Report on Field Samples and Data Collected by the Aquaculture Monitoring Program in Maritimes Region, 2023

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Numbers 1-25 in this series were issued as Fisheries and Marine Service Data Records. Numbers 26-160 were issued as Department of Fisheries and Environment, Fisheries and Marine Service Data Reports. The current series name was changed with report number 161.

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Les rapports statistiques sont produits à l'échelon régional, mais numérotés à l'échelon national. Les demandes de rapports seront satisfaites par l'établissement d'origine dont le nom figure sur la couverture et la page du titre.

Les numéros 1 à 25 de cette série ont été publiés à titre de Records statistiques, Service des pêches et de la mer. Les numéros 26-160 ont été publiés à titre de Rapports statistiques du Service des pêches et de la mer, ministère des Pêches et de l'Environnement. Le nom de la série a été modifié à partir du numéro 161.

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ABSTRACT

Chu, J.W.F., Neil, S., Wong, D., Kraska, P., Johnson, L., Jonah, L., Page, F. 2025. Report on Field Samples and Data Collected by the Aquaculture Monitoring Program in Maritimes Region, 2023. Can. Dat. Rep. Fish. Aquat. Sci. 1446: vi + 25p.

The Aquaculture Monitoring Program (AMP) is a national Fisheries and Oceans Canada (DFO) program initiated in 2017 to detect and quantify chemical and biological parameters in far-field areas neighboring aquaculture finfish and shellfish sites in Canada and to track changes in these parameters over the long-term. This report outlines sampling methods, design, and data resulting from field surveys of finfish aquaculture sites done by DFO's Maritimes region in 2023. During these trips, AMP sampling protocols were used to survey site F09. A reduced subset of 16 stations were sampled for sediment grain size, drugs, pesticides, antibiotics, trace metals, and total organic content. Total dissolved sulfides in the sediment were also measured in all stations using three methods (ISE, UV, and methylene blue).

RÉSUMÉ

Chu, J.W.F., Neil, S., Wong, D., Kraska, P., Johnson, L., Jonah, L., Page, F. 2025. Report on Field Samples and Data Collected by the Aquaculture Monitoring Program in Maritimes Region, 2023. Can. Dat. Rep. Fish. Aquat. Sci. 1446: vi + 25p.

Le Programme de surveillance de l'aquaculture (PSA) est une initiative nationale de Pêches et Océans Canada (MPO), lancée en 2017, visant à détecter et quantifier les paramètres chimiques et biologiques dans les zones de champ lointain adjacentes aux sites d'aquaculture de poissons et de mollusques au Canada, ainsi qu'à suivre leur évolution à long terme. Le présent rapport présente les méthodes et le plan d'échantillonnage mis en œuvre en 2023 par la région des Maritimes du MPO sur un site d'aquaculture de poissons, ainsi que les données recueillies. Conformément aux protocoles du PSA, un sous-ensemble de 16 stations a été sélectionné pour l'échantillonnage des sédiments au site F09. Les analyses réalisées sur les échantillons visaient à mesurer la granulométrie, la teneur totale en matières organiques, ainsi que les concentrations en métaux traces et en produits thérapeutiques utilisés en aquaculture (tels que les médicaments, pesticides et antibiotiques). De plus, les concentrations de sulfures totaux dissous dans l'eau interstitielle des sédiments ont été mesurées à toutes les stations à l'aide de trois méthodes : électrode sélective d'ions, spectroscopie UV et méthode au bleu de méthylène.

1 INTRODUCTION

1.1 THE AQUACULTURE MONITORING PROGRAM (AMP)

The Aquaculture Monitoring Program (AMP) assesses the far-field effects of Canadian finfish and shellfish aquaculture in coastal environments. It provides data and analyses that will contribute to research and science advice that can guide policies, regulations, and decisions supporting the sustainable aquaculture management. Monitoring involves data collection from areas of marine aquaculture production in the Atlantic and Pacific coasts of Canada with the goals of detecting and quantifying chemical and biological changes in far-field areas near aquaculture sites and tracking these variations over the long-term (i.e., >10 years). AMP revisits specific aquaculture sites regularly while applying a consistent approach for sampling and laboratory analysis, where feasible.

Field sampling is conducted to generate data for several benthic, pelagic, and oceanographic parameters. Sampling activities are carried out by the Newfoundland and Labrador, Maritimes, Gulf, Quebec and Pacific Regions based on the types of coastal aquaculture production present. Benthic parameter data are collected at all sites, pelagic parameter data are collected at shellfish sites, and oceanographic data is collected in some locations.

1.2 PURPOSE OF THIS REPORT

Annual data reports are published to provide an overview of AMP activities and are intended to be used as a companion source for data end-users. This report includes:

1) A description of sampling efforts, methodology, and processing used in the Maritimes region during the 2023 field season.
2) An overview of the data obtained, including descriptive statistics that are relevant to the program objectives.

1.3 SUMMARY OF AMP MARITIMES REGION SCIENCE FOR 2023

1.3.1 Science activities completed as part of standard AMP sampling protocols

In 2023, field work was completed in September and November at a single aquaculture farm (F09, here after referred to as the 'site') in coastal Southwest New Brunswick. During these surveys, standard AMP benthic sampling was completed in November. Sampling followed the program standardized, fitted-grid of stations established for this site during the 2022 AMP field season.

As a result of staffing difficulties, only 16 stations were sampled using AMP standardized protocols (Table 1). Samples were collected for sediment grain size (SGS), drugs, pesticides, and antibiotics (DPABs), trace metals and organic content (TM & OM), and total dissolved sulfides (TDS) measured using three methods: the ion selective electrode (ISE), Ultra-violet absorbance (UV), and methylene blue reaction (MB) methods.

1.3.2 Additional Science activities supported by AMP

Only standardized AMP survey data are summarized in this report. However, additional data collection and science activities that supported AMP objectives, leveraged AMP resources, or were supported by the AMP Maritimes program are also noted. For the additional science sampling that did not follow AMP standardized protocols and/or were led by external principle investigators (PI) with only AMP providing field support, downstream data management and summary are not reported here and remain with the projects respective PIs.

Additional sampling was completed for four projects during the 2022-2023 field season:

(1) Sediment samples were collected at site F09 for DPAB (n=10), TM (n=10), and three sulfide method analyses (n=10) for a study to compare sampling variability between benthic grabs and cores collected by SCUBA divers. Data for this study was retained and curated by AMP operational staff and are summarized in this report.
(2) Sediment samples were also collected near site F08 and F09 to support a different sediment sampling device comparison study (benthic grab versus SLOcorer) and assess small-scale horizontal and vertical variation for a CSRF project led co-led by Brent Law, Fred Page, and David Wong; data are retained by the project lead investigators.
(3) Sediment samples were also collected at sites F08 and F09 to support an ongoing study focused on detecting antimicrobial resistance genes (AMR) co-led by Dounia Hamoutene and Lisa Johnson of DFO-SABS and Derek Smith of Environment and Climate Change Canada (ECCC). For this AMR study, sediment was sub-sampled from the benthic grabs collected from two sites and at three stations (0 m, 50 m, and 125 m away from cages at each site) and were collected following protocols provided by the external collaborators (Johnson et al. 2025).
(4) Limited oceanographic instrument deployment and data were done in collaboration with Fred Page, Ed Horne, and Shawn Roach of DFO Maritimes. Pressure temperature recorders were deployed at wharves in shellfish site S04 and recovered in Jan-Mar 2024.

In 2023, AMP operational funding also subsidized research programs focusing on oceanography (Fred Page), aquaculture biological effects (Dounia Hamoutene) and eDNA (Anaïs Lacoursière-Roussel).

2 METHODOLOGY

2.1 FIELD SURVEY LOGISTICS

Standard AMP field sample and data collection occurred at site F09 on November 3, 2023. Sampling for the comparative methods study occurred on September 14, 2023.

Site F09 was established as long-term AMP monitoring site in 2022. The site is located in an area with high finfish aquaculture production and multiple active leases nearby. Additionally, the site has a long history of DFO science data collection, was adjacent to other on-going DFO research programs increasing the likelihood of data re-usability, and was located in relatively shallow waters (<30 m) with predominantly muddy-soft sediments that allowed for samples to be collected by both SCUBA divers and benthic grabs.

2.2 FINFISH SITE F09

Sampling stations at F09 were previously determined in 2022 using the fitted-grid design which is described in a draft internal AMP document (*AMMP 2019 Finfish Macrofauna Sampling Design*). The standard approach with this field design is to use a total of n=55 distance-stratified stations divided among the cage edge (n=4 at 0 m) and four buffer zones (n=14 at 200 m, n=14 at 500 m, n=20 at 1000 m, and n=7 at 1500 m) using a regular grid pattern. This design was primarily established using the setting of a single, geographically isolated site in Pacific region (Chu et al. 2025) and requires iterative modification to be applicable at new sites elsewhere.

Due to multiple aquaculture cage arrays within the studied lease, the proximity of islands, beaches, or rock outcrops, and a second AMP site (F08) located less than 3 km from F09, the final fitted grid of stations was irregular and varied in their distribution spanning over the study area. As such, the sampling grid was geospatially weighted between F08 and F09 so that there was a consistent distribution of distance-stratified stations spanning the two sites. For this area, a priori planned sampling stations were n=66 for F09 and n=41 for F08. These points where used to plan for the 2023 field season so that time-series data could be generated from repeat AMP surveys.

In 2023, the AMP survey at F09 occurred during year two of the ongoing production cycle. Fish counts and peak biomass (tonnes) for the most recent production cycle are not reported here because of confidentiality issues associated with facility-specific fish numbers and biomass.

2.3 SHELLFISH SITES

No shellfish aquaculture sites were surveyed by AMP Maritimes region in 2023.

2.4 VESSEL USED FOR SAMPLING

Benthic sampling was done onboard the Canadian Coast Guard Vessel Viola M. Davidson (CCGS VMD, 18 m length, hull width 5.2 m, 59.4 gross tonnes specialty research vessel). Standardized AMP benthic sampling protocols were applied for all core stations surveyed in 2023. Additional science objectives were integrated into the work plan prior the field dates and are described below.

2.4.1 Benthic sampling

Benthic sampling and processing of sediment followed standardized AMP protocols except as noted below.

For 2023, AMP in the Maritimes region used a 100 kg HAPS corer (KC Denmark A/S) with 4 L shock-proof polycarbonate core rubes (31.5 cm length, 12.7 cm internal diameter). The HAPS corer was deployed and recovered using a crane and hydraulic winch on the aft deck of the CCGS VMD. At each station when the corer reaches bottom, sampling time, bottom depth, latitude and longitude are recorded from the ship navigation and depth sounder. With the corer recovered on deck with a successful sample, the core is transferred to a stand and the core is pushed upwards to process sediment from the sediment-water interface. Qualitative sample characteristics for each core are recorded on a datasheet along with measurements of sediment temperature from a digital thermometer inserted into the top 2 cm of the sediment core.

The upper 2 cm of sediment from each core is processed into separate jars pre-assigned for analyses for sediment grain size analysis, drugs, pesticides, and antibiotics, trace metals and organic matter. 5 mL plastic syringes were used to collect surface sediment for total dissolved sulfide (TDS) analyses using the ISE method. Sediment porewater is also collected from the sediment for TDS analyses following standardized protocols for the UV sulfide and methylene blue sulfide methods. Further details on parameter-specific processing protocols are described below. Sediment-filled jars are placed in coolers with ice before being transferred to -20°C storage at the St. Andrews Biological Station (SABS) within hours after sampling. At the end of each day, samples for TDS analyses are performed at SABS. Samples that are shipped to external labs for analyses are shipped using priority overnight couriers, on ice, and arrive at their respective external labs within 48 h of leaving SABS with confirmation of receipt.

2.4.2 Pelagic sampling

AMP pelagic sampling protocols (water, zooplankton, CTD profiles) were not used in 2023.

2.5 LAB ANALYSES

2.5.1 Sample preparation

Physical samples requiring external science services for analyses were kept in storage at SABS until procurement could be completed. Prior to the confirmed day of sample shipping, frozen samples (DPAB, TM & OM) were briefly brought out of the -20°C freezer to be packaged in padded shipment coolers (U-Line P/N S18968) with frozen ice packs and returned to -20°C. Pickup courier was arranged for next day and packaged frozen samples were brought out the morning of pickup for next-day delivery.

2.5.2 Sediment grain size (SGS)

Until 2021, SGS samples at SABs had been analyzed using a Beckman-Coulter LS 13320 diffraction laser particle size analyzer. After program advice was developed (Milligan et al. 2025), a shift to SGS analyses using a Beckman-Coulter Multisizer 4e Coulter Counter was established for the 2024 fiscal year and applied to samples collected in 2023 and unanalyzed backlogged samples.

Each SGS sample is analyzed through a 30 μm, 200 μm, and 400 μm aperture tube to resolve a total particle size range of 1 to 296 μm. Following Milligan and Law (2005) and McCave et al. (1995), samples are thawed in a 4°C fridge and then chemically pretreated with 30% hydrogen peroxide (H_2O_2) to remove organic carbon from the sediment. Each SGS sample is homogenized, and a 0.1-0.2 g subsample is placed into a glass beaker (10 to 50 mL). 2-3 mL of 30% H_2O_2 is added to each subsample and then dried on a hot plate at 60ºC. This step is repeated until no further bubbling occurs with the addition of H_2O_2.

2.5.3 Drugs, pesticides, and antibiotics (DPAB)

DPAB samples were shipped to MB Laboratories (MB Labs, Sidney, BC) for analysis.

General methodological details on the sample preparation and analyses used by MB Labs are described in Chu et al. (2025).

MB Labs developed, validated, and uses two in-house extraction methods for measuring a suite of DPABs in sediment samples. The first is a modified QuEChERS method is used for measuring Abamectin, Azamethiphos, Cypermethrin, Deltamethrin, Erythromycin-H20, Desmethyl emamectin benzoate, Emamectin, Florfenicol, Ivermectin, Lufenuron, Sulfadimethoxine, Sulfadiazine, Teflubenzuron, and Trimethoprim in samples. Here, moisture content is first measured as the mass lost from oven-drying sediment samples at 60°C. Sediment samples (~5 g) are then weighed into 50 mL centrifuge tubes and spiked with either a four-compound surrogate mix or a 14-compound mix. High Performance Liquid Chromatography (HPLC) grade water (5 mL) is then pipetted into each sample followed by acetonitrile (10 mL). The tubes are then vortexed and shaken for 1 minute and then allowed to stand for 5 min. QuEChERS extraction salts (1.5 g anhydrous sodium acetate and 6 g magnesium sulfate) are added then vortexed again for 1.5 min, followed by centrifugation for 5 min at 4100 rpm. The supernatants are immediately decanted into fresh 50 mL centrifuge tubes. Aliquots (1 mL) of supernatants were pipetted into a dSPE tube containing 150 mg magnesium sulfate and 50 mg C18 sorbent. Internal standards are added, tubes are capped and then vortexed for 1 min followed by centrifugation at 4100 rpm for 5 min. The supernatant is then filtered through a 0.2 µM nylon filter into a 2 mL LC vial for LC-MS/MS analysis. The second in-house method uses a buffer extraction to measure Amoxicillin and Oxytetracyline in samples which cannot be sufficiently recovered using the modified QuEChERS method. Sediment samples (~3 g) were weighed into 50 mL centrifuges tubes. For spiked samples, a mix of amoxicillin and oxytetracycline is used. EDTA-McIlvaine buffer (10 mL) is added to each sample which is hand-shaken for 1 min, followed by mechanical shaking for 30 min. Samples are then centrifuged for 5 min at 4100 rpm. 5 mL aliquots of the supernatant are filtered into glass tubes through 0.2 µM nylon filters then 1 mL of each transferred into LC vials. Thiacloprid, used as internal control, is spiked into each vial then capped and mixed for 1 min prior to LC-MS/MS analysis.

All analysis were performed using a Waters ACQUITY UPLC coupled to a Waters Xevo TQ-S triple quadrupole mass spectrometer and the following in-house calibrated settings.

AMP samples analyzed by MB Labs for DPAB detection can result in values below method detection limits (MDL) and below levels of quantification (LOQ). The quantitative definition MB Labs provides for calculating their MDL and LOQ values are as follows: First, the lower theoretical value for a given method is calculated as the standard deviation of the zero-analyte concentration (S_o). If a compound is detected above the S_o but below the MDL, verification is used to prove they are real values. MDL values are defined as the statistical estimate of a compound’s value that is accepted as real without additional verification. An example calculation would be estimating MDL as $3*S_o$. LOQ threshold values are statistical estimates for the concentration of the analyte where concentrations above LOQ are considered statistically accurate. An example calculation of LOQ would be 10*MDL. MB Labs has done internal quality control and quality assurance to independently establish S_o, MBL, and LOQ values reported on their delivered datasets (W. Riggs, MB Labs, pers comm.).

2.5.4 Trace metals and total organic matter (TM & OM)

Samples were shipped to the New Brunswick Research and Productivity Council (RPC, Fredericton, NB) for trace metals and organic content analyses.

General details on the lab methods used by RPC for TM & OM sample analyses are described in Chu et al. (2025).

RPC performed trace metal analysis following protocols of the United States Environmental Protect Agency (EPA) method 3050B for acid digestion of sediments, sludges, and soils (US EPA, 1996). Samples are digested with repeated additions of nitric acid (HNO_3) and H_2O_2 before adding hydrochloric acid (HCl). In an optional step to increase the solubility of some metals, the digestate is filtered and the filter paper and residues are rinsed with hot HCl and then hot reagent water. Filter paper and residue are returned to the digestion flask, refluxed with additional HCl and then filtered again. The digestate is diluted to a final volume of 100 mL. After digestion, samples are analyzed using inductively coupled plasma atomic emission spectrometry. Performance Testing of samples are regularly completed by RPC through the Canadian Association Laboratory Accreditation. For quality control, a method blank is completed throughout the entire sample preparation and analytical process for each batch of samples processed. Spiked duplicate samples are also processed on a routine basis whenever a new sample matrix is being analyzed. The full suite of trace-elements analyzed by RPC included: Aluminum (Al), Antimony (Sb), Arsenic (As), Barium (Ba), Beryllium (Be), Bismuth (Bi), Boron (B), Cadmium (Cd), Calcium (Ca), Chromium (Cr), Cobalt (Co), Copper (Cu), Iron (Fe), Lead (Pb), Lithium (Li), Magnesium (Mg), Manganese (Mn), Mercury (Hg), Molybdenum (Mo), Nickel (Ni), Potassium (K), Rubidium (Rb), Selenium (Se), Silver (Ag), Sodium (Na), Strontium (Sr), Tellurium (Te), Thallium (Tl), Tin (Sn), Uranium (U), Vanadium (V), and Zinc (Zn) several of which can be used as tracers of aquaculture activities (e.g., Naylor et al., 1999; Smith et al., 2005; Sutherland et al., 2007; Sutherland and Yeats, 2011; Yeats et al., 2005), and their known conservative properties for normalization processes (e.g., Daskalakis and O'Connor,1995; Grant and Middleton, 1990; Loring and Rantala, 1992; Matthai and Birch, 2001). Total organic matter (%) is quantified as the sample fraction that is lost on ignition (ASTM Standard, 1993). In brief, ash content (inorganic content) of a sediment sample is determined by placing a 60°C oven-dried sample into a muffle furnace and gradually bringing the temperature in the furnace to 440°C. Then the temperature is held at 440°C until the specimen is completely ashed with no mass change occurring after additional heating.

Cadmium, Copper, Molybdenum, Uranium, and Zinc are chosen as the subset of TM for annual data reporting as tracers of anthropogenic enrichment following a regionally pooled analyses of past AMP samples identified their potential to be normalized with Lithium (Kingsbury et al. 2023). TM subsets were analyzed following standardized procedures for geochemical normalization (Sutherland et al. 2007; Sutherland and Yeats 2011; Hamoutene et al. 2021). Within the samples collected at a site and survey period, stations that were >350 m from the cages of the closest finfish farm were used to calculate a linear regression against Lithium. Regressions were calculated for F09 while also presenting R^2 values to indicate the goodness of fit. Stations where a measured trace metal value was greater than the 95% confidence interval of the regression against Li can be interpreted as enriched (Sutherland et al. 2007; Sutherland and Yeats 2011; Hamoutene et al. 2021) assuming a strong linear fit.

2.5.5 Sediment total dissolved sulfides (TDS)

The ion selective electrode (ISE), ultra-violet (UV), and methylene blue (MB) methods (Wildish et al 1999, 2004; Cranford et al. 2020; Cranford 2024) were used to quantify total dissolved sufides (TDS) in pore water samples sampled in 2023.

While each sediment core was still on the vessel deck, one 5 mL syringe of sediment is taken from the upper 2 cm of the undisturbed core, wrapped in Parafilm®, and placed in the cooler with ice; syringes are for the ISE method which is performed back at SABS. PA spring syringe with three-way valve and a Rhizocera pore-water sampler were inserted into the top 2 cm of the undisturbed sediment of the core sample. After 1-3 min, the syringe is removed from the sediments and 100 µL aliquots of pore water are extracted using a gas-tight syringe for both the UV and MB methods.

The porewater for the UV method is analyzed immediately on board the sampling vessel. 100 µL of the pore water was mixed with 1 ml of pH-adjusted distilled water in a Hellma Suprasil quartz cuvette. Absorbance was measured at wavelengths of 230, 240, and 250 nm using an Implens C40 spectrophotometer. TDS concentration was calculated from the 230 nm absorbance readings using a standard curve created from serial dilutions from a reference sulfide sample created at SABS by D. Wong. For the MB method, the second 100 µL aliquot of porewater is added to lab-prepared microcentrifuge tubes containing 1 mL of fixative solution (zinc acetate:EDTA: sodium hydroxide, 1:1:0.8%, w/v), capped, shaken, are stored in the ice-filled cooler until analyzed back at SABS. A stock solution of zinc acetate:EDTA:NaOH was created at SABS the day leading into each field sampling trip.

Lab-based analyses of samples collected for the ISE and MB methods are done back at SABS during the same day of collecting. For the ISE method, the samples are removed from the cooler and transferred to 4°C storage. For analysis, each 5 mL sediment sample is added to a 5 mL solution of alkaline EDTA solution containing L-ascorbic acid (sulfide antioxidant buffer – SAOB) then stirred using a glass rod to obtain a homogenous sample. A calibrated ISE probe (100 to 10,000 µM, Thermo Scientific Orion Silver/sulfide ionplus® Sure-Flow solid state combination ISE) with temperature compensation sensor (Fisher Scientific Accumet automatic temperature compensation probe) attached to an AP125 portable meter (Fisher Scientific Accumet AP125 portable pH/ion/mV/temperature meter) is then inserted into the homogenoized sample and sulfide content determined once the mV reading stabilizes or to a maximum measurement period of 2 min. For the MB method, TDS concentrations were determined by adding acidic solutions of N,N-dimethyl-p-phenylenediamine dihydrochloride and iron (III) chloride hexahydrate, which reacts with the sulfide to form methylene blue. The absorbance of the produced methylene blue was determined at a wavelength of 660 nm. Sulfide concentrations were then calculated against a prepared calibration curve.

2.5.6 Sediment macrofauna

NA for Maritimes region in 2023.

2.5.7 Seston

NA for Maritimes region in 2023.

2.5.8 Elemental carbon and nitrogen

NA for Maritimes region in 2023.

2.5.9 Chlorophyll

NA for Maritimes region in 2023.

2.5.10 Zooplankton

NA for Maritimes region in 2023.

2.5.11 Oceanography

Limited oceanographic instrument deployment and data were done in collaboration with Fred Page, Ed Horne, and Shawn Roach of DFO Maritimes. A RBR Solo D pressure and RBR Solo T temperature loggers were deployed at wharves in shellfish site S04 and recovered in Jan-Mar 2024.

RBR Solo P pressure loggers, RBR Solo T temperature loggers, and Onset Hobo Pressure and Temperature loggers were deployed at wharves in close proximity to a provincially proposed shellfish aquaculture development. Instruments were installed at the Wedgeport, West Pubnico, and Hubbard's Point wharves by DFO staff from the Bedford Institute of Oceanography (BIO) on January 18, 2023, and retrieved on September 1, 2023.

Opportunistic CTD profiles were collected at finfish site F09.

2.6 DESCRIPTION OF PRELIMINARY ANALYSES AND PLOTS

Piece-wise regressions were used to identify break points in the data for several benthic parameters (DPABs, TDS) as a function of distance away from the target sites' farm cages (Chu et al. 2025). Piece-wise regressions fit two linear regressions through a set of data to identify threshold relationships. When used on data as a function of distance, significant break points can be used to infer the maximum distance of a parameter's zone of effect relative to the target farm. Piece-wise regressions were done with the segmented R package (Muggeo 2008). All data summary, plots, and analyses were done in R 4.3.2 (R Core Team, 2023). Maps were created in ArcGIS Pro 2.9.8 using WGS1984 (ESPG: 4326) and WGS1984 UTM Zone 19N geographic and projected coordinate systems, respectively.

3 RESULTS

3.1 SAMPLING SUMMARY AND DATA AVAILABILITY

A summary of the number of grabs and samples collected in 2023 following standardized AMP benthic monitoring protocols is presented in Table 1.

The collection effort, number of samples sent to external lab for analyses during the current year, and the number of samples returned by the external labs at the time of writing of this report is summarized in Table 2. The number of samples collected corresponds to the sample sizes in the EQuIS database. The field sampling completed in 2023 by AMP Maritimes region was greatly reduced relative to previous years as a consequence of extended periods with no operational staff present. The AMP distance-stratified survey grid for this area has n=107 benthic stations which span sites F09 and F08; n=16 stations were completed this year. The staffing issue has since been addressed for the 2024 field season.

Annual AMP Maritimes datasets from 2018-2019, 2021-2023 have been finalized for submission into the AMP EQuIS database. Additional quality control and quality assurance work is ongoing to finalize remaining datasets from AMP Maritimes region. Finalized data files have been formatted by parameter following a standardized set of data columns for migration into EQuIS and are also currently stored on the National Aquaculture Monitoring Program MS Teams channel. Data access can be granted through direct request to program leads at National Capital Region.

3.2 SEDIMENT GRAIN SIZE (SGS)

Raw particle counts and dilutions for each sample and aperture tube flow rates from the SABS Beckman-Coulter Multisizer 4e are available and can be provided to end-users for analyses and end-user preferred SGS summation metrics upon request.

3.3 DRUGS, PESTICIDES, AND ANTIBIOTICS (DPAB)

Analyzed concentrations of DPABs and their respective lower limits as summarized by sample station are presented in Table 3.

Of the 17 DPABs of interest, only four (Desmethyl EB, Emamectin, Lufenuron, Oxytetracycline) were detected among the samples collected in 2023.

Of the n=10 samples collected in September for the sampling device comparison at site F09, detectable levels were found for Desmethyl EB (detected in n=10 samples, min-max: 0.34-1.20 ng/g), Emamectin (n=10, 1.49-4.85 ng/g), Lufeneron (n=6, 0.67-2.19 ng/g), and Oxytetracycline (n=10, 1.01-3.96 ng/g). Of the n=16 samples collected in November at the AMP F09 stations, the same four tracers were detected: Desmethyl EB (n=5, 0.16-0.69 ng/g), Emamectin (n=14, 0.08-3.51 ng/g), Lufeneron (n=2, 0.16-0.20 ng/g), and Oxytetracycline (n=16, 0.28-21.4 ng/g) (Table 3).

Piece-wise regressions of the AMP F09, distance-stratified samples showed significant distance break points of 222 m for Emamectin (Fig. 3, $p<0.05$) and 315 m for Oxytetracycline (Fig. 4, $p<0.05$) but not Desmethyl EB (Fig. 5, $p>0.05$). A regression was not attempted for the n=2 samples with detectable levels of Lufeneron.

3.4 TRACE METALS AND TOTAL ORGANIC MATTER (TM & OM)

A summary of trace metal (TM) concentrations and total organic content (OM) by site and sampling period is presented in Table 5. Unlike MB Labs, RPC does not distinguish values between zero (absence of the parameter) with their internal protocols for lower reporting limits. As a result, absence of a tracer in these data cannot be quantified.

The restricted distance-stratified sampling and the small number of samples resulted in poorly fitted linear regressions (R^2 range -0.14 to 0.78) for all trace metals presented as part of the geonormalization of the TM data (Fig. 7-11).

3.5 SEDIMENT TOTAL DISSOLVED SULFIDES (TDS)

A summary of sediment total dissolved sulfides as quantified by the ISE, UV, and MB methods is presented in Table 6. For the ISE sulfide method, 100% (26 of 26) of samples resulted in values registering above the method LOQ (100 µM). For the UV sulfide method, 64% of samples (16 of 25) resulted in values registering above the LOQ (37 µM). For the MB sulfide method, only 16% of samples (4 of 25) resulted in values registering above the LOQ (200 µM).

Given the small number of samples collected following AMP standardized survey protocols, data from all three TDS methods from only the core AMP survey at F09 were pooled prior to applying a piece-wise regression which resulted in no significant distance break point detected (Fig. 14, $p>0.05$).

3.6 SEDIMENT MACROFAUNA

NA for Maritimes region in 2023.

3.7 SESTON

NA for Maritimes region in 2023.

3.8 ELEMENTAL CARBON AND NITROGEN

NA for Maritimes region in 2023.

3.9 CHLOROPHYLL

NA for Maritimes region in 2023.

3.10 ZOOPLANKTON

NA for Maritimes region in 2023.

3.11 OCEANOGRAPHY

Oceanographic data were not processed in time for this report.

4 ACKNOWLEDGEMENTS

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Authorship contributions: JWFC led the writeup of this report, performed all data summary, analyses and syntheses, and revised text to address individual written comments and contributions to individual sections from SN, DW, PK, and FP. Field work was performed by SN, PK, LJ, and LJ. Sulfide analyses were performed by SN and DW. All authors contributed to finalization of this report.

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APPENDIX I: DATA TABLES

Table 1 - Field survey dates, sampling, and metadata of standard AMP parameters.

Site	Dates	Benthic grabs	Macrofauna grabs	DPAB	TM	OM	SGS	TDS - ISE	TDS - UV	TDS - MB
F09	Sep 14*	10	NA	10	10	0	NA	10	9	9
F09	Nov 3	16	NA	16	16	16	16	16	16	16
	TOTAL	26	NA	26	26	16	16	26	25	25

*Samples taken for Sep. 14 were not done following the established standardized AMP spatial survey protocols but leveraged AMP resources and external lab resources, therefore data are comparable. Samples are reported here but are not included in subsequent spatial summary statistics.

Table 2 -Total sampling effort for AMP Maritimes region in 2023. All samples collected in 2023 were sent out for analysis. Only core AMP parameters sent for analysis and returned for analysis are summarized in this report. Samples collected by AMP in support of other science programs (e.g. NA) were processed by collaborators.

Parameter	Samples collected	Samples sent for analysis	Samples returned from analyses
DPAB *(2cm depth)*	26	26	26
Grain size	16	16	16
TM	26	26	26
OM	16	16	16
TDS - UV	25	25	25
TDS - MB	25	25	25
TDS – ISE	26	26	26
Macrofauna	0	0	0
AMR	30[a]	NA	NA
Total	***160***	***160***	***160***

[a] 30 cryovial samples were collected for AMR and sent to external collaborators and excluded from totals.

Table 3 - DPAB and percent moisture content. DPAB units are in nanograms of analyte per gram of wet sample (ng/g).

			F09 – Sep (n=10)			F09 – Nov (n=16)		
	MDL	LOQ	No. Pres.	min	max	No. Pres.	min	max
Moisture Content (%)	na	na	10	62.7	77.2	16	23.8	67.1
Abamectin	0.44	1.39	0	0	0	0	0	0
Azamethiphos	0.05	0.16	0	0	0	0	0	0
Cypermethrin	2.70	8.58	0	0	0	0	0	0
Deltamethrin	1.01	3.20	0	0	0	0	0	0
Desmethyl EB	0.05	0.17	10	0.34	1.20	5	0.10	0.69
Emamectin	0.06	0.21	10	1.49	4.85	14	0.08	3.51
Erythromycin	0.14	0.44	0	0	0	0	0	0
Erythromycin-h2o	0.25	0.80	0	0	0	0	0	0
Florfenicol	0.12	0.37	0	0	0	0	0	0
Ivermectin	1.46	4.64	0	0	0	0	0	0
Lufenuron	0.07	0.22	6	0.67	2.19	2	0.16	0.20
Sulfadiazine	0.06	0.18	0	0	0	0	0	0
Suladimethoxine	0.06	0.19	0	0	0	0	0	0
Teflubenzuron	1.22	3.88	0	0	0	0	0	0
Trimethroprim	0.06	0.20	0	0	0	0	0	0
Amoxicillin	1.49	4.70	0	0	0	0	0	0
Oxytetracycline	0.08	0.26	10	1.01	3.96	16	0.28	21.4

No. present are the total stations where the DPAB was detected. The max represents the maximum value among stations at a site.

Table 4 - Trace metals and total organic content. Trace Metals units are reported in milligrams of analyte per kilogram of dry weight (mg/kg).

		F09 – Sep (n=10)			F09 – Nov (N=16)		
	RL	mean	min	max	mean	min	max
TOC (%)		NA	NA	NA	4.56	1.1	6.9
Aluminum	1	17673	15500	19100	19588	12000	21400
Antimony	0.1	0.11	0.1	0.2	0.13	0.1	0.6
Arsenic	1	8.8	8	9	9.5	8	12
Barium	1	56	54	59	59	39	67
Beryllium	0.1	1	0.9	1.1	1.1	0.7	1.2
Bismuth	1	<RL	<RL	<RL	<RL	<RL	<RL
Boron	1	47	43	50	42	22	48
Cadmium	0.01	0.4	0.3	0.5	0.3	0.1	0.5
Calcium	50	13080	9010	17800	8412	5010	21400
Chromium	1	32	30	35	33	19	36
Cobalt	0.1	11	10	12	12	10	13
Copper	1	49	33	154	22	11	38
Iron	20	29336	25200	31500	33688	22000	37100
Lead	0.1	19	18	20	23	16	28
Lithium	0.1	37	33	40	39	26	44
Magnesium	10	11436	10600	12300	10505	6780	11700
Manganese	1	350	317	370	401	209	457
Mercury	0.01	0.03	0.02	0.05	0.05	0.02	0.2
Molybdenum	0.1	9.0	2.6	16.6	1.1	0.5	4.1
Nickel	1	28	26	30	30	23	33
Potassium	20	5331	4710	5730	4920	2660	5580
Rubidium	0.1	26.3	24.3	28.2	27.5	14.8	30.3
Selenium	1	1	1	1	1.1	<RL	2
Silver	0.1	<RL	<RL	<RL	<RL	<RL	<RL
Sodium	50	27400	19800	40100	15107	6560	18700
Strontium	1	95	66	128	54	40	107
Tellurium	0.1	<RL	<RL	<RL	<RL	<RL	<RL
Thallium	0.1	0.3	0.2	0.3	0.2	0.2	0.3
Tin	1	<RL	<RL	<RL	<RL	<RL	<RL
Uranium	0.1	2.5	1.8	3.2	1.4	1.0	2.3
Vanadium	1	47	45	51	47	28	52
Zinc	1	197	139	261	93	62	159

RL = lower reporting limit. < RL values were excluded from mean and max calculations.

Table 5 - Sediment total dissolved sulfides (TDS) measured at 2 cm below sediment surface. Units are in μM.

	ISE method					UV-method					Methylene Blue method				
Site/Date	N	n	mean	min	max	N	n	mean	min	max	N	n	mean	min	max
F09 - Sep	10	10	972	529	1760	9	5	249	<LOQ	537	9	3	348	<LOQ	451
F09 - Nov	16	16	332	37	2120	16	11	174	<LOQ	760	16	1	805	<LOQ	805

N = Number of samples. n = number of samples where TDS was measured above the level of quantification (LOQ) and used for calculation of mean and max. LOQs were: ISE method = 100, UV method = 37 μM, MB method = 200 μM.

APPENDIX II: DATA FIGURES

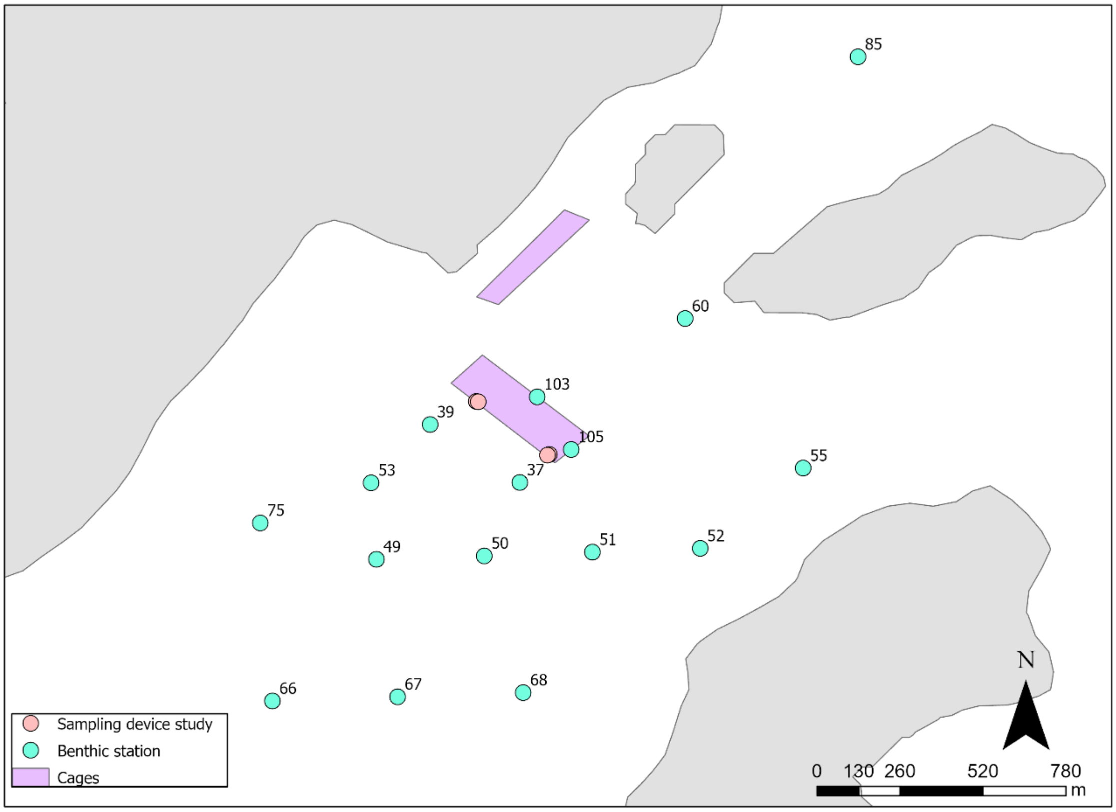

Figure 1 – AMP Maritimes benthic sampling stations at site F09 in 2023

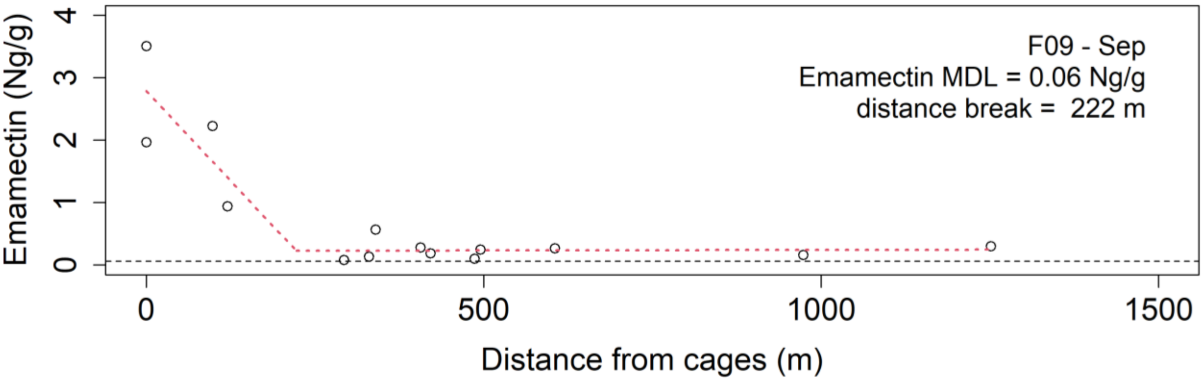

Figure 2 – Emamectin concentration relative to distance from target farm. Presence of a red dashed line indicates a significant distance breakpoint in Emamectin as a function of distance away from the farm cages (p<0.05). Black dashed line indicates the method detection limit reported by MB Labs for Emamectin (0.06 ng/g)

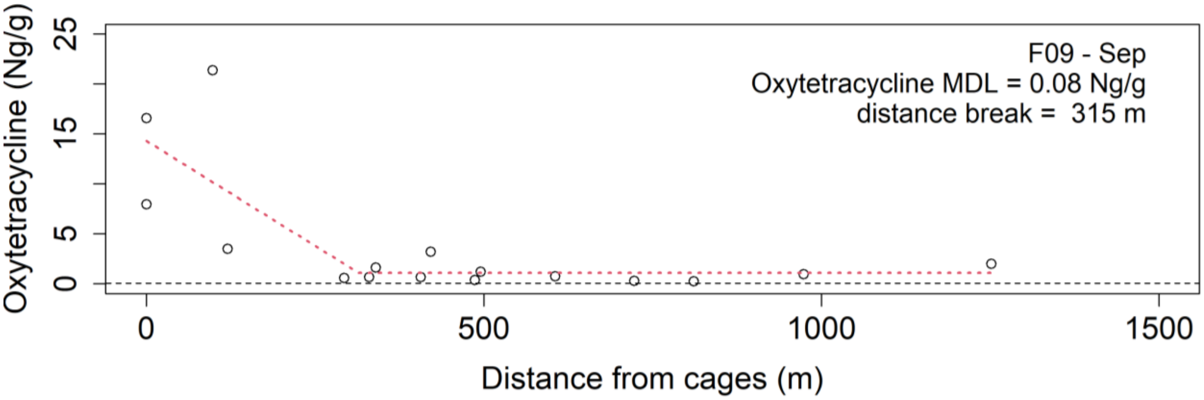

Figure 3 – Oxytetracycline (OTC) concentration relative to distance from target farm. Presence of a red dashed line indicates a significant distance breakpoint in OTC as a function of distance away from the farm cages (p<0.05). Black dashed line indicates the method detection limit reported by MB Lab for OTC (0.081 ng/g).

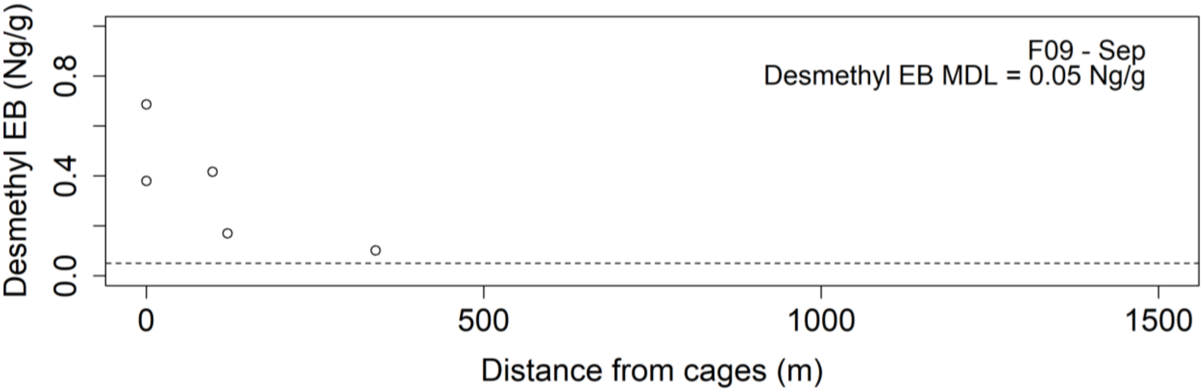

Figure 4 – Desmethyl EB concentration relative to distance from target farm. Black dashed line indicates the method detection limit reported by MB Labs for Desmethyl EB (0.05 ng/g). No significant distance breakpoint was detected for Desmethyl-EB.

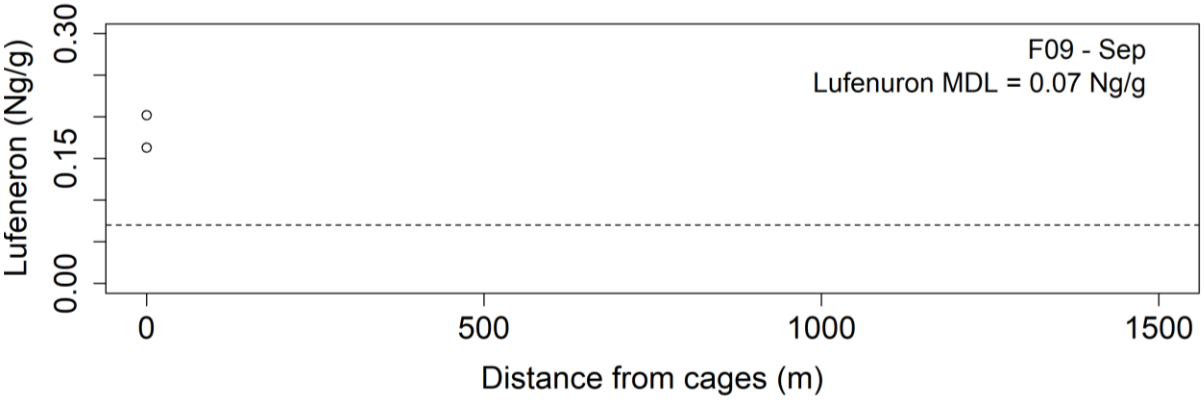

Figure 5 – Lufeneron concentration relative to distance from target farm. Black dashed line indicates the method detection limit reported by MB Labs for Lufenuron (0.07 ng/g)

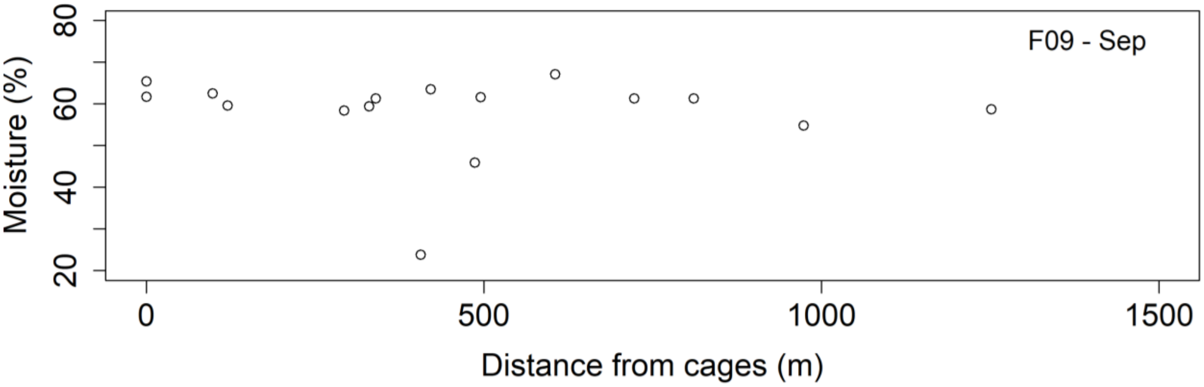

Figure 6 – Moisture content of benthic samples relative to distance from target farm.

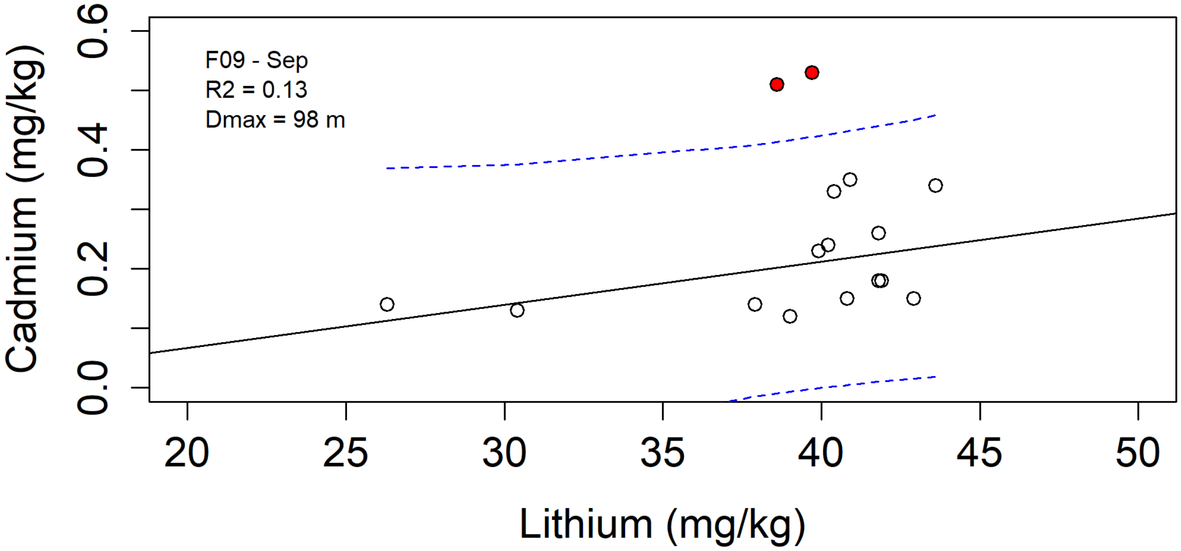

Figure 7 – Geochemical normalized cadmium levels by station. Enriched stations (solid red circles) plot above the 95% confidence interval (dashed-blue lines) from the normalization regression (black line) against Lithium. Dmax is the maximum distance an enriched station was located from the farm cages. Note the poor regression fit of the normalization procedure (R^2=0.13).

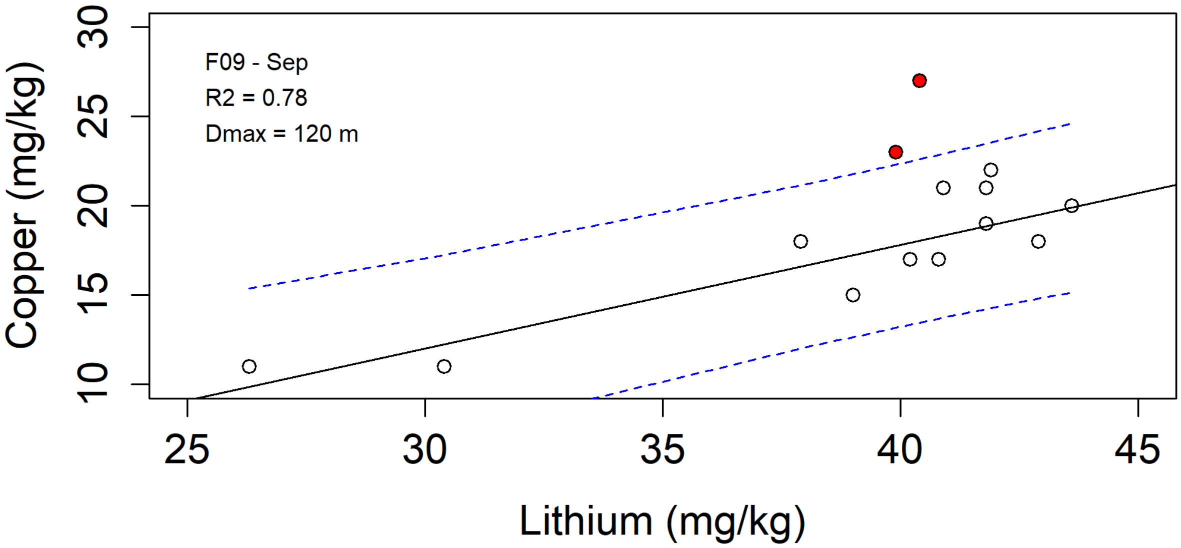

Figure 8 – Geochemical normalized copper levels by station. Enriched stations (solid red circles) plot above the 95% confidence interval (dashed-blue lines) from the normalization regression (black line) against Lithium. Dmax is the maximum distance an enriched station was located from the farm cages. Note the poor regression fit of the normalization procedure (R^2=0.78).

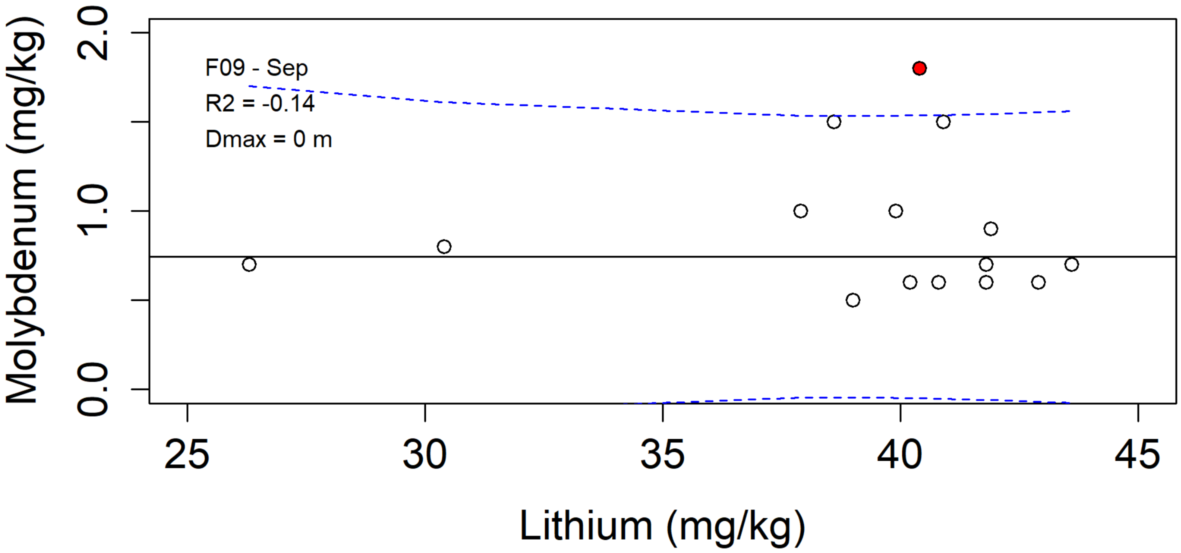

Figure 9 – Geochemical normalized molybdenum levels by station. Enriched stations (solid red circles) plot above the 95% confidence interval (dashed-blue lines) from the normalization regression (black line) against Lithium. Dmax is the maximum distance an enriched station was located from the farm cages. Note the poor regression fit of the normalization procedure (R^2=-0.14).

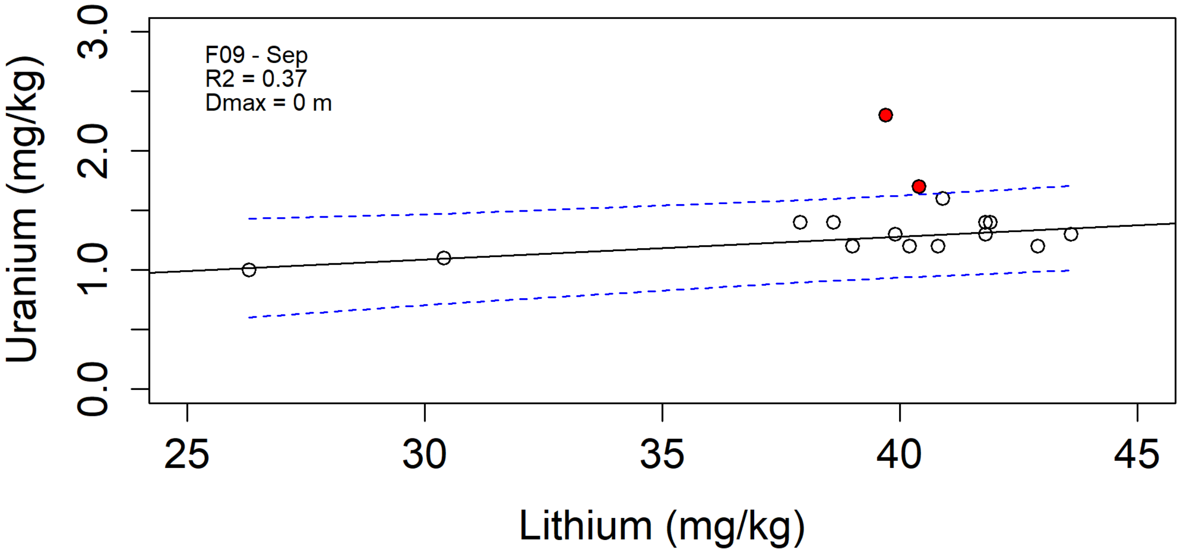

Figure 20 – Geochemical normalized uranium levels by station. Enriched stations (solid red circles) are above the 95% confidence interval (dashed-blue lines) from the normalization regression (black line) against Lithium. Dmax is the maximum distance an enriched station was located from the farm cages. Note the poor regression fit of the normalization procedure (R^2=0.37).

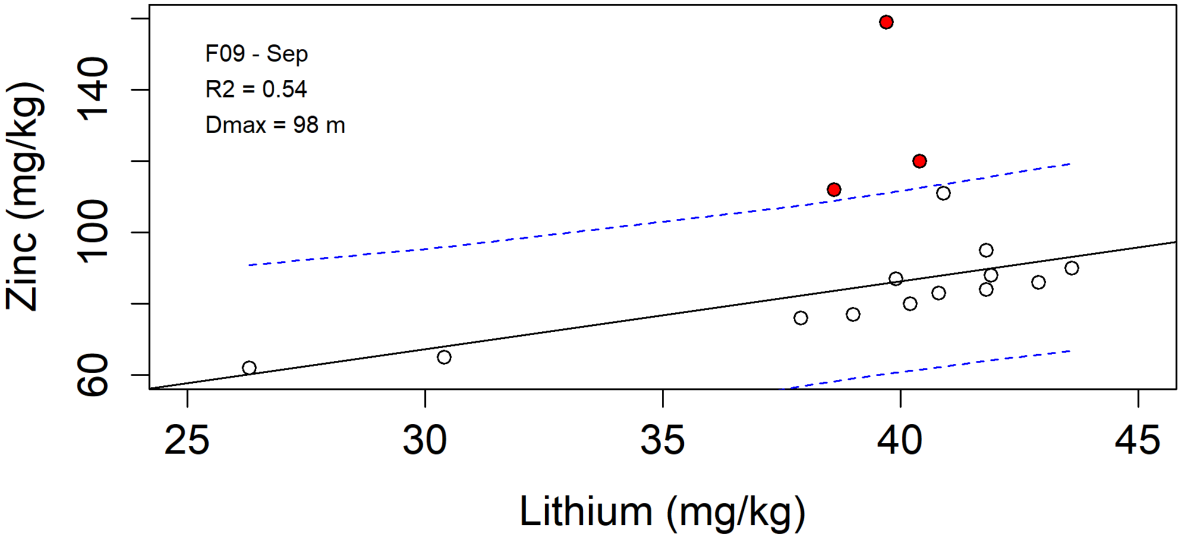

Figure 3 – Geochemical normalized zinc levels by station. Enriched stations (solid red circles) plot above the 95% confidence interval (dashed-blue lines) from the normalization regression (black line) against Lithium. Dmax is the maximum distance an enriched station was located from the farm cages. Note the poor regression fit of the normalization procedure (R^2=0.54).

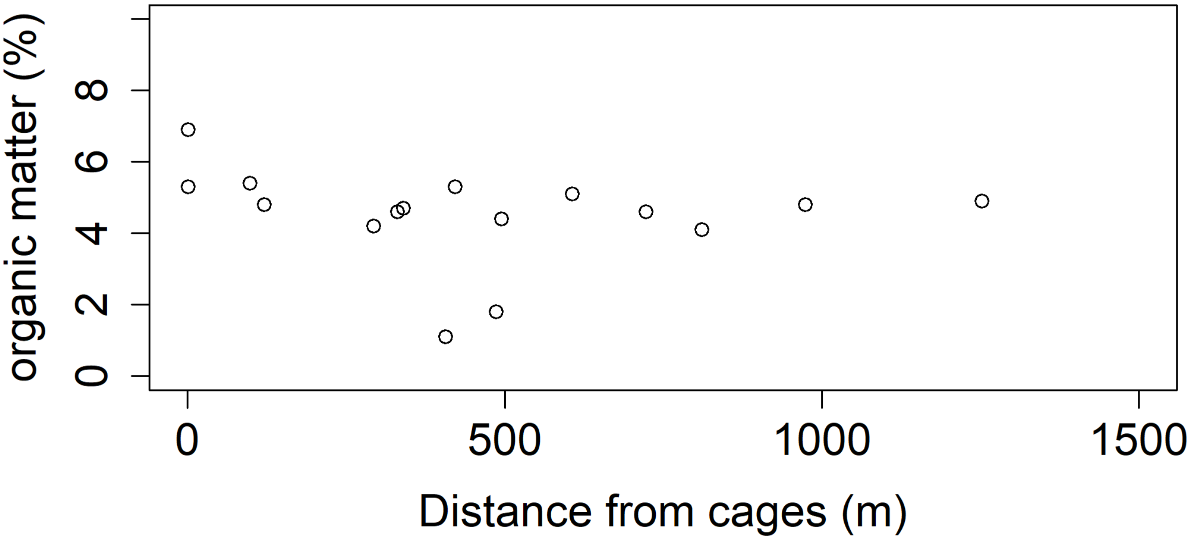

Figure 4 – Organic content relative to distance from target farm.

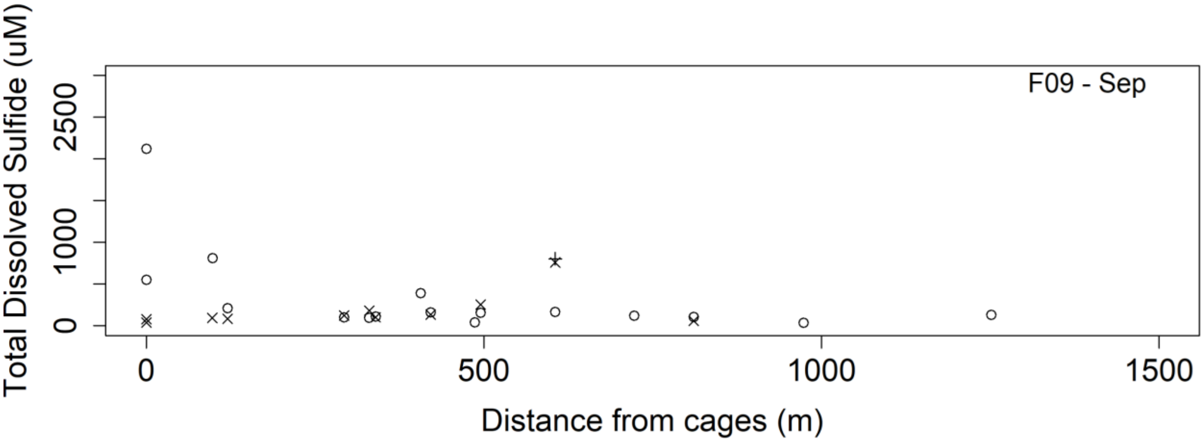

Figure 5 – Total dissolved sulfides (TDS) as a function of distance from target farm. No significant distance breakpoint was detected using the pooled data from the ISE (o), UV (x), and MB (+) methods for measuring TDS.