Analysis of benthic invertebrate communities downstream of land-based aquaculture facilities in Nova Scotia, Canada

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Abstract: Land-based aquaculture facilities are located throughout Nova Scotia. They are generally located beside streams, to which they discharge large quantities of used water, and their discharges are usually only monitored for some nutrient parameters at varying frequencies. However, intermittent water sampling is not sufficient to assess any aquatic ecosystem health impacts resulting from discharges. Monitoring benthic invertebrate populations’ characteristics can be used to assess aquatic ecosystem health, and this study evaluated the benthic invertebrate population characteristics downstream of five land-based aquaculture facilities in Nova Scotia. Total abundance and relative abundance of Chironomidae were elevated, while number of taxa, relative abundance of Ephemeroptera + Plecoptera + Trichoptera (EPT), Pielou’s evenness and diversity were reduced at three out of the five sampling locations. Furthermore, a comparison of populations of benthic invertebrates downstream of the facilities to those predicted by the Canadian Aquatic Biomonitoring Network Atlantic reference condition approach model revealed that population characteristics downstream at two out of the five facilities were noticeably different than those predicted by the model. Those population changes are consistent with other studies where nutrient enrichment was correlated to abundance and diversity.

Subjects: Aquaculture; Ecology - Environment Studies; Environmental Sciences

Keywords: benthic invertebrates; aquaculture; reference condition approach; land based fish farms

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PUBLIC INTEREST STATEMENT
This is the first study of this kind in Canada. As marine aquaculture products demand is increasing, the need for freshwater fish farms also increases as they are intrinsically linked. Freshwater fish farms produce one–two-year-old fish that are ultimately transferred to open-net systems in the marine environment. The novel part of this study is the use of the newly published Atlantic reference condition approach model that has just been developed. The model basically calculates the various benthic invertebrate assemblage characteristics based on samples obtained in non-impacted (reference) locations. The authors of this study then compared those expected values to the observed values calculated on the data obtained from five freshwater fish farms.
1. Introduction

Land-based aquaculture facilities in Nova Scotia serve two main purposes: stock enhancement for the sport fishery; grow out phases for fish destined to ocean-based fish farms. These facilities are usually located by streams since they require a great quantity of high-quality water for their day-to-day operations. Water flowing through the different ponds or pools at these facilities undergoes various treatments, depending on the facility, before being discharged back into the receiving environment. Since these facilities require high-quality water for their operations, they are often located in the upper reaches of their watersheds. Therefore, it is usually easy to detect slight changes in water quality downstream of these facilities. Water quality changes downstream of these facilities have been measured previously in Canada, the USA and Europe (Carmago, 1994; Doughty & McPhail, 1995; Guilpart et al., 2012; Selong & Helrich, 1998); however, changes in water quality are often difficult to associate directly with potential impacts to the residing biological community. Benthic invertebrates have been used in past studies to measure the biological impacts of land-based fish farms to the environment and results have indicated loss of richness and dominance of tolerant species at most facilities (Carmago, 1994; Carmago, Gonzalo, & Alonso, 2011; Doughty & McPhail, 1995; Guilpart et al., 2012; Selong & Helrich, 1998). Only one study which examined benthic invertebrate impacts due to land-based facilities was based in Canada (British Columbia) (Munro, Samis, & Nassichuk, 1985).

Most researchers have interpreted the biological response to land-based facilities using a measure of relative abundance of invertebrates. Recently, Armanini, Monk, Carter, Cote, and Baird (2013) developed a reference condition approach (RCA) model for Atlantic Canada based on the River Invertebrate Prediction and Classification System statistical approach for assessing the biological condition of streams. The Atlantic RCA model compares the expected (E) invertebrate assemblage, at minimal human activity levels, with the observed (O) assemblage at the test sites. The model uses climate and bedrock geology variables, which have been known to influence benthic invertebrate composition in rivers (Snelder, Cattanéo, Suren, & Biggs, 2004), to predict the expected assemblage. The output of the RCA model for Atlantic Canada provides observed/expected ratios (O/E) for five community metrics, namely taxa richness (R), Shannon–Weaver’s diversity index (D), the Berger–Parker dominance index (D), Hilsenhoff’s biotic index (HBI) and the Canadian environmental flow index (CEFI) (Armanini, Horrigan, Monk, Peters, & Baird, 2011; Armanini, Monk, Armellin, Mercier, & Baird, in press; Armanini et al., 2013). The HBI is based on tolerance of individual taxa to organic pollution (Hilsenhoff, 1982), while the CEFI measures the response of benthic assemblages to flow alterations (Armanini et al., 2011).

The purpose of this study was to describe the characteristics in benthic invertebrate populations downstream of land-based facilities in Nova Scotia, Canada, using standard population indices as well as using the outputs of the new RCA model for Atlantic Canada.

2. Materials and methods

Benthic invertebrates were obtained within 10-m downstream of the discharge from 5 land-based fish farm outfalls in September and October 2011 in Nova Scotia, Canada. Locations were as follows: Bailey’s, Barney’s, North, South and Westchester (Figure 1). The farms had flow through systems and were growing a variety of fish species such as Atlantic Salmon, Brook Trout and Arctic Char. The methodology to obtain the benthic invertebrates followed Environment Canada’s Canadian Aquatic Biomonitoring Network (CABIN) protocol (Environment Canada, 2012). The protocol contains standardised methodology for the collection of benthic macroinvertebrates as well as the associated stream information such as reach characteristics, water chemistry and channel measurements. Benthic invertebrates were obtained by a travelling kick-net method in a zigzag pattern across the stream for a period of three minutes (Environment Canada, 2012). Benthic invertebrates were collected in a 400-um mesh size triangular net and immediately preserved in the field using formalin. Samples were sent to Bio Tech Taxonomy (Smithtown, New Brunswick) for identification to the family level. Family-level taxonomy was chosen to reduce costs as well as to match the taxa level used in the RCA model.
On location, measurements of water temperature, pH, turbidity, conductivity and dissolved oxygen were obtained using a Hydrolab™ sonde. Water samples were also obtained at each location and immediately labelled and placed in an ice-filled cooler. Samples were kept cool until overnight delivery to the analytical laboratory. All water samples were analysed at Environment Canada’s Environmental Quality Laboratory in Moncton, New Brunswick. The samples were analysed for pH, conductivity, total organic carbon (TOC), turbidity, total phosphorus, total nitrogen, nitrate, ammonium, turbidity, alkalinity, major ions (calcium, chloride, magnesium, sodium, potassium and sulphate) and metals (aluminium, barium, iron, manganese and strontium). Laboratory duplicates and quality control samples were implemented by Environment Canada’s laboratory. Invertebrate and water quality data were analysed using R™, PRIMER™ 6 (Clarke & Gorley, 2006) and Systat11™.

Benthic invertebrate data collected at the five study locations (Figure 1) were compared in two different ways. Invertebrate data from three sites impacted by various anthropogenic activities (but non aquaculture related) or disturbances were compiled and compared against the study sites’ data. The three sites selected for inclusion were on Great Village, Middle and Pugwash rivers (Figure 1), which receive various disturbances from logging, old mining sites and agriculture, to name a few, and are located close to the study sites. These three locations are referred in text and/or figures as impacted. All three sites were sampled using the CABIN protocol (Environment Canada, 2012). Secondly, data from the five study sites were evaluated against the reference condition outputs of the Atlantic RCA model (Armanini et al., 2013, in press). The data in the RCA model were also obtained using the CABIN protocol (Environment Canada, 2012). The data from the RCA model are referred as reference in text, figures or tables.

Benthic invertebrate abundance was transformed with log10 (abundance + 1) and used in the calculations for these indices: Pielou’s evenness, Simpson’s and Shannon’s diversities. For comparison purposes, the indices were calculated for the three sampling locations closest to our study as well as for the Nova Scotia reference station used for the Atlantic RCA model.

The Atlantic RCA model (Armanini et al., 2013, in press) was used to calculate the O/E for taxa richness, Pielou’s evenness, Shannon–Weaver diversity, Berger–Parker dominance, HBI and CEFI. Mean O/E values of a reference location should be as close to 1 as possible in order to avoid under or overestimation of ecological quality at a sampling location (Armanini et al., 2013). Once the O/E values are calculated, Armanini et al. (in press) suggested a series of ecological classes based on the European Water Framework Directorate. A change of 25 percentile of the O/E measure was chosen as the first trigger point where ecological quality designation of a stream would change from a “normal” to a “divergent” designation. The second trigger point halfway between the lower 25th percentile and 0 would signal a biotic community considered “highly divergent”. Since the land-based facilities are mostly located in the headwaters of watersheds to obtain high water quality for their
operations, the importance of determining the change in ecological quality from “normal” to “divergent” quality was deemed appropriate. Armanini et al. (in press) calculated the O/E and the two trigger points for each of the 5 metrics from 188 reference stream sites located in Nova Scotia, New Brunswick and Newfoundland and Labrador (island portion). Use of the five different metrics allows the RCA model to provide more diagnostic measures of the changes occurring within the benthic community structures (Armanini et al., in press).

3. Results and discussion
In-situ measurements of water quality parameters and laboratory measurements are summarised in Table 1. All ranges of physicochemical parameters were within established Canadian Council of Ministers of the Environment (CCME, 2001) guidelines if guidelines exist. However, there were elevated nitrate, phosphorus, ammonium and total nitrogen concentrations at the Bailey’s Brook location compared to the other locations. The nitrate concentration at Bailey’s Brook (4.15 mg/L) is above the 3 mg/L CCME (2001) long-term freshwater toxicity guideline for the protection of aquatic life and well above levels likely to be associated with eutrophication and nuisance periphytic algal production (Dodds, 2006). Similarly, total phosphorus concentrations classified the sampling locations as eutrophic at Westchester and Barney’s River and hyper-eutrophic at North River and Bailey’s Brook, while South River could be classified as meso-eutrophic (CCME, 2001). Major ion (magnesium, potassium, sodium and chloride) and metal concentrations were similar at all locations (Table 1).

Reach characteristics, obtained according to the CABIN protocol (Environment Canada, 2012), are provided in Table 2. Stream order ranged from 2 to 4. Deciduous trees were the dominant vegetation

| Parameters       | Units | Bailey | Barney | North | South | Westchester |
|------------------|-------|--------|--------|-------|-------|-------------|
| Temperature      | °C    | 16.4   | 7.9    | 16.3  | 8     | 8.66        |
| Conductivity     | uS/cm | 204    | 63     | 101.4 | 66    | 35.1        |
| DO               | mg/L  | 8.2    | 9.6    | 9.22  | 10.2  | 11.3        |
| pH               |       | 6.29   | 6.31   | 7.14  | 6.67  | 7.4         |
| Chloride         | mg/L  | 12.1   | 9.78   | 11.59 | 6.27  | 4.99        |
| Sulphate         | mg/L  | 4.48   | 3.11   | 3.38  | 2.7   | 2.07        |
| Nitrate          | mg/L  | 4.15   | 0.2    | 0.08  | 0.1   | 0.16        |
| TOC              | mg/L  | 6.4    | 4      | 17.9  | 6.5   | 3.8         |
| Alkalinity       | mg/L  | 17.51  | 9.07   | 15.34 | 11.37 | 6.93        |
| Turbidity        | NTU   | 0.9    | 1.1    | 1.4   | 1.5   | 0.6         |
| Hardness         | mg/L  | 21.4   | 13.2   | 25.2  | 15.8  | 8.5         |
| Phosphorus       | mg/L  | 0.727  | 0.051  | 0.129 | 0.021 | 0.074       |
| Ammonium         | mg/L  | 2.776  | 0.268  | 0.389 | 0.086 | 0.17        |
| Unionised ammonia| mg/L  | 0.00165| 0.000086| 0.00161505| 0.000064| 0.000713 |
| Total nitrogen   | mg/L  | 4.73   | 0.59   | 1.24  | 0.41  | 0.63        |
| Calcium          | mg/L  | 6      | 3.59   | 7.54  | 4.47  | 2.32        |
| Magnesium        | mg/L  | 1.56   | 1.04   | 1.54  | 1.13  | 0.66        |
| Potassium        | mg/L  | 1.04   | 0.56   | 0.52  | 0.45  | <0.40       |
| Sodium           | mg/L  | 8.61   | 7.16   | 8.27  | 4.6   | 4.02        |
| Aluminium        | ug/L  | 63.5   | 81.1   | 34.5  | 100.2 | 78          |
| Barium           | ug/L  | 22     | 21.1   | 15.3  | 4.6   | 16          |
| Iron             | mg/L  | 0.36   | 0.22   | 0.1   | 0.18  | 0.14        |
| Manganese        | ug/L  | 95.6   | 32     | 19.7  | 39    | 21.9        |
| Strontium        | mg/L  | 24.5   | 15.6   | 39.6  | 23.7  | 15.1        |
type at all locations except North, where conifers dominated the stream banks. Stream substrates were dominated by cobble-size rocks at Bailey’s and Westchester, while pebble-size rocks dominated the other locations. Depth at the sampling locations averaged 12 to 41 cm and average velocity ranged from 0.37 to 0.98 m/s (Table 2). The highest velocity was measured at Westchester. Stream slope ranged from 0.36 to 0.88 m/m while wetted width ranged from 3.1 to 19.7 m (Table 2). The range of median size of rocks (Wolman D50) found in the substrate of the reach sampled was between 4.6 and 7.2 cm (Table 2).

### 3.1. Summary observations

Summary of benthic invertebrate characteristics, including total abundance, family groupings abundance (Chironomidae (Chiron), Ephemeroptera (E), Plecoptera (P), Trichoptera (T)) and relative abundance for some family groupings, are displayed in Table 3 and Figure 2. The table includes data for all Atlantic reference locations (188 sites) included in the RCA model, the 3 closest but impacted locations (Great Village River, Middle River and Pugwash River) and our 5 study sites. Among our hatchery study locations, abundance peaked at Barney’s with 87,700 individual invertebrates enumerated, while South had the lowest number of invertebrates at 2,927 individuals (Table 3). Chironomidae varied from 581 to 69,000 individuals, while relative abundance of this group ranged from 11 to 79% of the samples (Table 3 and Figure 2). The total abundance and the relative abundance of Chironomidae at Bailey’s and Barney’s were higher than the other 3 study sites, higher than the 3 closest impacted sites and higher than the 25–75 percentile range for all Atlantic reference locations (Table 3). Chironomidae are known to dominate polluted waters due to their adaptation to decreased dissolved oxygen in water (Beck, 1977). These results are similar to Guilpart et al. (2012), who described that total abundance, comprised of more tolerant species, also increased significantly at the outfalls of land-based facilities due to an increase in food supply. This is reflected in our

| Locations | Abundance | Chiron | E     | P     | T     | Relative abundance (Chiron) | Relative abundance (EPT-Hydro) |
|-----------|-----------|--------|-------|-------|-------|----------------------------|-------------------------------|
| Bailey’s  | 74,800    | 25,000 | 0     | 200   | 1,100 | 0.33                        | <0.01                        |
| Barney’s  | 87,700    | 69,000 | 0     | 100   | 1,700 | 0.79                        | 0.01                         |
| North     | 53,300    | 26,100 | 10,600| 1,300 | 3,600 | 0.49                        | 0.04                         |
| South     | 2,927     | 581    | 927   | 263   | 336   | 0.20                        | 0.11                         |
| Westchester| 15,400   | 4,350  | 1,370 | 1,100 | 2,000 | 0.28                        | 0.12                         |
| Great Village | 1,422  | 50     | 654   | 41    | 650   | 0.04                        | 0.44                         |
| Middle    | 2,918     | 45     | 2,136 | 81    | 445   | 0.02                        | 0.14                         |
| Pugwash   | 444       | 21     | 125   | 87    | 31    | 0.05                        | 0.05                         |
| Reference (25%) | 10,26 | 120    | 200   | 57    | 123   | 0.10                        | 0.34                         |
| Reference (75%) | 4,680 | 1,191  | 1,120 | 300   | 784   | 0.32                        | 0.73                         |

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Table 2. Reach characteristics of the five sampling locations

| Locations | Slope (m/m) | Average velocity (m/s) | Width − Bankfull (m) | Width − Wetted (m) | Median Wolman (cm) | Average depth (cm) |
|-----------|-------------|------------------------|----------------------|--------------------|--------------------|-------------------|
| Bailey’s  | 0.36        | 0.58                   | 9.3                  | 7.6                | 7.2                | 12.02             |
| Barney’s  | 0.88        | 0.64                   | 3.9                  | 3.1                | 4.6                | 18.8              |
| North     | 0.74        | 0.37                   | 15.3                 | 7                  | 5.9                | 12.92             |
| South     | 0.39        | 0.76                   | 19.7                 | 12.9               | 5.5                | 53                |
| Westchester | 0.6        | 0.98                   | 17.6                 | 16.7               | 7.1                | 35.63             |
results where Bailey’s and Barney’s had the highest number of chironomids, lowest DO and highest nutrient concentrations of all sampling locations.

Ephemeroptera were absent at both Barney’s and Bailey’s locations, while the lowest number of Plecoptera were also obtained at these two locations (Table 3 and Figure 2). Interestingly, EPT at North River and Westchester were above the upper 75 percentile of values found at the reference locations in Nova Scotia, suggesting that the discharge from these facilities doesn’t appear to negatively impact the habitat for these two family groupings (Ephemeroptera and Plecoptera). This elevated abundance of Ephemeroptera at North was largely composed of individuals in the families of Baetidae, Ephemereillidae and Heptageniida, while increases at Westchester were driven mostly by Ephemereillidae. Elevated Plecoptera counts at North were largely comprised of the Chloroperlidae and Perlidae families, while high counts at Westchester were composed mostly by Capniidae and Perlodidae. Great Village, Middle and Pugwash also had a noticeable lower number of Plecoptera than any of our study locations (Table 3 and Figure 2). The normal range (25th–75th percentile) for relative abundance of Ephemeroptera (E), Plecoptera (P) and Trichoptera (T), without Hydropsychidae,
is from 34 to 73% at the reference locations (Table 3). All our study locations had values below the lower 25 percentile of reference locations (Table 3). EPT (without Hydrospsychidae) is a useful tool to determine water quality as these taxa usually prefer well-oxygenated streams such as those with high slopes (Armanini et al., 2013) and their abundance decreases with increase in anthropogenic disturbance (Barbour et al., 1999). Other researchers have also indicated that sensitive taxa such as Ephemeroptera, Trichoptera and Plecoptera (EPT) were reduced significantly at the outfall of the majority of land-based farms (Carmago et al., 2011; Guilpart et al., 2012; Roberts et al., 2009; Selong & Helrich, 1998). The discharge from land-based facilities induced changes in feeding groups where shredders and scrapers decreased significantly and deposit feeders and filters increased significantly downstream of the outfalls (Guilpart et al., 2012; Selong & Helrich, 1998). The results from Guilpart et al. (2012) and those of this study indicate a shift in energy source in the stream where particulate organic matter from fish food-derived waste dominates the area downstream of the land-based outfall. Some of the authors have suggested that the changes to abundance and diversity were the reflection of nutrient enrichment rather than degradation (Munro et al., 1985). This seems to have occurred at Westchester and North River where Ephemeroptera and Plecoptera absolute counts were above the upper 75% of values for reference stations in Nova Scotia (Table 3).

3.2. Benthic invertebrate community characteristics

Numbers of taxa, dominance and diversity indices by sampling locations are presented in Table 4 and Figure 3. Bailey’s and Barney’s had similar low number of taxa while the rest of the sampling locations had a higher number of taxa identified (Table 4 and Figure 3). Taxa richness was highest at South and lowest at Barney’s, while Pielou’s evenness was lowest at Barney’s. Both Shannon’s and Simpson’s diversity indices were highest at South and lowest at Barney’s. South and Westchester had ranges of values for most community characteristics which fell between the lower 25% and upper 75% of the values for the Atlantic reference locations while both Bailey’s and Barney’s values were below the 25% percentile of the values for the reference locations (Table 4). The three impacted sites closest to our study locations had different values of benthic invertebrate community characteristics. While Pugwash had values above the upper 75 percentile for all community characteristics, Great Village and Middle had most values falling below the lower 25 percentile of the reference station values (Table 4). Previous studies corroborate our results and have shown that the abundance of pollution-tolerant taxa increased significantly (Carmago, 1994; Doughty & McPhail, 1995; Guilpart et al., 2012; Selong & Helrich, 1998) and diversity decreased significantly (Carmago et al., 2011; Loch et al., 1996) at the discharge locations of numerous land-based farms. Carmago (1992) found that dominance indices were the least sensitive marker while species composition (taxa) and richness were the most sensitive outputs.

### Table 4. Benthic invertebrate community characteristics at various locations (this study, impacted sites and reference sites)

| Locations      | Taxa | Richness | Pielou’s evenness | Shannon’s diversity | Simpson’s diversity |
|----------------|------|----------|-------------------|--------------------|--------------------|
| Bailey’s       | 17   | 1.43     | 0.40              | 1.13               | 0.56               |
| Barney’s       | 15   | 1.23     | 0.33              | 0.89               | 0.37               |
| North River    | 24   | 2.11     | 0.57              | 1.81               | 0.71               |
| South River    | 25   | 3.00     | 0.77              | 2.47               | 0.88               |
| Westchester    | 25   | 2.49     | 0.67              | 2.15               | 0.80               |
| Great Village  | 16   | 2.07     | 0.61              | 1.69               | 0.72               |
| Middle         | 23   | 2.76     | 0.57              | 1.77               | 0.65               |
| Pugwash        | 27   | 4.27     | 0.77              | 2.53               | 0.87               |
| Reference loca-| 18   | 2.12     | 0.64              | 1.86               | 0.74               |
| Reference loca-| 23   | 3.00     | 0.77              | 2.38               | 0.87               |
| (25%)          |      |          |                   |                    |                    |
| (75%)          |      |          |                   |                    |                    |
Generally, comparing our abundance results to those of the reference stations and to those from the three impacted sites closest to our study gave different results (Figure 2). The three closest locations had lower number of chironomids and some EPT than that of the lower 25 percentile of the reference station while our five study sites, generally, had higher number of chironomids and some EPT than the reference locations (except for South location). Chironomids (all sites), Plecoptera (all but South) and Trichoptera (all but South) were well above the range of values detected at the three closest stations (Figure 2). Ephemeroptera abundances were below at Bailey’s and Barney’s and above at North from the range of values at the three closest stations. This suggests that the anthropogenic disturbance associated with land-based aquaculture facilities is different from that of other industries such as agriculture or logging.

For richness and the other community indices (Pielou’s evenness and diversity), the values for the three closest stations were below the 25 percentile of the reference locations for Great Village and Middle and above the 75 percentile for Pugwash (Table 4). Similarly, our five locations were either below (Barney’s, Bailey’s and North) or within and/or above the 75 percentile (South and Westchester). However, richness, Pielou’s evenness and diversity values at Barney’s and Bailey’s sites only were below the range of values calculated for the three locations closest to the study sites (Table 4 and Figure 3). This suggests that the anthropogenic disturbance associated with land-based aquaculture facilities at these two of the five locations was more discernible in terms of benthic community characteristics than that of disturbances, such as agriculture or logging, at the three closest stations.

Reynoldson et al. (2001) describe the Bray–Curtis dissimilarity measure as a robust tool to differentiate benthic invertebrate samples based on their taxonomic composition. Bray–Curtis dissimilarities ranged from 57.9 between North and South Rivers while the sampling location Barney’s only had a 21.7% similarity to all of the other locations (Figure 4). The three closest locations to our study
locations (impacted locations) were not closely associated with our study locations (Figure 4). The results from the Bray–Curtis corroborate the results from the other indices calculated previously, with Barney’s having the most different benthic invertebrate characteristics of all the sampling locations.

### 3.3. Comparison to the Atlantic RCA model

Table 5 presents the ratios of observed/expected values calculated using the Atlantic RCA model (Armanini et al., 2013, in press) for all locations. O/E values below the 25 percentile of reference sites used in the model are considered “divergent” from reference conditions (Table 5), while values below the halfway mark between the 25 percentile and 0 are considered “highly divergent” (Table 5). Taxa richness appears to be the most sensitive metric as O/E values were rated as divergent at five sites and highly divergent at one site. Barney’s had the lowest O/E, followed by Bailey’s, Great Village and Middle, while South had an O/E value just below the threshold, demonstrating a shift towards fewer taxa than expected under reference conditions. Similarly, Barney’s and Bailey also had the lowest O/E ratios for Shannon–Weaver’s diversity, followed by Great Village and North, reflecting lower taxa richness and equitability in abundance among the taxonomic groups. Barney’s and Bailey’s also had low HBI O/E values, followed by North, demonstrating the shift towards a higher proportion of tolerant taxa. Barney’s was also rated as highly divergent for Berger–Parker’s dominance index, indicating that one taxa (Chironomidae) has a much higher proportional abundance than expected. The CEFI index identifies that three sites only are slightly under the O/E threshold, indicating potential impacts from flow alterations.

| Locations       | Richness | Shannon–Weaver | HBI   | Berger–Parker | CEFI  |
|-----------------|----------|----------------|-------|---------------|-------|
| Bailey’s        | 0.534    | 0.533          | 0.496 | 0.794         | 0.857 |
| Barney’s        | 0.454    | 0.421          | 0.584 | 0.360         | 0.918 |
| North           | 0.982    | 0.827          | 0.735 | 0.800         | 0.938 |
| South           | 0.934    | 1.320          | 1.042 | 1.561         | 1.014 |
| Westchester     | 1.079    | 1.037          | 1.208 | 1.142         | 1.123 |
| Great village   | 0.688    | 0.780          | 1.319 | 0.898         | 1.148 |
| Middle          | 0.708    | 0.920          | 1.299 | 0.800         | 1.306 |
| Pugwash         | 1.065    | 1.290          | 1.339 | 1.304         | 1.062 |
| Normal          | >0.95    | >0.91          | >0.96 | >0.77         | >0.97 |
| Divergent       | 0.95–0.47| 0.91–0.45      | 0.96–0.48| 0.77–0.38     | 0.97–0.48 |
| Highly divergent| <0.47    | <0.45          | <0.48 | <0.38         | <0.48 |
Consistent with observations made from taxa counts, community metrics and cluster analysis, the RCA model clearly identifies important variations in the assemblages found at Barney’s and Bailey’s. These variations include lower taxonomic richness, lower diversity, increased proportion of tolerant taxa and, for Barney’s, dominance of a single taxa. Such significant deviations from reference conditions are likely due to the discharge from the land-based facilities. North and Great Village also exhibit some deviation from reference with respect to richness and diversity, although to a lesser extent. Interestingly, the RCA model shows higher diversity and lower dominance at the South location, possibly due to the discharge from that land-based facility, while discharges at Westchester appear not to be having significant impact on benthic invertebrate assemblage.

Of the three nearest stations, O/E values for richness at both Great Village and Middle and the O/E value for diversity at Great Village were also below the divergent threshold, suggesting an impact on biological conditions at these sites. This was precisely why these sites were not chosen as part of the reference locations used in the Atlantic RCA model, despite their proximity to our study locations.

Armanini et al. (in press) stated that divergence from the O/E is to be a warning system and detailed local studies are warranted as a consequence of an O/E divergence. Therefore, results from this study suggest that detailed studies at both Bailey’s and Barney’s are warranted to determine the significance of these discharges, temporally and spatially to the benthic invertebrate populations. Spatially, changes in abundance and/or diversity have been detected up to a distance of 1,000-m downstream of a discharge from a land-based farm (Carmago, 1992; Munro et al., 1985) while, temporally, Doughty and McPhail (1995) described the recovery of stream fauna within 19 months of the discharge ceasing.

4. Conclusion
Discharge from land-based facilities was detectable using a variety of benthic invertebrate characteristics. Based on these characteristics, two out of the five locations (Bailey’s and Barney’s) have a probable impact on benthic invertebrates’ populations. One location (North) had a noticeable impact on benthic invertebrates depending on which characteristics and/or locations were used in the comparison. Two of the locations (South and Westchester) had no noticeable impact on the benthic invertebrate populations.

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