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Land Use Impact on Aquatic Macroinvertebrate Diversity in the Lake James Watershed

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Abstract

How a landscape is used in a watershed will ultimately affect aquatic ecology and water quality. Aquatic macroinvertebrates are sensitive to the effects various land use types have on the water quality. Three common types of land use classification are forested, agricultural and developed. Forested land classifications have been shown to improve water quality which results in greater aquatic biodiversity. Agricultural and developed, or urban, land use are generally associated with various negative effects on streams which result in poorer water quality, reducing the biodiversity in an aquatic habitat. This study analyzes land use classifications in three subwatersheds of the Lake James watershed. It also analyzes how the Index of Biotic Integrity is affected in each of forested, agricultural and developed subwatersheds. The results of this study indicate that the IBI in the three selected subwatersheds ranges from 2.31 to 3.92 with a general trend of the best IBI score in the forested watershed. Additionally, there is a correlation between increased urbanization and higher conductivity levels in the Lake James watershed. This data illustrates that these aquatic ecosystems are negatively affected by developed and agricultural landscapes, and that the developed subwatershed is associated with higher conductivity in the aquatic ecosystem.

1. Introduction

Land use changes can lead to habitat loss for many aquatic species [1], decreasing diversity and abundance. Forested land helps reduce surface runoff which reduces potential chemical pollution from agricultural and urban land [2]. Forests also reduce sedimentation, as there is usually vegetation present which prevents erosion. Open land types such as grasslands and agricultural fields allow wind and rain to force greater erosion of sediment and banks [3]. Additionally, watersheds with high percentages of impervious surfaces, such as in developed areas, have higher discharge rates which generally increase erosion and sedimentation in urbanized stream channels. These streams also see an increase in harmful compounds washed from impervious surfaces such as roads and buildings during storm events[4,5,6]. Some human actions in a watershed pose a threat to aquatic ecology and biological diversity. Activities such as dam installation and invasive species introductions can impact aquatic habitat and water quality by the altering of sediment supply and channel stabilization. Anthropogenic activity in the encompassing watershed disrupt natural geomorphic processes and can lead to degraded and more homogenous aquatic habitat [7]. Aquatic macroinvertebrate populations are heavily impacted by environmental conditions influenced by hydraulic stress, temperature and water chemistry [7,8,9,10,11], and they are often used as water quality indicators due to their specific tolerances to physical and chemical disturbances [12]. Similar studies have been conducted on land transformations and their impacts on species assemblage and richness of aquatic macroinvertebrates from the order Odonata [13]. These impacts are measured using an Index of Biotic Integrity (IBI). This is a broad but ecologically sound tool that evaluates many attributes of aquatic macroinvertebrate communities in order to determine human impacts on streams and watersheds [14].

The objective of this study was to map the Lake James watershed and determine land use type, collect benthic macroinvertebrates and perform analysis in order to measure any changes in taxa diversity that may be attributed to forested, agriculture or developed land use classification. It is hypothesized that there will be a positive correlation between IBI and conductivity in developed and agricultural watersheds, with a negative correlation between a forested watershed and the variable mentioned above. Additionally, a negative relationship was expected between IBI and development and a positive relationship with IBI and forested watersheds [7].

2. Methodology

This project was two fold in identifying land cover types as well as measuring an Index of Biotic Integrity for subwatersheds within the Lake James watershed. This watershed borders the mountain and piedmont ecoregions. It consists of the headwaters of the Catawba River flowing east into the west side of the lake, while the Linville River flows southward into the eastern side of Lake James. The overall watershed land use is classified at over 90% forested. The study sites were selected from the primary tributaries in each of Lake James' subwatersheds that consisted of the greatest amount of forested, agriculture, and developed land cover type. There were a total of nine sampling sites - three sites in each subwatershed with a majority of 1 of 3 land cover types. Aquatic macroinvertebrates, dissolved oxygen (DO) and conductivity data were collected at each site. Conductivity can be used as a potential measurement of pollution, negative biological impact on aquatic biodiversity and is often influenced by surrounding, especially urban, land use [15].

2.1 Land Cover Mapping

All GIS analyses was completed using ArcMap v10.6, ESRI, Inc. The major tributaries of the subwatersheds were calculated using Digital Elevation Models from USGS's Earth Explorer [16] . Using the "Fill", "Flow Direction" and "Accumulation" tools, the main accumulation and flow direction of water were predicted. Minor streams and tributaries were removed by isolating the larger water accumulation values using conditional filtering, identifying the primary tributary in each subwatershed. The stream file was then exported as a polyline file. This polyline file was then combined with the Hydrologic Unit Code (HUC) boundaries obtained from the Watershed Boundary Dataset [17] to form cohesive subwatershed boundaries with the primary tributaries overlaying it. Placing HUC subwatershed boundaries around each major tributary allowed for the isolation of a single subwatershed for more refined analysis.

The land cover dataset for the state of North Carolina was retrieved from the 2016 National Land Cover Database (NLCD) [18]. Using the previously mentioned HUC boundaries, the land cover data were clipped with the "Image Analysis" tool to fit subwatershed boundaries. Once each subwatershed's land cover had been clipped from the North Carolina statewide dataset, the resulting land cover file was exported allowing for the removal of the data. At this point, a map outlined in HUC boundaries, a polyline file of streams, a shapefile with lakes, and clipped land cover files remained.

After producing the entire Lake James watershed land cover map, the 11 subwatersheds were separated based on 12-digit HUCs. The selected subwatersheds for the study included Curtis Creek (Figure 1), Crooked Creek (Figure 2) and the Upper Linville River (Figure 3).

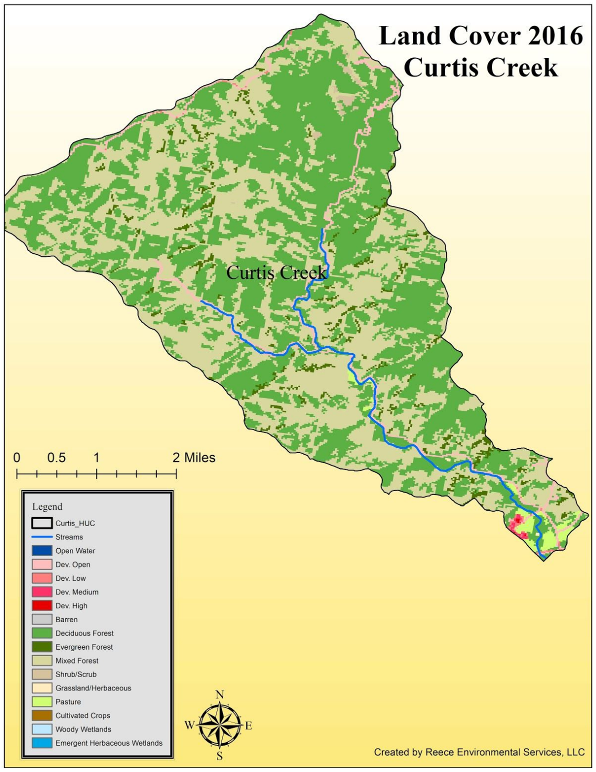

Figure 1. Curtis Creek watershed land cover.

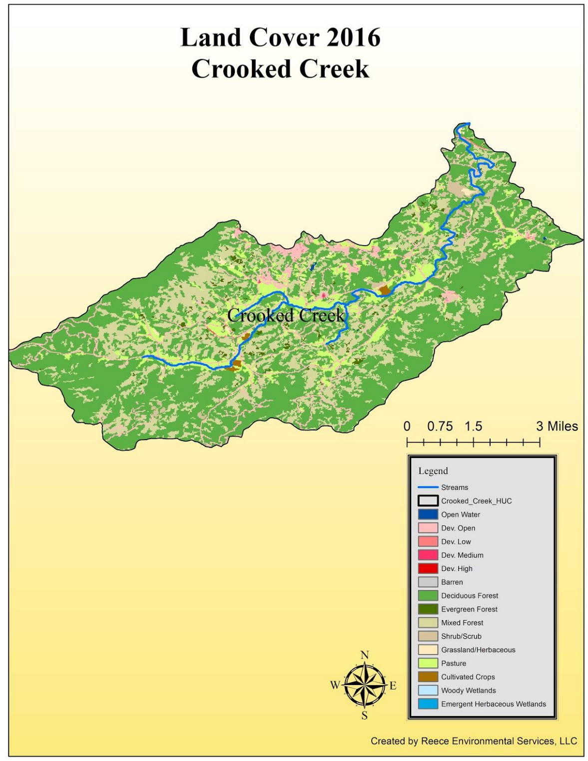

Figure 2. Crooked Creek watershed land cover.

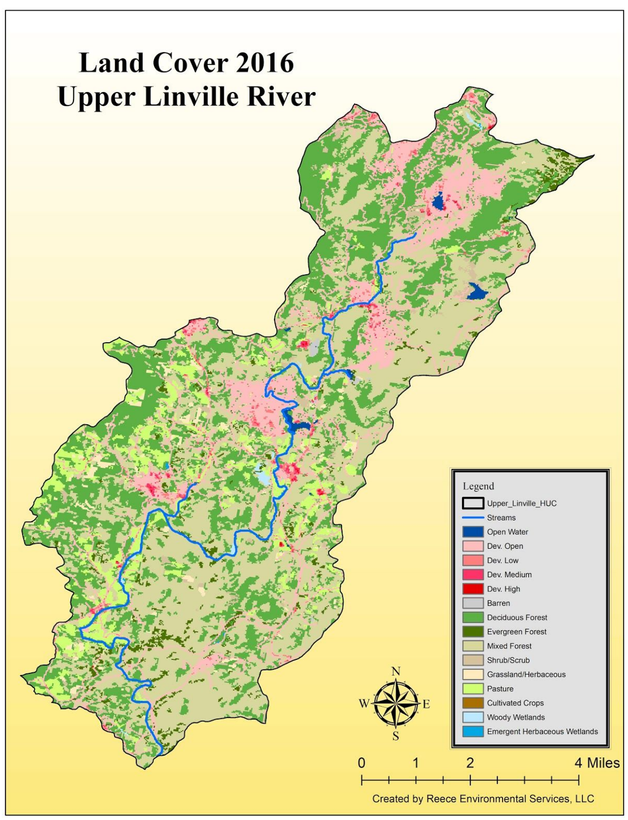

Figure 3. Upper Linville River watershed land cover.

Once broken up into subwatersheds, pixels were recolored and assigned corresponding land cover type values through the "Unique Values" option in the display properties for the datasets, based on the NLCD Legend [18]. These pixels were then summed for each code and color. Each pixel represented 300 m^2 of land area. Therefore, by summing the pixels for each land cover type, a total area was determined for each subwatershed. This calculation was then converted to acres to provide a more relatable unit of measurement (Tables 1-3).

Table 1: Curtis Creek land cover classification, percentage and data tabulation.

Curtis Creek 2016					
Pixel ID	**Pixel Count**	**Pixel Value (m2)**	**Name**	**Percent of Land Covered**	**Acreage**
11	0	0	Open Water	0.00%	0.0
21	1,247	1,122,300	Developed, Open Space	2.54%	277.3
22	97	87,300	Developed, Low Intensity	0.20%	21.6
23	41	36,900	Developed, Medium Intensity	0.08%	9.1
24	8	7,200	Developed, High Intensity	0.02%	1.8
31	0	0	Barren (Rock/Sand/Clay)	0.00%	0.0
41	24,750	22,275,000	Deciduous Forest	50.39%	5,504.3
42	1,287	1,158,300	Evergreen Forest	2.62%	286.2
43	21,077	18,969,300	Mixed Forest	42.91%	4,687.4
52	190	171,000	Shrub/Scrub	0.39%	42.3
71	13	11,700	Grassland/Herbaceous	0.03%	2.9
81	406	365,400	Pasture	0.83%	90.3
82	0	0	Cultivated Crops	0.00%	0.0
90	1	900	Woody Wetlands	0.00%	0.2
95	0	0	Emergent Herbaceous Wetlands	0.00%	0.0
TOTALS	**49,117**	**44,205,300**			**10,923.4**

Table 2: Crooked Creek land cover classification, percentage and data tabulation.

Crooked Creek 2016					
Pixel ID	**Pixel Count**	**Pixel Value (m2)**	**Name**	**Percent of Land Covered**	**Acreage**
11	41	36,900	Open Water	0.04%	9.1
21	7,276	6,548,400	Developed, Open Space	7.14%	1,618.1
22	271	243,900	Developed, Low Intensity	0.27%	60.3
23	24	21,600	Developed, Medium Intensity	0.02%	5.3
24	1	900	Developed, High Intensity	0.00%	0.2
31	1	900	Barren (Rock/Sand/Clay)	0.00%	0.2
41	59,688	53,719,200	Deciduous Forest	58.59%	13,274.3
42	972	874,800	Evergreen Forest	0.95%	216.2
43	23,870	21,483,000	Mixed Forest	23.43%	5,308.6
52	1,223	1,100,700	Shrub/Scrub	1.20%	272.0
71	557	501,300	Grassland/Herbaceous	0.55%	123.9

81	7,663	6,896,700	Pasture	7.52%	1,704.2
82	261	234,900	Cultivated Crops	0.26%	58.0
90	9	8,100	Woody Wetlands	0.01%	2.0
95	12	10,800	Emergent Herbaceous Wetlands	0.01%	2.7
TOTALS	**101,869**	**91,682,100**			**22,655.1**

Table 3: Upper Linville River land cover classification, percentage and data tabulation.

Upper Linville River 2016					
Pixel ID	**Pixel Count**	**Pixel Value (m2)**	**Name**	**Percent of Land Covered**	**Acreage**
11	506	455,400	Open Water	0.39%	112.5
21	18,600	16,740,000	Developed, Open Space	14.50%	4,136.5
22	1,741	1,566,900	Developed, Low Intensity	1.36%	387.2
23	523	470,700	Developed, Medium Intensity	0.41%	116.3
24	77	69,300	Developed, High Intensity	0.06%	17.1
31	249	224,100	Barren (Rock/Sand/Clay)	0.19%	55.4
41	39,275	35,347,500	Deciduous Forest	30.63%	8,734.5
42	3,137	2,823,300	Evergreen Forest	2.45%	697.7
43	50,868	45,781,200	Mixed Forest	39.67%	11,312.8
52	2,122	1,909,800	Shrub/Scrub	1.65%	471.9
71	1,875	1,687,500	Grassland/Herbaceous	1.46%	417.0
81	8,894	8,004,600	Pasture	6.94%	1,978.0
82	0	0	Cultivated Crops	0.00%	0.0
90	319	287,100	Woody Wetlands	0.25%	70.9
95	52	46,800	Emergent Herbaceous Wetlands	0.04%	11.6
TOTALS	**128,238**	**115,414,200**			**28,519.4**

2.2 Aquatic Macroinvertebrate Sampling

Aquatic macroinvertebrates were sampled at the nine selected sites in July, 2019. Three sites were selected along the major tributary of each 12-digit HUC displaying the highest quantities of forested, agriculture and developed land types. The selected watersheds consisted of the Curtis Creek watershed with the highest percentage of forested land type (96%), the Crooked Creek watershed with the most active agriculture (9%) and the Upper Linville River watershed with the greatest percentage of developed land (16%). All percentages were calculated based on all 11 subwatersheds in the overall Lake James watershed.

Once sites were selected, aquatic macroinvertebrates were sampled following the EPA rapid bioassessment protocol adapted by the state of North Carolina [12]. Procedures from the North Carolina Department of Water Resources Standard Operating Procedure for the Collection and Analysis of Benthic Macroinvertebrates Version 5.0 were utilized for the sampling of each site. Based on stream and watershed size, the "Qual 4" method was used. This consisted of one kicknet sample from a riffle, one leaf pack sample, one sweep net sample, and visual inspections in search of more cryptic taxa. A team of 2 people deployed a 1m^2 1000 micron mesh kicknet for 1 minute in an appropriate riffle and disturbed the substrate and sediment to flush the macroinvertebrates into the net. The net was then flushed into a 600 micron sieve bucket which was rinsed into a picking tray. The same 2 individuals picked any visible macroinvertebrates out of the tray for 20 minutes using forceps and preserved all specimens. For the sweep net collection, a 900 micron D-frame sweep net was used to sample bank vegetation and root masses. The net was then turned inside out over the picking tray and all matter was rinsed into the tray. Macroinvertebrates were picked out of the tray with special attention given to taxa not already collected. Once adequate individuals and unique taxa were collected, the tray and net were once again rinsed in the stream. For the leaf pack collections, handfuls of dark, decaying leaves were collected and placed into the 600 micron sieve bucket. The bucket was then mostly submerged so that the leaves within were submerged in water. Small amounts of leaves were vigorously washed in order to dislodge any detritivore macroinvertebrates clinging to them, inspected for remaining animals while over the bucket and, if clean, discarded. After the majority of leaf matter had been washed and discarded, the bucket was dumped and rinsed into the picking tray to obtain unique taxa not already collected. Once unique taxa were collected, the bucket and tray were again rinsed in the stream. Visual inspections were completed last. Researchers identified unique habitats not sampled by other methods and searched for cryptic or as-of-yet unfound taxa. These habitats included woody debris, bedrock and cobble and boulder-sized substrate in fast, slow, deep and shallow water, including substrate along the thalweg of the channel. Taxa that were present were placed in the same collection vials with the other macroinvertebrates.

Once all macroinvertebrates were collected and preserved, they were identified to family level using a stereo microscope. These identifications were tallied and computed to display total macroinvertebrate abundance and richness, EPT richness, EPT abundance, number of taxa with <2.5 biotic index value, and the IBI (0 - 10; Excellent - Poor).

2.3 Data Analysis

After completing the mapping and macroinvertebrate sections of the study, data analysis was performed. Using Pearson's correlation coefficient, correlation was tested among percentage Forested, Agriculture, Developed, conductivity and dissolved oxygen. An Analysis of Variance (ANOVA) test was used to test for significant variation in IBI among the land classifications. A 2-sample t-test was computed after the ANOVA to examine significant differences in the results.

3. Results

The nine selected biological sites had IBI scores between 2.31 to 3.92 ranging in classifications from Excellent to Good (Table 4). The maximum score of 3.92 is still relatively low when compared to more impaired watersheds. Trends in scoring generally rose, resulting in "lesser" ratings, from forested to agricultural and developed land classifications. Although, it must be noted that one site in the Upper Linville River and one site in the Crooked Creek watershed went against the general trend and were classified as Excellent, albeit with higher IBI scores than the forested sites. This is possibly related to the whole watershed being classified as >90% forested land type. Five of the nine sites were classified as "Excellent", and the remaining four sites as "Good".

Table 4: Aquatic macroinvertebrate IBI results by land classification type.

Stream Name	**Upper Mill Cr**	**Mill Cr**	**Curtis Cr**	**Crook. Cr**	**Crook. Cr**	**Mackey Cr**	**Linville R**	**Mill Tim Cr**	**Liville R**
Site Number	9	10	11	12	13	14	17	18	19
Site Location	**Andrews Geyser**	**Old Fort**	**Curtis Cr**	**Bat Cave**	**McHn.**	**Hwy 70**	**New. Hwy**		**Hwy 221**
Sample Date	July 2019	July 2019	July 2019	July 2019	July 2019	July 2019	July 2019	July 2019	July 2019
Total Abundance	243	139	152	210	53	259	220	138	134
Total Family Richness	19	14	20	13	6	20	22	17	16

EPT Family Richness	12	7	11	8	4	13	14	10	8
EPT Abundance	196	109	130	164	39	216	180	112	94
% EPT	80.7	78.4	85.5	78.1	73.6	83.4	81.8	81.2	70.2
Taxa < 2.5 Tolerance Value	8	5	6	4	1	8	8	5	5
IBI (0-10)	**2.81**	**2.72**	**2.31**	**3.92**	**3.71**	**3.08**	**2.92**	**3.62**	**3.45**
NCBI Qual 4 Bioclassifications	Excellent	Excellent	Excellent	Good	Good	Excellent	Excellent	Good	Good

The nine sites were separated into 3 land classification categories - forested, agriculture and developed, resulting in 3 sites in each of the 3 land classifications. The ANOVA showed significant differences in IBI scores among land classifications ($p = 0.041$) (Figure 4). The *t*-test results indicated that IBI scores for the forested watershed were significantly lower than those for agricultural and developed watersheds ($p = 0.025$).

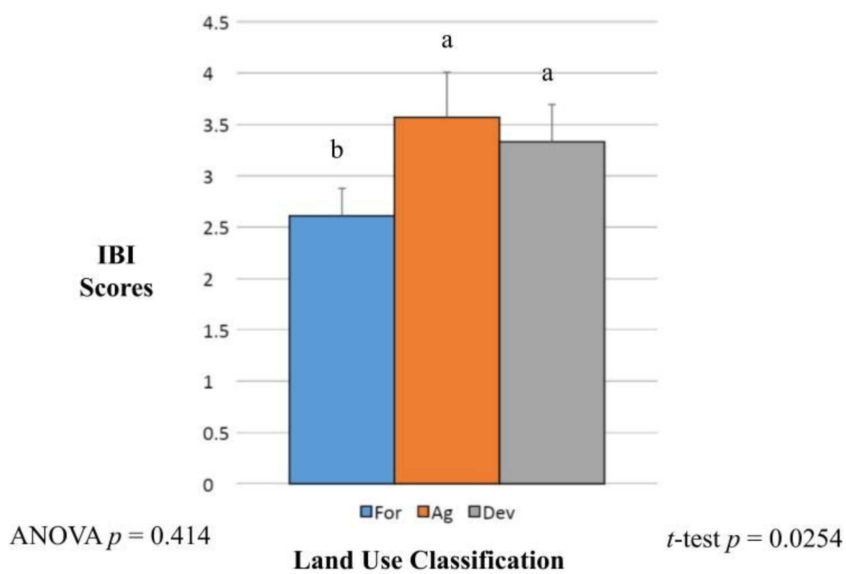

Figure 4. Analysis of Variance results comparing IBI by land classification type; groups sharing lowercase letters do not differ significantly.

Five significant correlations were found among the four variables examined. A significant positive correlation exists between percent Agriculture and percent Developed ($R = 0.788$, $p < 0.05$). This suggests that an increase in developed land use is associated with an increase in agricultural land and vice versa. Negative correlations exist between percent Forested and percent Agriculture ($R = - 0.920$, $p < 0.05$) as well as percent Forested and percent Developed ($R = - 0.965$, $p < 0.05$). This data shows that an increase in developed or agricultural land use will decrease the forested land cover. Conductivity also had a negative relationship with percent Forested ($R = - 0.828$, $p < 0.05$), maintained a positive relationship with percent Developed ($R = 0.890$, $p < 0.05$) and was not significant in its correlation with percent Agriculture ($p > 0.05$). This suggests that conductivity increases in a watershed with more impervious and urban land use, and it decreases with increased forest land use.

4. Discussion

Overall, the water quality in the Lake James watershed is good. The results of this study show that aquatic macroinvertebrate IBI scores are better in forested watersheds when compared to watersheds with higher concentrations of agriculture and developed land types. Watersheds that have more landscape intact have better water quality which generally results in higher ecological functions, more available aquatic habitat and therefore improved aquatic macroinvertebrate diversity. Our results agree with other researchers who have related intact forested watersheds with improved aquatic diversity [4]. The data also suggests that forested watersheds correlate with lower conductivity in the waterways which result in better IBI scores.

The positive relationship of agricultural and developed land is also of interest. As urbanization increases along with impervious surfaces, the data show that agriculture increases as well. This relationship results in aquatic habitat and diversity potentially receiving twice as much degradation compared to just one type of land type increasing and bringing its potential habitat threats. The conductivity in these three land classifications also implies that forested watersheds are somehow reducing, or not recieving, elements that increase the conductivity of the waterways.

The data in this study leaves open the possibility to further refine and focus work in order to better isolate variables. In order to isolate the effects of a forested watershed and conductivity, further study could be completed by isolating the 100 m riparian buffers along the primary tributaries [19]. Similar analyses could be completed by isolating the land type in the riparian zones of these streams, and that data could be compared with IBI and conductivity readings again in order to assess the impact of forests in whole watersheds versus riparian areas. Further expansion of these results is possible when relating land use classification with aquatic macroinvertebrate diversity. Since aquatic macroinvertebrates are used as water quality indicators, the lack of diversity and the presence of tolerant species also suggests that water quality in developed and agricultural watersheds is more degraded that water in forested watersheds. This has implications for human populations living and recreating in those waters. There is increased potential for the poorer water quality to impact human residents not only in the developed or agricultural watersheds, but also to residents living many miles downstream as the degraded water travels and pollutes waterways further downstream.

This study shows that landscape in a watershed affects the water quality of its streams and therefore affects the aquatic life and ecology that inhabit these waterways. As organisms reliant on freshwater sources, it becomes apparent that humans must value the aquatic ecology in order to value their own future.

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