Determining Suitable Habitats for Red Wolves Using Fuzzy Logic-Based Modeling and Monte Carlo Simulation

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Outline

• Red wolf conservation history
• Research questions and study goals
• Methodology
• Results
• Discussion
• Future research directions
• Conclusions

Photo credit: Animal Reference Photo (Deviant Art)
Introduction

- Red wolves declared extinct in 1980
- Wide historic range, now restricted to a small area along NC Coast
- Anthropogenic and environmental stresses encourage exploring alternative reintroduction sites
Research Question: What is the area of suitable habitat available for red wolves in South Carolina, Arkansas, and West Virginia? Of the variables considered in the habitat model, which is the most limiting in terms of restricting habitat area?

Assumptions of the Model:
1. Habitat vs. Niche
2. Static vs. Dynamic
3. Single Species vs. Species in Community
4. Perfect vs. Imperfect Habitat Use
5. Probability vs. Possibility

Conventional Suitability Models:
Fuzzy Membership

How do we determine the ‘membership’ of slope? How do we know whether a slope is definitely a member of one of these classes, or a member of one or more these classes to a varying degree?

How do we determine the ‘membership’ of slope? How do we know whether a slope is definitely a member of one of these classes, or a member of one or more these classes to a varying degree?

- It’s possible cell is a member of Class X
- Somewhat a member of Class X
- It’s not possible cell is a member of Class X
Fuzzy Overlay

More Conventional Overlay Approaches:

- Weighted Overlay
- Boolean Overlay
- Number of Criteria Met

Limitations of these approaches:
1. Individual information of inputs lost when aggregated
2. Little detail provided with outputs

What information do Fuzzy Overlays provide that conventional approaches do not?
Fuzzy Overlay

Types of Fuzzy Overlay:

- Fuzzy And - Outputs minimum fuzzy number in set
  Bottleneck approach, identify lowest membership among elements
- Fuzzy Or - Outputs the maximum fuzzy number in set
  Identify cells with high membership among elements
- Fuzzy Sum - Outputs the sum of the fuzzy set
  Combination more important than individual inputs
- Fuzzy Product - Outputs the algebraic product of fuzzy set
  Individual inputs more important than combination

‘Fuzzy And’ Approach for High Suitability Habitat

Fuzzy And Overlay Inputs:
- High Suitability
- Fuzzy Memberships
Of 4 input variables

Fuzzy And Overlay Output
High Membership (1)
Low Membership (0)
Defuzzification

Fuzzy And Overlay Output

After Defuzzification

- Green: Meets Minimum Membership of 0.5
- Red: Does not meet minimum membership of 0.5
But there is uncertainty in suitability analysis based on the classification of the input variables and the value of the membership within that class.
Monte Carlo Simulation

- Used to quantify possible outcomes given uncertainty in the input data

- Ran 500 iterations of the habitat model randomly changing the min/max of the fuzzy membership

- Recorded the range of uncertainty regarding area of high suitability wolf habitat habitat after Fuzzy And approach

#Run the Process
for i in xrange(500):
Fuzzy Membership

1. **Slope**
   - Class 1: Good Quality
   - Class 2: Medium Quality
   - Class 3: Low Quality

2. **Road Density**
   - Class 1: Good Quality
   - Class 2: Medium Quality
   - Class 3: Low Quality

3. **Distance from Water**
   - Class 1: Low Quality
   - Class 2: Medium Quality
   - Class 3: High Quality

4. **Distance from Major Road**
   - Class 1: Low Quality
   - Class 2: Medium Quality
   - Class 3: High Quality

The diagrams show the fuzzy membership for each class based on the different factors.
Results

- Distribution of High Suitability Habitat Area Determined by a Monte Carlo Simulation After 500 Runs
  - South Carolina
  - West Virginia
  - Arkansas

- Histograms showing frequency distribution of area of high quality habitat in sq. km.
  - South Carolina: Area ranges from 5500 to 8000 sq. km.
  - West Virginia: Area ranges from 1400 to 19000 sq. km.
  - Arkansas: Area ranges from 15000 to 19000 sq. km.
Discussion

• This approach can be useful to determine the possibility of habitat suitability

• Fuzzy overlays provide more detail and information that is useful for habitat modeling compared with conventional approaches

• Different fuzzy overlay approaches can also be informative as the process maintains individual input values and their membership value

• The fuzzy classification provides a common and relative scale by which we can compare the suitability of different areas

• Monte Carlo simulations can be used to quantify the uncertainty regarding the minimum and maximum fuzzy membership values
Discussion

• Possible habitat variables were omitted, niche factors were not part of the model

• All variables were equally weighted, might be an oversimplification

• Membership curves were all linear in this analysis, more information might be found exploring other membership curve shapes

• Fuzzy represented possibility, however, uncertainty related to probability is also useful to model for conservation purposes

• Monte Carlo simulations and fuzzy analysis can be computationally expensive
Future Research

• Identify which variables are limiting factors based on fuzzy-based logic
• See how fuzzy logic changes calculations of patch distance/patch size and apply network based connectivity models to fuzzify process and quantify uncertainty of this measure
• More work can be done to understand medium suitability habitat and low suitability habitat areas using different fuzzy memberships and overlays
• Additional rule-based systems can be developed for analysis of habitat based on fuzzy class memberships
Conclusions

- Fuzzy logic-based approach to habitat model can provide useful information on the possibility of habitat suitability for different areas

- Arkansas has the largest area of high suitability habitat of the three study sites based on this method

- Only presented the area of high suitability habitat, but there are many other important characteristics of habitat

- Future directions include exploring more membership curves and seeing how this uncertainty affects measures of connectivity and fragmentation
References


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