Benthic Monitoring Program To Evaluate Potential Impacts Of Range Training Activities On Aquatic Ecosystem Health At 4 CDTC (Meaford, Ontario)

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Keywords: risk assessment and monitoring; benthic monitoring; aquatic health; surface water quality; range training monitoring

ABSTRACT

Benthic invertebrates are sensitive to a variety of stressors such as metal contamination, and are widely used in environmental effects monitoring programs. The objective of this study was to develop an aquatic biomonitoring program using benthic invertebrates as indicators of ecological condition for watercourses at the 4th Canadian Division Training Centre (4 CDTC) located near Meaford, Ontario. Between 2011 and 2018, annual monitoring of habitat characteristics, water and sediment chemistry, and benthic communities at six test sites was conducted using the Canadian Aquatic Biomonitoring Network (CABIN) protocols at locations receiving drainage from 4 CDTC training areas. Similar data were collected from a set of regional stream reference sites to enable development of a statistical approach for determining whether benthic communities at the 4 CDTC test sites show evidence of effects using the reference condition approach recommended by CABIN. Occasional exceedances of the relevant water quality guidelines and consistent exceedances of the lower tier of sediment quality guidelines were observed for several inorganic elements during the monitoring period. Despite these exceedances, benthic communities in 4 CDTC watercourses were characteristic of "good" to "fair" water quality overall, with high proportions of Ephemeroptera, Plecoptera, and Trichoptera taxa, which are sensitive to metal contamination. For most monitoring events, benthic assemblages at 4 CDTC test sites were similar to those found in off-base watercourses not affected by military activities. Adopting an effects-based indicator such as benthic invertebrates is useful for determining whether exceedances of surface water and sediment quality guidelines correspond with actual effects on aquatic ecosystems.

1.0 INTRODUCTION

Aquatic environments on many bases have the potential to be impacted by military training activities through alterations of water quality, aquatic habitat, and rate of flow. Potential stressors include the addition of inorganic elements and energetic compounds from munitions constituents associated with training activities. Loss of vegetation and manoeuvre training may also lead to increased soil erosion, with subsequent augmented sediment loads in nearby watercourses. Environmental monitoring programs at military installations typically evaluate surface water quality, but water chemistry can be highly variable with low statistical power to detect long-term trends. Exceedances of water quality guidelines also do not always correlate well with biological effects. A direct risk-based measure of aquatic ecosystem health, such as the benthic invertebrate community, can be useful to determine whether guideline exceedances are indicative of actual effects on aquatic ecosystems.

Benthic invertebrates integrate the cumulative effects of all environmental stressors to which they are exposed and the community composition reflects the level of disturbance. Consequently, this form of biomonitoring can provide data for an assessment of long-term exposure and effects that may be difficult to evaluate using physical and/or chemical data alone. Benthic invertebrates are sensitive to a variety of environmental stressors, including metal contamination, and are widely used in environmental effects monitoring programs and ecological risk assessments for aquatic sites. Studies have shown that differences in land use can result in variation to the benthic macroinvertebrate assemblage through a variety of mechanisms, both direct and indirect (Sponseller et al., 2001). These impacts may include changes to the natural flow regime, sediment load, thermal regime, or water quality (e.g., dissolved oxygen (DO), pesticides, metals, organic and inorganic nutrients) (Mebane, 2001; Sponseller et al., 2001; Maret et al., 2003). For example, metals may impact benthic invertebrate communities and other aquatic organisms both through exposure in water and sediments and as contaminants within the food supply (e.g., Carlisle and Clements, 1999; Maret et al., 2003). Community effects include lower richness (number of taxa) and abundance (total number of organisms) within the benthic invertebrate community (e.g., Carlisle and Clements, 1999; Mebane, 2001; Maret et al., 2003).

The 4th Canadian Division Training Centre (4 CDTC) located near Meaford, Ontario is a Canadian Armed Forces training facility on the south shore of Georgian Bay (Lake Huron) that has been operated as a tank range and artillery and small arms training facility for over 70 years. The range training area encompasses Sucker Creek, which drains the western and central portions of the property, and Mountain Lake, which forms the northern boundary of the Restricted Impact Area. An aquatic biomonitoring program for 4 CDTC was initiated in 2011 to assess the water and sediment quality and the health of the benthic community. The goals of the 4 CDTC benthic invertebrate monitoring program are: (1) to assess the condition of the aquatic ecosystem on the 4 CDTC property; and (2) to enable early detection of changes to the aquatic environment related to range activities. The following paper outlines the approach taken to develop the benthic monitoring program for 4 CDTC and provides a summary of the significant findings to date.

2.0 APPROACH

2.1 Sampling Protocols

Rapid bioassessment protocols have been increasingly adopted over the past decades for benthic monitoring programs because of their cost-effective and scientifically rigorous approach to benthos surveys (e.g., Borisko et al., 2007). These include standardized methods for collecting and analysing invertebrate samples and assessing related habitat and environmental factors. In Canada, examples of well-developed rapid bioassessment benthic invertebrate sampling protocols include those developed by the Ontario Benthos Biomonitoring Network (OMOE, 2007) and the Canadian Biomonitoring Network (CABIN; Environment Canada, 2012).

There are several important advantages to adopting the CABIN approach for benthic biomonitoring (Environment Canada, 2012; 2014). First, the training and field certification program for CABIN is available at locations across Canada, with a team of scientific experts for technical support. CABIN also maintains an on-line database where reference data from different projects can be shared, and has developed regional models and data analysis tools that are available to CABIN users. The CABIN sampling protocols are well-established for wadeable streams and there are a number of corresponding stream reference models available for different geographic regions in Canada. There are also CABIN protocols for sampling lakes and wetlands, although there is much less reference data available for these latter types of water bodies. Use of the CABIN sampling and laboratory protocols facilitates a nationally consistent approach to biomonitoring and also enables cost-effective leveraging of resources and data, especially in geographic regions where reference models are available through CABIN. For these reasons, CABIN protocols were adopted for the 4 CDTC benthic monitoring program.

2.2 Monitoring Site Selection

2.2.1 Stream Sites

Stream monitoring test site locations for 4 CDTC were selected based on a review of past environmental reports for 4 CDTC and consultation with base environmental staff, as well as a site visit to groundtruth potential locations. The following considerations were used to guide monitoring site selection. First, stream test site locations were selected on the basis of their potential sensitivity to site activities. For example, locations were chosen on stream tributaries that drain the RTA and in areas where soil, surface water and/or groundwater contamination has been previously observed. Monitoring test sites were also positioned to provide good spatial coverage of the potentially impacted watercourses across the property. In addition, stream test sites were also chosen to fulfill the following criteria required under CABIN (Environment Canada, 2012):

- in riffle/run sequence on wadeable streams (not pools or rapids)
- on permanent watercourses (i.e., streams that run all year)
- representative of the major characteristics of the overall reach
- accessible and safe

Compliance with the above criteria was confirmed in the field and the exact location of each sampling site was determined based on a site visit.

An important consideration for biomonitoring programs is to account for the influence of natural factors (e.g., bedrock geology, climate, hydrology) and off-base human activities in structuring benthic communities. This is addressed through use of the reference condition approach (RCA), where a set of reference sites from the region with minimal impacts from human activities is used to characterize the natural variability in benthic assemblages. Benthic assemblages at test sites can then be compared statistically to those reference sites with similar natural habitat features to determine whether test site assemblages are outside the range of natural variability for the region (i.e., “stressed”). Establishing reference condition is critical to the ability to set management targets for the monitoring program and is therefore an important component of any biomonitoring program design.

Although there are existing RCA models for other geographic regions in Canada (e.g., Great Lakes, Fraser region, Yukon), no set of regional CABIN stream reference sites or appropriate RCA model was available for the Meaford region when the pilot monitoring study was initiated. Consequently, effort was undertaken as part of the pilot monitoring study to sample appropriate stream reference sites in the Meaford region and develop a statistical approach for assessing test site condition. The reference sites for the Meaford region were identified in using a geographic information system-based land-use analysis to distinguish “least-disturbed” reference areas (Jones, 2010). As part of the 4 CDTC pilot program, 27 reference sites from the Jones (2010) study were sampled using CABIN methodology. Data for 14 additional regional reference sites were provided by

Environment and Climate Change Canada as part of a study that occurred during the same period as the 4 CDTC pilot monitoring program. Data from the set of Meaford stream reference sites were used to set normal-range benchmarks for benthic community metrics at 4 CDTC test sites and to establish a bioassessment model to evaluate test site condition based on the observed benthic assemblages (Environmental Sciences Group, 2017b).

2.2.2 Mountain Lake

The Mountain Lake sampling program is intended to provide a measure of baseline conditions for future monitoring and to determine whether activities in the adjacent training area are negatively affecting sediment and water quality in the lake. The program was initiated in 2013. Two benthic monitoring locations were selected in near-shore wadeable areas that are most likely to receive overland flow from areas affected by surrounding military activities. The near-shore areas were chosen as benthic communities are typically more diverse and abundant in the near-shore areas compared with profundal (deep) locations, and therefore more sensitive to detecting potential impacts with increased statistical power to detect trends over time. The near-shore areas can also provide an early warning for potential basin-wide impacts.

2.3 Methodology

2.3.1 Sample Collection

The CABIN sampling protocols indicate the types of samples to collect for a particular water feature (e.g., stream, lake, wetland), and also outline supplementary information to record to define the habitat characteristics of each site. The index period for sampling streams and lakes under CABIN is the late summer/early fall (late August to late October). Samples collected at each monitoring location included a benthic invertebrate sample as well as water samples for chemical analyses (see list of analytes in section 2.3.2). As chemical concentrations in water samples are typically variable, sediment samples were also collected from each monitoring location as a measure of chronic inputs of munitions constituents to the water feature.

Supplementary information on habitat characteristics at each monitoring location was recorded to account for the influence of habitat variables in structuring benthic communities. For streams, this included morphological measures such as stream width and depth; substrate characteristics; surrounding vegetation; and stream flow velocity. For Mountain Lake, information was collected on the water depth at time of sampling; coverage and types of aquatic and shoreline vegetation; presence and extent of algal blooms, periphyton, and biofilms; and substrate characteristics. Detailed methodology for recording these variables is provided in the CABIN field sampling protocols (Environment Canada, 2012).

Water samples were collected using sampling bottles designated for each analysis (see section 2.3.2). For stream sites, water samples were collected from flowing water near the middle of the stream; for lake sites, samples were collected approximately 0.5 m below the water surface. Sediment samples were collected as a surface grab, which is representative of the top 10 cm of the sediment column. Field duplicate samples for water and sediments were collected at a rate of 10% for quality assurance quality control (QA/QC) purposes. Detailed sampling protocols are available in CCME (2016).

2.3.2 Sample Analysis and Processing

Water and sediment analyses were carried out by laboratories certified by the Canadian Association of Laboratory Accreditation (CALA) under the International Organization for Standardization and International Electrotechnical Commission (ISO/IEC) 17025 standard. The suite of analyses for water samples required by

CABIN includes major ions, alkalinity, nutrients (e.g., nitrogen and total phosphorus) and total suspended solids. Analysis of inorganic element (metals) concentrations is recommended under CABIN, and was considered important for 4 CDTC because many inorganic elements are important munitions constituents. For sediment samples, analysis of inorganic element concentrations was recommended to evaluate chronic inputs of inorganic elements that may be missed by an episodic surface water sampling program. Energetic material residues were analysed for four locations at 4 CDTC where potential inputs of these compounds may have occurred from nearby firing activities.

The taxonomic identification of benthic invertebrate samples was subcontracted to a CABIN-certified laboratory in Ontario. The subsampling, sorting, and identification procedures were carried out in accordance with the protocols described in the CABIN Laboratory Methods Manual (Environment Canada, 2014). The taxonomic resolution (i.e., the level of identification of the invertebrates in the sample, from phylum to species) was carried out to the genus level for the 4 CDTC monitoring program because reference samples were included as part of the study. Benthic community metrics were calculated at the genus level, while family-level identifications were used for the Meaford bioassessment RCA model.

2.4 Quality Assurance

QA/QC procedures for collecting and analyzing samples for chemical analysis were similar to those adopted for a Phase II environmental site investigation. An overview of QA/QC recommendations for environmental site investigations is provided in CCME (2016). These included, for example, the analysis of field duplicates and analytical duplicates to ensure the reproducibility of the data.

QA/QC procedures for taxonomic sample preparation, sorting and identification of taxa are summarized in the CABIN laboratory methods manual (Environment Canada 2014). Quality-control audits were performed by an external taxonomist to ensure ≥95% sorting efficiency and ≤5% identification error rate for taxonomic identifications based on the re-identification of 10% of samples, as outlined in the CABIN laboratory methods manual.

2.5 Data Interpretation Approach

2.5.1 Benthic Community Metrics

Univariate metrics are tools used to describe the benthic community in terms of its basic composition, structure, and function as a single summary statistic (e.g., Norris and Georges. 1993; Maret et al., 2003). They are commonly used in benthic invertebrate studies and are considered most applicable for assessing communities at sites within the same stream or at the same monitoring location over time. Metrics can be used to describe the basic composition and abundance of the invertebrate community as well as its function and structure, and can also provide information about the ecological condition of a site. Tools for calculating benthic community metrics for monitoring site data are available in the CABIN online database.

Potential contamination of water and sediment by metals and explosive residues from on-site activities is one of the primary concerns at the 4 CDTC site. Metals may impact benthic invertebrate communities in a variety of ways (e.g., lower richness (number of taxa), changes in abundance (total number of organisms)) (Canfield et al., 1994; Carlisle & Clements, 1999; Mebane, 2001; Maret et al., 2003). *Ephemeroptera* (mayflies), *Plecoptera* (stoneflies), and *Trichoptera* (caddisflies) are taxa groups that are commonly found in streams and rivers; these "EPT" taxa are generally sensitive to disturbance from contaminants and may decrease in abundance to the point where they will no longer be found at metal-contaminated sites. The relative abundance of *Chironomidae* taxa has also been shown to increase in streams subject to metal enrichment (Canfield et al., 1994). The main benthic community metrics adopted for the 4 CDTC stream monitoring program include taxonomic richness (i.e., the total number of taxa); the relative abundance of EPT taxa (% EPT); the total number of EPT taxa; the Shannon-Weiner diversity index (SWI); and the relative abundance of *Chironomidae* taxa (% *Chironomidae*).

Normal ranges for the Meaford area were established for the benthic community metrics to provide quantitative limits to evaluate metrics observed at the 4 CDTC test sites. These benchmarks are based on the 25th to 75th percentile ranges of calculated metrics for benthic invertebrate assemblages from the set of reference streams located around Meaford and the 4 CDTC site (see section 2.2.1). Metrics for test sites that fall within this range can be considered representative of good environmental quality. When metrics for test sites are outside the percentile range found at reference sites, the metric is classified as representative of “fair” environmental quality. The metric is classified as representative of “poor” environmental quality when the metric value is less than one half the value of the 25th percentile or more than 150% of the 75th percentile. The selection of the 25th and 75th percentiles as benchmarks is consistent with values used in benthic bioassessment programs for other regions.

Similar benthic community metrics were adopted for the Mountain Lake benthic monitoring program with the exception of the EPT metrics, which are not appropriate for lakes. Evaluation of reference condition for the program was not possible as there are no lakes in the area that could be considered suitable reference sites for sampling. Data interpretation for the monitoring program focusses on the detection of potential changes in the aquatic communities over time through comparison with the baseline data collected annually from 2013 to 2018. Normal range benchmarks for the metrics have been established for the baseline data at each monitoring test site in Mountain Lake using a similar approach as outlined in the previous paragraph.

Table 1: Ecological status classification scheme for benthic community metrics at 4 CDTC stream test sites based on the normal ranges for Meaford area reference streams.

Metric	“Good”	“Fair”	“Poor”
Taxonomic richness	>39	20 - 39	<20
% EPT	>33	17 - 33	<17
SWI	>2.2	1.1 – 2.2	<1.1
% *Chironomidae*	<32	32 - 48	>48

2.5.2 Meaford Bioassessment Model

Use of an RCA bioassessment model to evaluate test site condition typically has more power to detect impairment if present, because this method controls for the confounding influence of different habitat features on benthic community composition. An RCA bioassessment model first identifies a subset of reference sites that are closely matched to an individual test site with respect to important habitat features that are natural determinants of benthic community composition. Observed benthic assemblages at the individual test site are then compared to assemblages in the analogous reference sites using multivariate statistical techniques. In essence, this approach evaluates whether the observed benthic assemblage at an individual test site is different from expected assemblages on the basis of sites with similar habitat features.

The Meaford bioassessment model was developed for the 4 CDTC stream monitoring program in 2016 (Environmental Sciences Group, 2017b). Reference condition in the model was defined based on observed benthic assemblages in the set of regional reference sites described in section 2.2.1, with family-level taxonomic resolution. The statistical approach used for the model was selected based on a scientific literature review as well as discussion with CABIN science experts, and the methodology was verified through expert peer review. Tests of model performance and sensitivity indicated that the Meaford RCA model performs well overall, with low Type I errors and good sensitivity to impairments that would be expected if benthic communities are being affected by contamination inputs (Environmental Sciences Group, 2018b). The model was applied to evaluate the ecological status of the 4 CDTC stream monitoring sites from 2011 to 2018 based on the observed benthic assemblage data for each monitoring event.

3.0 SUMMARY OF RESULTS TO DATE

Water quality at the 4 CDTC monitoring test sites over 2011 to 2018 was generally good with respect to relevant water quality criteria, with a few exceptions (Environmental Sciences Group 2012; 2013a; 2014; 2015; 2016; 2017a; 2018a; 2019). Sporadic exceedances of either the CCME Guidelines for Protection of Aquatic Life or the Ontario Ministry of the Environment Provincial Water Quality Guidelines were observed for aluminum, cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), and silver at some monitoring locations over the 2011 to 2018 period. However, these inorganic element concentrations were elevated only slightly above guidelines and did not consistently exceed the relevant guidelines between years. Most other inorganic element concentrations and energetic material residues in water were below the analytical limits of detection and the relevant environmental guidelines.

For sediment, concentrations of several inorganic elements (arsenic (As), Cd, Cr, Cu, Fe, manganese, nickel (Ni), and phosphorus) at the 4 CDTC monitoring test sites were found to exceed the lower tier of the relevant federal and provincial guidelines for most or all monitoring events between 2011 and 2018. Many of these elements are also munitions constituents. However, it is likely that the slightly elevated concentrations of these elements at 4 CDTC sites can be explained by local geology rather than by influence from site activities, with the possible exception of Cu. A detailed characterization of background soil and sediment geochemistry at 4 CDTC identified that concentrations of As, boron, cobalt, Cu, and Ni were naturally elevated in the area; site-specific background criteria for these five elements were developed for 4 CDTC (Environmental Sciences Group, 2013b). In comparison with the site-specific background levels, only Cu concentrations in sediment exceeded the site-specific criteria sporadically at several 4 CDTC test sites over the monitoring period. Energetic material residue concentrations in sediment were generally below the analytical limits of detection and consistently below the available environmental guidelines for all monitoring years.

Taxonomic richness and the proportion of *Ephemeroptera*, *Plecoptera*, and *Trichoptera* (EPT) taxa are generally considered to be two of the more sensitive benthic community metrics for detecting effects due to metal contamination (Canfield et al., 1994; Carlisle & Clements, 1999; Mebane, 2001; Maret et al., 2003). Summary graphs of these two metrics for the 4 CDTC benthic stream monitoring program are provided in Figures 1 and 2. Taxonomic richness at the 4 CDTC stream test sites varied between 27 and 53 taxa, including high proportions of EPT taxa. Normal-range benchmarks for the 4 CDTC benthic community metrics have been established on the basis of metric values observed in the Meaford stream reference sites (see section 2.5.1). Comparison to the normal-range benchmarks indicated that the 4 CDTC stream test sites were generally classified as being in "good" to "fair" ecological condition according to the benthic community metrics.

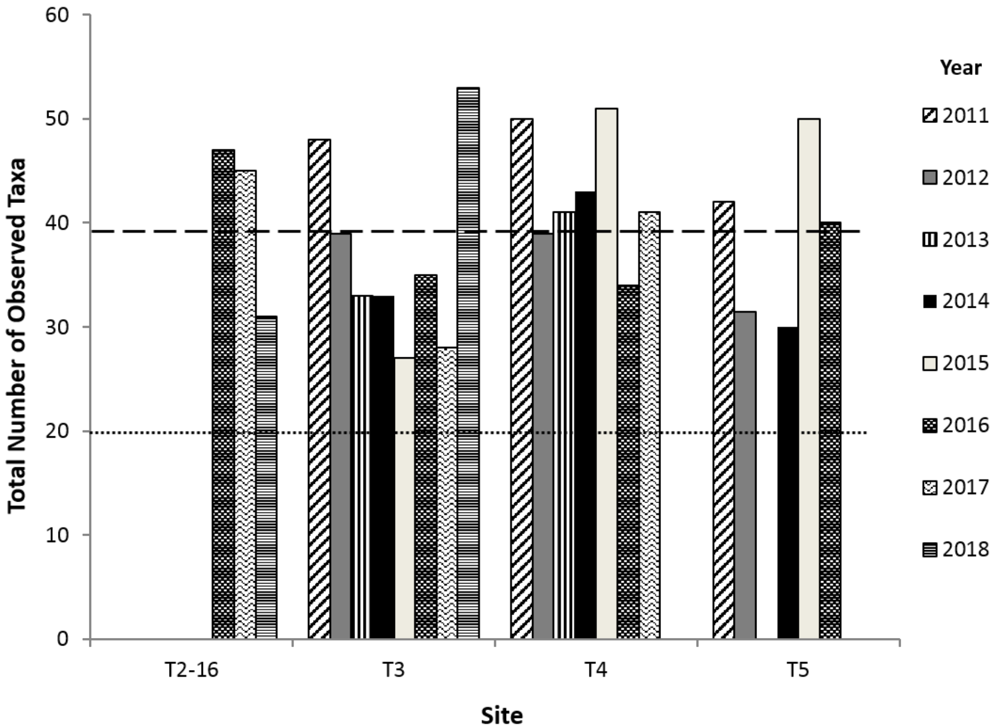

Figure 1. Taxonomic richness at the genus level from 2011 to 2018 for stream test sites sampled for the 4 CDTC benthic invertebrate monitoring program. The dashed line (the 25th percentile of richness at Meaford area stream reference sites; 39 taxa) represents the class boundary between "good" and "fair" ecological condition. The dotted line (half of the 25th percentile; 20 taxa) represents the class boundary between "fair" and "poor" ecological condition for stream sites.

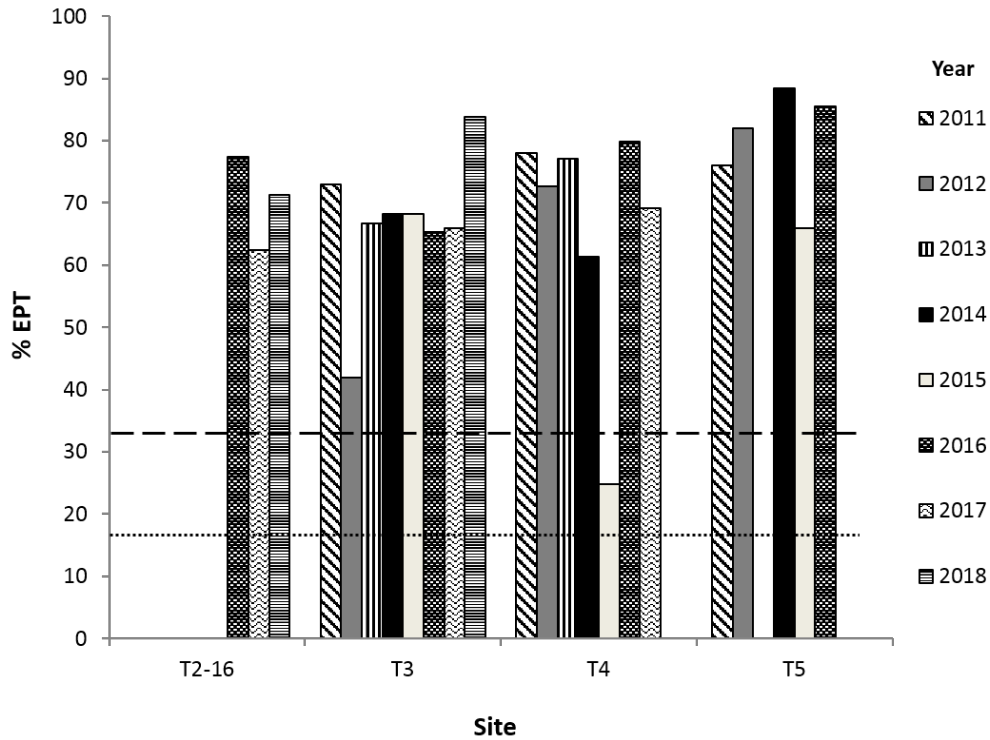

Figure 2. Proportion of population represented by EPT taxa (% EPT) in benthic invertebrate samples collected from the 4 CDTC stream test sites from 2011 to 2018. The dashed line (the 25th percentile of the % EPT at Meaford area stream reference sites; 33) represents the class boundary between "good" and "fair" ecological condition. The dotted line (half of the 25th percentile; 17) represents the class boundary between "fair" and "poor" ecological condition for stream sites.

The Meaford bioassessment model was applied to evaluate the ecological status of the 4 CDTC stream monitoring sites from 2011 to 2018 based on the observed benthic assemblage data. Outcomes of the model runs are summarized in Table 1. Two monitoring events had benthic assemblages that were classified as "very different from reference" (site T2-16 in 2018; site T5 in 2014); taxonomic richness was also lower at these sites for these years. However, benthic assemblages at 4 CDTC stream test sites were most often characterized as "equivalent to reference", indicating that similar benthic communities were found in regional reference sites undisturbed by military training activities.

Table 2: Assigned ecological status for 4 CDTC stream test sites compared with reference condition defined using the Meaford bioassessment model.

Site	Year	Status – null model
T2-16	2016	Different from reference
	2017	Equivalent to reference
	2018	Very different from reference
T3	2011	Equivalent to reference
	2012	Equivalent to reference
	2013	Different from reference (just)*
	2014	Equivalent to reference
	2015	Different from reference
	2016	Different from reference (just)*
	2017	Different from reference (just)*
	2018	Equivalent to reference
T4	2011	Equivalent to reference
	2012	Equivalent to reference
	2013	Equivalent to reference
	2014	Equivalent to reference
	2015	Different from reference (just) *
	2016	Equivalent to reference
	2017	Equivalent to reference
T5	2011	Equivalent to reference
	2012	Equivalent to reference
	2014	Very different from reference
	2015	Equivalent to reference (just)*
	2016	Different from reference

4.0 CONCLUSION

Overall, results from the benthic monitoring program at 4 CDTC have not identified significant impairment for aquatic communities related to site activities. Water and sediment quality measures indicated occasional exceedances of water quality guidelines and consistent exceedances of sediment quality guidelines for some inorganic elements that are munitions constituents. Despite these exceedances, benthic communities at most 4 CDTC stream monitoring test sites are similar to those in comparable local reference streams that are not impacted by military training activities. Benthic monitoring is a direct risk-based measure of ecological effects that can be a useful complement to surface water environmental monitoring of watercourses potentially impacted by range training activities. Periodic benthic monitoring is ongoing at 4 CDTC to investigate aquatic community health and aid in determining if future mitigation measures may be needed.

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