ALLEGHENY COLLEGE
DEPARTMENT OF ENVIRONMENTAL SCIENCE AND SUSTAINABILITY

Aquatic Macroinvertebrates in Streams Within and Outside the Erie National Wildlife Refuge

A Report Submitted to the Erie National Wildlife Refuge

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2 September, 2020

Allegheny College Department of Environmental Science Publication 2020-1

Citation: Tisch, A., V. Bajek, A.L. Blaisdell, L. Blum, N.A. Fischer, S.G. Galley, T.D. Gates, D.L. Heffner, S.E. Hill, S.M. Holler, E.D. Kauchak, L.E. Lewis, M.R. Malley, A.N. Martin, E. Smith, S.M. Spotts, N.M. Storer, S.G. Thompson, I.S. Wolter and R.D. Bowden. 202_. Aquatic mmacroinvertebrates in streams within and outside the Erie National Wildlife Refuge. Allegheny College Department of Environmental Science and Sustainability Publication 2020-1.

ABSTRACT

Agricultural land use directly influences stream integrity through erosion and sedimentation, riparian zone loss, and infiltration of pesticides and nutrients. The Erie Wildlife Refuge, administered by the U.S. Fish and Wildlife Service, manages the approximately 9000-acre refuge for biodiversity and wildlife habitat, and is surrounded by a land matrix of forest and agricultural land use. To protect and manage streams flowing through the refuge, it is important to know how the aquatic macroinvertebrate community in streams on the refuge compares to the community in streams flowing through the surrounding agricultural land matrix. In fall 2018, we sampled stream morphology and macroinvertebrate density in two streams that flow through the protected land of the Erie National Wildlife Refuge. We also used the Pennsylvania Department of Environmental Protection protocol for riffle/run habitat assessment. Sites were located within the refuge, and at sites off the refuge immediately before the streams enter the refuge. Streams were small and relatively shallow, and on-and off-refuge sites were comparable in width (11-22 cm) and depth (1.8-4.2 m). Habitat assessment values indicated that the sites had sub-optimal to optimal quality. Macroinvertebrate densities did not differ between on- and off-refuge sites in either stream. Slightly more orders and families were identified at off-refuge than on-refuge sites, but Shannon-Weaver diversity indices were slightly higher on the refuge. Proportions of Ephemeroptera, Plecoptera, and Trichoptera ranged from 62-97% of total organisms and were not different between the sites on either stream. Overall, differences in macroinvertebrate communities between on- and off-refuge sites are slight or non-existent, indicating that streams on the refuge are reflective of communities outside the refuge.

Keywords: Aquatic macroinvertebrates, streams, Erie National Wildlife Refuge, land use, agriculture, habitat quality

INTRODUCTION

Streams are directly affected by land use type and intensity, as human activities in watersheds and along streambanks can directly and indirectly degrade stream quality leading to loss of habitats and biodiversity (Sutherland et al. 2002, Maloney and Weller 2011, dos Reis Oliveira 2018). Agricultural activities are a leading cause of impairment to streams and rivers (Lenat and Crawford 1994, Blann et al. 2009, Clapcott et al. 2011), with increased nutrient loading (Allan 2004), stream-bank erosion, and sedimentation from overland soil loss (Costa 1975, Berkman and Rabeni 1987, Cooper and Lipe 1992, Sponseller et al. 2001, Ostrofsky et al. 2018) contributing to ecosystem disruption. Livestock grazing and crop production often alter surrounding riparian zones, reducing streambank integrity and altering nutrient dynamics and organic matter inputs that govern aquatic food webs (Stauffer et al. 2000, Whitman 2009). These stream alterations are harmful to many aquatic species, resulting in adverse chain reactions to stream trophic structure (Walser and Bart 2006).

Aquatic macroinvertebrates in unimpaired streams are typically abundant and diverse (Silveira-Manzotti et al. 2016), and serve essential ecosystem processes, including nutrient cycling and organic matter processing (Clarke et al. 2008). Macroinvertebrates are frequently used as bioindicators of stream integrity due to their sensitivity and responses to stream stressors (Genito et al. 2002, Karr 2006). Stressors on macroinvertebrates decrease the abundance of pollution-intolerant species while increasing the abundance of tolerant species, usually resulting in decreases in macroinvertebrate diversity (Genito et al. 2002, Watzin and McIntosh 1999). The orders Empheroptera, Plecoptera, and Trichoptera are indicators of environmental stress, and hence their relative abundance in the macroinvertebrate community has been used to indicate water quality (Rosenberg and Resh 1993, Lenat and Penrose 1996).

The Erie National Wildlife Refuge (ENWR), established in 1959, is charged with maintaining wildlife habitat and diversity and contains several small streams that are part of the French Creek watershed (USFWS 2020). French Creek is considered to contain exceptional biological diversity, and contains globally rare freshwater mussels and fish (FCVC 2020). Much of the land base of the refuge was used historically for agricultural production; maintenance and restoration of the riparian-riverine ecosystem is a priority for management. The landscape outside of the refuge, and though which most incoming streams flow, contains a mosaic of forested and agricultural land use. Because agricultural practices can alter riparian zones, nutrient inputs, and sediment flow that may reduce water quality and reduce macroinvertebrate biotic diversity, we sought to determine if the stream habitat and macroinvertebrate taxa were more abundant and more indicative of healthy conditions at sites within the refuge compared to sites in those same streams that were downstream of the surrounding agricultural landscape matrix, but immediately upstream of the refuge.

METHODS

Site Description

The study area is located northwestern Pennsylvania (Fig. 1), which experiences a lake effect climate, an annual precipitation of approximately 112.5 cm, and mean daily temperature of 4.4°C in January and 21.1°C in July (U.S. Climate Data 2018). Precipitation is slightly seasonal, with inputs lowest in winter (January 7.2 cm) and highest in summer (July 10.7 cm). The region has an approximate four-month growing season and approximately four months of snow cover. The study was conducted in the Sugar Lake division of the ENWR in northwestern Pennsylvania; the terrestrial landscape is a matrix of temperate deciduous forest and agricultural lands used primarily for dairy and forage operations. In September and October 2018, two streams were examined, Lake Creek and Woodcock Creek, with two approximately 30-50m reaches studied on each stream. In each stream, one reach was located on the protected land of the ENWR and one was on land adjacent to the refuge. The off-refuge sites were located immediately upstream of the refuge. Both the Lake Creek Woodcock Creek sites were located downstream from a mix of agricultural and forested land use; the lake Creek site was downstream of the small village of Guys Mills. The Lake Creek site in the refuge was located approximately 2 km downstream from the off-refuge site; the Woodcock Creek site we about 7 km downstream of the off-refuge site. All four sites had intact riparian zones and were surrounded primarily by forest cover. Within each reach, six sites were selected randomly for measurements. Stream bottoms at all locations were gravelly, although the Lake Creek refuge site had areas of bedrock that were not covered by gravel.

Habitat Assessment

The PA DEP protocol (PA DEP 2018; Appendix A) for riffle/run habitat assessment was completed at each of the six sample sites for each stream reach. Six teams of 3-4 persons each evaluated one site per stream reach. An initial training was conducted to create uniformity in assigning scores to each of twelve in-stream and riparian zone parameters. The sums of scores were used to rank overall habitat quality category (optimal: 240-192; suboptimal: 191-132; marginal: 131-72; poor: 71 or less). Mean values at each stream reach were calculated from the assessments from each of the six teams.

Morphology Assessment

Stream width and maximum depth were measured at each sampling site at the location of macroinvertebrate sampling. Flow velocity was measured using a portable velocity meter.

Macroinvertebrate Assessment

Macroinvertebrates were assessed based upon the Pennsylvania Department of Environmental Protection (PA DEP) protocol for riffle/run stream macroinvertebrate assessment (PA DEP 2018). At each sampling location, 60-second kicks were performed in riffles, in approximately 10 cm of water, that were immediately upstream of a D-frame net with 100-micron mesh. Kick samples were collected in a downstream to upstream order so that organisms that were dislodged upstream were not collected in downstream samples. Collected samples were placed in 70% ethanol for preservation and subsequently identified to family. Macroinvertebrate diversity was assessed using a Shannon-Weaver index; data from all six samples at each site were combined to calculate a single index for each site.

Data Analysis

Differences between locations on each stream were analyzed using SigmaPlot ver. 12.5 and Meta-calculator.com (https://www.meta-calculator.com/t-test-calculator.php). We used t-tests when data were normally distributed and equal variance existed between samples. For comparisons of non-normally distributed data, a Mann-Whitney Rank Sum Test was used. Differences were assumed at $p<0.05$.

RESULTS

Stream width and depth of Woodcock Creek and Lake Creek did not differ between on- and off-refuge sites (Table 1). Water velocity at Woodcock Creek was the same both on and off the refuge, but velocity at Lake Creek was higher at the off-refuge site than on-refuge site ($p = 0.034$). Total habitat quality, which averaged from 168 to 202 among the four sites, did not differ between on- and off-refuge sites in either stream (Fig.2). However, there were some differences in some individual parameters between on- and off-refuge locations. At Woodcock Creek, the stream embeddedness ($p = 0.005$) and bank vegetative ($p = 0.04$) values were significantly greater at the on-refuge than the off-refuge site. At Lake Creek, the bank vegetation index indicated better conditions off the refuge than at the on-refuge site ($p = 0.003$).

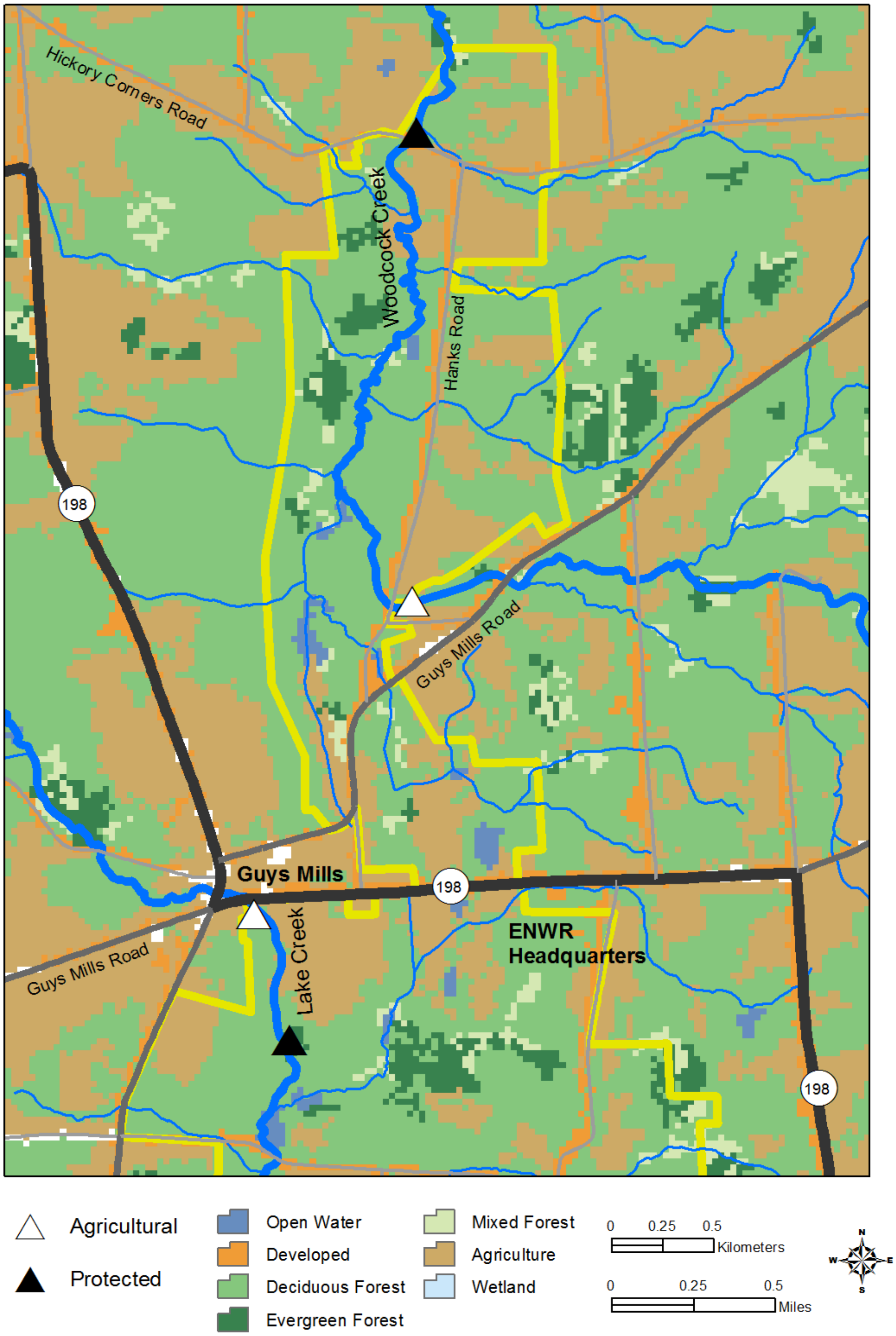

Fig.1. Location of stream sample sites at on-refuge and off-refuge stream sites of the Erie National Wildlife Refuge.

Table 1. Mean (±SE) stream velocity, depth, and width at on-refuge and off-refuge stream sites of the Erie National Wildlife Refuge.

	Woodcock Creek		Lake Creek	
	Off-Refuge	On-Refuge	Off-Refuge	On-Refuge
Stream Width (m)	4.6 (0.8)	4.2 (1.3)	1.8 (0.3)	2.7 (0.6)
Maximum Depth (cm)	20 (2)	21 (3)	22 (6)	11 (2)
Velocity (mps)	0.52 (0.12)	0.52 (0.15)	0.40 (0.06)	0.15 (0.09)

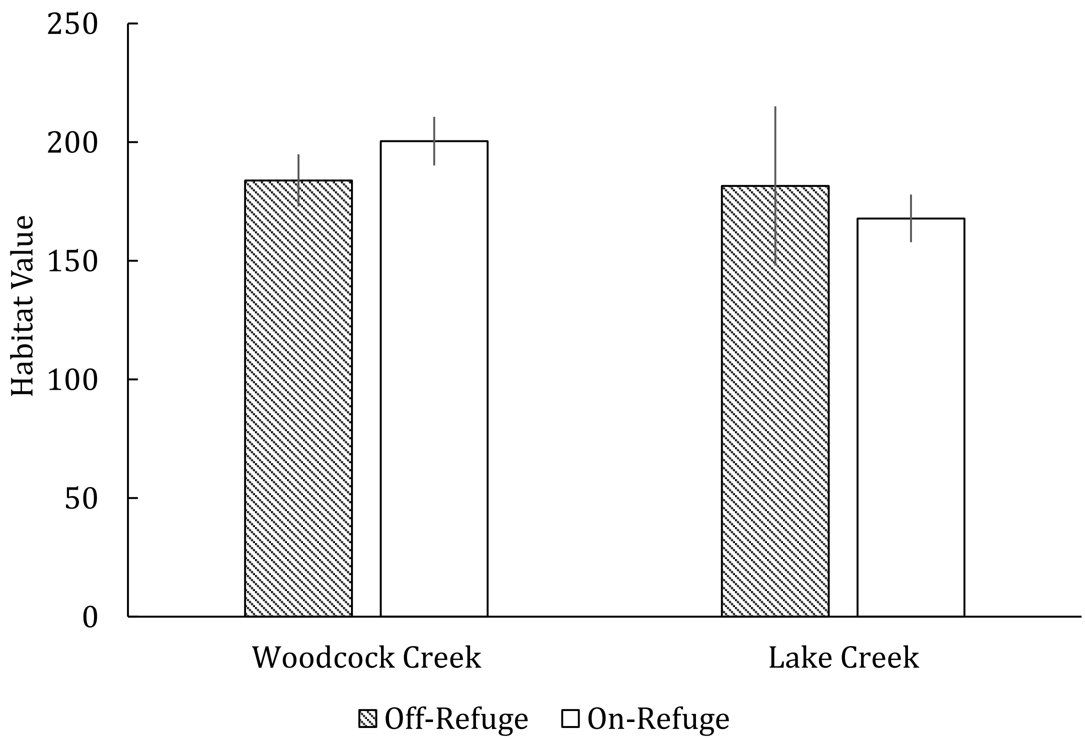

Figure 2. Habitat value scores for streams at on- and off-refuge stream sites of the Erie National Wildlife Refuge.

There was no difference in macroinvertebrate density between on- and off-refuge sites in either stream (Fig.2). Mean density among all sites ranged from 14.8 organisms m^{-2} at the Lake Creek on-refuge site to 32.3 organisms m^{-2} at the Woodcock Creek off-refuge site. The percentage of combined Ephemeroptera, Plecoptera, and Trichoptera (EPT) among the macroinvertebrates did not differ between on-refuge and off-refuge sites (Fig.3.). EPT composition ranged from 62 to 97 % among the four sites. Biodiversity was similar between upstream and downstream sites (Table 2). On-refuge sites had slightly fewer orders and families, as well as Shannon-Weaver diversity values than off-refuge sites.

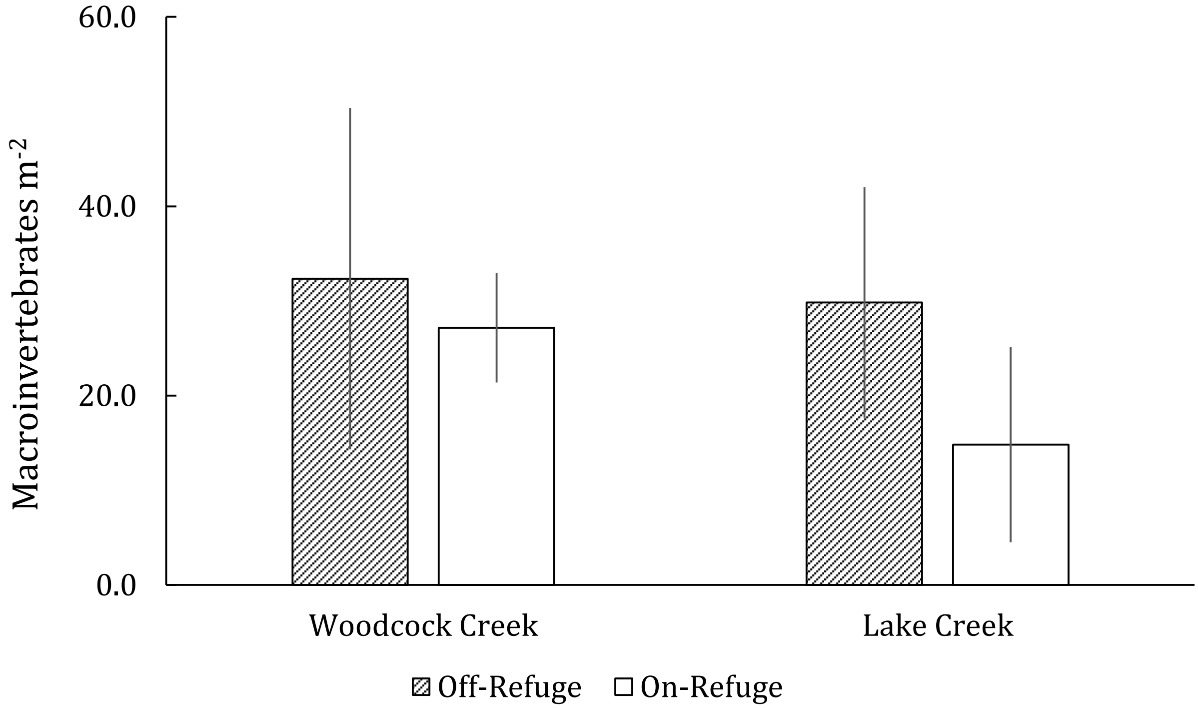

Figure 3. Macroinvertebrate density at on- and off-refuge stream sites in streams of the Erie National Wildlife Refuge.

Table 2. Macroinvertebrate biodiversity at on-refuge and off-refuge stream sites of the Erie National Wildlife Refuge.

	Woodcock Creek		Lake Creek	
	Off-Refuge	On-Refuge	Off-Refuge	On-Refuge
Number of orders identified	8	6	6	5
Number of families identified	13	12	11	8
Shannon-Weaver Diversity Index	1.69	1.65	1.61	1.41

DISCUSSION

Stream velocity at the off-refuge site of Lake Creek was greater than the on-refuge site at the time of measurement, however both were relatively low. We do not have sufficient measurements to estimate the actual volume of water flow to determine the actual flow rates. The off-refuge site should have as much or more flow as the on-refuge site, given that it is upstream of the on-refuge location. Precipitation inputs between sampling times, as well as differences in stream morphology, would explain differences in stream velocity between the sites.

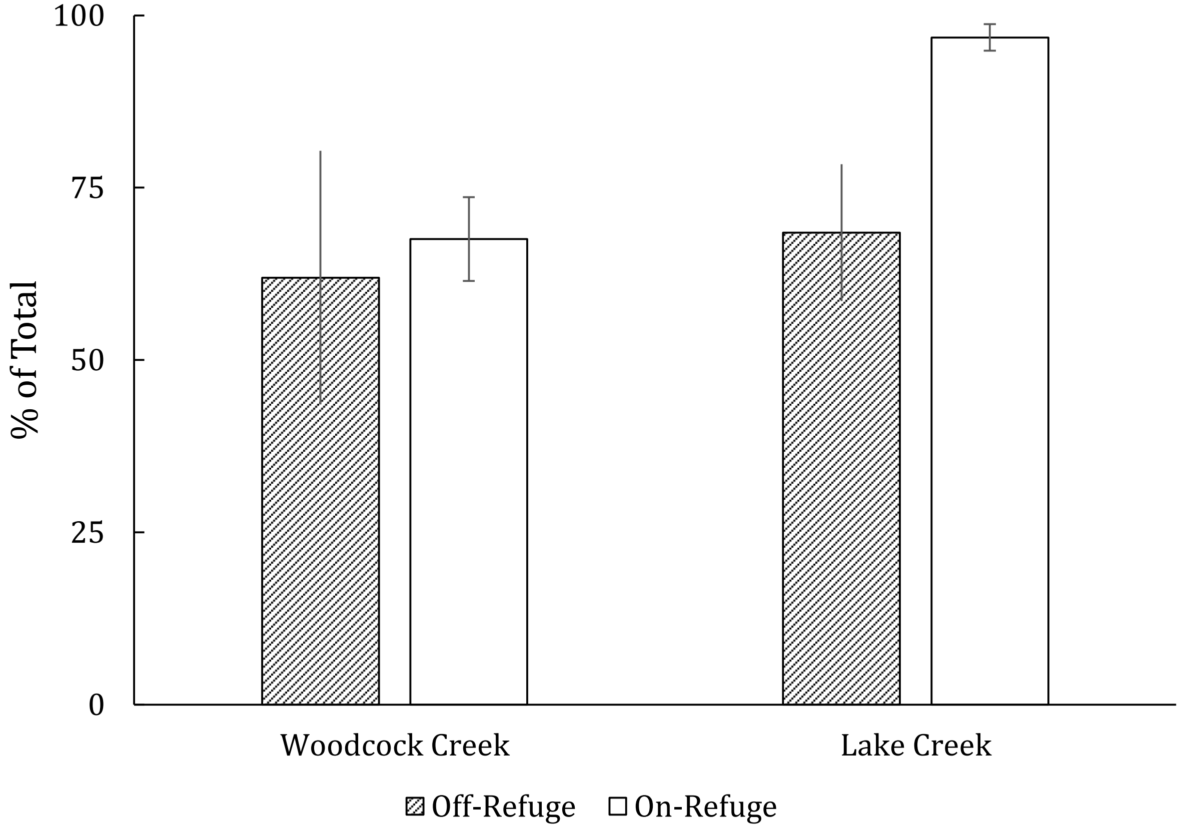

Figure 4. Percent EPT proportion of total macroinvertebrates collected within streams at on- and off-refuge sites of the Erie National Wildlife Refuge.

Although we did not measure streambed particle size distribution, the habitat assessment stream embeddedness parameter (the amount of sediment in the interstices of gravel) indicated that embeddedness was greater and bank protection was poorer in the off-refuge site than the on-refuge site in Woodcock Creek, indicating a landuse effect. Agricultural practices commonly affect stream substrata, usually due to enhanced sediment inputs (Lisle and Hilton 1992, Oeurng et al. 2010) that fill gravel deposits on the bottoms of stream beds. Sediments derived directly from the streambank, as well as upland erosion that was not trapped by an intact riparian zone, likely contributed to increased embeddedness in the stream.

Surprisingly, at Lake Creek, the bank condition was considered to be better at the off-refuge site than the on-refuge site. The bank condition parameter of the habitat assessment describes that apparent stability of the streambank and its potential resistance to erosion. At Lake Creek, the on-refuge site was located in a mixed hardwood-hemlock forest, and the site, even though it had a full overstory of mature trees, was noticeably lacking in an understory, likely due to low light levels. In comparison, the off-refuge site had a deciduous, and slightly more open tree overstory, and a much denser composition of shrubs along the streambank. The lower scores on the refuge site may be due to higher observed surface erosion of forest floor material and less apparent protection by understory vegetation. However, we did not observe erosion of mineral soil; the forest floor was primarily intact. Maintenance of intact riparian zones is critical due their role in maintaining the ecological integrity of streams; riparian zones can be highly effective in trapping upland sediments and preventing their deposition in streams (Lowrance et al. 1986, Lovisa et al. 2019).

Despite some differences in individual habitat parameters, total habitat quality did not differ with stream locations on the protected land of the Erie National Wildlife Refuge and those on the surrounding agricultural land. Three of the four sites had suboptimal conditions, and one was optimal (on-refuge, Woodcock Creek). We found no differences among macroinvertebrate densities between on-and off-refuge sites, and EPTs represented a high proportion of total organisms each site. High proportions of EPTs indicate high habitat quality (Ruaro et al. 2016, Lunde and Resh 2012); agricultural land use often reduces the proportion of EPTs in streams located in agriculturally-dominated watersheds (Hall et al. 2001). This indicates that the streams on and off the refuge have characteristics that are not adversely altered by agriculture or urbanization stressors, and that the biotic community is not dramatically altered by agricultural activities on the terrestrial landscape, as has been documented elsewhere (Jones et al. 2011, Kemp et al. 2011, Piggott et al. 2015). We note that we do not have estimates of the proportions of the watershed in each stream that are in agriculture, especially upstream of the off-refuge sites. Similarly, we do not have estimates of the intactness of riparian zones in the streams beyond the habitat assessment scores. Clearly the proportion of the landscape in agriculture, as well as eth intactness of riparian zones, can influence the macroinvertebrate community. We also point out that the on-refuge sites are not entirely independent from activities off the refuge, as the streams flow through the agricultural landscape before entering the refuge sites. Hence, it is possible that upstream agricultural activities are influencing the on-refuge sites, even though they are two (Lake Creek) to five (Woodcock Creek) km downstream of the off-refuge sites. It is also possible that disturbance of land through agricultural practices was not enough to cross a threshold that would demonstrably alter the stream macroinvertebrate community.

Overall, we found that habitat conditions and the macroinvertebrate community was similar on and off the refuge, and that despite flowing through an agricultural landscape, the streams had high habitat and macroinvertebrate quality.

ACKNOWLEDGEM ENTS

We thank M. Althouse of the ENWR for assistance in located field sites, V. Muller of the ENWR for project support, S. Reese and C. Bradshaw-Wilson for laboratory and logistical assistance, and M. Ostrofsky for constructively reviewing this manuscript. We also thank Chris Shaffer for assistance with the site map.

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Appendix A. Pennsylvania Department of Environmental Protection water quality network habitat assessment index.

Physical Habitat Evaluation Form for Riffle/Run Prevalence

Waterbody Name:	GIS Key (YYYYMMDD-hhmm-User):
Location:	
Investigators:	Completed By:

Parameter	Optimal	Suboptimal	Marginal	Poor
1. Instream Cover (Fish)	Greater than 50% mix of boulder, cobble, submerged logs, undercut banks, or other stable habitat.	30-50% mix of boulder, cobble, or other stable habitat; adequate habitat.	10-30% mix of boulder, cobble, or other stable habitat; habitat availability less than desirable.	Less than 10% mix of boulder, cobble, or other stable habitat; lack of habitat is obvious.
	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1
2. Epifaunal Substrate	Well-developed riffle and run; riffle is as wide as stream and length extends two times the width of stream; abundance of cobble.	Riffle is as wide as stream but length is less than two times width; abundance of cobble; boulders and gravel common.	Run area may be lacking; riffle not as wide as stream and its length is less than 2 times the stream width; gravel or large boulders and bedrock prevalent; some cobble present.	Riffles or run virtually nonexistent; large boulders and bedrock prevalent; cobble lacking.
	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1
3. Embeddedness	Gravel, cobble, and boulder particles are 0-25% surrounded by fine sediment.	Gravel, cobble, and boulder particles are 25-50% surrounded by fine sediment.	Gravel, cobble, and boulder particles are 50-75% surrounded by fine sediment.	Gravel, cobble, and boulder particles are more than 75% surrounded by fine sediment.
	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1
4. Velocity/Depth Regimes	All four velocity/depth regimes present (slow-deep, slow shallow, fast-deep, fast shallow)	Only 3 of the 4 regimes present if fast-shallow is missing, score lower than if missing other regimes.)	Only 2 of the 4 habitat regimes present (if fast-shallow or slow-shallow are missing, score lower than if missing other regimes).	Dominated by 1 velocity/depth regime (usually slow-deep).
	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1
5. Channel Alteration	No channelization or dredging present.	Some channelization present, usually in areas of bridge abutments; evidence of past channelization, i.e. dredging (greater than 20 yr.) may be present, but recent channelization is not present.	New embankments present on both banks; and 40 to 80% of stream reach channelized and disrupted.	Banks shored with gabion or cement over 80% of the stream reach channelized and disrupted.
	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1
6. Sediment Deposition	Little or no enlargement of islands or point bars and less than 5% of the bottom affected by sediment deposition.	Some new increase in bar information, mostly from coarse gravel; 5-30% of the bottom affected; slight deposition in pools.	Moderate deposition of new gravel coarse sand on old and new bars; 30-50% of the bottom affected; sediment deposits at obstruction, construction and bends, moderate depositions of pools prevalent.	Heavy deposits of fine material increased bar development; more than 50% of the bottom changing frequently; pools almost absent due to substantial sediment deposition.
	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1

Cont.

Parameter	Optimal	Suboptimal	Marginal	Poor
7. Riffle Frequency	Occurrence of riffles relatively frequent;; distance between riffles divided by the width of the stream equals 5 to 7; variety of habitat.	Occurrence of riffles infrequent; distance between riffles divided by the width of the stream equals 7 to 15.	Occasional riffle or bend; bottom contours provide some habitat; distance between riffles divided by the width of the stream is between 15 to 25.	Generally all flat water or shallow riffles; poor habitat; distance between riffles divided by the width of the stream is >25.
______________	**20 19 18 17 16**	**15 14 13 12 11**	**10 9 8 7 6**	**5 4 3 2 1**
8. Channel Flow Status	Water reaches base of both lower banks and minimal amount of channel substrate is exposed.	Water fills >75% of the available channel; or <25% of channel substrate is exposed.	Water fills 25-75% of the available channel and/or riffle substrates are mostly exposed.	Very little water in channel and mostly present as standing pools.
______________	**20 19 18 17 16**	**15 14 13 12 11**	**10 9 8 7 6**	**5 4 3 2 1**
9. Condition of Banks	Banks stable; no evidence of erosion or bank failure.	Moderately stable; infrequent, small areas of erosion mostly healed over.	Moderately unstable; up to 60% of banks in reach have areas of erosion.	Unstable; many eroded areas; "raw" areas frequent along straight sections and bends; on side slopes, 60-100% of bank has erosional scars.
______________	**20 19 18 17 16**	**15 14 13 12 11**	**10 9 8 7 6**	**5 4 3 2 1**
10. Bank Vegetative Protection	More than 90% of the stream bank surfaces covered by vegetation.	70-90% of the stream bank surfaces covered by vegetation.	50-70% of the stream bank surfaces covered by vegetation.	Less than 50% of the stream bank surfaces covered by vegetation.
	20 19 18 17 16	**15 14 13 12 11**	**10 9 8 7 6**	**5 4 3 2 1**
11. Grazing or Other Disruptive Pressure	Vegetative disruption through grazing or mowing is minimal or not evident; almost all plants allowed to grow naturally.	Disruption evident but not affecting full plant growth potential to any great extent; more than one-half of the potential plant stubble height remaining.	Disruption obvious; patches of bare soil or closely cropped vegetation common; less than one-half of the potential plant stubble height remaining.	Disruption of stream bank vegetation is very high; vegetation has been removed to 2 inches or less in average stubble height.
______________	**20 19 18 17 16**	**15 14 13 12 11**	**10 9 8 7 6**	**5 4 3 2 1**
12. Riparian Vegetative Zone	Width or riparian zone >18 meters; human activities (i.e. parking lots, roadbeds, clear-cuts, lawns or crops) have not impacted zone.	Width of riparian zone 12-18 meters; human activities have impacted zone only minimally.	Width of riparian zone 6-12 meters; human activities have impacted zone a great deal.	Width of riparian zone <6 meters; little or no riparian vegetation due to human activities.
______________	**20 19 18 17 16**	**15 14 13 12 11**	**10 9 8 7 6**	**5 4 3 2 1**

TOTAL ______

Appendix B. Woodcock Creek habitat assessment raw data at on- and off-refuge sites of the Erie National Wildlife Refuge (nd = no data).

Woodcock Creek								
	Off-refuge Site							
	Sample							
Parameter	**1**	**2**	**3**	**4**	**5**	**6**	**Ave**	**SE**
Instream Cover	19	13	13	20	18	14	**16.2**	**1.3**
Epifaunal Substrate	18	13	8	20	19	20	**16.3**	**2.0**
Embeddness	12	8	3	18	9	16	**11.0**	**2.3**
Velocity/Depth Regimes	10	6	7	15	10	15	**10.5**	**1.6**
Channel Alteration	19	13	18	19	18	20	**17.8**	**1.0**
Sediment Deposition	18	15	8	18	9	16	**14.0**	**1.8**
Frequency of Riffles	20	18	15	20	17	19	**18.2**	**0.8**
Channel Flow Status	16	15	14	18	13	15	**15.2**	**0.7**
Condition of Banks	12	14.5	10	15	5	6	**10.4**	**1.7**
Bank Vegetative Protection	17	19	15	20	18	14	**17.2**	**0.9**
Grazing or other disruptive pressure	19	19	18	20	20	19	**19.2**	**0.3**
Riparian Vegetation Zone Width	19	20	16	20	15	18	**18.0**	**0.9**
Total	199	173.5	145	223	171	192	**183.9**	**11.0**
	On-refuge Site							
	Sample							
Parameter	**1**	**2**	**3**	**4**	**5**	**6**	**Ave**	**SE**
Instream Cover	nd	20	14	17	19	14	**16.8**	**1.2**
Epifaunal Substrate	nd	19	8	17	7	20	**14.2**	**2.8**
Embeddness	nd	18	19	18	16	19	**18.0**	**0.5**
Velocity/Depth Regimes	nd	19	9	20	10	19	**15.4**	**2.4**
Channel Alteration	nd	20	13	19	18	17	**17.4**	**1.2**
Sediment Deposition	nd	17	18	17	15	17	**16.8**	**0.5**
Frequency of Riffles	nd	15	12	20	18	18	**16.6**	**1.4**
Channel Flow Status	nd	19	18	18	14	18	**17.4**	**0.9**
Condition of Banks	nd	15	10	16	13	16	**14.0**	**1.1**
Bank Vegetative Protection	nd	20	20	20	20	18	**19.6**	**0.4**
Grazing or other disruptive pressure	nd	20	14	20	18	15	**17.4**	**1.2**
Riparian Vegetation Zone Width	nd	20	20	20	10	14	**16.8**	**2.1**
Total	**nd**	**222**	**175**	**222**	**178**	**205**	**200.4**	**10.2**

Appendix C. Lake Creek habitat assessment raw data at on- and off-refuge sites of the Erie National Wildlife Refuge. (nd = no data).

Lake Creek								
	Off-refuge Site							
	Sample							
Parameter	**1**	**2**	**3**	**4**	**5**	**6**	**Ave**	**SE**
Instream Cover	nd	18	20	18	7	19	**16.4**	**2.4**
Epifaunal Substrate	nd	6	11	19	20	19	**15.0**	**2.8**
Embeddness	nd	8	15	16	16	18	**14.6**	**1.7**
Velocity/Depth Regimes	nd	8	5	20	16	13	**12.4**	**2.7**
Channel Alteration	nd	20	20	18	12	13	**16.6**	**1.7**
Sediment Deposition	nd	19	14	12	13	16	**14.8**	**1.2**
Frequency of Riffles	nd	5	17	19	13	19	**14.6**	**2.6**
Channel Flow Status	nd	9	12	14	19	15	**13.8**	**1.7**
Condition of Banks	nd	14	17	12	15	16	**14.8**	**0.9**
Bank Vegetative Protection	nd	20	20	16	17	20	**18.6**	**0.9**
Grazing or other disruptive pressure	nd	20	20	13	20	14	**17.4**	**1.6**
Riparian Vegetation Zone Width	nd	15	13	12	9	14	**12.6**	**1.0**
Total	**nd**	**162**	**184**	**189**	**177**	**196**	**181.6**	**5.8**
	On-refuge Site							
	Sample							
Parameter	**1**	**2**	**3**	**4**	**5**	**6**	**Ave**	**SE**
Instream Cover	10	13	15	18	18	14	**14.7**	**1.3**
Epifaunal Substrate	12	15	18	14	16	19	**15.7**	**1.1**
Embeddness	18	6	17	13	17	14	**14.2**	**1.8**
Velocity/Depth Regimes	8	9	10	16	19	10	**12.0**	**1.8**
Channel Alteration	19	20	20	19	20	20	**19.7**	**0.2**
Sediment Deposition	19	20	17	10	10	8	**14.0**	**2.1**
Frequency of Riffles	5	10	19	16	18	19	**14.5**	**2.3**
Channel Flow Status	5	5	10	14	9	9	**8.7**	**1.4**
Condition of Banks	9	10	4	9	15	8	**9.2**	**1.4**
Bank Vegetative Protection	3	20	13	19	3	19	**12.8**	**3.3**
Grazing or other disruptive pressure	11	20	19	20	20	19	**18.2**	**1.4**
Riparian Vegetation Zone Width	1	20	20	20	5	20	**14.3**	**3.6**
Total	120	168	182	188	170	179	**167.8**	**10.0**

Appendix D. Woodcock Creek **a**quatic macroinvertebrates at on- and off-refuge sites of the Erie National Wildlife Refuge.

Woodcock Creek		**Off-refuge**							**On-refuge**					
		Sample							Sample					
Order	**Family**	**1**	**2**	**3**	**4**	**5**	**6**		**1**	**2**	**3**	**4**	**5**	**6**
Ephemeroptera	Heptageniidae				36	2	30		18	5	13	13	11	22
	Ephemerellidae						3							
	Unidentified	1							1					
	Oligoneuriidae				5									
Plecoptera	Perlidae						2		3					
Trichoptera	Hydropsychidae	1		2	12		30		1	1	1	5		
	Philopotamidae				11		35		1					
	Climidae											9		
Diptera	Tipulidae						3					7	1	
	Chironomidae						1							
	Athericidae									1	3			
	Nymphomyiidae													
Colleoptera	Psephenidae								1			1	5	1
	Elmidae	13					2		21		2	3	6	1
Megaloptera	Sialidae													4
	Corydalidae					1	2		1					1
Annelida	Unidentied		1											
Arachnida	Hydrachnidae	1												
Amphiphoda	Gammaridae													

Appendix E. Lake Creek aquatic macroinvertebrates at on- and off-refuge sites of the Erie National Wildlife Refuge.

Lake Creek		**Off-refuge**							**On-refuge**					
		Sample							Sample					
Order	**Family**	**1**	**2**	**3**	**4**	**5**	**6**		**1**	**2**	**3**	**4**	**5**	**6**
Ephemeroptera	Heptageniidae		1	3	23	1	2					2	11	16
	Ephemerellidae	1					1							
	Unidentied	1							1					
	Oligoneuriidae													
Plecoptera	Perlidae													
Trichoptera	Hydropsychidae	2			17	6	5						13	2
	Philopotamidae	1			23	20	44		1			1	35	1
	Climidae													
Diptera	Tipulidae													
	Chironomidae						2							
	Athericidae													
	Nymphomyiidae		1											
Colleoptera	Psephenidae	4			1	1	1						1	1
	Elmidae	1	1	2	9		4						3	
Megaloptera	Sialidae													
	Corydalidae					1								
Annelida	Unidentied													
Arachnida	Hydrachnidae	10							2					
Amphiphoda	Gammaridae												1	