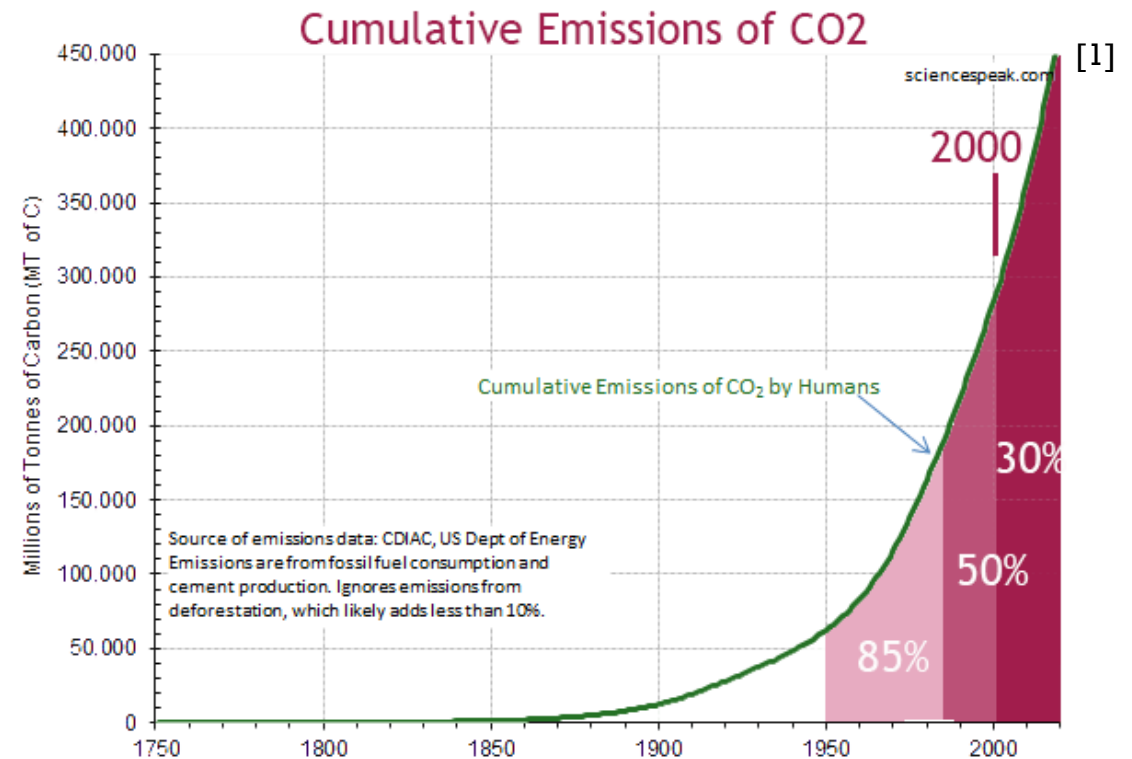# ANALYZING REFORESTATION STRATEGIES

By Zachary Stein
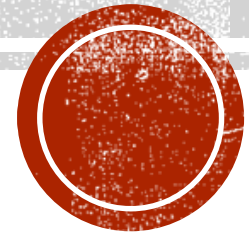
DEALING WITH CLIMATE CHANGE

- 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]

Cumulative Emissions of CO2

sciencespeak.com

Millions of Tonnes of Carbon (MT of C)

2000

Cumulative Emissions of CO_2 by Humans

30%

50%

Source of emissions data: CDIAC, US Dept of Energy
Emissions are from fossil fuel consumption and
cement production. Ignores emissions from
deforestation, which likely adds less than 10%.

85%

CLIMATE AGREEMENTS

- Multiple international agreements have been signed in order to reduce greenhouse gas emissions.

- Some examples:
  - Kyoto Protocol (1997)
  - Paris Agreement (2016)

[2]

COUNTRIES THAT JOINED THE PARIS CLIMATE AGREEMENT

Ratified (146) Signed (48) Not signed/Withdrawing (3)
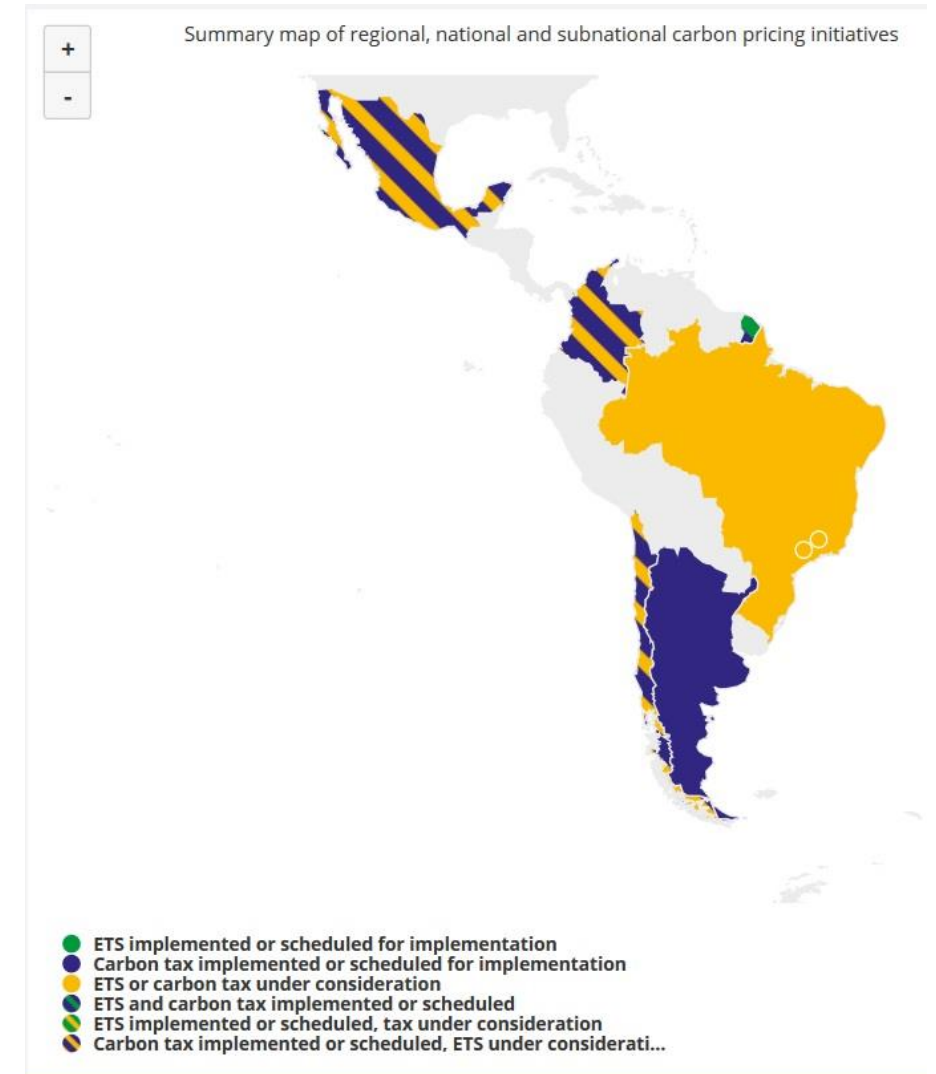
United States
Nicaragua
Syria

SOURCE: UNFCCC   NOTE: Denmark's agreement excludes Greenland. Map is updated as of May 31, 2017.   BUSINESS INSIDER

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.

Summary map of regional, national and subnational carbon pricing initiatives

- ETS implemented or scheduled for implementation
- Carbon tax implemented or scheduled for implementation
- ETS or carbon tax under consideration
- ETS and carbon tax implemented or scheduled
- ETS implemented or scheduled, tax under consideration
- Carbon tax implemented or scheduled, ETS under considerati...

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

teak	eucalyptus	other broadleaf	oak	pine	other conifer	NATURAL REGENERATION 0-20y rate, tC/ha/y	20-60y rate, tC/ha/y	MANGROVE TREE RESTORATION 0-20y rate, tC/ha/y	20-60y rate, tC/ha/y	MANGROVE SHRUB RESTORATION 0-20y rate, tC/ha/y	20-60y rate, tC/ha/y	AGROFORESTRY 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

Column group: PLANTATIONS & WOODLOTS (0-20y rate, tC/ha/y) covers teak, eucalyptus, other broadleaf, oak, pine, other conifer.

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

	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												

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

```
53    OCArea <- runif(1,treedata$Other_Conifers[2],treedata$Other_Conifers[3])
54
55    five_ran <- TArea+EArea+OArea+PArea+OCArea
56
57    TArea <- (TArea/five_ran)*Left
58    EArea <- (EArea/five_ran)*Left
59    OArea <- (OArea/five_ran)*Left
60    PArea <- (PArea/five_ran)*Left
61    OCArea <- (OCArea/five_ran)*Left
62
63        #Calculate if the species is out of the ideal range.
64        if (TArea>treedata$Teak[5]){
65          TAreacalc = 0
66        } else if (TArea<treedata$Teak[4]){
67          TAreacalc = 0
68        } else {
69          TAreacalc = 1
70        }
71
72        if (EArea>treedata$Eucalyptus[5]){
73          EAreacalc = 0
74        } else if (EArea<treedata$Eucalyptus[4]){
75          EAreacalc = 0
76        } else {
77          EAreacalc = 1
78        }
79
80        if (OArea>treedata$Oak[5]){
81          OAreacalc = 0
82        } else if (TArea<treedata$Oak[4]){
83          OAreacalc = 0
84        } else {
85          OAreacalc = 1
86        }
87
88        if (PArea>treedata$Pine[5]){
89          PAreacalc = 0
90        } else if (TArea<treedata$Pine[4]){
91          PAreacalc = 0
92        } else {
```

```
161    return(hitRate)
162  }
163
164  for(i in varList){
165
166    yName = "Viable" ; xName = c(i)
167    fileNameRoot = "output"
168    numSavedSteps=15000 ; thinSteps=2
169
170    mcmcCoda = genMCMC( data=trainData , xName=xName , yName=yName ,
171                        numSavedSteps=numSavedSteps , thinSteps=thinSteps ,
172                        saveName=fileNameRoot )
173  #-------------------------------------------------------------------------
174  # Display diagnostics of chain, for specified parameters:
175    parameterNames = varnames(mcmcCoda) # get all parameter names
176    for ( parName in parameterNames ) {
177      diagMCMC( codaObject=mcmcCoda , parName=parName ,
178                saveName=fileNameRoot , saveType=graphFileType )
179    }
180  #-------------------------------------------------------------------------
181  # Get summary statistics of chain:
182    summaryInfo = smryMCMC( mcmcCoda ,
183                            saveName=fileNameRoot )
184    show(summaryInfo)
185  # Display posterior information:
186    plotMCMC( mcmcCoda , data=trainData , xName=xName , yName=yName ,
187              pairsPlot=TRUE , showCurve=FALSE ,
188              saveName=fileNameRoot , saveType=graphFileType )
189  #-------------------------------------------------------------------------
190
191    parameter_file = read.csv(paste0(fileNameRoot,"SummaryInfo.csv"),row.names = 1)
192
193    parameter = parameter_file[1:2,"Mode"]
194
195    hitRates[i] = bayesLog(trainData, testData[[xName]], testData[[yName]], parameter, xName)
196
197  }
198
199  print(hitRates)
200
```
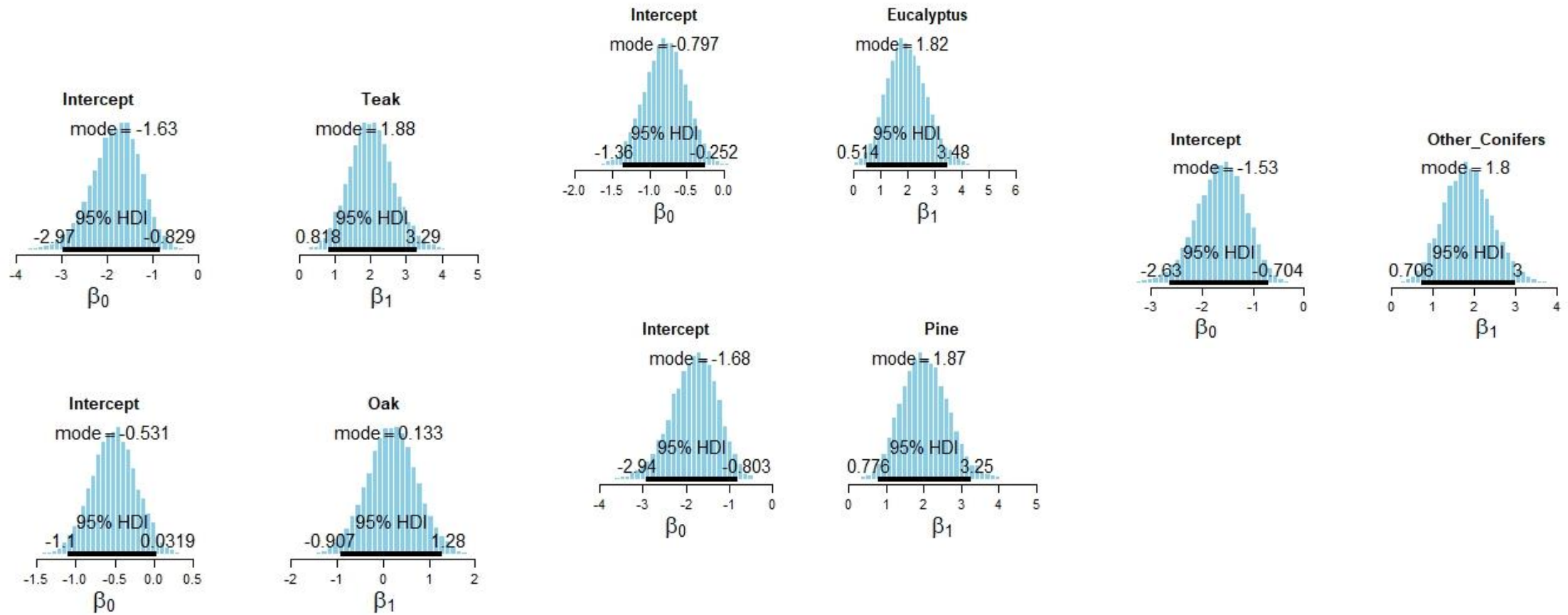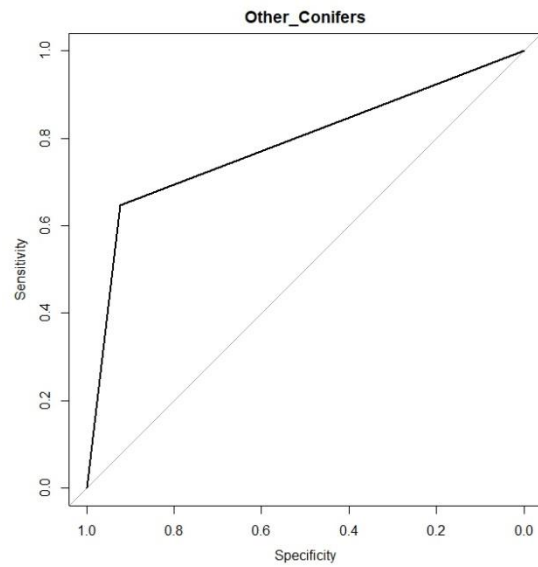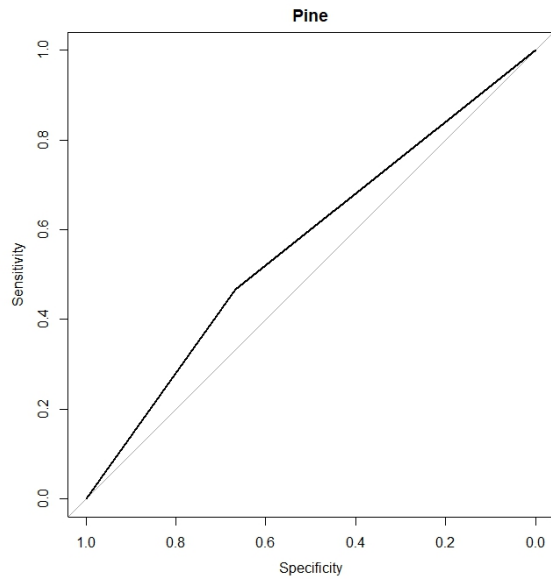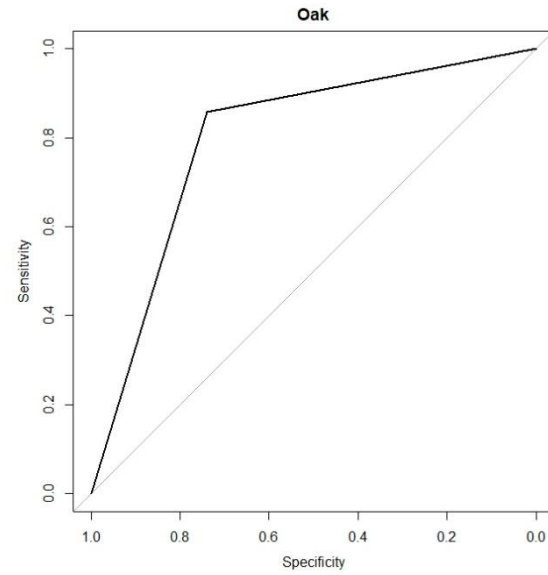
FIRST TEST DATA SET

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

ROC CURVES
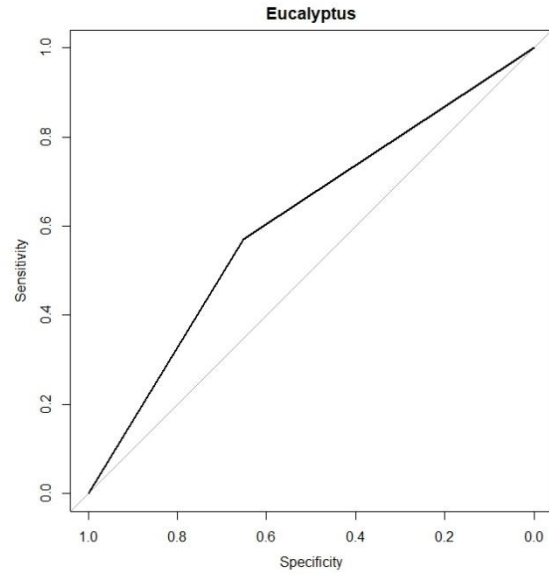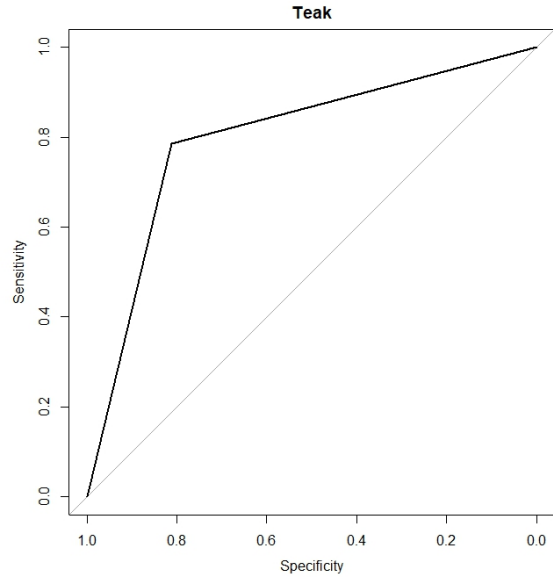
SECOND TEST DATA SET

	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
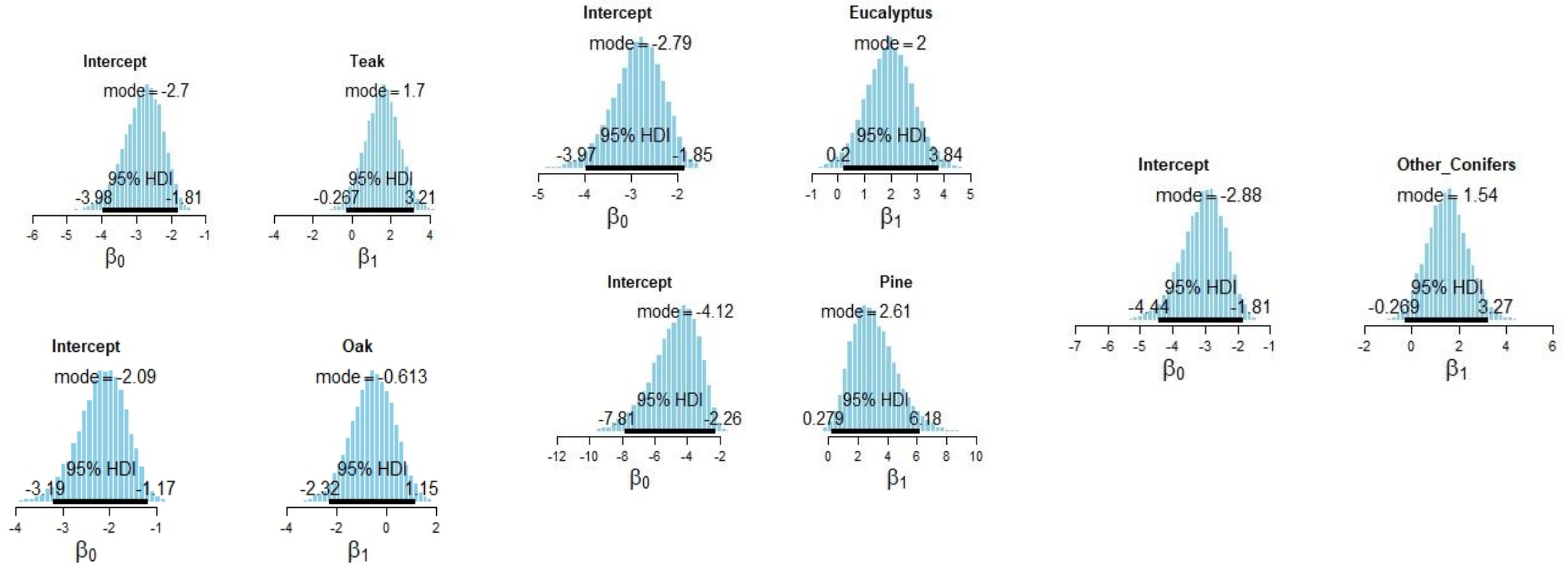
ROC CURVES
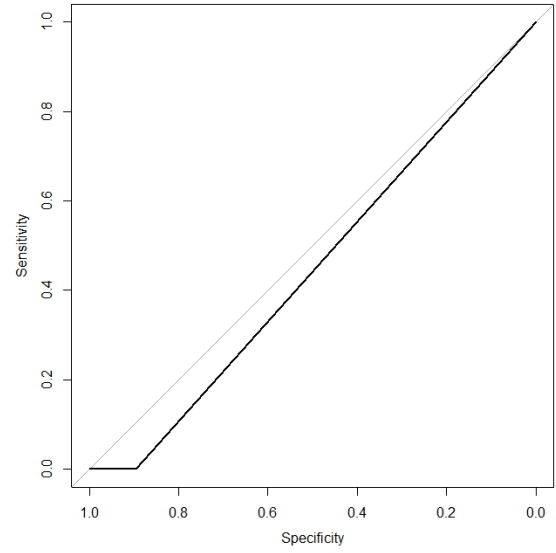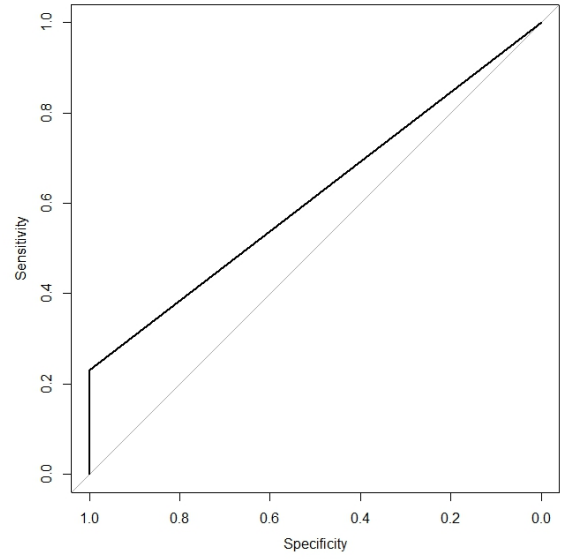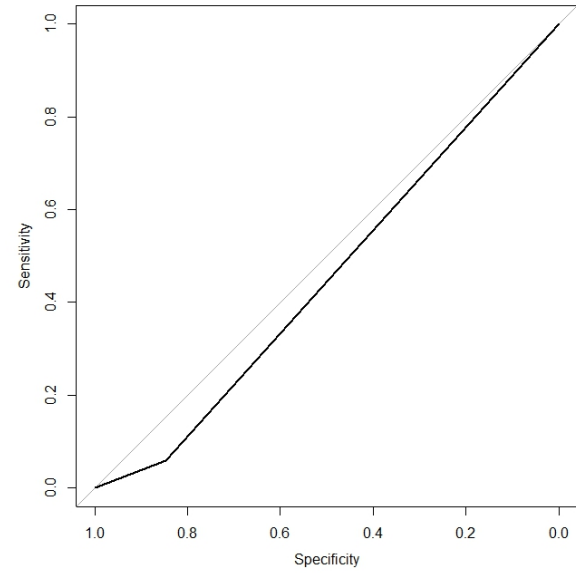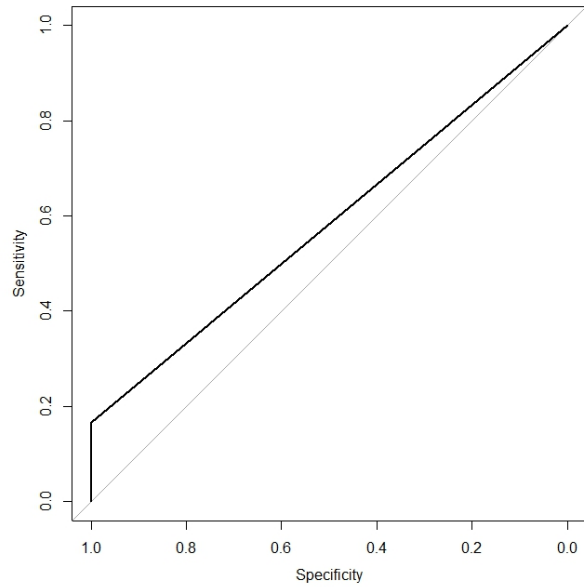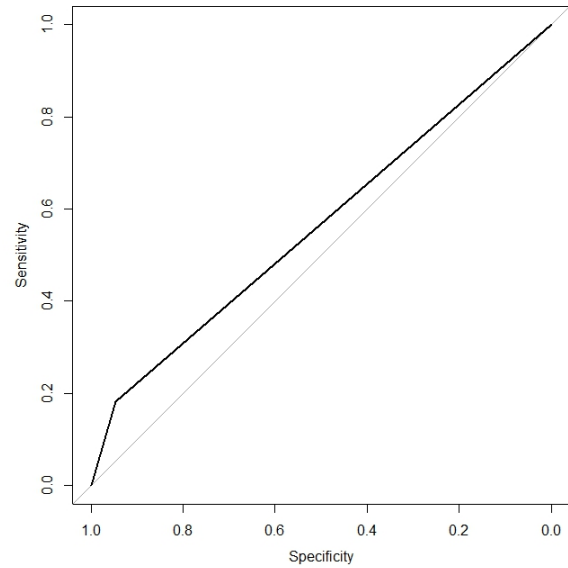
THIRD TEST DATA SET

	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
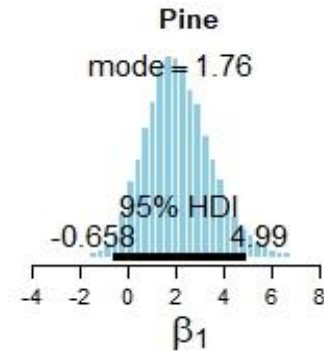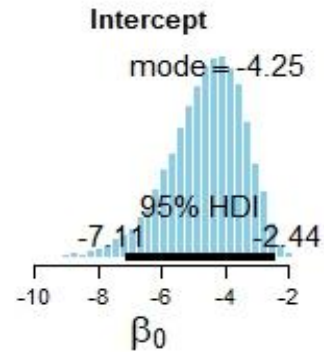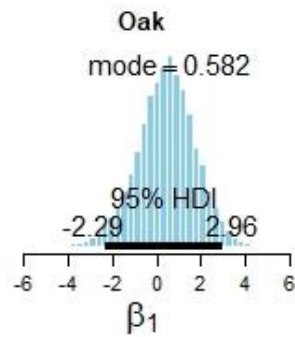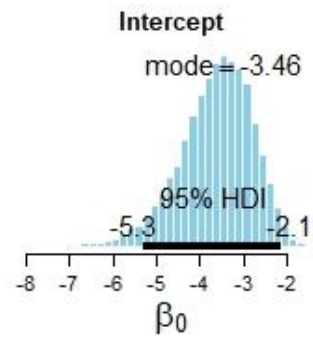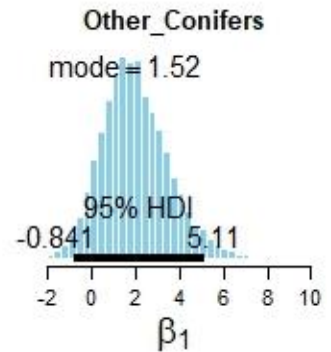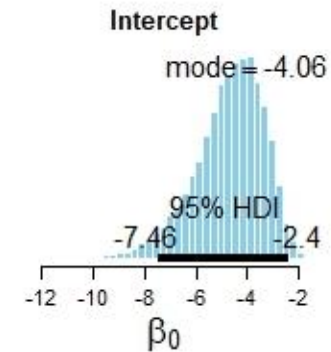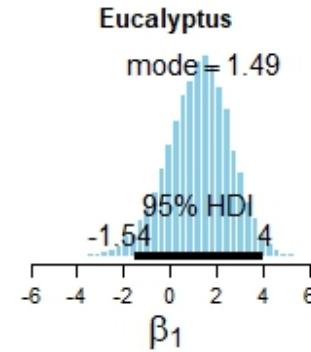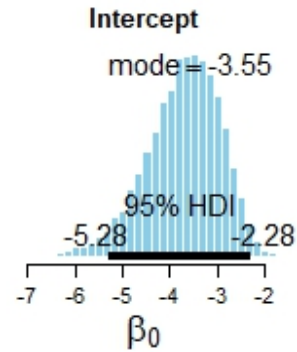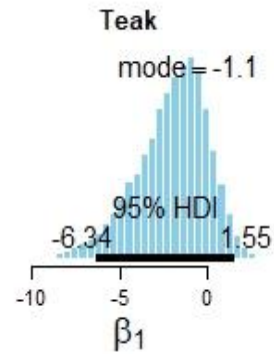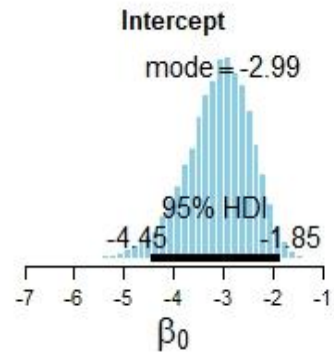
ROC CURVES
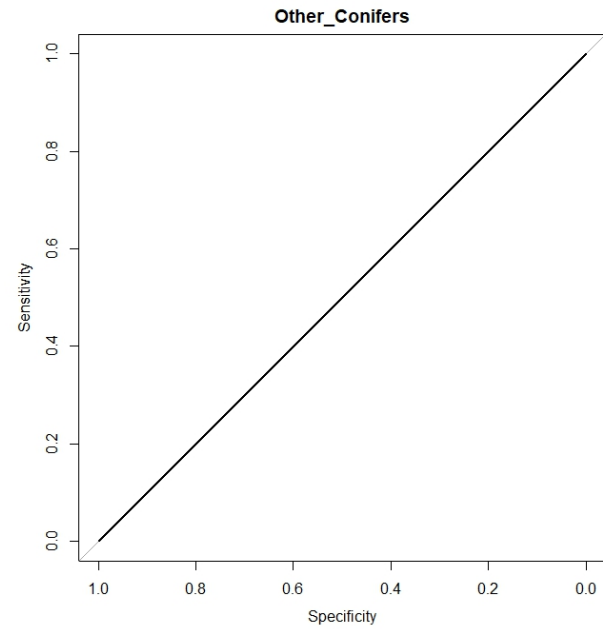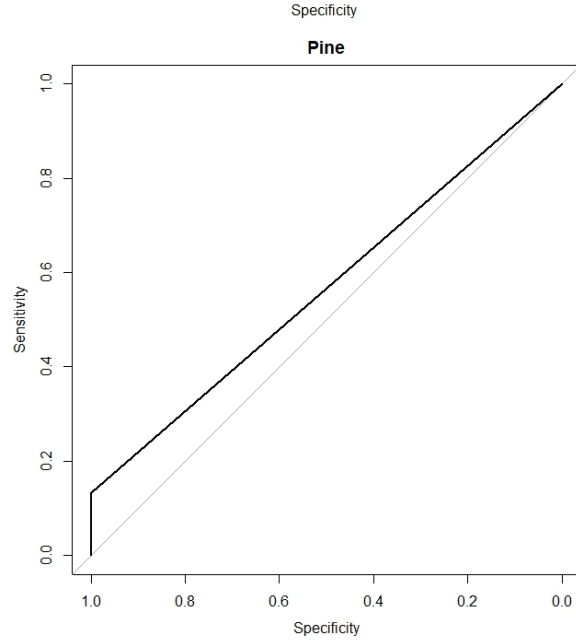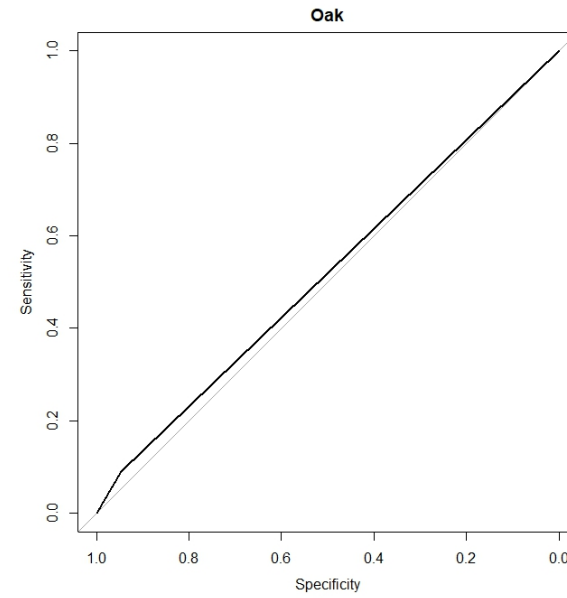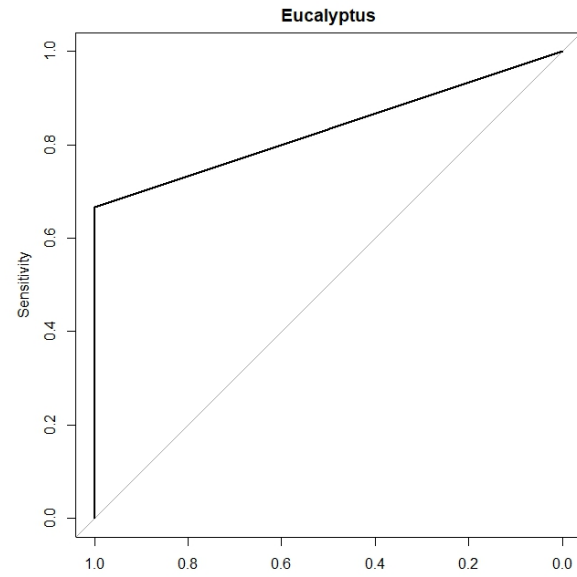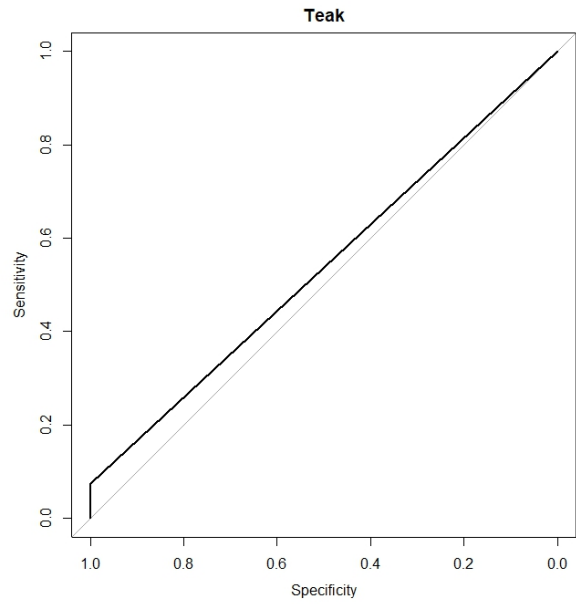
COMPARING RESULTS

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	0	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!