Using Regression-based Sensitivity Analysis in Exploratory Modeling of Complex Spatial Systems: An Example of Simulating the Impact of Agricultural Water Withdrawals on Fish Habitat

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http://mi.water.usgs.gov/reports/images/cover_med01_4227.jpg

Research Question:

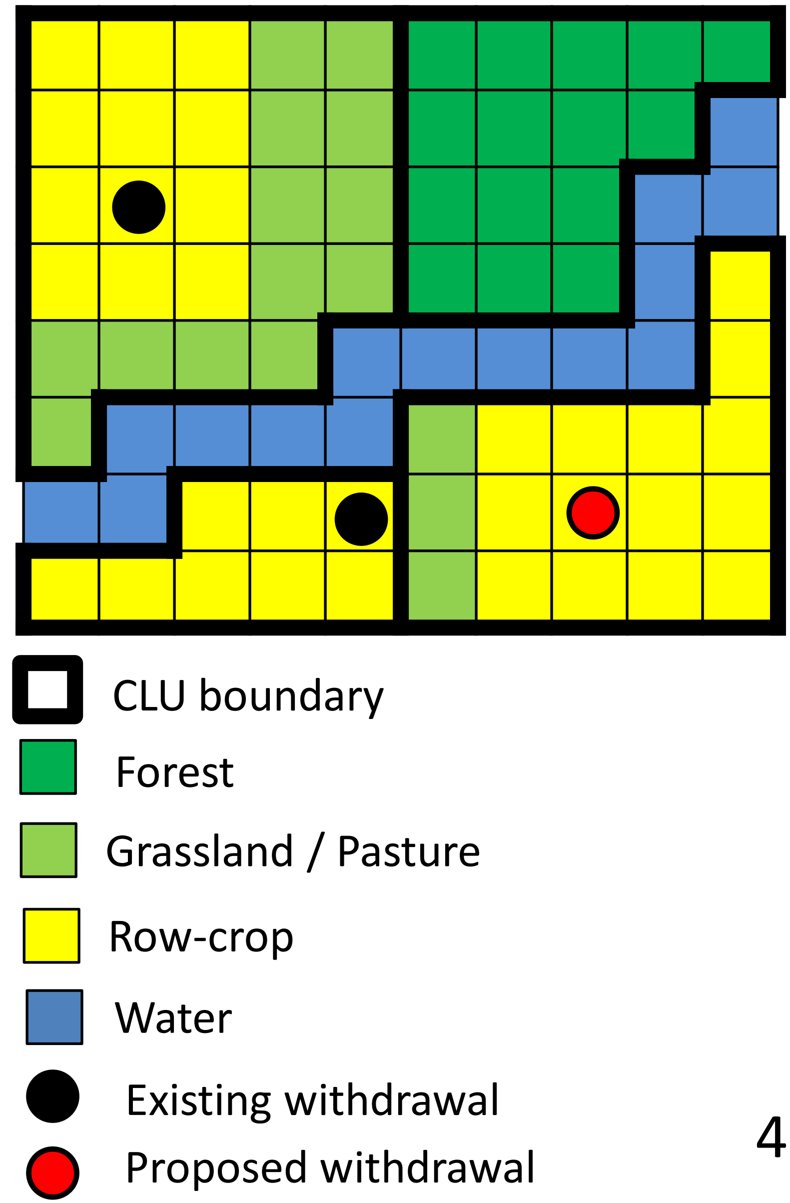
What issues arise in employing regression techniques to evaluate the sensitivity of a complex, agent-based spatial model to its individual parameters?

Overview:

- Conceptual agent-based model of fish habitat impacts from agricultural water withdrawals.
- Model sensitivity analysis through OLS regression.
- Issues with count data
- OLS alternative: negative binomial with hurdle

Conceptual Model

- Farmlands (CLUs) (land owner agents)
- Agricultural Demand Index
- Likelihood of CRP enrollment
- Land use change decisions – withdrawal installations
- **Reductions in baseflow**[1]
- **Decline in fish sustainability**[2]

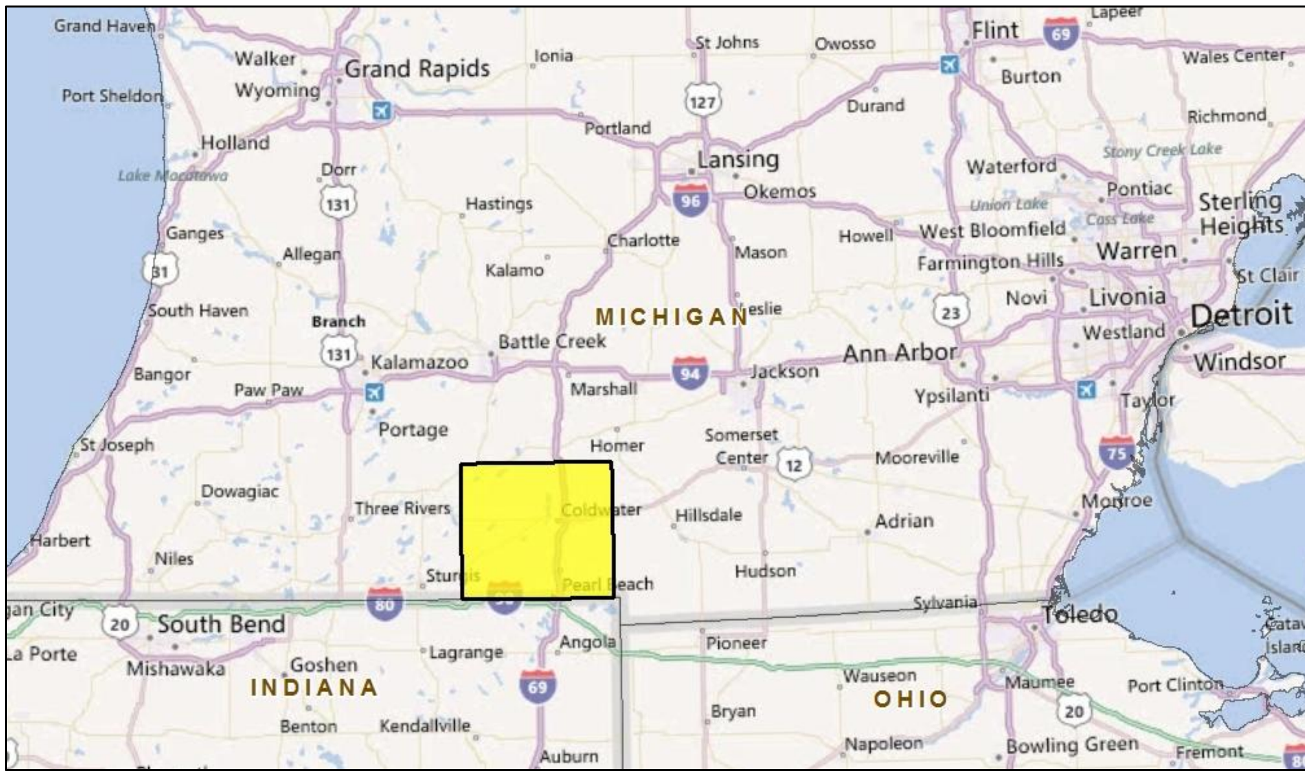


1. Reeves 2008.
2. Zorn, et. al. 2008.

Study Area

Branch County , Michigan

- Mainly Ag (65%)
- Well draining soils (85% B soils, 10% A)
- CLU data available



Fish Habitat Data

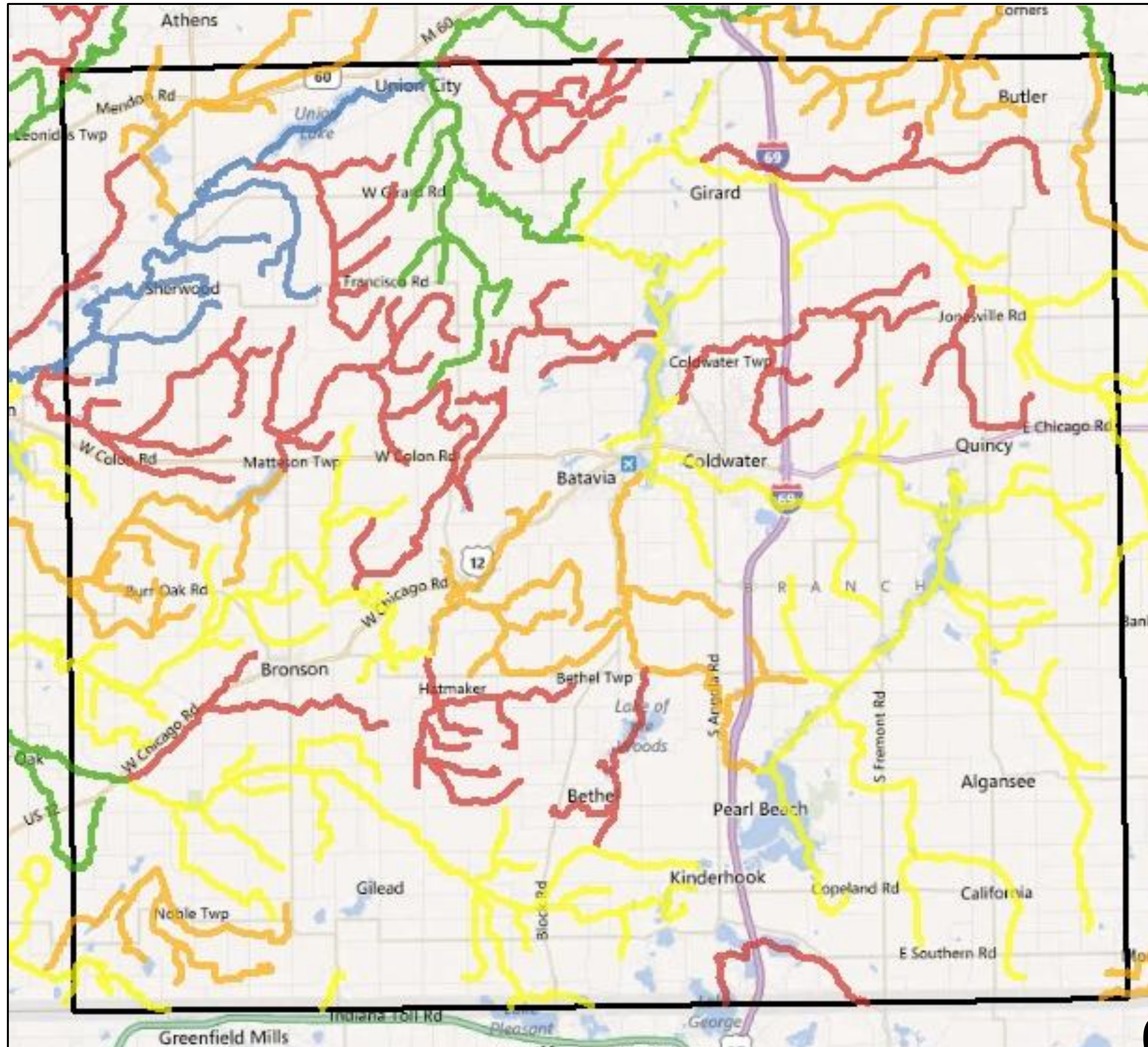
M-DNR:

- Tolerable baseflow reductions

Sensitive Fish Sustainability

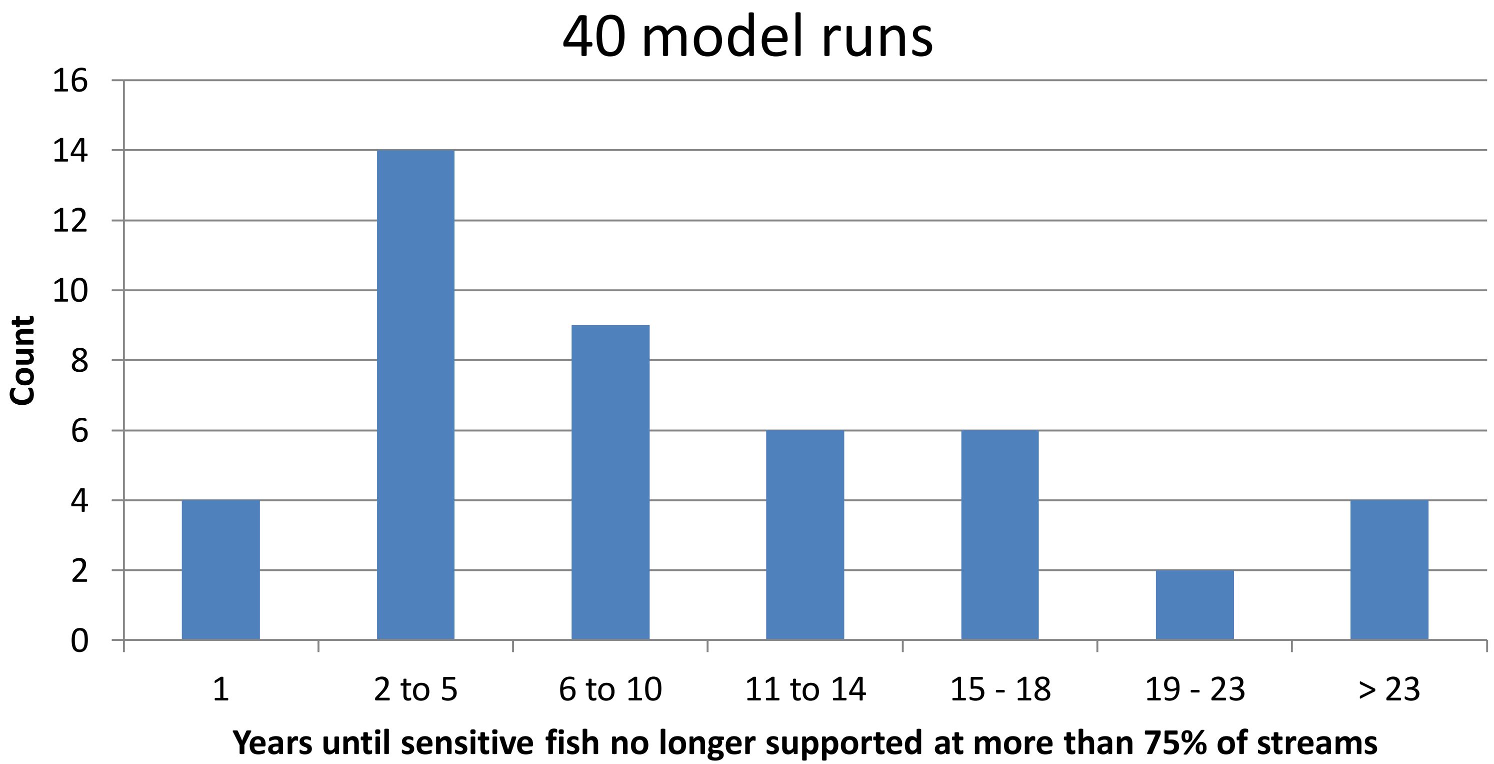
Available GW Depletion (GPM)

- 107 - 243
- 244 - 515
- 516- 1,887
- 1,888 - 3,140
- 3,141 - 10,507



Model Output / Dependent Variable

- Change in fish habitat sustainability over time (*Years To Stop*)
  - Reduction in baseflow
  - Change in stream fish habitat classification



Model Parameter Categories / Regression Independent Vars.

- Crops
  - area %
  - prices
  - price variability
- CRP enrollment
  - starting enrollment
  - probability of re-enrollment
  - contract length
- Land cover change probabilities
  - Given revenues of $X, probability that a producer would convert Y to Z.
- Decision thresholds
  - revenue level above which producers will consider increased irrigation, below which they will consider CRP

Model Sensitivity Analysis

- Ran the model over 1,400 times with randomly selected parameter values
- Employed OLS regression
  - -DV: Years until 75% of streams no longer support sensitive fish
  - - IVs: model parameters
- Expectations

Starting corn prices	-
Starting soy prices	-
Corn area %	-
Soy area %	-
Crop price variability	?
Soy price variability	?
Corn yield per acre	-
Soy yield per acre	-

Revenue threshold to move land into production	+
Revenue threshold to move land into conservation	-
Ratio of market increase to CRP decrease	-
Starting % enrolled in CRP	+
CRP contract length	+
CRP renewal probability	+
Probability of conversion to pasture	+
Probability of conversion to forest	+
Probability of conversion to wetland	+

Model Sensitivity Analysis

- Identified best models through an exhaustive approach
  - 17 model parameters
  - max of 7 independent variables at a time
  - 41,226 regressions
  - sorted by R2, F-statistic, % of significant terms

- Is this rummaging?
  - Not trying to explore or discover variable relationships
  - The model is programmed to have relationships
  - Trying to identify weights of individual variables

Model Sensitivity Analysis

- Best OLS model

ln(Years to stop) =	2.23 – (0.173* corn price) – (0.141*corn price variability) – (0.009*corn yield) – (0.010*soy yield) + (0.002 * land production revenue threshold)
R2	0.35
F-statistic prob.	< 0.001
Sig. ind. vars	all

- Standardized coefficients

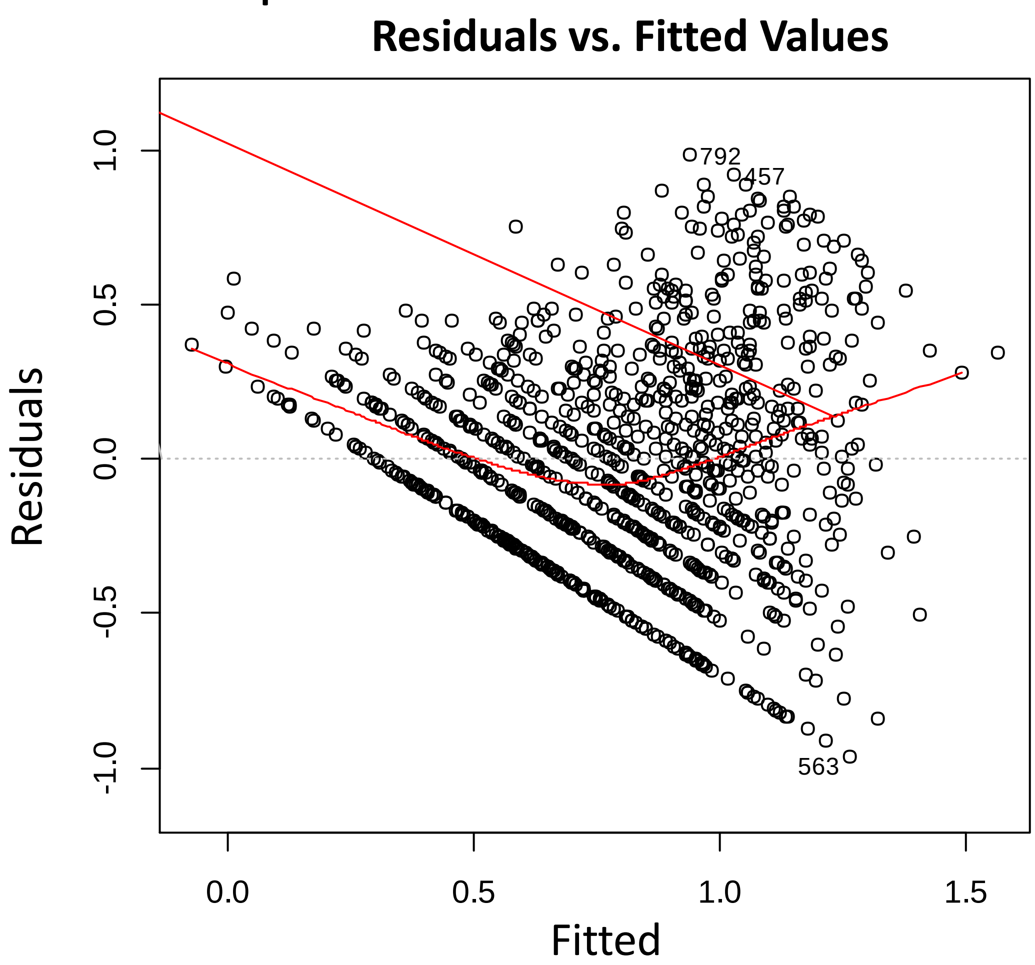
Corn price	-0.444
Soy yield	-0.328
Corn yield	-0.303
Land production revenue threshold	0.268
Corn price variability	-0.230

Model Sensitivity Analysis

Further inspection showed a poor fit

Why?

DV is a count, OLS won't work

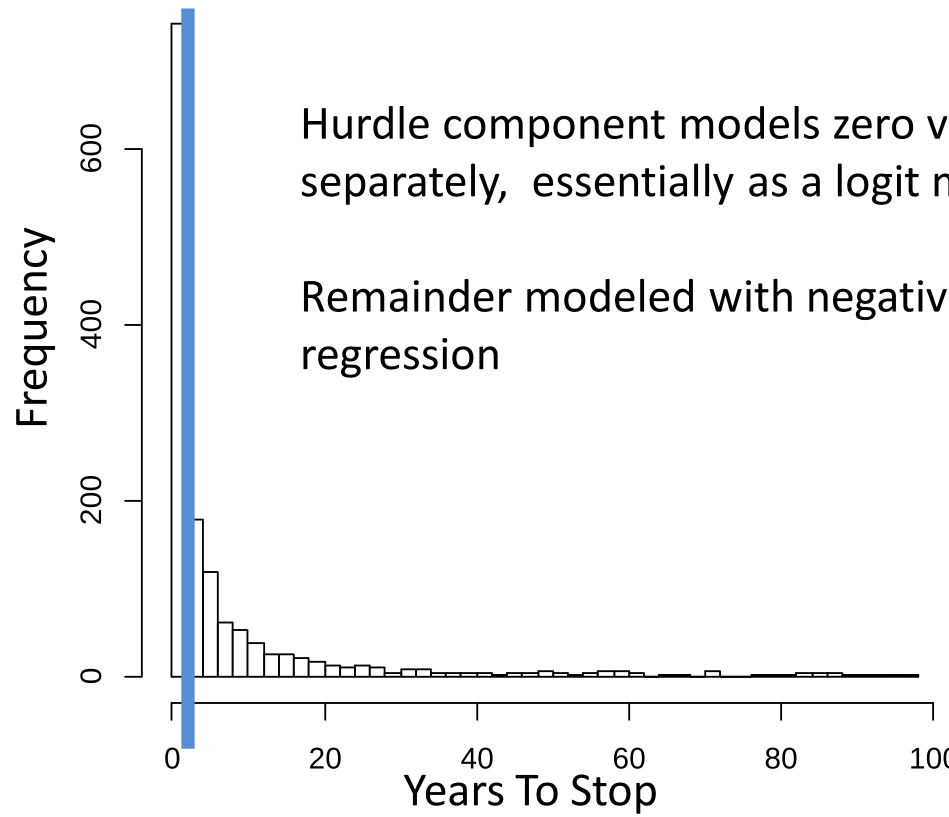


Model Sensitivity Analysis

- Employed a negative binomial regression, with a hurdle component as an alternative[3,4].

- Useful for over-dispersed, skewed data with large zero counts.

- Function *hurdle()* from the *pscl* R package.



Hurdle component models zero values separately, essentially as a logit model.

Remainder modeled with negative binomial regression

3. cran.**r**-project.org/web/packages/pscl/vignettes/**countr**eg.pdf
4. http://www.ats.ucla.edu/stat/mplus/dae/nbreg.htm

Model Sensitivity Analysis

- Best negative binomial hurdle model (sorted by AIC)

Years to stop = **(count model)**	7.72 – (0.731* corn price) – (0.657*corn price variability) – (0.038*corn yield) – (0.047*soy yield) + (0.009 * land production revenue threshold) - ln(θ)
Years to stop = **(zero model)**	6.76 – (0.352*corn price) – (0.019*corn yield) – (0.020*soy yield) - ln(θ)
Sig. ind. Vars	All but θ
AIC	74741

- Difficult to standardize coefficients

Model Sensitivity Analysis

- Hurdle coefficient standardization options
  - z-score ratios

count model

Corn price	-0.349
Soy yield	-0.298
Corn yield	-0.260
Corn price variability	-0.229
Land production revenue threshold	0.137

zero model

Corn price	-0.386
Soy yield	-0.309
Corn yield	-0.305

  - hierarchical partitioning
    - Murray and Connor 2009
    - R package *hier.part*

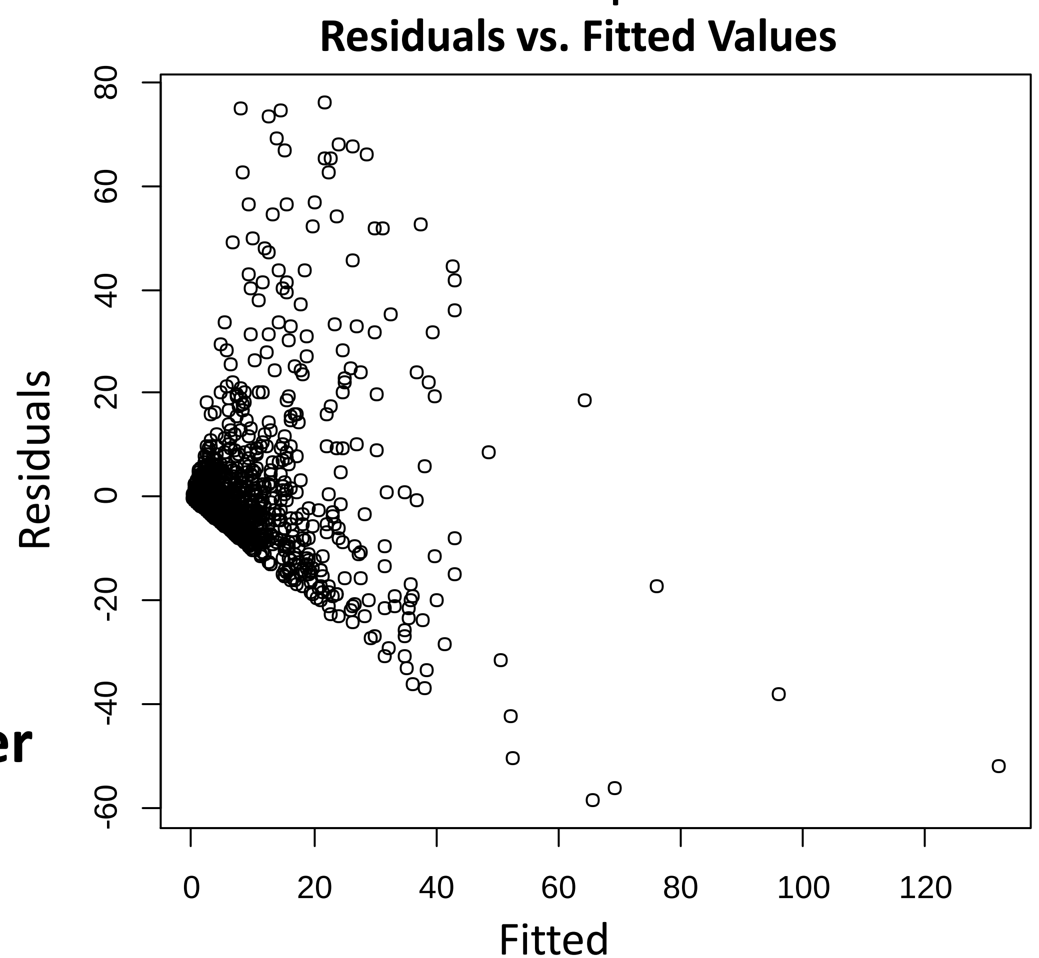
Model Sensitivity Analysis

Further inspection showed hurdle was still a poor fit

Why?

Still struggling with skewness.

Transformation of DV makes it no longer a count.



- Regression can be utilized to estimate parameter weights in complex spatial model.
- Issues arise when the dependent variable is count data
  - Poisson and negative binomial regression are viable alternatives for over-dispersed data
  - hurdle models for large zero counts
- Dependent variable skewness is significant challenge
  - normally distributed continuous data is preferable
  - not always feasible for agent-based models based on steps
- The example fish habitat sustainability model was most sensitive to market-based parameters (corn price, price variability, production revenue thresholds).

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References:

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