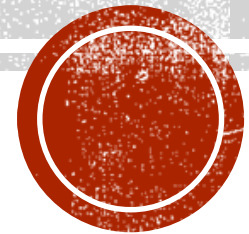




THE GEORGE
WASHINGTON
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CREATING A COMPLEX REFORESTATION STRATEGY

By Zachary Stein



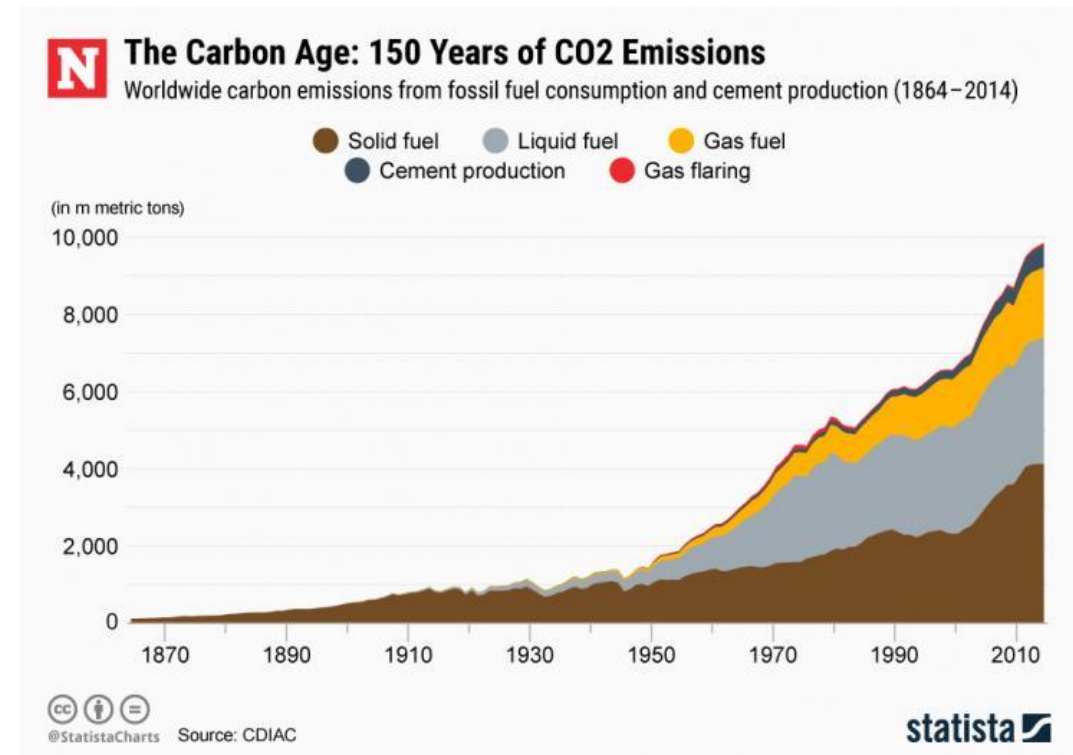
DEALING WITH CLIMATE CHANGE

- 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 CO₂ released into the atmosphere is exponential.
- We need to reduce the amount of CO₂ 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)

COUNTRIES THAT JOINED THE PARIS CLIMATE AGREEMENT



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

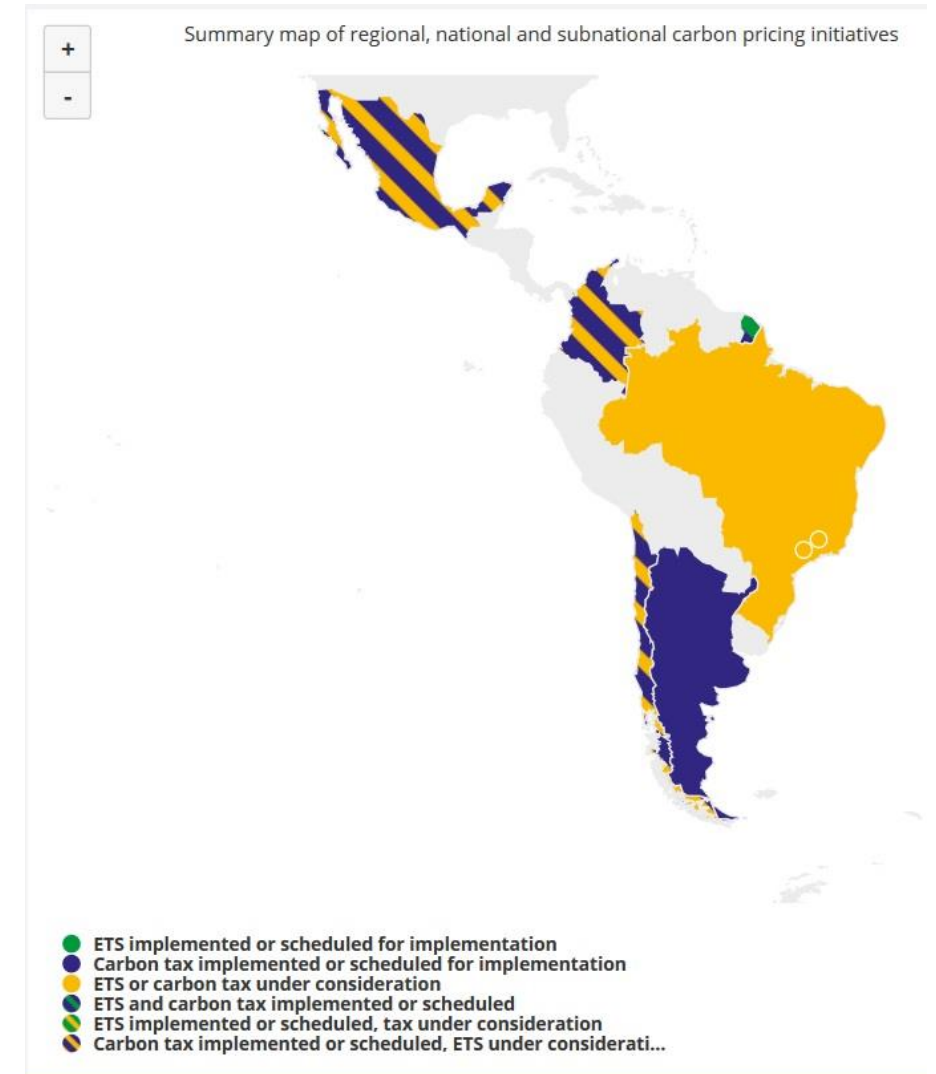
BUSINESS INSIDER

[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 CO₂.
 - 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 CO₂, 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	
							20-60y		20-60y				20-60y	
eucalypt other					other		0-20y rate,	rate,	0-20y rate,	rate,	0-20y rate,	20-60y rate,	0-20y rate,	rate,
teak	us	broadleaf		oak	pine	conifer	tC/ha/y	tC/ha/y	tC/ha/y	tC/ha/y	tC/ha/y	tC/ha/y	tC/ha/y	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

	A	B	C	D	E	F	G	H	I	J	K	L
1		Teak	Eucalyptus	Oak	Pine	Other_Conifers	Mangrove_Tree	Mangrove_Shruh	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 OArea <- 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 = gerMCMC( data=trainData , xName=xName , yName=yName ,
171                       numSavedSteps=numSavedSteps , thinSteps=thinSteps ,
172                       saveName=fileNameRoot )
173
174   #-----
175   # Display diagnostics of chain, for specified parameters:
176   parameterNames = varnames(mcmcCoda) # get all parameter names
177   for ( parName in parameterNames ) {
178     diagMCMC( codaObject=mcmcCoda , parName=parName ,
179              saveName=fileNameRoot , saveType=graphFileType )
180   }
181   #-----
182   # Get summary statistics of chain:
183   summaryInfo = smryMCMC( mcmcCoda ,
184                           saveName=fileNameRoot )
185   show(summaryInfo)
186   # Display posterior information:
187   plotMCMC( mcmcCoda , data=trainData , xName=xName , yName=yName ,
188            pairsPlot=TRUE , showCurve=FALSE ,
189            saveName=fileNameRoot , saveType=graphFileType )
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
```

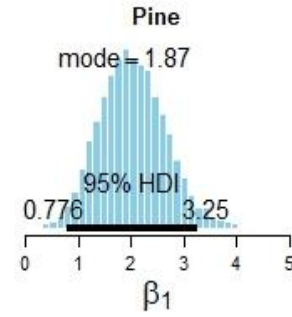
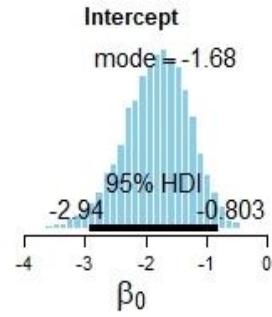
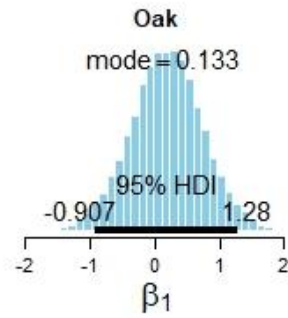
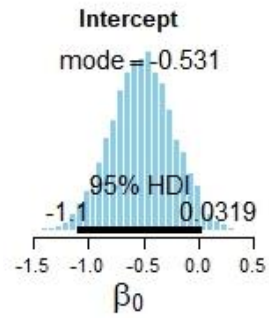
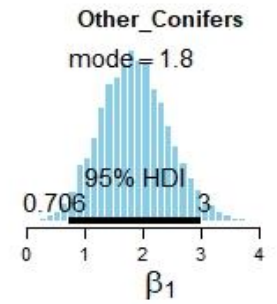
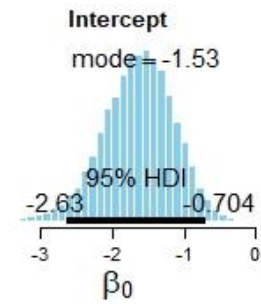
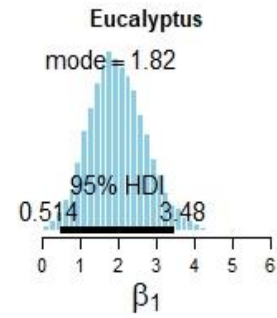
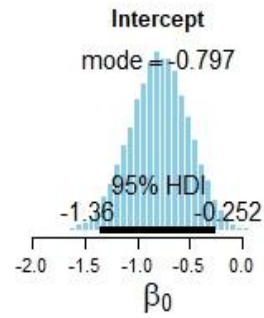
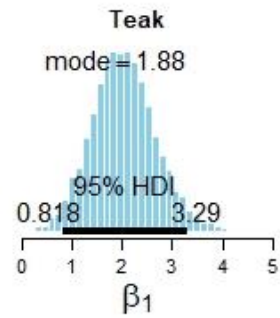
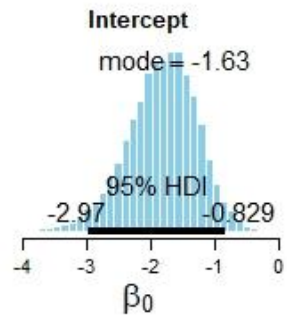


FIRST TEST DATA SET

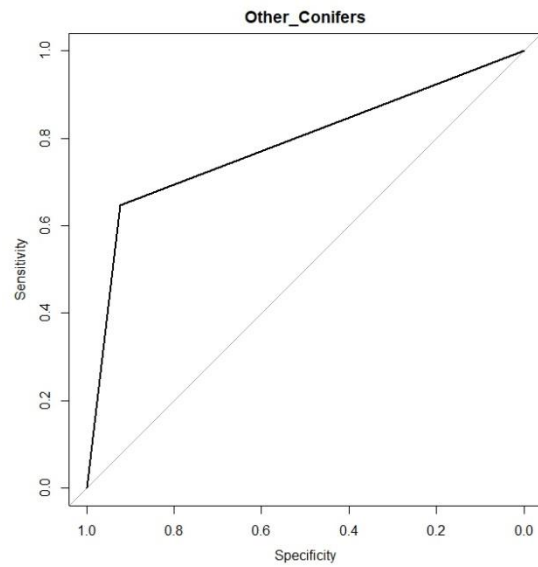
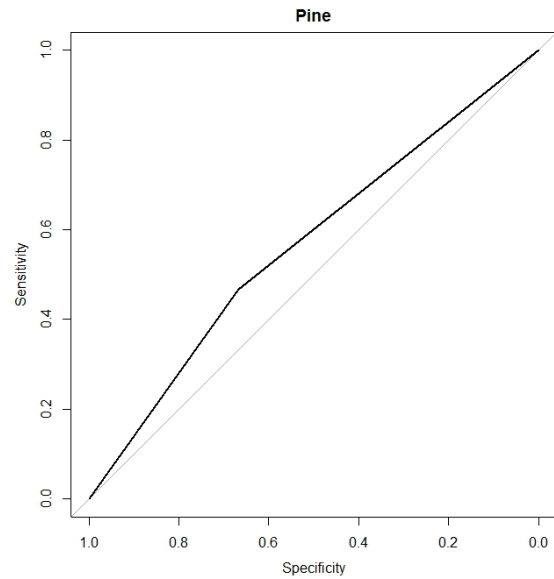
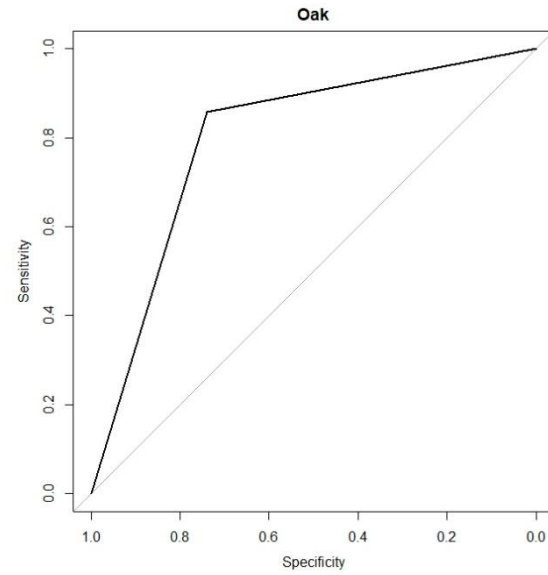
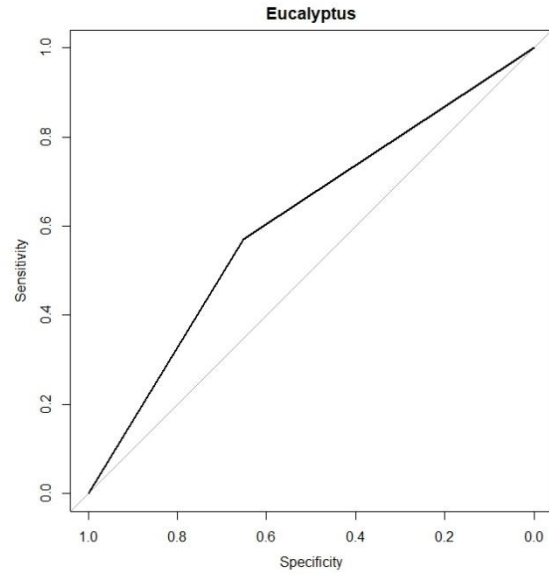
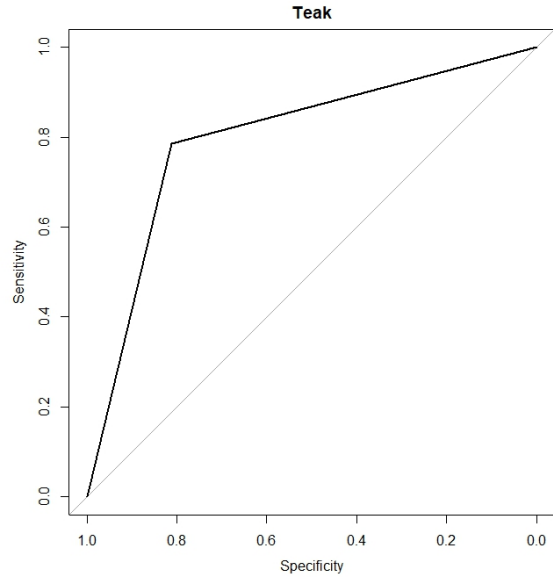
Input	Teak	Eucalyptus	Oak	Pine	Other Conifers	SWater	FWater
Carbon_Absorption	8.4	11.1	5	5	5.9	0.11	0.05
Min_Per	0.01	0.01	0.01	0.01	0.01		
Max_Per	0.2	0.2	0.2	0.2	0.2		
Low_Cutoff	0.02	0.05	0.03	0.07	0.07		
High_Cutoff	0.19	0.11	0.12	0.18	0.18		



INTERCEPTS



ROC CURVES

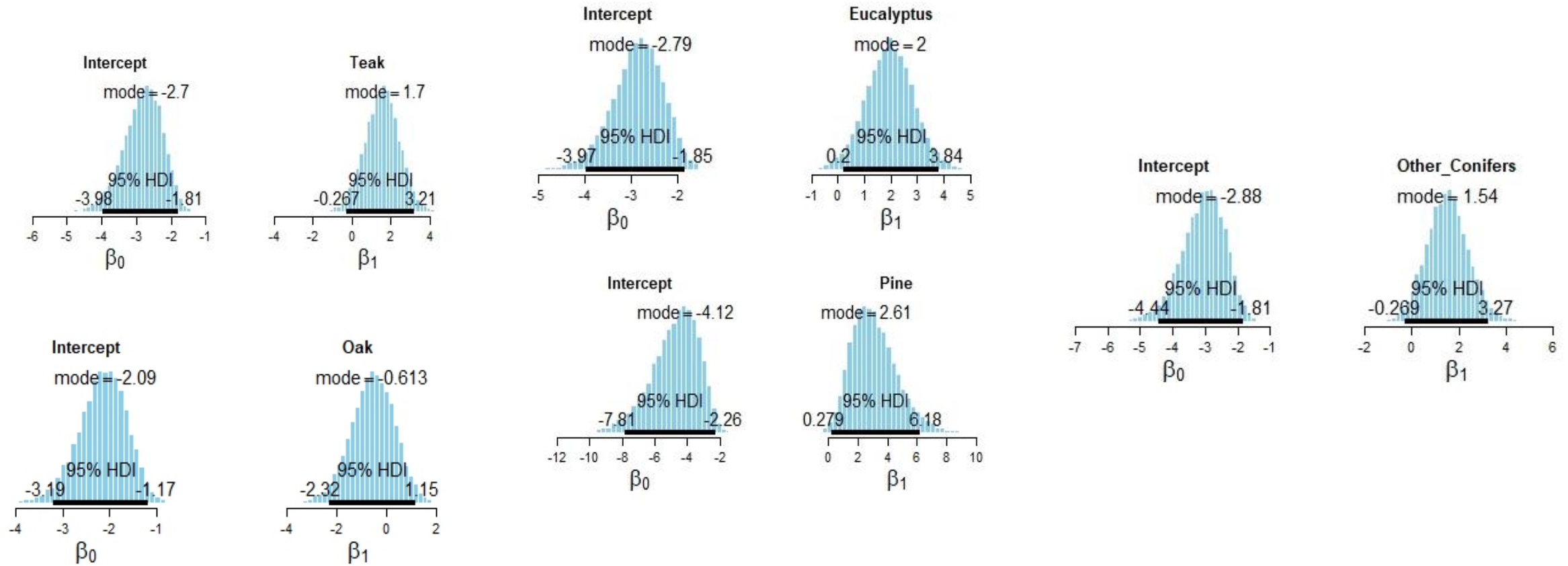


SECOND TEST DATA SET

	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		

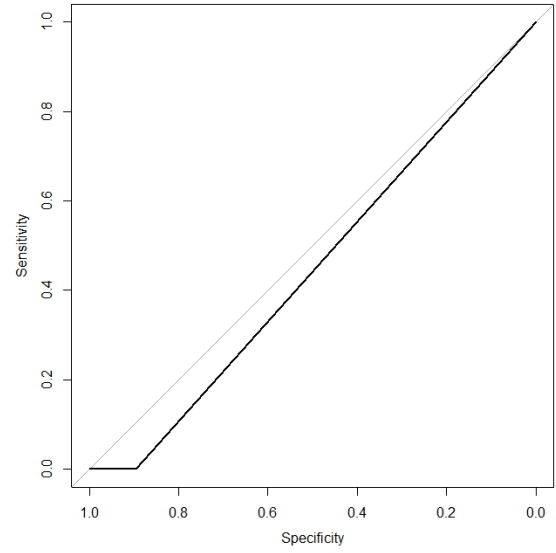


INTERCEPTS

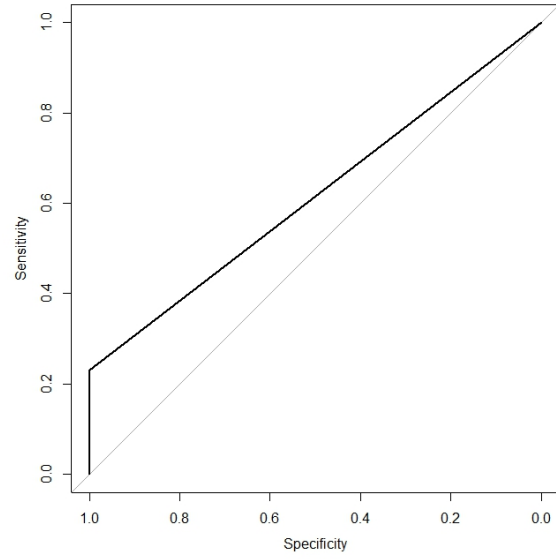


ROC CURVES

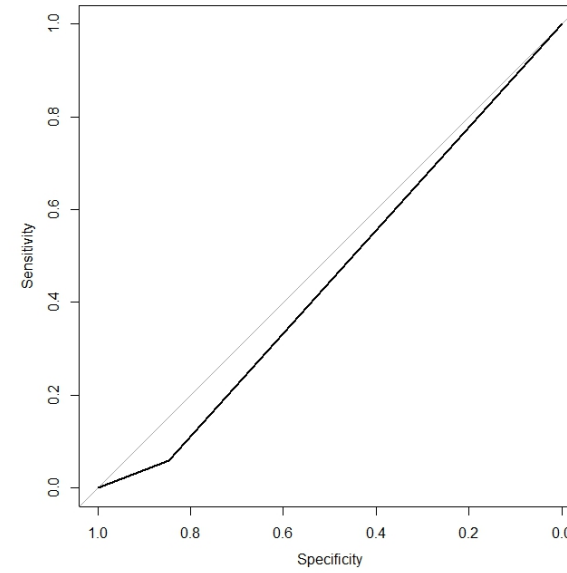
Teak



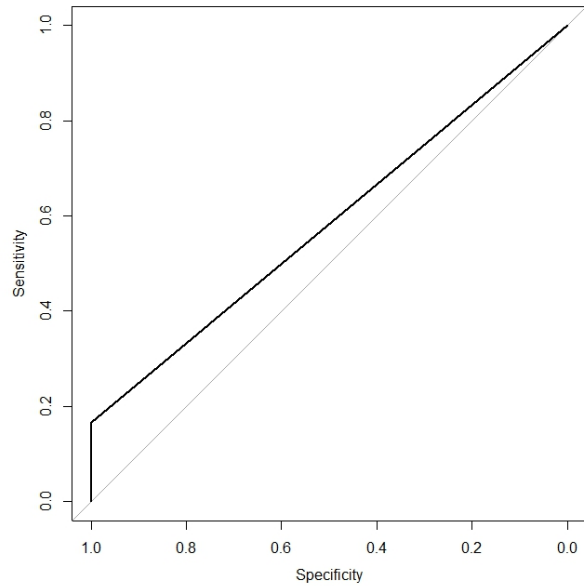
Eucalyptus



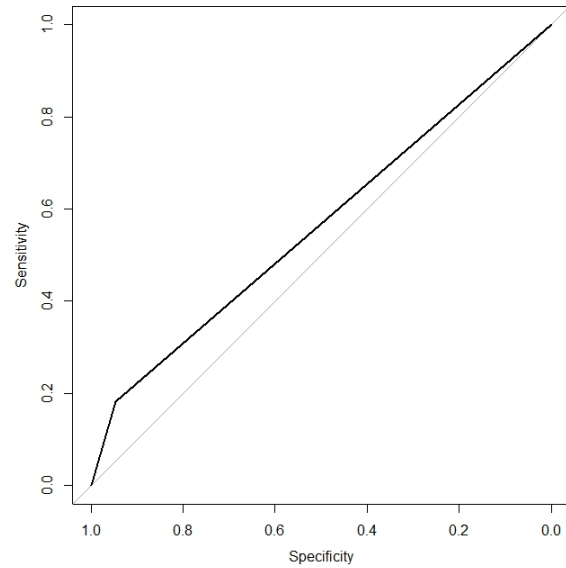
Oak



Pine



Other_Conifers

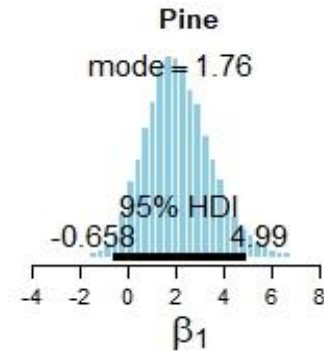
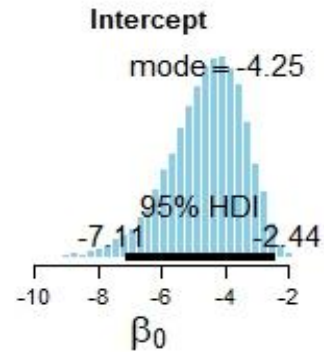
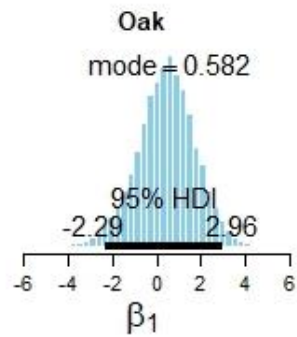
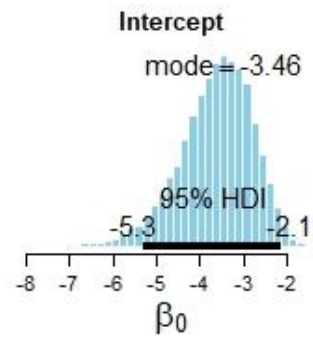
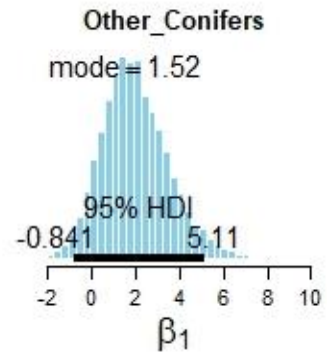
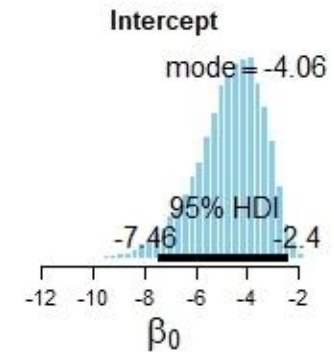
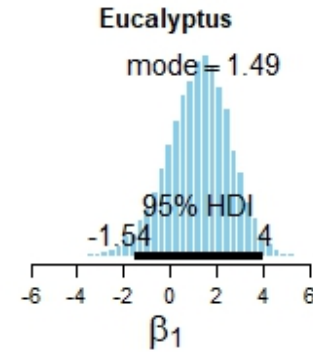
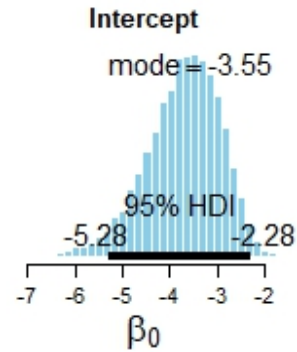
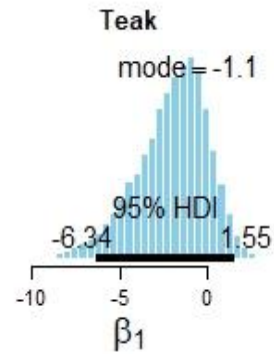
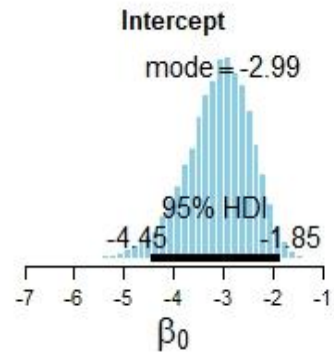


THIRD TEST DATA SET

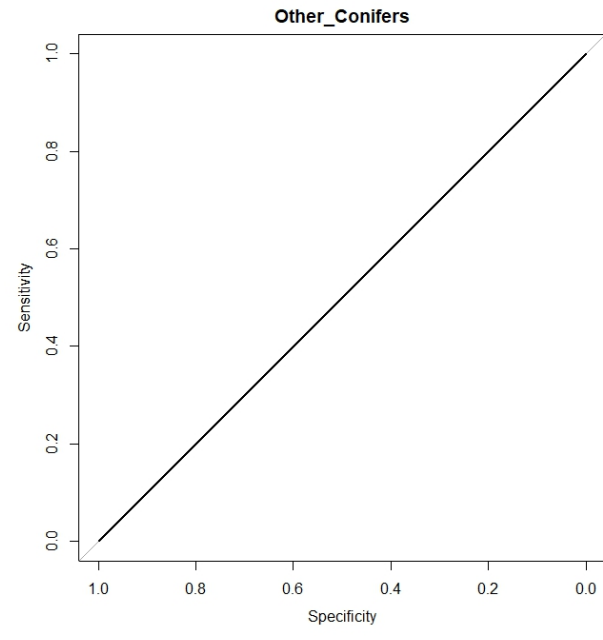
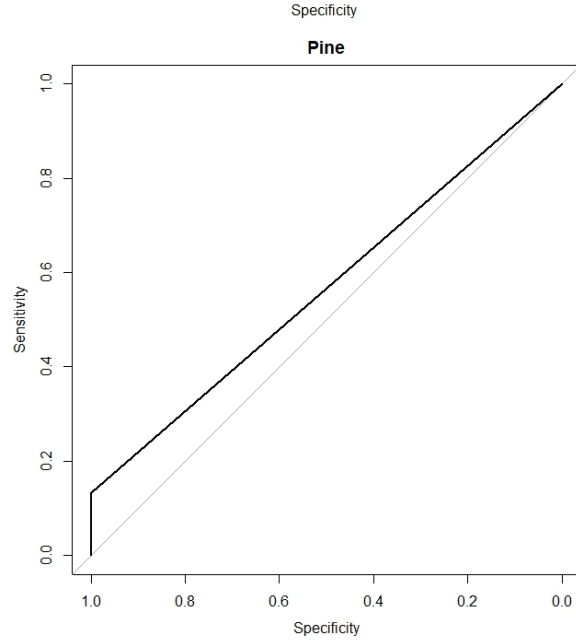
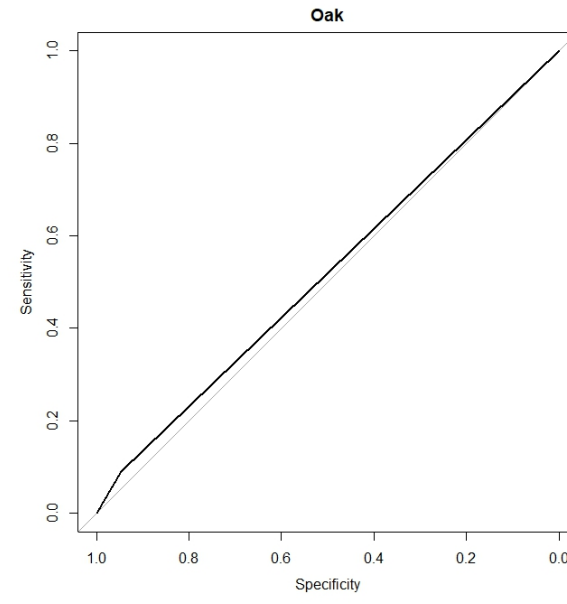
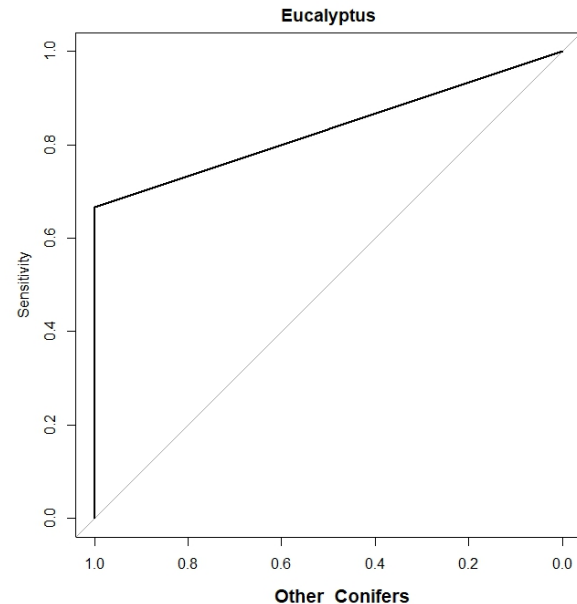
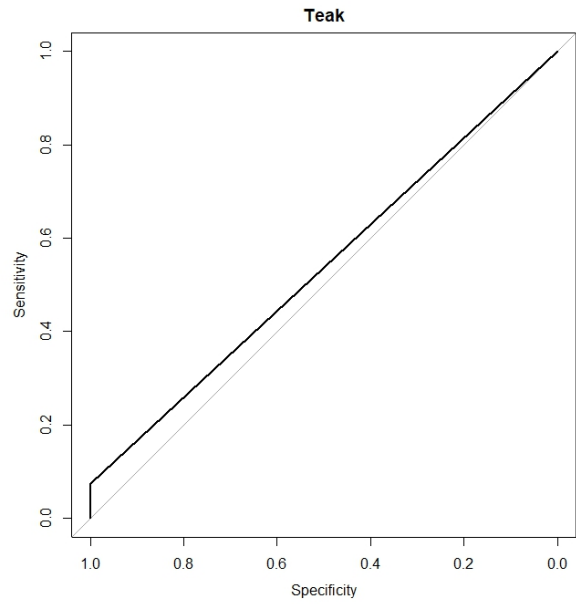
	Teak	Eucalyptus	Oak	Pine	Other Conifers	SWater	FWater
Carbon_Absorption	8.4	11.1	5	5	5.9	0	0.09
Min_Per	0.01	0.01	0.01	0.01	0.01		
Max_Per	0.2	0.2	0.2	0.2	0.2		
Low_Cutoff	0.03	0.06	0.05	0.035	0.055		
High_Cutoff	0.13	0.1	0.15	0.139	0.19		



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	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, though it does have room for improvement.



THANK YOU!

