Assessing Land Use Intensity on Stream Health Using Macroinvertebrates

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Graphical Abstract

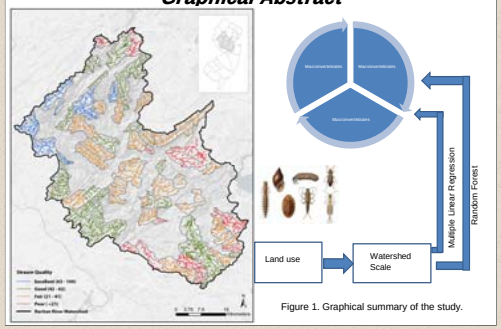


Figure 1. Graphical summary of the study.

Introduction

- The population in the Raritan River Watershed(RRW) has an increasing trend. During 1990 to 2010, an increase in 25.6 percent of population was observed.
- Similar to population trend, an increasing housing density was found in the RRW. As a result; upland forest, agricultural lands, and wetlands are converted into low, medium, and high density residential, as well as new urban centers.

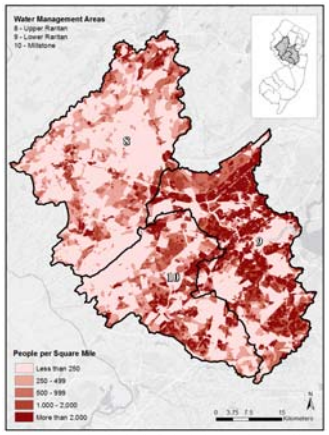


Figure 2. Population density distribution in the RRW (source: Giri et al., 2017. Sustainable Raritan report).

- Resulting increases in impervious surface (road, parking lots, and residential areas) are expected to have negative consequences on water quality and watershed health.

Rationale

- The composition of the macroinvertebrate community is often used as an indicator of the biological integrity of aquatic ecosystems. The intensity and type of human land uses may affect the macroinvertebrate community through multifaceted ways: water chemistry/quality, runoff patterns, habitat composition.

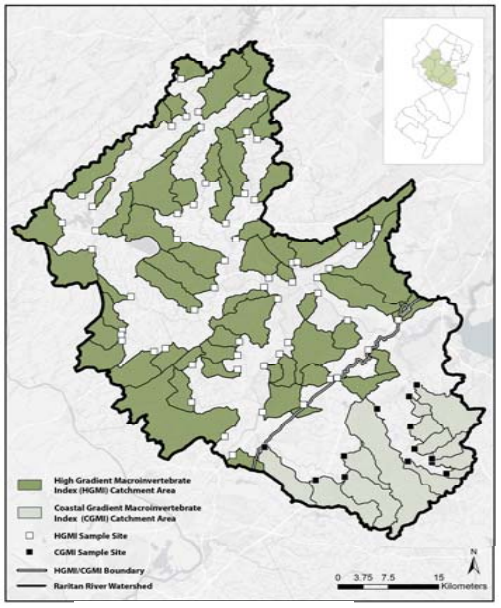
Objectives

- To determine the relationship between land use intensity and stream health using macroinvertebrate data.
- To determine how different types of urban and other land covers affect stream health.

Materials and Methods

Study Area

- The study area includes the entire Raritan River basin in central New Jersey including parts of Hunterdon, Mercer, Middlesex, Monmouth, Morris, Somerset, and Union Counties.
- Out of 71 watersheds, 58 are distributed randomly in high gradient macroinvertebrates index boundary and 13 are located in the coastal gradient macroinvertebrates index boundary.

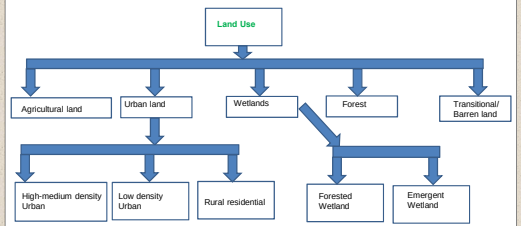


Location of 71 study sub-basins in the study area.

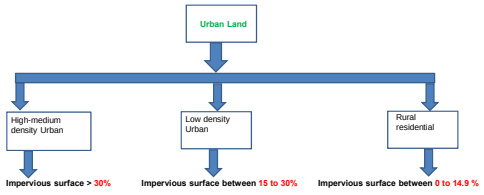
- A total of 139 sub-basins were delineated using Streamstats based on macroinvertebrates data from New Jersey Department of Environmental Protection (NJDEP). Out of which, half of the watersheds were eliminated using following two criteria, i) no nestedness and spatial autocorrelation among watersheds, ii) threshold watershed area (>1,000 acre).

Land Use Matrix

- 2012- land use/cover data obtained from NJDEP was used in this study. Level III NJDEP plus Hasse-Lathrop reclassification systems were used to get the final land use matrix presented below:



Urban Land Classification



- Analysis I(land use matrix): Agricultural land, forest, barren land, high medium density urban, low density urban, rural residential, wetlands
- Analysis II(land use matrix): Agricultural land, forest, barren land, high medium density urban, low density urban, rural residential, forested wetlands, emergent wetlands.

Stream Health

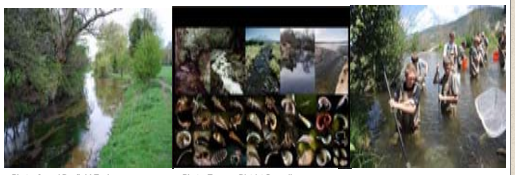


Photo: Jacqui Banfield-Taylor | Photo: Tasman District Council | Photo: National Forest Foundation

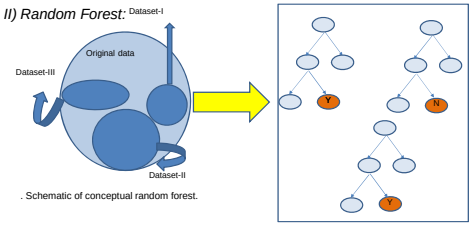
- Stream health can be evaluated through biological monitoring of fresh water. The Ambient Biomonitoring Network (AMNET) of the NJDEP conducts monitoring of macroinvertebrate communities at each station in the stream to evaluate the ecological condition.
- Taxanomic analysis of macroinvertebrates is conducted to calculate a multimetric index of stream health known as the New Jersey Impairment Score (NJIS).

Statistical Analysis

i)Multiple Linear Regression:

- A multiple linear regression was used in R platform between NJIS score of each watershed and its land use matrix.
- $Y_i = X_i\beta + \varepsilon_j$; where Y_i = NJIS of watershed, X_i = land use matrix, β = fixed effect of land uses on NJIS, ε_j = residuals.

II) Random Forest:



. Schematic of conceptual random forest.

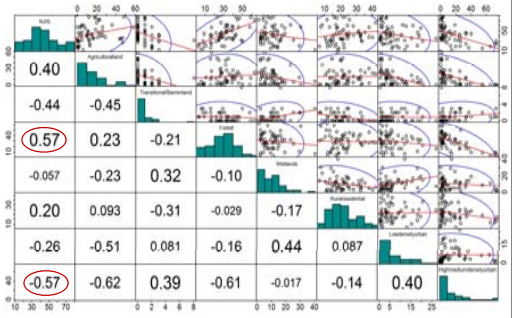
- Random forest is a non parametric method applied in variety of environmental research and it uses multiple learning algorithms to obtain better predictive performance.
- Decision trees are developed based on random selection of data and variables.

Results and Discussion

1)Stream Health of High Gradient Watersheds (Analysis I):

- Response variable: NJIS
- Predictors: Agricultural land, forest, barren land, high medium density urban, low density urban, rural residential, wetlands

i) Data Visualization:



Spearman's correlation matrix for stream health and land use.

ii) *Land Use and Stream Health (Multiple Linear Regression):*

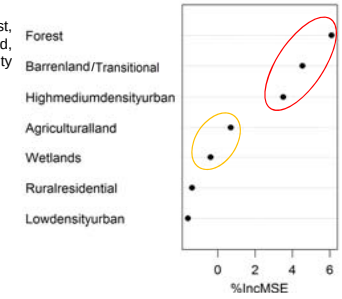
Multiple linear regression modeling results of different predictors at watershed level.

Predictors	β- value	P-value
Intercept	31.74	0.06
Agricultural land	0.05	0.84
Barren land / Transitional	-3.83	0.009**
Forest	0.58	0.02*
Wetlands	0.12	0.69
Low density urban	-0.43	0.29
High medium density urban	-0.11	0.63

* Indicates 5% level of significance and ** indicates 1% level of significance.

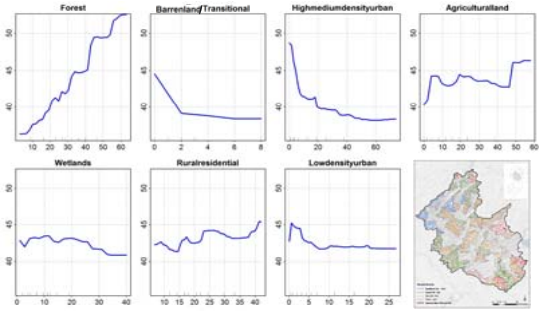
iii) *Land Use and Stream Health (Random Forest):*

- Highly important: Forest, transitional/barren land, and high medium density urban land.
- Least important: Rural residential and low density urban land.



Variable of importance.

Partial Dependence Plot:



Partial dependence plot of different predictors.

Model Evaluation:

Comparison of model with and without least influential predictors.

Parameter	5-fold cross validation	Final model
Using all predictors		
NSE	0.34	0.26
RMSE	13.32	14.44
PBIAS	1.48	0.75
Removing least influential predictors		
NSE	0.36	0.28
RMSE	13.11	14.22
PBIAS	-0.75	-2.15

- Land use is able to explain nearly 30 percent of NJIS and Model predicting power increases with removal of least influential predictors.

Future Work

- Incorporate Coastal Plain Watersheds.
- Collaborate with various watershed associations to incorporate their macroinvertebrate/stream health data collected as part of their citizen science monitoring programs to more fully elucidate patterns across the Raritan Basin.

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