HOPE NITZA

NEW PALTZ CENTRAL HIGH SCHOOL

THE EFFECT OF LAND DEVELOPMENT ON STREAM ECOSYSTEM HEALTH IN THE MILL BROOK PRESERVE IN NEW PALTZ, NY, USA

TABLE OF CONTENTS

LIST OF FIGURES AND TABLES

ABSTRACT

As the human population continues to rise, the constant development of land impacts the health of stream ecosystems. Macroinvertebrates act as indicators of the impact that land development has on the ecosystem health of any particular stream. This study was designed to evaluate the effects of land development on stream ecosystem health within the Mill Brook Preserve in New Paltz, NY. The objective was to assess the relationship between the percentage of developed land within a watershed and stream ecosystem health. Analyses of macroinvertebrate samples as quantified by biodiversity indices were used as indicators of stream ecosystem health. Land development was quantified using geographic information system (GIS) mapping. It was hypothesized that the indicators would show a negative correlation between the percent of developed land and stream ecosystem health within a watershed. Results were determined by comparing the biodiversity indices to the percentages of developed land within each stream watershed. The results supported the hypothesis; there was a negative correlation between the percent of developed land and stream ecosystem health within each watershed. Further research is needed to determine the different resulting effects of varying types of land use on ecosystem health.

INTRODUCTION

Land use management is a growing issue around the world as agriculture, industry, and urbanization expand exponentially. As more land is converted for human use, the impacts of this land development on the health of its ecosystem(s) are growing in severity and expansiveness, especially in stream ecosystems. Understanding the impact of land development on stream ecosystems is essential because, in addition to transporting nutrients and sediments that all other ecosystems depend on, streams act as a habitat for their own ecosystems and are home to a diverse array of organisms.

Ecosystem health can be defined as an ecosystem's adaptability and resilience capabilities toward change (3). Stream ecosystem health acts as a barometer of land use pressures on a watershed because stream conditions change in conjunction with surrounding land use changes(6)(4) .

One measure of stream ecosystem health is the count of macroinvertebrates present in a stream. Macroinvertebrates are organisms without a spine that are large enough to be seen with the naked eye. They provide crucial signals of stability and resource management status within a stream(3). Macroinvertebrates are affected by what is both above and below them in the food chain and are more susceptible to environmental factors, such as pollution, than most organisms, thus acting as prime indicators of stream ecosystem health(3). As increasing demands are placed on water resources worldwide, the value of macroinvertebrates in the assessment of water quality is increasing(3). Land development can alter the species composition and distribution of macroinvertebrates(2).

This study is designed to test how land development effects stream ecosystem health. Macroinvertebrate samples were used to indicate ecosystem health in selected streams. The streams tested in this study are within the Mill Brook Preserve in New Paltz, NY. Past studies conducted in the Mill Brook indicate some degradation of water quality in the preserve over the past 20 years as development of surrounding land increased(1)(5)(7). The Mill Brook Preserve is a 134-acre nature preserve created to conserve biodiversity and provide recreational and educational opportunities(5). It is located in the Town and the Village of New Paltz and the preserve's tributaries are one of the last remaining undeveloped areas in the Village of New Paltz.

The macroinvertebrate samples were analyzed using three biodiversity indices: EPT Richness Estimate, Major Group Biotic Index, and Percent Model Affinity. The percent of developed land in each stream's watershed was calculated using GIS mapping.

HYPOTHESIS

There is a negative correlation between the percent of developed land in a stream watershed and the health of the stream as indicated by EPT Richness Estimate, Major Group Biotic Index, and Percent Model Affinity scores.

METHODOLOGY

STREAMS

In order to quantify stream ecosystem health, macroinvertebrate and water quality samples were taken from streams within the Mill Brook Preserve in New Paltz, NY (figure 1).

Four streams were chosen for sampling within the Mill Brook Preserve (figure 1): The streams were chosen based on varying types of land use, availability for sampling, and similarity to one another. Streams 1, 2, and 3 all flow into stream 4. The watershed of stream 4 is comprised of the watersheds of streams 1, 2, and 3 and the watershed of stream 4 downstream of the convergence of the 3 streams up until the sampling site. Each stream had one designated macroinvertebrate sampling site (figure 1).The locations of the sample sites within the streams were chosen based on adequate size of rocks, fast stream flow, and a sufficient amount of riffles. Samples were gathered just above the confluence of each stream in the study in order to isolate the extent of impact to each stream. Each sampling site was 200 feet long and contains a designated riffle that is less than one meter deep with a velocity between .40 and .75 meters/second. A riffle is an area that is shallow enough for the surface to be broken by the substrate (9).

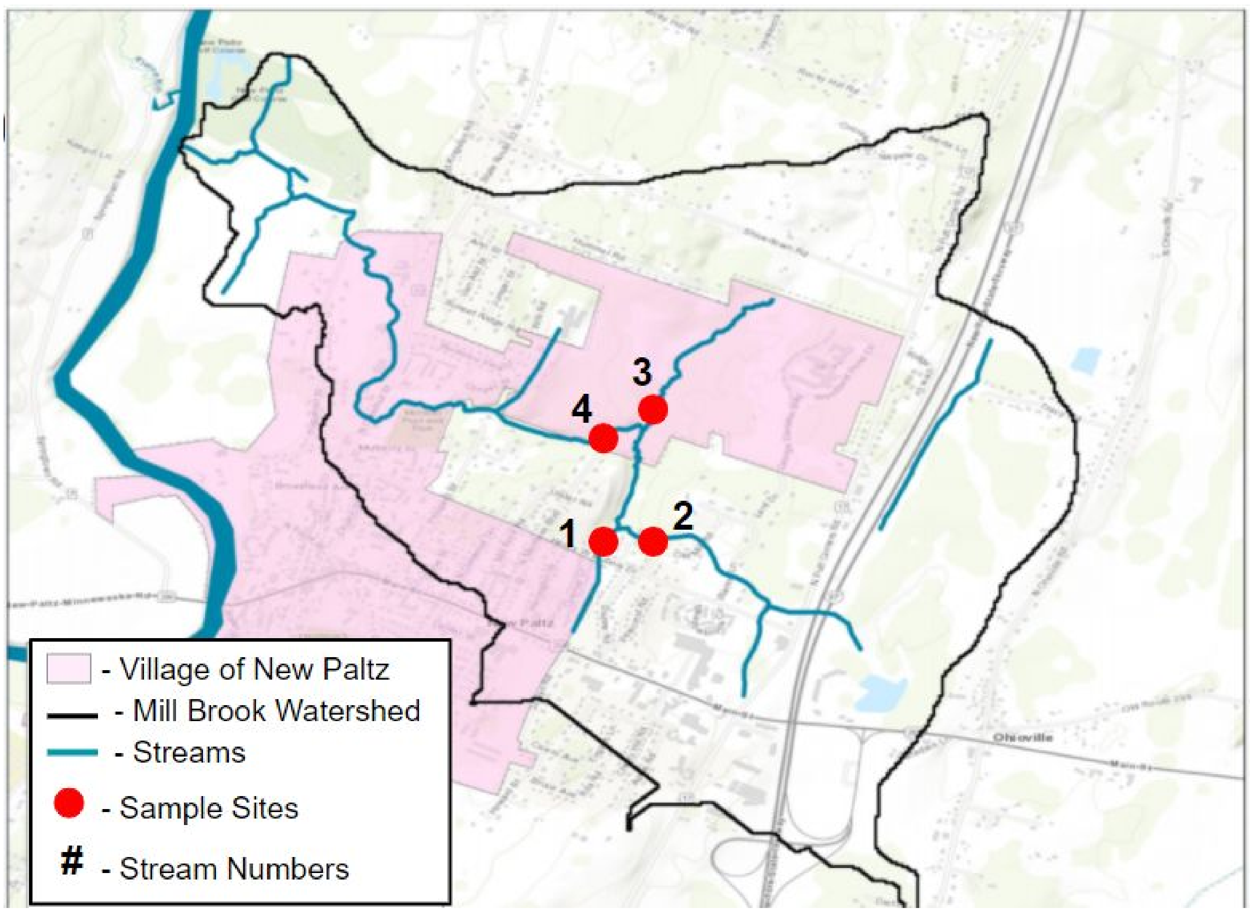


Figure 1: Mill Brook Preserve (5)

MACROINVERTEBRATE SAMPLING

Macroinvertebrates were sampled from each sampling site. In total, there was 1 round of sampling per sample site during the month of September, 2020.

Sampling and analysis methods were derived from the collection method guidelines of the New York State Department of Environmental Conservation (NYSDEC) (9).

The sampling procedure at each sampling site was conducted as follows:

1. Upon arrival at the site, a physical survey was conducted for the 200 feet of the sampling site using habitat assessment and assessment of recreational use perception survey sheets.
2. An 18” x 8" 0.8 mm mesh size net was then placed into the designated riffle with at least 5 meters of riffle upstream of the net in a diagonal direction. The net was placed and held on the river bottom with the opening of the net facing upstream.
3. While the net was held in place 0.5 meters directly upstream from the net opening, the stream bottom was disturbed by foot for 30 seconds using a shuffling motion.
4. The net was then carefully lifted out of the stream, carried upstream 0.5 meters in a diagonal direction while leaving the sample in the net, and step 3 was repeated.
5. Step 4 was repeated until a total of 5 meters were sampled along a diagonal transect as wide as the net. This was completed in a total of 5 minutes.
6. Fine sediment was removed from the resulting sample in the net by moving the sample into a 30 mm mesh sieve bucket and submerging the bucket partially into the stream until the fine sediment was washed out.
7. The sample was then brought to the shore and transferred out of the sieve bucket and into a wide mouth glass jar. The jar was then filled with 90% ethyl alcohol for preservation, tightly capped, and labeled.
8. Steps 1 through 7 were repeated at each designated sampling site of each of the 4 streams (4 sampling sites total).

The 4 preserved samples were then each separately analyzed using the following procedure:

1. The sample was transferred into a 30 mm sieve and rinsed off.
2. A 1-inch deep white tray was marked into a grid of 12 equal sized squares using a permanent marker and filled with water. The sample was then transferred into the tray and spread out evenly.

3. One of the 12 squares was then chosen at random. All of the macroinvertebrates were picked out of that square while using a lighted magnifier.
4. Step 4 was repeated for separate squares until 100 macroinvertebrates were taken in total out of the sample.
5. The 100 macroinvertebrates were then identified to the order level using a dichotomous key and a 10X hand lens.
6. Steps 1 through 5 were repeated for each sample (4 samples in total).
7. Biodiversity indices were calculated for the sample. The biodiversity indices used were EPT Richness Estimate, Major Group Biotic Index, and Percent Model Affinity.
8. EPT Richness Estimate was calculated by adding up the total number of different mayfly, caddisfly, and stonefly taxa found in the sample. The resulting sum was the EPT Richness score. The score correlates with the following indication of how impacted the stream ecosystem is:

   >7 = non-impacted

   3-7 = slightly impacted

   1-2 = moderately impacted

   0 = severely impacted

   This metric is an estimate of the number of different kinds of mayfly (Ephemeroptera), stonefly (Plecoptera), and caddisfly (Trichoptera) in a stream, which tend to be particularly sensitive to pollution.
9. Major Group Biotic Index was calculated by first recording the number of macroinvertebrates in each order and multiplying these values by each order's assigned biotic index. All the resulting products were added together and the resulting sum was divided by the total number of macroinvertebrates in the sample. The resulting quotient was the Biotic Index score. The score correlates with the following indication of how impacted the stream ecosystem is:

   0-4.50 non-impacted

   4.51-5.50 slightly impacted

   5.51-7.00 moderately impacted

   7.01-10 severely impacted

This metric takes into account pollution tolerance values specifically assigned to each major group of organisms. It also takes into account the density of organisms found in each major group. Generally the more pollution intolerant organisms are found, the less impacted the stream.

10. Percent Model Affinity was calculated by dividing the number of macroinvertebrates in each order by the total number macroinvertebrates in the sample and multiplying each resulting quotient by 100. The resulting values were the percent composition of each order within the sample. The absolute difference of each calculated percent composition and the percentages of that order in a model, unimpacted community established by the NYSDEC was taken. The absolute differences were added up and the resulting sum was multiplied by 0.5 and subtracted from 100. The resulting value was the Percent Model Affinity score. The score correlates with the following indication of how impacted the stream ecosystem is:

    > 64 non-impacted

    50-64 slightly impacted

    35-49 moderately impacted

    <35 severely impacted

    This metric compares Percent Composition values of a sample to a model community established by the NYSDEC for an un-impacted stream.

LAND DEVELOPMENT

Land use was quantified using GIS mapping to produce percentages of each type of land use within the watersheds of each sampled stream. The percentages were produced using the following procedure:

1. Using ArcGIS, the watershed of each stream was delineated using a topographic map of the Mill Brook Preserve area.
2. The USA National Land Cover Database (NLCD) Land Cover data set was utilized to calculate the percentage of developed land in each watershed. The total percentage of developed land in each watershed was calculated as the sum of the percentages of developed open space, developed low intensity, developed medium intensity, and developed high intensity land in each watershed.

3. The USA NLCD Land Cover data set (8) defined each of the developed land categories as follows:
    a. Developed Open Space: areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20% of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes.
    b. Developed Low Intensity: areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20% to 49% percent of total cover. These areas most commonly include single-family housing units.
    c. Developed Medium Intensity: areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50% to 79% of the total cover. These areas most commonly include single-family housing units.
    d. Developed High Intensity: highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial areas. Impervious surfaces account for 80% to 100% of the total cover.

ANALYSIS

The relationship between the percent of developed land and the biodiversity indices scores was calculated on a graph using a trendline for each relationship. The correlation between percent land development and the biodiversity indices score was calculated using the coefficient of determination (R^2) for each relationship. A trendline and coefficient of determination was calculated for the relationship between the percent of developed land and the Percent Model Affinity scores and between the percent of developed land and the Major Group Biotic Index scores.

RESULTS

PHYSICAL SURVEYS

Habitat Assessment

Question	Site 01	Site 02	Site 03	Site 04
Epifaunal Substrate/Available Cover	A	A	B	B
Embeddedness	B	A	A	A
Velocity/Depth Combinations	B	A	B	B
Sediment Deposition	B	B	A	B
Channel Flow Status	A	A	A	B
Channel Alteration	A	B	A	A
Frequency of Riffles	A	A	B	A
Bank Stability Left	A	B	A	A
Bank Stability Right	A	A	A	A
Bank Vegetative Protection Left	A	B	A	A
Bank Vegetative Protection Right	A	A	A	B
Riparian Vegetation Zone Left	B	A	A	A
Riparian Vegetation Zone Right	B	B	A	A

Optimal	A
Marginal	B
Poor	C

Chart 1: Habitat Assessment

A physical survey was conducted for the 200 feet of each sampling site to assess the quality of the each stream's habitat.

- Site 1 had 8 optimal habitat qualities and 5 marginal habitat qualities
- Site 2 had 8 optimal habitat qualities and 5 marginal habitat qualities
- Site 3 had 10 optimal habitat qualities and 3 marginal habitat qualities
- Site 4 had 8 optimal habitat qualities and 5 marginal habitat qualities

While individual variable ratings were different, Sites1, 2, and 4 had identical overall habitat quality scores, while Site 3 had a slightly higher overall habitat quality score than the others.

Assessment of Recreational Use Perception				
Question 1, Site 1	Ability to participate in 1° contact recreation slightly impacted			
Question 1, Site 2	The ability to participate in 1° contact recreation fully attained			
Question 1, Site 3	The ability to participate in 1° contact recreation fully attained			
Question 1, Site 4	The ability to participate in 1° contact recreation fully attained			
Question 2, Site 1	Ability to participate in 2° contact recreation fully attained			
Question 2, Site 2	Ability to participate in 2° contact recreation fully attained			
Question 2, Site 3	Ability to participate in 2° contact recreation fully attained			
Question 2, Site 4	Ability to participate in 2° contact recreation fully attained			
	Site 01	**Site 02**	**Site 03**	**Site 04**
Weather, Current	Rain/Clouds	Rain/Clouds	Rain/Clouds	Sun
Weather, Past 24 hours	Clouds	Clouds	Clouds	Sun
Other Parameters				
Water Clarity	0	1	2	0
Trash	3	1	0	0
Discharge/Pipes	3	2	0	0
Negative Effect on Recreational Use	Odor, Trash	Homes Encroaching	Trash	None

Chart 2: Assessment of Recreational Use Perception

A physical survey was conducted for the 200 feet of each sampling site to assess the perception of the ability of each stream to be used for recreational use. The survey also assessed the weather currently and for the past 24 hours.

- Question 1: "What is your ability to participate in 1 degree contact (swimming), from 1 (fully attained) to 5 (impossible)?"
- Question 2: "What is your ability to participate in 2 degree contact (boating/fishing), from 1 (fully attained) to 5 (impossible)?"
- "Other Parameters" (water quality, trash, and discharge/pipes) were assessed on their presence at each site on a scale of from 0 (none/natural) to 10 (severe).

The ability to participate in 1 degree contact recreation at Site 1 was slightly impaired, while the ability to participate in 1 degree contact recreation at Sites 1, 2, and 3 were fully attained.

Site 4 had a total "Other Parameters" score of 0, Site 3 had a score of 2, Site 2 had a score of 4, and Site 1 had a score of 6.

BIODIVERSITY INDICES

Test Scores				
Tests	**Stream 01**	**Stream 02**	**Stream 03**	**Stream 04**
EPT Richness	3 - Slightly Impacted	3 - Slightly Impacted	7 - Non Impacted	3 - Slightly Impacted
Major Group Biotic Index Score	4.82 - Slightly Impacted	4.94 - Slightly Impacted	4.54 - Non Impacted	4.06 - Non Impacted
Percent Model Affinity	55.0% - Slightly Impacted	52.0% - Slightly Impacted	65% - Non Impacted	65.5% - Non Impacted

Chart 3: Biodiversity Indices Scores

- EPT Richness is an estimate of the number of different kinds of mayfly (Ephemeroptera), stonefly (Plecoptera), and caddisfly (Trichoptera) in a stream, which tend to be particularly sensitive to pollution.
- Biotic Index takes into account pollution tolerance values specifically assigned to each major group of organisms. It also takes into account the density of organisms found in each major group. Generally the more pollution intolerant organisms are found, the less impacted the stream.
- Percent Model Affinity compares Percent Composition values of a sample to a model community established by the NYSDEC for an un-impacted stream.

Streams 1 and 2 had ratings of “slightly impacted” on all three tests. Stream 4 had a rating of “non-impacted” on the Biotic Index and Percent Model Affinity and a rating of “slightly impacted” on EPT Richness. Stream 3 had a rating of “non-impacted” for all three tests.

LAND DEVELOPMENT

Percent of Land Use Types Per Watershed

Land Cover	Watershed No. 1 (m2)	Percent (%)	Watershed No. 2 (m2)	Percent (%)	Watershed No. 3 (m2)	Percent (%)	Watershed No. 4/All (m2)	Percent (%)
Open Water	-	0%	98,100	4%	8,100	0%	106,237	2%
Developed Open Space	356,204	41%	362,188	15%	164,583	9%	900,432	17%
Developed Low Intensity	194,823	22%	289,776	12%	31,360	2%	515,053	10%
Developed Medium Intensity	71,244	8%	182,665	8%	-	0%	253,790	5%
Developed High Intensity	36,805	4%	80,104	3%	-	0%	116,791	2%
Barren Land	-	0%	2,700	0%	-	0%	2,700	0%
Deciduous Forest	140,568	16%	485,266	21%	1,020,176	58%	1,787,685	35%
Evergreen Forest	-	0%	11,700	0%	43,327	2%	55,027	1%
Mixed Forest	-	0%	15,300	1%	172,158	10%	190,427	4%
Shrub/Scrub	-	0%	-	0%	-	0%	-	0%
Grassland/Herbaceous	-	0%	2,700	0%	-	0%	2,700	0%
Pasture/Hay	55,997	6%	147,028	6%	151,651	9%	350,604	7%
Cultivated Crops	-	0%	12,181	1%	-	0%	12,181	0%
Woody Wetlands	10,957	1%	666,559	28%	175,871	10%	865,913	17%
Emergent Herbaceous Wetlands	4,482	1%	10,497	0%	900	0%	15,878	0%
Total	871,080	100%	2,366,764	100%	1,768,126	100%	5,175,419	100%

Watersheds	Developed Land (Combined)
Watershed 1	76%
Watershed 2	39%
Watershed 3	11%
Watershed 4/All	35%

Chart 4: Percent Of Land Use Types Per Watershed

This chart displays the percent of each type of land cover in each watershed in the study. The total percentage of developed land for each watershed was calculated by adding the percentage of developed open space, low intensity, medium intensity, and high intensity land cover together in each watershed.

- Watershed 1: 76% total developed land
- Watershed 2: 39% total developed land
- Watershed 3: 11% total developed land
- Watershed 4: 35% total developed land

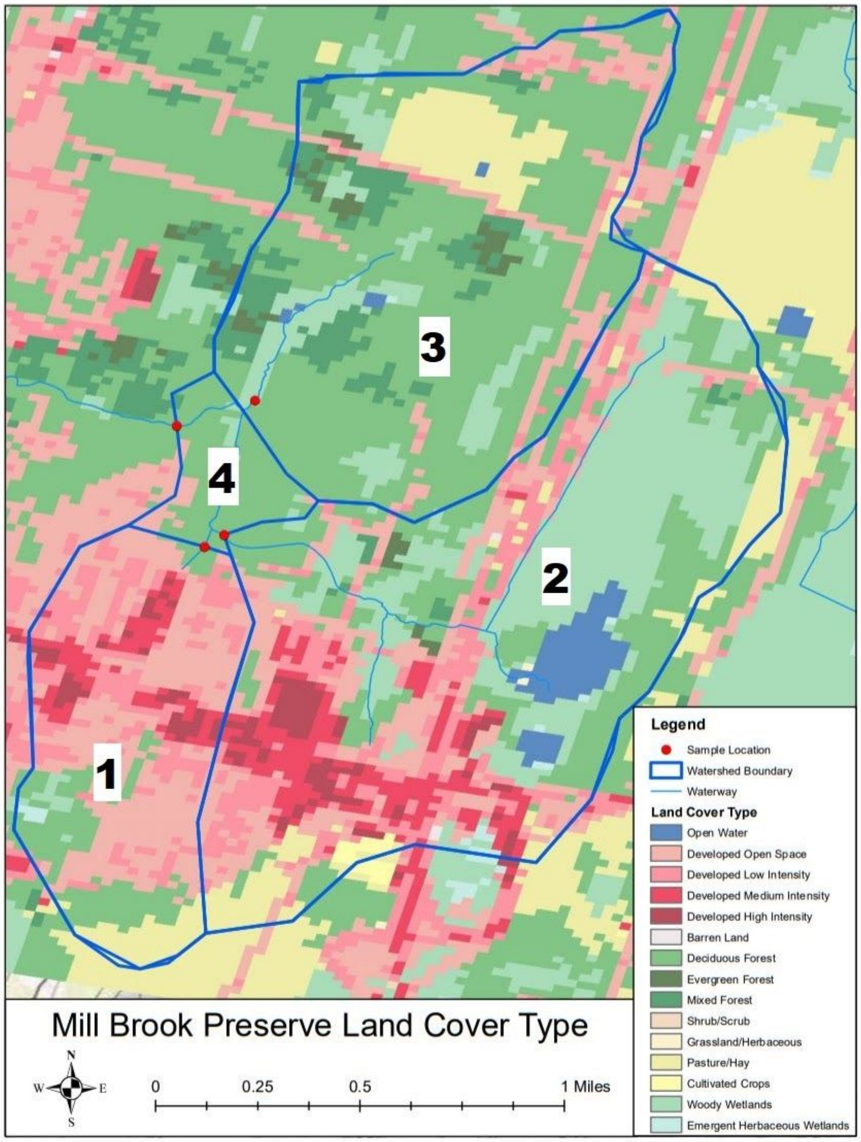


Figure 2: Mill Brook Preserve Land Cover Type

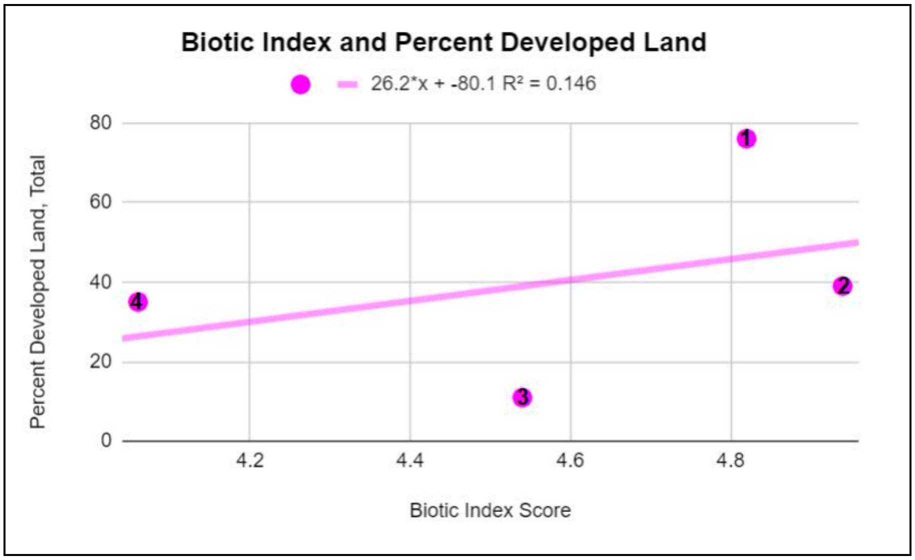
This figure is a visual representation of the data presented in Chart 4.

1 = the watershed of stream 1

2 = the watershed of stream 2

3 = the watershed of stream 3

1, 2, 3, and 4 = the watershed of stream 4

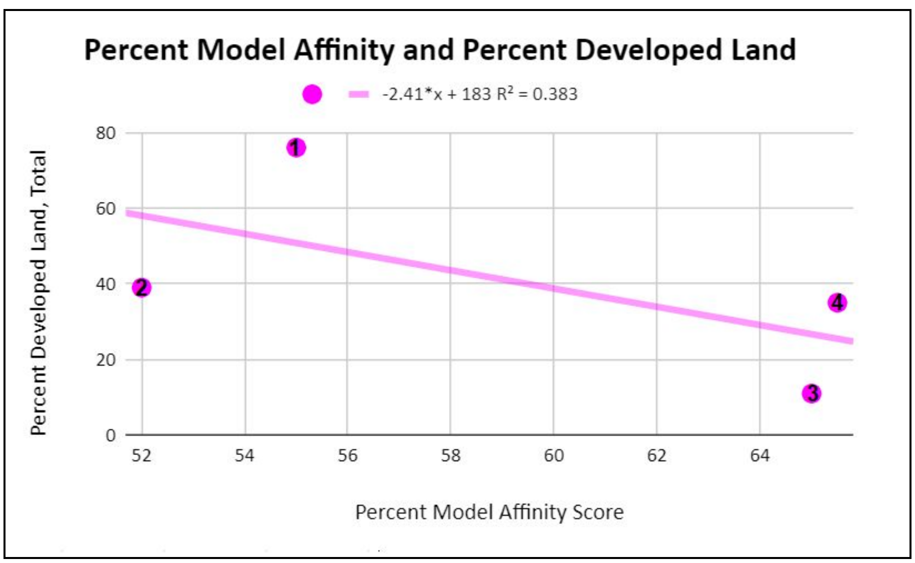


Graph 1: Biotic Index and Percent Developed Land

This graph shows the relationship between the percent of developed land and the Major Group Biotic Index score for each watershed using a trendline. The correlation between percent land development and Biotic Index (R^2) is .146.

= Watershed number

A higher Biotic Index score indicates a more impacted stream



Graph 2: Biotic Index and Percent Developed Land

This graph shows the relationship between the percent of developed land and the Percent Model Affinity score for each watershed using a trendline. The correlation between percent land development and Percent Model Affinity (R^2) is .383.

= Watershed number

A higher Percent Model Affinity score indicates a less impacted stream

DISCUSSION

This study was designed to test how land development affects stream ecosystem health. Overall, results indicated that land development negatively affects stream ecosystem health. There is a negative correlation between the percent of total developed land of a stream watershed and the extent to which the stream ecosystem health is impacted, as quantified by the 3 biodiversity indices.

In Graph 1, the positive trendline shows that there is a positive relationship between the percent of developed land and the Major Group Biotic Index score. The positive relationship suggests that there is a negative correlation between the percent of developed land in a watershed and stream ecosystem health because a higher Biotic Index score indicates a more impacted stream. In Graph 2, the negative trendline shows that there is a negative relationship between the percent of developed land and the Percent Model Affinity score. The negative relationship suggests that there is a negative correlation between the percent of developed land in a watershed and stream ecosystem health because A higher Percent Model Affinity score indicates a less impacted stream. The correlation between percent land development and Biotic Index (R^2) is 0.146. The correlation between percent land development and Percent Model Affinity (R^2) is 0.383. These correlations suggest that there is a negative impact of land development on the health of stream ecosystems.

Streams 1 and 2 had ratings of “slightly impacted” on all three tests. Stream 4 had a rating of “non-impacted” on the Biotic Index and Percent Model Affinity and a rating of “slightly impacted” on EPT Richness. Stream 3 had a rating of “non-impacted” for all three tests (Chart 3). Stream 3 has the lowest percent of developed land (11%) out of all 4 watersheds and is indicated to be the least impacted stream. Stream 4 has the second lowest percent of developed land (35%) and is indicated to be the second least impacted streams. Streams 1 and 2 have the highest percentages of developed land (11%) and are indicated to be the most impacted streams. Since the streams with the lowest percentages of developed land are indicated to be the least impacted and the streams with the highest percentages of developed land are indicated to be the most impacted, these biodiversity index scores support the conclusion that there is a negative impact of land development on the health stream ecosystems.

The habitat assessment data (Chart 1) indicates that Stream 3 has a slightly higher habitat quality than the other streams since it has a higher overall habitat quality score. Since the watershed of stream 3 has the lowest percent of developed land (11%) out of all 4 watersheds (Chart 4), the habitat assessment data supports the conclusion that there is a negative impact of land development on the health of stream ecosystems.

The Assessment of Recreational Use Perception data (Chart 2) indicates that Stream 3 and Stream 4 had lower total “Other Parameters” scores than streams 1 and 2. The lower the “Other Parameters” score, the less factors there are that negatively affect the health of the stream. Since the watersheds of stream 3 and 4 have the lowest percentages of developed land (11% and 35%) out of all 4 watersheds (Chart 4), the Assessment of Recreational Use Perception data supports the conclusion that there is a negative impact of land development on the health of stream ecosystems.

It should be noted that stream 4 exists as an anomaly because it’s Percent Model Affinity score and Major Group Biotic Index score indicate that it is less impacted than stream 3 and has a higher percentage of developed land than stream 3. However, the conclusions are still supported when looking at the data as a whole despite this anomaly.

CONCLUSION

This study examined the relationship between land development and stream ecosystem health. The data shows a negative correlation between the percent of total developed land of a stream watershed and the extent to which the stream ecosystem health is impacted, as quantified by the 3 biodiversity indices. These findings support the hypothesis that there is a negative correlation between the percent of developed land in a stream watershed and the health of the stream. More research is needed to determine the different resulting effects of varying types of land use on ecosystem health.

REFERENCES

(1) Cheo, Martha. 2004. Assessment of the Mill Brook Stream in the Town of New Paltz, New York. Village of New Paltz EnCC and Hudson Basin River Watch.

(2) Limburg, K., & Schmidt, R. (1990). Patterns of Fish Spawning in Hudson River Tributaries: Response to an Urban Gradient? *Ecology, 71*(4), 1238-1245. doi:10.2307/1938260

(3) Wallace, J. B., & Webster, J. R. (1996). The role of macroinvertebrates in stream ecosystem function. *Annual review of entomology*, *41*, 115–139. https://doi.org/10.1146/annurev.en.41.010196.000555

(4) Stainbrook, K.M., Limburg, K.E., Daniels, R.A. *et al.* Long-term changes in ecosystem health of two Hudson Valley watersheds, New York, USA, 1936–2001. *Hydrobiologia* 571, 313–327 (2006). https://doi.org/10.1007/s10750-006-0254-5

(5) Stolzenburg, AICP, Nan, and Don Meltz, AICP. The Mill Brook Preserve A Plan for Its Creation and Management. (2014, August). Retrieved January 07, 2021, from https://www.townofnewpaltz.org/sites/g/files/vyhlif3541/f/file/file/mill_brook_preserve_management_plan-final_08.28.2014_01.pdf

(6) Landers, M. N., Geological Survey (U.S.). (2002). *Does land use affect our streams?: a watershed example from Gwinnett County, Georgia, 1998-2001.* [Reston, Va.]: U.S. Dept. of the Interior, U.S. Geological Survey.

(7) Zeoli, Frank. 2007. Benthic Macroinvertebrate Analysis: Mill Brook Stream, New Paltz, NY. (Fieldwork for Biology 494). State University of New York at New Paltz, New Paltz, NY.

(8) *USA NLCD Land Cover*. (2019, June 5). ArcGIS Online.

(9) Behar, S., & Cheo, M. (2004). Hudson Basin River Watch Guidance Document: Helping to coordinate monitoring of freshwater wadeable rivers throughout the watershed. Retrieved January 07, 2021, from http://www.communityscience.org/wp-content/uploads/2017/05/HBRWGD04.pdf