# Analyzing the Impact of Natural Gas Pipeline Corridors on Headwater Stream Productivity in Central Pennsylvania

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**ABSTRACT**

The need for cleaner domestic energy sources has driven hydraulic fracking for natural gas resources into Pennsylvania and the Marcellus Shale region over the past few decades. This boom has led to the construction of 7,788 currently active well sites, 832 of which are in Lycoming County. Our objective was to assess stream productivity where pipeline corridors intersect headwater streams to evaluate potential effects of pipeline corridors. We examined stream primary and secondary productivity by measuring benthic chlorophyll *a* and macroinvertebrate richness, dominance, and diversity at 3 sites with pipeline corridors cut into the forest canopy. Stream measurements were collected in areas upstream, downstream and within the canopy removals of the corridor. Our results indicate a clear difference between chlorophyll *a* content within the corridors (27.00 mg/m$^2$) compared to the average of the upstream and downstream sites (19.66 mg/m$^2$). Invertebrate family richness and diversity decreased in the corridor at two of the three sample locations. This loss of diversity may be associated with increased autochthonous productivity in an ecosystem that is adapted to mainly allochthonous productivity. We suggest that management strategies should be considered when removing forest canopies near streams in order to mitigate the negative impacts on invertebrate diversity and the diversity of higher trophic levels of organisms.
**Keywords**: Chlorophyll *a*; hydraulic fracturing; macroinvertebrates; riparian corridor

## INTRODUCTION

The Marcellus and Utica Shale region lays beneath approximately 280,000 km$^2$ of the Appalachian Basin in the northeastern United States. A majority of this region is below Pennsylvania, New York, and West Virginia. This large deposit of organic-rich marine shale was deposited in the Middle Devonian and Ordovician periods. Tapping into natural gas resources for extraction in much of northcentral Pennsylvania requires a well to be drilled approximately 1.5 km vertically down to the shale bed, and may continue another 1.5 km horizontally after reaching the shale. After drilling, fracturing fluid (containing water, chemicals, and sand) is pumped under high pressure down into the shale, allowing for the valuable natural gas to be extracted from the well (Kiviat 2013). Gathering pipelines then transport the natural gas in shallow underground transport lines that eventually carry it to market. Although these pipelines are buried, they require the clearing of right-of-way forest corridors in order to properly construct, monitor, and maintain them. In doing so, the natural gas industry is permanently impacting both terrestrial and aquatic natural habitats through deforestation (Johnson et al. 2011).

As of March 2015, there were 7,788 active wells in Pennsylvania, 832 wells located in Lycoming County alone. There are almost 11,000 km (6,800 miles) of existing natural gas pipelines and an additional 7,400 km (4,600 miles) to be constructed by 2018, at an average of 30 meters wide which will translate to approximately 55,000 hectares of Pennsylvania land being impacted by pipeline construction alone (Amico et al. 2015). This estimate matches those from a Pennsylvania Energy Impacts Assessment which proposes that 48,500 to 121,000 hectares will be impacted by natural gas pipeline construction in Pennsylvania by the year 2030. Half of the total area lost will most likely be comprised of forested habitats. These numbers are only inclusive of the acreage that will be impacted by the natural gas pipelines, excluding other Marcellus gas infrastructure such as well pads, roads, and staging/storing stations (Johnson et al. 2011). The construction of pipelines requires extensive deforestation, forest fragmentation, and in many places pipeline corridors that intersect headwater streams (Johnson et al. 2011; Drohan et al. 2012; Kiviat 2013).

Headwater streams contribute significantly to the health of the entire downstream watershed by providing biodiversity through creating unique habitats and refuge from predators, competitors, and alien species. These attributes allow for the preservation of genetic linkages between upstream and downstream fish populations, rich feeding grounds for macroinvertebrates from large inputs of leaves, and areas of thermal refuge for many species. Native species such as the brook trout (*Salvelinus fontinalis*) are one example, as they rely on headwater streams for clean, cold, well-oxygenated water. Despite their small size, headwater streams maintain strong biological linkages to downstream ecosystems (Meyer et al. 2007) and are areas increasingly recognized for important connections between instream food webs and food webs in the riparian zone (Baxter et al. 2005). Construction of natural gas pipelines through forests and across headwater streams poses a major threat to many organisms dependent on these headwaters by increasing sedimentation, increasing surface runoff from well pads and roads, altering hydrological regimes, destroying riparian habitat, and opening up forest canopies that are adjacent to streams (Kiviat 2013; Weltman-Fahs and Taylor 2013).

Most current research on the impact of natural gas pipelines is related to human health, not on how they influence stream communities (Kiviat 2013). Therefore, our research focused on how natural gas pipeline corridors affect headwater stream primary and secondary productivity. Deforestation across watersheds results in an increase in sunlight to normally shaded headwaters, causing potential impacts such as warming the stream waters and altering algal concentrations. One major implication of increased exposure to sunlight is that autochthonous inputs (in-stream primary productivity by algal communities) will increase. This disrupts the normal flow of energy as described by the river continuum concept: the primary source of production in headwater streams is allochthonous input of coarse particulate organic matter, such as large quantities of fallen leaves from the riparian zone, which is broken down and transported downstream (Vannote et al. 1980). The impact of increased sunlight in headwater streams could influence the types of organic matter in the stream as well as the macroinvertebrate and fish communities. Since headwater streams are a habitat containing strongholds of many native brook trout populations, examining the influence of natural gas pipelines also involves broader fisheries management issues (Weltman-Fahs and Taylor 2013).

Our objective was to examine the impact of natural gas pipeline corridors on the stream productivity of three headwater streams in central Pennsylvania. We hypothesized that (1) chlorophyll *a* will be greatest in the area where pipeline construction removed riparian forest canopies, exposing the stream to direct sunlight and (2) that the macroinvertebrate communities will differ between pipeline corridor and adjacent stream segments located up or downstream from the corridor.

## METHODS

We chose sample locations within a heavily forested area of northcentral Pennsylvania that has been subjected widely to hydraulic fracture drilling and construction of pipeline corridors. The vast majority of the land north of Lock Haven and Williamsport, Pennsylvania, is publicly held as State Forest and State Game Lands. These areas are predominantly forested with mature, second growth forest. The sample locations were selected based on accessibility, presence of a clear-cut corridor, and watershed containment. The first and second sites were located near the town of Salladasburg, PA in the Larrys Creek watershed (Larrys Creek: corridor at 41.322540, -77.190895) and First Fork Larrys Creek (Figure 1; corridor at 41.324252, -77.296357). The third site was located near the town of Waterville, PA, in the Pine Creek watershed, along Lower Pine Bottom Run (corridor at 41.277773, -77.414085). Each site was separated into three areas for collection and analysis: downstream of the corridor, corridor, and upstream of the corridor. Downstream and upstream sites were at least 25 meters from the ends of the corridor (within the shaded canopy of the forest) to avoid influence from elevated sunlight in the corridor. We did not take specific measurements of the degree of canopy present at upstream and downstream sites, however the forest at each site was mature and provided a dramatic contrast to the fully exposed streambed at the corridor site (Figure 1).

**Figure 1.** Natural gas pipeline corridor intersecting First Fork Larrys Creek, showing the clear-cut of the riparian zone for the installation and maintenance of an underground pipeline.

Data collection took place on September 10, 11, and 13 of 2016 between the hours of 1300-1600. At each site we measured the corridor length, pH, temperature, five stream widths, and 10 substrate depths and lengths. We collected periphyton from three rocks at each downstream, corridor, and upstream location to obtain an estimate of the chlorophyll *a* content in each location. Periphyton samples were brushed off each rock with a soft brush into a bucket using a small amount of stream water, and the total volume of water used to wash the rock was recorded. Then a 5.0 mL sample of the washed solution was filtered through a 47 µm diameter filter paper, removed with forceps, folded in half, wrapped securely in aluminum foil, and frozen until analysis in the lab. The planar area for each rock was traced onto a standard letter sheet of paper to calculate the rock surface area scraped for periphyton (Rasband 1997). In the lab, the filter was removed from the aluminum foil, soaked in 10.0 mL of 70% ethanol overnight in the refrigerator, and 3.0 mL of green colored solution transferred to a vial. Each sample's absorbance was then measured using a mass spectrometer at wavelengths of 750 and 665 nm, two drops of 0.1N HCl acid were added to each, mixed lightly, and measured again at wavelengths 750 and 665 nm. Absorbance values and rock surface area measurements were then used to approximate the chlorophyll *a* concentration in each periphyton sample (Wetzel 1964).

Macroinvertebrates were collected at each sample site using a Surber sampler. Six Surber frames were collected at each location from riffle habitats, and preserved in a bottle with 70% ethanol until processing in the lab. To standardize effort, picking invertebrates from each sample was performed for either a 45 minute time period or until 250 individuals were collected (Barbour et al. 1999). After all the samples were picked, the individuals were identified to their order and family for each sample using a macroinvertebrate key

(McCafferty and Provonsha 1983; Merritt et al. 2008). Once identified to family we calculated the family richness, dominant family, percent dominant taxon (% dominance), percent of the sample comprised of ephemeroptera, plecoptera, and trichoptera (% EPT), Simpson's diversity, and Hilsenhoff Biotic Index for each sample (Hilsenhoff 1988).

**Table 1.** Average chlorophyll *a* content (mg/m2) for the coupled upstream and downstream sites vs. corridors with standard deviations and percent change. DOWN, COR, and UP indicate the downstream, in corridor, and upstream location, respectively.

| | Larrys Creek | Lower Pine Bottom Run | First Fork Larrys Creek | Combined Average |
|---|---|---|---|---|
| DOWN/UP | 40.22 ± 14.7 | 3.01 ± 2.8 | 15.74 ± 7.6 | 19.66 |
| COR | 55.44 ± 25.9 | 17.46 ± 9.9 | 8.10 ± 3.4 | 27.00 |
| % Change | 37.84 | 480.07 | -48.54 | 27.19 |

## RESULTS

### Chlorophyll *a* Content

Average chlorophyll *a* values were highest in the open corridors. By site, chlorophyll *a* at downstream, corridor, and upstream locations, respectively, were: (Larrys Creek) 39.01±19.0 mg/m$^2$, 55.44±25.9 mg/m$^2$, and 41.43±13.2 mg/m$^2$; (Lower Pine Bottom Run) 1.05±1.8 mg/m$^2$, 17.46±9.9 mg/m$^2$, and 4.98±2.2 mg/m$^2$; (First Fork Larrys Creek) 14.35±2.3 mg/m$^2$, 8.10±3.4 mg/m$^2$, and 17.14±11.6 mg/m$^2$ (Figure 2). The percent change in chlorophyll *a* content between coupled upstream/downstream sites and their respective corridor were 37.84% for Larrys Creek, 480.07% for Lower Pine Bottom Run, -48.54% for First Fork Larrys Creek, and 27.19% for the average of all sites (Table 1).

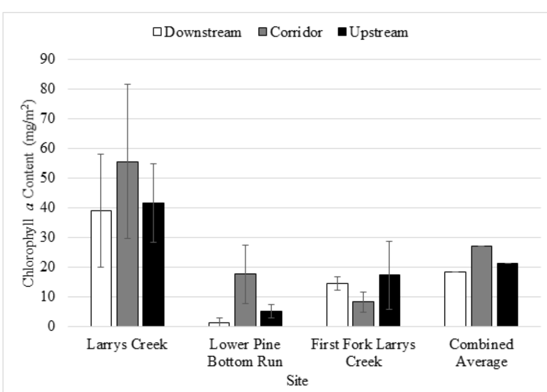


**Figure 2.** Average chlorophyll *a* +/- SD (mg/m$^2$) for each site's downstream, corridor, and upstream sample locations and standard deviations. Corridors had the highest average benthic chlorophyll *a* compared to upstream/downstream locations.

### Macroinvertebrates

Macroinvertebrate family richness was measured for downstream, corridor, and upstream samples at each sample site (Table 2). All samples from Larrys Creek contained 17 total families; Lower Pine Bottom Run sample sites contained 20 total families downstream, 16 in the corridor, and 18 in the upstream sample; First Fork Larrys Creek contained 14 total families downstream, 13 in the corridor, and 14 upstream. The following invertebrate community data are reported in the same order (downstream, corridor, and upstream). Percent of the dominant family represent the number of individuals from the most common macroinvertebrate family relative to the number of individuals in the sample. In Larrys Creek the percentages were 62.8, 62.4, and 56.4 (all dominated by Hydropsychidae). At Lower Pine Bottom Run, the percent dominant values were 28.7 Chloroperlidae, 36.4 Ephemerellidae, and 17.7 Chloroperlidae. For First Fork Larrys Creek the values were 40.0, 61.6, and 35.2 (all dominated by Hydropsychidae). Percent of EPT at each site was greater than 75%. These values ranged from 82.0-86.4% at Larrys Creek, 76.2-85.1% at Lower Pine Bottom Run, and 78.4-92.0% at First Fork Larrys Creek. Simpson's diversity values were 0.591, 0.594, and 0.660 at Larrys Creek. At Lower Pine Bottom Run the diversity values were 0.972, 0.880, and 0.953. First Fork Larrys Creek values were 0.789, 0.605, and 0.826. Hilsenhoff Biotic Index values for families determined each sample to have excellent water quality (FBI ≤ 3.75) except the downstream sample at Larrys Creek which determined the water quality to be very good (FBI: 3.76-4.25). At Larrys Creek there were two families contained in the downstream and upstream samples that were not contained in the corridor sample (Diptera Chaoboridae and Plecoptera Chloroperlidae). Lower Pine Bottom Run only had one family missing from the corridor sample (Tricoptera Polycentropodidae). First Fork Larrys Creek had three families missing that were in the downstream and upstream samples (Diptera Culicidae, Tricoptera Rhyacophilidae, and Ephemeroptera Heptageniidae).

**Table 2.** Macroinvertebrate Community Data Summary: Family Richness, Dominance, Abundance, % EPT, Simpson's Diversity, and Hilsenhoff Biotic Index. LC: Larrys Creek, LP: Lower Pine Bottom Run, FF: First Fork Larrys Creek. DOWN, COR, and UP indicate the downstream, in corridor, and upstream location, respectively.

| Site | Family Richness | Most Dominant Family | % Dominance | % EPT | Simpson's Diversity | Hilsenhoff Biotic Index |
|---|---|---|---|---|---|---|
| LC-DOWN | 17 | Hydropsychidae | 62.8 | 86.4 | 0.591 | 3.76 |
| LC-COR | 17 | Hydropsychidae | 62.4 | 82.0 | 0.594 | 3.50 |
| LC-UP | 17 | Hydropsychidae | 56.4 | 82.8 | 0.660 | 3.62 |
| LP-DOWN | 20 | Chloroperlidae | 28.7 | 76.2 | 0.972 | 2.64 |
| LP-COR | 16 | Ephemerellidae | 36.4 | 82.0 | 0.880 | 2.38 |
| LP-UP | 18 | Chloroperlidae | 17.7 | 85.1 | 0.953 | 2.66 |
| FF-DOWN | 14 | Hydropsychidae | 40.0 | 82.8 | 0.789 | 3.09 |
| FF-COR | 13 | Hydropsychidae | 61.6 | 92.0 | 0.605 | 3.34 |
| FF-UP | 14 | Hydropsychidae | 35.2 | 78.4 | 0.826 | 3.20 |

## DISCUSSION

We found average stream productivity based on chlorophyll *a* content to increase as a result of clearing natural gas pipeline corridors. Natural gas pipeline corridors are impacting the three central Pennsylvania streams we sampled by generally altering chlorophyll *a* content and macroinvertebrate communities. Larrys Creek and Lower Pine Bottom Run both displayed higher average chlorophyll *a* content for corridor samples compared to downstream and upstream sites. Samples collected from First Fork Larrys Creek displayed a lower average chlorophyll *a* content for the corridor, opposite of our hypothesized trend. To better understand why the First Fork Larrys Creek site showed lower productivity in the corridor we would need to further study how much sunlight hits the stream channel across all three streams because of differing solar aspect (orientation) and valley shape. In future studies, site selection with stream channel orientation in mind may clarify whether aspect is a strong factor in determining productivity relative to the influence of complete canopy removal. Additional studies should also measure abiotic factors such as substrate size, flow regime, and nutrient limitation as possible factors affecting productivity.

Although the macroinvertebrate communities did not show dramatic shifts between upstream, corridor, and downstream locations, the corridor samples at Lower Pine Bottom Run and First Fork Larrys Creek had higher percent dominance and Simpson's diversity than the upstream and downstream locations. At Lower Pine Bottom Run, the most dominant invertebrate taxa was Ephemerellidae, a mayfly grazer, that is probably more common within the corridor due to the increase in periphyton: this location had a greater than 400% increase in chlorophyll *a* in the corridor compared to the upstream and downstream locations. Gap creation in riparian forest canopies by natural events (wind blow-downs, woolly adelgid kills) have also found increases in algal biomass (Bechtold et al. 2017). In the normal river continuum, grazers typically fill a niche downstream of headwaters (in higher order streams) where autochthonous inputs are greater, not in headwater streams where autochthonous inputs are usually much lower (Vannote at al. 1980). The consistent percent dominant values and family (Hydropsychidae) at upstream, corridor, and downstream locations for Larrys Creek and First Fork Larrys Creek may be masking an increase in the functional feeding groups at these sites. Additionally, the percent of the sample that was comprised of EPT, Simpson's diversity, and the Hilsenhoff biotic index are typically used to compare health of entire communities of macroinvertebrates and therefore may be masking subtle, but potentially important, shifts in invertebrate taxa. Simply put, changes in macroinvertebrate communities may need to be studied at a more specific taxonomic level than our study to identify potential shifts related to changes in instream productivity.

Our findings suggest that chlorophyll *a* content increase in the stream when riparian habitat is removed for pipeline construction. This shift in productivity may influence the macroinvertebrate communities, as we saw increases in the dominant family at two out of three sample locations. As acknowledged by Vannote et al. (1980), clear-cutting could act as a reset mechanism by shifting the productivity from allochthonous to mainly autochthonous, then returning to allochthonous once again downstream of the corridor. A larger sample size, including several dozens of watersheds with pipeline corridors, could provide more concrete evidence regarding the impacts to chlorophyll *a* in the stream, as well as the macroinvertebrate communities. Lower Pine Bottom Run displayed the most significant difference in productivity within the corridor; chlorophyll *a* increased considerably, corresponding with macroinvertebrate community composition.

When the impacts are multiplied across all stream crossings, these differences could have major implications for downstream communities. Other studies have demonstrated that the accumulation of headwater disruptions largely impact the entire downstream watershed (Meyer et al. 2007). The genetic linkage between populations in river networks has distinctly shown that headwater macroinvertebrate populations do not vary greatly from the populations as far downstream as 20 km in some cases (Monaghan et al. 2001; Schultheis et al. 2002; Wilcock et al. 2003). Leaf-shredding macroinvertebrates break down the large quantities of leaves falling into the stream from the riparian zone into fine organic material that is transported downstream and utilized by subsequent ecosystems (Vannote et al. 1980). Even headwater streams not supporting fish communities are of vital importance because the macroinvertebrates inhabiting these streams, and the organic matter they break down, supports downstream fish and invertebrate populations. An example of this is displayed in Alaska where fishless headwater streams carry sufficient macroinvertebrates and detritus to support up to 2,000 young of the year salmonids per kilometer of salmon-bearing streams (Wipfli and Gregovich 2002). Restoring riparian habitat and limiting the number of pipelines intersecting headwater streams will minimize the loss of allochthonous inputs, and should be recognized as a vital component in the management of headwater stream communities.

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