# ASSESSING MODEL ACCURACY

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# OVERVIEW

- The confusion matrix
- Measures of model accuracy
- Thresholds for continuous predictions
- Application to Species Distribution Models

# MODIS LAND COVER CLASSIFICATION

| Site Class | Class Name | Classification Outcome | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 14 | 15 | 16 | Total |
| 1 | Evergreen Needleleaf | 1460 | 42 | 18 | 11 | 266 | 7 | 9 | 17 | 23 | 10 | 15 | 21 | 2 | 0 | 0 | 1901 |
| 2 | Evergreen Broadleaf | 31 | 4889 | 0 | 14 | 14 | 11 | 18 | 79 | 23 | 17 | 4 | 38 | 10 | 0 | 1 | 5149 |
| 3 | Deciduous Needleleaf | 87 | 0 | 104 | 25 | 118 | 0 | 0 | 4 | 0 | 0 | 0 | 10 | 0 | 0 | 0 | 348 |
| 4 | Deciduous Broadleaf | 22 | 56 | 16 | 384 | 278 | 0 | 3 | 11 | 1 | 3 | 0 | 47 | 82 | 0 | 0 | 903 |
| 5 | Mixed Forest | 405 | 63 | 94 | 148 | 1355 | 3 | 1 | 27 | 7 | 8 | 40 | 41 | 17 | 0 | 0 | 2209 |
| 6 | Closed Shrubland | 34 | 35 | 2 | 12 | 5 | 140 | 124 | 29 | 15 | 30 | 2 | 158 | 19 | 0 | 8 | 613 |
| 7 | Open Shrubland | 10 | 12 | 3 | 9 | 1 | 41 | 1002 | 33 | 45 | 203 | 0 | 210 | 6 | 0 | 213 | 1788 |
| 8 | Woody Savanna | 62 | 133 | 0 | 16 | 110 | 11 | 104 | 577 | 141 | 71 | 0 | 221 | 22 | 0 | 3 | 1471 |
| 9 | Savanna | 10 | 53 | 1 | 0 | 21 | 18 | 48 | 93 | 440 | 43 | 1 | 252 | 79 | 0 | 16 | 1075 |
| 10 | Grasslands | 2 | 16 | 0 | 2 | 20 | 4 | 179 | 6 | 101 | 632 | 0 | 249 | 13 | 0 | 363 | 1587 |
| 11 | Pmnt Wtlnd | 63 | 24 | 0 | 5 | 28 | 23 | 1 | 2 | 36 | 2 | 89 | 1 | 7 | 0 | 0 | 281 |
| 12 | Cropland | 6 | 75 | 2 | 7 | 16 | 8 | 61 | 42 | 132 | 133 | 2 | 5168 | 183 | 0 | 18 | 5853 |
| 14 | Cropland/Natural Vegn | 2 | 133 | 0 | 48 | 28 | 2 | 8 | 16 | 66 | 8 | 1 | 320 | 832 | 0 | 7 | 1471 |
| 15 | Snow+ice | 1 | 0 | 0 | 0 | 0 | 1 | 2 | 0 | 0 | 0 | 5 | 1 | 0 | 1297 | 5 | 1312 |
| 16 | Barren | 0 | 2 | 1 | 0 | 0 | 1 | 162 | 4 | 5 | 126 | 3 | 56 | 5 | 14 | 3537 | 3916 |
| | Total | 2195 | 5533 | 241 | 681 | 2260 | 270 | 1722 | 940 | 1035 | 1286 | 162 | 6793 | 1277 | 1311 | 4171 | 29877 |

Accuracy = 21906 / 29877 = 73.3%

# A SIMPLER CONFUSION MATRIX

Zoom in on just two of those categories:

| Site Class | Class Name | | |
|---|---|---|---|
| | | 1 | 2 |
| 1 | Evergreen Needleleaf | 1460 | 42 |
| 2 | Evergreen Broadleaf | 31 | 4889 |

Model predicts: Is this evergreen forest needleleaf or broadleaf

# ACCURACY

Easy to calculate **accuracy**:

| | Pred. Needle | Pred. Broad | Sum |
|---|---|---|---|
| Obs. Needle | 1460 | 42 | 1502 |
| Obs. Broad | 31 | 4889 | 4920 |
| Sum | 1491 | 4931 | 6422 |

$$A = \frac{1460 + 4889}{1460 + 4889 + 42 + 31} = 98.9$$

# ACCURACY

But **random** models can have reasonable accuracy!

| | Pred. Needle | Pred. Broad | Sum |
|---|---|---|---|
| Obs. Needle | 729 | 773 | 1502 |
| Obs. Broad | 2465 | 2455 | 4920 |
| Sum | 3194 | 3228 | 6422 |

$$A = \frac{729 + 2455}{6422} = 49.6$$

# ACCURACY

And so can stupid ones: **everything is a broadleaf**.

| | Pred. Needle | Pred. Broad | Sum |
|---|---|---|---|
| Obs. Needle | 0 | 1502 | 1502 |
| Obs. Broad | 0 | 4920 | 4920 |
| Sum | 0 | 6422 | 6422 |

$$A = \frac{0 + 4920}{6422} = 76.6$$

# PREVALENCE

**Prevalence** is simple the proportion of the observed positive outcomes:

$$\text{Prevalence} = \frac{1502}{6422} = 0.234$$

# ACCURACY

And **accuracy is affected by prevalence**

| | Pred. Needle | Pred. Broad | Sum |
|---|---|---|---|
| Obs. Needle | 0 | 35 | 35 |
| Obs. Broad | 0 | 6407 | 6407 |
| Sum | 0 | 6442 | 6442 |

$$A = \frac{0 + 6407}{6422} = 99.5$$

# PREDICTION OUTCOMES

Giving some simple names to the four outcomes:

| | **Pred. Needle** | **Pred. Broad** |
|---|---|---|
| Obs. Needle | True Positive | False Negative |
| Obs. Broad | False Positive | True Negative |

# PREDICTION OUTCOMES

Other more confusing names do get used:

| | **Pred. Needle** | **Pred. Broad** |
|---|---|---|
| Obs. Needle | True Positive | Type II Error |
| Obs. Broad | Type I Error | True Negative |

# RATES OF OUTCOMES

Divide the four outcomes by the **observed** positive and negative counts to give **rates**:

| | **Pred. Needle** | **Pred. Broad** |
|---|---|---|
| Obs. Needle | True Positive Rate | False Negative Rate |
| Obs. Broad | False Positive Rate | True Negative Rate |

# RATES OF OUTCOMES

Calculate those values:

| | Pred. Needle | Pred. Broad | Sum |
|---|---|---|---|
| Obs. Needle | $\frac{1460}{1502} = 97.2$ | $\frac{42}{1502} = 2.8$ | 1502 |
| Obs. Broad | $\frac{31}{4920} = 0.6$ | $\frac{4889}{4920} = 99.4$ | 4920 |

# SENSITIVITY AND SPECIFICITY

## Sensitivity

- Another name for the True Positive Rate
- The proportion of correctly predicted positive observations

## Specificity

- Another name for the True Negative Rate
- The proportion of correctly predicted negative observations

# SENSITIVITY AND SPECIFICITY

| | Pred. Needle | Pred. Broad | Sum |
|---|---|---|---|
| Obs. Needle | 1460 | 42 | 1502 |
| Obs. Broad | 2010 | 2910 | 4920 |
| Sum | 3470 | 2952 | 6422 |

Outcome rates for the new model above

| | Pred. Needle | Pred. Broad |
|---|---|---|
| Obs. Needle | 97.2% | 2.8% |
| Obs. Broad | 40.9% | 59.1% |

# COHEN'S KAPPA

Cohen's kappa ($\kappa$) is a measure of agreement that rescales accuracy ($A$) to account for chance agreement ($P_e$):

$$\kappa = \frac{A - P_e}{1 - P_e}$$

It can take values from $-\infty$ to 1, where 1 is perfect prediction and anything below zero is worse than chance.

# COHEN'S KAPPA

Multiply proportions of observed and predicted to get probability of each outcome

| | Pred. Needle | Pred. Broad | Sum |
|---|---|---|---|
| Obs. Needle | 1460 | 42 | 1502 |
| Obs. Broad | 31 | 4889 | 4920 |
| Sum | 1491 | 4931 | 6422 |

$$P_{YY} = \frac{1491}{6422} \times \frac{1502}{6422} = 0.054$$

# COHEN'S KAPPA

| | Pred. Needle | Pred. Broad | p |
|---|---|---|---|
| Obs. Needle | 0.054 | 0.180 | 0.234 |
| Obs. Broad | 0.178 | 0.588 | 0.766 |
| p | 0.232 | 0.768 | 1.000 |

$$P_e = P_{YY} + P_{NN}\kappa = \frac{0.989 - (0.054 + 0.588)}{1 - (0.054 + 0.588)} = 0.969$$

# TRUE SKILL STATISTIC

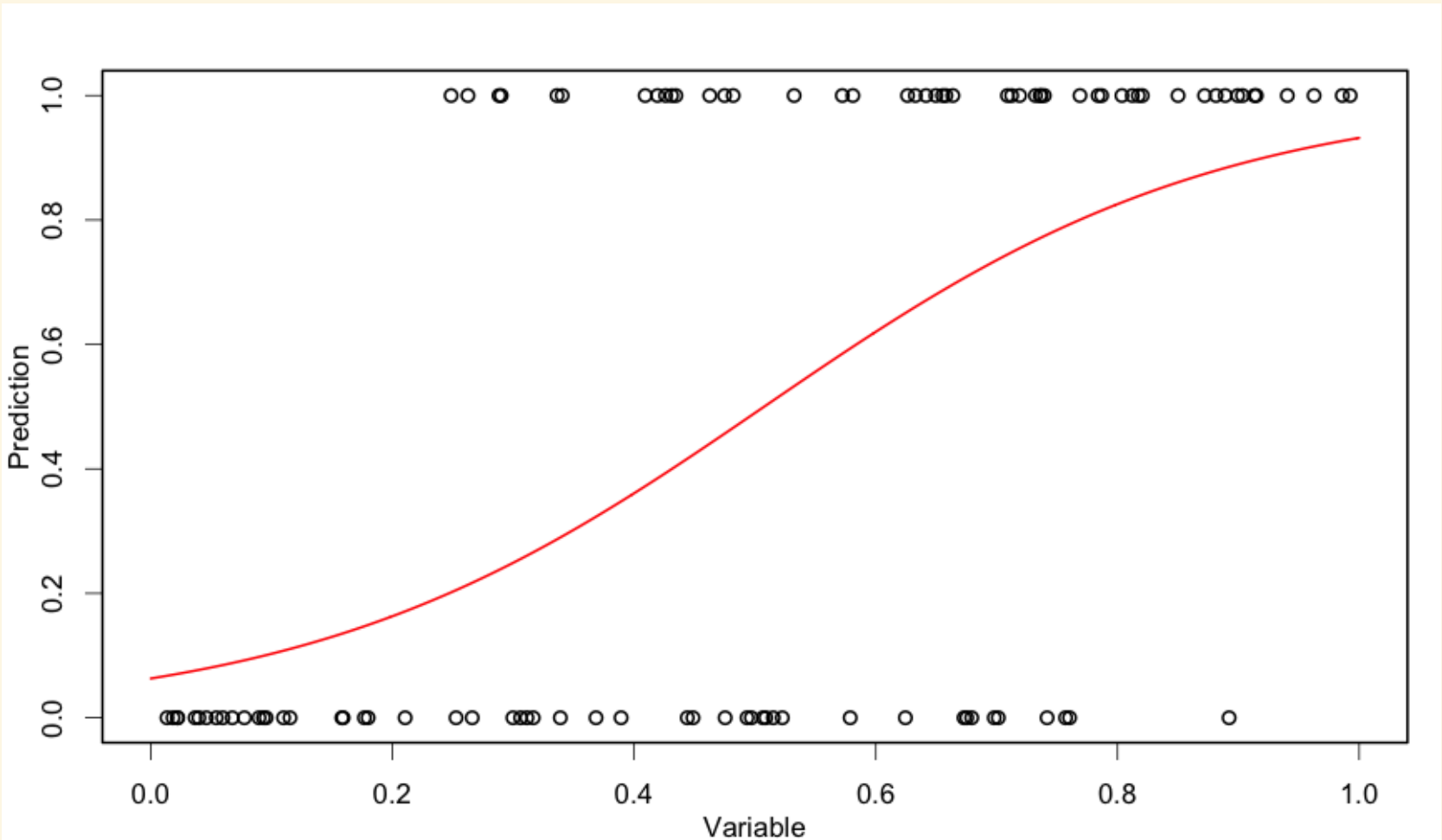
TODO - MathJax linebreak fix?
An alternative measure is TSS:

$$\text{TSS} = \text{Sensitivity} + \text{Specificity} - 1 \; \text{TSS} = [0, 1] + [0, 1] - 1$$

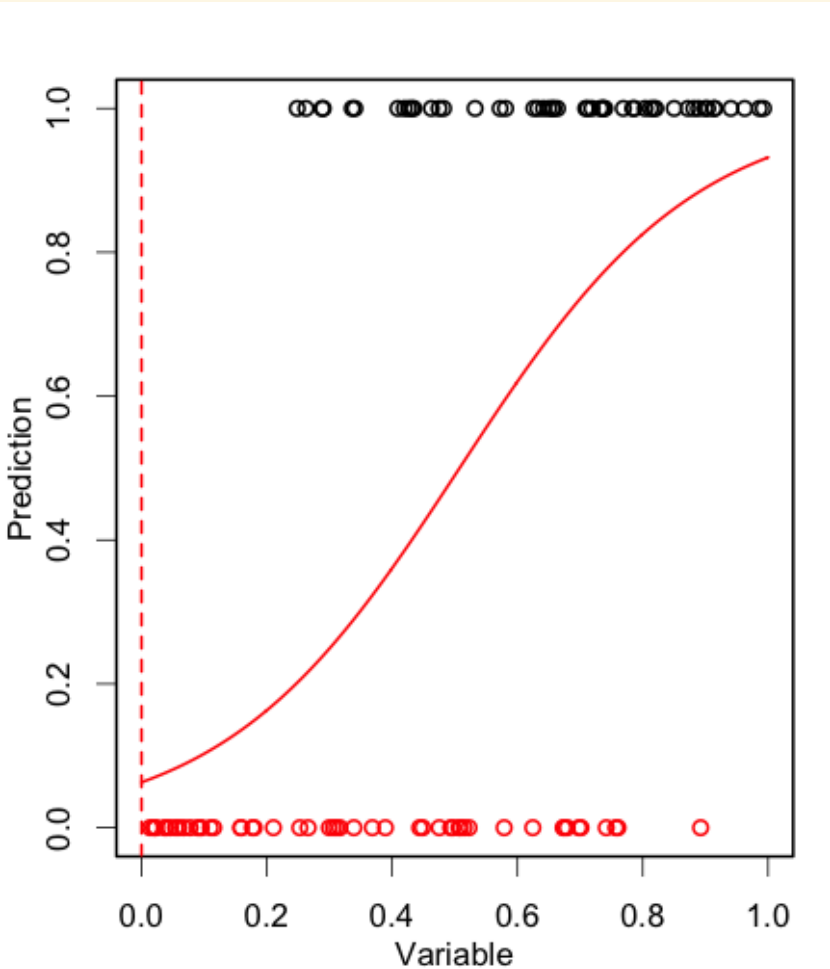
- TSS = 1 (perfect)
- TSS = 0 (random)
- TSS = -1 (always wrong)
- Unaffected by prevalence.

# THRESHOLD MODEL

A model predicting the probability of success.



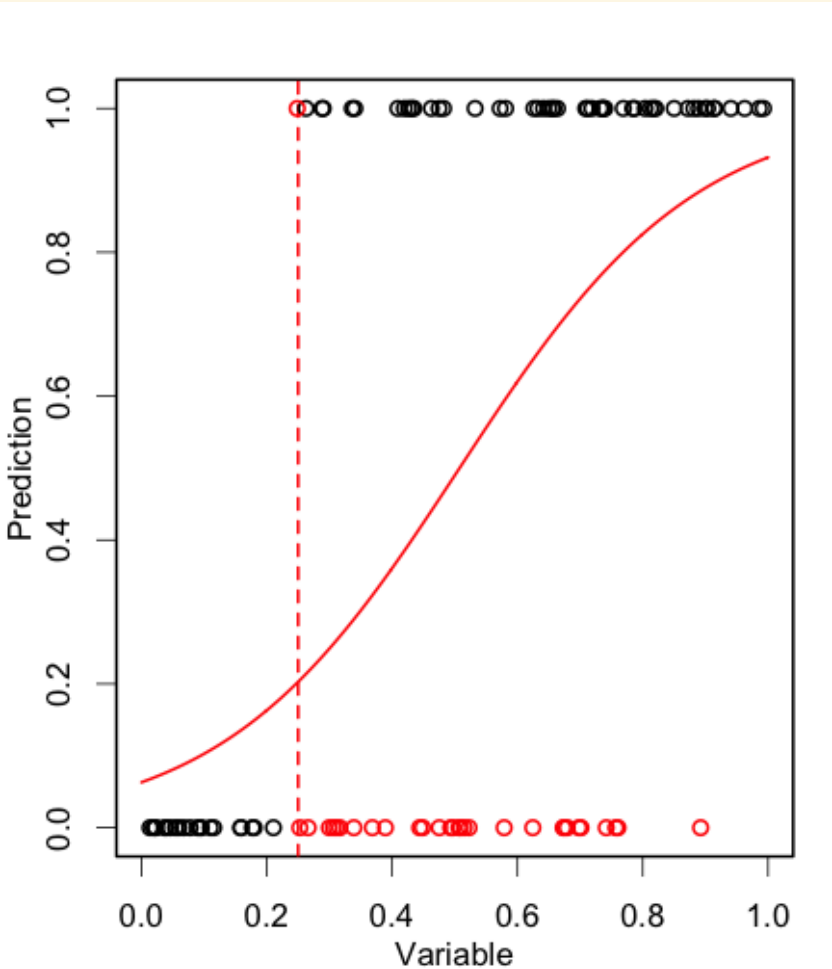
# THRESHOLD MODEL




| | 0 | 1 |
|---|---|---|
| 1 | 0 | 50 |
| 0 | 0 | 50 |

| | value |
|---|---|
| Sens | 1 |
| Spec | 0 |
| TSS | 0 |

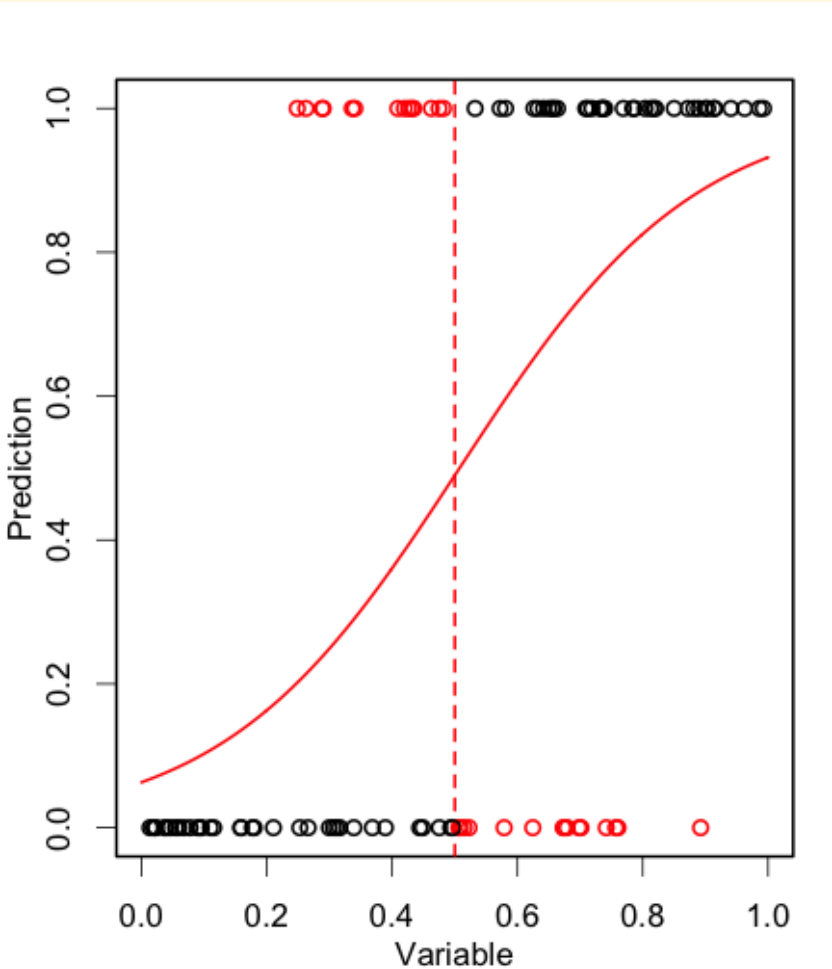
# THRESHOLD MODEL




| | 0 | 1 |
|---|---|---|
| 1 | 1 | 49 |
| 0 | 21 | 29 |

| | value |
|---|---|
| Sens | 0.98 |
| Spec | 0.42 |
| TSS | 0.40 |

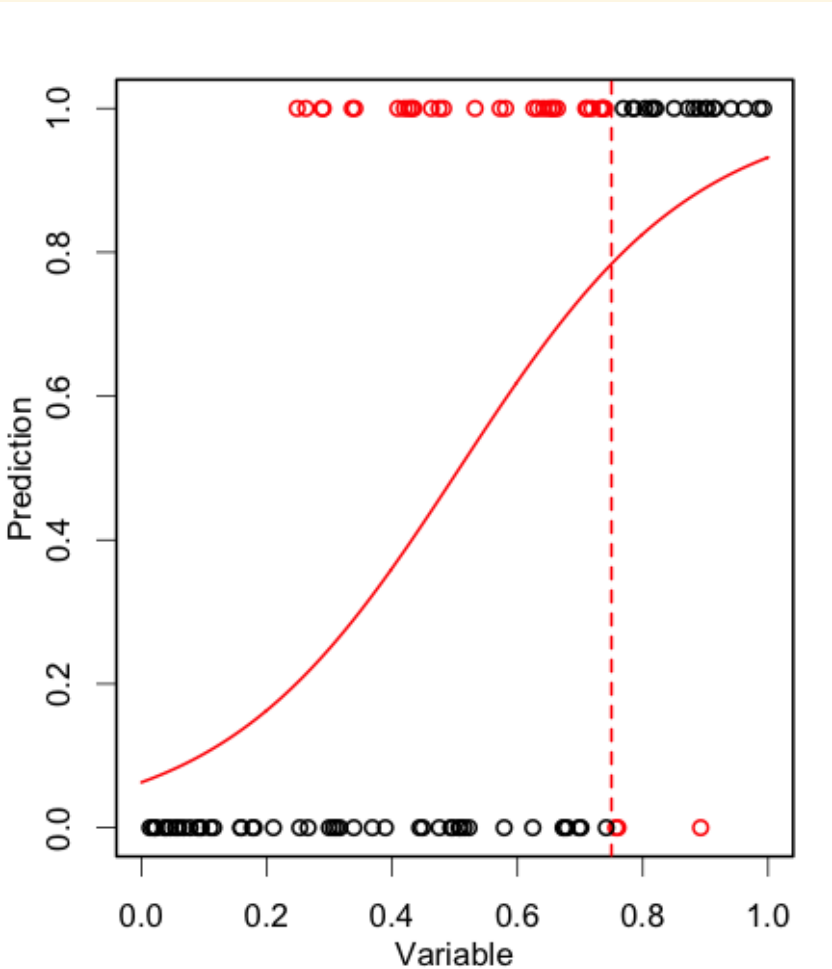
# THRESHOLD MODEL




| | 0 | 1 |
|---|---|---|
| 1 | 14 | 36 |
| 0 | 35 | 15 |

| | value |
|---|---|
| Sens | 0.72 |
| Spec | 0.70 |
| TSS | 0.42 |

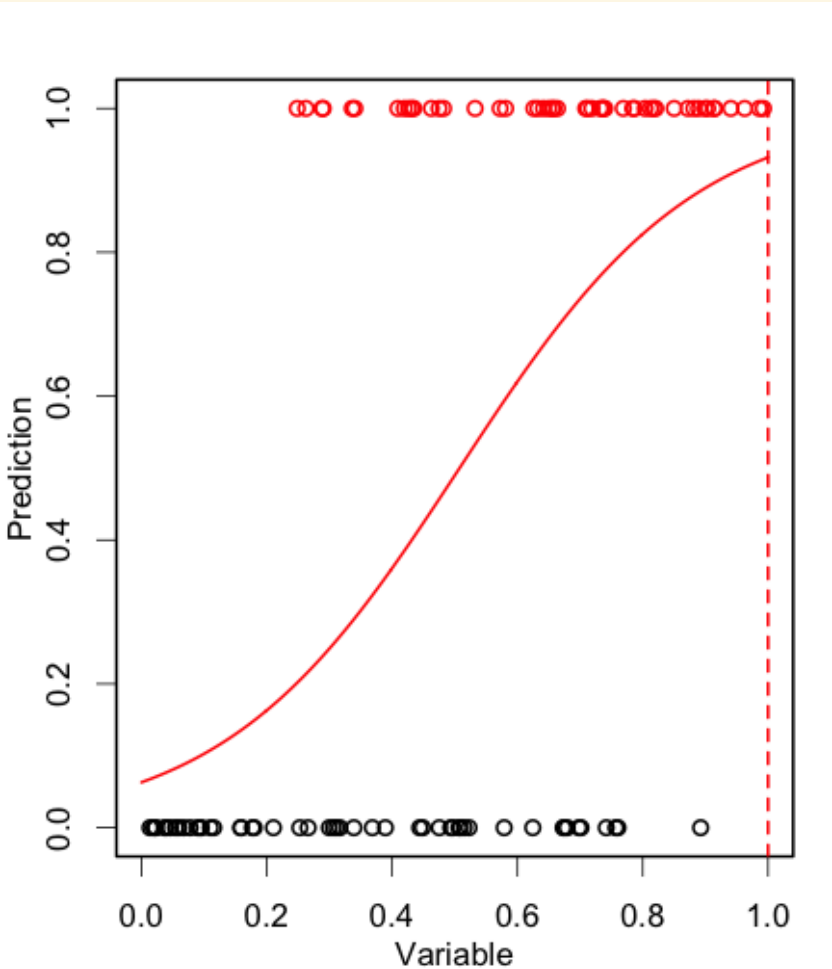
# THRESHOLD MODEL




| | 0 | 1 |
|---|---|---|
| 1 | 31 | 19 |
| 0 | 47 | 3 |

| | value |
|---|---|
| Sens | 0.38 |
| Spec | 0.94 |
| TSS | 0.32 |

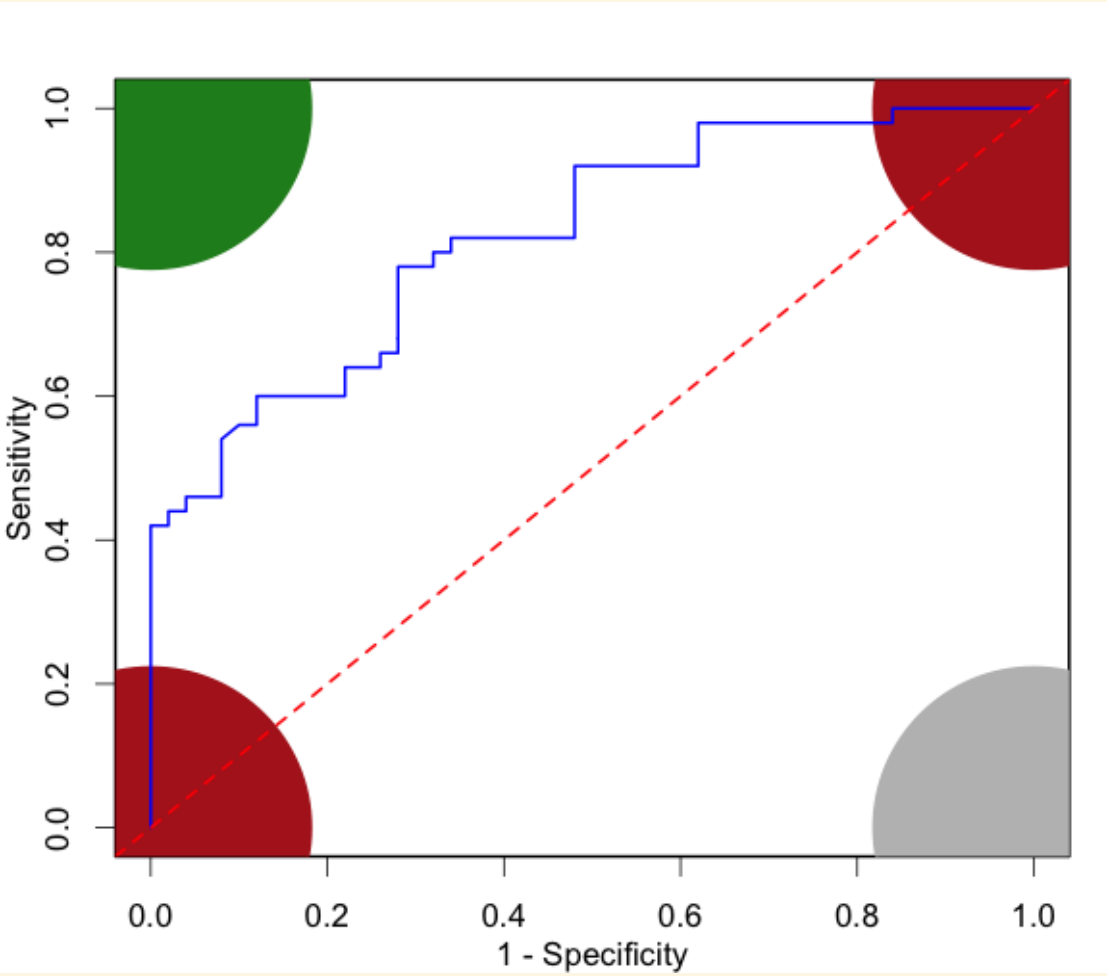
# THRESHOLD MODEL




| | 0 | 1 |
|---|---|---|
| 1 | 50 | 0 |
| 0 | 50 | 0 |

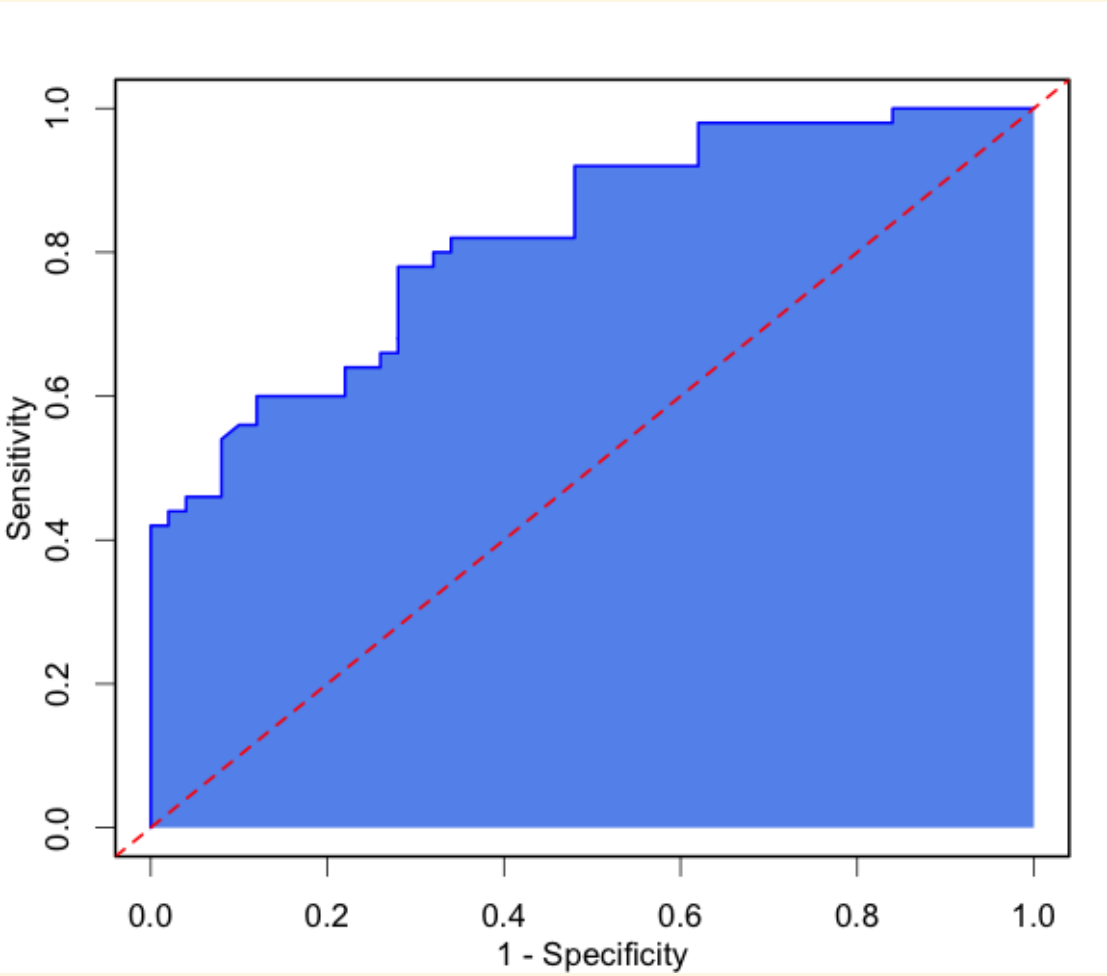
| | value |
|---|---|
| Sens | 0 |
| Spec | 1 |
| TSS | 0 |

# ROC CURVE




- Receiver operating characteristic (ROC)
- A random model gives the red line

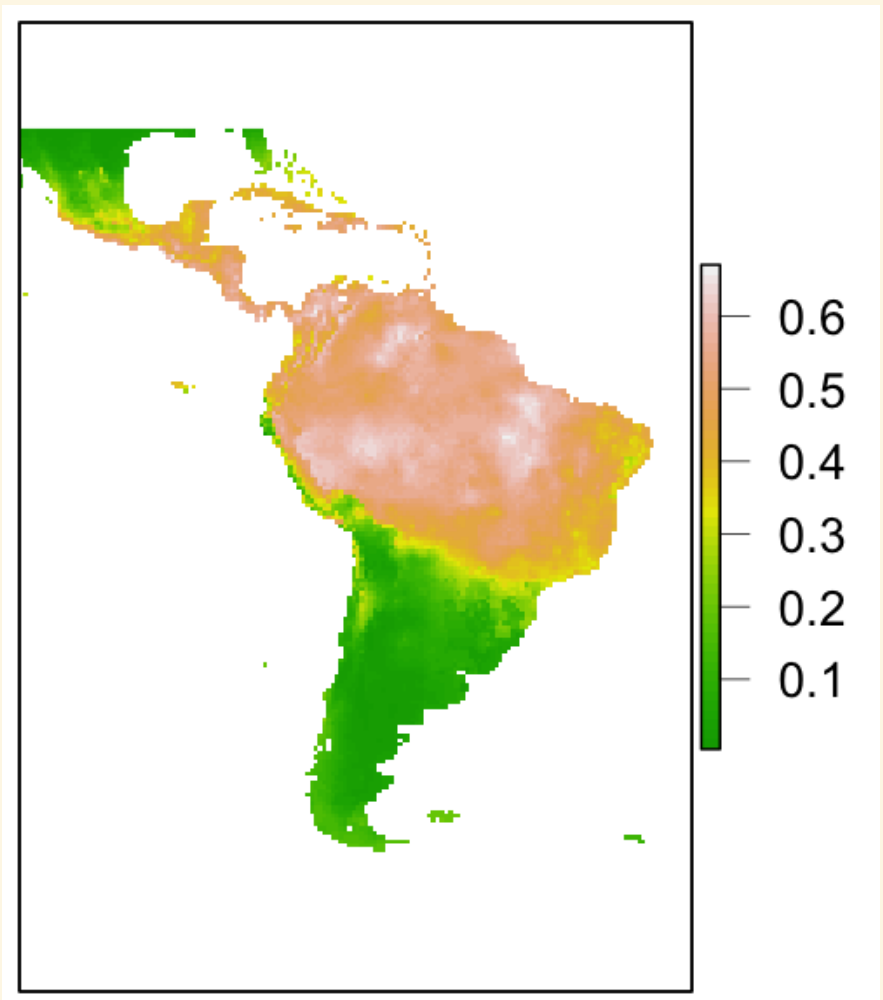
# AREA UNDER ROC CURVE (AUC)




- AUC varies between 0 and 1.
- AUC = 0.5 is random.
- Overall model performance

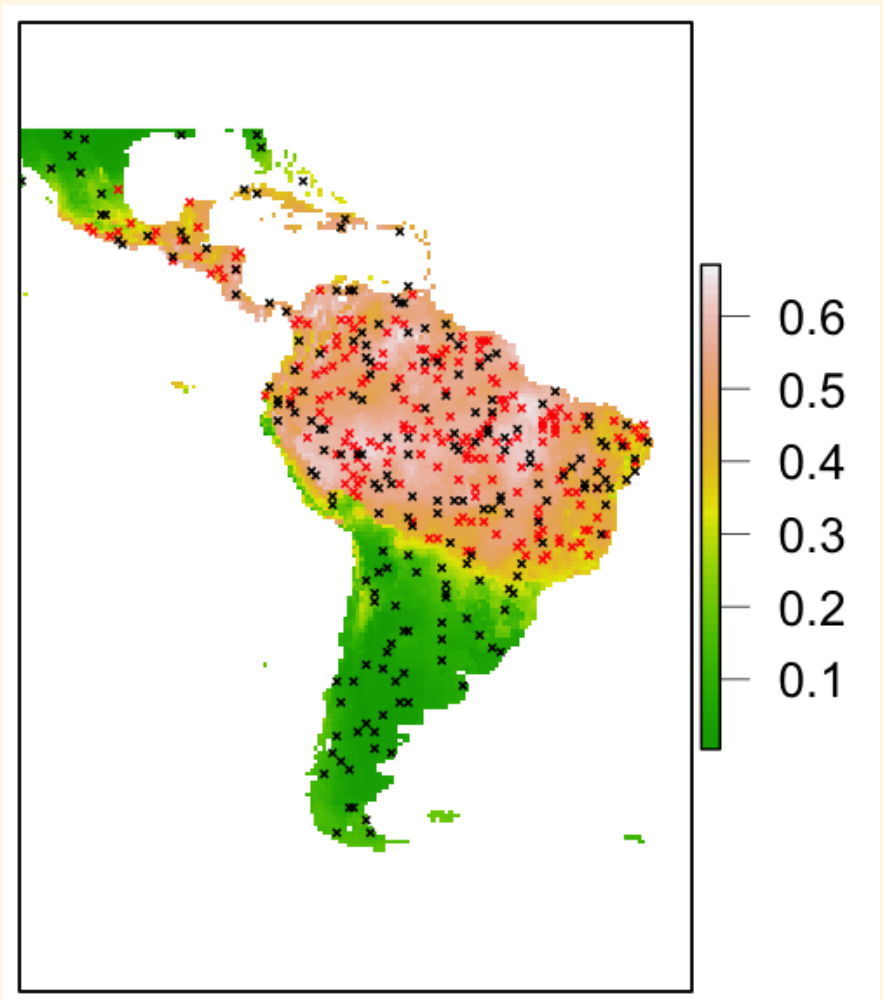
# SPECIES DISTRIBUTION MODELS

Kinkajou (*Potos flavus*)

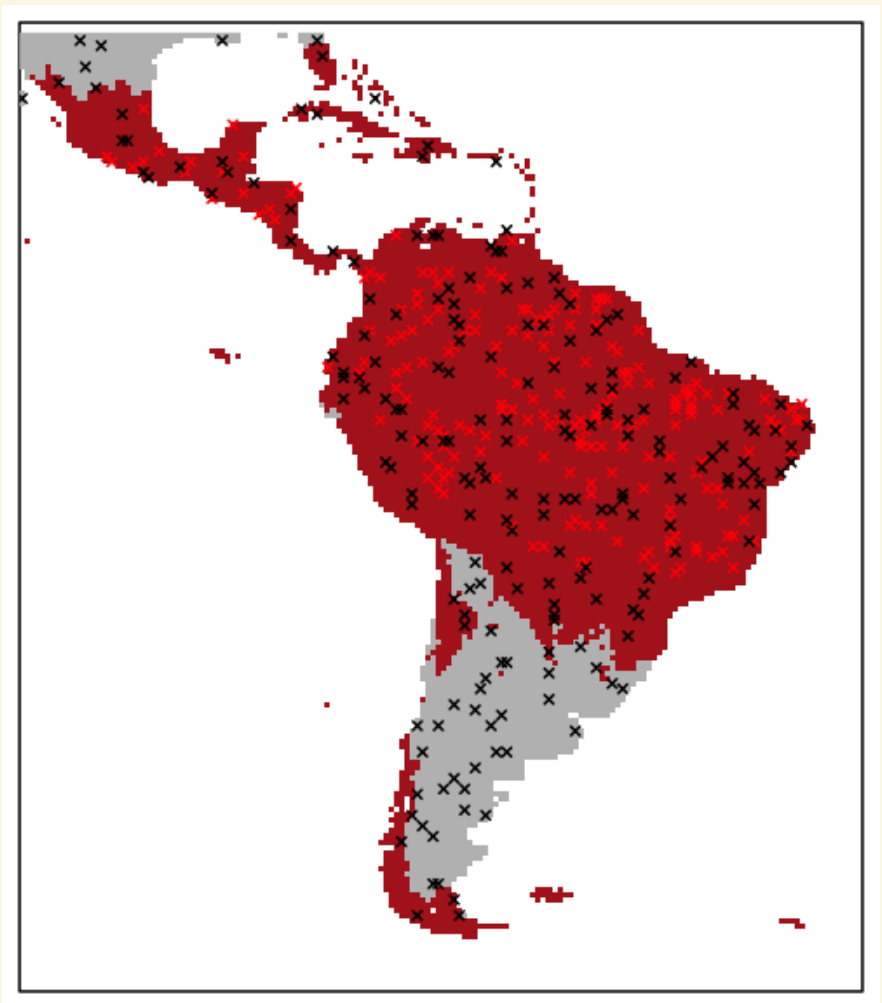


# SPECIES DISTRIBUTION MODELS

- Observed (red)
- Background (black)



# SPECIES DISTRIBUTION MODELS

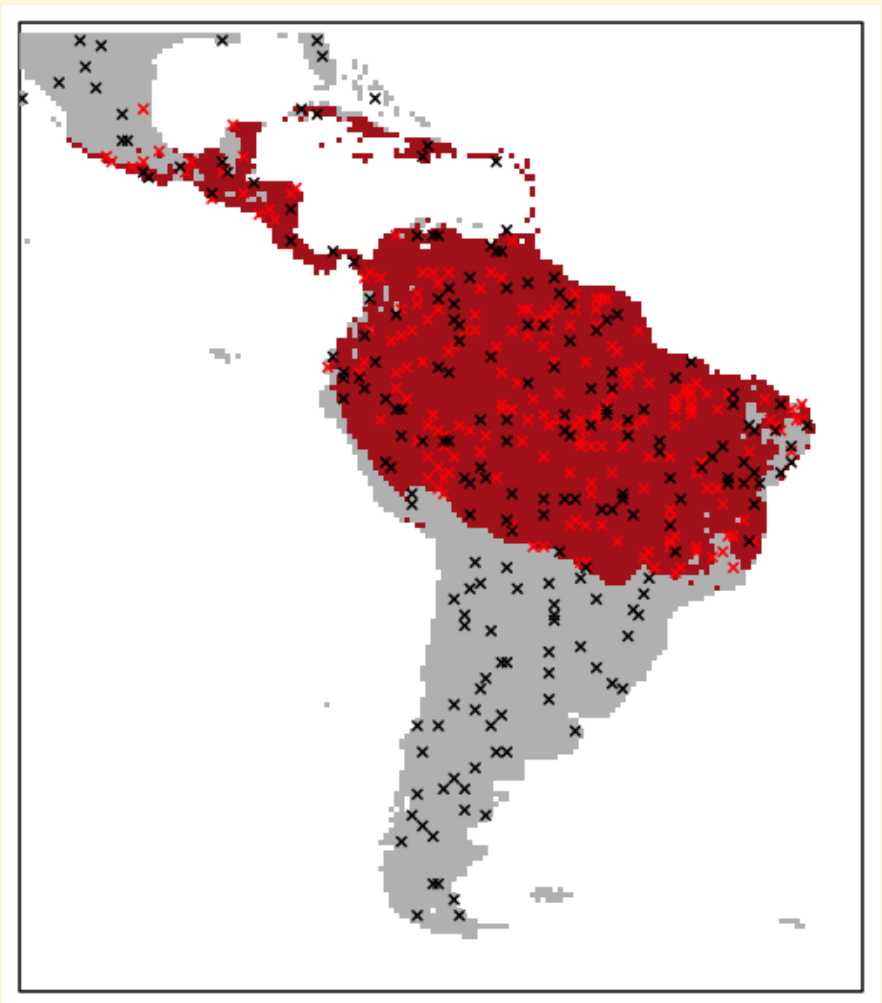


Threshold = 0.1

| | Present | Absent |
|---|---|---|
| Obs | 200 | 0 |
| Back | 159 | 41 |

| | value |
|---|---|
| Sens | 0.205 |
| Spec | 1.000 |
| TSS | 0.205 |

# SPECIES DISTRIBUTION MODELS

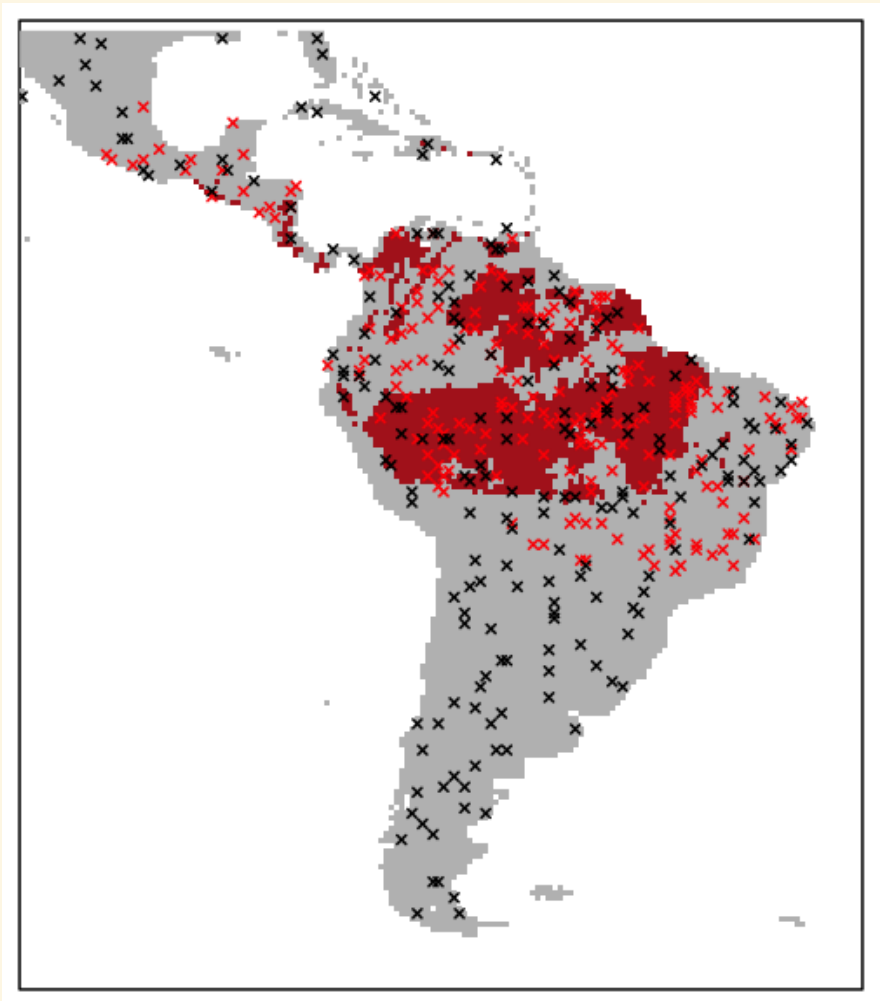


Threshold = 0.4

| | Present | Absent |
|---|---|---|
| Obs | 186 | 14 |
| Back | 121 | 79 |

| | value |
|---|---|
| Sens | 0.395 |
| Spec | 0.930 |
| TSS | 0.325 |

# SPECIES DISTRIBUTION MODELS



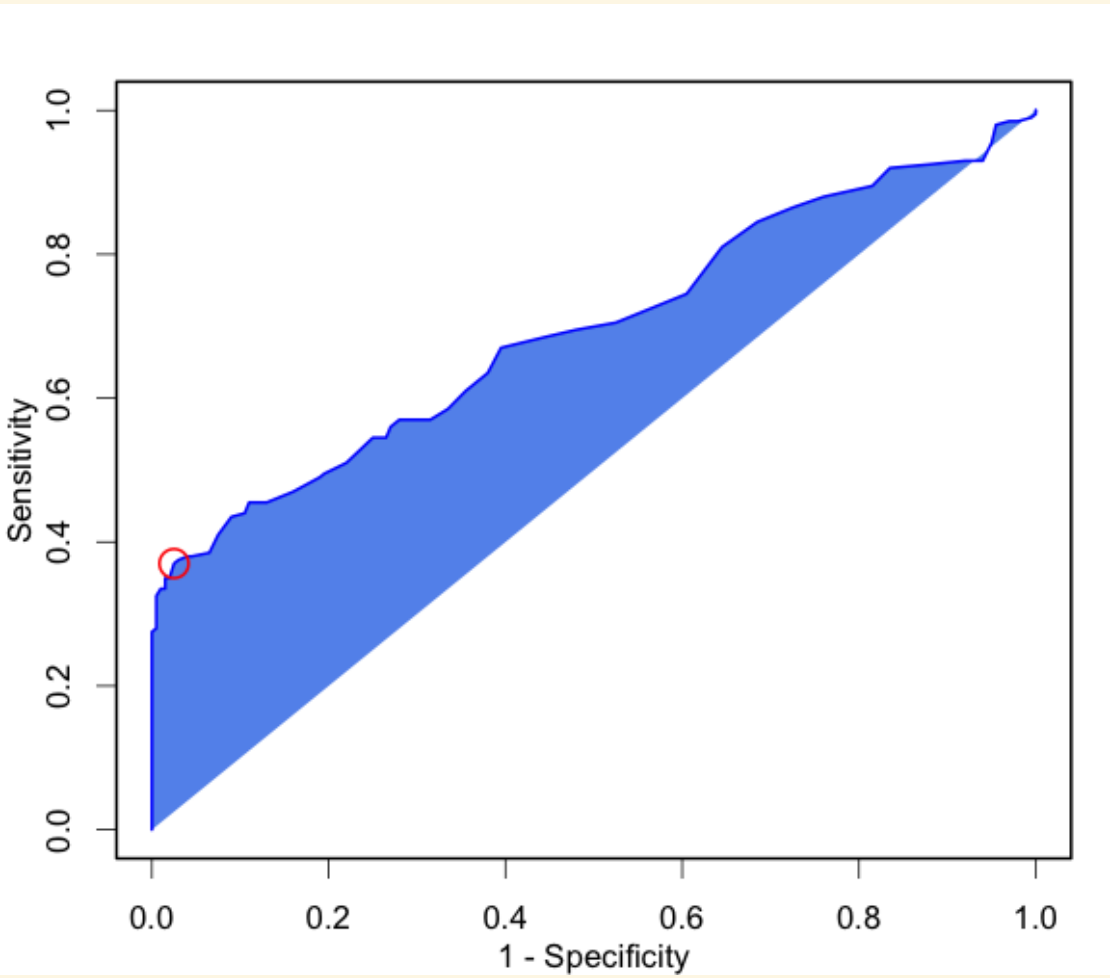
Threshold = 0.55

| | Present | Absent |
|---|---|---|
| Obs | 80 | 120 |
| Back | 51 | 149 |

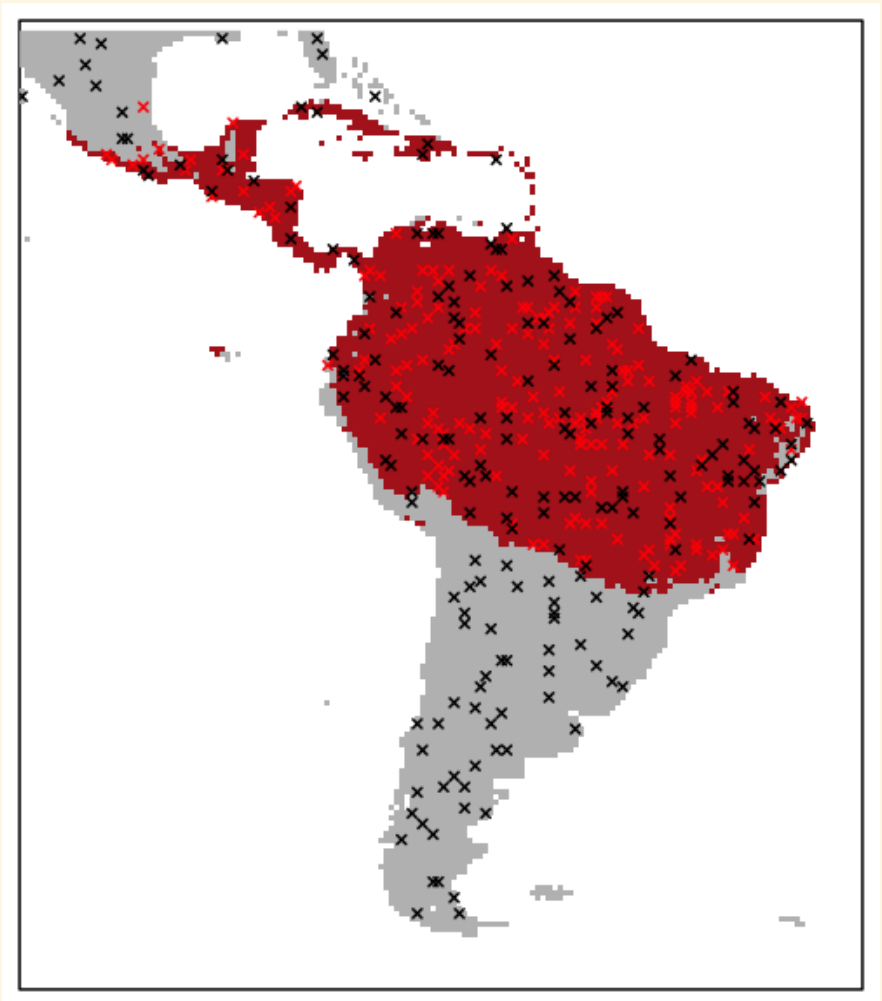
| | value |
|---|---|
| Sens | 0.745 |
| Spec | 0.400 |
| TSS | 0.145 |

# AUC FOR THE KINKAJOU

Maximum sensitivity + specificity shown in red.



# SPECIES DISTRIBUTION MODELS



Threshold = 0.371

| | Present | Absent |
|---|---|---|
| Obs | 195 | 5 |
| Back | 126 | 74 |

| | value |
|---|---|
| Sens | 0.370 |
| Spec | 0.975 |
| TSS | 0.345 |

# THRESHOLD CHOICES

| Method | Definition |
|---|---|
| Fixed value | An arbitrary fixed value (e.g. probability = 0.5) |
| Lowest predicted value | The lowest predicted value corresponding with an observed occurrence record |
| Sensitivity-specificity equality | The threshold at which sensitivity and specificity are equal |
| Sensitivity-specificity sum maximization | The sum of sensitivity and specificity is maximized |
| Maximize Kappa | The threshold at which Cohen's Kappa statistic is maximized |
| Equal prevalence | Propn of presences relative to the number of sites is equal in prediction and calibration data |

# FAST MOVING FIELD