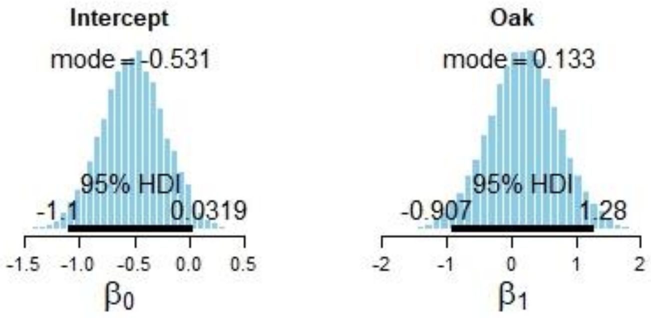
# INTERCEPTS


Intercept
mode = -0.797
95% HDI
-1.36
-0.252
-2.0 -1.5 -1.0 -0.5 0.0
$\beta_0$
Eucalyptus
mode = 1.82
95% HDI
0.514
3.48
0 1 2 3 4 5 6
$\beta_1$

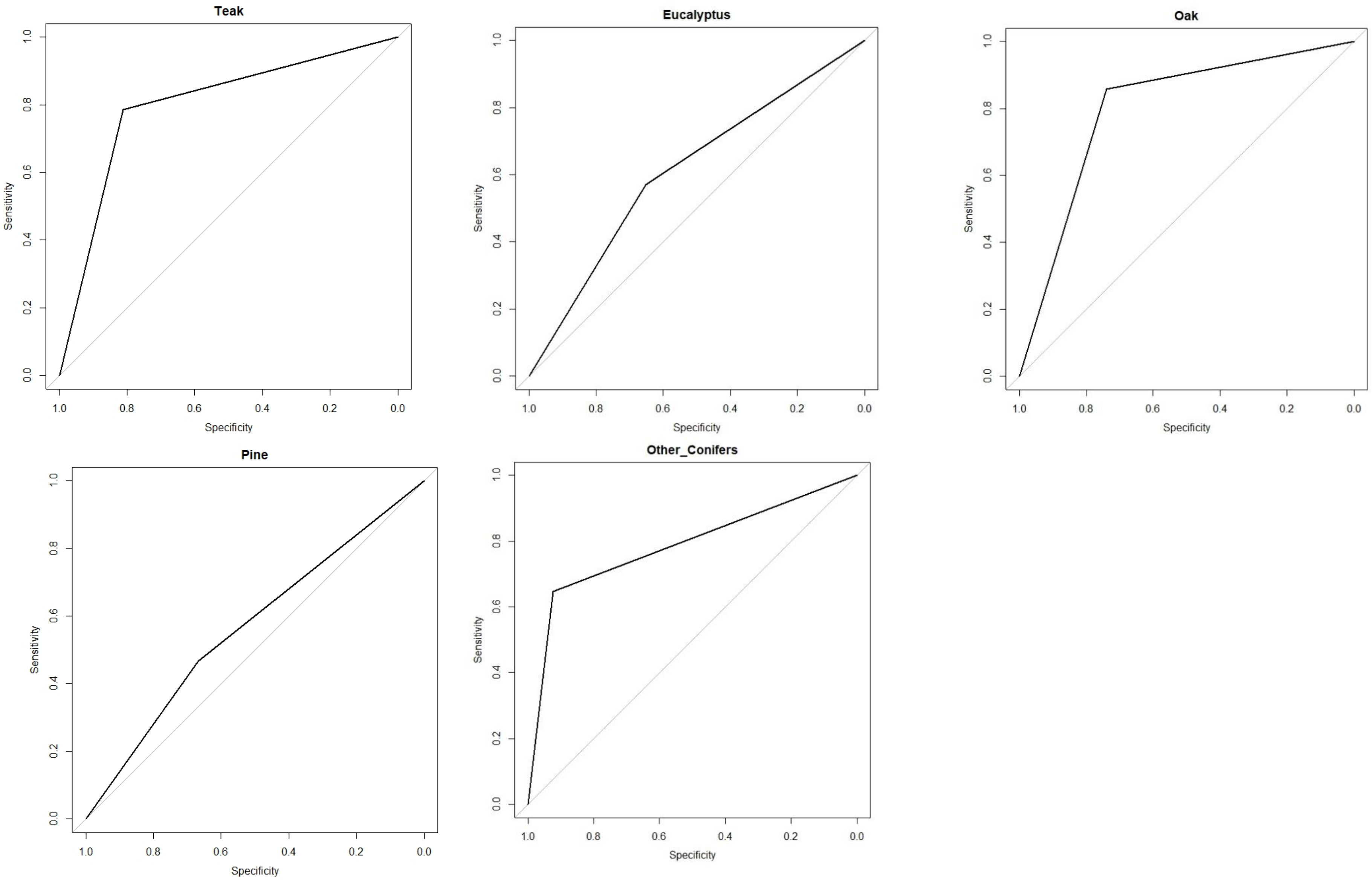

Intercept
mode = -1.63
95% HDI
-2.97
-0.829
-4 -3 -2 -1 0
$\beta_0$
Teak
mode = 1.88
95% HDI
0.818
3.29
0 1 2 3 4 5
$\beta_1$


Intercept
mode = -1.53
95% HDI
-2.63
-0.704
-3 -2 -1 0
$\beta_0$
Other_Conifers
mode = 1.8
95% HDI
0.706
3
0 1 2 3 4
$\beta_1$


Intercept
mode = -1.68
95% HDI
-2.94
-0.803
-4 -3 -2 -1 0
$\beta_0$
Pine
mode = 1.87
95% HDI
0.776
3.25
0 1 2 3 4 5
$\beta_1$


Intercept
mode = -0.531
95% HDI
-1.1
0.0319
-1.5 -1.0 -0.5 0.0 0.5
$\beta_0$
Oak
mode = 0.133
95% HDI
-0.907
1.28
-2 -1 0 1 2
$\beta_1$

# ROC CURVES

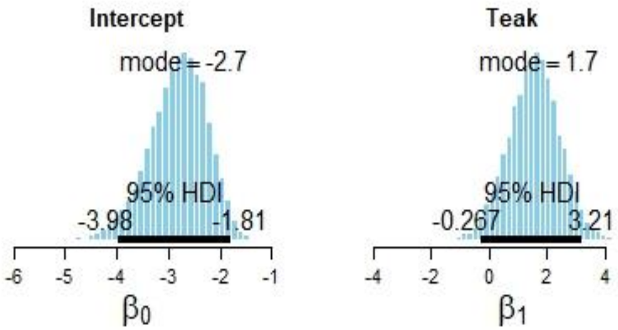


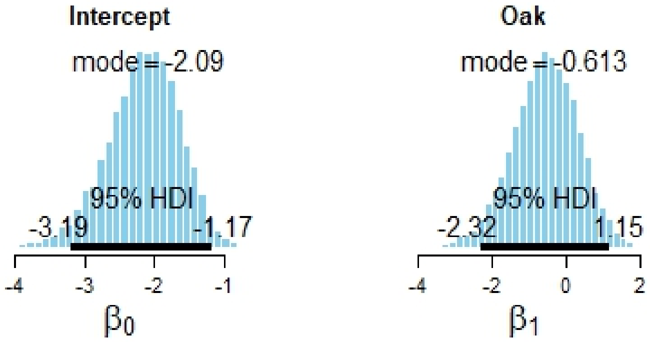
Teak
Eucalyptus
Oak
Pine
Other_Conifers
Sensitivity
Specificity
0.0
0.2
0.4
0.6
0.8
1.0

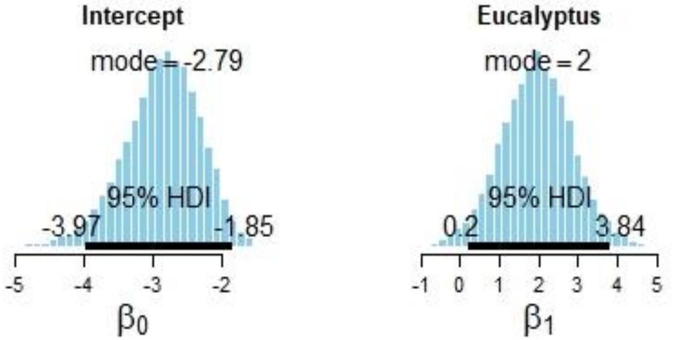
# SECOND TEST DATA SET

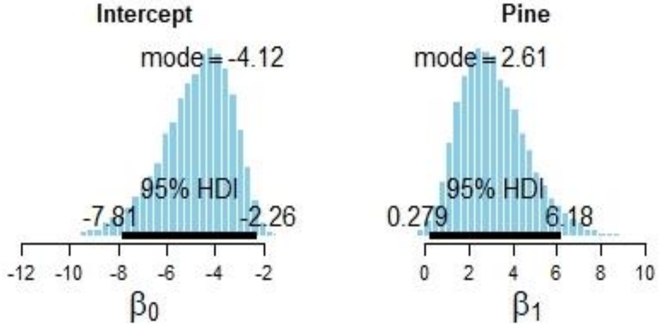
| | Teak | Eucalyptus | Oak | Pine | Other_Conifers | SWater | FWater |
|---|---|---|---|---|---|---|---|
| Carbon_Absorption | 8.4 | 11.1 | 5 | 5 | 5.9 | 0.11 | 0.05 |
| Min_Per | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | | |
| Max_Per | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | | |
| Low_Cutoff | 0.015 | 0.07 | 0.02 | 0.05 | 0.03 | | |
| High_Cutoff | 0.09 | 0.11 | 0.15 | 0.17 | 0.13 | | |

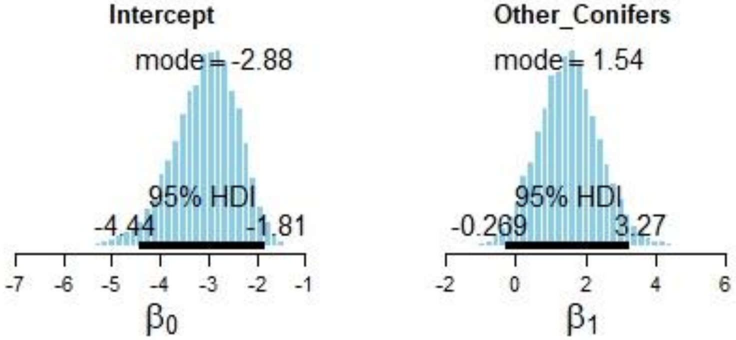
# INTERCEPTS


Intercept
mode = -2.7
95% HDI
-3.98
-1.81
-6 -5 -4 -3 -2 -1
$\beta_0$
Teak
mode = 1.7
95% HDI
-0.267
3.21
-4 -2 0 2 4
$\beta_1$

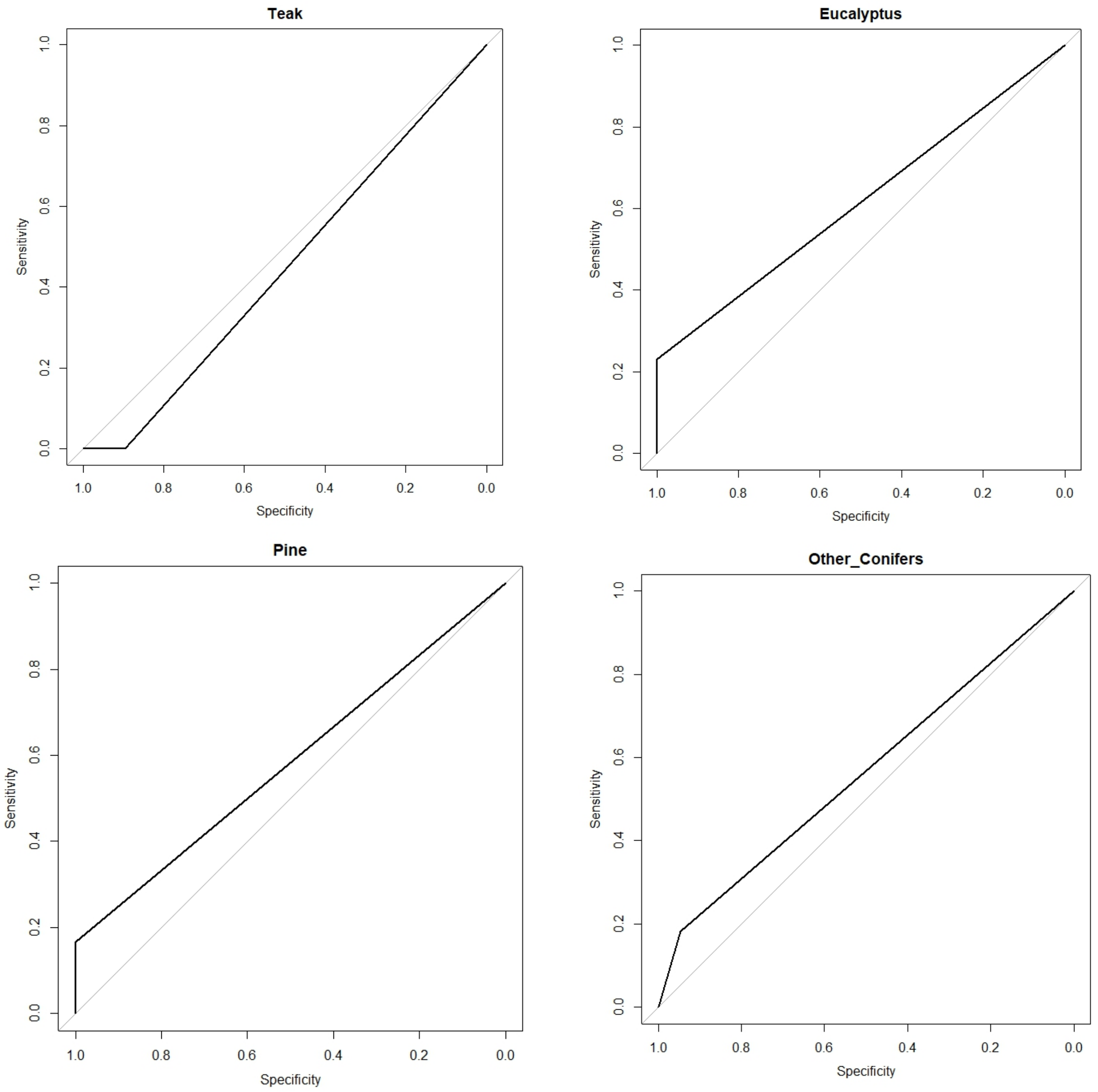

Intercept
mode = -2.09
95% HDI
-3.19
-1.17
-4 -3 -2 -1
$\beta_0$
Oak
mode = -0.613
95% HDI
-2.32
1.15
-4 -2 0 2
$\beta_1$


Intercept
mode = -2.79
95% HDI
-3.97
-1.85
-5 -4 -3 -2
$\beta_0$
Eucalyptus
mode = 2
95% HDI
0.2
3.84
-1 0 1 2 3 4 5
$\beta_1$


Intercept
mode = -4.12
95% HDI
-7.81
-2.26
-12 -10 -8 -6 -4 -2
$\beta_0$
Pine
mode = 2.61
95% HDI
0.279
6.18
0 2 4 6 8 10
$\beta_1$


Intercept
mode = -2.88
95% HDI
-4.44
-1.81
-7 -6 -5 -4 -3 -2 -1
$\beta_0$
Other_Conifers
mode = 1.54
95% HDI
-0.269
3.27
-2 0 2 4 6
$\beta_1$

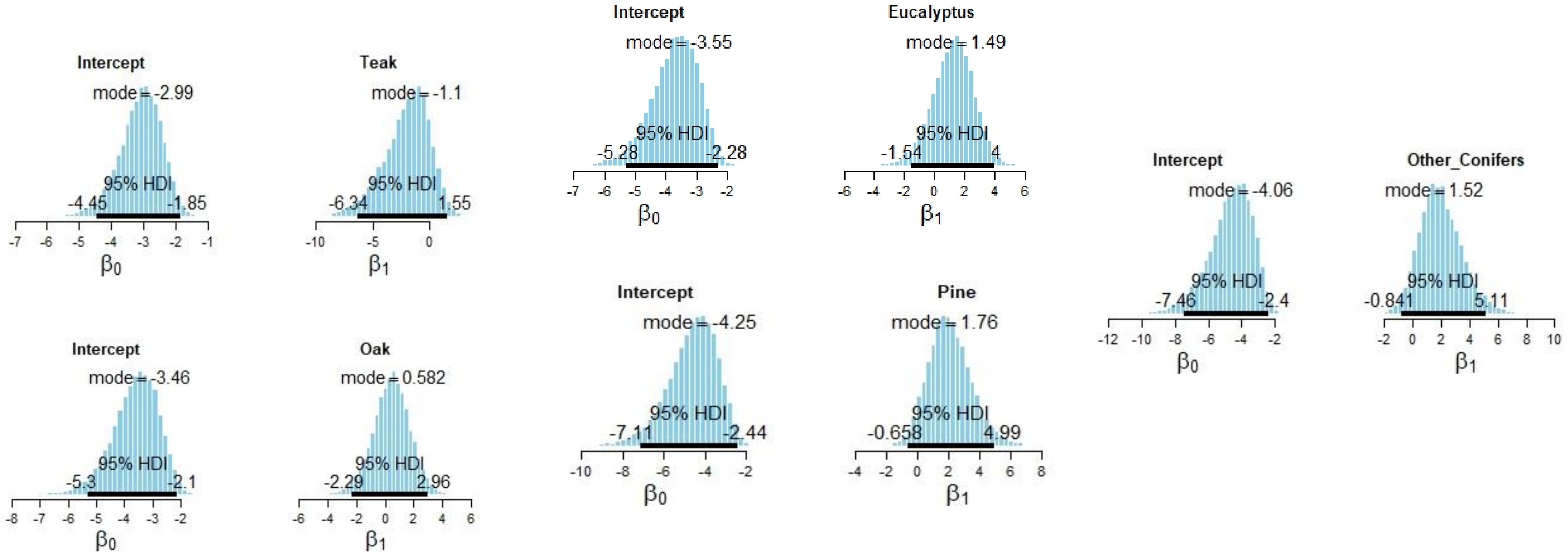
# ROC CURVES


Teak
Eucalyptus
Oak
Pine
Other_Conifers
Sensitivity
Specificity
0.0
0.2
0.4
0.6
0.8
1.0

# THIRD TEST DATA SET

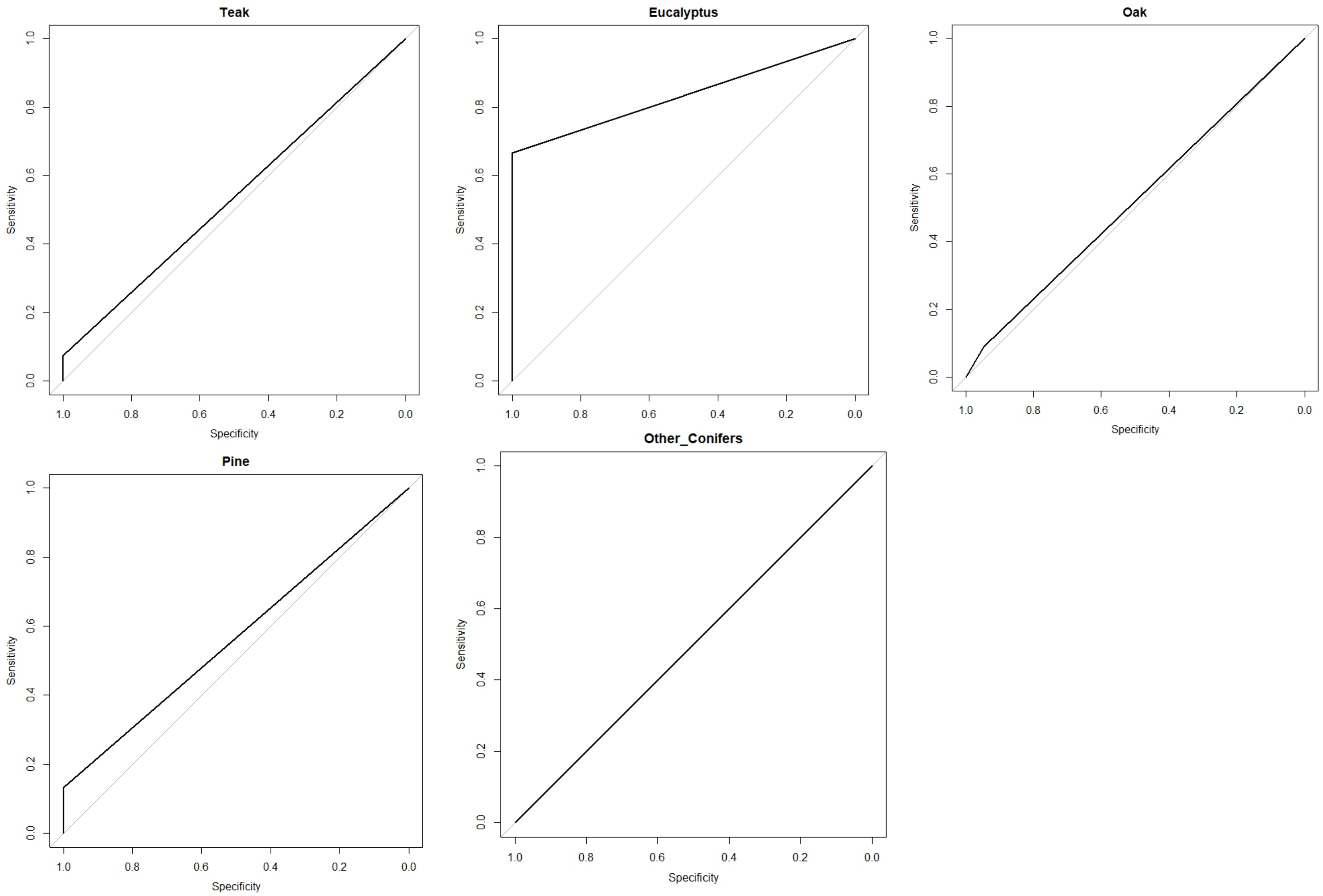
| | Teak | Eucalyptus | Oak | Pine | Other_Conifers | SWater | FWater |
|---|---|---|---|---|---|---|---|
| Carbon_Absorption | 8.4 | 11.1 | 5 | 5 | 5.9 | 0 | 0.09 |
| Min_Per | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | | |
| Max_Per | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | | |
| Low_Cutoff | 0.03 | 0.06 | 0.05 | 0.035 | 0.055 | | |
| High_Cutoff | 0.13 | 0.1 | 0.15 | 0.139 | 0.19 | | |

# INTERCEPTS



Intercept
mode = -2.99
95% HDI
-4.45
-1.85
β0
Teak
mode = -1.1
95% HDI
-6.34
1.55
β1
Intercept
mode = -3.46
95% HDI
-5.3
-2.1
β0
Oak
mode = 0.582
95% HDI
-2.29
2.96
β1
Intercept
mode = -3.55
95% HDI
-5.28
-2.28
β0
Eucalyptus
mode = 1.49
95% HDI
-1.54
4
β1
Intercept
mode = -4.25
95% HDI
-7.11
-2.44
β0
Pine
mode = 1.76
95% HDI
-0.658
4.99
β1
Intercept
mode = -4.06
95% HDI
-7.46
-2.4
β0
Other_Conifers
mode = 1.52
95% HDI
-0.841
5.11
β1

# ROC CURVES



Teak
Eucalyptus
Oak
Pine
Other_Conifers
Sensitivity
Specificity
1.0
0.8
0.6
0.4
0.2
0.0

# COMPARING RESULTS

| Test_Data1 | Test_Data2 | Test_Data3 |
|---|---|---|
| 122.87 tC | 122.39 tC | 129.85 tC |

| A | B | C | D | E | F | G | H | I |
|---|---|---|---|---|---|---|---|---|
| | Teak | Eucalyptus | Oak | Pine | Other_Conifers | Mangrove_Tree | Mangrove_Shrub | Carbon_Absorb |
| 1 | 0.135709182 | 0.035448886 | 0.149480895 | 0.213935542 | 0.305425494 | 0.055 | 0.055 | 105.5806474 |
| 2 | 0.183641195 | 0.056814445 | 0.191233028 | 0.256804762 | 0.151506569 | 0.055 | 0.055 | 108.6760818 |
| 3 | 0.179521118 | 0.157899653 | 0.143649934 | 0.185904165 | 0.17302513 | 0.055 | 0.055 | 121.1156461 |
| 4 | 0.112632239 | 0.038283334 | 0.299301454 | 0.182226756 | 0.207556217 | 0.055 | 0.055 | 102.5955709 |
| 5 | 0.17544669 | 0.234988646 | 0.239275623 | 0.119334688 | 0.070954353 | 0.055 | 0.055 | 128.4061681 |
| 6 | 0.124644889 | 0.105841083 | 0.260333217 | 0.177429168 | 0.171751644 | 0.055 | 0.055 | 111.0099941 |
| 7 | 0.159397571 | 0.07260497 | 0.209607663 | 0.1854203 | 0.212969496 | 0.055 | 0.055 | 110.0602921 |
| 8 | 0.036064917 | 0.164231074 | 0.220427739 | 0.207693958 | 0.211582311 | 0.055 | 0.055 | 112.827087 |
| 9 | 0.217821131 | 0.185000965 | 0.184159942 | 0.057184494 | 0.195833469 | 0.055 | 0.055 | 127.436957 |
| 10 | 0.166279174 | 0.379910981 | 0.149582192 | 0.099866476 | 0.044361177 | 0.055 | 0.055 | 144.9846247 |
| 11 | 0.195236737 | 0.304893874 | 0.113313676 | 0.033223785 | 0.193331928 | 0.055 | 0.055 | 140.4831254 |
| 12 | 0.038858571 | 0.169457913 | 0.125955986 | 0.199484075 | 0.306243455 | 0.055 | 0.055 | 115.3586304 |
| 13 | 0.224870966 | 0.211309206 | 0.119123253 | 0.101021764 | 0.18367481 | 0.055 | 0.055 | 130.9070954 |
| 14 | 0.213923694 | 0.196939865 | 0.108251603 | 0.233630355 | 0.087254483 | 0.055 | 0.055 | 126.6740554 |
| 15 | 0.018185505 | 0.178987605 | 0.248075508 | 0.202748266 | 0.192003116 | 0.055 | 0.055 | 113.0591583 |
| 16 | 0.024864064 | 0.253131681 | 0.161398872 | 0.249942669 | 0.150662713 | 0.055 | 0.055 | 121.8147503 |
| 17 | 0.201968891 | 0.184623444 | 0.187167889 | 0.167232672 | 0.099007104 | 0.055 | 0.055 | 124.5700727 |
| 18 | 0.050383554 | 0.311098141 | 0.219771485 | 0.143032566 | 0.115714255 | 0.055 | 0.055 | 129.9929114 |
| 19 | 0.181750735 | 0.184743164 | 0.049860919 | 0.279752456 | 0.143892726 | 0.055 | 0.055 | 124.0177851 |
| 20 | 0.300713724 | 0.123008671 | 0.13389364 | 0.249509514 | 0.032874451 | 0.055 | 0.055 | 122.5773313 |
| 21 | 0.339169443 | 0.099057726 | 0.056581013 | 0.048160645 | 0.297031173 | 0.055 | 0.055 | 127.0251258 |

| A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|
| | Teak | Eucalyptus | Oak | Pine | Other_Conifers | Viable |
| 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| 2 | 1 | 1 | 0 | 0 | 1 | 1 |
| 3 | 1 | 0 | 0 | 0 | 1 | 0 |
| 4 | 1 | 0 | 0 | 0 | 0 | 0 |
| 5 | 1 | 0 | 0 | 1 | 1 | 1 |
| 6 | 1 | 1 | 0 | 1 | 1 | 1 |
| 7 | 1 | 1 | 0 | 0 | 0 | 0 |
| 8 | 1 | 0 | 0 | 0 | 0 | 0 |
| 9 | 0 | 0 | 0 | 1 | 0 | 0 |
| 10 | 1 | 0 | 0 | 1 | 1 | 1 |
| 11 | 0 | 0 | 1 | 1 | 0 | 0 |
| 12 | 1 | 0 | 0 | 0 | 0 | 0 |
| 13 | 0 | 0 | 1 | 1 | 0 | 0 |
| 14 | 0 | 0 | 1 | 0 | 1 | 0 |
| 15 | 0 | 0 | 0 | 0 | 0 | 0 |
| 16 | 1 | 0 | 0 | 0 | 0 | 0 |
| 17 | 0 | 0 | 0 | 1 | 1 | 0 |
| 18 | 1 | 0 | 0 | 0 | 0 | 0 |
| 19 | 1 | 0 | 1 | 0 | 1 | 1 |
| 20 | 0 | 0 | 0 | 0 | 1 | 0 |
| 21 | 0 | 1 | 1 | 1 | 0 | 1 |

# CONCLUSIONS

- Using this code, the following things can be accomplished:
  - Take in data on a wide variety of species and their habitat, then run them through the code.
  - Determine what mix of species will be viable, both as a species and for the ecosystem.
  - Determine which species are most important for a particular habitat.
  - Calculate the amount of carbon dioxide the area will absorb over a 20 year period.
- This looks to be a good initial method, thought it does have room for improvement.

# THANK YOU!