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Red and Bonita Mine Bulkhead Test Closure Analytical Report

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List of Abbreviations and Acronyms

AT	American Tunnel
BPMD	Bonita Peak Mining District
CFS	Cubic Feet per Second
D&A	Deere and Ault Engineering Inc.
DM	Draining Mine
DRMS	Division of Reclamation and Mining Safety
USEPA	U.S. Environmental Protection Agency
GKM	Gold King Mine
GPM	Gallons Per Minute
IWTP	Interim Water Treatment Plant
MSI	Mountain Studies Institute
NO	Natalie Occidental Mine
PCA	Principal Component Analysis
R&B	Red and Bonita Mine
REE	Rare Earth Elements
S&S	Seeps and Springs
SW	Surface Water
USGS	United States Geologic Survey

1. Overview

1.1 Introduction

The Bonita Peak Mining District (BPMD), located in San Juan County, Colorado, consists of 48 mining legacy sites with potential environmental risk. Six legacy mines in the Cement Creek watershed have mine drainage that contribute substantial metal loads to Cement Creek and ultimately the Animas River: Mogul, Mogul South, Red and Bonita (R&B), Gold King, American Tunnel, Natalie/Occidental, Blackhawk, (Cowie and Roberts 2019; 2020). The installation of cement bulkheads to plug or seal off mine drainage has been used as a mitigation approach throughout BPMD including several mine sites within the Cement Creek watershed at Mogul, American Tunnel, and R&B. The R&B bulkhead was installed in 2015 by the Colorado Division of Mining Reclamation and Safety (DRMS) to provide an opportunity in the future to shut off flow from the R&B and theoretically eliminate or reduce mine drainage from exiting the R&B portal, and to return the local water table closer to its pre-mining level. The R&B bulkhead was equipped with a main valve which has remained open since 2015 allowing mine drainage to discharge from the portal and into Cement Creek. In 2020, the EPA conducted a bulkhead test closure in which the main value was closed, and the R&B bulkhead was temporarily pressurized to assess bulkhead performance. The bulkhead test closure provided an opportunity to evaluate whether the short-term closure of the R&B bulkhead caused measurable changes in hydrology and water quality in the vicinity.

The R&B bulkhead and closure test have been described in several previous reports. The R&B bulkhead design was presented by DRMS (DRMS 2015). Reports by Deere and Ault Consultants, Inc. present the execution plan (2020) and final report for the R&B Bulkhead Test (2021). During the test closure period, weekly update reports detailing actions taken and key observations were prepared by Deere and Ault Consultants, Inc., Mountain Studies Institute (MSI), EPA, Environmental Restoration, and Weston Solutions. MSI produced a report that summarized field observations from the R&B bulkhead test closure investigation (2021). The purpose of this report (tasked by TechLaw to MSI on 4/13/21) is to incorporate analytical lab results from samples collected during the bulkhead test closure investigation into a holistic evaluation of water quality and water quantity data associated with the test closure. Previous research has demonstrated downstream water quality improvements associated with long-term bulkhead closures (Runkel et al. 2009; Clements et al. 2021; Walton-Day et al 2021). The study presented here is unique in that we are assessing hydrologic and water quality response during a short-term bulkhead closure rather than a long-term closure.

1.2 Objectives

Our objective was to determine whether there was a measurable hydrologic and/or water quality response to the temporary R&B bulkhead test closure. Furthermore, we assess whether that response can be detected and definitively attributed to the test closure, at sites on Cement Creek and the Animas River downstream of R&B. Specifically, we are evaluating whether there were changes in water quality and water quantity at three types of monitoring locations: draining mines, seeps and springs (emergence points), and surface water (streams and rivers).

2. Methods

2.1 Monitoring Locations

Monitoring locations were selected in the vicinity of R&B at sites where historical water quality and water quantity data had been collected, and where it was thought that a response from the R&B test closure was most likely to occur (Table 1). The selection was based on the professional judgement of scientists from EPA, MSI, and others, and documented in the field sampling plan (MSI 2020). In addition to the monitoring locations outlined in the field sampling plan, in this report we include additional locations that add relevancy and value to our evaluation. These include Natalie/Occidental Mine and Blackhawk Mine.

During the closure period, we monitored the R&B vicinity for new expressions or emergences of water that could be related to the closure. We documented twenty-five locations where we observed water seepage or flow at the surface that was not observed prior to the test closure and incorporated these new locations into our weekly inspection routines.

2.2 Timeline

The timeline for the bulkhead test closure and associated monitoring are described in detail in the Red and Bonita Mine Bulkhead Test Closure Field Activity Summary Report (MSI 2020) and the Red and Bonita Bulkhead Test Final Report (Deere and Ault 2021). Key dates include:

- July 15, 2020 = Valve on R&B bulkhead was closed.
- September 21, 2020 = Valve on R&B bulkhead was opened. The water that had backed up behind the bulkhead was gradually drained and conveyed by pipe to the Gladstone Interim Treatment Facility for treatment.
- October 22, 2020 = Drainage from R&B was returned to pre-test route, flowing across R&B fen and into Cement Creek.

We conducted weekly inspections of sites beginning the week of July 6 (one week prior to the bulkhead valve closure) through 9/22, then bi-weekly until the week of October 19 (just prior to the return of R&B discharge to Cement Creek). We collected water quality samples from select locations for laboratory analysis on four sampling events (Table 2).

2.3 Weekly Inspections and Field Measurements

We visited monitoring locations weekly during the test closure from July 6 to October 19, 2020 to assess whether any changes had occurred since the last visit. During inspections, we documented conditions by photograph, descriptive observations, and the collection of field measured water quality parameters including pH, conductivity, water temperature, and discharge. We used YSI Professional Plus and/or Oakton probes to measure field water quality parameters. Due to the complexity and variability in flow regimes of sites, we used several techniques to measure discharge. For draining mines and surface water locations, we used a combination of deployed instrumentation, flow meters, and flumes. For locations with lower flow rates, we used volumetric methods to measure discharge including graduated cylinders (MSI 2020). For instrumented sites, we downloaded deployed instrument data loggers and transducers during weekly inspections if no automated data were available. When persistent new emergences of water were encountered, we incorporated these new locations into our weekly inspection regime moving forward.

2.4 Water Sampling

We collected discrete grab samples in accordance with FSP protocols (MSI 2020) for analysis of total recoverable metals, dissolved metals, alkalinity/anions, stable isotopes, total rare earth elements, and dissolved rare earth elements (Table 3).

2.5 Analytical and Statistical Analysis

EPA maintains a SCRIBE database containing environmental data that has been collected in recent years from BPMD. We obtained surface water quality analytical results discussed in this report from SCRIBE in April, 2021.

When laboratories report analytical results, they also report the numerical limitations of their instruments and analytical methods. For trace metals, it is common for analytical results to be reported as being below a Minimum Reporting Level (MRL), which is the level that can be reliably detected by laboratory analytical methods. MRLs vary between laboratories and methodologies. In an effort to minimize the influence of MRL variability, we treated all non-detections as zeros. This approach is consistent with Colorado Public Health and the Environment water quality standard assessment (CDPHE 2017).

We applied principal component analysis (PCA) within PC-ORD software (McCune & Mefford 1999) to assess differences in water quality among sites and years. We log-transformed analytical results prior to PCA ordination. PCA plots depict similarity and dissimilarity among samples from different sites and different years based on a suite of water quality parameters. Samples plotted more closely together have more similar water quality parameters while samples plotted further apart have less similar water quality parameters. PCA also provides loading plots with vectors that indicate the strength and direction of how strongly each water quality parameter influenced the plotted variability among samples depicted in PCA plots. The position of vectors to one another indicate whether water quality parameters may be correlated.

Additionally, we applied K-means clustering in R (R Core Team, 2017) using the package cluster (Maechler et al. 2018). K-means clustering is an unsupervised method that seeks to find relationships between the n observations without being trained by a response variable. Observations are partitioned into a set of k groups (i.e., k clusters), where k is representative of the number of groups that is specified by the researcher. Observations are classified in multiple groups (i.e., clusters), where observations within the same cluster have high intra-class similarity and observations from different clusters have low inter-class similarity. Each cluster is represented by its center (i.e., centroid) which corresponds to the mean of points assigned to that cluster. Cluster analysis is a valuable technique to use to classify and identify true groups amongst observations in a data set. We used K-means clustering to evaluate relationships between seeps and springs, newly document surface water expressions, and R&B drainage. Data for cluster analysis was scaled using a Euclidean distance measure.

3. Results

3.1 Analytical approach

Immediately prior to the bulkhead closure, drainage from the R&B on 7/6/2020 was ~228 gpm and was contributing metal loads at a rate of approximately 3.8 kg/day aluminum, 0.01 kg/day cadmium, 0.08 kg/day copper, 142 kg/day iron, 0.12 kg/day lead, 51.7 kg/day manganese, and 20.6 kg/day zinc.

The primary objective of our analysis was to examine whether, after the bulkhead was closed, the flow and metal loads that otherwise would be discharging from the R&B portal, would:

a) be routed to known emergence points at historically draining mines and/or existing seeps and springs.
b) find a new route to the surface and express as new emergence points at historically dry mines and/or as new surface water expressions on hillslopes.
c) or; if the R&B drainage was effectively contained within the mine workings, we assessed whether a reduction in metal loads could be detected at surface water sites downstream of R&B.

The primary challenge in evaluating a potential response from the bulkhead test closure is whether or not we can definitively isolate the influence of the bulkhead closure from unrelated watershed wide phenomena. For example, if we were to assess whether a reduction in zinc load downstream of R&B during the closure could be solely attributable to the R&B closure, we could look at whether a similar reduction occurred in other drainages that are not influenced by R&B. Additionally, we could examine whether the observed reduction was typical for the observation period based on data from previous years when the bulkhead test closure did not occur. Fortunately, there are several data sources that allow for a baseline understanding of pre-closure conditions. Notably, a hydrologic water balance report was completed in 2021, which describes the seasonality of metal loadings from draining mines in the R&B vicinity (Cowie and Rock 2021). In 2019, high frequency monthly water quality sampling was conducted at surface water and draining mine sites within the Cement Creek watershed. This 2019 dataset is valuable for interpreting whether conditions observed during the 2020 test closure were a departure from pre-closure conditions. It is important to note that hydrologic conditions in 2020 differed greatly from 2019. The winter of 2018/19 delivered above average snow accumulations to the San Juan Mountains and subsequent high river flows in the spring of 2019. Conversely, 2020 was characterized by drought conditions and low river levels exacerbated by a weak monsoon season. Annual average streamflow at the Cement Creek USGS gage (CC48) was more than twice as high in the 2018-19 water year (54.6 cfs) compared to 2019-20 water year (26.9 cfs). This pattern persisted into the late summer and fall, when during the R&B bulkhead test closure (July 15-October 22), average streamflow at CC48 was still more than twice as high in 2019 (33.7 cfs) than in 2020 (15.2 cfs). Therefore, comparisons of water quality data from 2019 to 2020 should be interpreted within the context of these contrasting hydrologic regimes (Figure 1; Table 4).

Our analytical approach compared observations from potential R&B-influenced sites to non-R&B-influenced sites (e.g., CCSG-7, M34, A68) and compared observations from the closure period (which occurred during late summer and fall when flows were transitioning from the receding limb of the hydrograph to fall low-flow conditions) to observations from the same hydrologic period in previous years. This approach has been used elsewhere and is often referred to as Before-After Control-Impact assessment (e.g., Kotalik et al. 2021; Underwood 1992).

We have conducted a before/after assessment in two ways. First, we compared the trend in water quality across test closure phases, from pre-closure to drain down, to trends from the same time period in previous years. This evaluation is facilitated by examining trends in water quality concentrations and loads in 2020 compared to previous years (Figures 2-5 & Appendix A). Second, we compared water quality conditions measured during the fall low-flow period of 2020 when bulkhead pressure was at its highest prior to drain down, to water quality conditions measured during the fall low flow period in previous years. We illustrate this comparison of low-flow conditions in box plots (Figure 6-8 & Appendix B); calculated zinc load reductions (Figures 9-17); a longitudinal comparison along Cement Creek (Figures 18-21); and statistical ordination and clustering (Figures 22-23 & Appendix D.

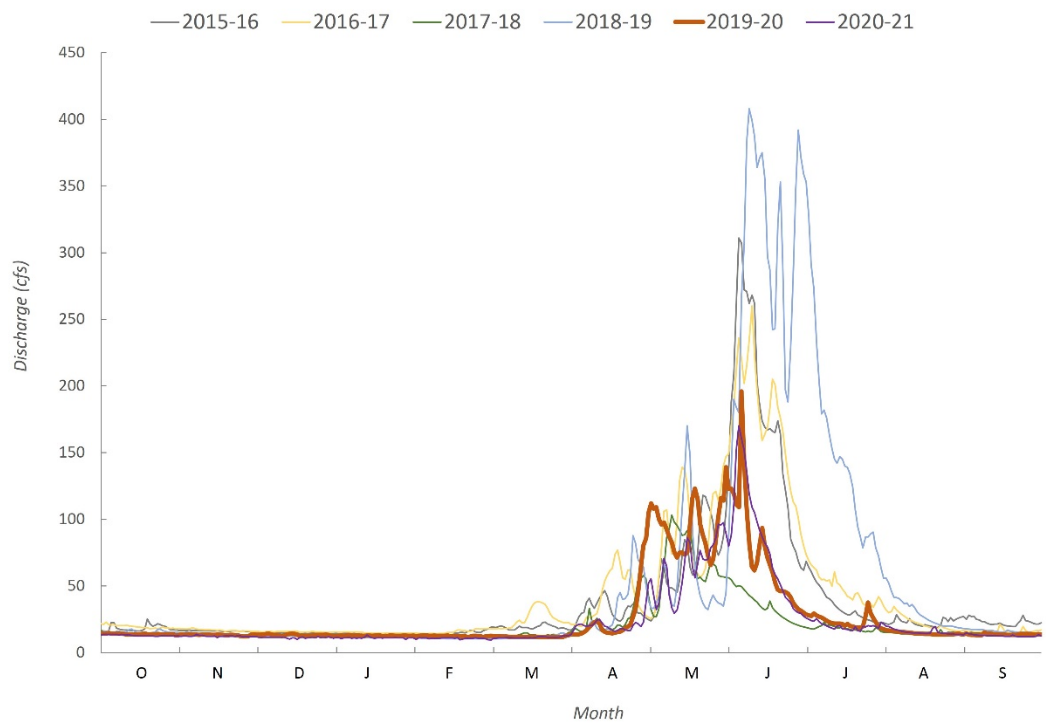


Figure 1: Streamflow at Cement Creek USGS gage (CC48) from 2015-16 water year to 2020-21 water year. 2019-20 water year of R&B bulkhead test emphasized in red.

Among the suite of metals analyzed by the ESAT laboratory, we chose to focus our analysis on aluminum, cadmium, copper, iron, manganese, lead, and zinc due to several factors: a) R&B is known to contribute relatively large loads of these metals to Cement Creek (Cowie and Roberts 2019; 2020); b) these metals generally appear to shape BPMD aquatic life communities (Roberts 2017); and c) other metals (e.g., Ag, Se, etc.) typically occur at such low concentrations in R&B drainage that their laboratory analytical results are below method detection limits.

3.2 Trends during the bulkhead test closure

As described by Deere and Ault (2020), data from deployed instruments in neighboring draining mines during the closure demonstrated very little change in mine discharge rates that could be attributable to the closure. The closure effectively reduced R&B discharge from about 228 gpm prior to the closure to approximately 0.3 gpm during the closure. The trends in mine discharge from other monitored mines varied over the closure period but were markedly similar to seasonal trends in discharge observed from the same time period in 2019 (Figures 2-4). There was a slight increase in average discharge at Mogul from July to November during the closure period, but this pattern generally mimicked the 2019 pattern in discharge over the same time period. In both 2019 and 2020, discharge at Blackhawk gradually increased from June to October, but began decreasing in November. Discharge from Natalie/Occidental decreased over the closure period in 2020 and 2019. Flows from Gold King and American Tunnel varied over the closure period, but generally decreased. In 2019, flows from Gold King and American Tunnel increased from June to July and then decreased from July to November. This difference in the trend in discharge of Gold King and American Tunnel from 2019 to 2020 reflects the greater snowpack and later runoff period that occurred in 2019 as compared to 2020 (Figure 1).

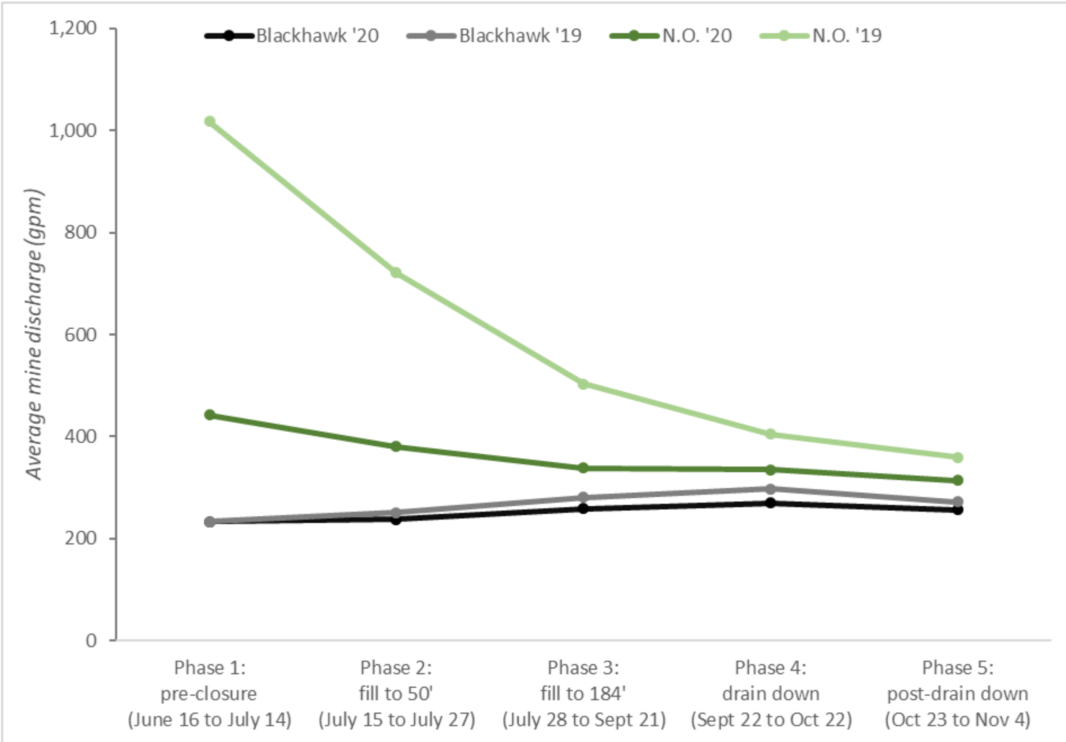


Figure 2: Discharge of Blackhawk Mine and Natalie Occidental Mine in 2019 and 2020.

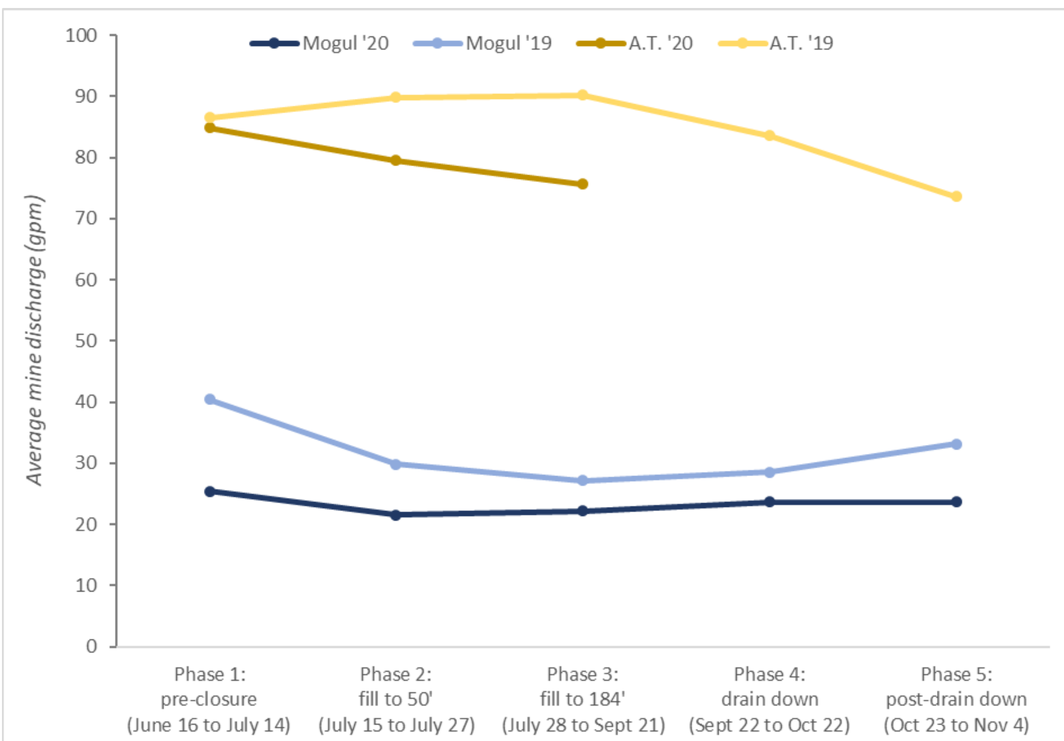


Figure 3: Discharge of Mogul Mine and American Tunnel in 2019 and 2020.

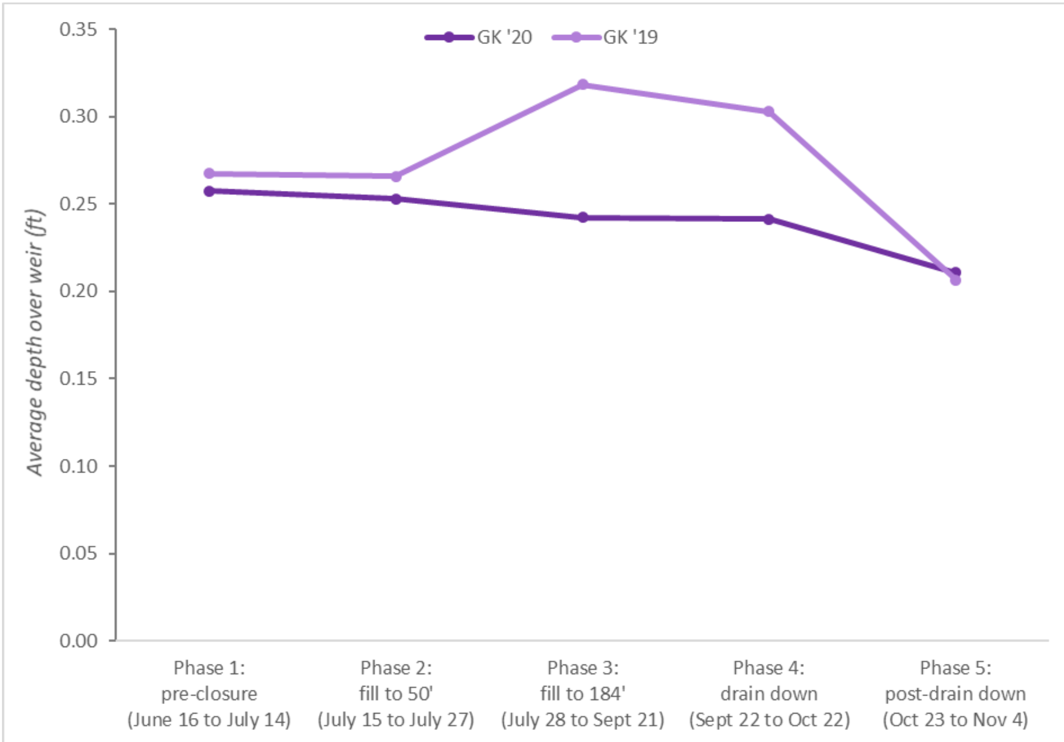


Figure 4: Discharge of Gold King Mine in 2019 and 2020.

We investigated whether water quality during the test closure differed from previous years at draining mines in the R&B vicinity and downstream surface water sites. Water quality trends during the closure period were generally consistent with seasonal trends from previous years described by Cowie and Roberts (2019; 2020) and Cowie and Rock (2021), and depicted in Appendix A. For example, the concentration of total aluminum at Gold King typically increases during spring runoff to a maximum concentration in June or July, and then begins to decrease from June/July through the fall (Figure 5). Total aluminum load at Gold King typically follows a similar pattern as the total aluminum concentration but has a small increase in September before continuing to decrease through the fall (Appendix A). In 2020, these typical seasonal patterns of metal concentrations and loads at draining mine sites and surface water locations had a similar trend shape and direction as documented in previous years. However, the influence of differing hydrologic conditions between years is distinct with maximum concentrations and loads generally occurring earlier, and at a smaller magnitude, in 2020 compared to 2019.

We also focused on the August to September time period when pressure was building behind the bulkhead to examine whether there were increases in metal concentrations or loads at draining mines that could be attributable to the closure. We found that mine drainage loads of several metals did increase from August to September of 2020 during the closure but loads increased similarly during the same time period in 2019. This illustrates the value of robust pre-test data. Without the availability of pre-test data for comparison, one may incorrectly conclude that all metal load increases from draining mines during the closure period in 2020 were directly attributable to the test closure.

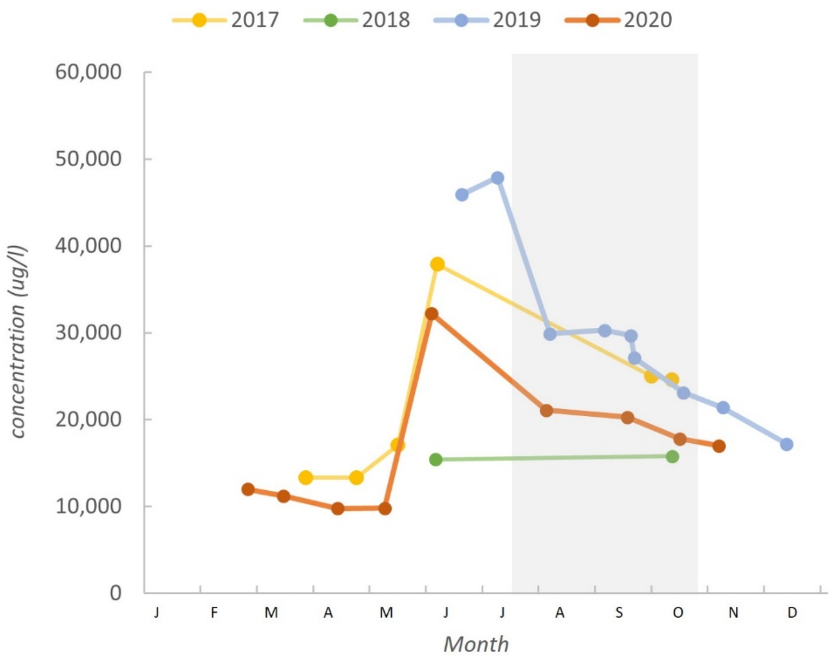


Figure 5: Total zinc concentration of Gold King Mine (CC06) from 2017-2020.
Gray shading represents timeframe of 2020 R&B bulkhead test closure.
See Appendix A for trend plots from all sites.

3.3 2020 Low-flow conditions in context of previous years

In late September during phase 3 of the closure, we collected water samples from draining mines, seeps and springs, and surface water sites to characterize conditions when bulkhead pressure had been raised to 184', the highest level of the test. Using box plots depicted in Appendix B, we compared low-flow water quality observed during the closure to a) low-flow conditions from previous years; and b) high-flow conditions documented just prior to the test closure. As an example, examination of box plots indicates that the low-flow total zinc concentration at seep/spring site SS084 measured during the closure was higher than the pre-test low-flow median, but within the low-flow range of variability for this site from previous years (Figure 6). The high-flow observations provide additional context of how 2020 may compare to previous years regardless of the bulkhead test closure. Similar to the 2020 low-flow observation, the 2020 high-flow total zinc concentration at SS084 was higher than the high-flow median from previous years. A consistency between the 2020 observations compared to previous years in both high-flow and low-flow conditions further suggests that a signal from the R&B closure was not readily discernable for this site.

We found that water quality of draining mines and most seeps and springs during the Phase 3 fall 2020 low-flow conditions were consistent with low-flow conditions from previous years and were within 2020 expectations based on how 2020 high-flow water quality compared to previous years (Appendix B).

One hypothesis was that metal concentrations and/or loads may increase at draining mines in the R&B vicinity during the closure. Of the handful of instances where low-flow 2020 concentrations or loads were higher than the median of previous years, they were preceded by high-flow conditions that demonstrated

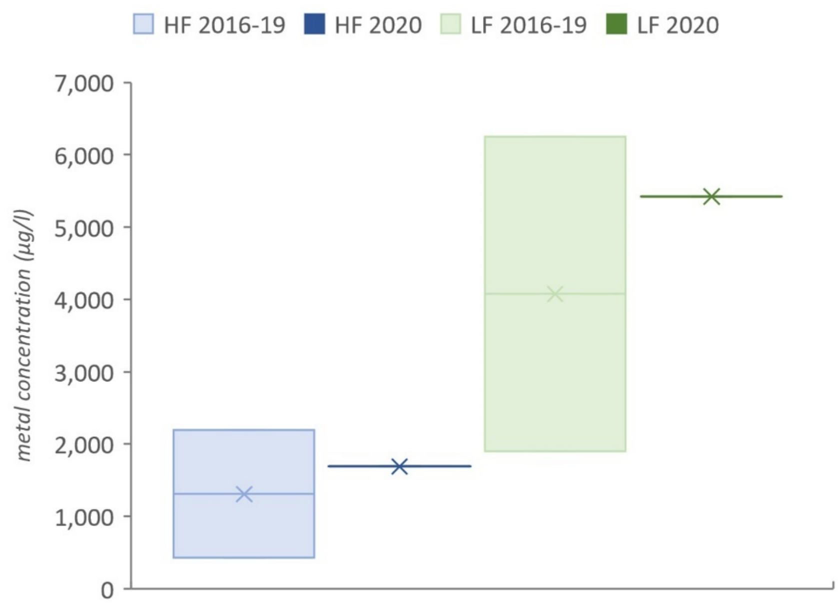


Figure 6: Total zinc concentration of SS084 during high-flow (HF) and low-flow (LF) of 2020 compared to HF and LF observations from 2016-2019.
See Appendix B for box plots from all sites.

that the same departure from previous years existed even before the test closure began (e.g., total iron concentration at Mogul). Conversely to the hypothesis, for most metals, concentrations and loads from draining mines were markedly lower during low-flow 2020 than in previous years. Although a load reduction at R&B was the intention of the test closure, it was surprising that large load reductions also occurred at Gold King and other draining mines during the test closure. Given that loads of several metals at Gold King and other mines were also reduced during high-flow conditions prior to the test, it is more likely that the continuation of lower loads during the low-flow period was attributable to climatic and hydrologic conditions that preceded the test closure. The lower metal loads of draining mines in both high-flow and low-flow of 2020 reflect increased drought conditions (*Palmer Drought Severity Index in the Colorado Basin was -4.95 in September of 2020 compared to -1.14 in September of 2019*), reduced snowpack (*April 1 SWE at Red Mountain Pass was 104% of April 1 median in 2020 compared to 171% in 2019*), and reduced streamflow (*Cement Creek peak streamflow was 196 cfs in 2020 compared to 408 cfs in 2019*) compared to the previous year.

Of the existing seeps and springs in the R&B vicinity, two locations had low-flow water quality that differed from what would be expected based on previous years. In 2020, SS062 and SS236 both had low-flow total iron and total lead concentrations that were substantially higher than low-flow observations from previous years, and well above what would be expected based on 2020 high-flow data (Figures 7-8 & Appendix B). These two springs are located downslope of the R&B portal and adjacent to the R&B fen. These locations warrant closer attention during future R&B bulkhead tests.

Another hypothesis was that metal concentrations and/or loads may decrease at surface water locations in the vicinity of, and downstream of R&B during the closure due to decreased contribution from R&B. During the test closure, low-flow metal loads at surface water sites were generally lower than previous

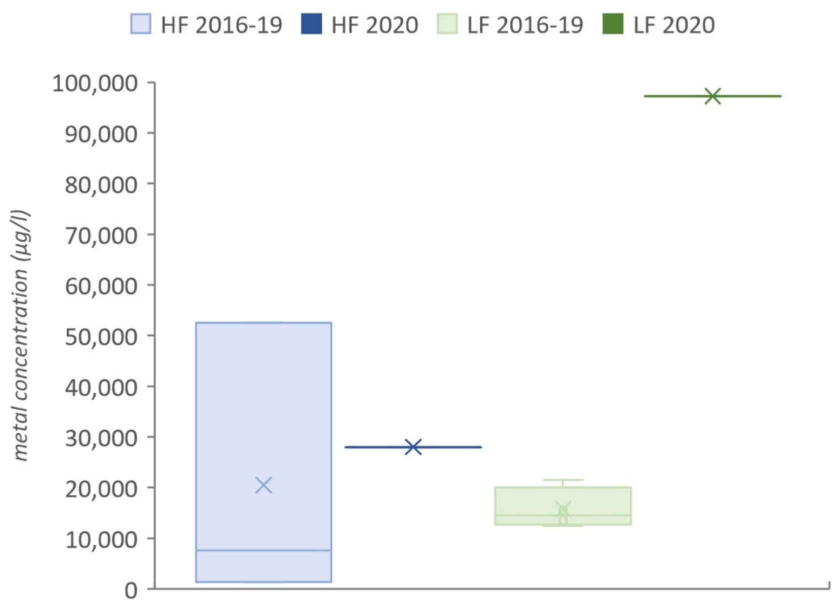


Figure 7: Total iron concentration of SS062 during high-flow (HF) and low-flow (LF) of 2020 compared to HF and LF observations from 2016-2019.
See Appendix B for box plots from all sites.

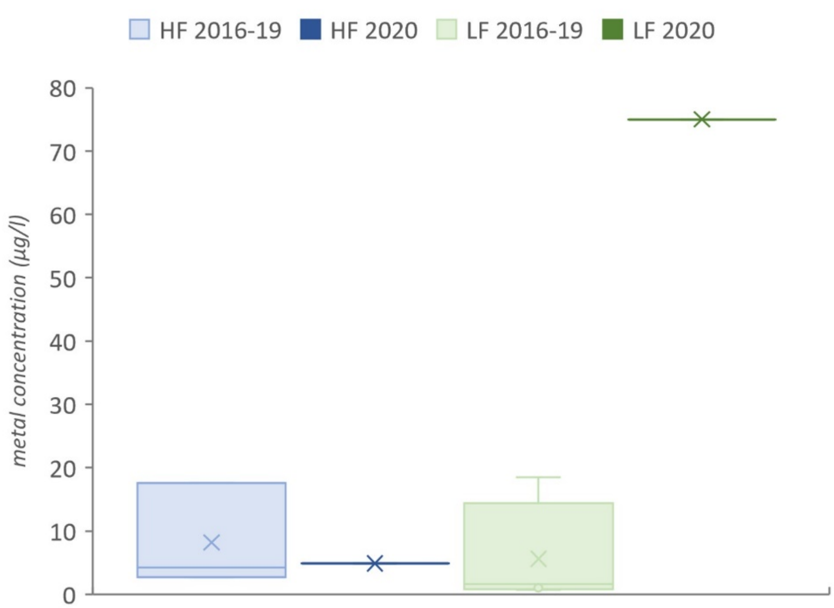


Figure 8: Total lead concentration of SS062 during high-flow (HF) and low-flow (LF) of 2020 compared to HF and LF observations from 2016-2019.
See Appendix B for box plots from all sites.

years. However, metal loads at surface water sites during 2020 high-flow conditions were also generally lower than previous years. Furthermore, metal loads were reduced during 2020 high-flow and low-flow conditions at surface water sites, regardless of whether the site was located downstream of R&B; loads were lower at CCSG-7 (Cement Creek upstream of R&B), A68, and A72 compared to previous years as well.

In an attempt to differentiate load reductions that may be related to the test closure from broader watershed-wide reductions related to drought conditions, we combined two different metrics that assess how 2020 conditions differed from previously documented conditions. We chose to focus this analysis on potential changes in total zinc load since R&B is known to discharge high total zinc loads (Cowie and Roberts 2019; 2020) and due to the strong influence of zinc toxicity on aquatic life downstream of R&B (Roberts 2016). Plotting the numerical reduction (kg/day) of zinc load from July 2020 (just prior to test closure) to September 2020 (at the height of the test closure), and from the 2016-19 low-flow median to the measured 2020 low-flow load further differentiates the response of surface water sites and draining mine sites along a gradient of zinc load reduction (Figure 9). It is clear from both metrics of change that surface water locations in closest downstream proximity to R&B (CCSG-3; CCSG-1) had greater numeric reductions of total zinc load than surface water locations upstream of R&B (CCSG-6; CCSG-7), or those locations not influenced by R&B (A68; M34). Surface water sites CCSG-3, CCSG-1, CC48, and A72, all located downstream of R&B, had greater than about a 20 kg/day reduction in total zinc load in low-flow 2020 regardless of whether you used the comparison to the 2016-19 low-flow median or to the July 2020 load. All other surface water sites had zinc load reductions less than 7 kg/day from 2016-19 low-flow median. The large total zinc load reduction at A72 (28.6 kg/day reduction from 2016-19 low-flow

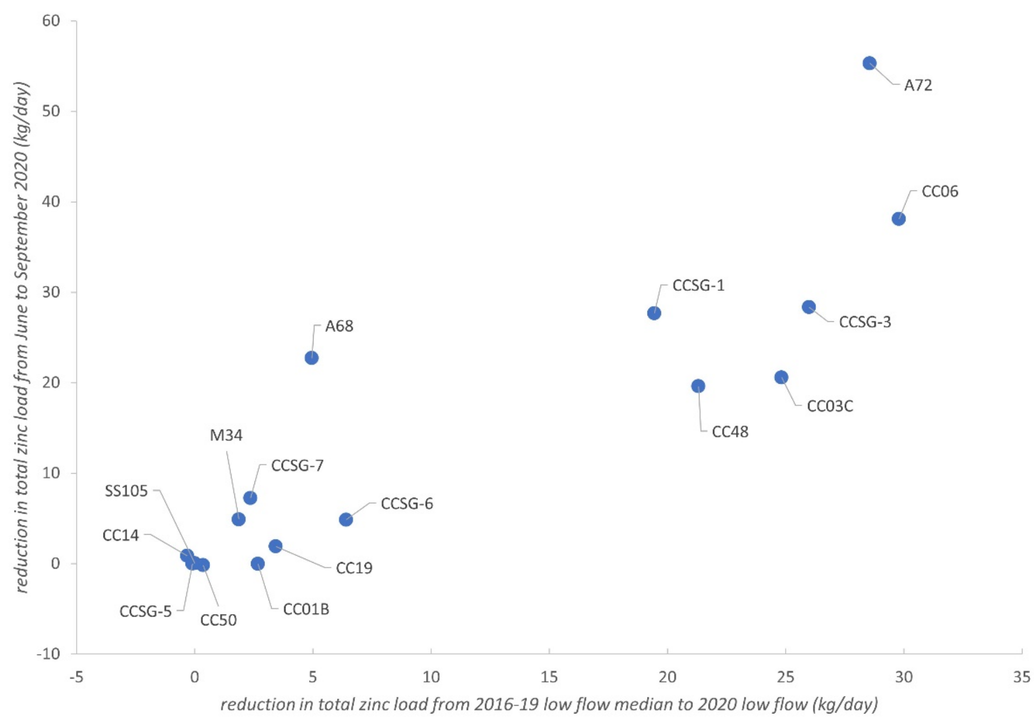


Figure 9: Reduction in total zinc load from 2016-19 low flow median to 2020 low flow; and reduction in total zinc load from June to September 2020.

median) reflects the load reductions of the three major upstream tributaries that contribute flow to A72: A68 (Animas River upstream of Silverton), CC48 (Cement Creek upstream of Silverton), and M34 (Mineral Creek at Silverton) had reductions, respectively, of 5.0, 21.3, and 1.9 kg/day, from the 2016-19 low flow median. We discussed previously that Gold King (CC06) had large reductions in the loads of several metals during 2020 low-flow conditions. Figure 9 illustrates that total zinc load of Gold King in low flow 2020 was 29.8 kg/day lower than the 2016-19 median.

So far, we've compared low-flow zinc loads from 2020 to aggregated median low-flow zinc loads from previous years (e.g., Figure 9). This approach effectively compares samples collected during a similar hydrologic period (low flow to low flow) but does not specifically address the variability in flows that can occur during low flow conditions. Another method to differentiate load reductions that may be related to the test closure from broader watershed-wide hydrologic conditions is to compare loads not as aggregate medians, but rather on a sample by sample basis. This analysis necessitates water quality and flow data collected at a high enough temporal frequency (e.g., monthly) to obtain samples to compare with similar flow levels regardless of calendar date. For each sample collected from surface water sites during the 2020 test closure, we compared zinc loads to samples collected in previous years that met the following criteria: a) samples from previous years must be from the same hydrologic regime (low-flow; Aug-Nov); b) samples from previous years must have been collected when flows were within 10% of the flow level recorded at the time of the 2020 sample (*in the absence of available samples within the 10% threshold, we compared 2020 samples to the sample from previous years with the closest flow numerically*).

Using this refined approach, we found that zinc loads were reduced across all surface water sites in 2020 low-flow compared to samples from previous years, but the magnitude of load reduction differed among surface water sites. Samples from reference sites that are not downstream of R&B (CCSG-6, A68, and M34) had zinc load reductions during the test closure calculated on a sample-by sample basis that ranged from 0.57 kg/day to 19.28 kg/day, with a median of 3.06 kg/day (Figures 10, 14, and 15). Sites downstream of R&B had reductions that ranged from 4.06 kg/day to 37.45 kg/day, with a median of 15.35 kg/day (Figures 11, 12, 13, 16, and 17). By comparing the load reductions of reference surface water sites to load reductions of surface water sites downstream of R&B, it is clear that samples collected downstream of R&B had greater zinc load reductions than would be expected based on the reference sites. Zinc load reductions related to R&B become more difficult to discern with increasing downstream distance from R&B. For example, the zinc load reduction among samples collected during the test closure at A72 (median zinc load reduction of 30.3 kg/day) reflects reductions originating from the Upper Animas (A68, median zinc load reduction of 9.0), Cement Creek (CC48, median zinc load reduction of 14.0), and Mineral Creek (M34, median load reduction of 2.6 kg/day). Further downstream on the Animas River below Cascade Creek (A75B), using data collected by EPA and the Bonita Peak Community Advisory Group, zinc load reductions among samples collected during the test closure range from 4.1 kg/day to 23.2 kg/day, with a median of 12.8 kg/day (Figure 17). It is possible that some of the zinc load reduction this far downstream was related to the R&B test closure but would also be reflective of zinc load reductions that occurred in the Upper Animas, Mineral Creek, and other tributaries un-related to the R&B closure.

To further examine possible load reductions along Cement Creek, we used synoptic USGS data to compare zinc loads measured during low-flow conditions in 2019 and 2020 at surface water sampling locations along Cement Creek (Figures 18-19; Runkel in review). This Cement Creek profile reveals a) at the upper sites (UC-1331 and CCSG-7), zinc loads were higher in 2019 than in 2020, possibly due to a higher water table associated with 2019 being a wetter year than 2020 (Runkel, personal communication); b) a divergence in how zinc loads respond downstream of Red and Bonita Mine in 2019 vs. 2020. The

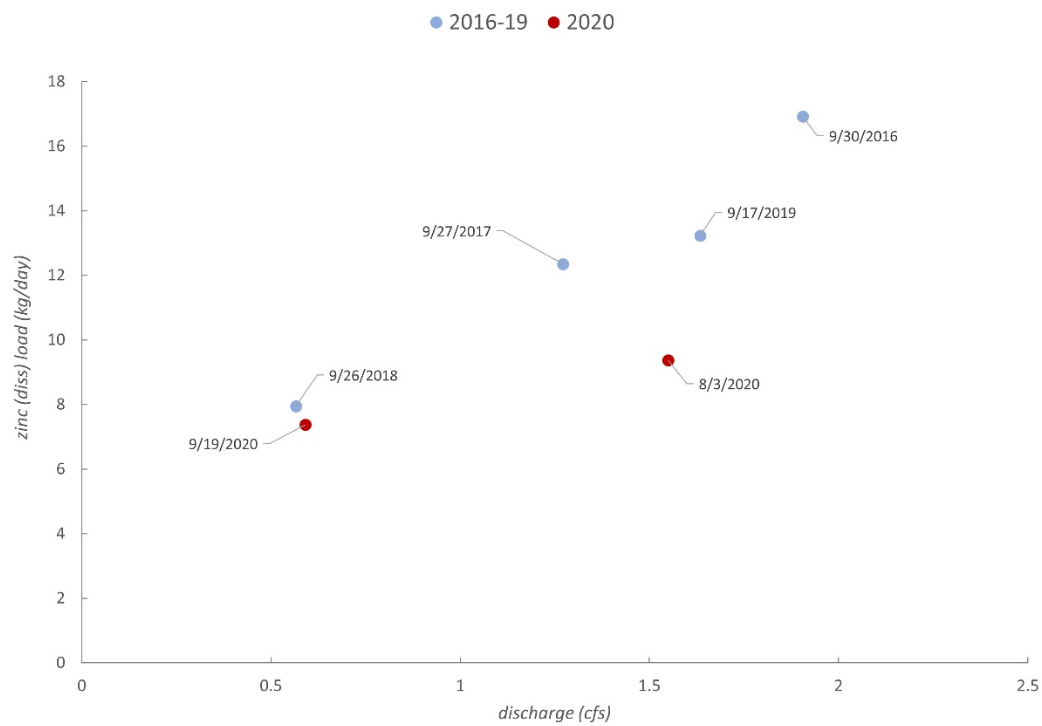


Figure 10: CCSG-6 zinc loads during 2020 bulkhead test compared to 2016-19 zinc loads recorded during similar flows.

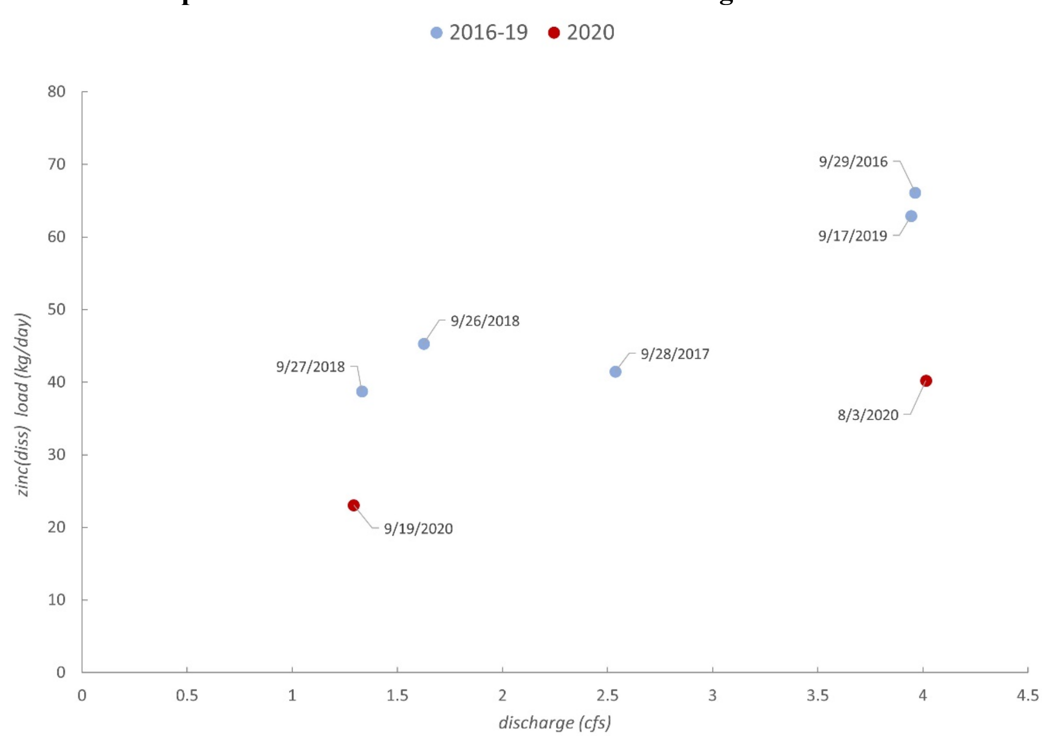


Figure 11: CCSG-3 zinc loads during 2020 bulkhead test compared to 2016-19 zinc loads recorded during similar flows.

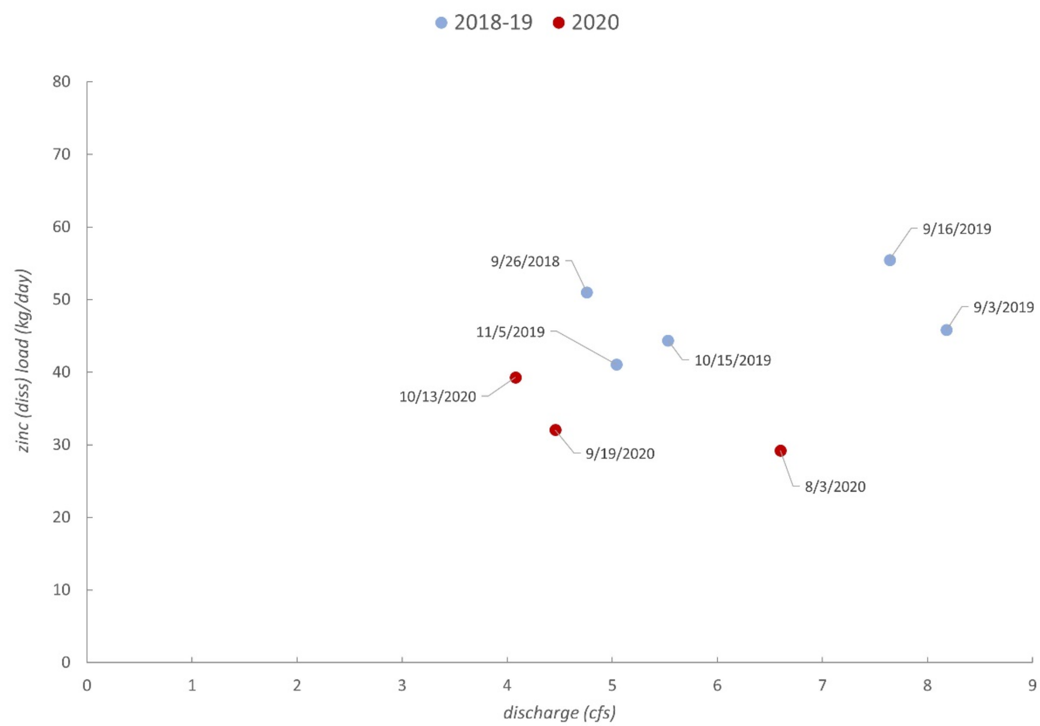


Figure 12: CCSG-1 zinc loads during 2020 bulkhead test compared to 2016-19 zinc loads recorded during similar flows.

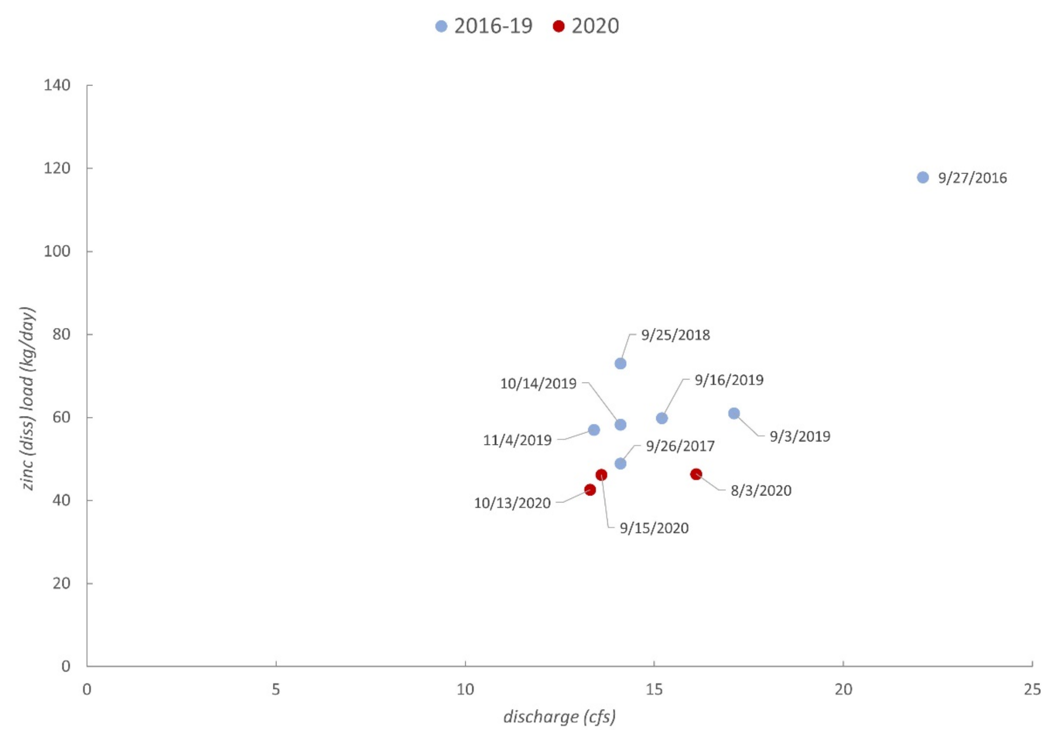


Figure 13: CC48 zinc loads during 2020 bulkhead test compared to 2016-19 zinc loads recorded during similar flows.

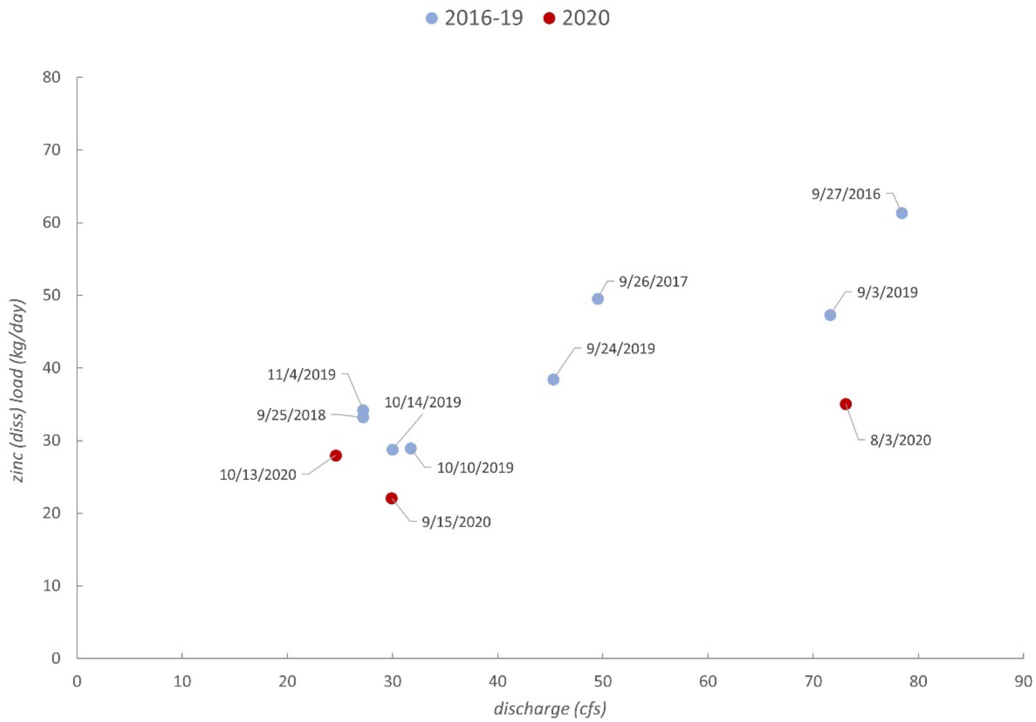


Figure 14: A68 zinc loads during 2020 bulkhead test compared to 2016-19 zinc loads recorded during similar flows.

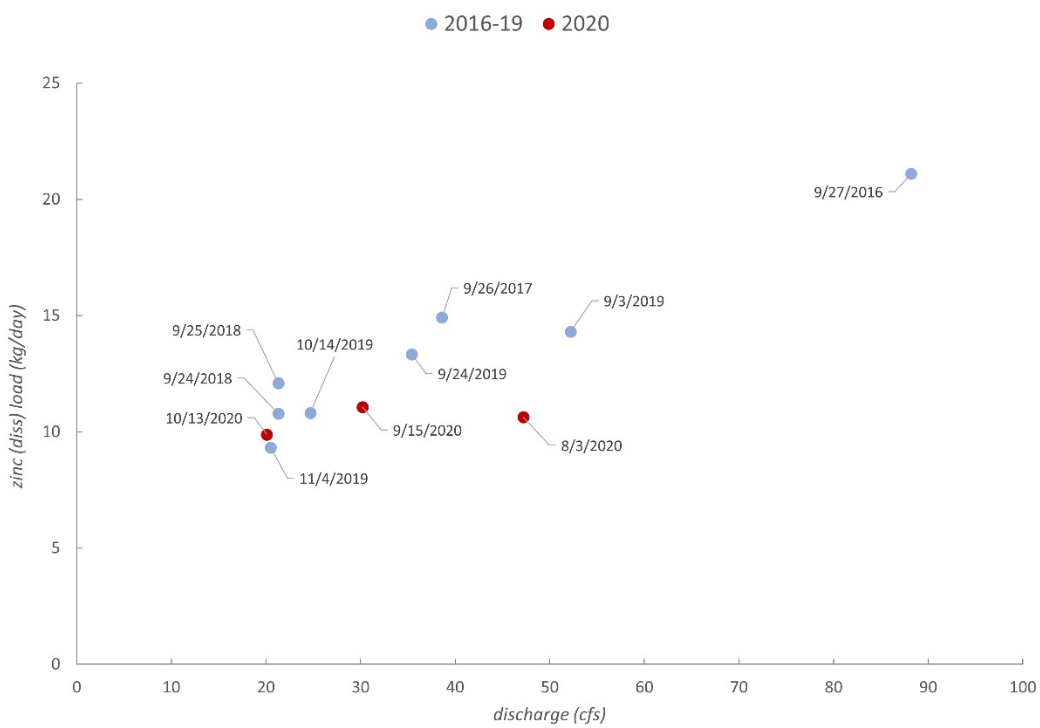


Figure 15: M34 zinc loads during 2020 bulkhead test compared to 2016-19 zinc loads recorded during similar flows.

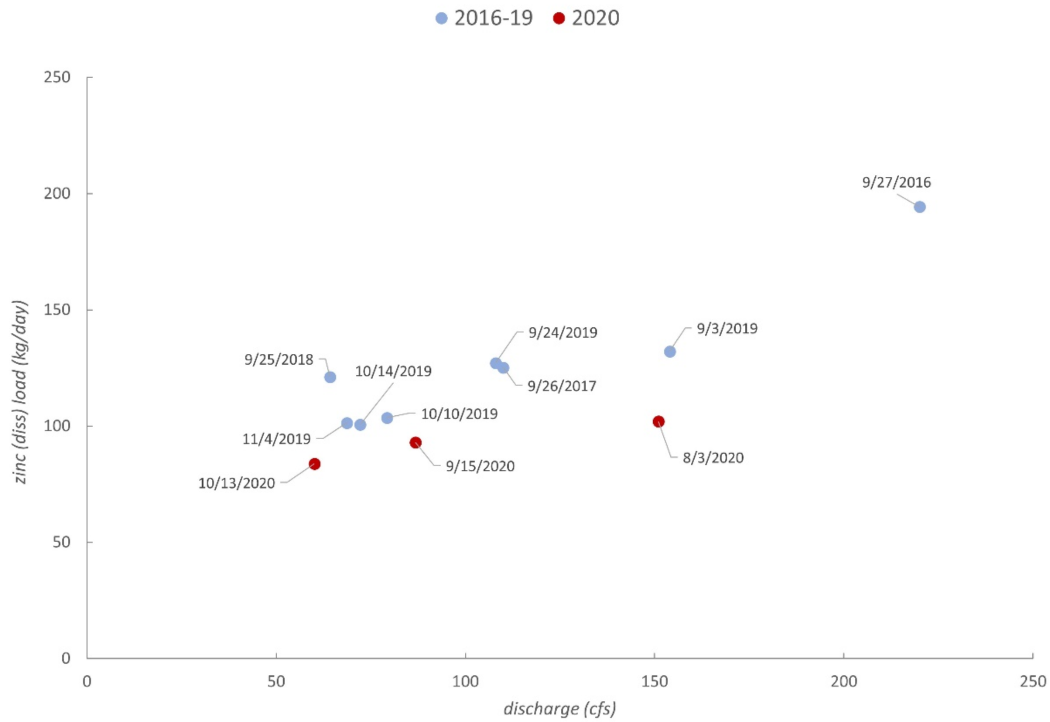


Figure 16: A72 zinc loads during 2020 bulkhead test compared to 2016-19 zinc loads recorded during similar flows.

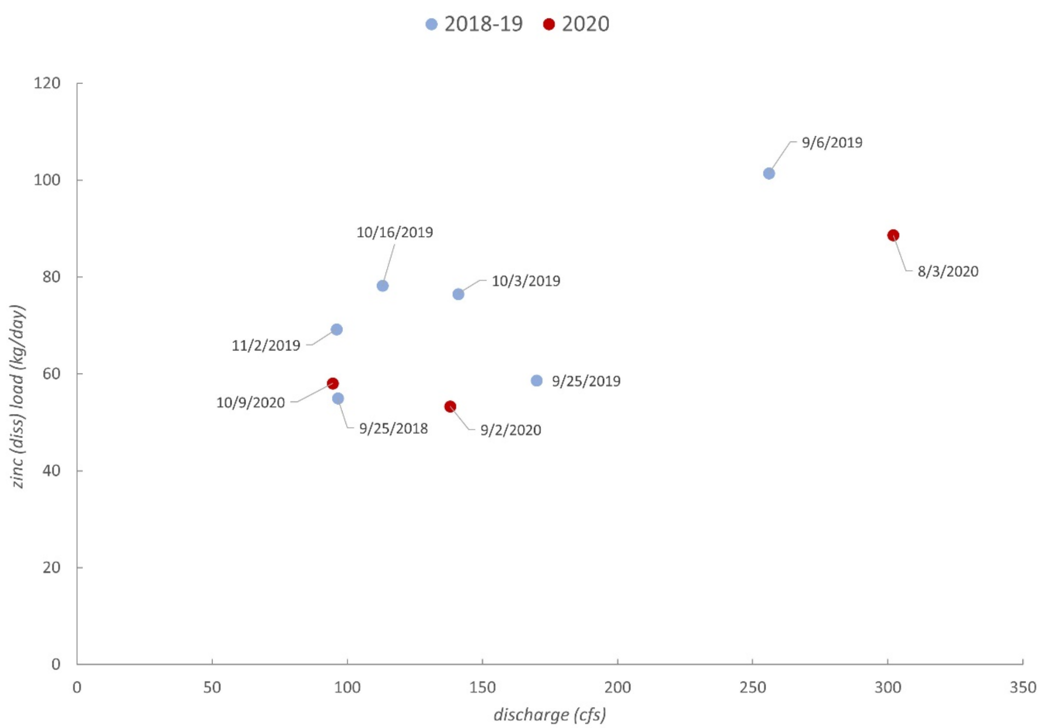


Figure 17: A75B zinc loads during 2020 bulkhead test compared to 2016-19 zinc loads recorded during similar flows.

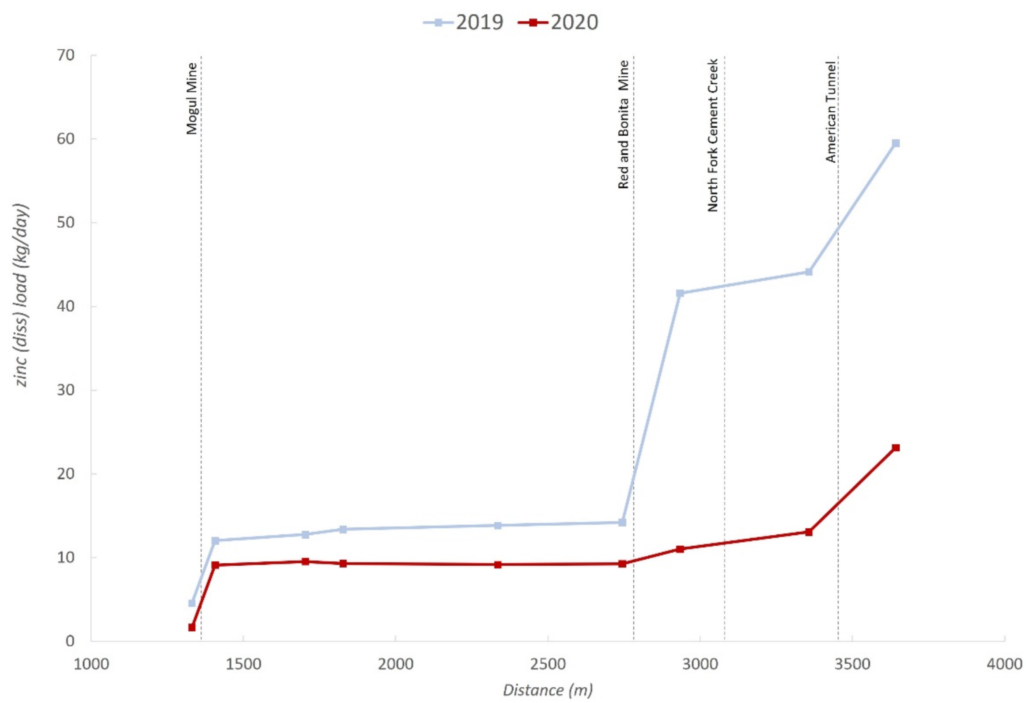


Figure 18: Cement Creek zinc load profile – low flow 2020 compared to 2019.

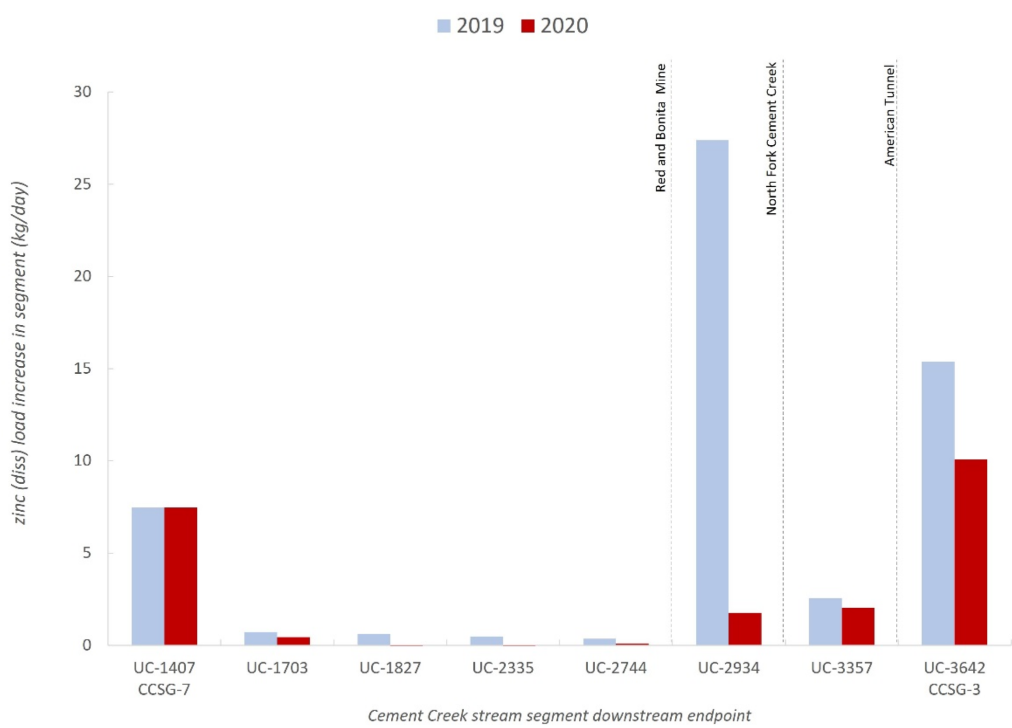


Figure 19: Cement Creek zinc load by segment during low flow 2019 and 2020.

zinc load increased in 2019 from UC-2744 (upstream of R&B) to UC-2934 (downstream of R&B) by 27.3 kg/day, but only increased by 1.8 kg/day in this same segment in 2020. Differences in zinc load between 2019 and 2020 in other Cement Creek segments were much more muted, suggesting that the large downstream increase in zinc load below the segment of Cement Creek that brackets Red and Bonita Mine is likely attributable to the test closure. USGS synoptic data from 2019 and 2020 allowed for an examination of zinc loads at a high spatial resolution along Cement Creek. Previous synoptic sampling events have occurred along Cement Creek in the past decade, but at a lower spatial resolution than the USGS dataset. We compared zinc loads during synoptic sampling events across hydrologic periods from 2010 to 2020 from three locations: CCSG-6, CCSG-3, and CC48 (Figures 20 and 21). All synoptic sampling events recorded a varied, but notably sharp increase in zinc load from CCSG-6 (upstream of R&B) to CCSG-3 (downstream of R&B) whereas the zinc load increase recorded in this segment during the test closure in September 2020 was much reduced; an increase of 15.7 kg/day compared to the 2010-2019 median of 56.1 kg/day. When examining the most recent synoptic sampling events, the zinc load increases from CCSG-6 to CCSG-3 in August 2020 (30.9 kg/day; beginning of test closure), November 2020 (51.2 kg/day) after the test closure was complete), and September 2019 (46.8 kg/day; 1 year prior to the test closure) were all substantially higher than the zinc load increase observed during the test closure in September 2020 (15.7 kg/day). Of note, is that the highest increase in zinc load from CCSG-6 to CCSG-3, 122.6 kg/day, was recorded in September 2015 following the Gold King Mine release and prior to the implementation of the Gladstone treatment plant.

In order to assess how 2020 low-flow water quality conditions compared to previous years across multiple analytes, we employed PCA. PCA reflects water quality results for samples where low-flow water quality data was collected during 2016-2020 and includes analytes that were consistently collected across samples and were not highly skewed (<3) after log transformation (Figures 22-23). Axis 1 accounted for 75% of the plotted variation in water quality among samples and has a strong negative correlation with numerous parameters including total manganese, dissolved manganese, total zinc, dissolved zinc, total magnesium, dissolved magnesium, total sulfate, conductivity, total fluoride, total nickel, and dissolved nickel (r^2 >0.6). Axis 2 accounted for an additional 12% of the plotted variation in water quality and is positively correlated with total and dissolved copper and negatively correlated with total alkalinity (r^2 >0.4) (Table 5). PCA resulted in a distinct separation in ordination space among most locations. Among draining mines, Gold King occurs on the upper right-hand side of the PCA plot, distinct from other locations, perhaps indicating a unique water quality signal that PCA loading vectors suggest could be related to elevated copper concentrations. R&B, American Tunnel, and ATPZ occur on the lower right-hand side of the PCA plot. Mogul occurs in the center-right in close proximity to CCSG-3, SS067, CCSG-5, and SS301, indicating a similarity in water quality among those sites. Cement Creek surface water locations were distributed generally in the middle of the plot while stream gauge sites on the Animas and Mineral Creek occur on the left-hand side of the plot. The variability in water quality in seeps and springs sites is evident as those sites are distributed throughout the PCA plot. In addition to illuminating differences in water quality among locations, PCA also depicts differences in water quality among years for the same location. This allows us to further assess whether low-flow water quality in 2020 differed from previous years. Another utility of PCA is to assess whether 2020 low-flow water quality conditions moved toward (i.e., became more similar to) or away from (i.e., became less similar to) typical R&B water quality. We calculated the two-dimensional distance in ordination space from 2020 low-flow samples to the R&B centroid (Tables 6-7). The vast majority of sites had samples in the 2016-19 period that were closer in ordination space to the R&B centroid than 2020 samples were. Of locations with at least two pre-2020 samples, only SS086 was closer in two-dimensional ordination space to the

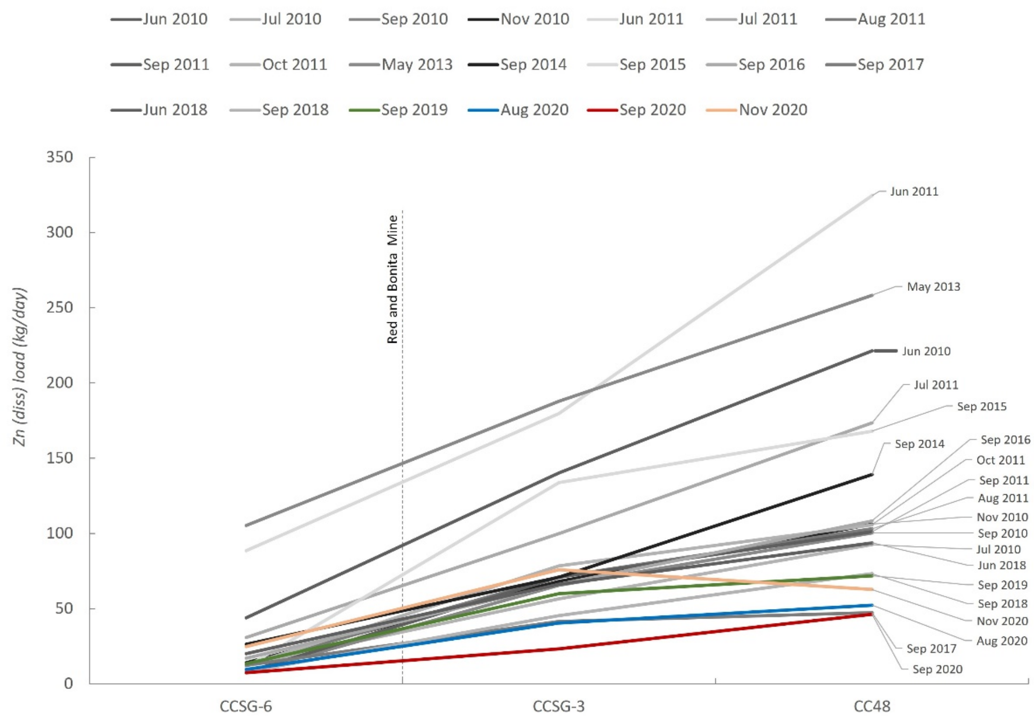


Figure 20: Cement Creek zinc load profile across synoptic sampling events from 2010 to 2020.

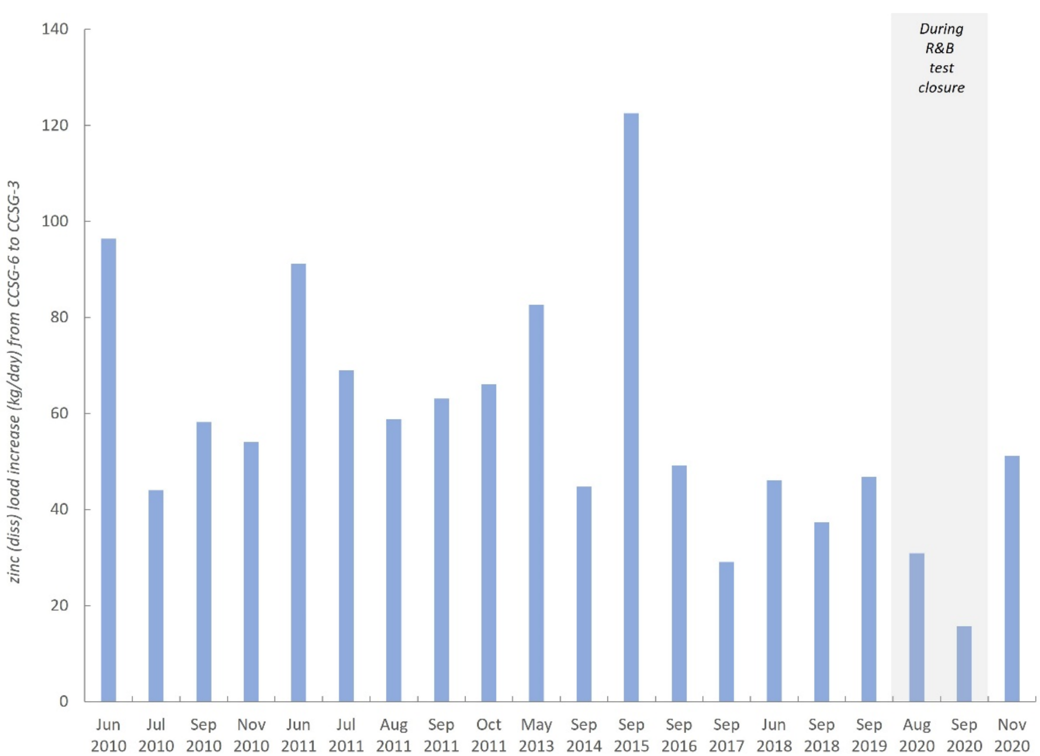


Figure 21: Cement Creek zinc load increase from CCSG-6 (upstream of R&B) to CCSG-3 (downstream of R&B) across synoptic sampling events from 2919 to 2020.

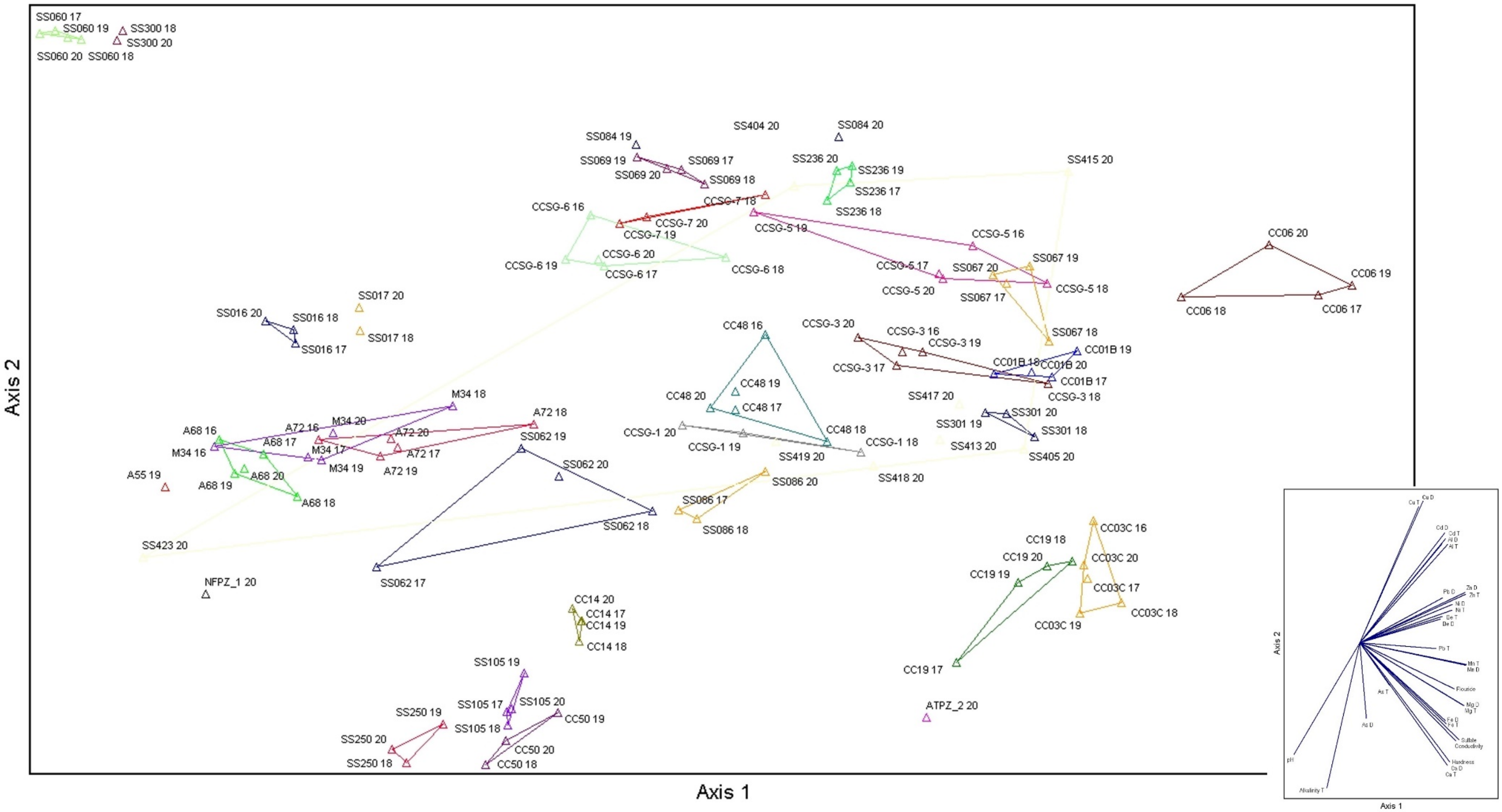


Figure 22: Principal Component Analysis (PCA) plot reflecting analytical results of samples collected during low flow 2016-2020.

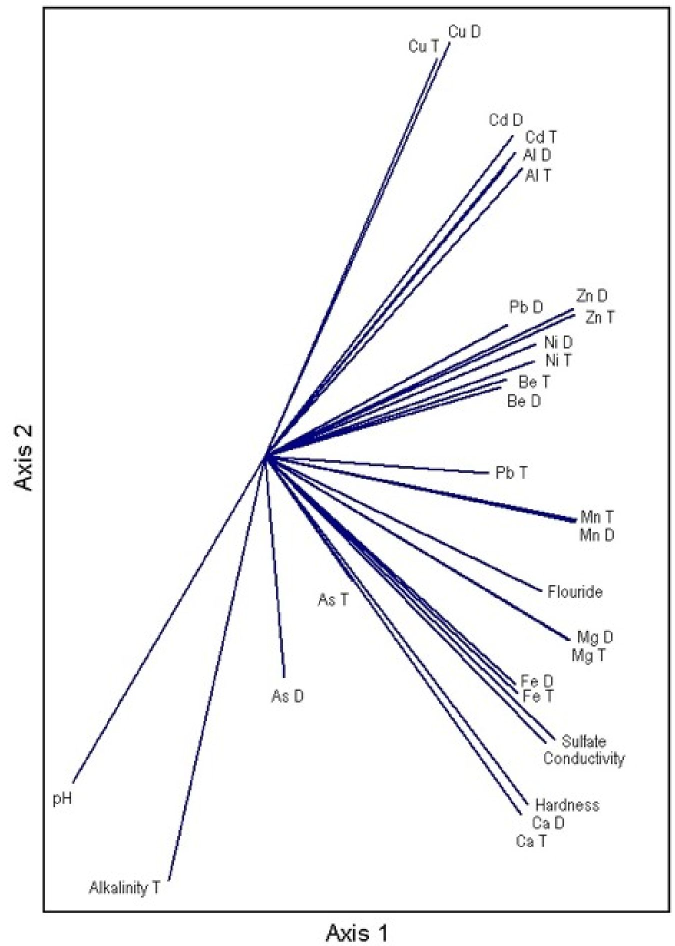


Figure 23: Principal Component Analysis (PCA) loading vectors indicating the strength and direction of how strongly each water quality parameter influenced the plotted variability among samples depicted in PCA plots.

R&B centroid in 2020 compared to previous years. Interestingly, SS086 had greater concentrations of Al, Mn, Pb, Zn, and SO_4^{2-} in both high-flow and low-flow conditions of 2020 compared to previous years, indicating that water quality conditions in 2020 were already different from previous years even before the bulkhead test closure began. SS084 also moved closer to the R&B centroid in 2020, reflecting an increase in the concentration of several metals in both high-flow and low-flow conditions, but interpretation is limited by only having one pre-2020 sample with complete analytical records for comparison. As evidenced by PCA plots and distances from the R&B centroid, metal concentrations at many sites, including all surface water sites, were highest in the 2018 drought year; 2018 samples trend toward the right-hand side of the PCA plot, the same direction that vectors indicate increasing concentrations of several metals. For several surface water sites, the distance from 2020 samples to the R&B centroid was greater than the average distance of 2016-19 samples to the R&B centroid. This pattern is most evident at CCSG-1, CCSG-3, and CC48, indicating that during the test closure, low-flow water quality at these sites was less similar to R&B water quality than previous years.

3.4 Evaluating a response of potential new surface water expressions

3.4.1 Dry Mines

We conducted weekly site inspections during the closure period at seven mine sites in the R&B vicinity that are categorized as "dry mines" where dry conditions have been documented over multiple years with no water discharging from their portals. Most of these dry mine locations are either collapsed or have safety closures which prevent access for underground assessment of hydrologic conditions. Instead, we surveyed the outside of the portal for evidence of discharging surface water. The one exception is Adams Mine, which is accessible. During a mine entry assessment of the Adams Mine in June, prior to the bulkhead test closure, a small stagnant pool of water was observed near the portal, but gradually dried up by September (D&A 2021). All other dry mine sites remained dry during the closure with no evidence of newly expressed water at their portals.

3.4.2 New surface water expressions

We documented twenty-five locations in the R&B vicinity where we observed water seepage or flow at the surface that was not observed immediately prior to the test closure (see Appendix C for representative photos). Most of these new expressions were located within R&B waste rock, the R&B fen, along roadcuts, or within previously mapped bogs, and areas of ferricrete and manganocrete (D&A 2021; Yager et al. 2007) (Maps 1-3). For context, the R&B portal is located at an elevation of 3,345 m (10,975'). Twenty-three of the twenty-five locations are located downgradient to the west and south of R&B between an elevation of 3,233m (10,608') and 3,314 m (10,876'). The majority of these locations were first documented between 8/18/20 and 8/24/20, about a month after the R&B bulkhead valve was closed and when bulkhead pressure was between approximately 140' and 155' of head. Two other locations, SS424 and SS421, are perched near the drainage between SS127 and Adit 268-20 to the north, and slightly higher than R&B at elevations of 3,353 m (11,000') and 3,401 m (11,159'). SS424 and SS421 were first documented on 9/22/20, which coincides within a day of when the R&B bulkhead pressure had been raised to its maximum of approximately ~184' of head. Interestingly, SS421 is located at the highest elevation of the new surface water expressions and is located 184' higher than the R&B portal. At the end of the closure in late September 2020, combined flows from all new emergences were 23 gpm, which is equivalent to roughly 10% of R&B flow rate of 228 gpm prior to the test closure. New emergences with the highest average flow rates were SS404 at 5.3 gpm, SS415 at 3.0 gpm, and SS419 at 2.8 gpm. Results from a USGS stream tracer study conducted along Cement Creek above Gladstone in September 2020 are pending and will provide greater detail on groundwater interactions along Cement Creek during the test closure.

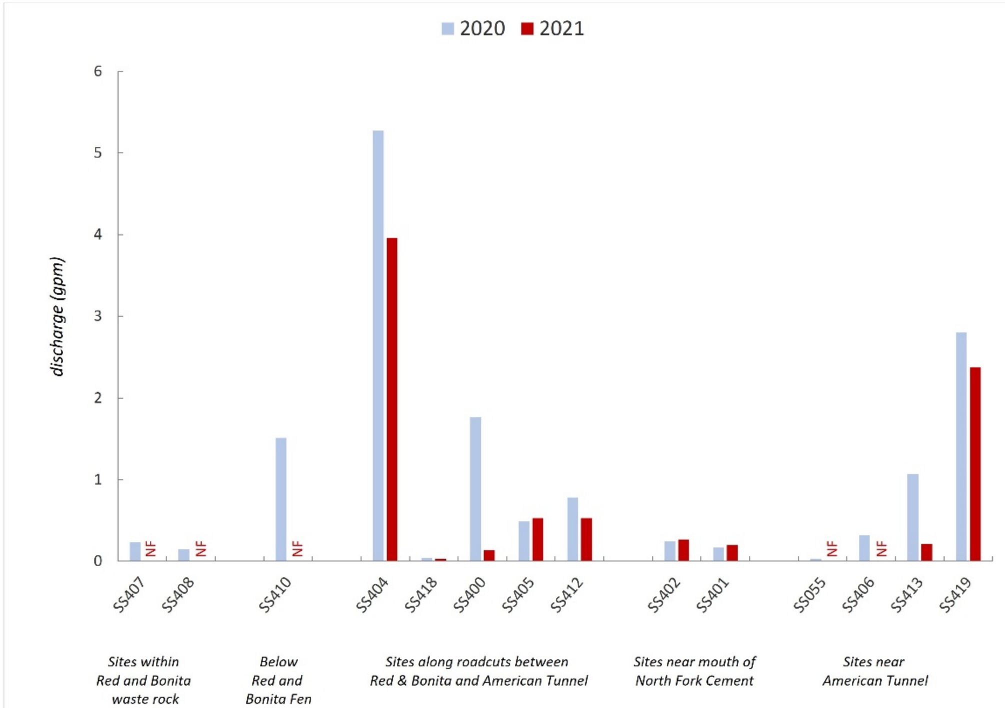
The existence of bogs, ferricrete, and manganocrete suggest historical expression of groundwater. It is possible that as water backed up behind the closed R&B bulkhead, some water was rerouted to pre-existing pathways and emerged to the surface at these locations of older groundwater expressions (D&A 2021).

We collected water quality samples from eight of the new expressions of surface water. Of those sampled sites, PCA indicated that SS405, SS413, SS417, and SS418 generally had higher concentrations of metals and had water quality most similar to R&B. SS405 and SS413 are located along roadcuts between R&B and Gladstone. SS417 is located within the R&B fen and SS418 is located along the North Fork of Cement Creek. In PCA plots, SS415 occurs in the upper right quadrat, indicating that water quality at this location has higher concentrations of aluminum, copper, and cadmium, and is more similar to the water quality of drainage from Gold King than the R&B, despite being located in the R&B outflow channel. In addition to PCA, we employed K-means cluster analysis to further explore water quality similarities and differences between seeps and springs, new surface water expressions, and R&B drainage (Appendix D). K-means cluster plots represent 2019-20 low-flow water quality samples from the R&B and new surface water expressions. Samples are grouped into clusters based on similarity of water quality. The first cluster plot reflects groups of sites based on 2019 low-flow water quality conditions. SS067 and SS301 were assigned to Cluster 2 due to their similarity in water quality to R&B. The second cluster plot reflects groups of sites based on 2020 low-flow water quality conditions. SS067 and SS301 remained in a cluster with R&B, indicating that their water quality did not change enough from 2019 to 2020 to warrant separation to a different cluster assignment. Of the sampled new surface water expressions, SS405, SS413, SS415, SS417, SS418 were grouped with R&B indicating similarity in water quality. While the purpose of cluster analysis is to identify patterns in the data and group observations into clusters based on the similarity of these patterns, there is not much interpretation of the variables that are driving the similarity and dissimilarity of the clusters. We plotted the standard deviations of each of the scaled analytes in order to understand what analytes were driving the clusters. The sites clustered with R&B generally had higher levels of sulfate and total and dissolved cobalt, manganese, magnesium, nickel, and zinc (Appendix D). There was broad agreement between PCA and K-means cluster analysis as to which locations of new surface water expression were most similar to R&B drainage.

It is possible that some of these new seeps and springs were not "new," but were omitted or obscured during previous surveys. For example, there were many new expressions of water documented within the R&B fen. Prior to the test, R&B drainage flowed across the fen and could have obscured any small surface expressions that became distinct once flow from the R&B was stopped. Additionally, the original BPMD seeps and springs surveys initiated in fall 2016 had a goal of covering a large spatial area (all of Bonita Peak from Cement Creek to the Upper Animas) and in some small geographic areas (e.g., one hillslope) the largest and most prominent seeps and springs were sampled to represent the area without exhausting resources. The fine-scale resolution of detailed "seep hunting" for the purpose of the R&B test may have documented a few sites that have been producing water since 2016 but were not individually quantified and demarcated in the original catchment scale surveys.

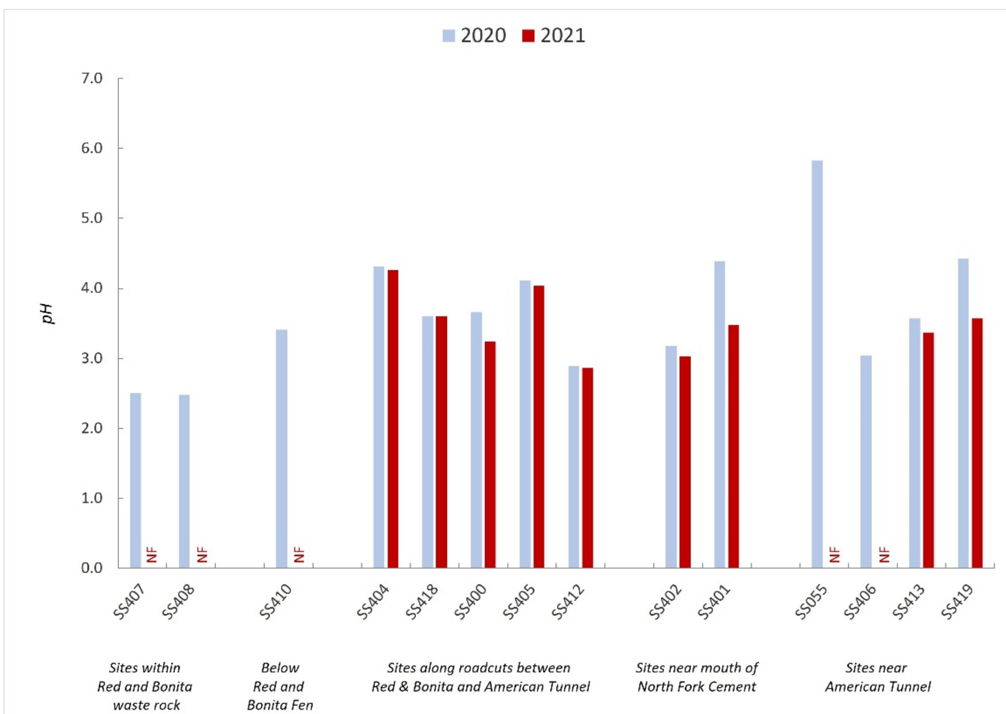
To investigate the persistence of these new expressions of surface water, we visited a subset of these locations in the fall of 2021 to coincide with the hydrologic low-flow period when these expressions were documented during the 2020 test closure. The persistence of surface water at these locations at a time when the R&B bulkhead was not closed could suggest that the expression documented in 2020 was unrelated to the bulkhead test closure and was simply missed during previous surveys. Conversely, surface water expressions that were flowing during the test closure, but were found to be dry in 2021 could suggest that these expressions were more likely related to the test closure.

The 2021 condition of new surface water expressions documented during the R&B test closure can be categorized as a) site was dry or standing water was present but not enough to measure flow; b) reduced flow from 2020 to 2021; or c) slight increase in flow from 2020 to 2021 (Figure 24; Map 5). Several surface water expressions documented as new during the test closure were located in the R&B fen and were found to be indiscernible from R&B drainage in 2021 (i.e., water draining the R&B flows across the fen and thus it is not possible to differentiate R&B drainage water from any water that may be associated with surface water expressions documented during the test closure when R&B drainage water was not flowing across the fen). There appears to be a spatial pattern in the 2021 condition of new surface water expressions compared to 2020 observations. Sites that were flowing in 2020 during the test closure that were located within the R&B waste rock and/or below the Red and Bonita Fen were found to be dry in 2021. Of the five new surface water expressions documented during the test closure along roadcuts



NF = no flow; site was dry or standing water was present with no flow

Figure 24: Discharge of new surface water expressions in 2020 and 2021.



NF = no flow; site was dry or standing water was present with no flow

Figure 25: pH of new surface water expressions in 2020 and 2021.

between R&B and AT, four of the sites had reductions in flow from 2020 to 2021 and one site had a slight increase in flow from 2020 to 2021. Both new surface water expression sites near the mouth of the North Fork of Cement Creek had slight increases (<0.005 gpm) in flow from 2020 to 2021. New surface water expressions near the American Tunnel were either dry in 2021 or had reduced flow from 2020 to 2021. Most new surface water expression sites did not have substantial changes in pH from 2020 to 2021 (Figure 25). Exceptions include SS401 which had a pH of 4.39 during low flow of 2020 and 3.48 during low flow of 2021, and SS419 which had a pH of 4.42 during low flow of 2020 and 3.57 during low flow of 2021. When evaluating these data, one could hypothesize that the greatest change in the condition of surface water expressions between the test closure period and the non-test closure period would occur at sites that were found to have water quality most similar to R&B drainage according to PCA and K-means cluster analysis (SS405, SS413, SS415, SS417, SS418). SS415 and SS417 are located within the R&B fen and were obscured in 2021 by R&B drainage. SS405 and SS418 are located along roadcuts between R&B and AT and changed very little from 2020 low flow to 2021 low flow. SS413 is located near the AT and did have reduced flow from 2020 to 2021. Our ability to draw assured conclusions as to whether new surface water expressions changed from 2020 to 2021 is limited by only one site visit in 2021 and the compounding influence of different meteorological and hydrological conditions between 2020 and 2021 (see Figure 1).

4. Discussion and Recommendations

We used multiple analytical approaches to assess whether there was a measurable hydrologic and/or water quality response to the temporary R&B bulkhead test closure. The test closure occurred from July to October, a time when there is enormous seasonal variability in the magnitude and timing of discharge and water quality as the snowmelt period ends, surface water levels recede, and as groundwater transitions to post-runoff fall low-flow conditions. The variability that occurs during this seasonal time frame can hinder efforts to differentiate anthropogenic influences from broader watershed-wide seasonal trends. For example, during the July to October period surface water discharge is typically decreasing while metal concentrations are increasing, and metal loads are decreasing. The total zinc load at A68 in 2019 effectively demonstrates the challenge of differentiating a signal from the R&B test closure from typical seasonal trends. Although 2019 was not the year of the R&B test closure and A68 is on the Animas River upstream of Cement Creek and thus not readily influenced by R&B, the trend in total zinc load follows a pattern that one could anticipate occurring downstream of the R&B closure. Total zinc load decreases from July to September, the same seasonal time frame that the test closure was enacted, and one could reasonably expect to see a downstream reduction in metal loading. Then, total zinc load increases from October to November, the same seasonal time frame that the test closure ended and R&B drainage was returned to Cement Creek and one could reasonably expect to see a downstream increase in metal loading. The occurrence of a natural seasonal pattern of metal loading that generally mimics the experimental design timeframe greatly limited our ability to readily quantify measurable hydrologic and water quality responses to the R&B test closure. The most ideal period of time to quantify local and downstream water quality changes associated with a source water change (e.g., closing a bulkhead) would be during the baseflow (winter) period of the annual hydrograph when discharges are in a steadier state and the relative % contribution of a mine discharge to surface discharge is at its greatest (see figure 14 in Cowie and Rock (2021) for more information).

Analytical data collected during the R&B bulkhead test closure demonstrate the following:

- The shape and direction of water quality trends during the test closure were generally similar to previous years (Appendix A).

- Hydrologic and climatic conditions preceding the test closure strongly influenced water quality trends observed during the test closure. For example, metal concentrations were elevated and metal loads were reduced in 2020 at many sites compared to 2019; a reflection of an average snowpack in the winter of 2019/20 and subsequent average stream flows compared to an above average snowpack in the winter of 2018/19 and subsequent above average stream flows (Figure 1; Table 4).

- Low-flow water quality conditions during the test closure were generally within the range of variability documented in previous years. Or, in instances where low-flow conditions were substantially different than previous years, they were preceded by high-flow conditions that demonstrated that the same departure from previous years existed even before the test closure began (Appendix B). Exceptions include:

    - SS062 and SS236 had higher low-flow concentrations of total iron and total lead that were not preceded by the same condition during the pre-test high-flow period.

- During the test closure, there was a reduction of total zinc load compared to median low-flow conditions from previous years at sites in close downstream proximity to R&B: CCSG-3 (26 kg/day reduction); CCSG-1 (19 kg/day); CC48 (21 kg/day); and A72 (17 kg/day). Zinc load reductions were smaller at other surface water sites including A68 (5 kg/day) and M34 (2 kg/day) that serve as controls as they are not influenced by R&B (Table 8-10 and Figure 9). For context, immediately prior to the bulkhead closure, drainage from R&B on 7/6/2020 discharged 21 kg/day of total zinc.

- Data from USGS synoptic sampling further demonstrate a reduction in zinc load at Cement Creek locations in closest downstream proximity to R&B during the test closure. In 2019, there was a substantial increase in the zinc load in the segment of Cement Creek that brackets Red and Bonita Mine, but there was not a corresponding increase in 2020 during the bulkhead test closure (Figures 18-19).

- PCA demonstrated that samples collected in the 2018 drought year generally had water quality characterized by higher metal concentrations and were more similar to R&B drainage than samples collected during the 2020 test closure. Surface water sites in closest downstream proximity to R&B (CCSG-1; CCSG-3; and CC48) were less similar to R&B drainage water quality during the 2020 test closure than in previous years (Figures 22-23).

- Dry mine sites in the vicinity of R&B remained dry during the closure with no evidence of newly expressed water at their portals.

- We documented twenty-five locations in the R&B vicinity where we observed water seepage or flow at the surface that was not observed immediately prior to the test closure in June of 2020. Most of these new expressions were located downgradient to the west and south of R&B within R&B waste rock, the R&B fen, along roadcuts, or within previously mapped bogs, and areas of ferricrete and manganocrete. PCA and K-means cluster analysis revealed that the new surface water expressions with water quality most similar to R&B drainage are SS405, SS413, SS417, and SS418. SS405 and SS413 are located along roadcuts between R&B and Gladstone. SS417 is located within the R&B fen and SS418 is located along the North Fork of Cement Creek. We revisited a subset of these surface water expressions in the fall of 2021 to assess their persistence one year later and at a time when the R&B bulkhead was not closed. Surface water expressions in closest downstream proximity to R&B (within the waste rock and below the R&B fen), were dry in 2021 suggesting that these locations may represent flow paths associated with the bulkhead test closure (Figure 24; Map 5).

- Stable water isotope data provided a first-order quality control check on water quality analytical results. The conservative nature of stable water isotopes can highlight significant changes or departures from previous conditions that could be erroneously interpreted or assumed from changes in non-conservative analytes such as metals. In this study there were no major red flags or departures from previous values in the stable isotope data across sites. Further water isotopic analysis such as tritium sampling would be the next step in using isotopes to infer changes in source waters and/or flow paths arriving at any particular source location.

As a result of this interpretive effort, we have several recommendations to guide potential evaluations of the R&B or other BPMD mine bulkhead closures in the future:

- Interpretive ability can be improved by the inclusion of several types of control or reference sites. For the 2020 R&B bulkhead test, the only control sites with complete analytical data available were CCSG-6, A68 and M34. The availability of water quality data from draining mines, seeps and springs, and surface water sites from other basins not influenced by a test closure during the same time period would allow for stronger inferences and a greater ability to differentiate a signal from a bulkhead test closure from watershed wide phenomena such as drought.

- There are several advantages to conducting a longer bulkhead test closure through the fall and winter low-flow period. These include a) more stable hydrologic conditions; b) late fall and winter is the time period when draining mines make up the highest proportion of surface water flow in BPMD (Cowie and Rock 2021); c) elevated metal toxicity can occur in late fall and winter when flows are low; d) allow mine pool level to reach equilibrium; and e) allow more time for new surface water expressions to potentially develop.

- High frequency monthly water quality sampling is vital for being able to compare water quality during similar hydrologic conditions across years. High-flow conditions do not occur on the same calendar dates each year and a July 1st sample in one year may not be comparable to a July 1st sample in another year. Currently, the 2018-19 water year is the only year where monthly water quality samples have been collected and analyzed from the major draining mines in the Cement Creek watershed. High frequency monthly water quality sampling across multiple years would strengthen our understanding of interannual variability and would enable potential improvements form remedial actions to be more easily disentangled from climate variability.

- Collection of water quality samples immediately before and after the initial bulkhead closure (i.e., immediately after the valve is closed) at closely bracketed sites could help minimize the influence of seasonal variability.

- It is advantageous to collect a consistent suite of water quality analytes across years so that all samples can be included in statistical analysis such as PCA and other multivariate approaches.

- Ensure the quality and completeness of field and analytical data is assessed routinely by field personnel who are most familiar with sampling locations and collection methodologies.

Recommendations specific to R&B closure:

- In fall 2021, revisit new surface water expressions that were documented during the 2020 test closure to determine if these expressions have persisted.
- Include as monitoring sites:
    - All seeps and springs identified by Cowie and Roberts (2020) as having a unique Bonita Peak groundwater isotopic signature.
    - Draining mines and seeps along the South Fork of the Animas that could be connected to Bonita Peak groundwater via faults and fractures extending from the Hinge Fault (Map 6).
    - SS062 and SS236 which had higher concentrations of total iron and lead during the R&B bulkhead test closure.
    - Control/reference sites: Prospect Gulch; Mineral Creek; Upper Animas.
    - Increase frequency of sampling at CCSG-6 and CCSG-3 before, during, and after bulkhead closure test to better quantify load reduction directly attributable to the closure.
- Closely monitor locations where the existence of bogs, ferricrete, and manganocrete suggest historical expression of groundwater.
- Conduct more in-depth evaluation of R&B fen stratigraphy and flowpaths of surface water expressions prior to closing R&B bulkhead. We found that surface water expressions SS417 and SS415 differed in water quality despite being both located in the R&B fen. It is possible that surface water expressions within R&B fen have differing flow paths related to R&B mine workings and/or are influenced by legacy tailings from the R&B mill near the fen (see DRMS 2015). Containing R&B discharge in a defined channel adjacent to the fen would greatly improve ability to monitor changes in water quantity and quality emerging in the fen/wetland complex below the R&B.

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6. Tables

Table 1. Monitoring site types

Type	# of sites	Locations
Draining Mines	7	Mogul, Mogul South, Red & Bonita, Gold King, American Tunnel, Natalie/Occidental, Blackhawk
Dry Mines	7	SS128 (Pride of Bonita); SS129; Adit xx; SS127 (Adams); Adit 268-20; Adit 268-21; SS130
Wells	5	ATPZ, NFPZ, RBPZ1, RBPZ2, RBPZ3
Seeps/Springs	13	SS016, SS017, SS060, SS062, SS067, SS069, SS084, SS086, SS130, SS236, SS250, SS300, SS301
Newly emergent Seeps/Springs	25	SS400 series
Surface Water	9	CCSG-1, CCSG-3, CCSG-5, CCSG-6, CCSG-7, CC48, A72, A68, M34

Table 2. Monitoring phases and sampling events

Sampling Event #	Test Closure Phase	Dates (2020)	Type of Site Sampled	Sample Objective
1 (RB1)	Phase I – *Prior to bulkhead closure*	7/6-7	Draining mines seeps & springs surface water wells	Characterize baseline conditions one week prior to initial filling of R&B
2 (RB5)	Phase III – *Filling to 200'*	8/3	Draining mines surface water	Characterize conditions as bulkhead pressure was raised from 100 to 150'
3 (RB 11 and 12)		9/14-22	Draining mines seeps & springs surface water wells	Characterize conditions during the final week that bulkhead pressure was close to 200'
4 (RB 15)	Phase V – *Post Drain Down*	11/3/20	Draining mines surface water	Characterize conditions after completion of drain down process

Table 3. Water quality sample collection type

Analyte	Sample Container	Sample Filtration & Acid Preservation
Total recoverable metals	250mL High Density Polyethylene (HDPE)	unfiltered, HNO_3
Dissolved metals	250mL High Density Polyethylene (HDPE)	filtered, HNO_3
Alkalinity/anions	250mL HDPE	unfiltered and unpreserved
Stable isotopes	40mL glass vial	unfiltered and unpreserved
Total rare earth elements	150mL HDPE	unfiltered, HNO_3
Dissolved rare earth elements	150mL HDPE	unfiltered, HNO_3

Table 4. Climatic and hydrologic conditions from 2015-2020

Water Year	Palmer Drought Severity Index – September, end of water year (CO Basin)	SWE % of April 1 Median (Animas River Basin)	SWE April 1 (Red Mountain Pass)	SWE % of April 1 Median (Red Mountain Pass)	Cement Creek Peak Stream Discharge at CC48 (cfs)	Cement Creek Average Annual Stream Discharge at CC48 (cfs)
2015-16	-0.68	77	20	88	311	37.9
2016-17	-1.84	120	26.6	117	260	41.4
2017-18	-8	47	14.1	62	103	21.1
2018-19	-1.14	171	33	145	408	54.6
2019-20	-4.95	104	23.6	104	196	26.9

Table 5. Principal Component Analysis (PCA) correlation coefficients

Analyte	Axis 1	Axis 2
Aluminum D	0.57	0.232
Aluminum T	0.497	0.233
Arsenic D	0.003	0.137
Arsenic T	0.065	0.043
Conductivity	0.678	0.23
pH	0.32	0.298
Water temp	0.042	0.004
Beryllium D	0.477	0.013
Beryllium T	0.502	0.017
Cadmium D	0.532	0.288
Cadmium T	0.542	0.258
Calcium D	0.565	0.36
Calcium T	0.566	0.36
Copper D	0.295	0.48
Copper T	0.256	0.443
Fluoride T	0.66	0.051
Hardness D	0.595	0.339
Iron D	0.541	0.146
Iron T	0.548	0.157
Lead D	0.506	0.048
Lead T	0.427	0.001
Magnesium D	0.797	0.095
Magnesium T	0.796	0.094
Manganese D	0.834	0.011
Manganese T	0.832	0.012
Nickel D	0.632	0.035
Nickel T	0.626	0.025
Sulfate	0.723	0.225
Total Alkalinity	0.081	0.502
Zinc D	0.82	0.061
Zinc T	0.825	0.057

Table 6. Distance in Principal Component Analysis (PCA) ordination space from each low flow observation for draining mines, seeps and springs, and new surface water expressions to the Red and Bonita centroid.

Site ID	Site Name	2016	2017	2018	2019	2020	Average distance of pre-test years ('16, '17, '18, '19) to R&B centroid
Draining Mines							
CC01B	Mogul		2.58	2.85	2.86	2.70	2.76
SS105	Mogul South		7.63	7.65	7.32	7.56	7.53
CC06	Gold King		4.56	3.72	4.93	4.76	4.40
CC19	American Tunnel		2.05	0.33	0.95	0.60	1.11
CC14	Natalie/Occidental		6.50	6.57	6.51	6.61	6.53
CC50	Blackhawk			8.06	7.00	7.73	7.53
Seeps and Springs							
SS016			10.54	10.61		10.98	10.57
SS017				9.79		9.91	9.79
SS060			15.02	14.53	14.87	14.69	14.80
SS062			9.09	5.65	7.43	6.89	7.39
SS067			3.87	3.03	4.02	4.03	3.64
SS069			7.33	7.00	7.85	7.48	7.39
SS084					7.97	6.44	7.97
SS086			5.32	5.08		4.36	5.20
SS236			5.87	5.83	6.03	6.08	5.91
SS250				9.02	8.45	9.16	8.73
SS300				14.12		14.11	14.12
SS301				1.92	2.48	2.33	2.20
New surface water expressions							
SS404						6.23	
SS405						1.84	
SS413						2.60	
SS415						5.14	
SS417						2.77	
SS418						3.12	
SS419						4.36	
SS423						12.04	

Note: highlight indicates year with shortest distance in ordination space to R&B centroid.

Table 7. Distance in Principal Component Analysis (PCA) ordination space from each low flow observation for surface water and well sites to the Red and Bonita centroid.

Site ID	Site Name	2016	2017	2018	2019	2020	Average distance of pre-test years ('16, '17, '18, '19) to R&B centroid
Surface Water							
CCSG-1	Cement Creek			3.34	4.79	5.55	4.07
CCSG-3	Cement Creek	3.73	3.65	2.51	3.58	4.25	3.36
CCSG-5	Cement Creek	4.46	4.30	3.76	6.31	4.23	4.71
CCSG-6	Cement Creek	7.85	7.34	6.17	7.80	7.44	7.29
CCSG-7	Cement Creek			6.37	7.49	7.26	6.93
CC48	Cement Creek	5.17	5.00	3.78	5.10	5.30	4.76
A72	Animas River	9.97	8.96	7.34	9.17	9.06	8.86
M34	Mineral Creek	11.26	10.07	8.40	9.89	9.81	9.90
A68	Animas River	11.21	10.63	10.14	10.96	10.84	10.74
Wells							
ATPZ_2						2.77	
NFPZ_1						11.25	

Note: highlight indicates year with shortest distance in ordination space to R&B centroid.

Table 8. Comparison of 2020 total zinc load during low-flow test conditions compared to high-flow conditions and previous years for draining mines.

Location	Season	N	Min (kg/day)	Max (kg/day)	Median (kg/day)	2020 (kg/day)	Change from pre-test median to 2020 (kg/day)	Percent change from pre-test median to 2020 (%)	Relationship of 2020 load to pre-test variability	Percent outside of pre-test variability (%)	Change from June 2020 to Sept 2020 (kg/day)	Percent change from June 2020 to Sept 2020 (%)
Draining Mines												
CC01B	HF	5	3.92	13.20	6.09	4.41	-1.68	-27.61	Within		0.02	0.37
	LF	8	4.72	13.27	7.10	4.43	-2.68	-37.68	Lower	6.23		
SS105	HF	2	0.43	0.68	0.56	0.16	-0.40	-71.84	Lower	63.72	-0.06	-36.38
	LF	3	0.06	0.14	0.10	0.10	0.00	0.69	Within			
CC03C	HF	5	17.27	28.11	21.96	20.63	-1.33	-6.04	Within		-20.61	-99.90
	LF	7	14.22	43.60	24.85	0.02	-24.83	-99.91	Lower	99.85		
CC06	HF	4	35.20	134.45	88.76	72.97	-15.80	-17.80	Within		-38.11	-52.23
	LF	7	34.96	90.25	64.66	34.86	-29.80	-46.09	Lower	0.30		
CC19	HF	6	8.14	18.44	11.06	10.13	-0.93	-8.44	Within		-1.92	-18.94
	LF	7	6.01	13.75	11.64	8.21	-3.43	-29.47	Within			
CC14	HF	4	3.95	8.90	6.62	2.13	-4.50	-67.89	Lower	46.22	-0.87	-41.05
	LF	7	1.04	2.22	1.56	1.25	-0.31	-19.80	Within			
CC50	HF	4	0.54	1.31	1.25	0.62	-0.63	-50.16	Within		0.18	29.30
	LF	5	0.45	1.28	1.16	0.81	-0.36	-30.66	Within			

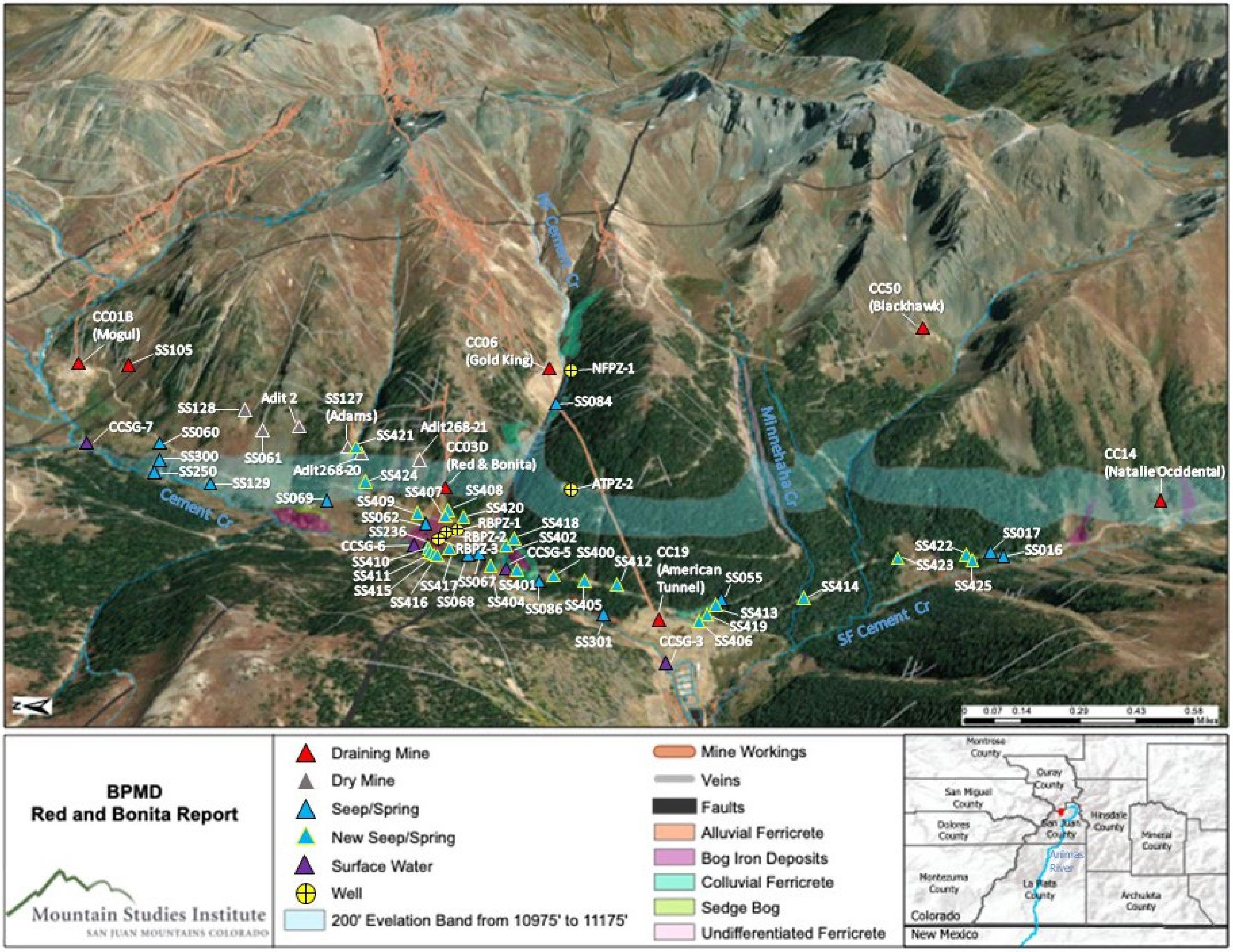
Table 9. Comparison of 2020 total zinc load during low-flow test conditions compared to high-flow conditions and previous years for seeps and springs.

Location	Season	N	Min (kg/day)	Max (kg/day)	Median (kg/day)	2020 (kg/day)	Change from pre-test median to 2020 (kg/day)	Percent change from pre-test median to 2020 (%)	Relationship of 2020 load to pre-test variability	Percent outside of pre-test variability (%)	Change from July 2020 to Sept 2020 (kg/day)	Percent change from July 2020 to Sept 2020 (%)
Seeps and Springs												
SS016	HF	2	0.0002	0.0002	0.0002						0.00	
	LF	3	0.0002	0.005	0.002	0.0004	-0.002	-80.77	Within			
SS017	HF	2	0.003	0.006	0.005						0.01	
	LF	2	0.001	0.001	0.001	0.006	0.005	597.20	Higher	542.90		
SS060	HF	3	0.006	0.050	0.011	0.009	-0.001	-12.44	Within		-0.01	-76.41
	LF	4	0.001	0.007	0.003	0.002	-0.001	-30.80	Within			
SS062	HF	3	0.0002	0.128	0.006	0.001	-0.006	-87.40	Within		0.00	194.15
	LF	4	0.0003	0.021	0.001	0.002	0.002	223.81	Within			
SS067	HF	3	0.008	0.041	0.016	0.011	-0.005	-33.23	Within		0.00	43.20
	LF	4	0.009	0.026	0.017	0.016	-0.002	-9.10	Within			
SS069	HF	3	0.009	0.138	0.036	0.010	-0.026	-71.08	Within		-0.01	-51.88
	LF	4	0.004	0.040	0.012	0.005	-0.007	-58.02	Within			
SS084	HF	2	0.009	0.350	0.180	0.088	-0.092	-51.26	Within		-0.08	-95.14
	LF	2	0.018	0.057	0.038	0.004	-0.034	-88.73	Lower	76.41		
SS086	HF	2	0.003	0.006	0.004	0.003	-0.001	-36.20	Within		0.00	11.35
	LF	3	0.001	0.004	0.001	0.003	0.002	119.78	Within			
SS236	HF	2	0.547	3.316	1.932	0.036	-1.896	-98.15	Lower	93.47	0.09	260.85
	LF	3	0.056	0.173	0.089	0.129	0.040	44.39	Within			
SS250	HF	3	0.004	0.067	0.006						0.01	
	LF	2	0.008	0.011	0.010	0.011	0.002	16.42	Within			
SS300	HF	1	0.011	0.011	0.011	0.009	-0.003	-25.20	Lower	25.20	-0.01	-73.26
	LF	1	0.001	0.001	0.001	0.002	0.001	95.95	Higher	95.95		
SS301	HF	1	0.226	0.226	0.226	0.107	-0.119	-52.59	Lower	52.59	-0.01	-5.18
	LF	2	0.222	0.242	0.232	0.102	-0.130	-56.18	Lower	54.23		

Table 10. Comparison of 2020 total zinc load during low-flow test conditions compared to high-flow conditions and previous years for surface water locations.

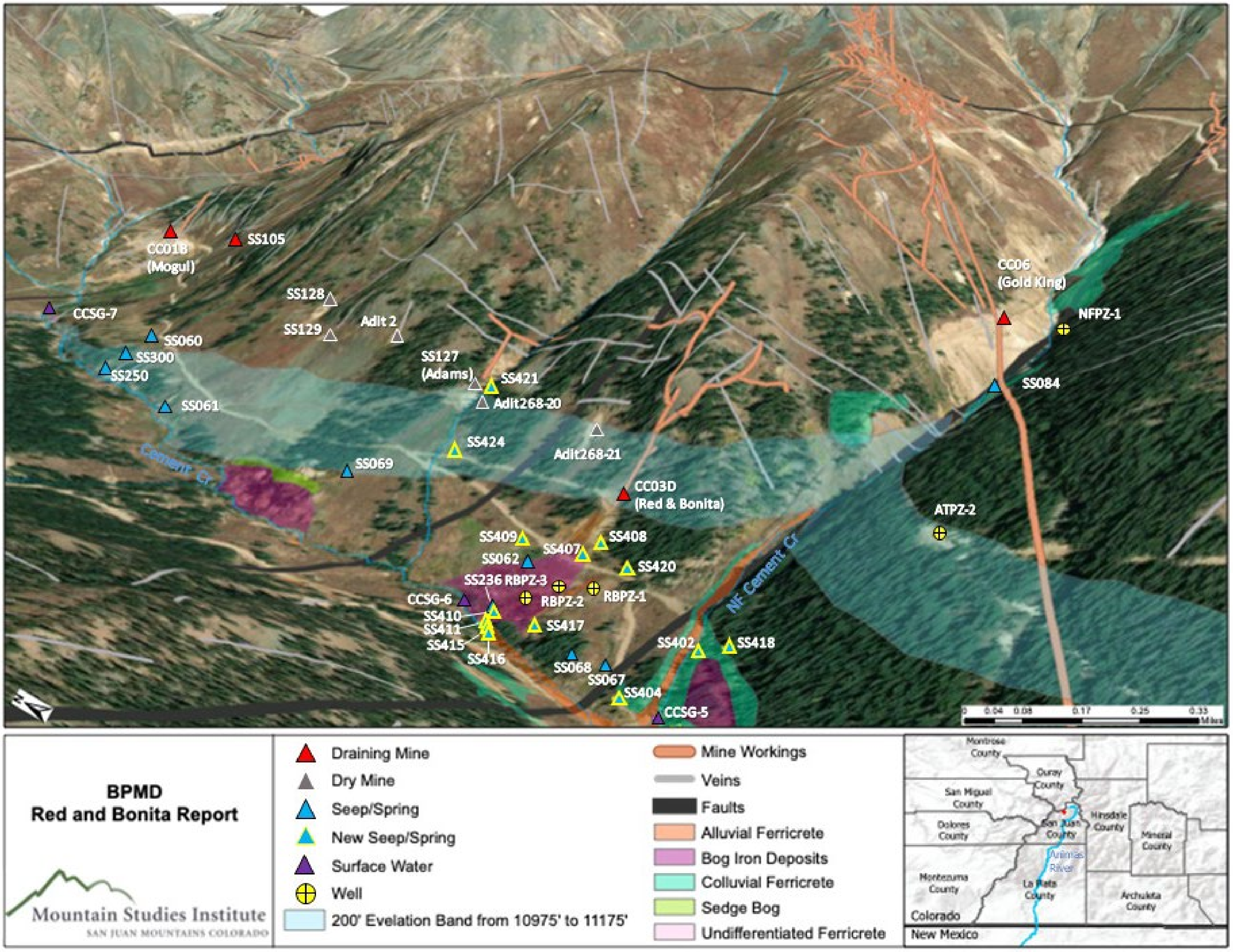
Location	Season	N	Min (kg/day)	Max (kg/day)	Median (kg/day)	2020 (kg/day)	Change from pre-test median to 2020 (kg/day)	Percent change from pre-test median to 2020 (%)	Relationship of 2020 load to pre-test variability	Percent outside of pre-test variability (%)	Change from June 2020 to Sept 2020 (kg/day)	Percent change from June 2020 to Sept 2020 (%)
Surface Water												
CCSG-1	HF	4	73.35	209.33	139.75	58.36	-81.39	-58.24	Lower	20.44	-27.71	-47.48
	LF	4	44.23	56.08	50.09	30.65	-19.44	-38.82	Lower	30.71		
CCSG-3	HF	2	66.71	71.16	68.94	50.06	-18.88	-27.38	Lower	24.96	-28.34	-56.62
	LF	5	40.38	126.46	47.71	21.72	-25.99	-54.48	Lower	46.22		
CCSG-5	HF	3	1.77	10.42	10.36	0.65	-9.72	-93.77	Lower	63.58	0.00	0.51
	LF	4	0.15	0.93	0.56	0.65	0.09	16.42	Within			
CCSG-6	HF	1	19.76	19.76	19.76	11.89	-7.87	-39.84	Lower	39.84	-4.89	-41.12
	LF	4	8.41	17.01	13.41	7.00	-6.41	-47.81	Lower	16.74		
CCSG-7	HF	1	16.16	16.16	16.16	14.87	-1.29	-7.99	Lower	7.99	-7.28	-48.97
	LF	2	7.11	12.80	9.96	7.59	-2.37	-23.79	Within			
CC48	HF	7	95.15	574.59	195.65	65.18	-130.47	-66.69	Lower	31.50	-19.59	-30.06
	LF	6	48.58	107.77	66.90	45.58	-21.32	-31.86	Lower	6.16		
A68	HF	6	141.37	710.63	473.22	51.35	-421.87	-89.15	Lower	63.68	-22.71	-44.22
	LF	7	10.07	61.64	33.61	28.64	-4.96	-14.77	Within			
M34	HF	7	14.49	164.77	60.06	16.20	-43.86	-73.03	Within		-4.90	-30.24
	LF	7	5.03	23.47	13.17	11.30	-1.87	-14.22	Within			
A72	HF	6	245.54	1503.17	797.51	151.73	-645.78	-80.97	Lower	38.21	-55.31	-36.46
	LF	7	103.69	206.69	124.98	96.41	-28.57	-22.86	Lower	7.02		

7. Maps



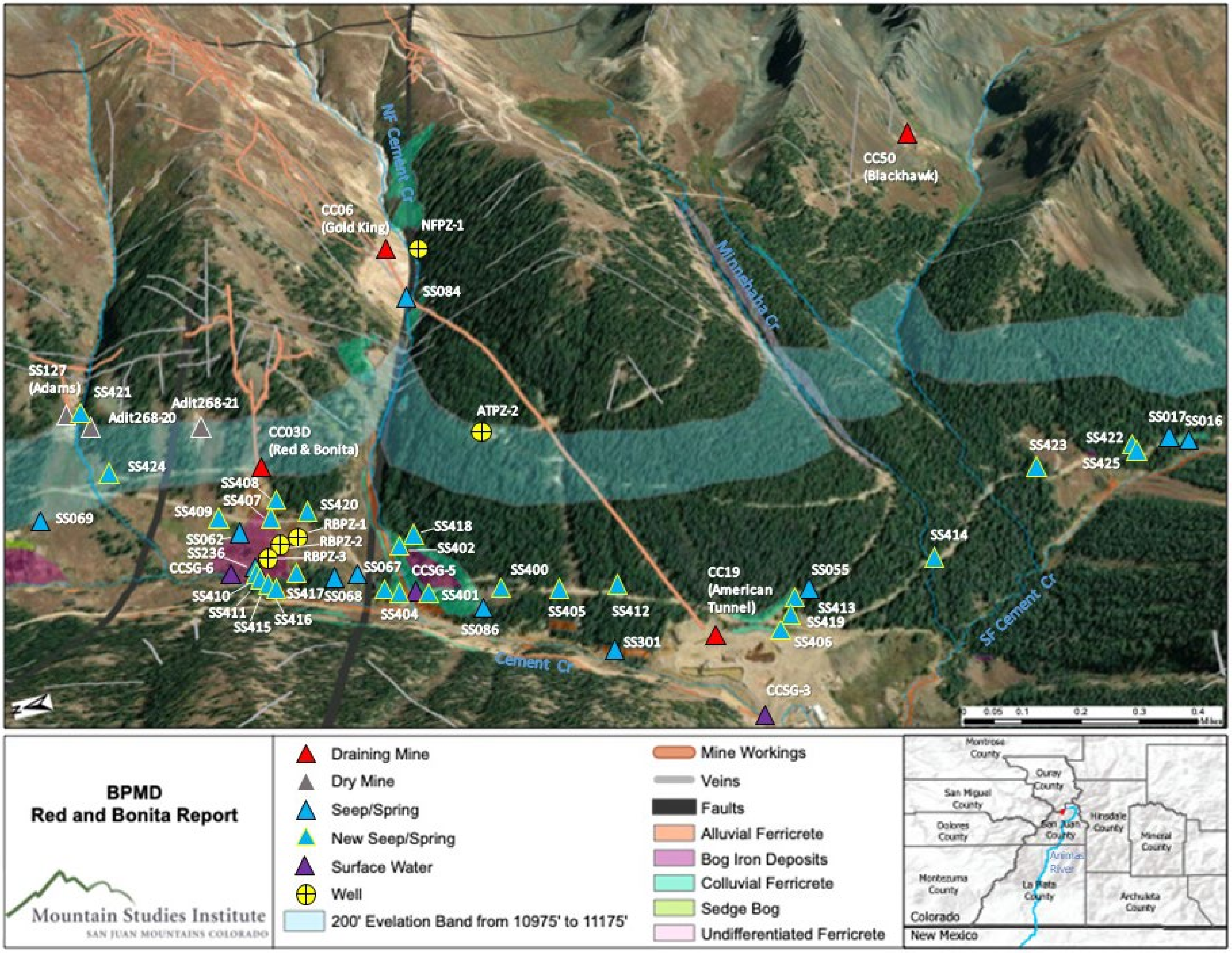
Map1: Red and Bonita vicinity

Source of ferricrete deposit spatial data: Yager et al. 2007



Map 2: Red and Bonita vicinity and north to Mogul

Elevation band extends 200' above R&B portal elevation; source of ferricrete deposit spatial data: Yager et al. 2007.



Map 3: Red and Bonita vicinity and south to Gladstone

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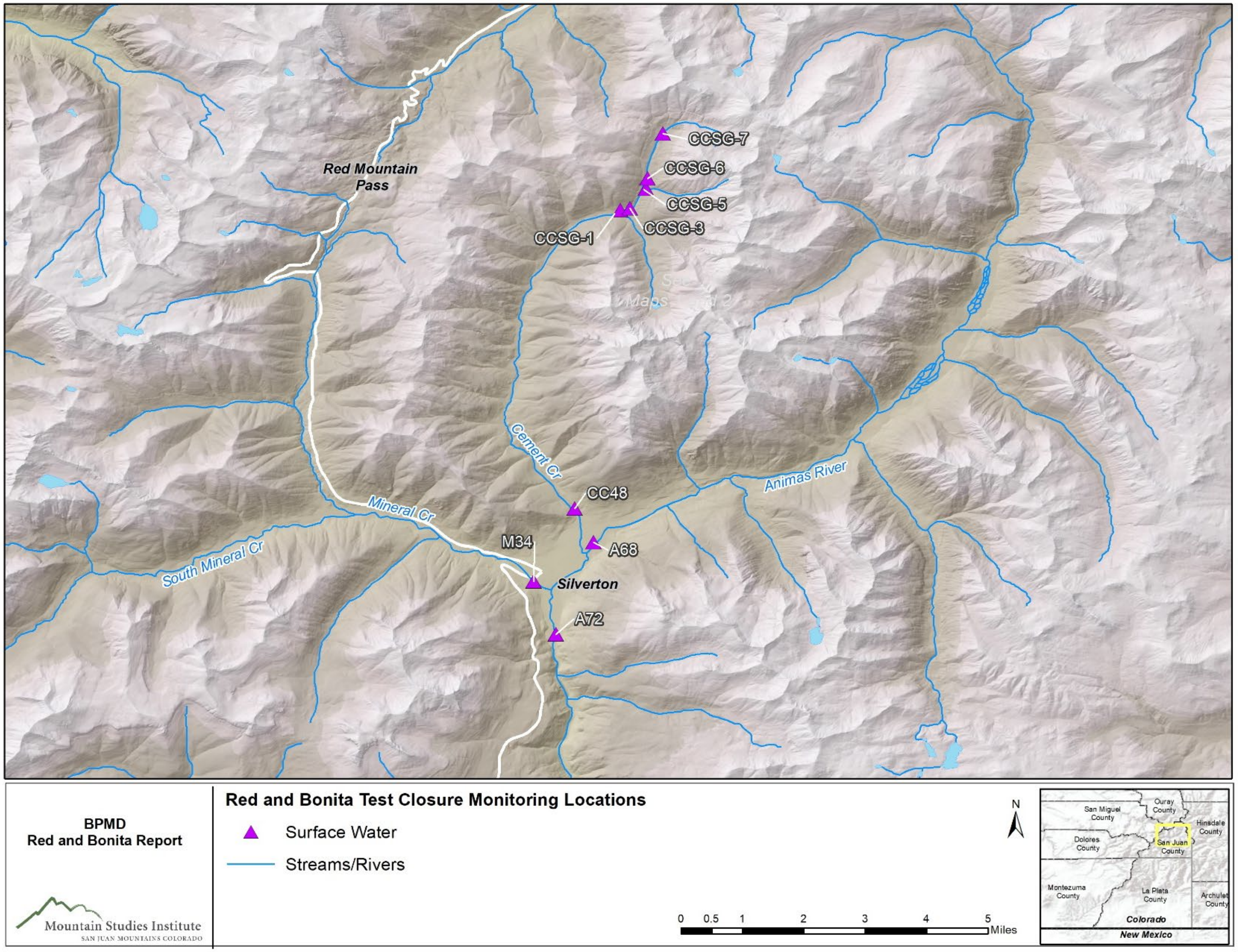
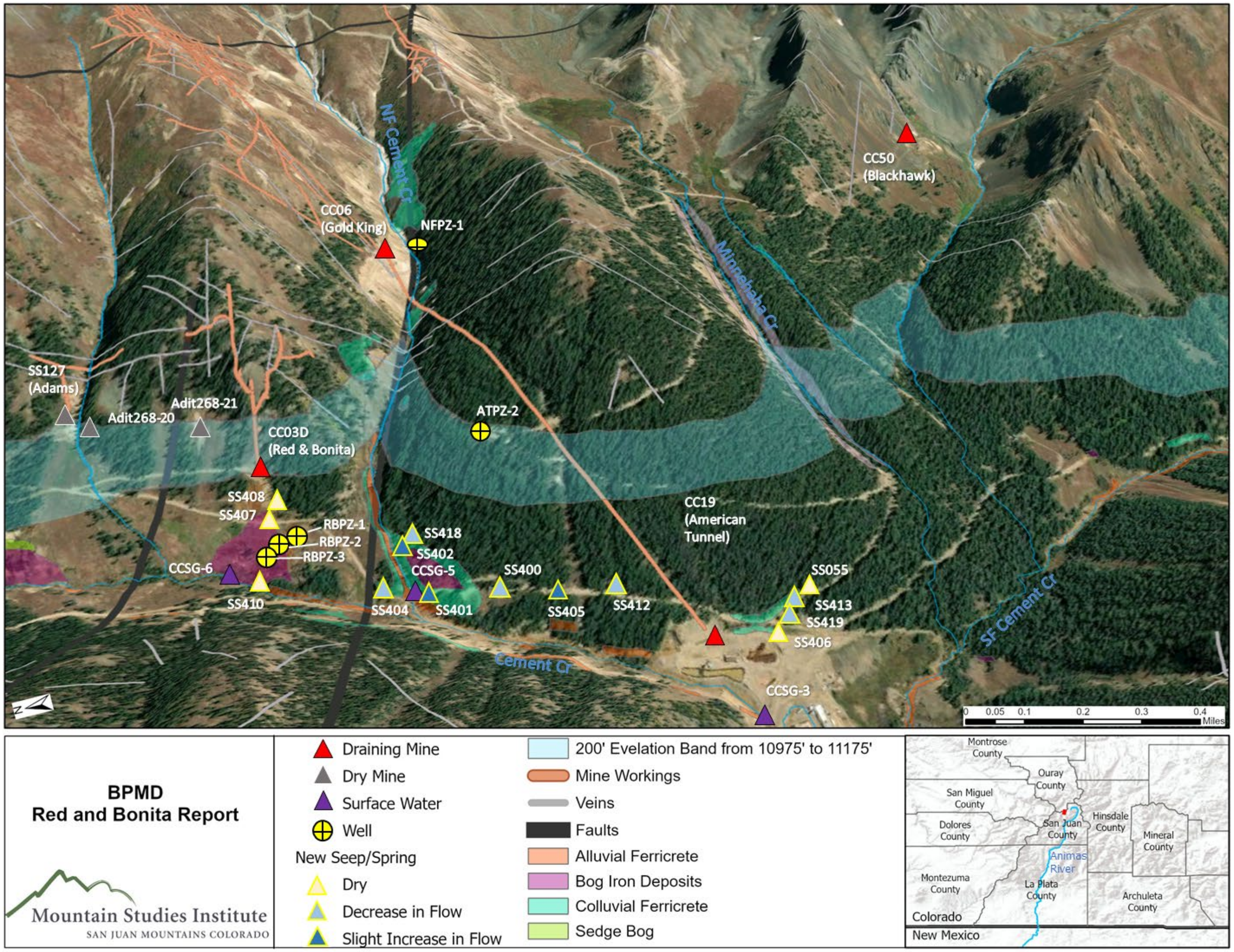
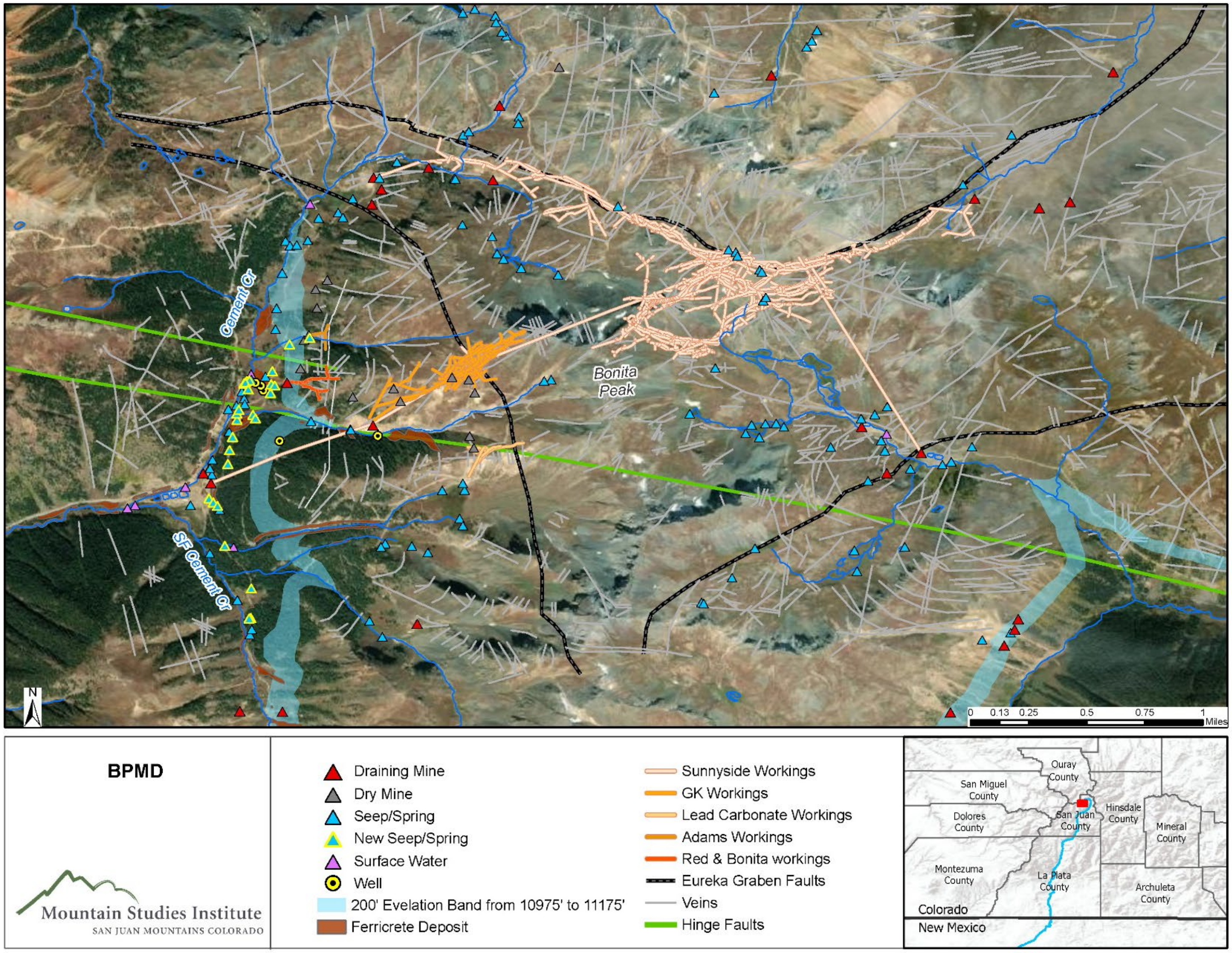


Map 4: Silverton vicinity



Map 5: Fall 2021 hydrologic condition of new surface water emergences compared to Fall 2020 during test closure

Elevation band extends 200' above R&B portal elevation; source of ferricrete deposit spatial data: Yager et al. 2007.

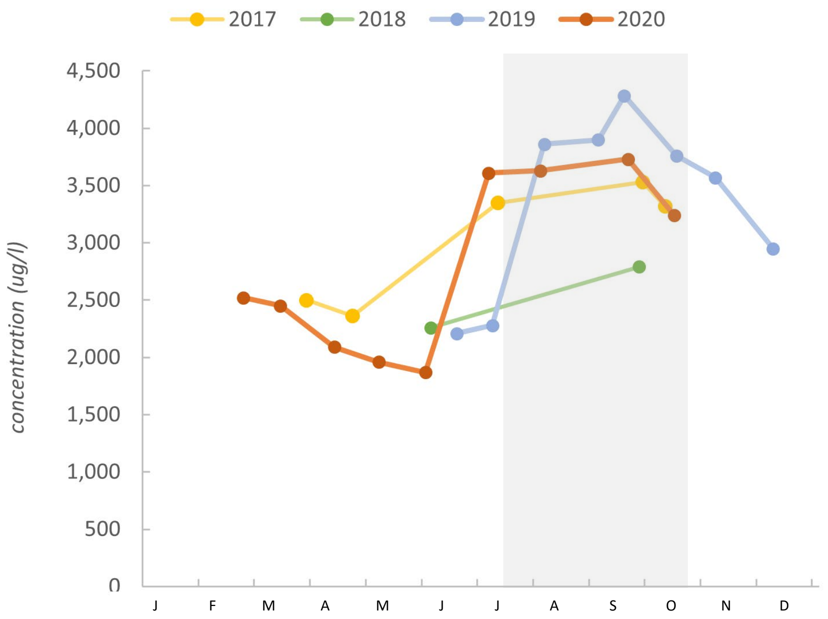


Map 6: Bonita Peak complex with monitoring locations, mine workings, faults, and veins.
Elevation band extends 200' above R&B portal elevation; source of ferricrete deposit spatial data: Yager et al. 2007.

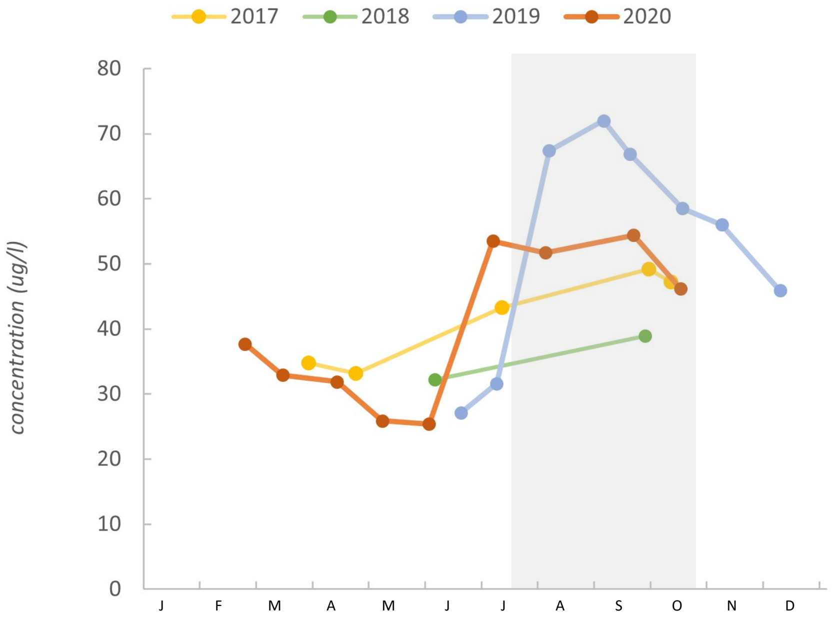
Appendices

A. Water quality trends from 2017-2020

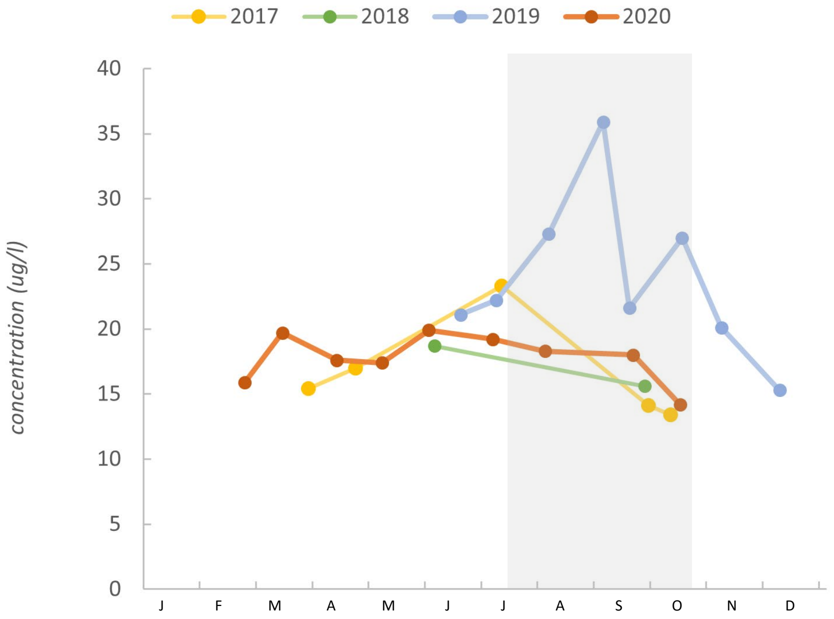
Mogul (CC01B)



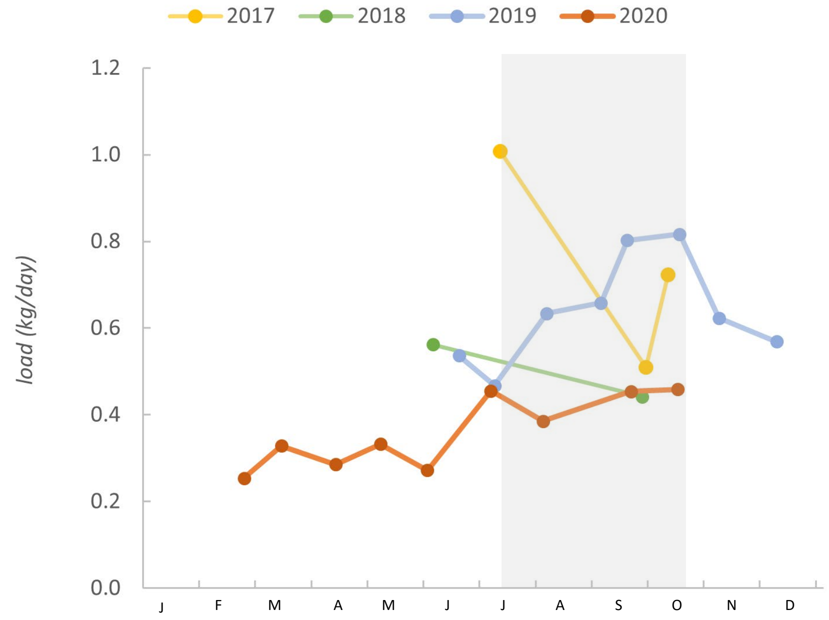
Al, total (concentration)



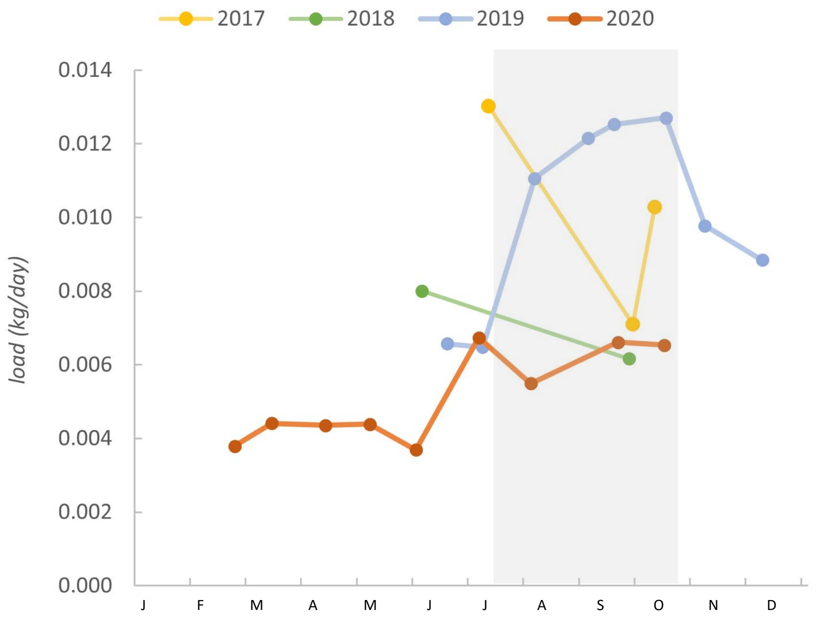
Cd, total (concentration)



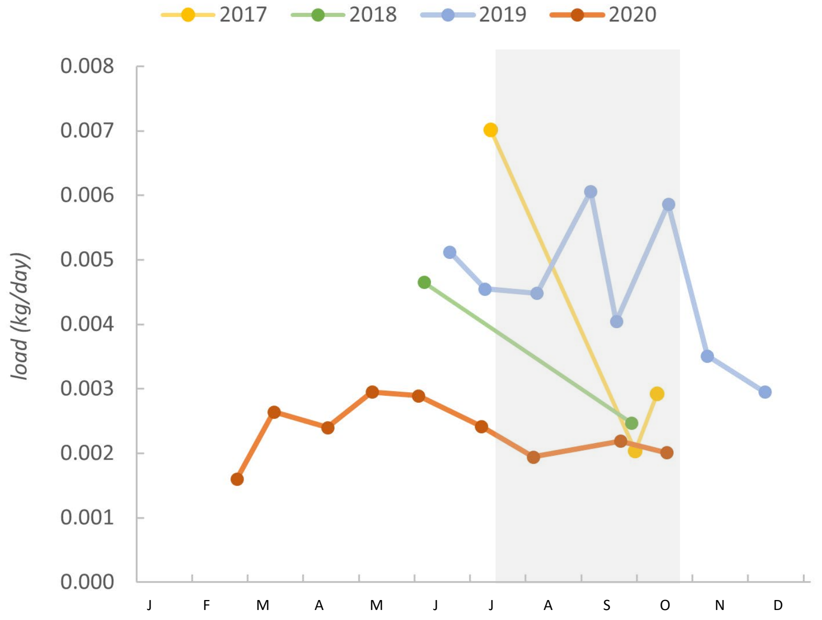
Cu, total (concentration)



Al, total (load)

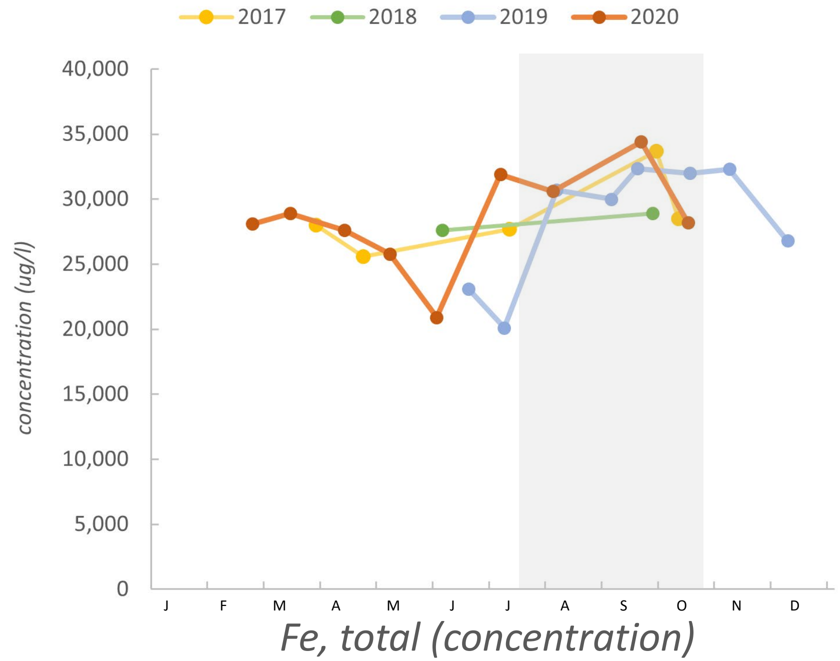


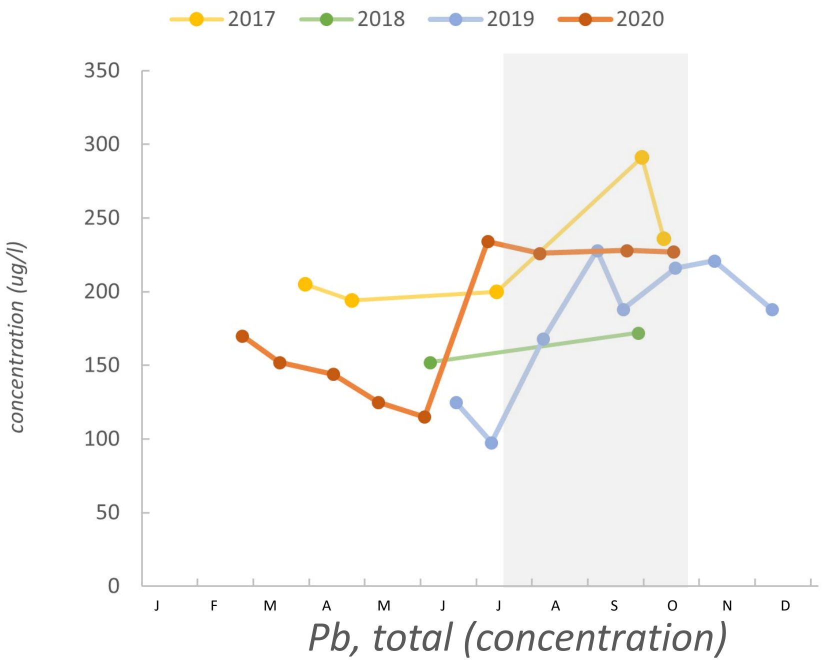
Cd, total (load)

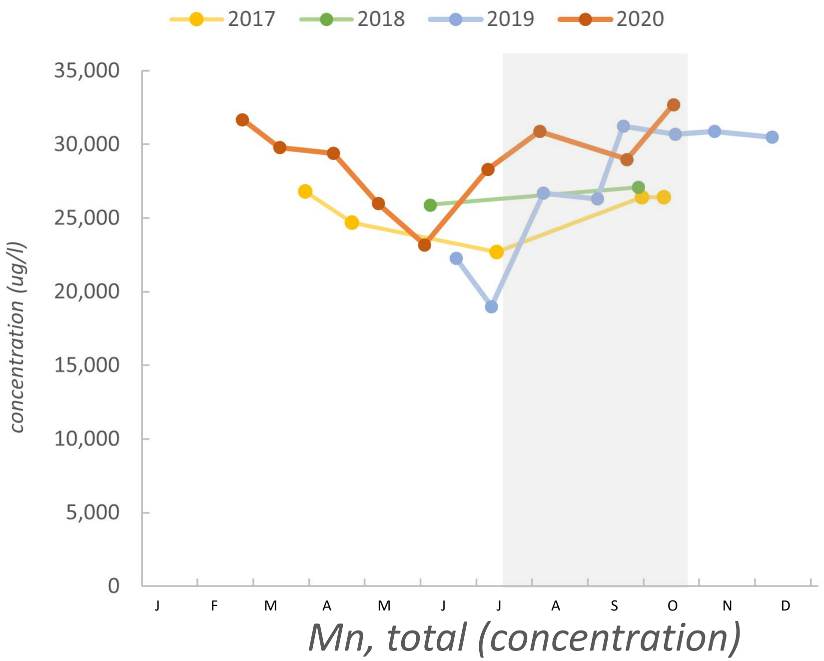


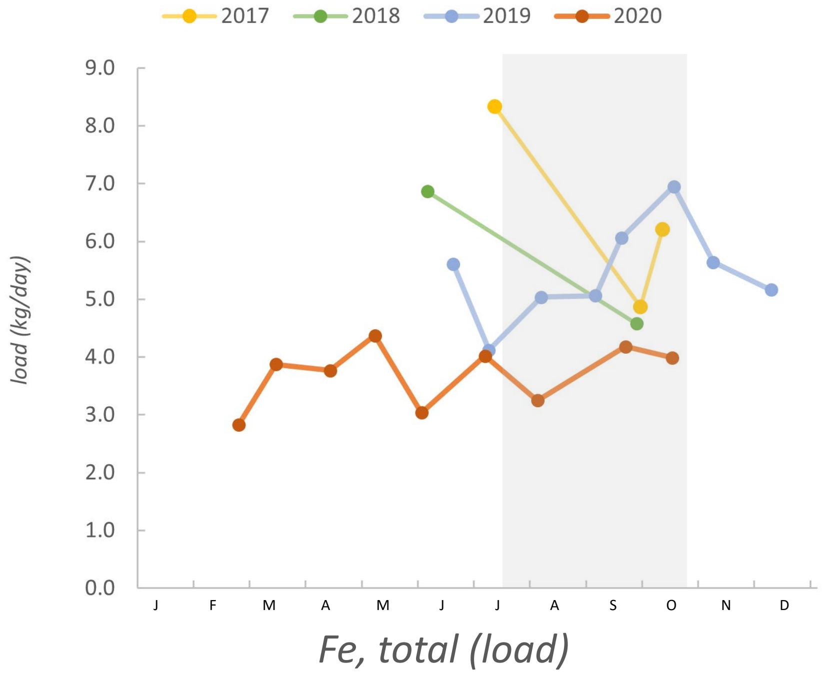
Cu, total (load)

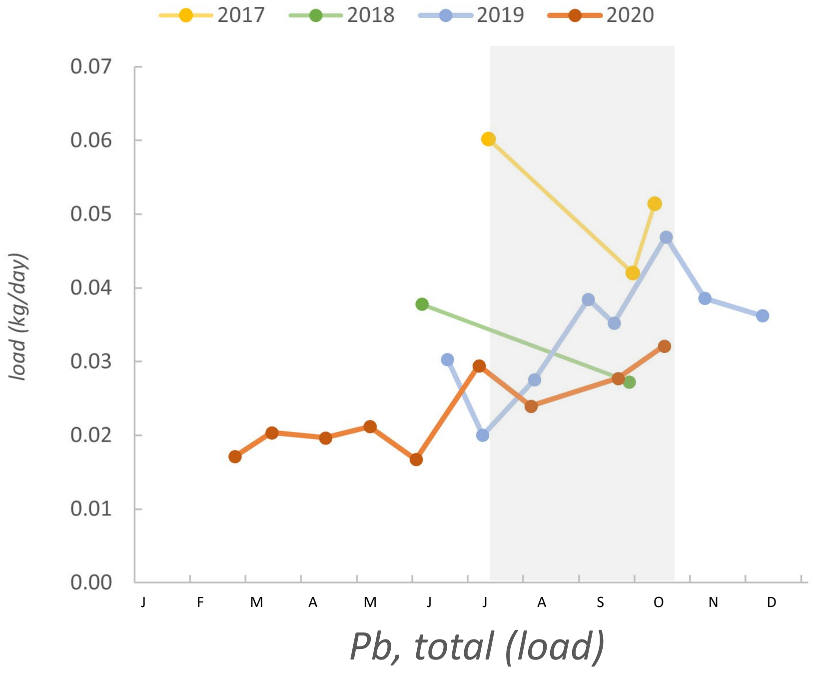
Mogul (CC01B)

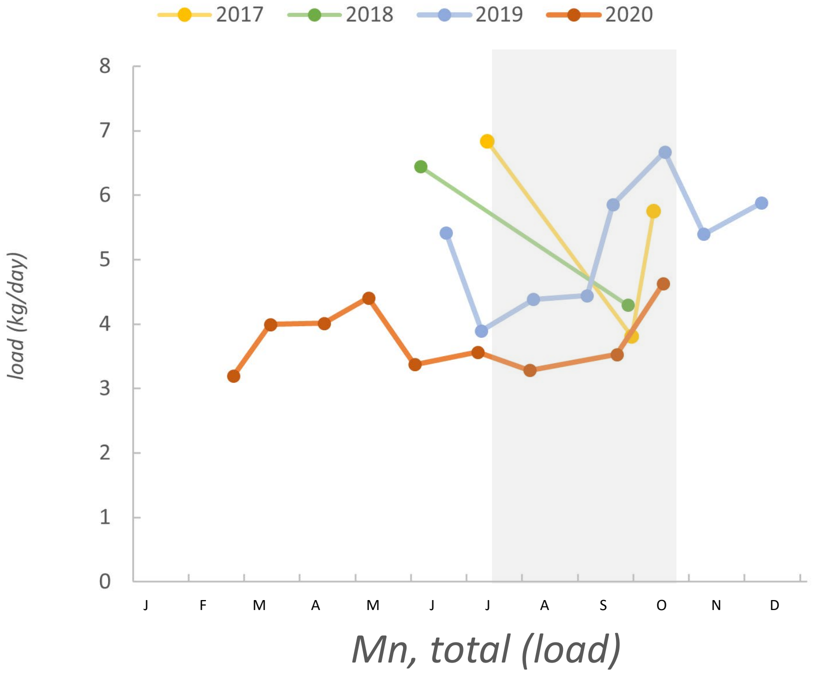

2017
2018
2019
2020
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
concentration (ug/l)
J F M A M J J A S O N D
Fe, total (concentration)


2017
2018
2019
2020
350
300
250
200
150
100
50
0
concentration (ug/l)
J F M A M J J A S O N D
Pb, total (concentration)

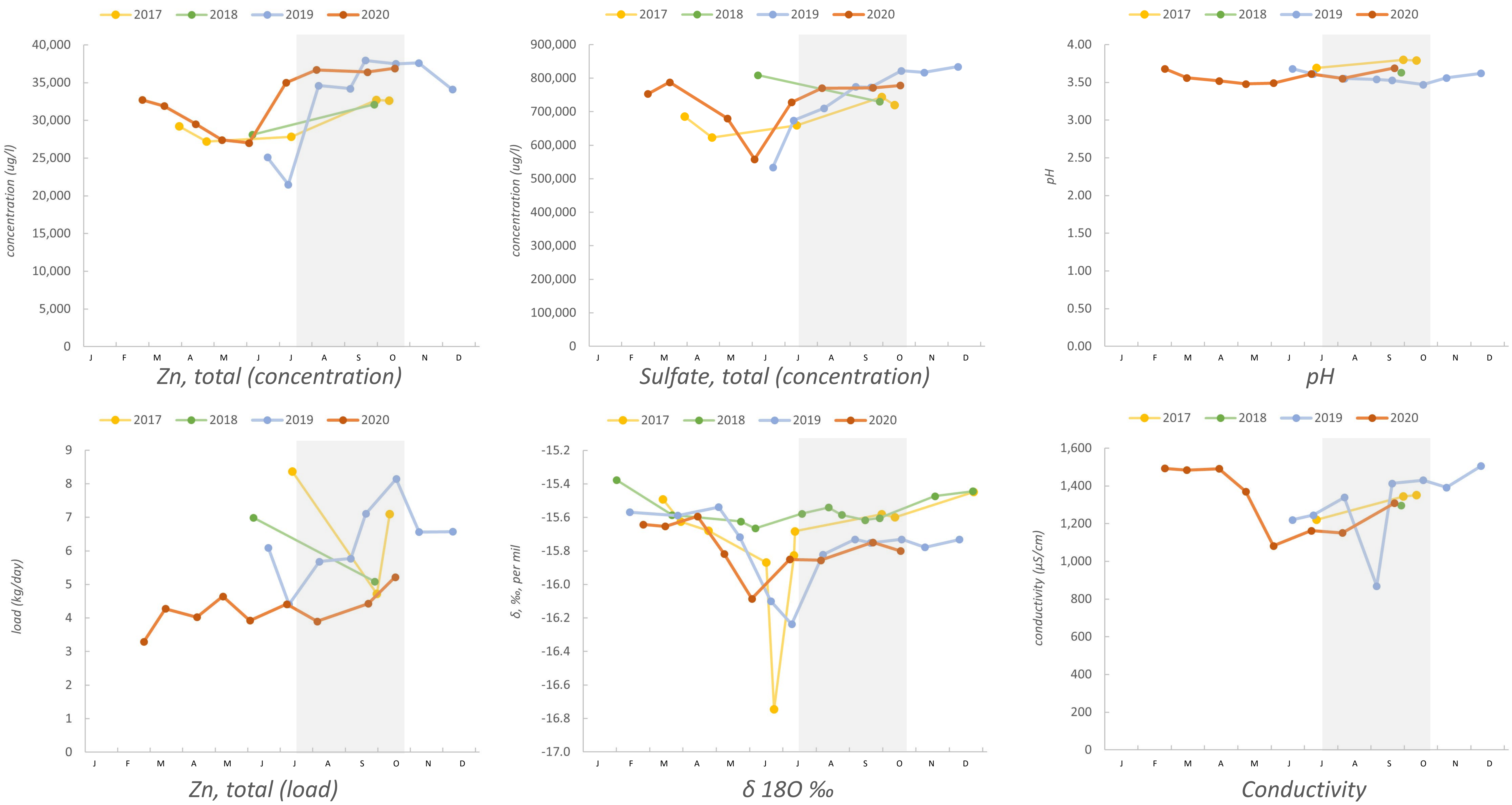

2017
2018
2019
2020
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
concentration (ug/l)
J F M A M J J A S O N D
Mn, total (concentration)


2017
2018
2019
2020
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
load (kg/day)
J F M A M J J A S O N D
Fe, total (load)

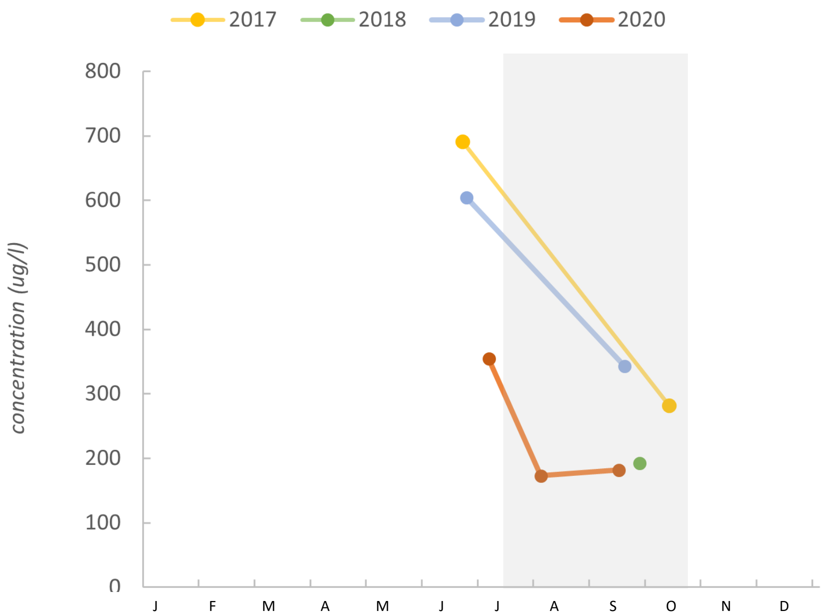

2017
2018
2019
2020
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
load (kg/day)
J F M A M J J A S O N D
Pb, total (load)


2017
2018
2019
2020
8
7
6
5
4
3
2
1
0
load (kg/day)
J F M A M J J A S O N D
Mn, total (load)

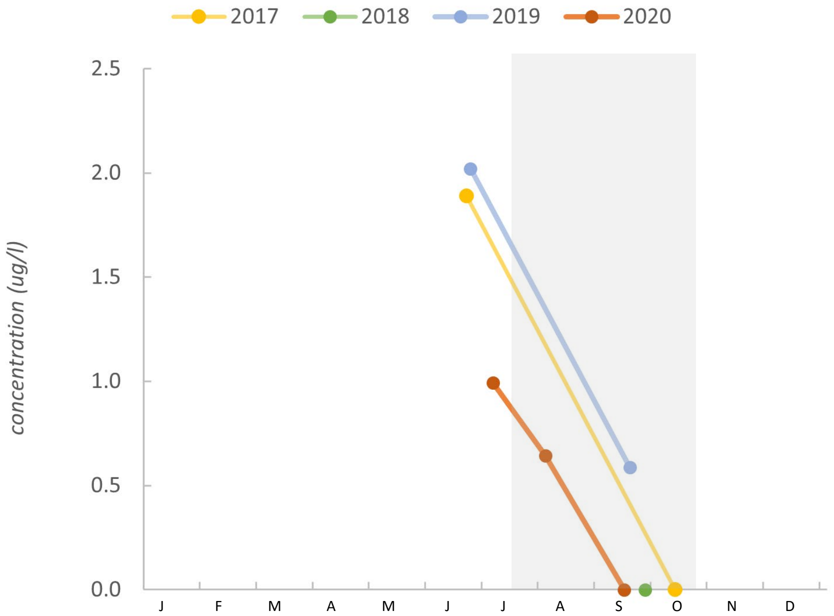
Mogul (CC01B)


2017
2018
2019
2020
concentration (ug/l)
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
J F M A M J J A S O N D
Zn, total (concentration)
concentration (ug/l)
900,000
800,000
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
Sulfate, total (concentration)
pH
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
pH
load (kg/day)
9
8
7
6
5
4
3
2
1
0
Zn, total (load)
δ, ‰, per mil
-15.2
-15.4
-15.6
-15.8
-16.0
-16.2
-16.4
-16.6
-16.8
-17.0
δ 18O ‰
conductivity (µS/cm)
1,600
1,400
1,200
1,000
800
600
400
200
0
Conductivity

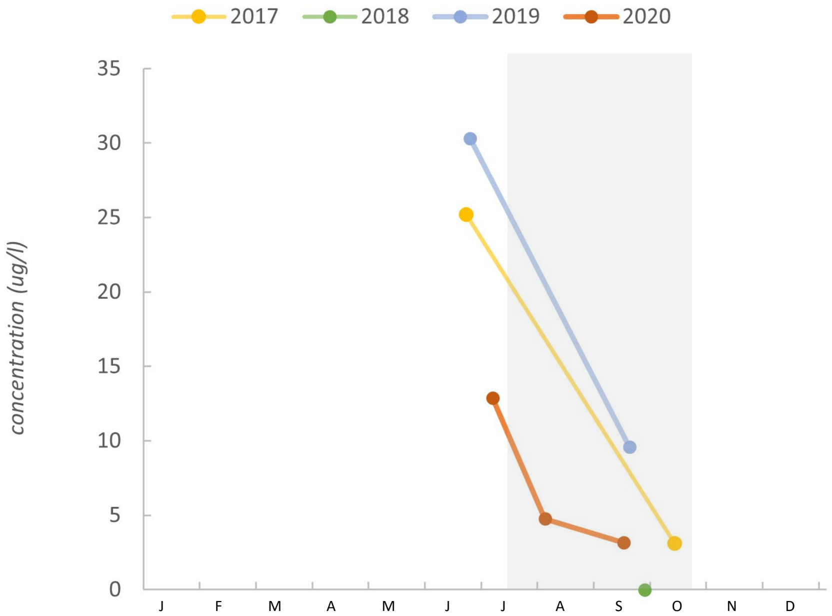
Mogul South (SS105)



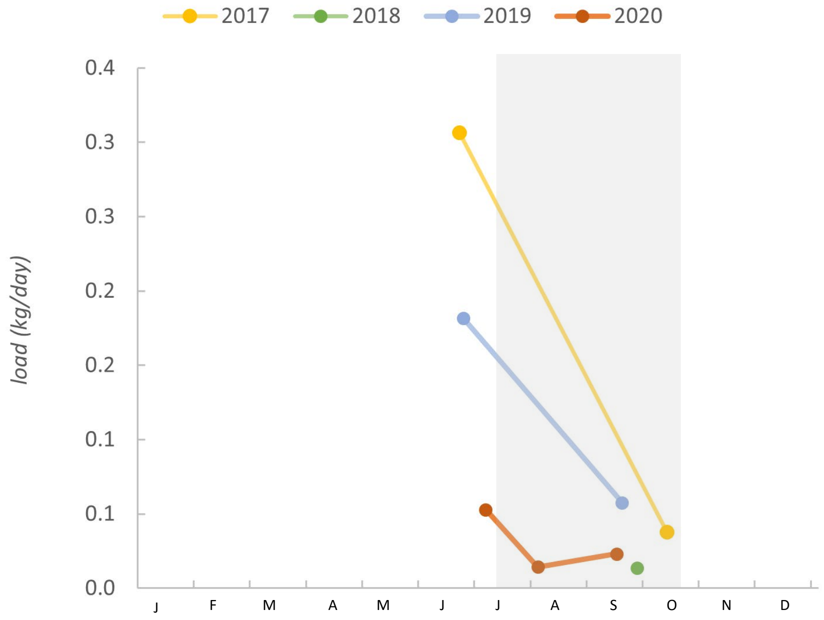
Al, total (concentration)



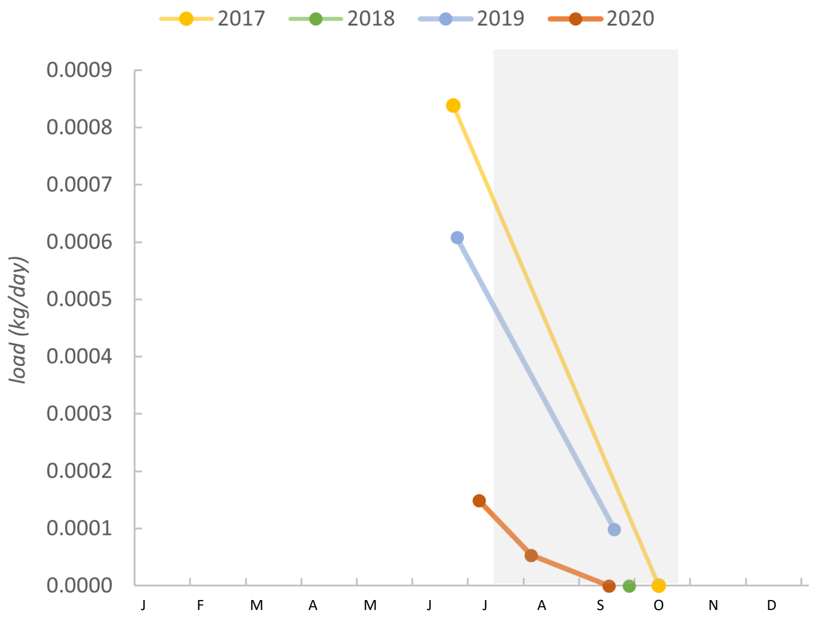
Cd, total (concentration)



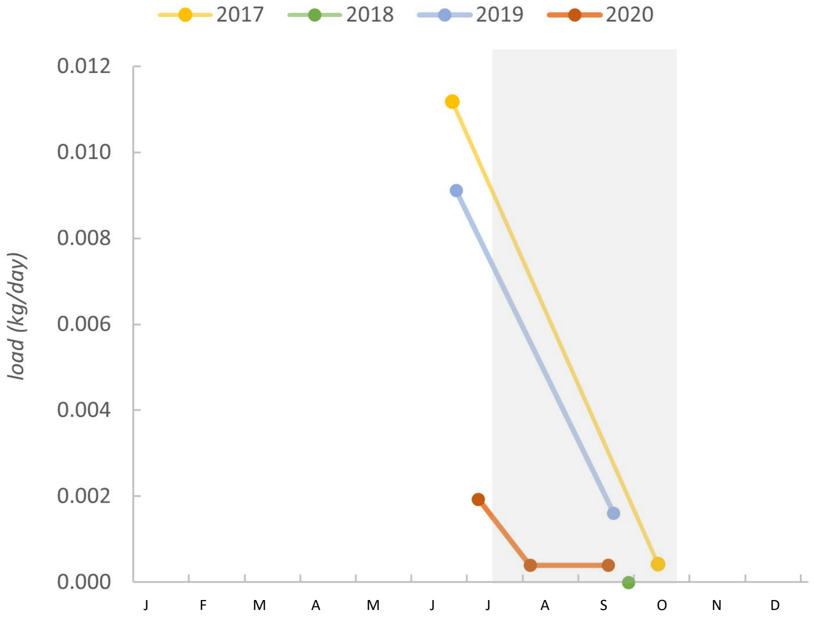
Cu, total (concentration)



Al, total (load)

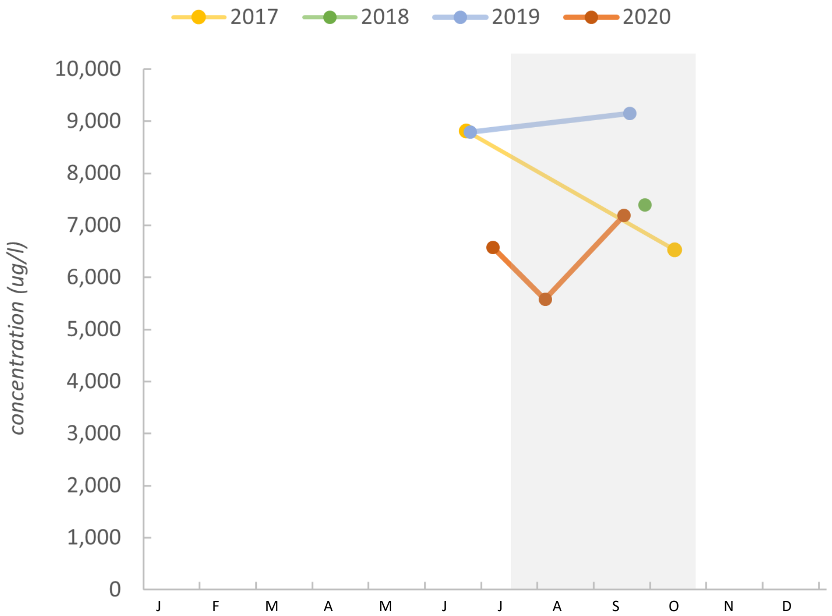


Cd, total (load)

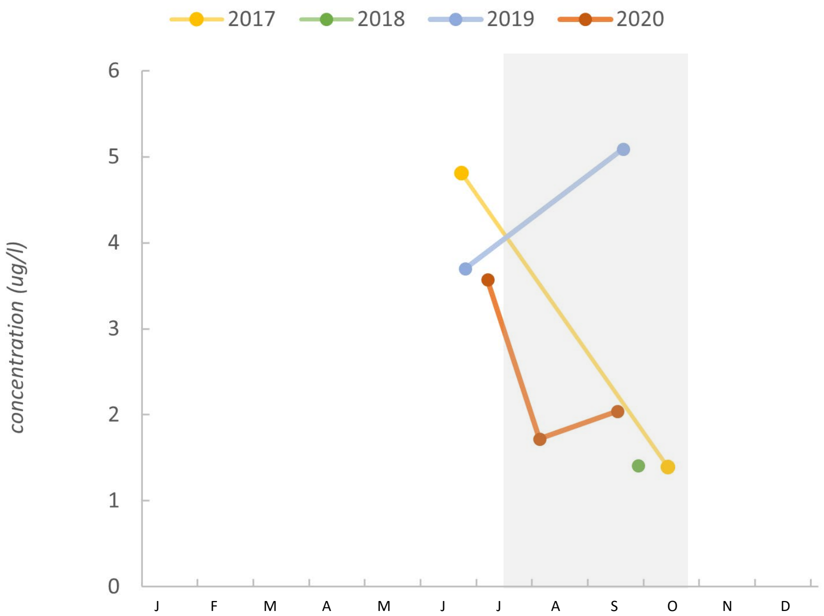


Cu, total (load)

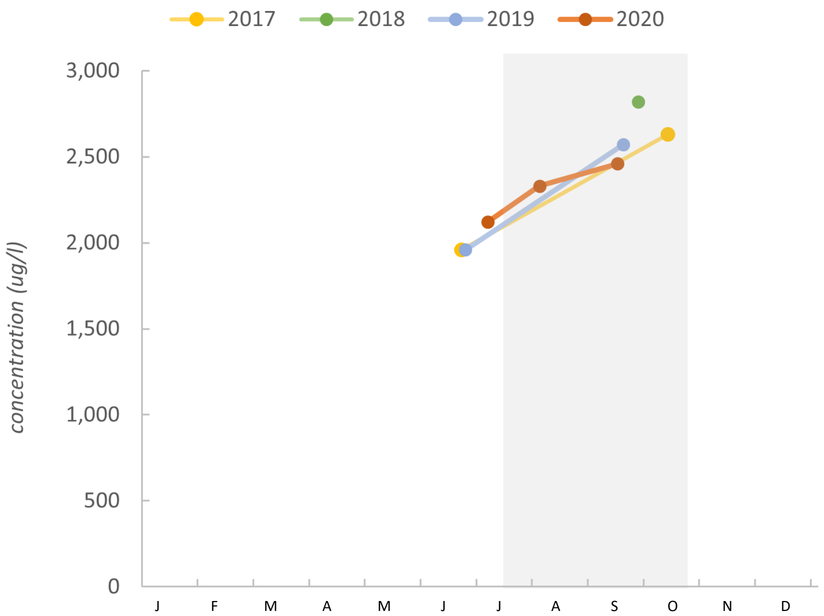
Mogul South (SS105)



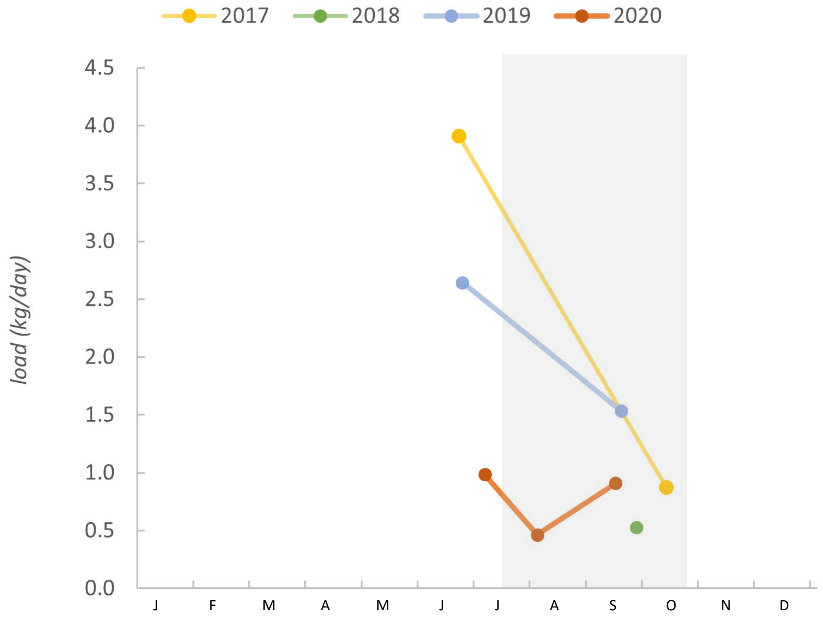
Fe, total (concentration)



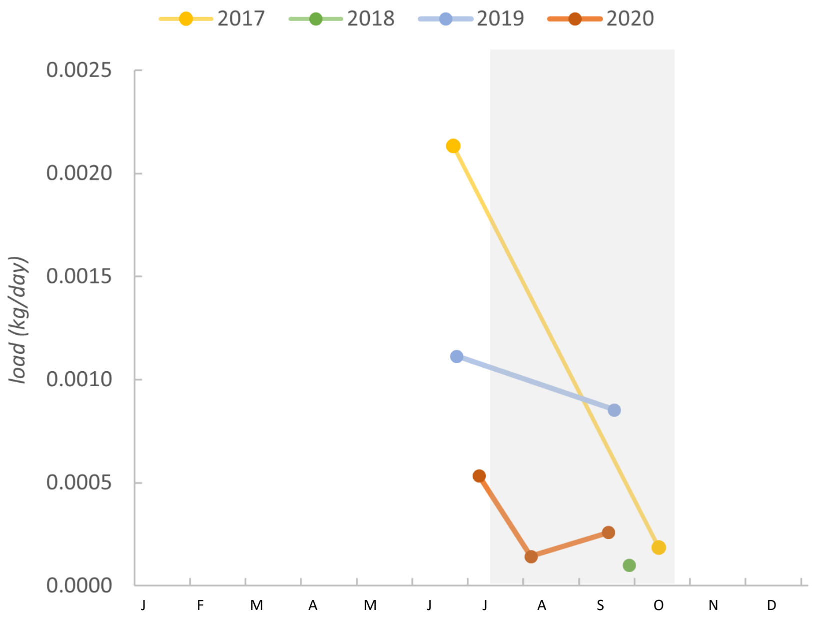
Pb, total (concentration)



Mn, total (concentration)



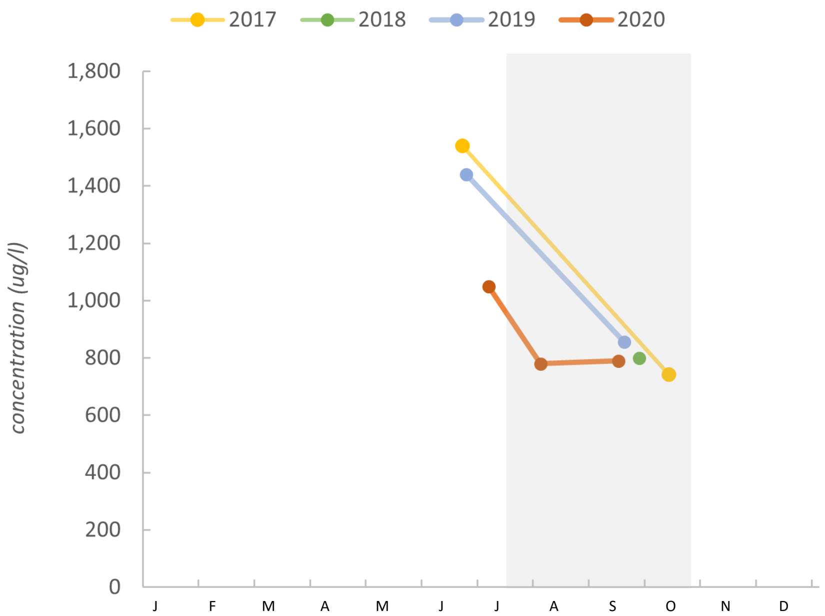
Fe, total (load)



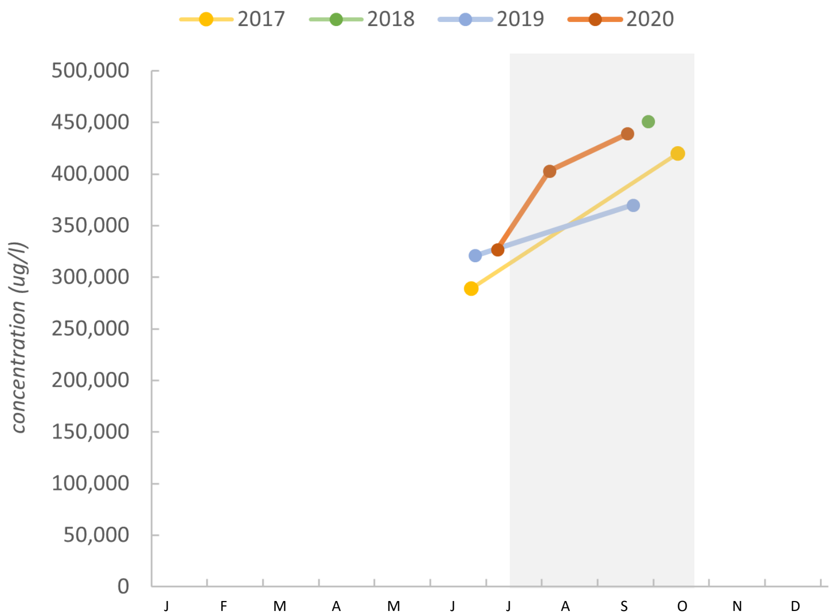
Pb, total (load)

Mn, total (load)

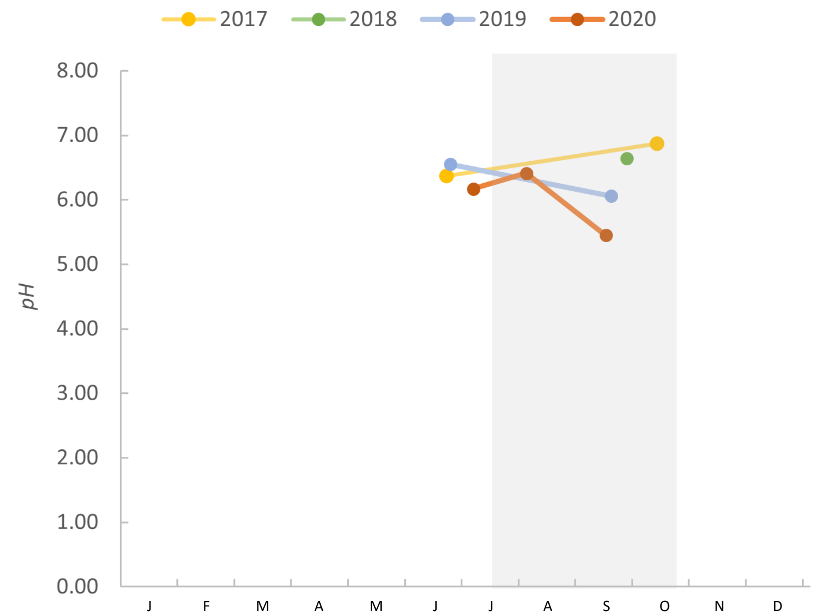
Mogul South (SS105)



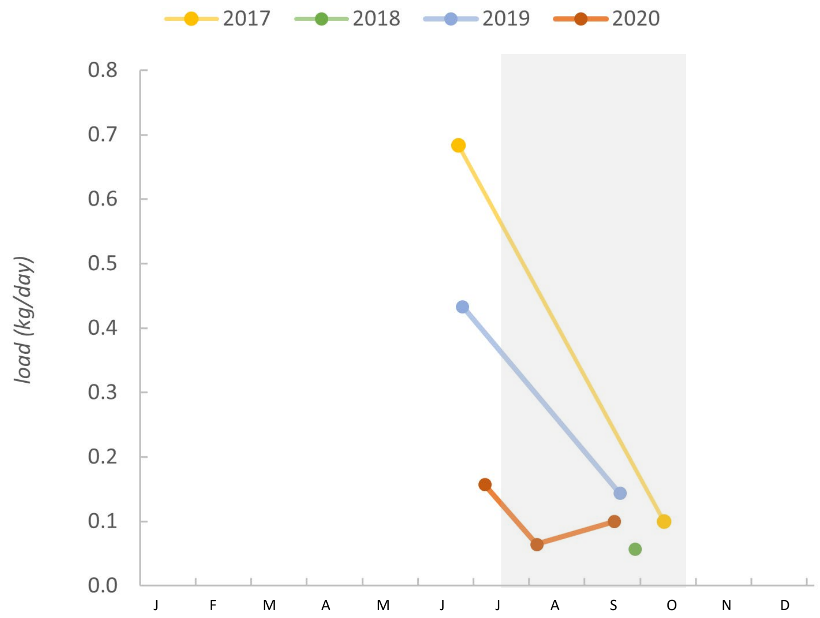
Zn, total (concentration)



Sulfate, total (concentration)

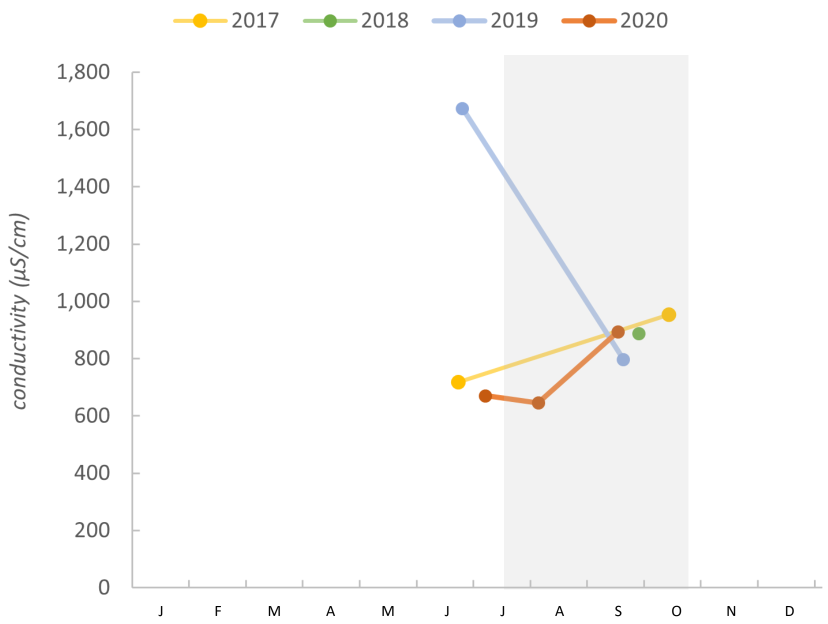


pH



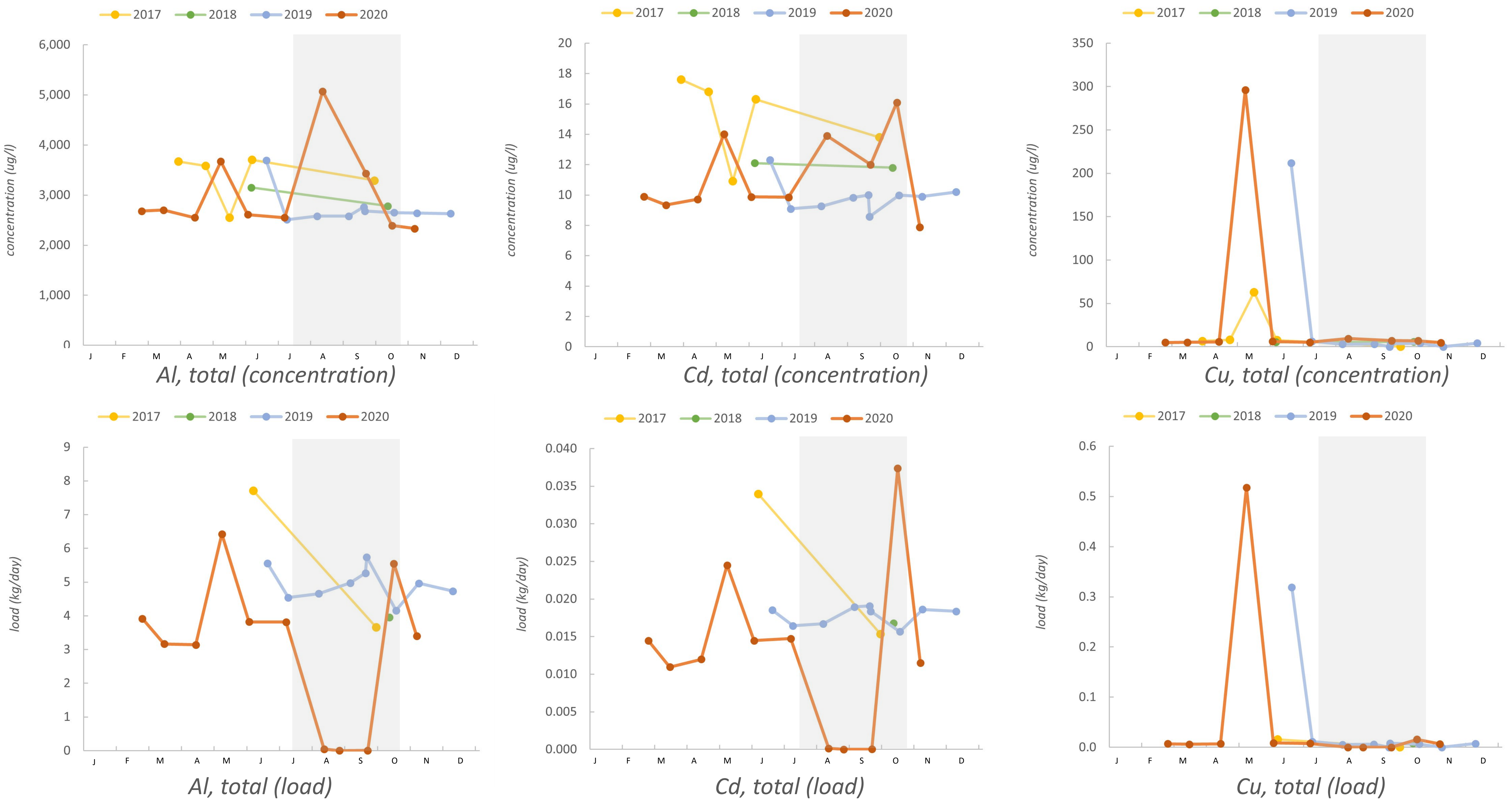
Zn, total (load)

δ 18O ‰

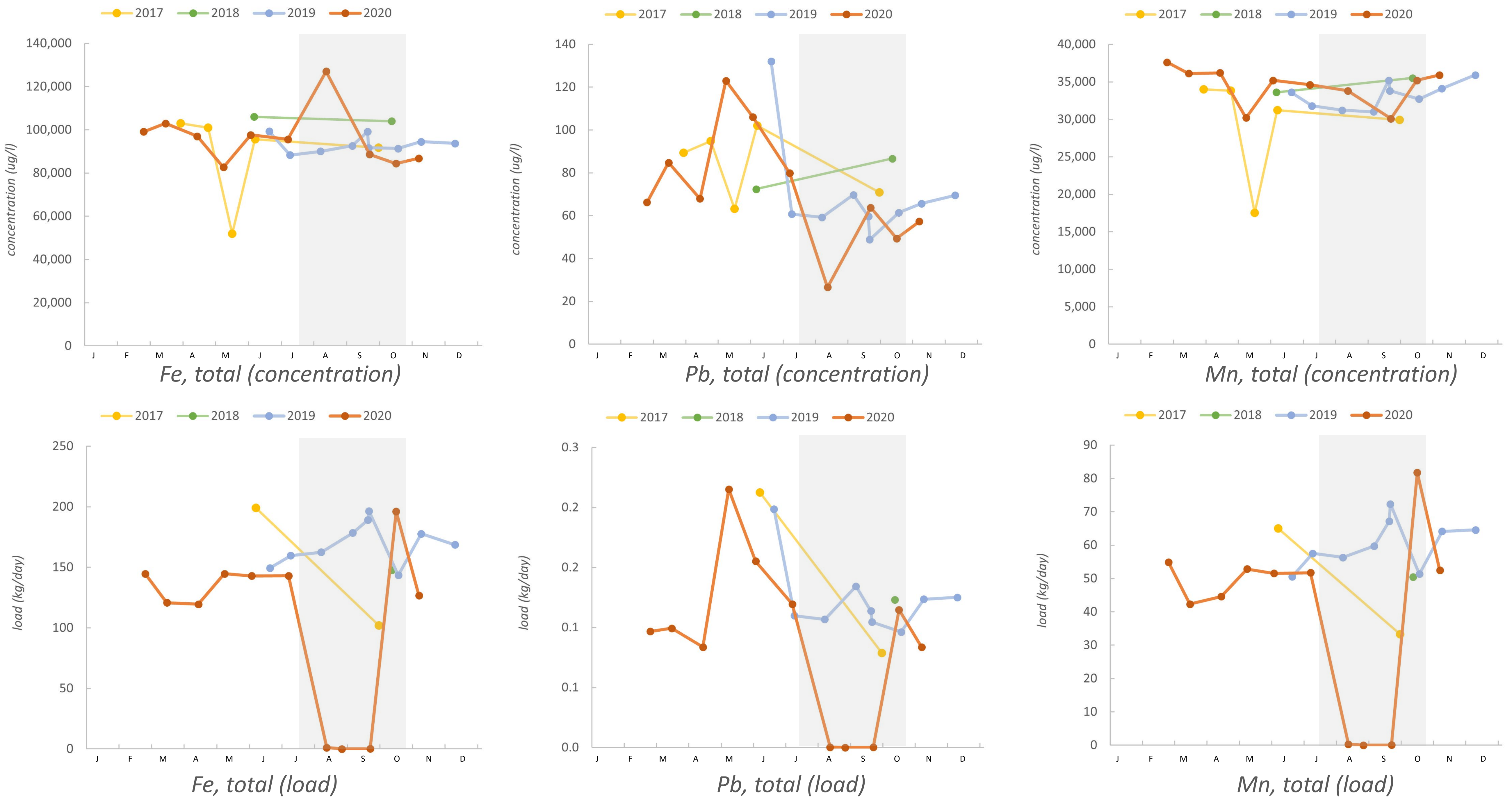


Conductivity

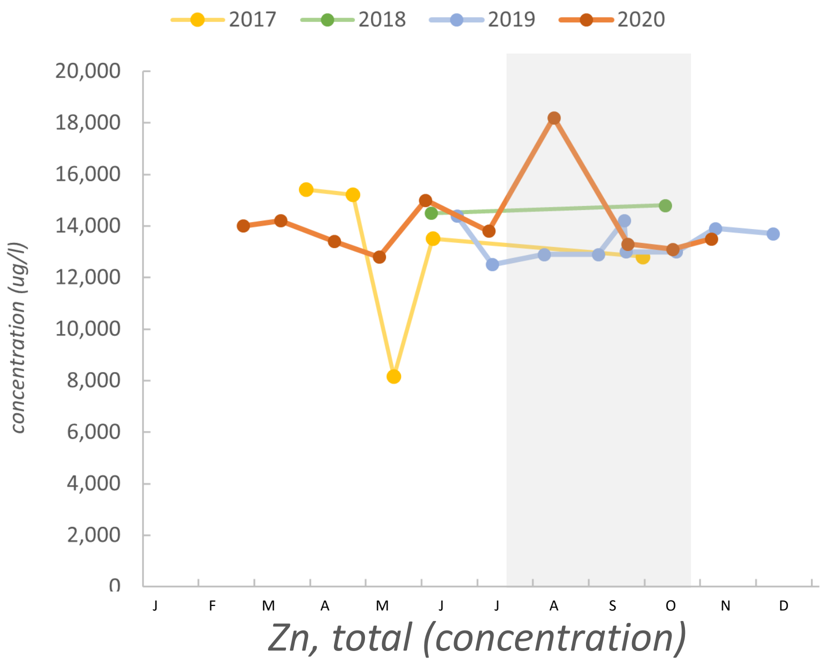
Red & Bonita (CC03C)

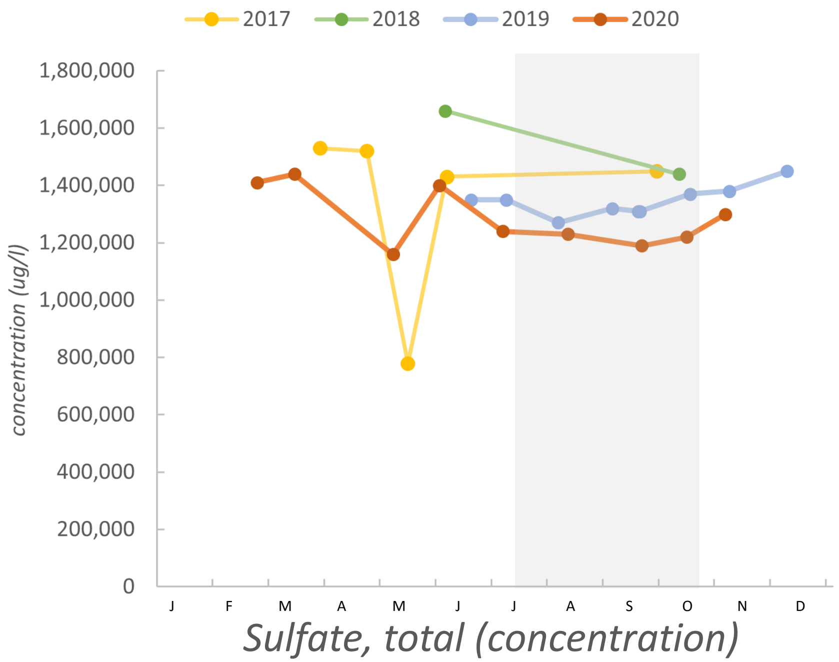


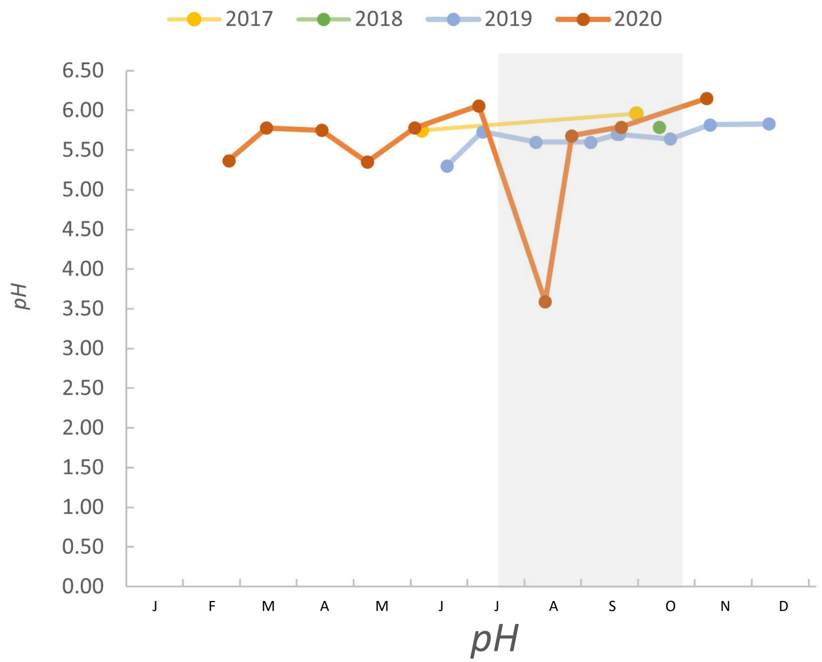
Red & Bonita (CC03C)

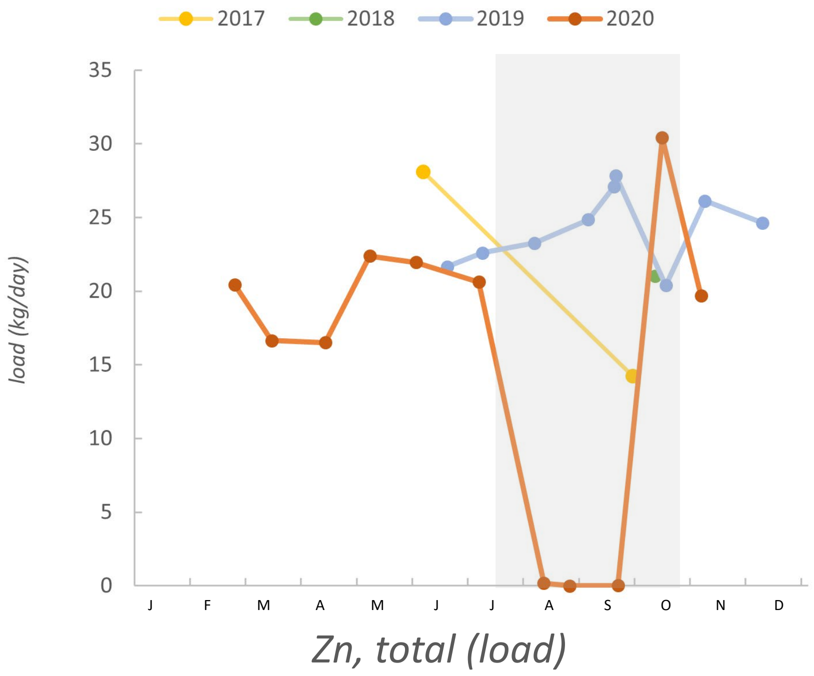


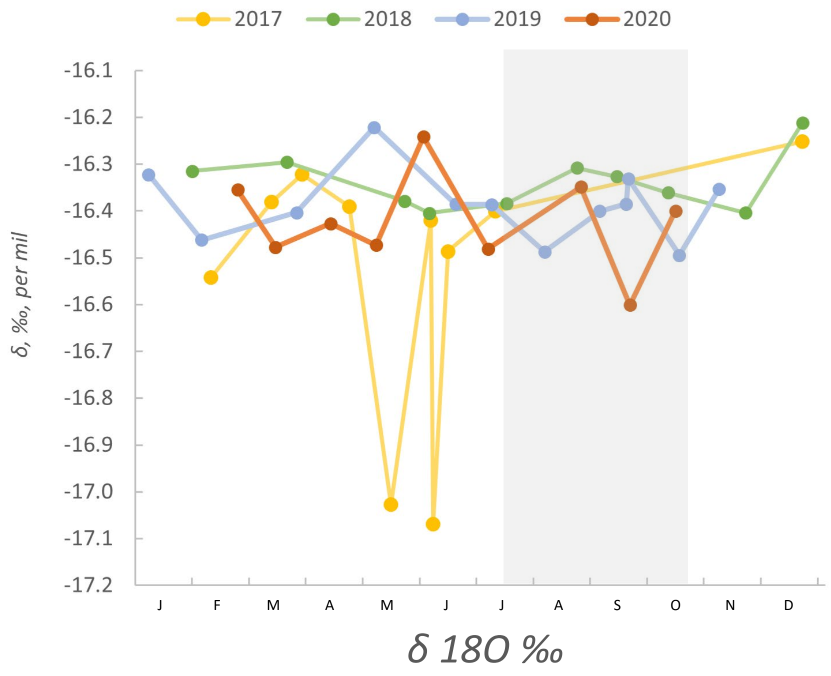
Red & Bonita (CC03C)

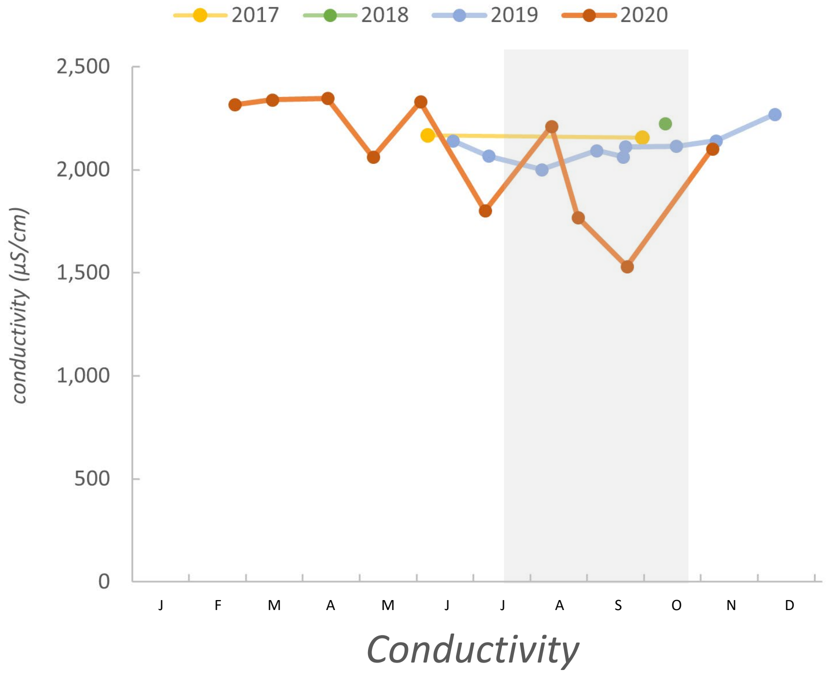




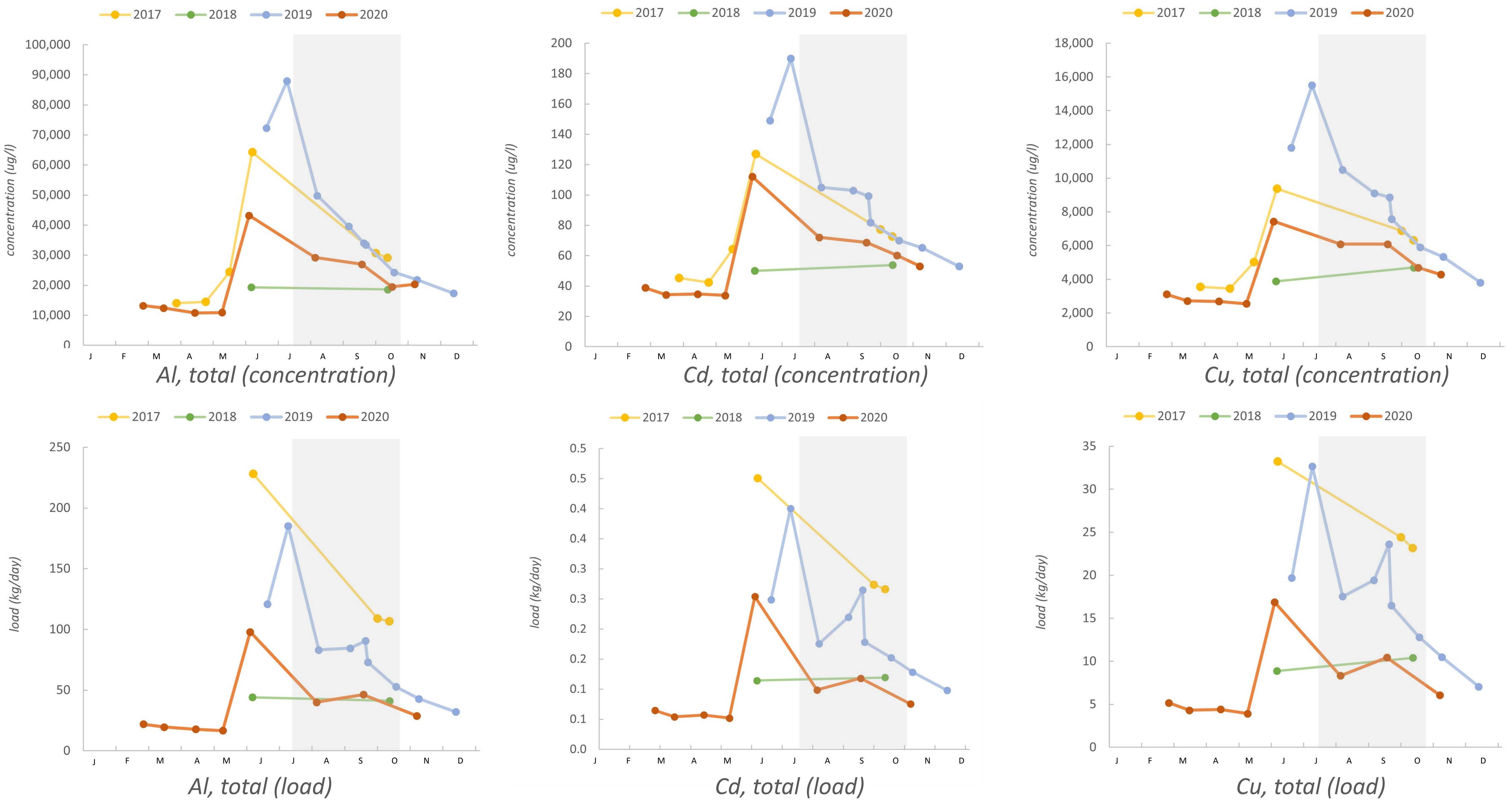




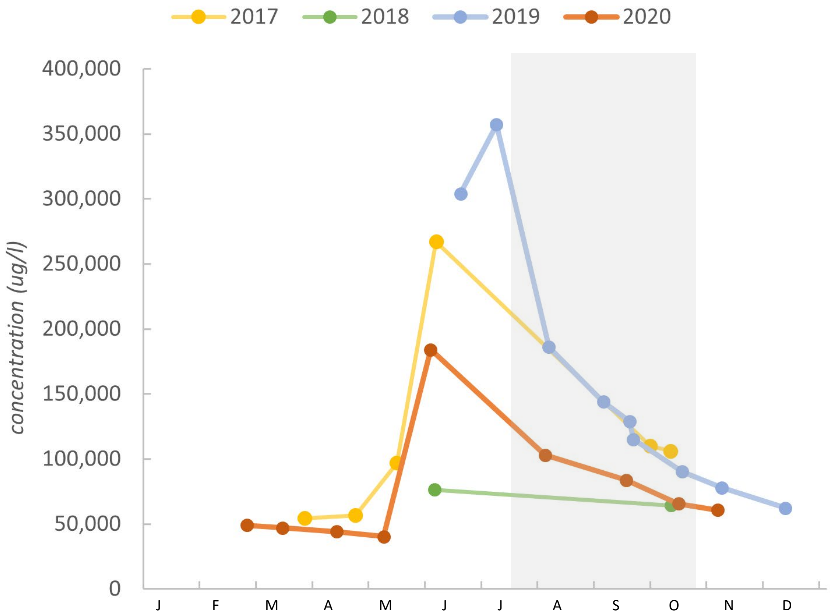




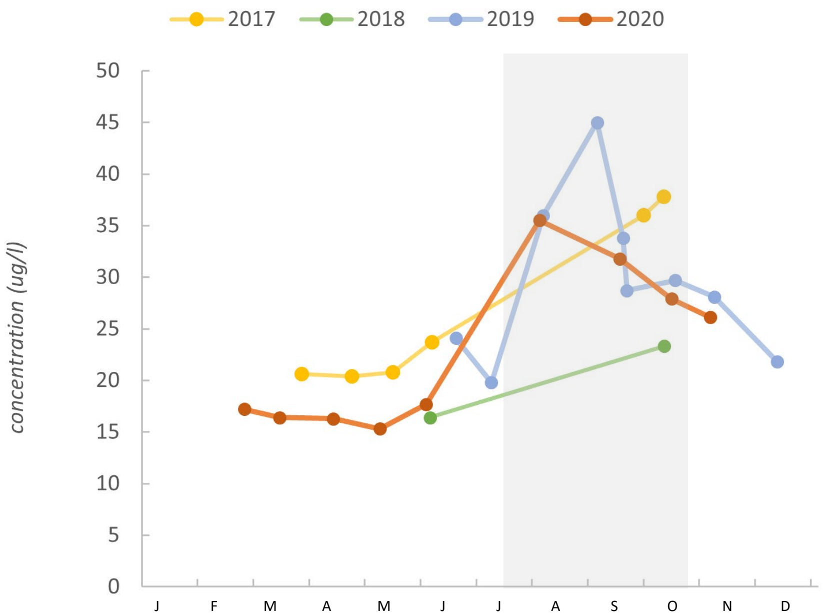
Gold King (CC06)



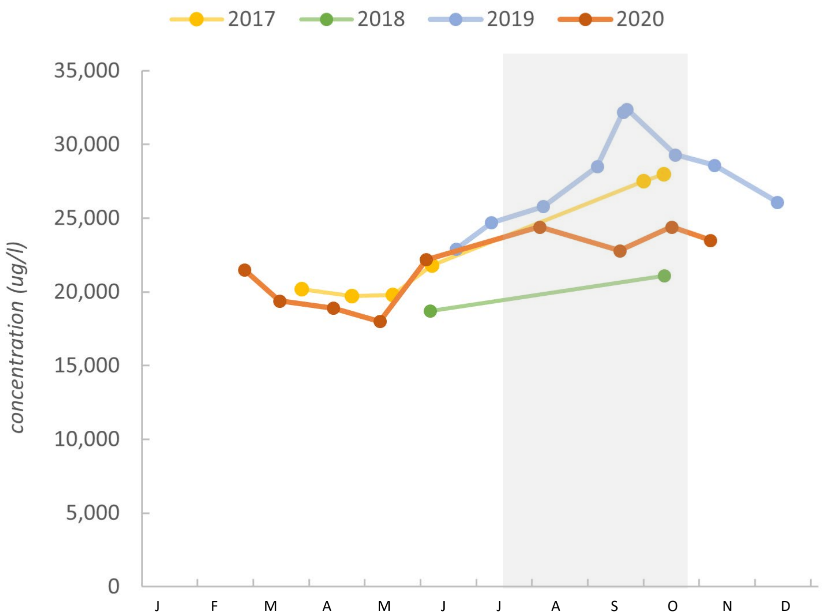
Gold King (CC06)



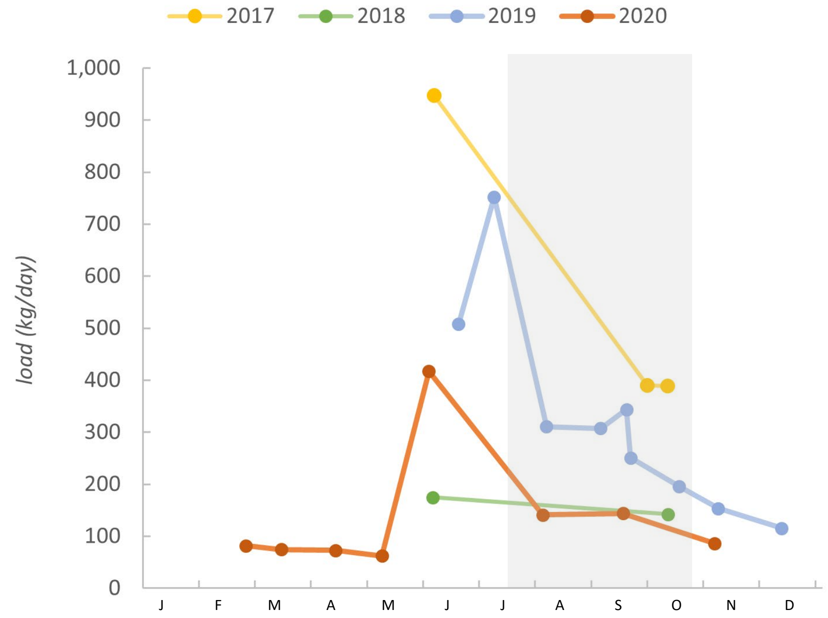
Fe, total (concentration)



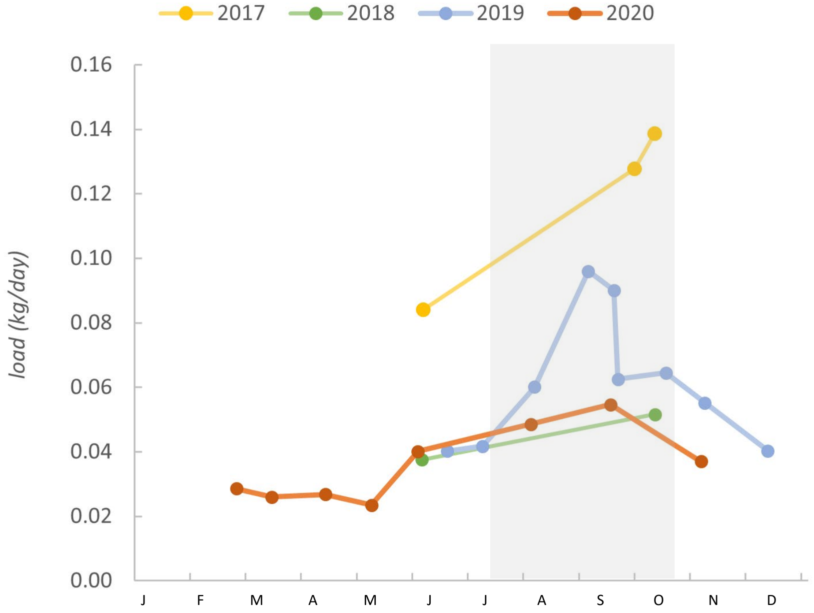
Pb, total (concentration)



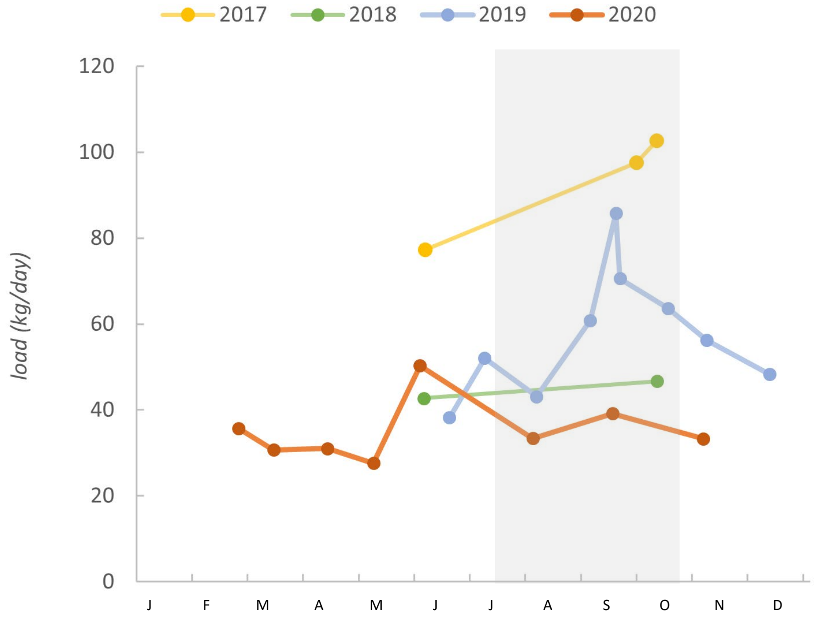
Mn, total (concentration)



Fe, total (load)

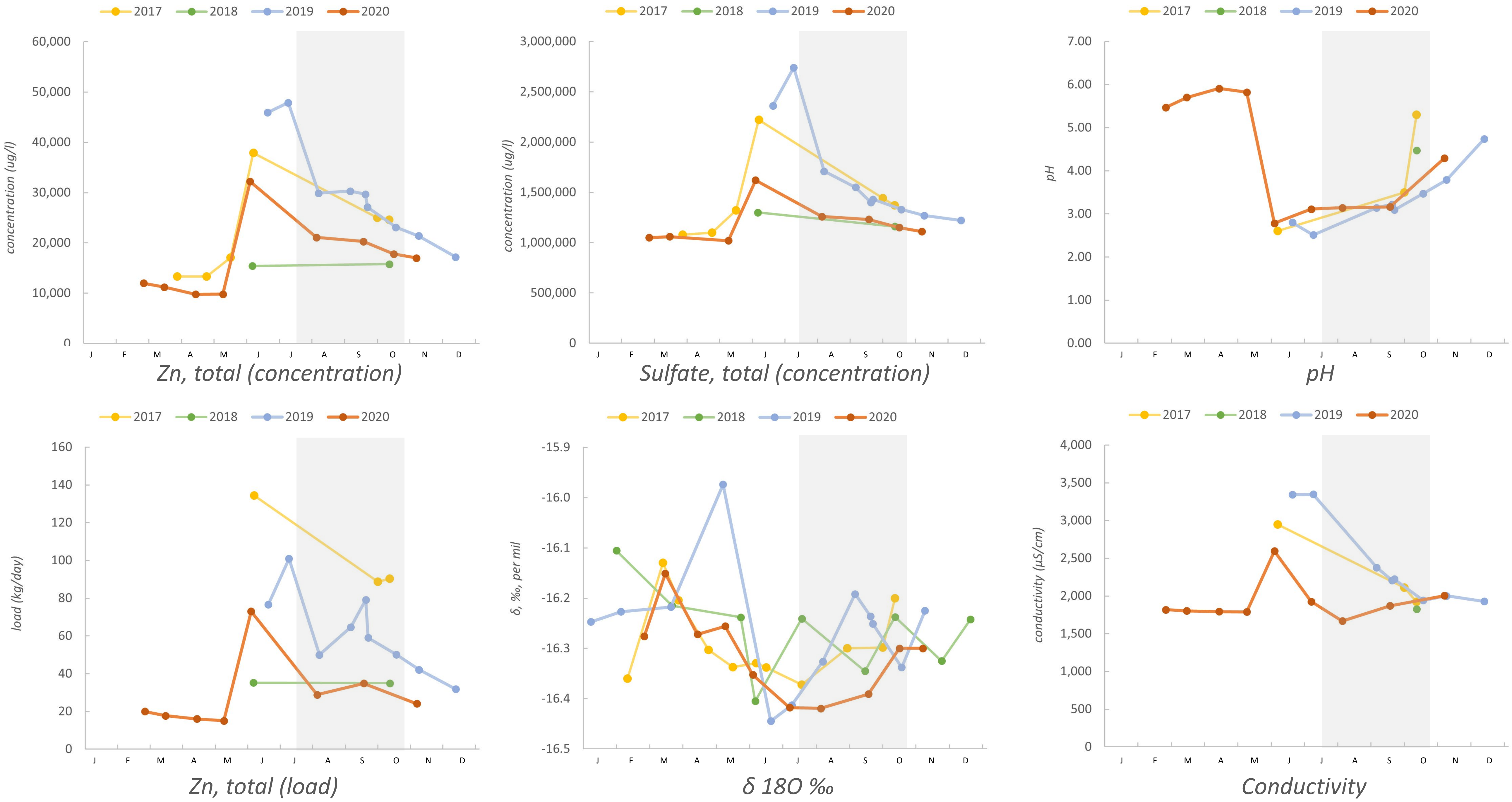


Pb, total (load)

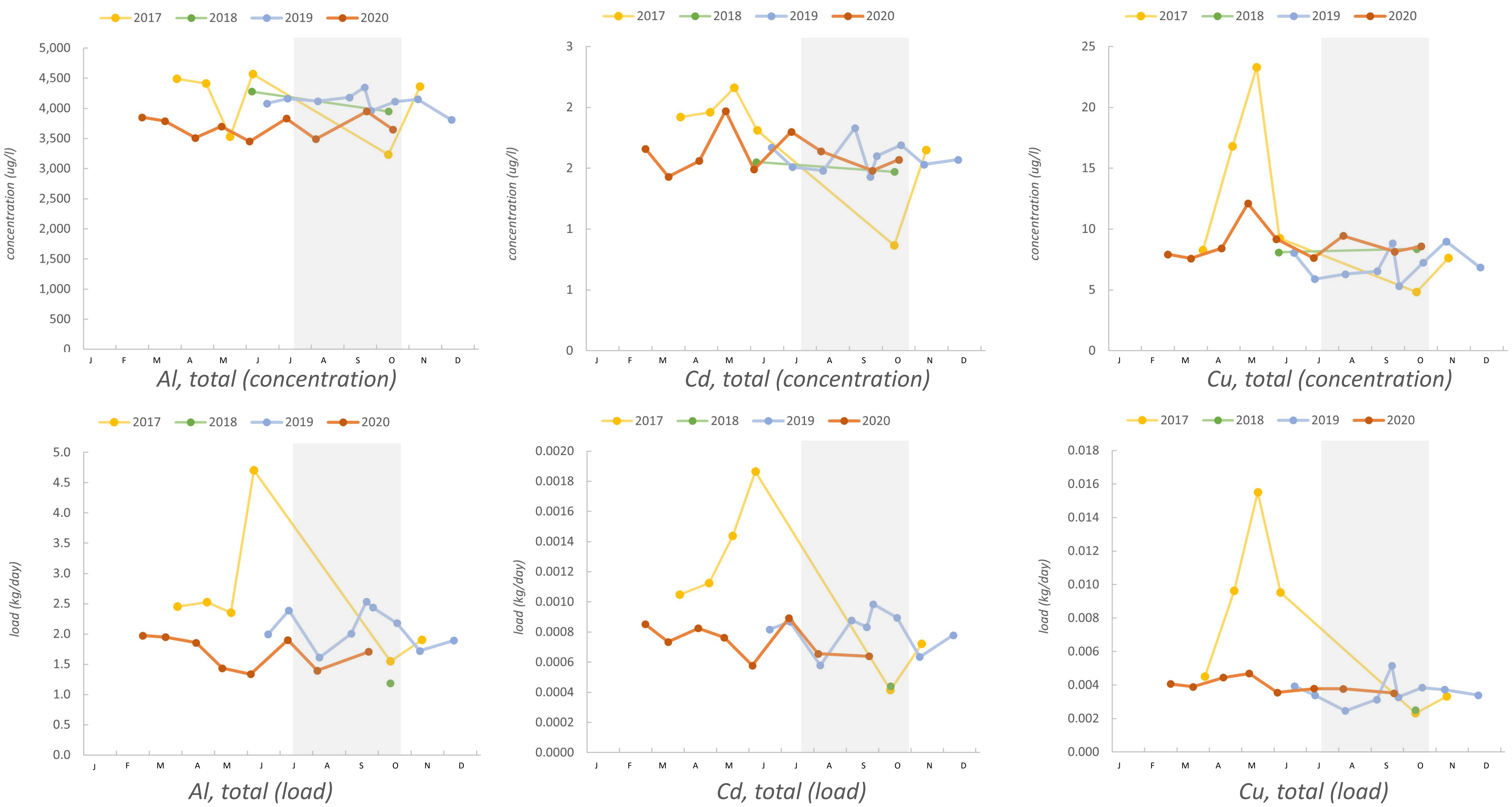


Mn, total (load)

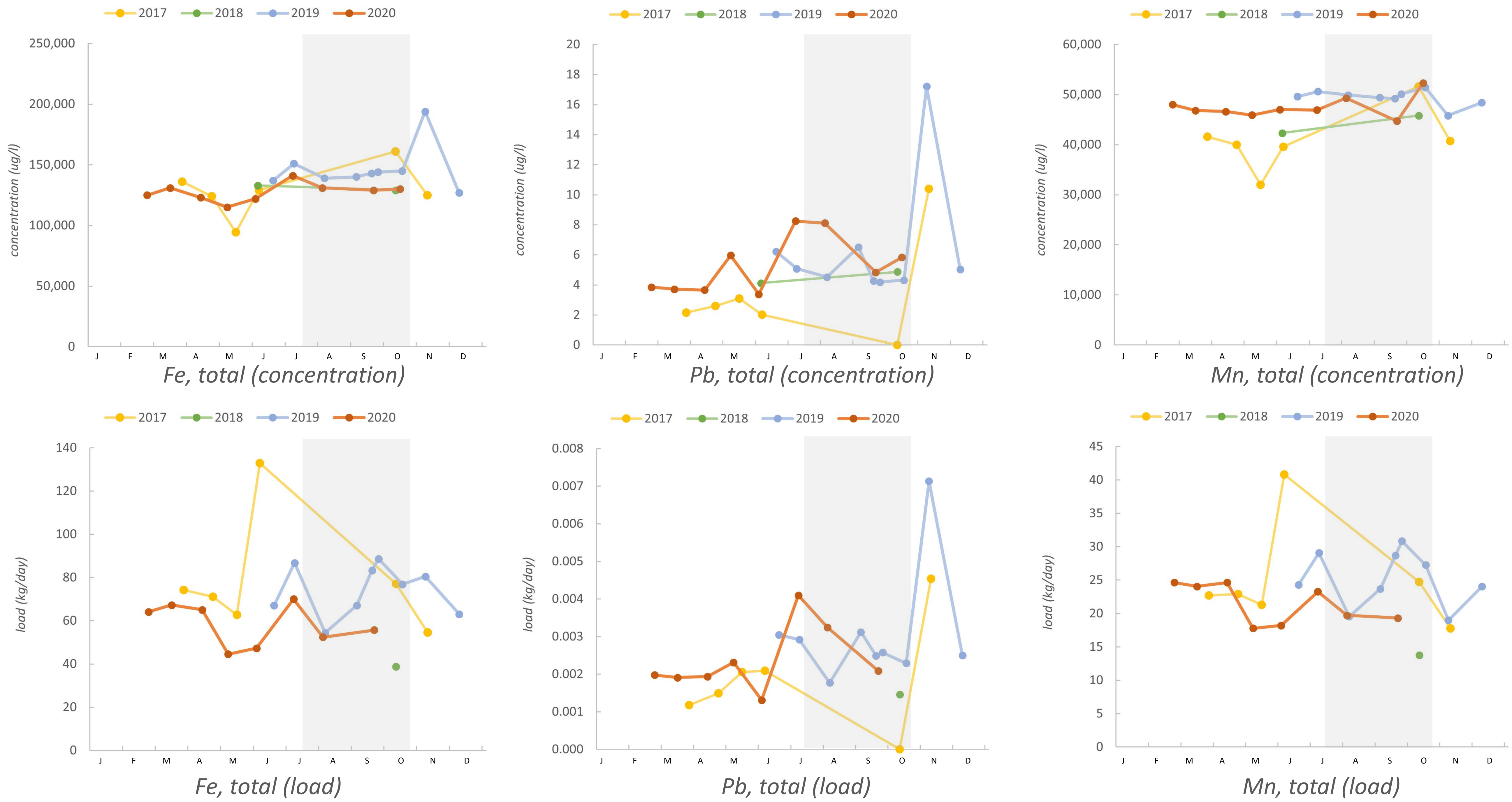
Gold King (CC06)



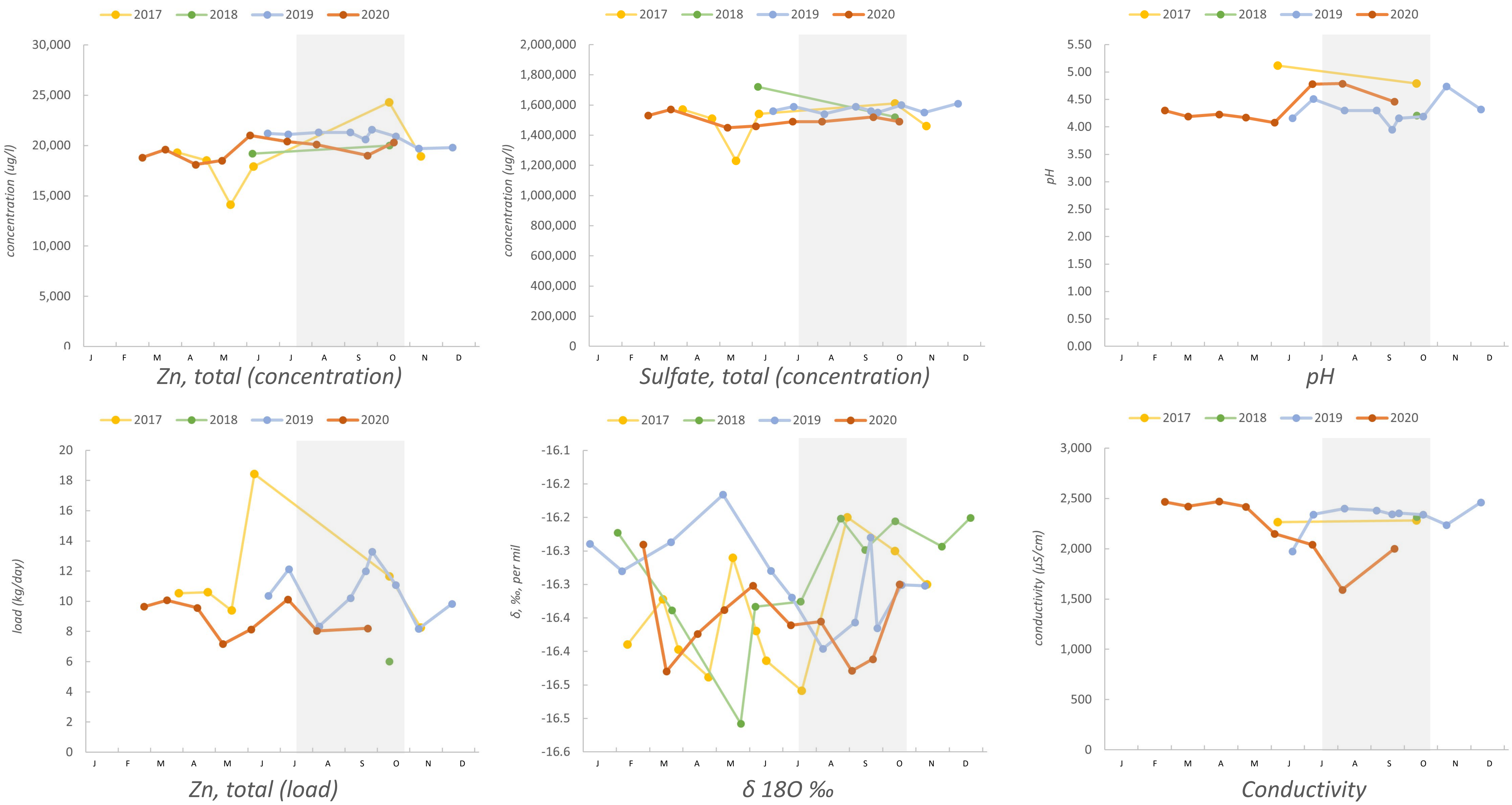
American Tunnel (CC19)



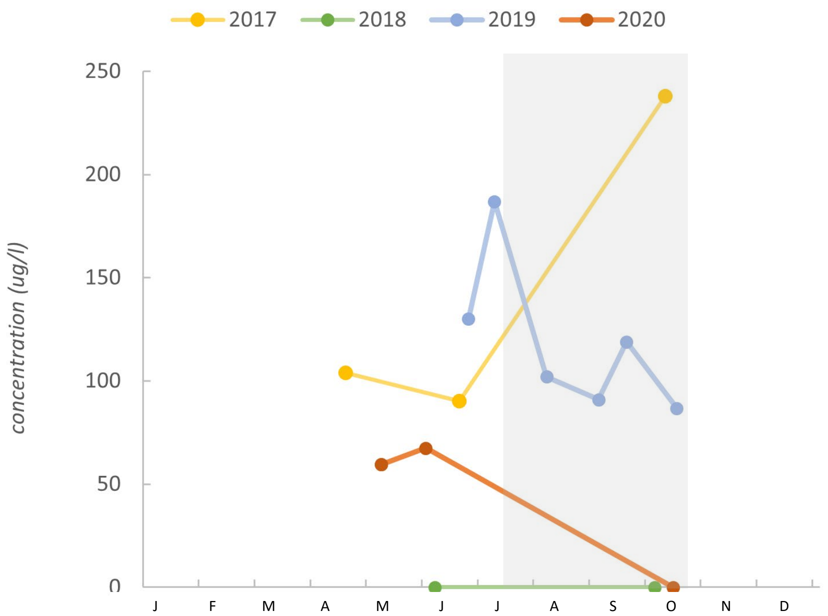
American Tunnel (CC19)



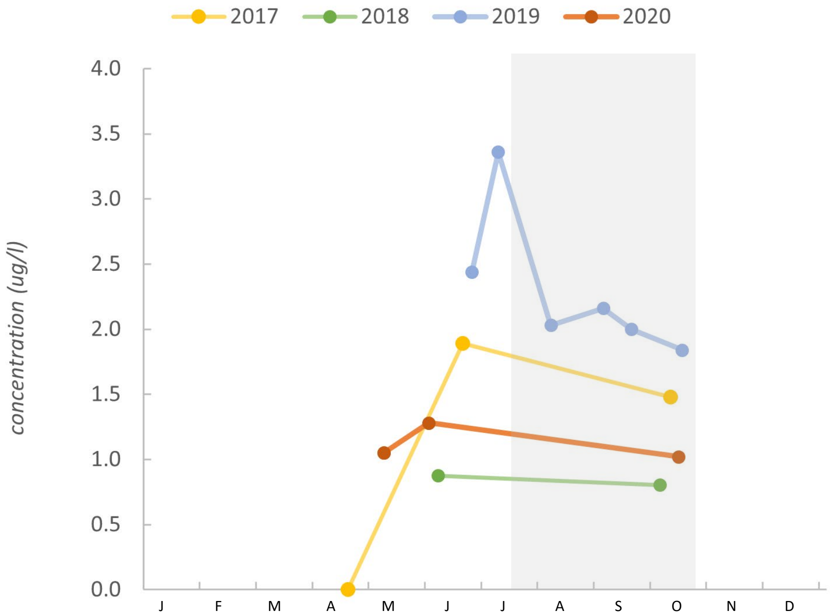
American Tunnel (CC19)



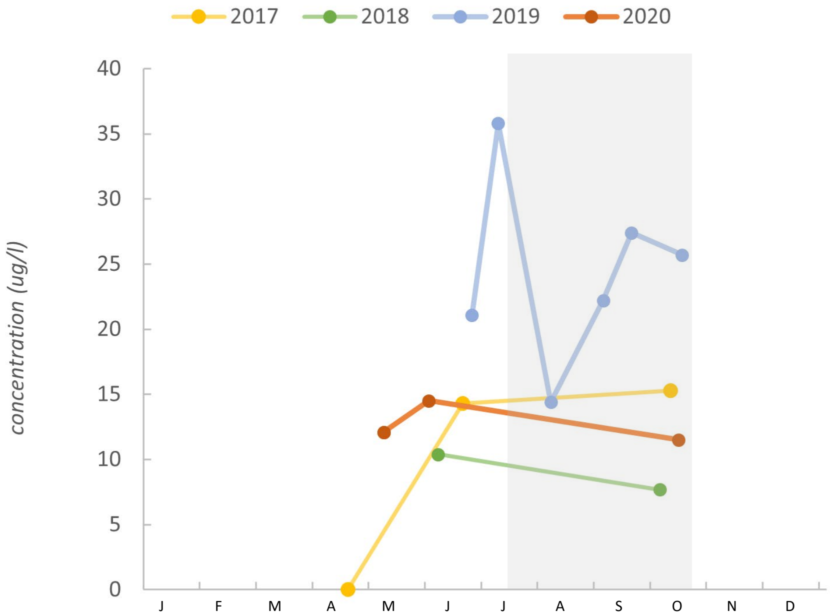
Blackhawk (CC50)



Al, total (concentration)

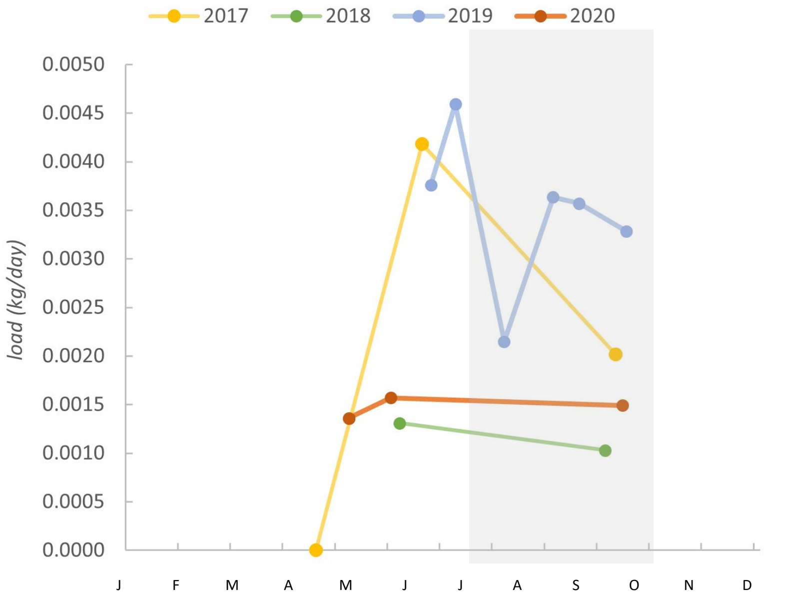


Cd, total (concentration)

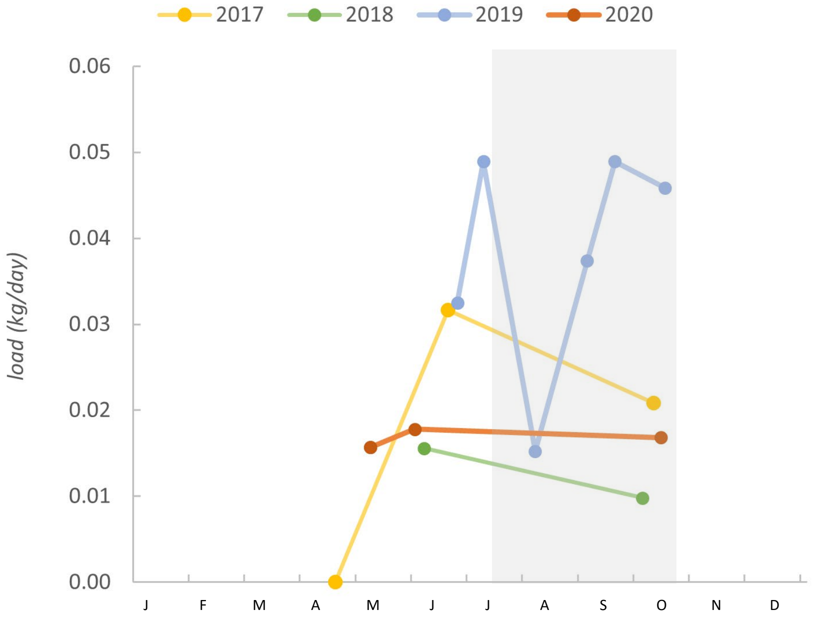


Cu, total (concentration)

Al, total (load)

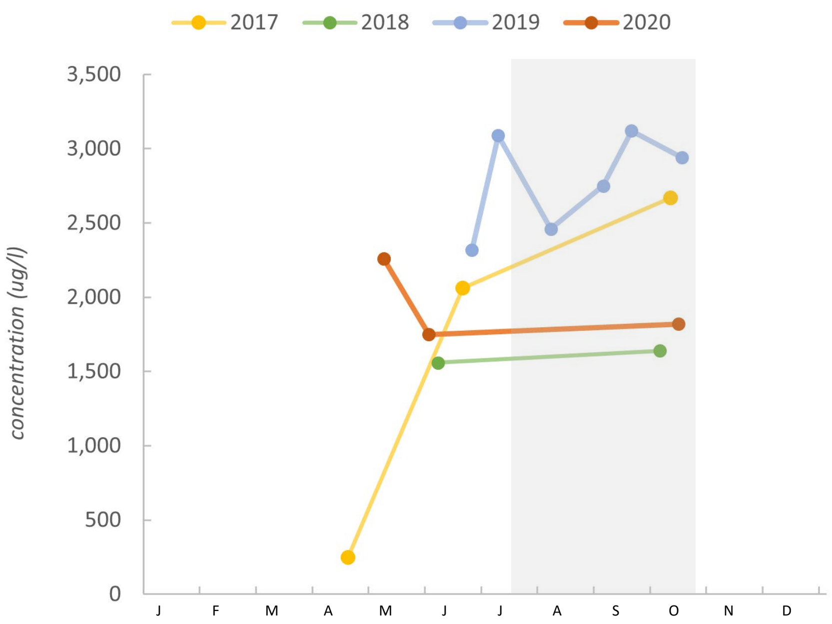


Cd, total (load)

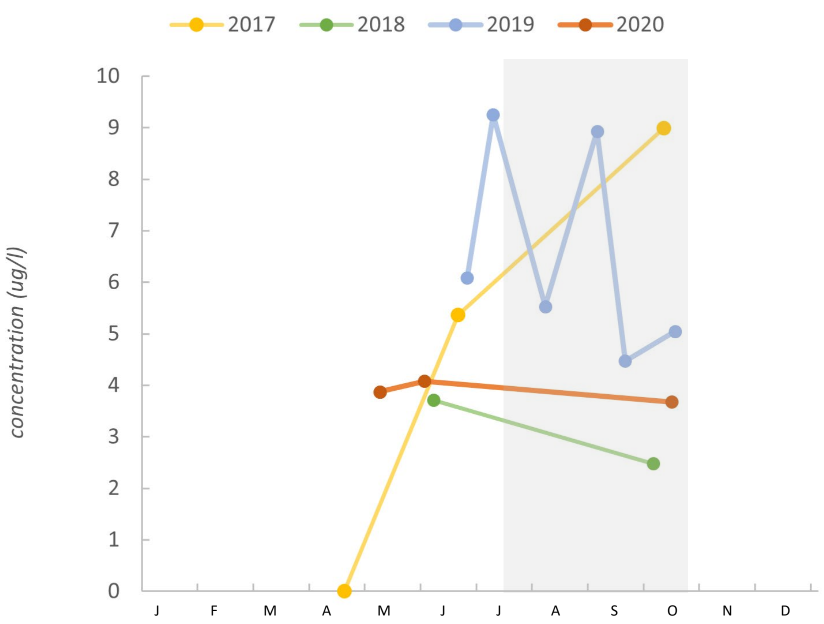


Cu, total (load)

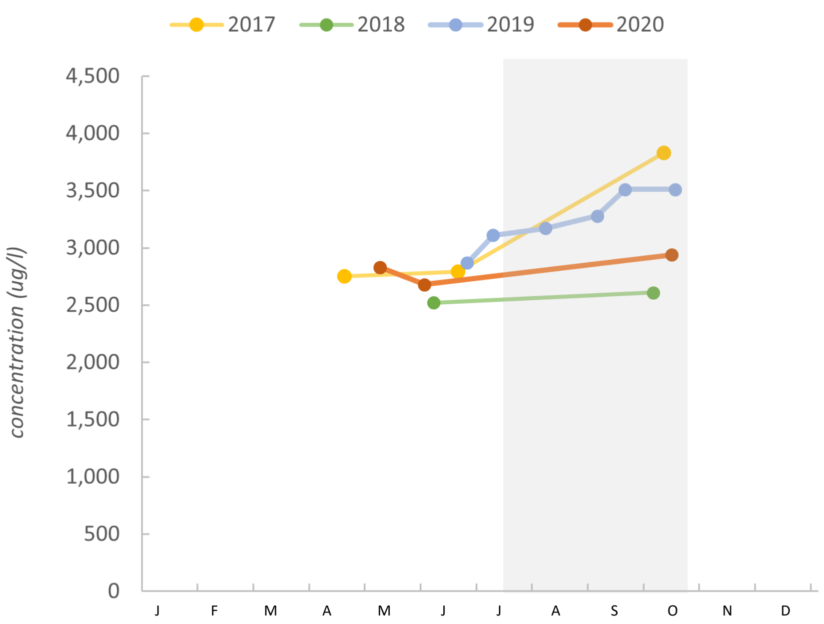
Blackhawk (CC50)



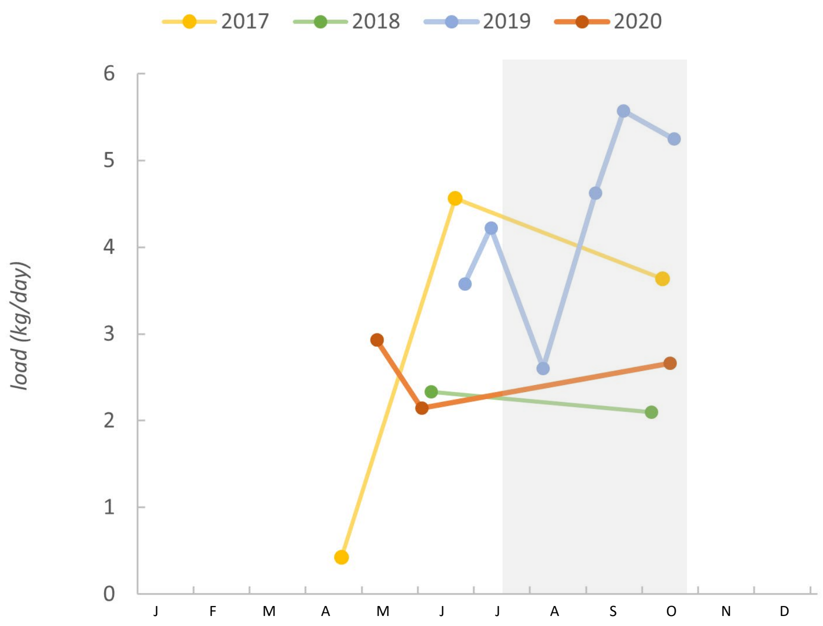
Fe, total (concentration)



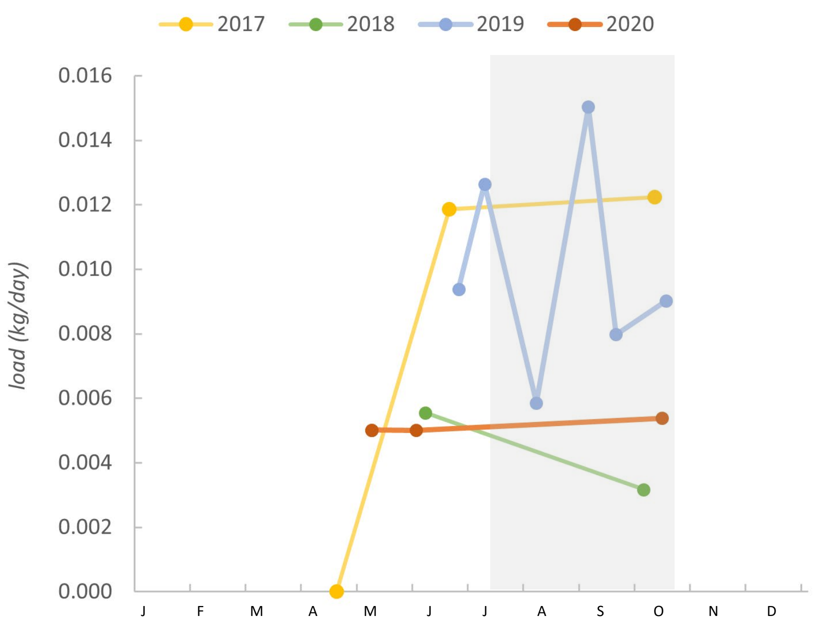
Pb, total (concentration)



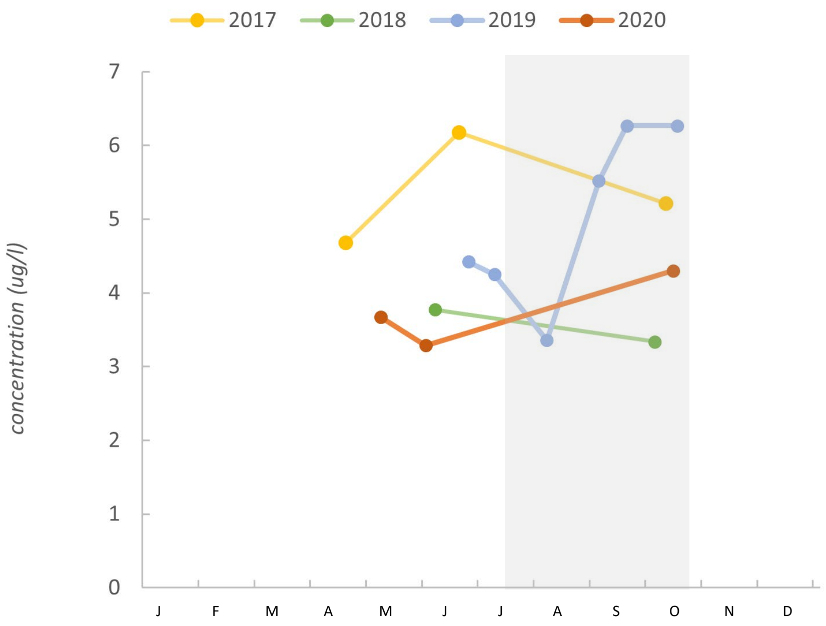
Mn, total (concentration)



Fe, total (load)

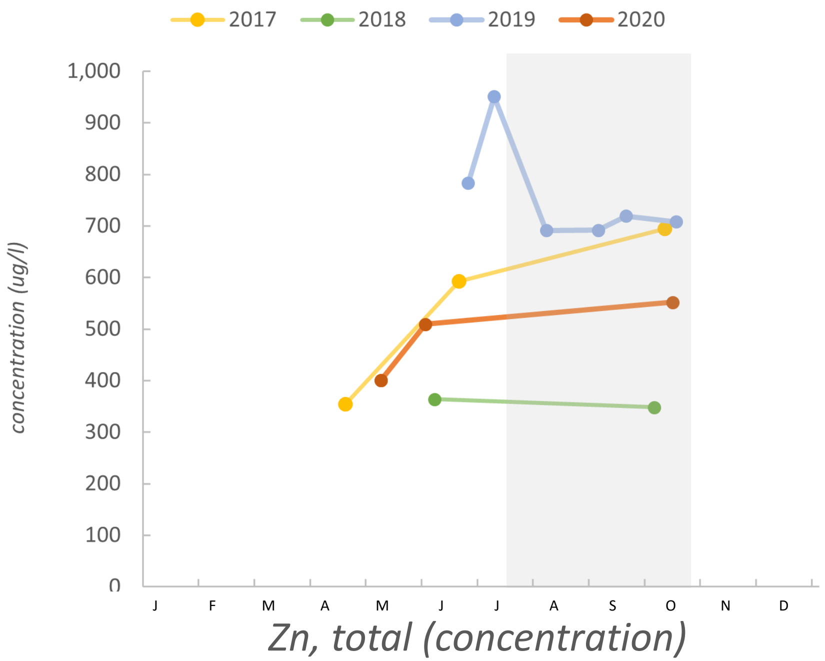


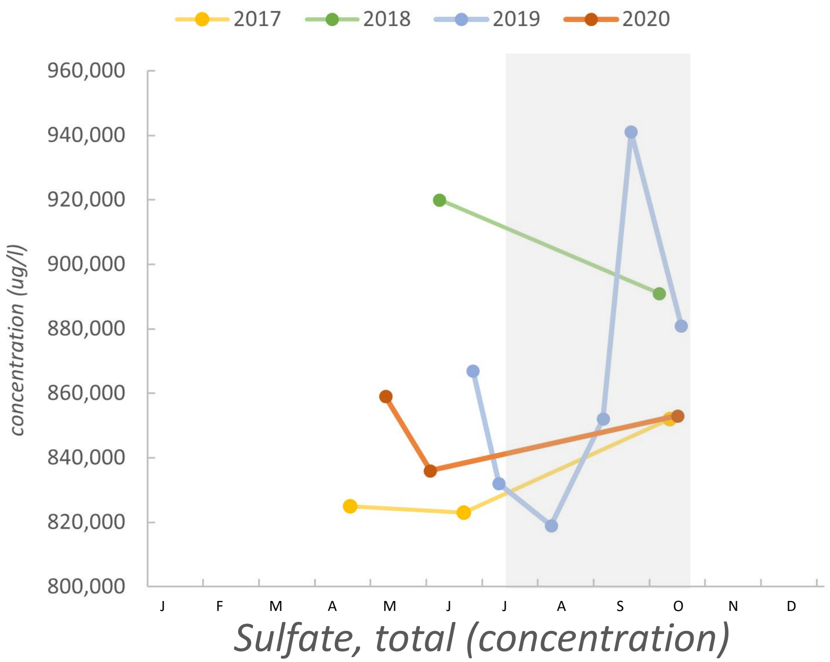
Pb, total (load)

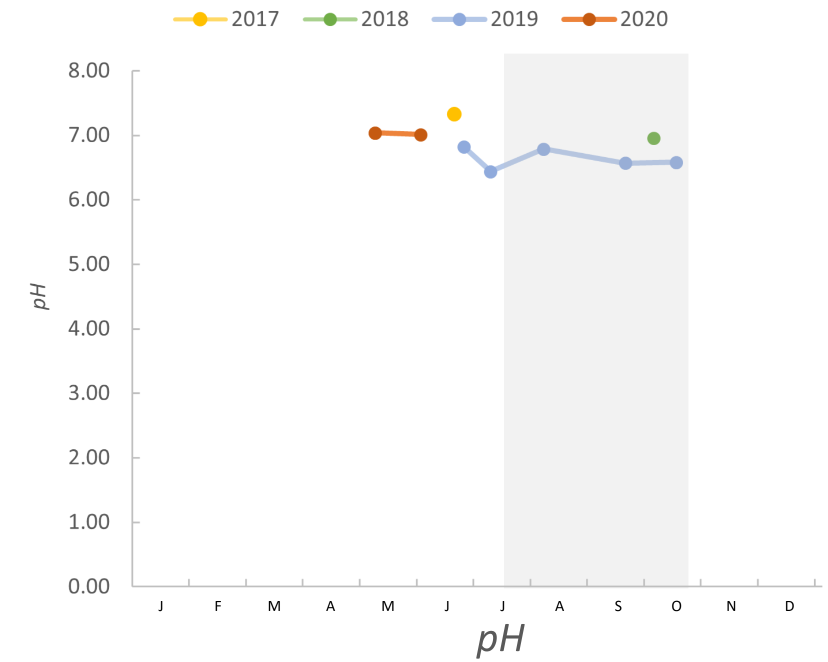


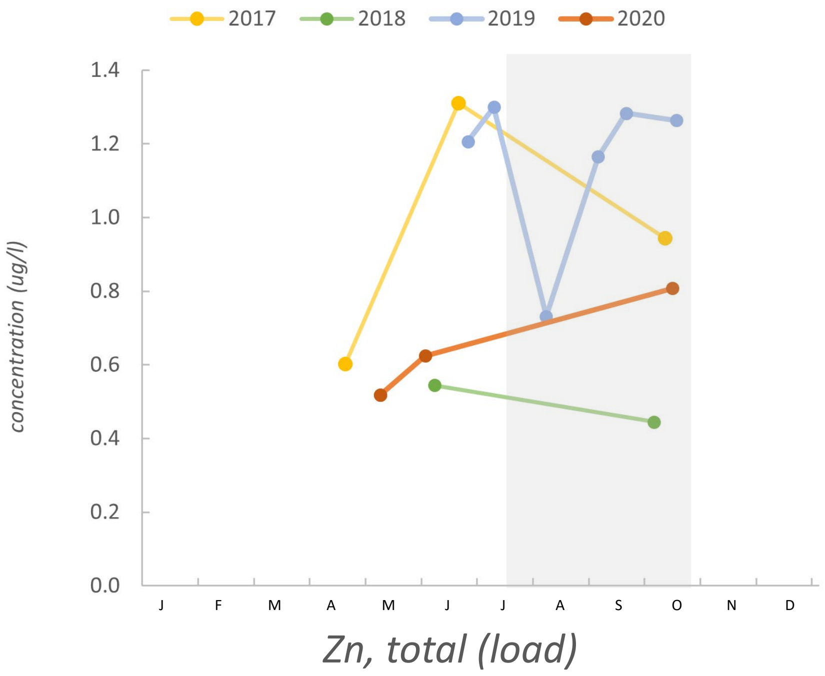
Mn, total (load)

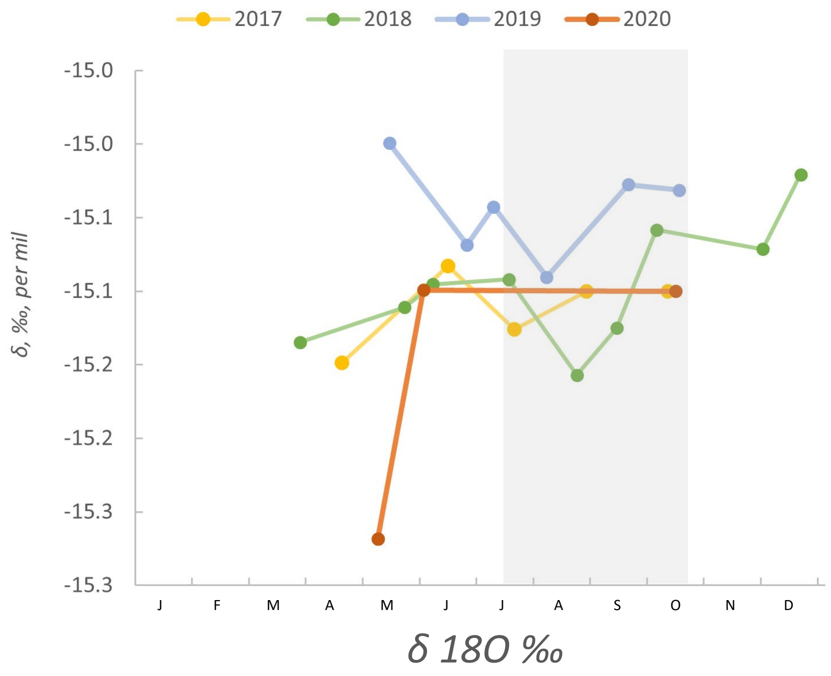
Blackhawk (CC50)

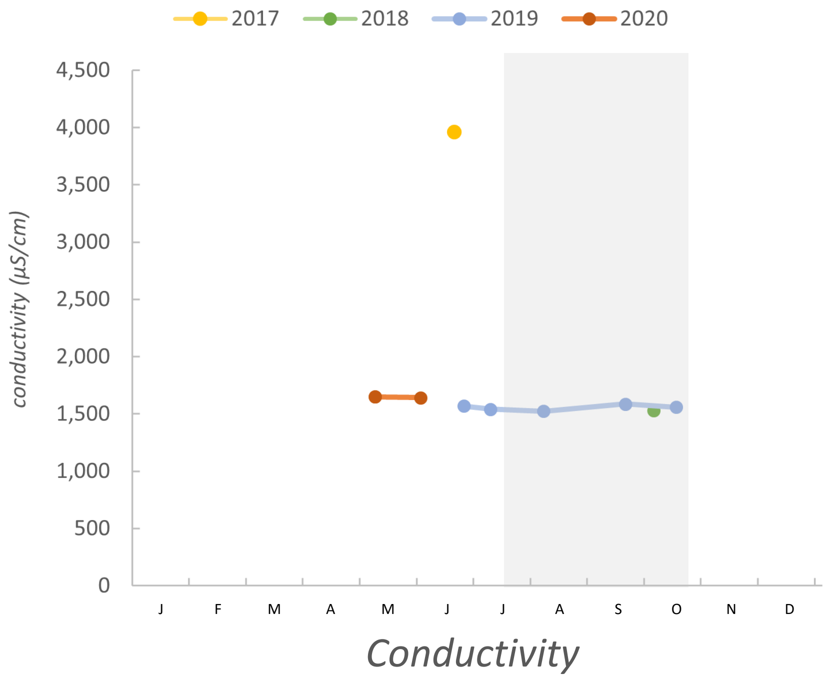




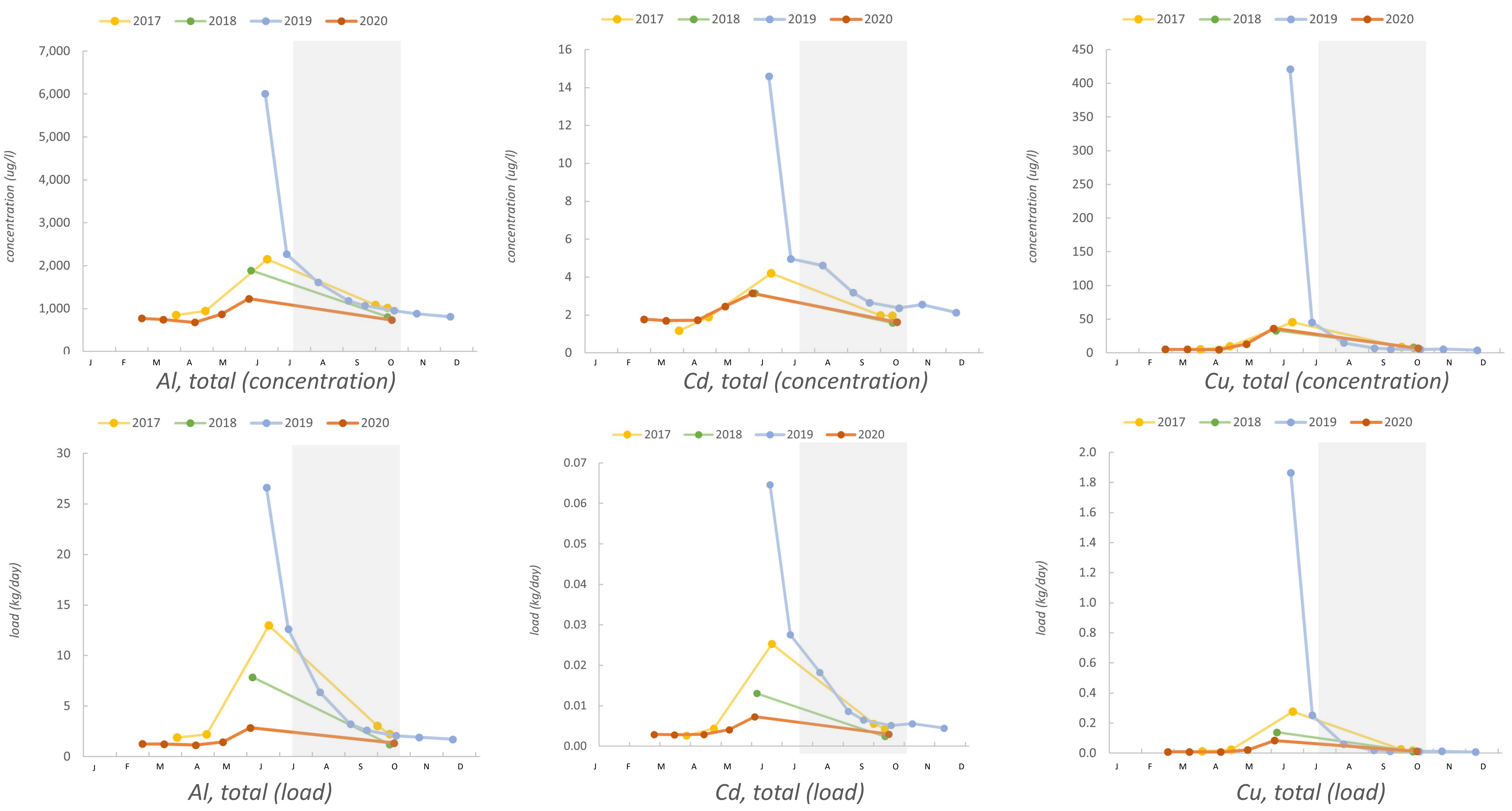




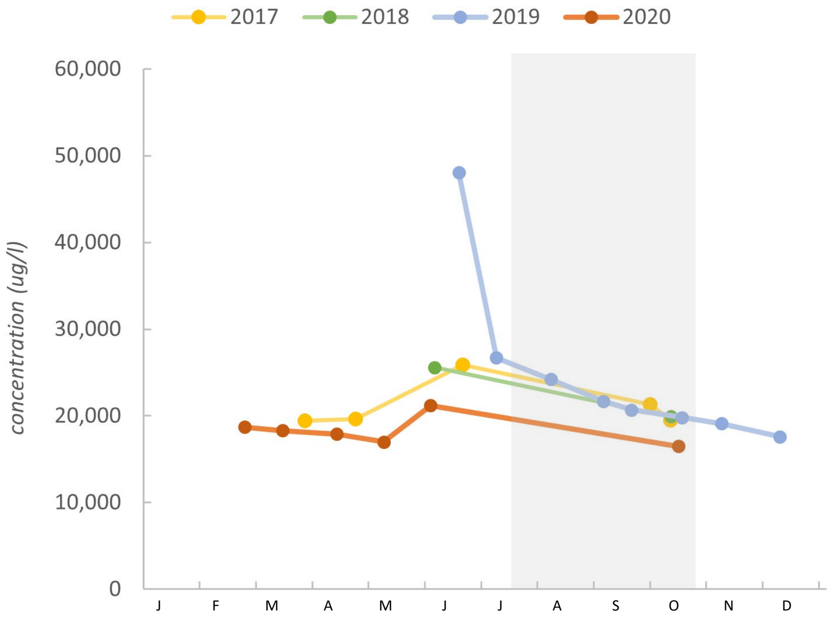




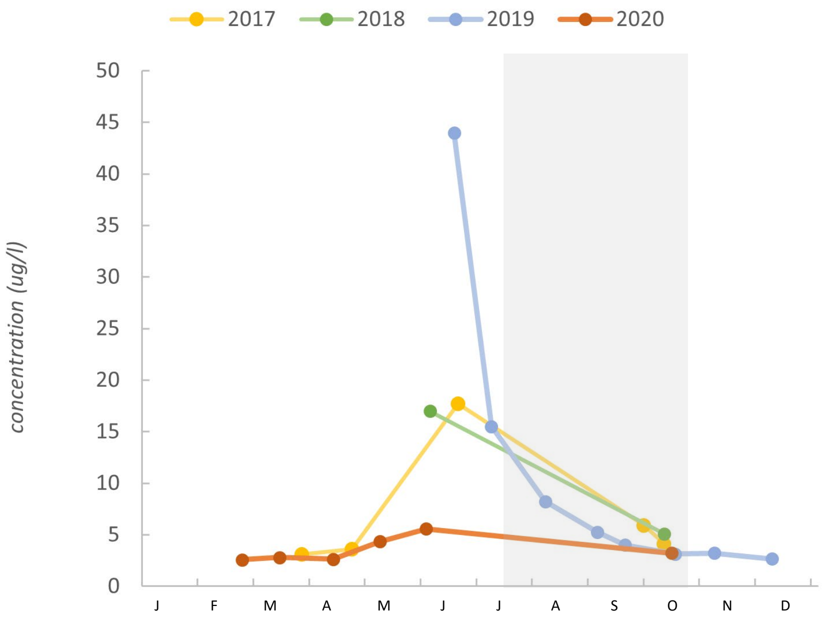
Natalie/Occidental (CC14)



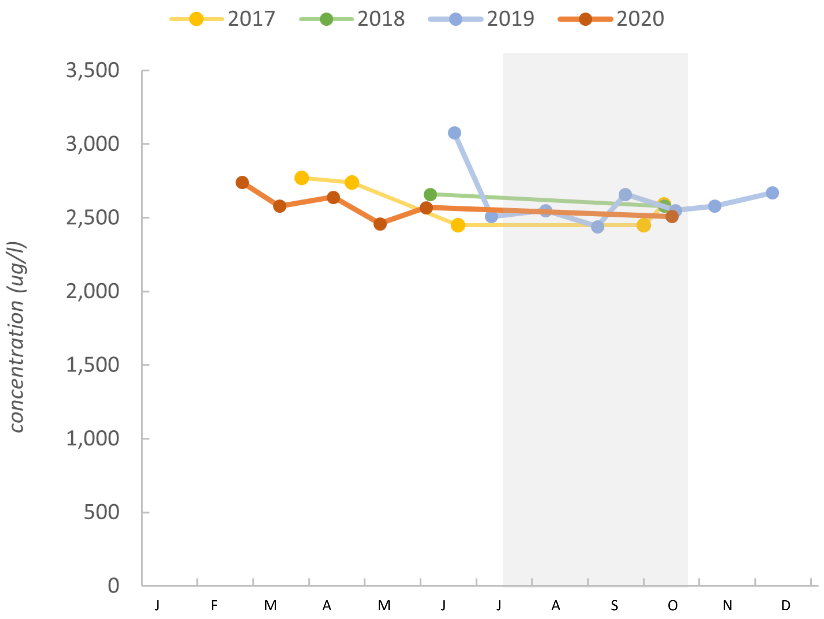
Natalie/Occidental (CC14)



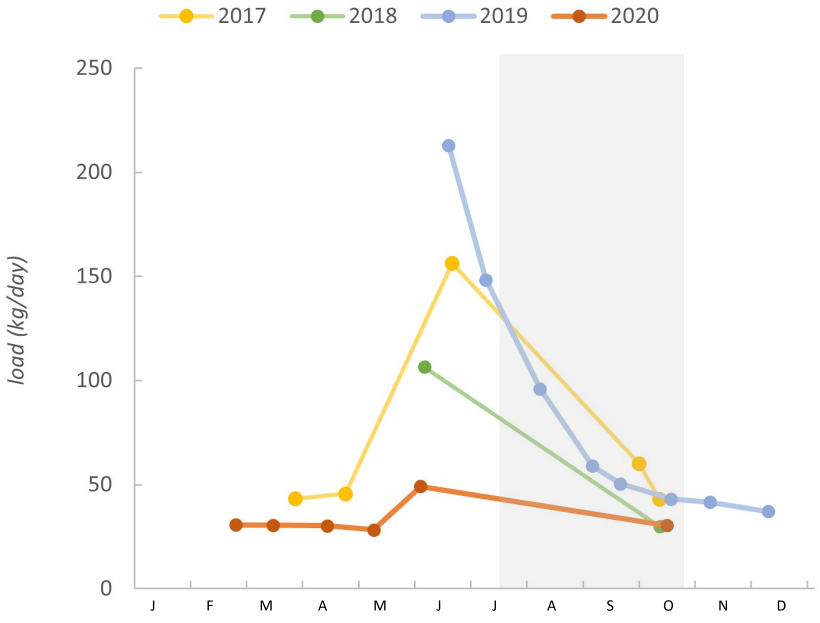
Fe, total (concentration)



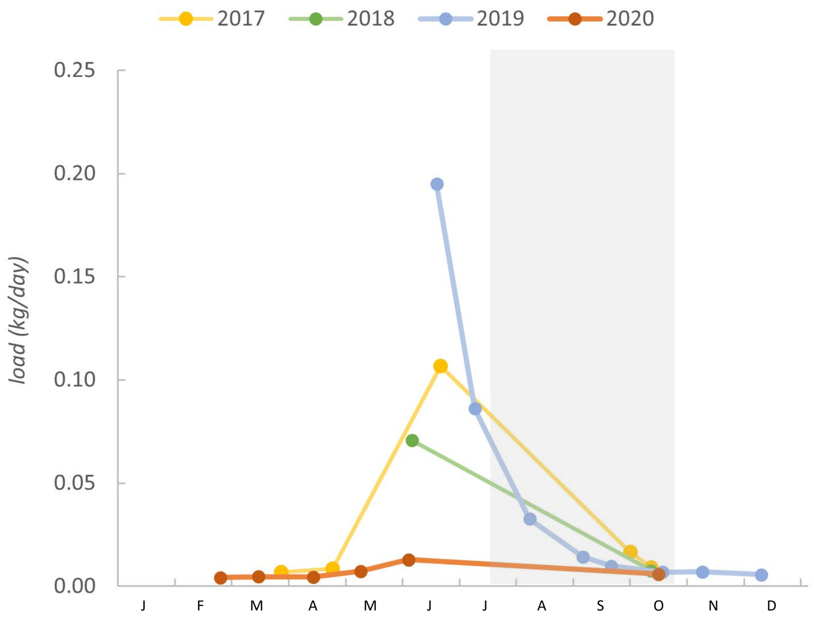
Pb, total (concentration)



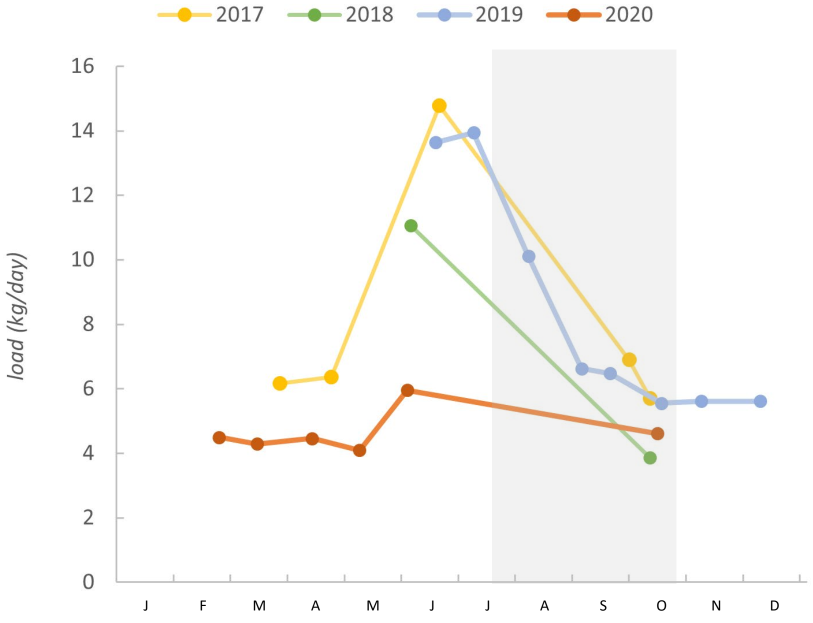
Mn, total (concentration)



Fe, total (load)

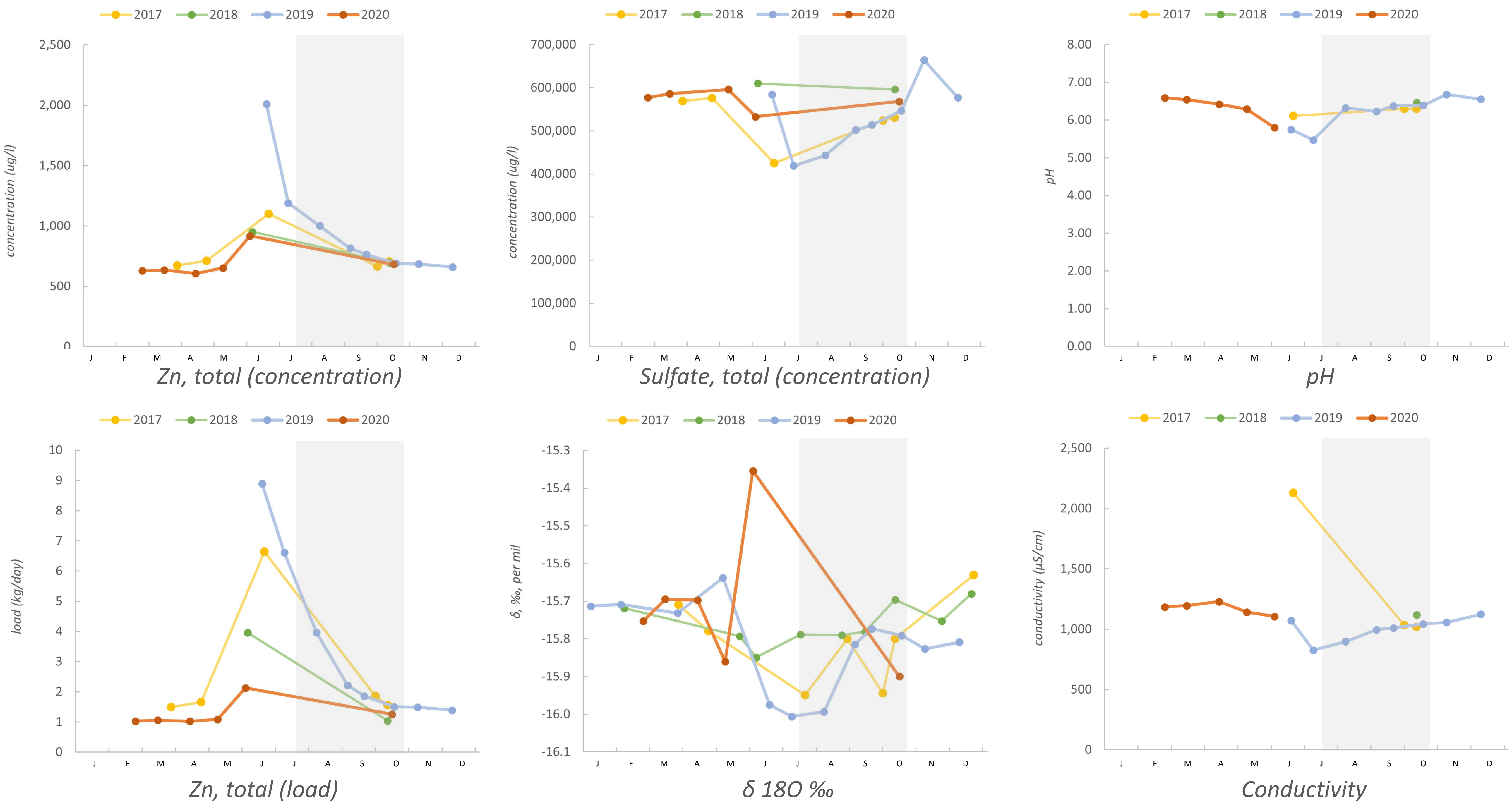


Pb, total (load)

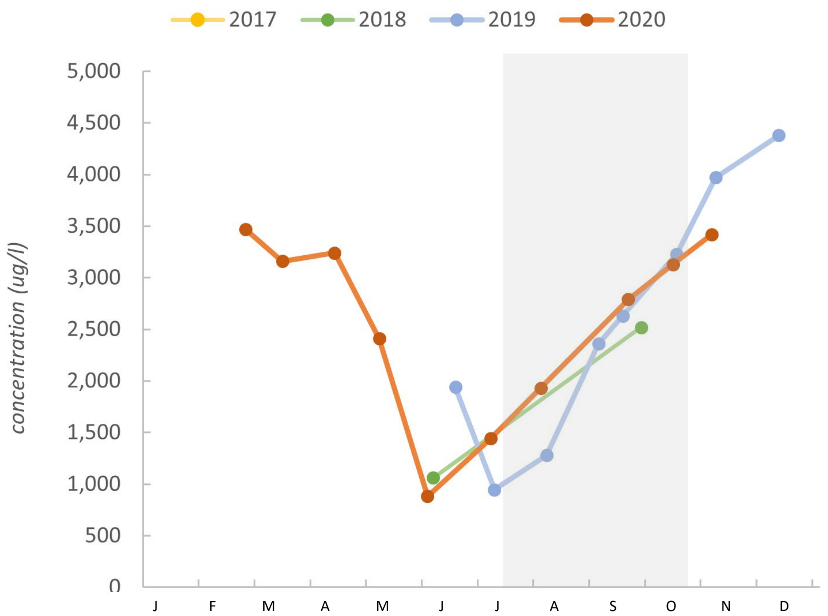


Mn, total (load)

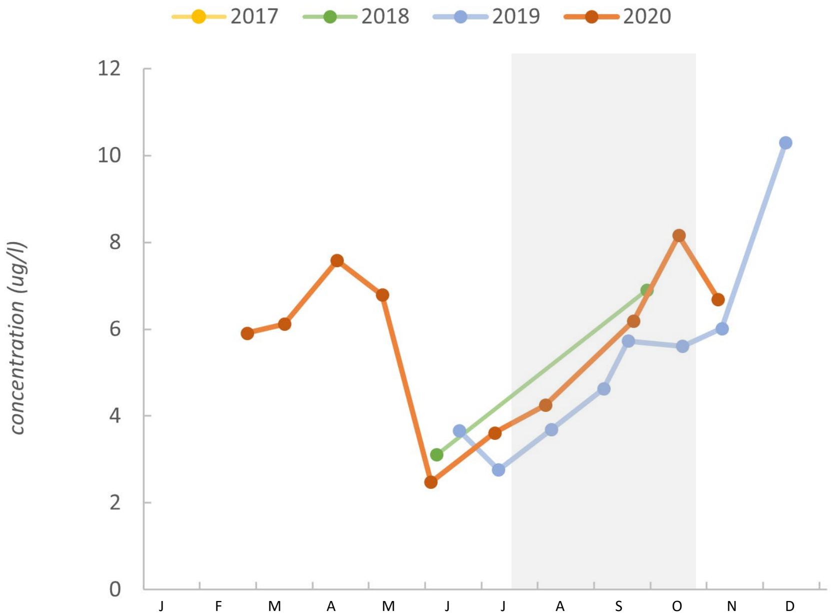
Natalie/Occidental (CC14)



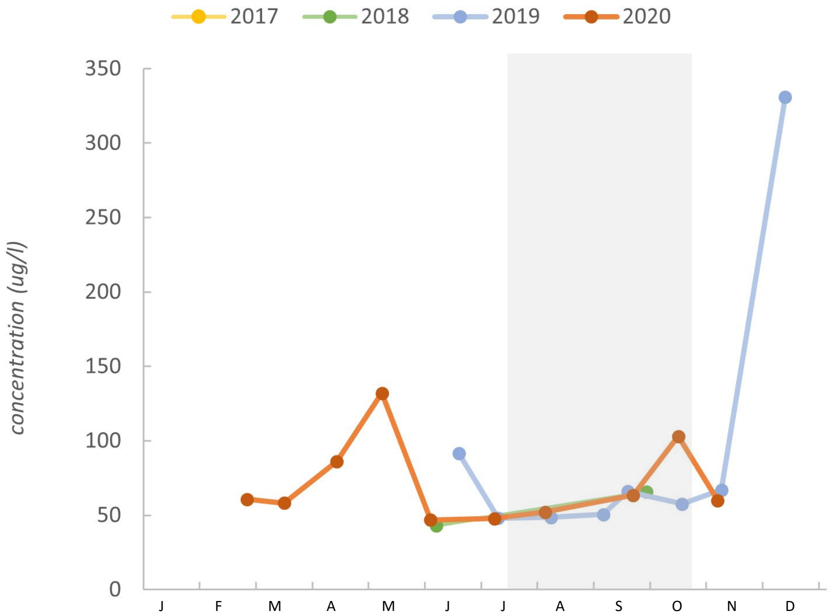
CCSG-1



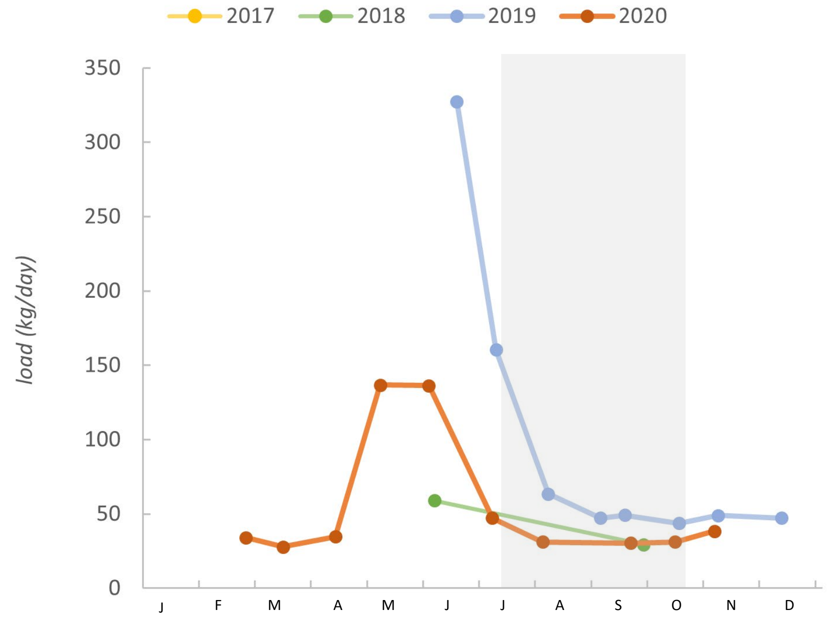
Al, total (concentration)



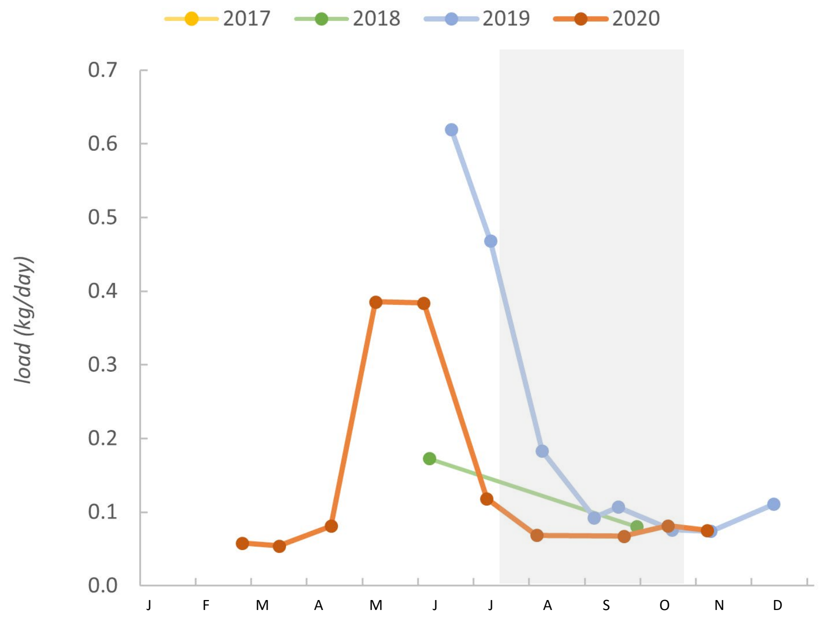
Cd, total (concentration)



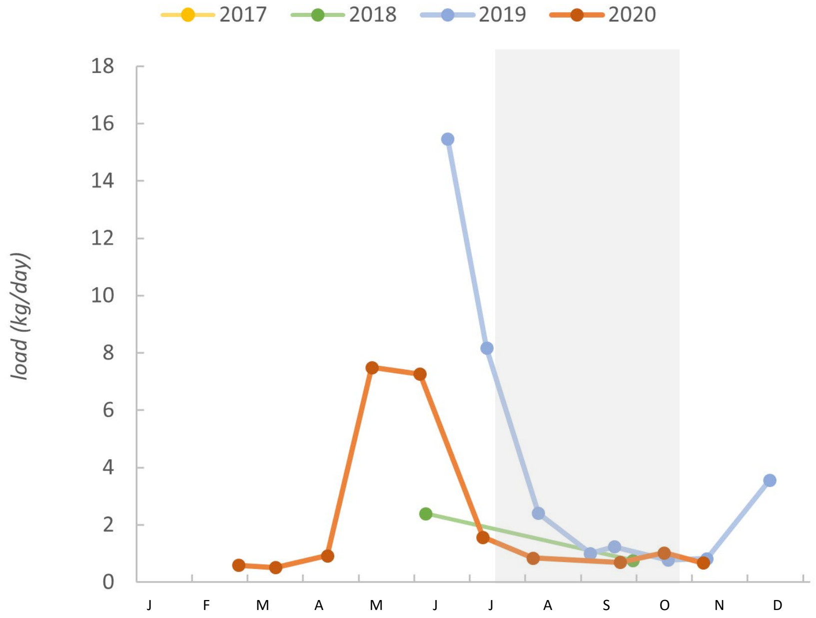
Cu, total (concentration)



Al, total (load)

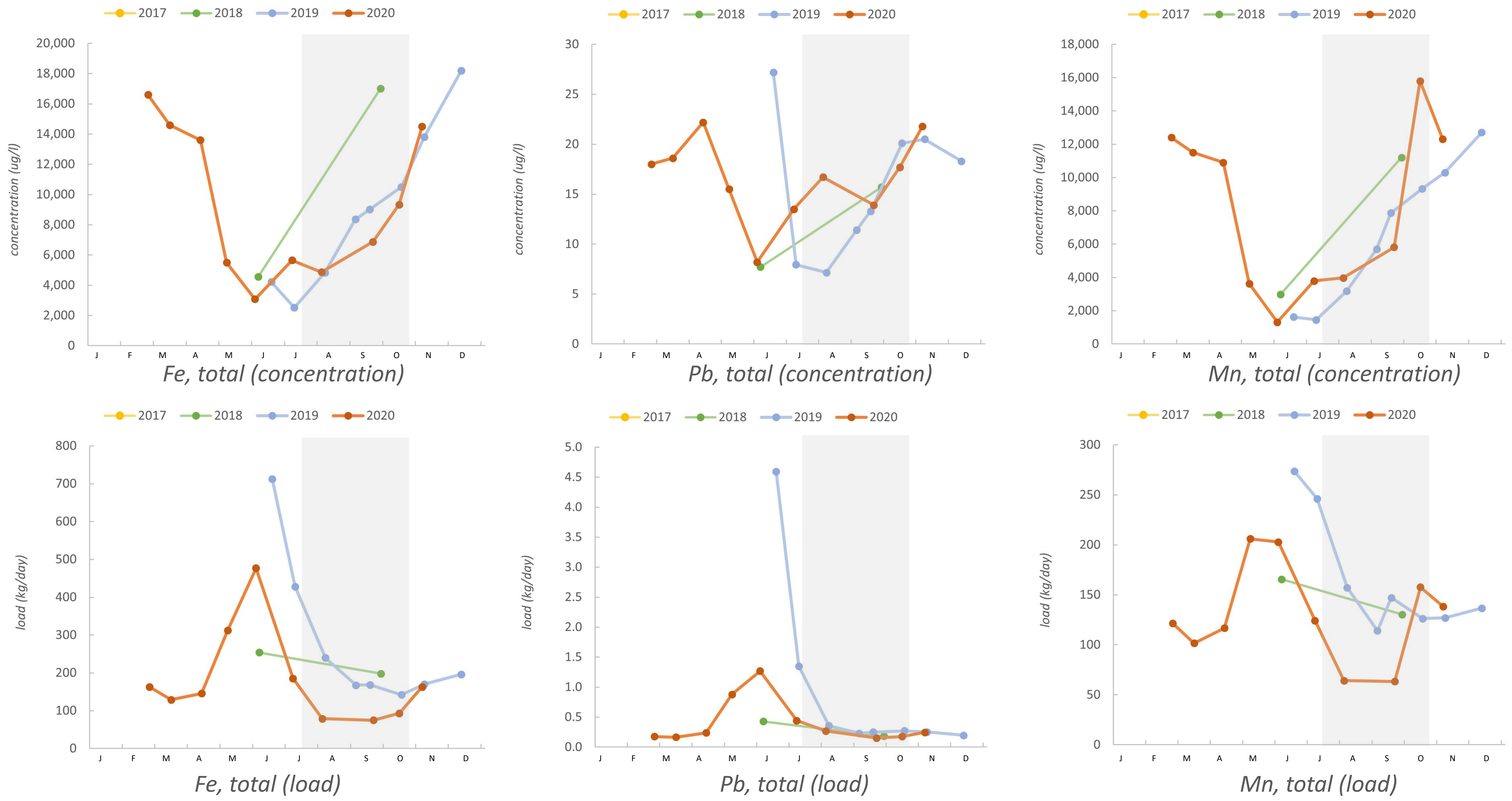


Cd, total (load)

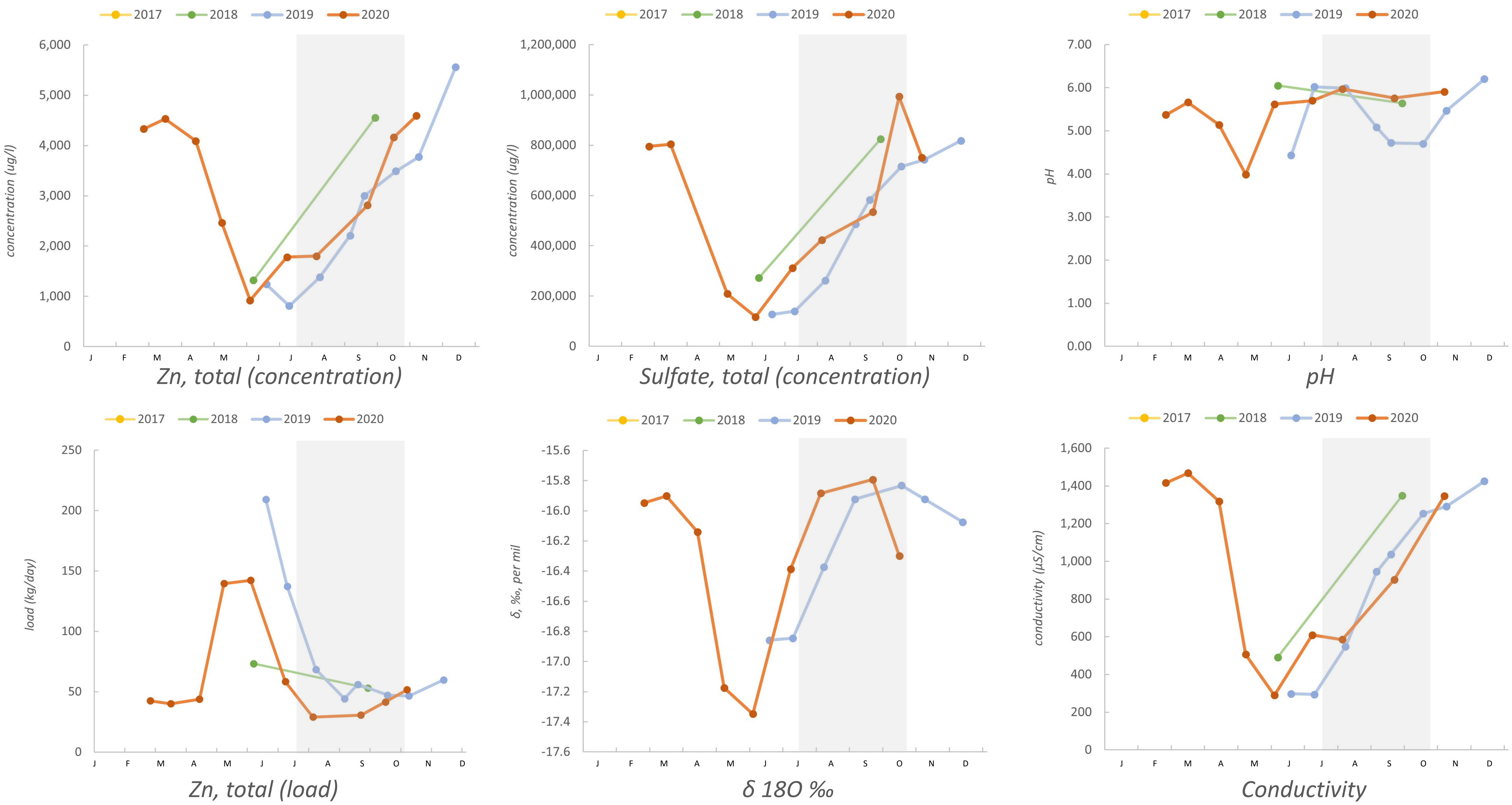


Cu, total (load)

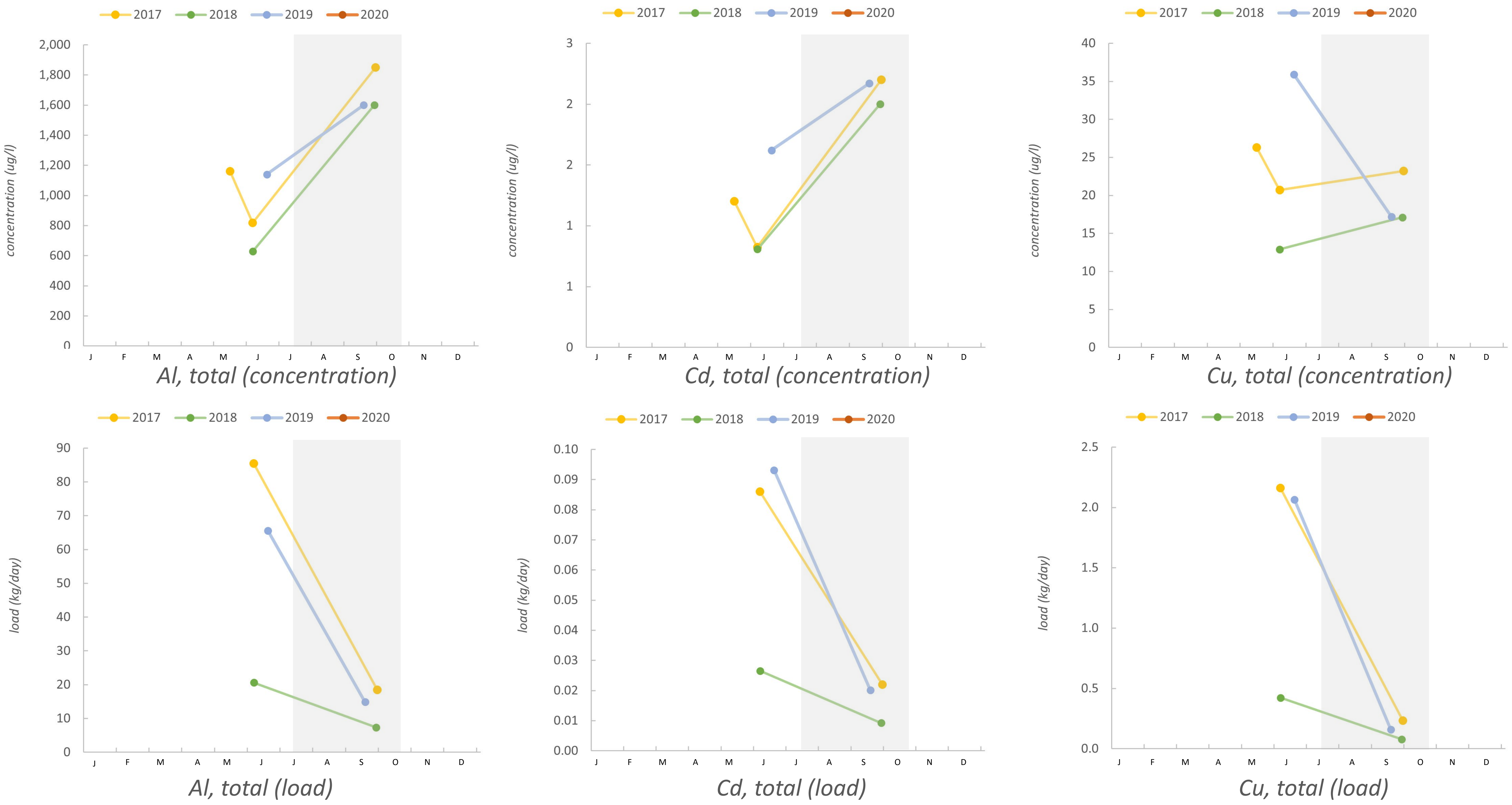
CCSG-1


2017 2018 2019 2020
concentration (ug/l)
20,000 18,000 16,000 14,000 12,000 10,000 8,000 6,000 4,000 2,000 0
J F M A M J J A S O N D
Fe, total (concentration)
concentration (ug/l)
30 25 20 15 10 5 0
Pb, total (concentration)
concentration (ug/l)
18,000 16,000 14,000 12,000 10,000 8,000 6,000 4,000 2,000 0
Mn, total (concentration)
load (kg/day)
800 700 600 500 400 300 200 100 0
Fe, total (load)
load (kg/day)
5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
Pb, total (load)
load (kg/day)
300 250 200 150 100 50 0
Mn, total (load)

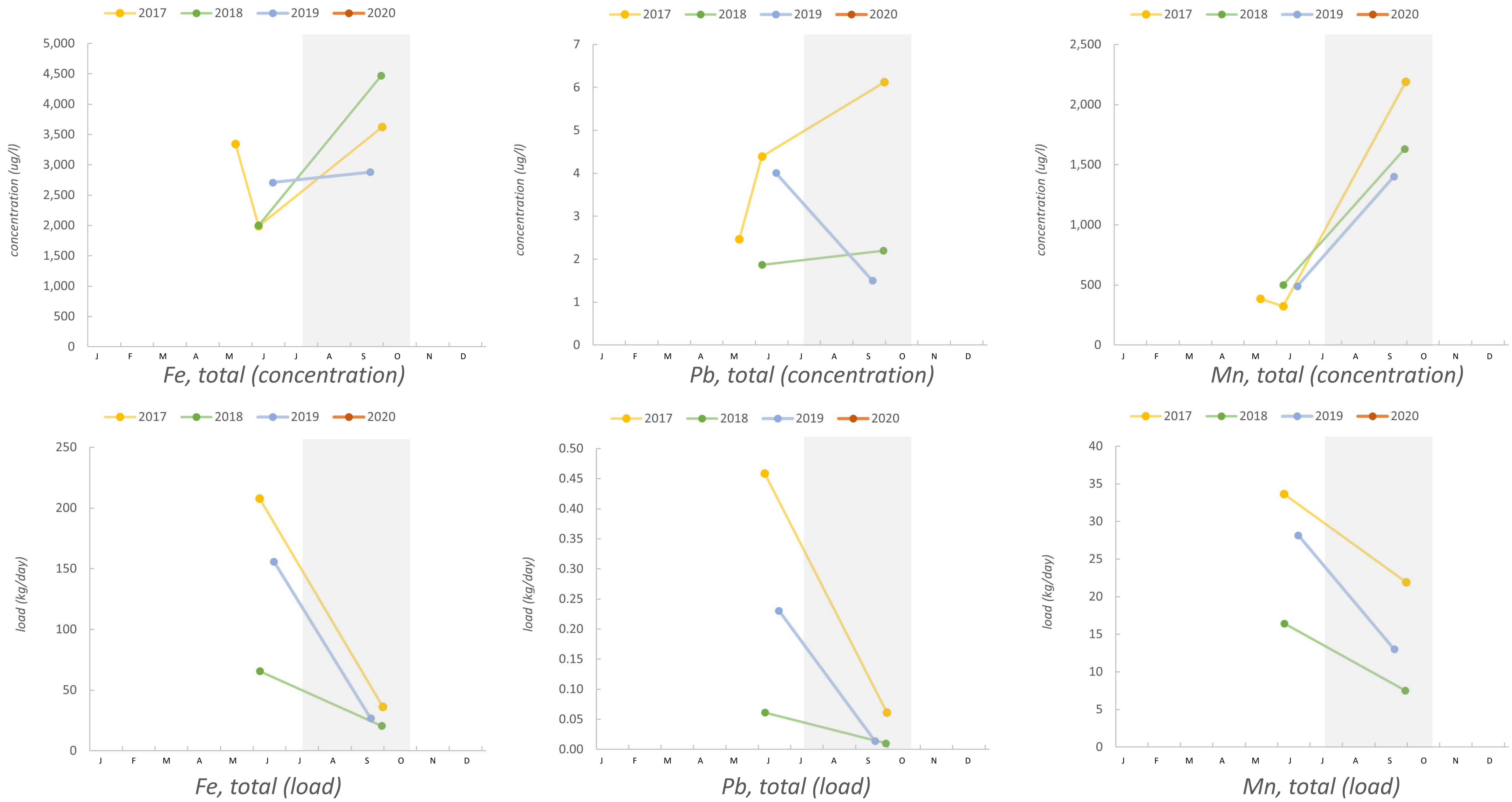
CCSG-1


2017 2018 2019 2020
concentration (ug/l)
Zn, total (concentration)
Sulfate, total (concentration)
pH
load (kg/day)
Zn, total (load)
δ, ‰, per mil
δ 18O ‰
conductivity (µS/cm)
Conductivity
J F M A M J J A S O N D

CCSG-2

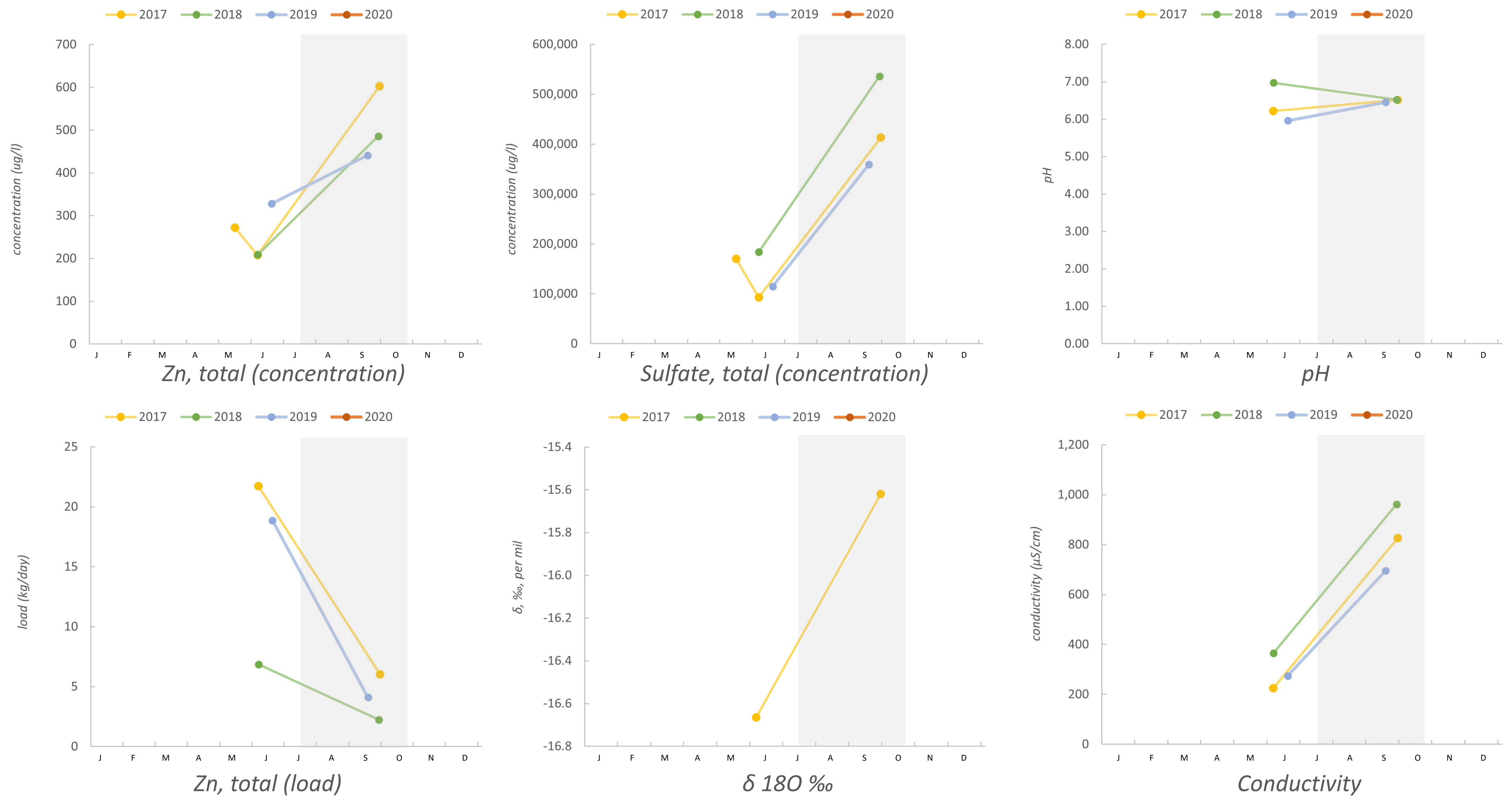

2017
2018
2019
2020
concentration (ug/l)
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
J F M A M J J A S O N D
Al, total (concentration)
3
2
2
1
1
0
Cd, total (concentration)
40
35
30
25
20
15
10
5
0
Cu, total (concentration)
load (kg/day)
90
80
70
60
50
40
30
20
10
0
Al, total (load)
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
Cd, total (load)
2.5
2.0
1.5
1.0
0.5
0.0
Cu, total (load)

CCSG-2

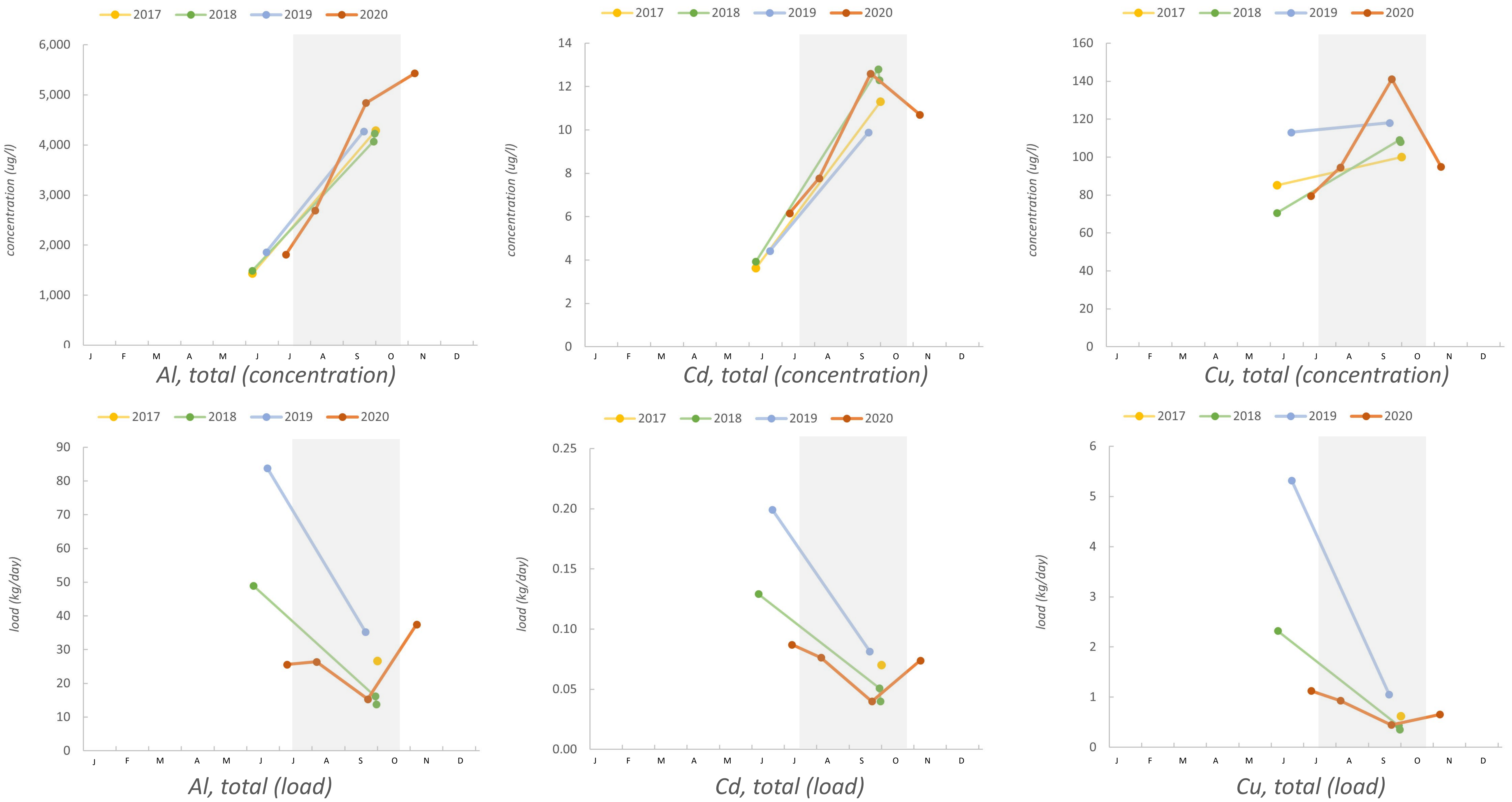


2017
2018
2019
2020
concentration (ug/l)
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
J F M A M J J A S O N D
Fe, total (concentration)
7
6
5
4
3
2
1
0
Pb, total (concentration)
2,500
2,000
1,500
1,000
500
0
Mn, total (concentration)
load (kg/day)
250
200
150
100
50
0
Fe, total (load)
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Pb, total (load)
40
35
30
25
20
15
10
5
0
Mn, total (load)

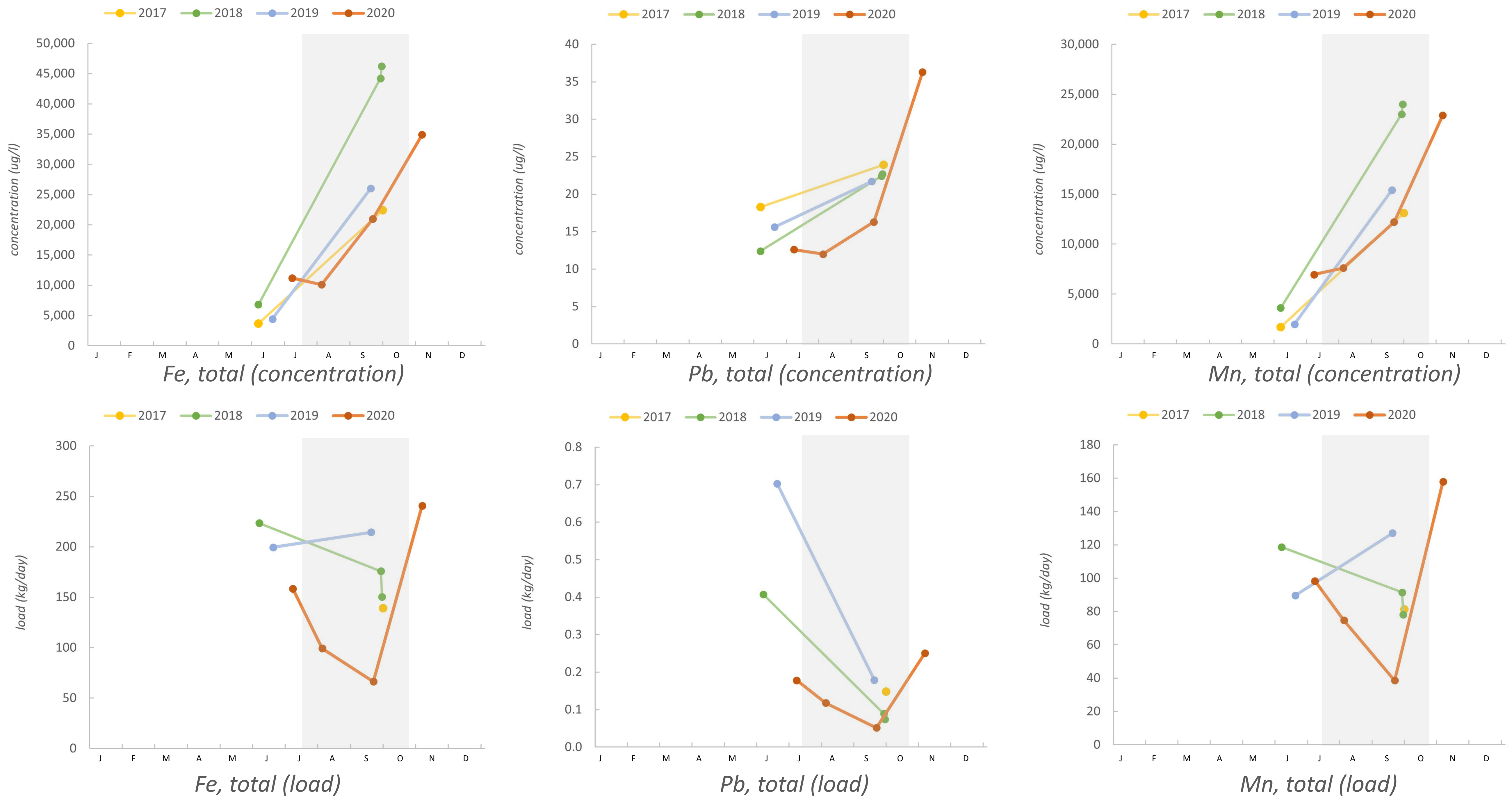
CCSG-2


2017
2018
2019
2020
concentration (ug/l)
700
600
500
400
300
200
100
0
J F M A M J J A S O N D
Zn, total (concentration)
concentration (ug/l)
600,000
500,000
400,000
300,000
200,000
100,000
0
Sulfate, total (concentration)
pH
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
pH
load (kg/day)
25
20
15
10
5
0
Zn, total (load)
δ, ‰, per mil
-15.4
-15.6
-15.8
-16.0
-16.2
-16.4
-16.6
-16.8
δ 18O ‰
conductivity (µS/cm)
1,200
1,000
800
600
400
200
0
Conductivity

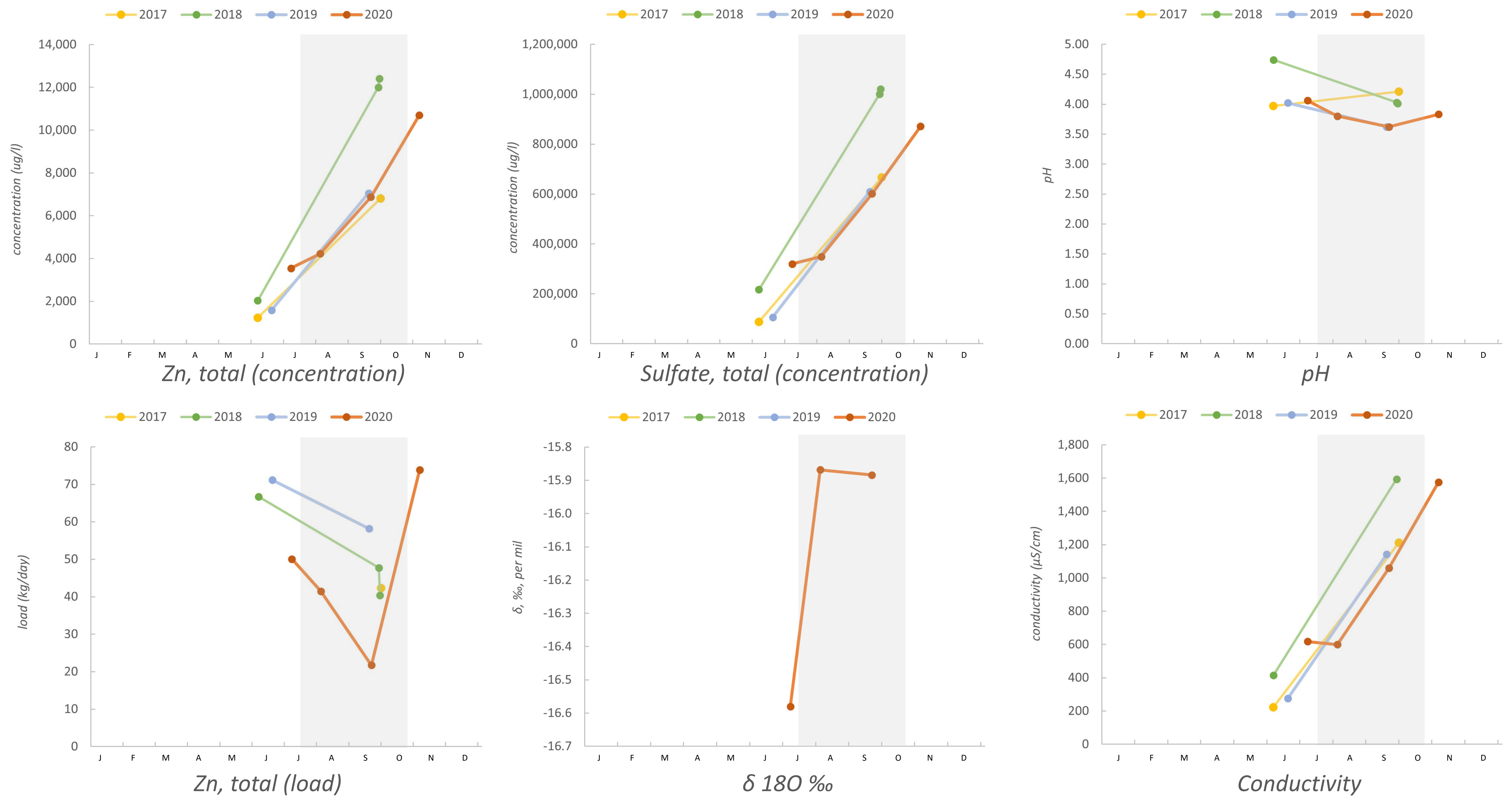
CCSG-3


2017
2018
2019
2020
concentration (ug/l)
0
1,000
2,000
3,000
4,000
5,000
6,000
J F M A M J J A S O N D
Al, total (concentration)
concentration (ug/l)
0
2
4
6
8
10
12
14
Cd, total (concentration)
concentration (ug/l)
0
20
40
60
80
100
120
140
160
Cu, total (concentration)
load (kg/day)
0
10
20
30
40
50
60
70
80
90
Al, total (load)
load (kg/day)
0.00
0.05
0.10
0.15
0.20
0.25
Cd, total (load)
load (kg/day)
0
1
2
3
4
5
6
Cu, total (load)

CCSG-3

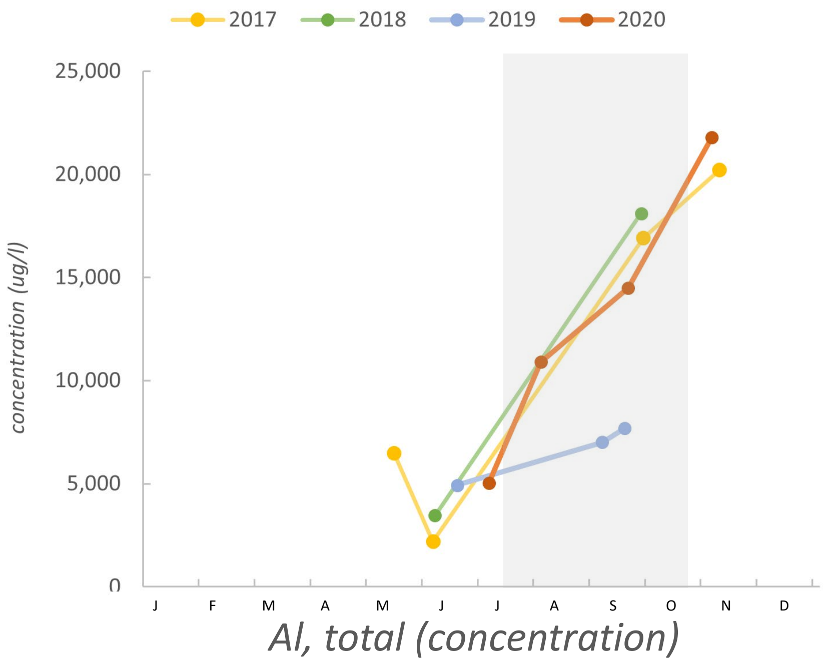

2017
2018
2019
2020
concentration (ug/l)
load (kg/day)
J F M A M J J A S O N D
Fe, total (concentration)
Pb, total (concentration)
Mn, total (concentration)
Fe, total (load)
Pb, total (load)
Mn, total (load)

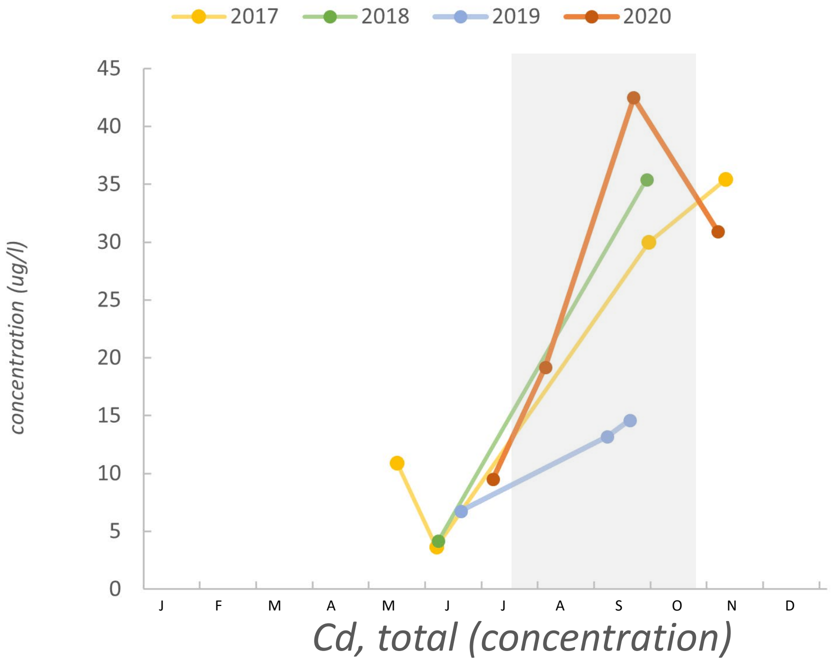
CCSG-3

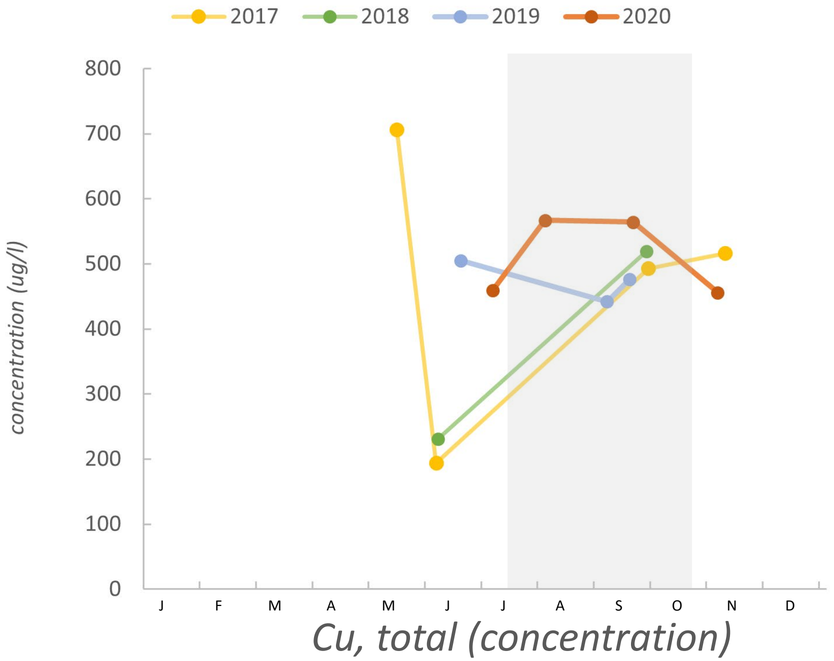


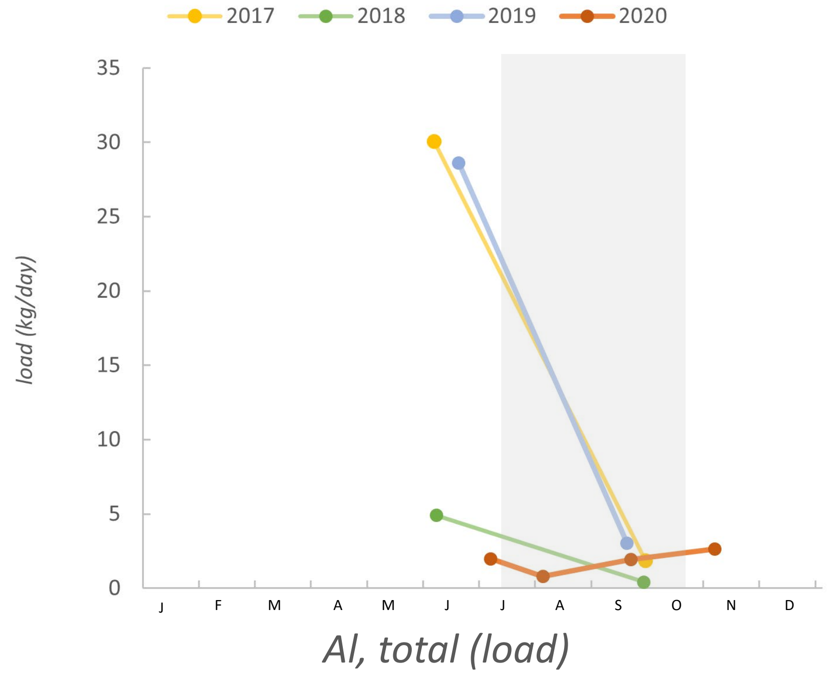
2017
2018
2019
2020
concentration (ug/l)
Zn, total (concentration)
concentration (ug/l)
Sulfate, total (concentration)
pH
pH
load (kg/day)
Zn, total (load)
δ, ‰, per mil
δ 18O ‰
conductivity (µS/cm)
Conductivity
J F M A M J J A S O N D

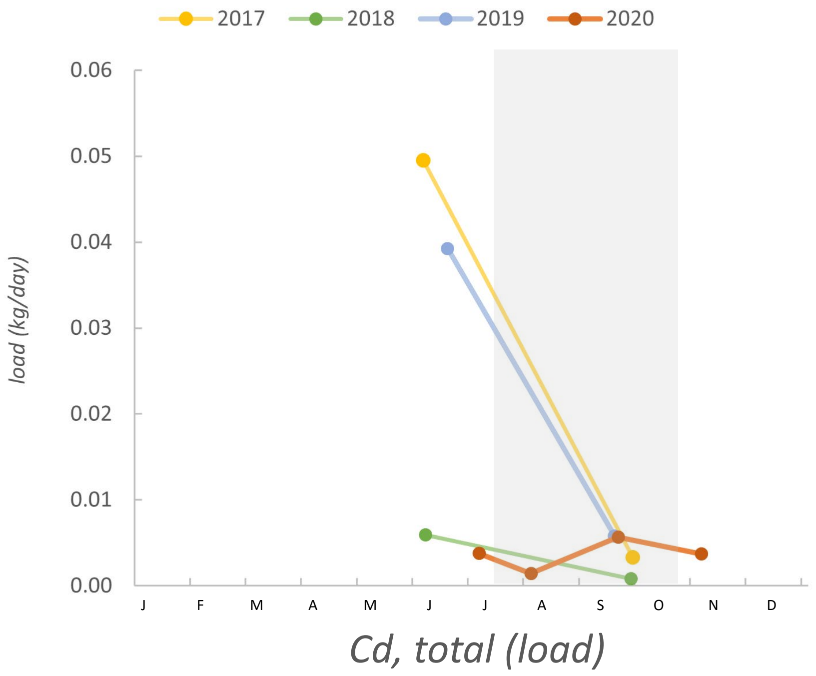
CCSG-5

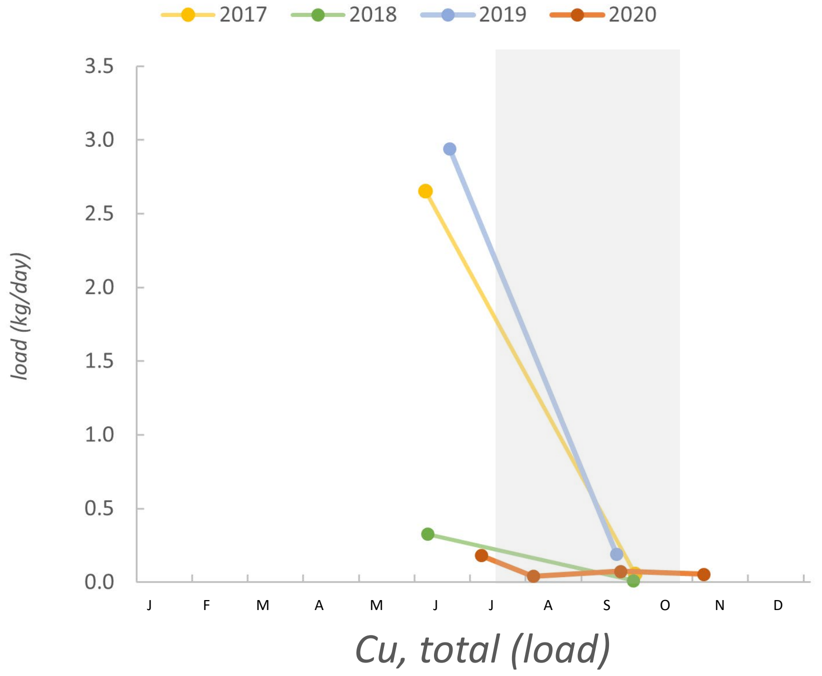

2017 2018 2019 2020
concentration (ug/l)
25,000
20,000
15,000
10,000
5,000
0
J F M A M J J A S O N D
Al, total (concentration)


2017 2018 2019 2020
concentration (ug/l)
45
40
35
30
25
20
15
10
5
0
J F M A M J J A S O N D
Cd, total (concentration)


2017 2018 2019 2020
concentration (ug/l)
800
700
600
500
400
300
200
100
0
J F M A M J J A S O N D
Cu, total (concentration)


2017 2018 2019 2020
load (kg/day)
35
30
25
20
15
10
5
0
J F M A M J J A S O N D
Al, total (load)


2017 2018 2019 2020
load (kg/day)
0.06
0.05
0.04
0.03
0.02
0.01
0.00
J F M A M J J A S O N D
Cd, total (load)

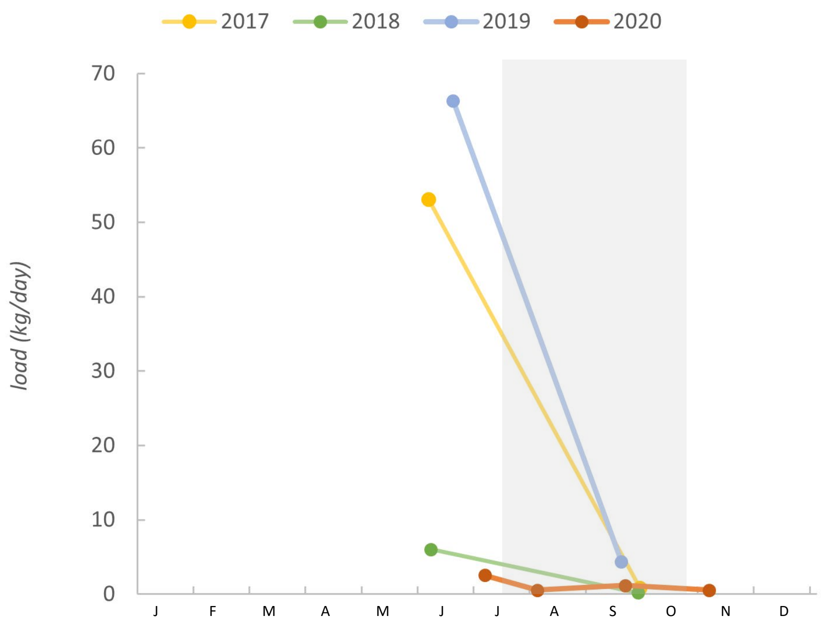

2017 2018 2019 2020
load (kg/day)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
J F M A M J J A S O N D
Cu, total (load)

CCSG-5

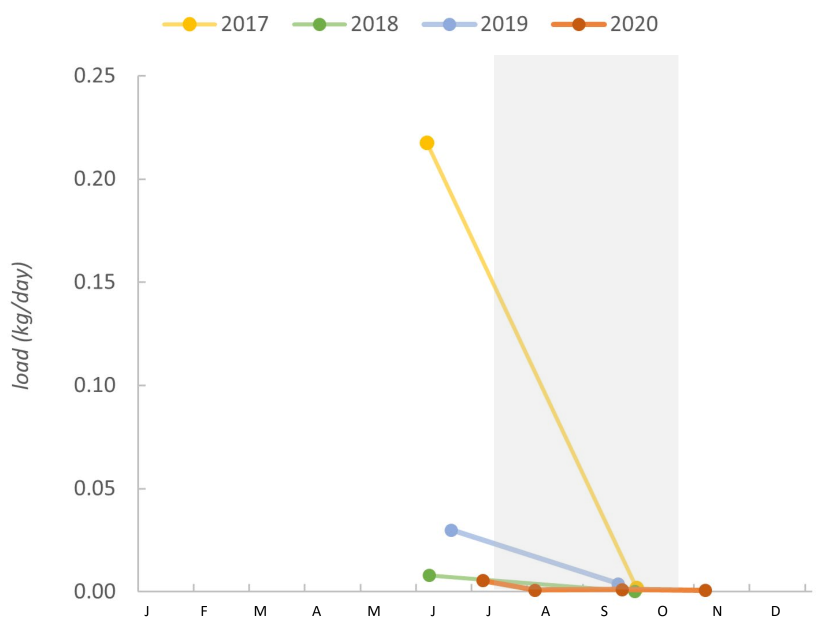
Fe, total (concentration)

Pb, total (concentration)

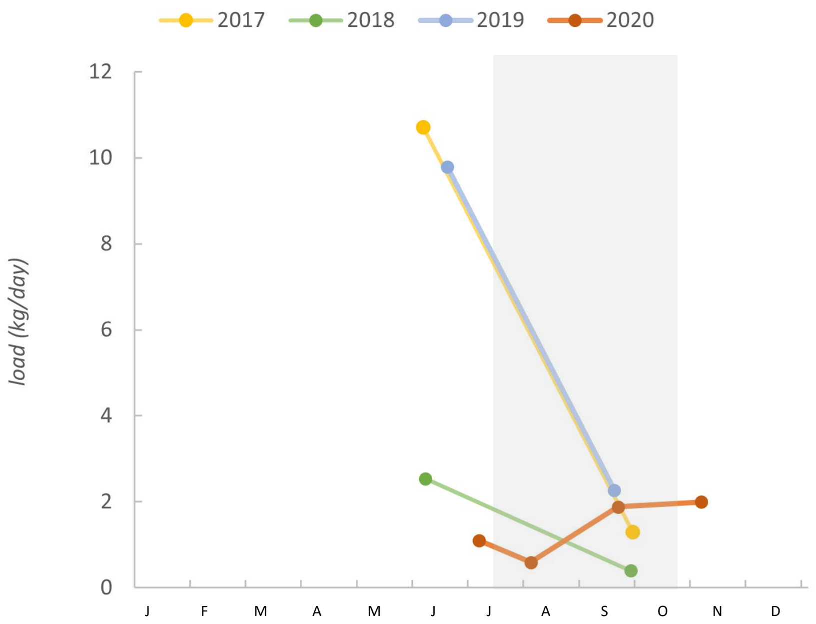
Mn, total (concentration)



Fe, total (load)

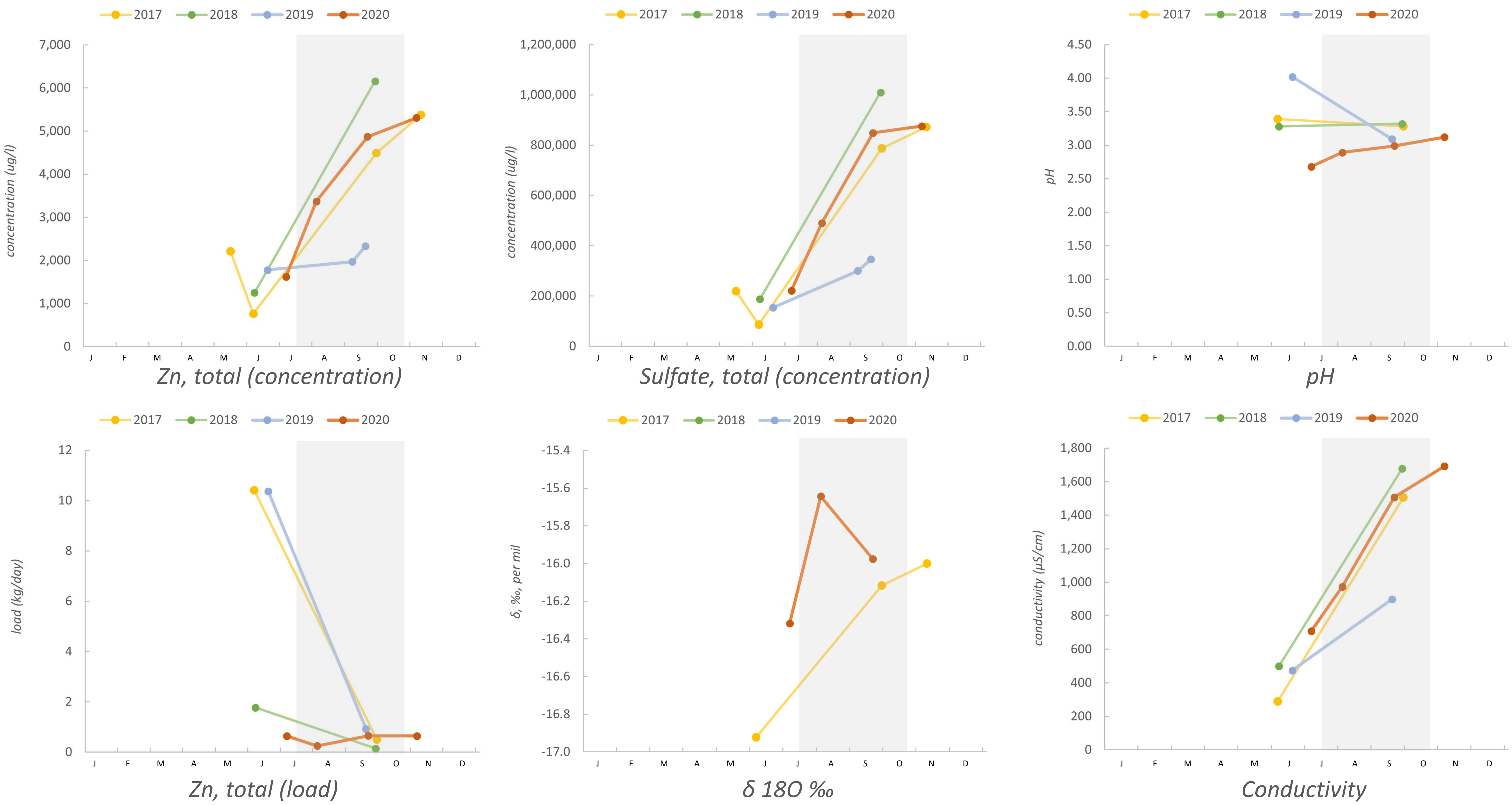


Pb, total (load)

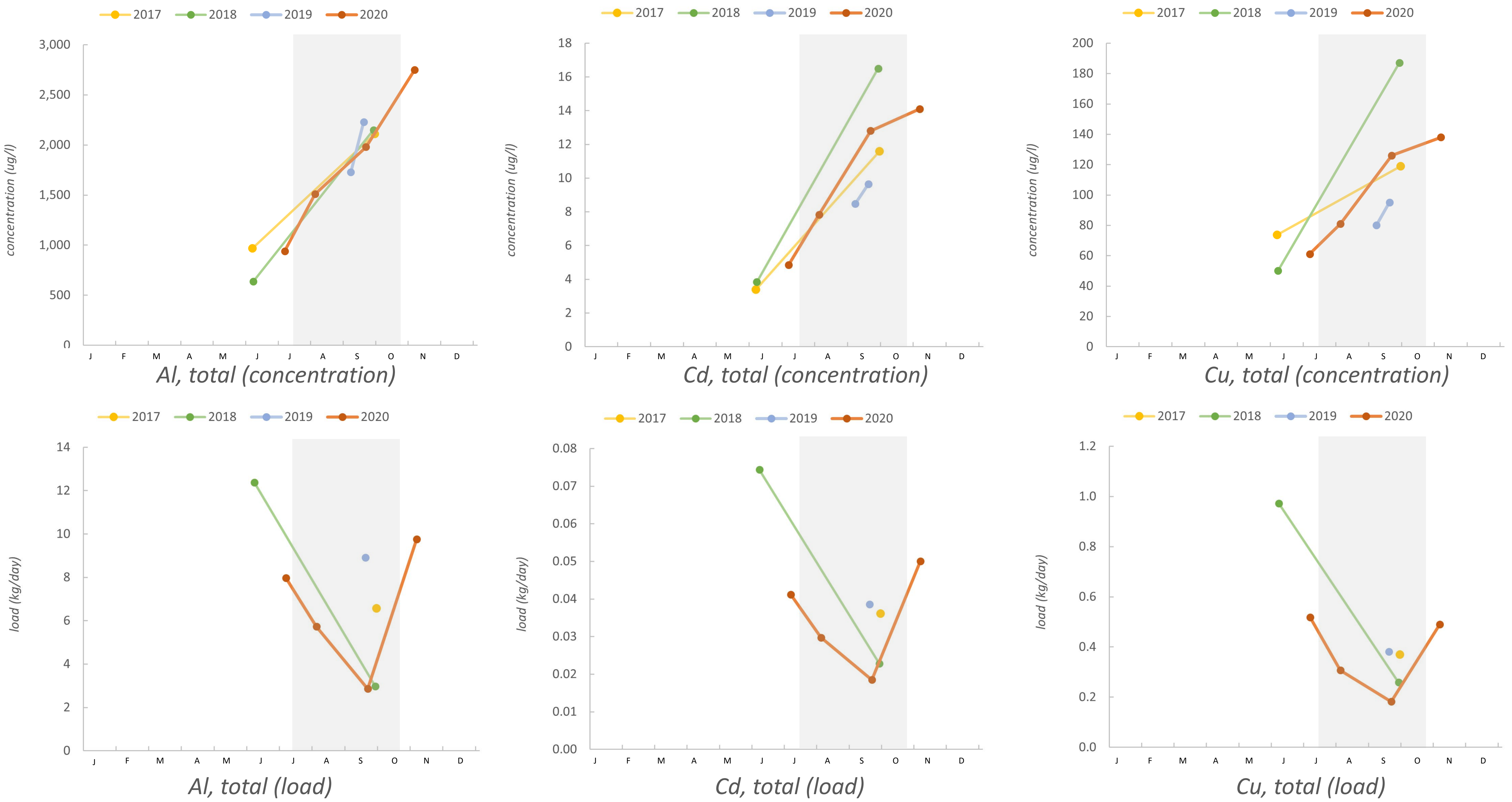


Mn, total (load)

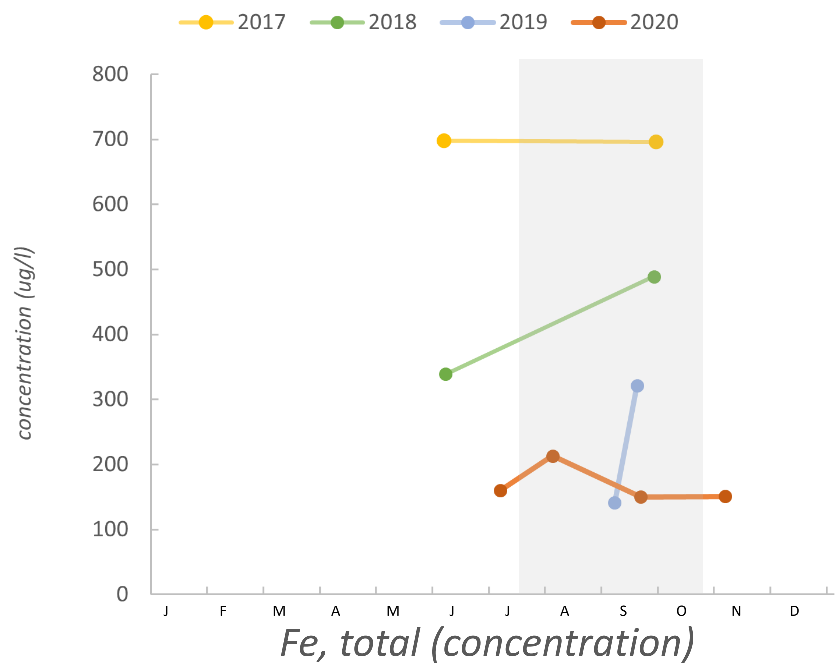
CCSG-5

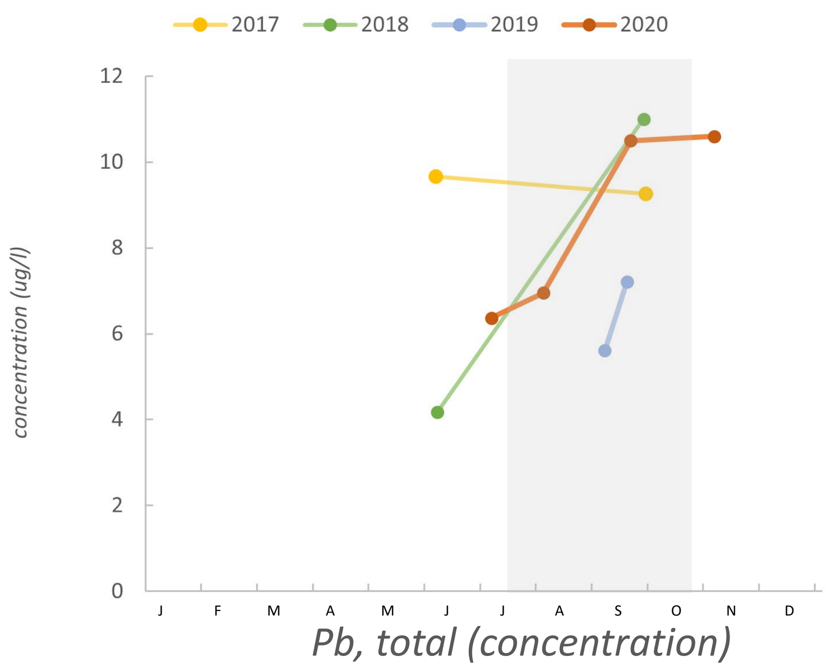

2017
2018
2019
2020
concentration (ug/l)
J F M A M J J A S O N D
Zn, total (concentration)
Sulfate, total (concentration)
pH
load (kg/day)
Zn, total (load)
δ, ‰, per mil
δ 18O ‰
conductivity (µS/cm)
Conductivity

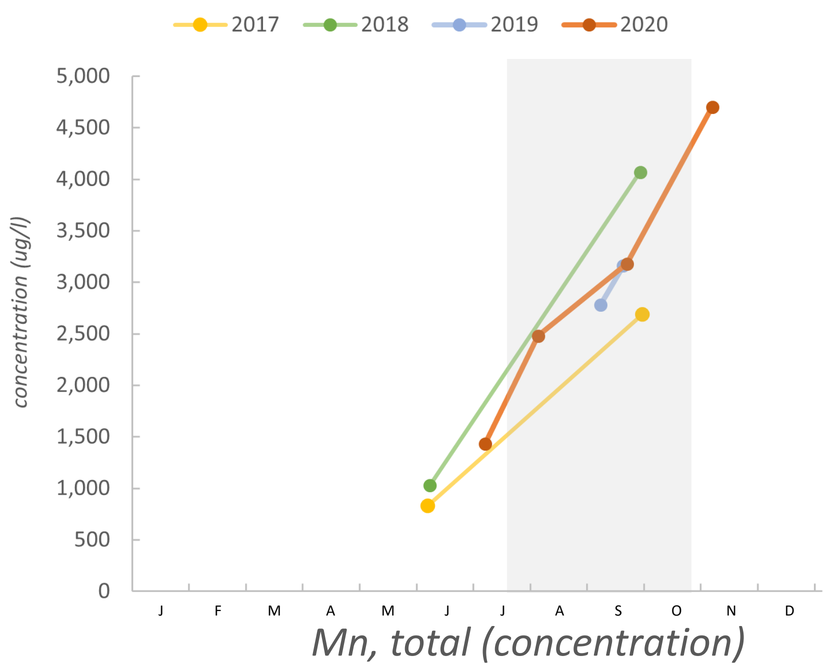
CCSG-6

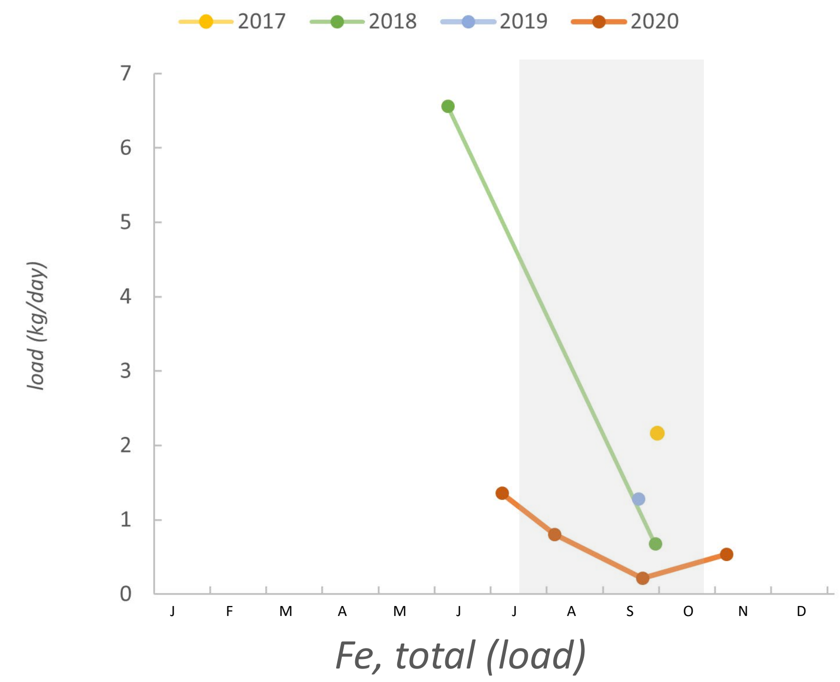

2017
2018
2019
2020
3,000
2,500
2,000
1,500
1,000
500
0
concentration (ug/l)
J F M A M J J A S O N D
Al, total (concentration)
18
16
14
12
10
8
6
4
2
0
concentration (ug/l)
Cd, total (concentration)
200
180
160
140
120
100
80
60
40
20
0
concentration (ug/l)
Cu, total (concentration)
14
12
10
8
6
4
2
0
load (kg/day)
Al, total (load)
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
load (kg/day)
Cd, total (load)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
load (kg/day)
Cu, total (load)

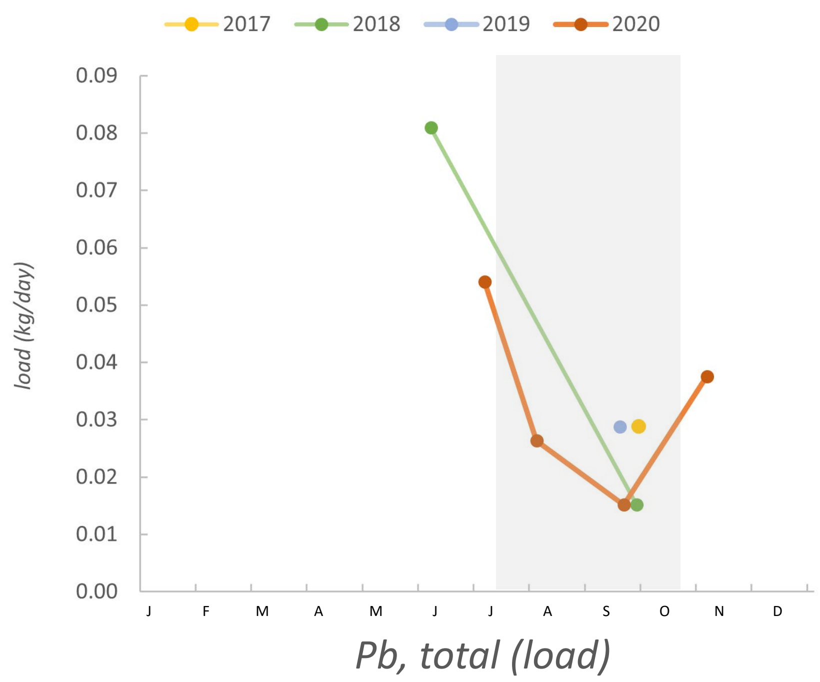
CCSG-6


2017
2018
2019
2020
800
700
600
500
400
300
200
100
0
concentration (ug/l)
J F M A M J J A S O N D
Fe, total (concentration)


2017
2018
2019
2020
12
10
8
6
4
2
0
concentration (ug/l)
J F M A M J J A S O N D
Pb, total (concentration)

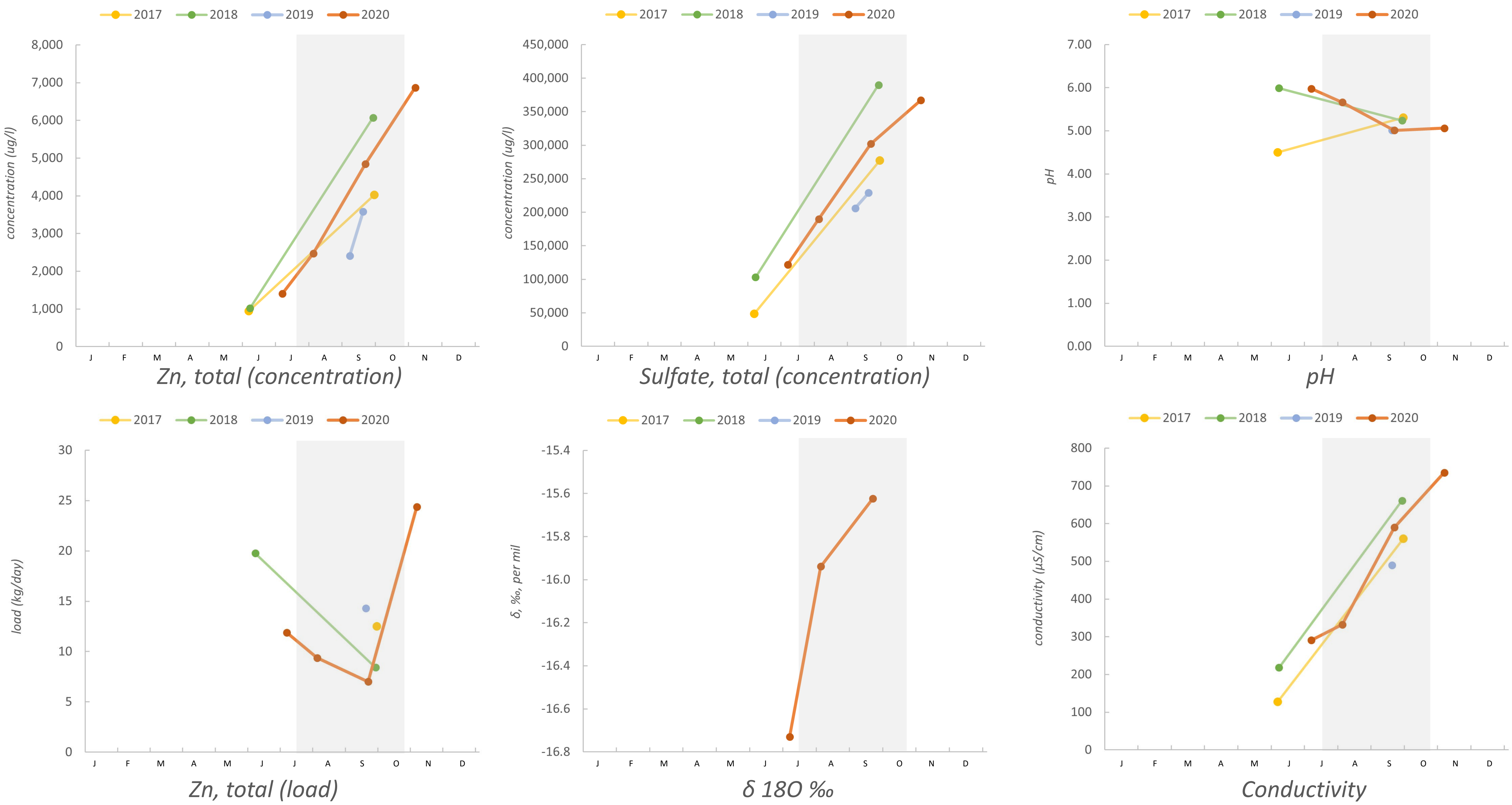

2017
2018
2019
2020
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
concentration (ug/l)
J F M A M J J A S O N D
Mn, total (concentration)


2017
2018
2019
2020
7
6
5
4
3
2
1
0
load (kg/day)
J F M A M J J A S O N D
Fe, total (load)


2017
2018
2019
2020
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
load (kg/day)
J F M A M J J A S O N D
Pb, total (load)

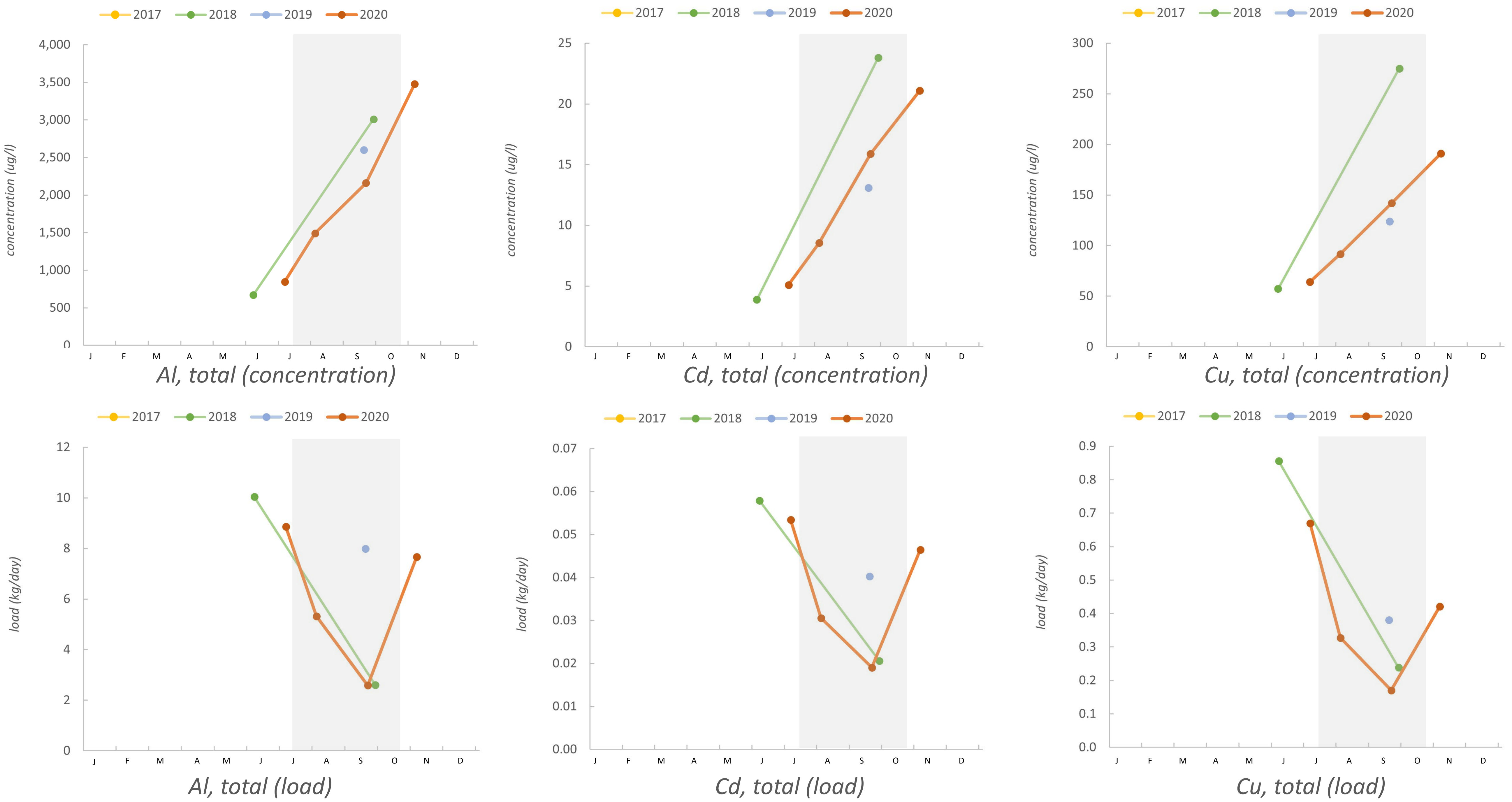

2017
2018
2019
2020
25
20
15
10
5
0
load (kg/day)
J F M A M J J A S O N D
Mn, total (load)

CCSG-6

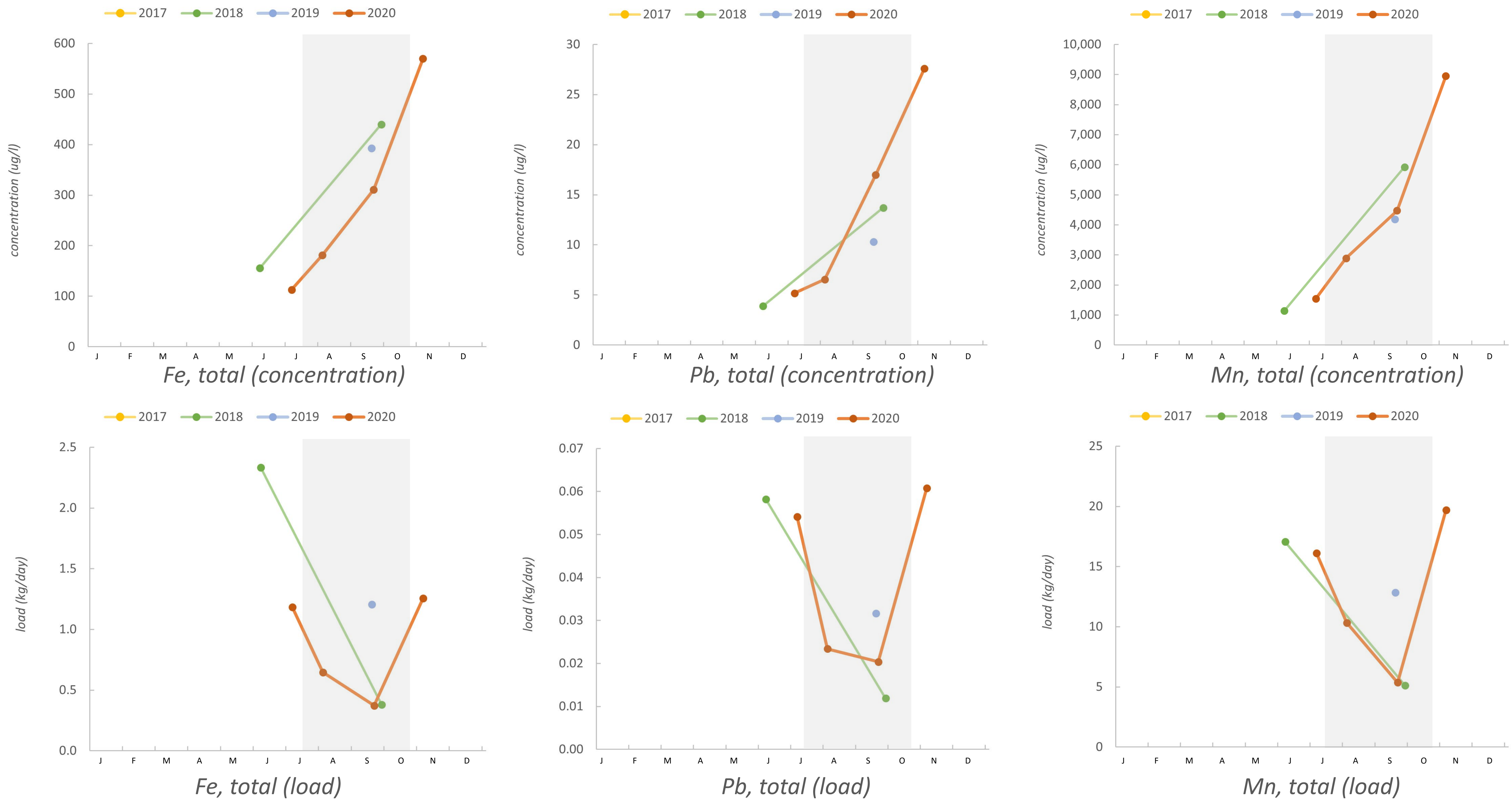


2017
2018
2019
2020
concentration (ug/l)
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
J F M A M J J A S O N D
Zn, total (concentration)
concentration (ug/l)
450,000
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
Sulfate, total (concentration)
pH
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
pH
load (kg/day)
30
25
20
15
10
5
0
Zn, total (load)
δ, ‰, per mil
-15.4
-15.6
-15.8
-16.0
-16.2
-16.4
-16.6
-16.8
δ 18O ‰
conductivity (µS/cm)
800
700
600
500
400
300
200
100
0
Conductivity

CCSG-7

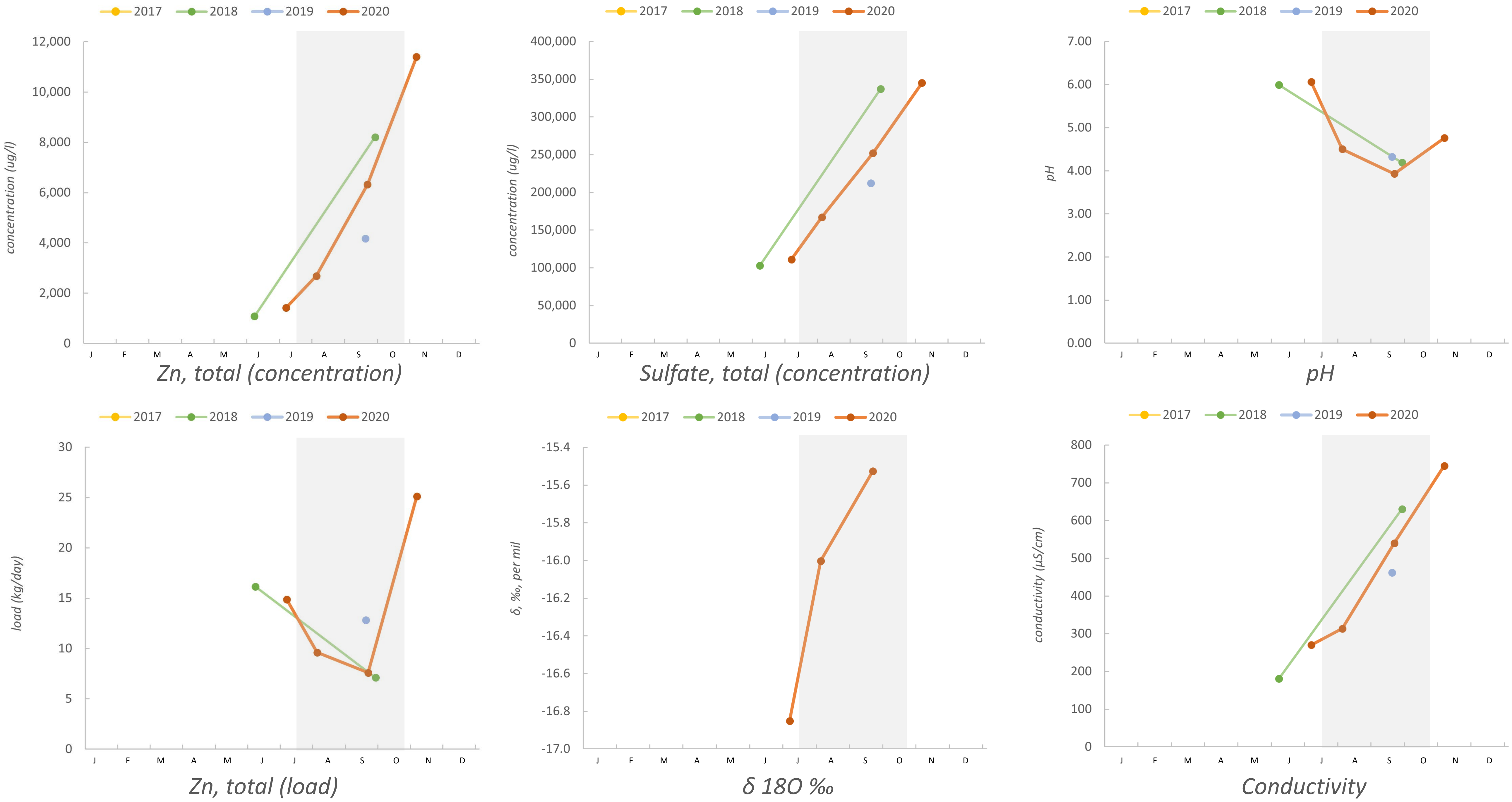

2017
2018
2019
2020
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
concentration (ug/l)
J F M A M J J A S O N D
Al, total (concentration)
25
20
15
10
5
0
concentration (ug/l)
Cd, total (concentration)
300
250
200
150
100
50
0
concentration (ug/l)
Cu, total (concentration)
12
10
8
6
4
2
0
load (kg/day)
Al, total (load)
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
load (kg/day)
Cd, total (load)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
load (kg/day)
Cu, total (load)

CCSG-7

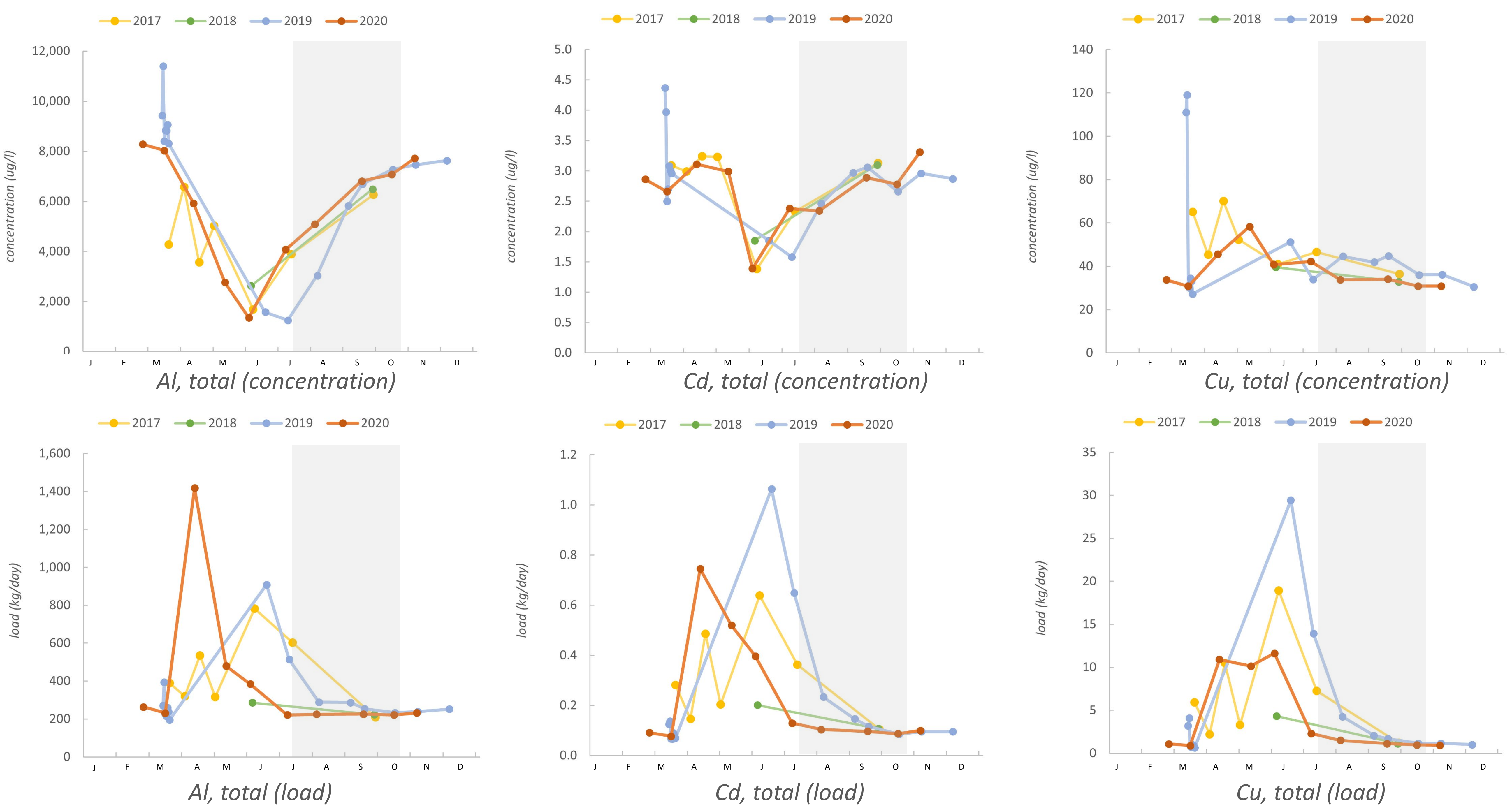


2017
2018
2019
2020
concentration (ug/l)
load (kg/day)
J F M A M J J A S O N D
Fe, total (concentration)
Pb, total (concentration)
Mn, total (concentration)
Fe, total (load)
Pb, total (load)
Mn, total (load)

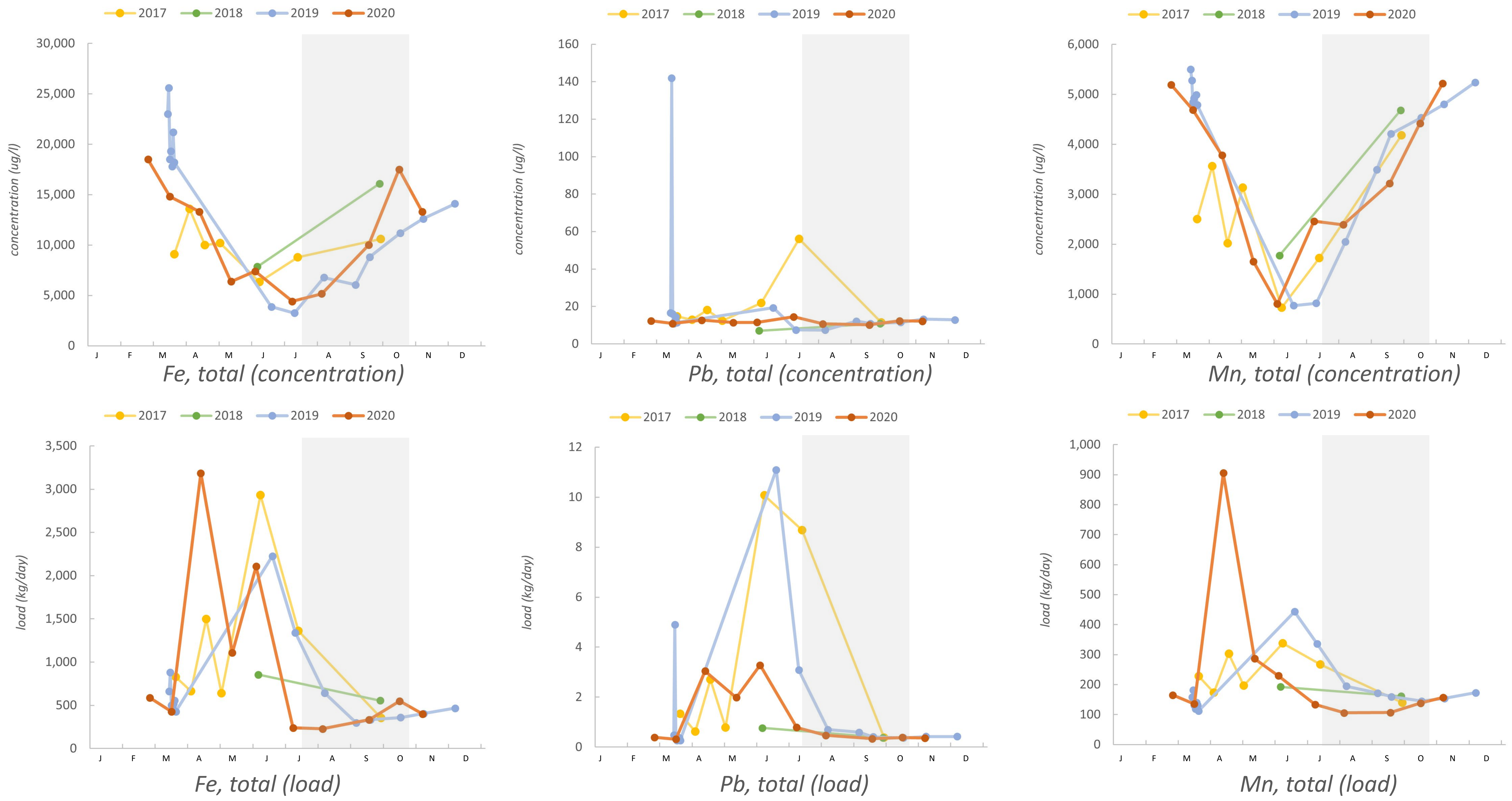
CCSG-7


2017
2018
2019
2020
12,000
10,000
8,000
6,000
4,000
2,000
0
concentration (ug/l)
J F M A M J J A S O N D
Zn, total (concentration)
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
concentration (ug/l)
Sulfate, total (concentration)
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
pH
pH
30
25
20
15
10
5
0
load (kg/day)
Zn, total (load)
-15.4
-15.6
-15.8
-16.0
-16.2
-16.4
-16.6
-16.8
-17.0
δ, ‰, per mil
δ 18O ‰
800
700
600
500
400
300
200
100
0
conductivity (µS/cm)
Conductivity

CC48

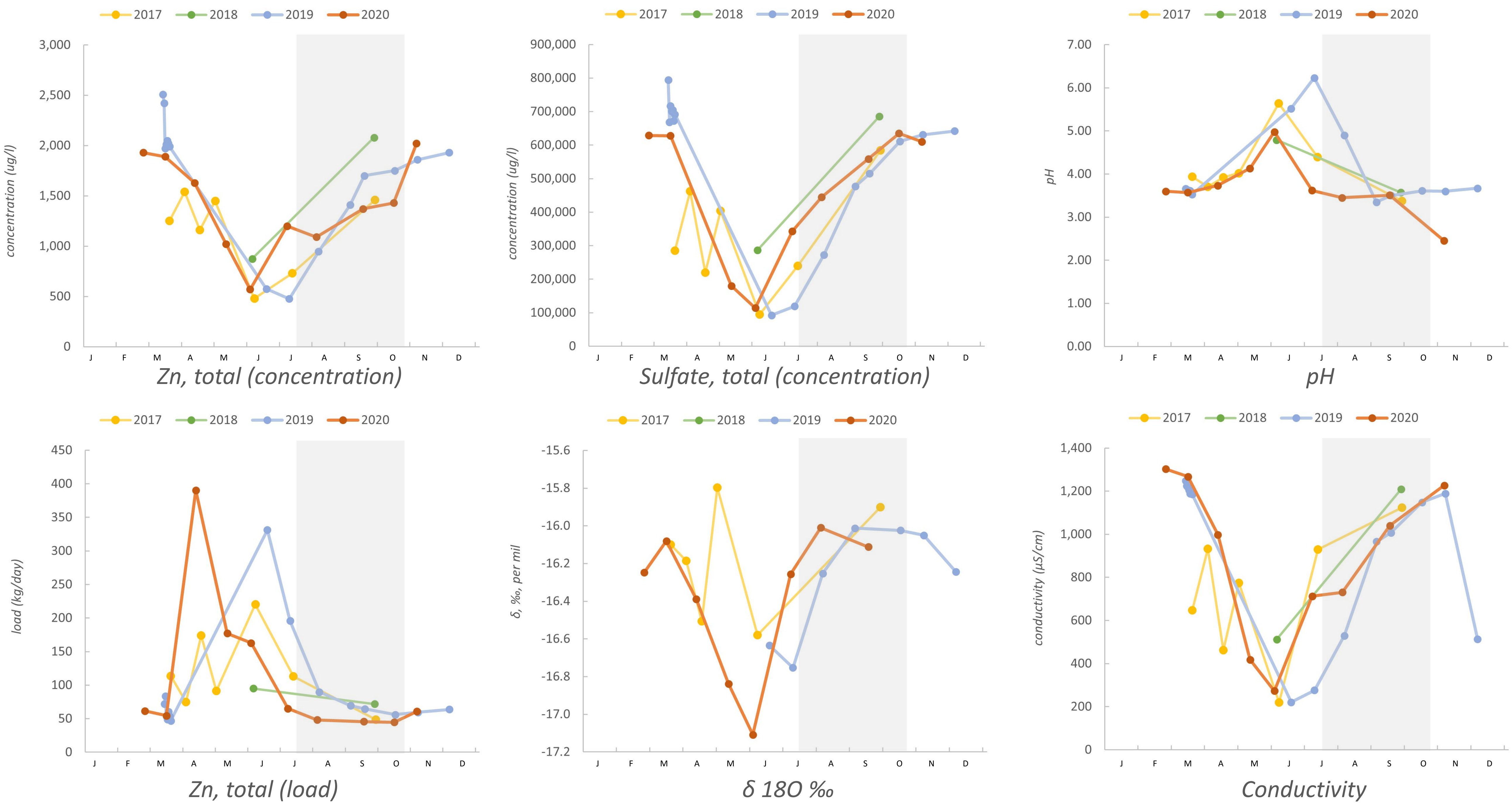

2017
2018
2019
2020
concentration (ug/l)
load (kg/day)
J F M A M J J A S O N D
Al, total (concentration)
Cd, total (concentration)
Cu, total (concentration)
Al, total (load)
Cd, total (load)
Cu, total (load)

CC48

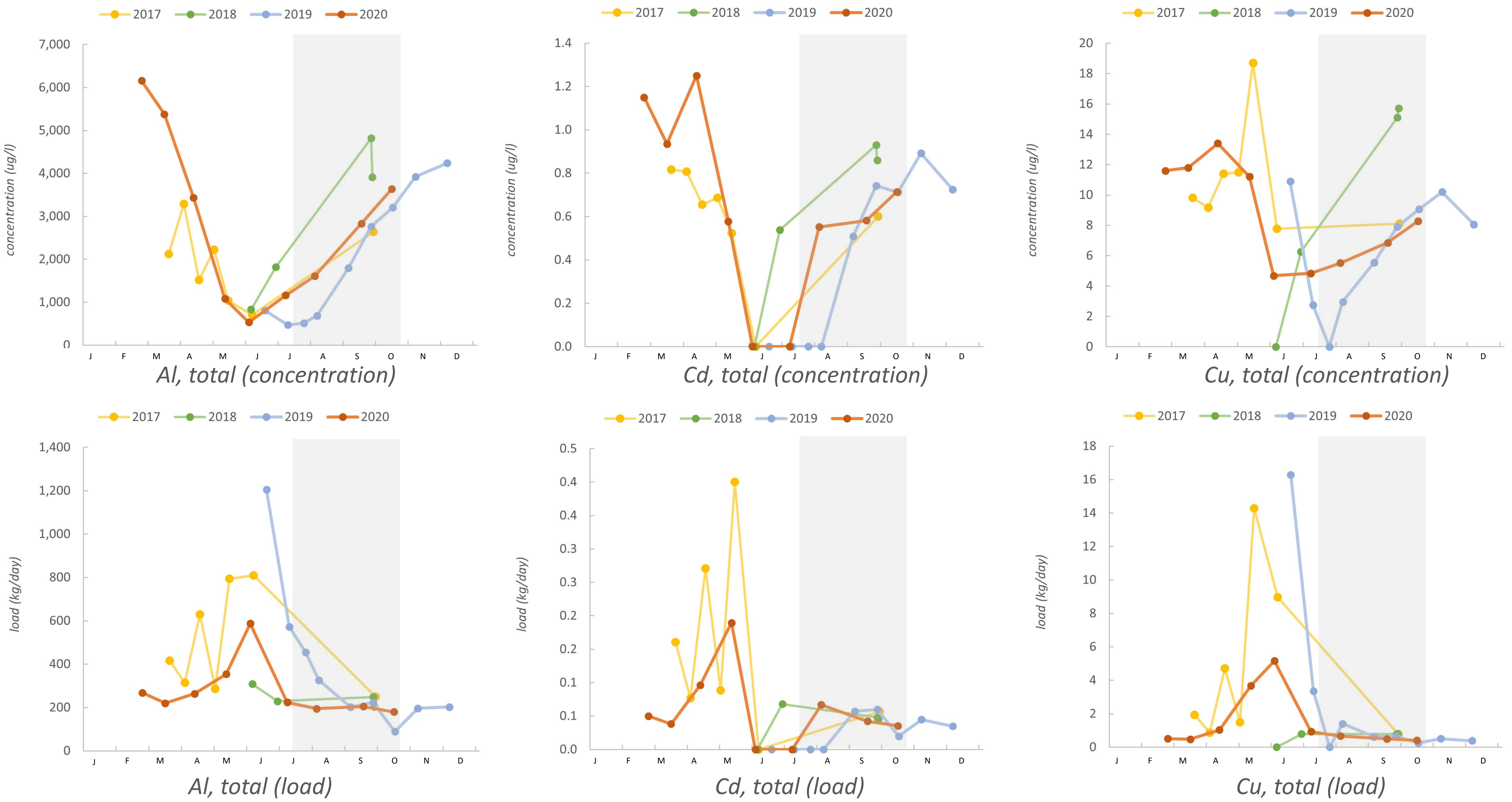


2017
2018
2019
2020
30,000
25,000
20,000
15,000
10,000
5,000
0
concentration (ug/l)
J F M A M J J A S O N D
Fe, total (concentration)
160
140
120
100
80
60
40
20
0
concentration (ug/l)
Pb, total (concentration)
6,000
5,000
4,000
3,000
2,000
1,000
0
concentration (ug/l)
Mn, total (concentration)
3,500
3,000
2,500
2,000
1,500
1,000
500
0
load (kg/day)
Fe, total (load)
12
10
8
6
4
2
0
load (kg/day)
Pb, total (load)
1,000
900
800
700
600
500
400
300
200
100
0
load (kg/day)
Mn, total (load)

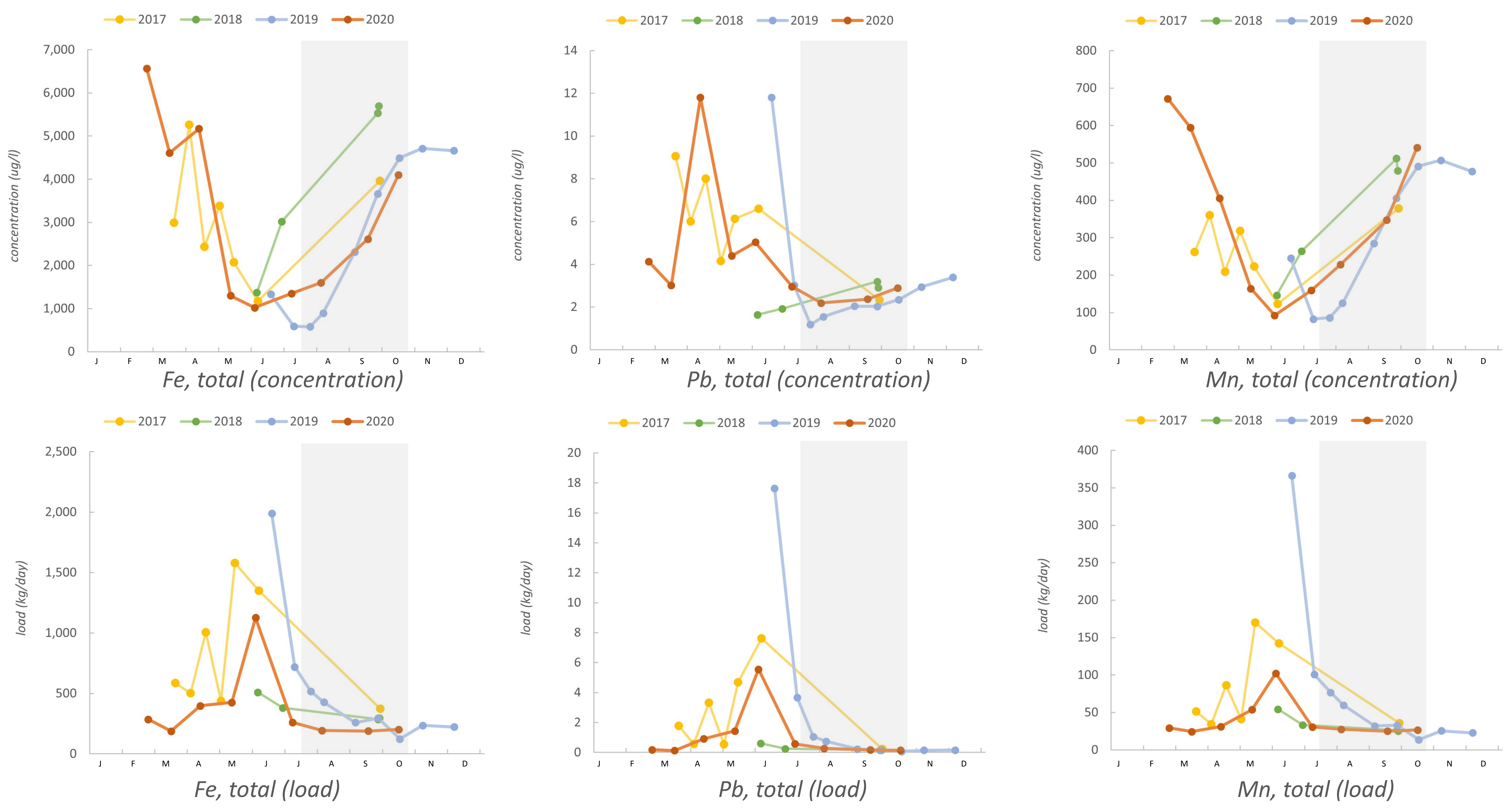
CC48


2017
2018
2019
2020
concentration (ug/l)
3,000
2,500
2,000
1,500
1,000
500
0
J F M A M J J A S O N D
Zn, total (concentration)
concentration (ug/l)
900,000
800,000
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
Sulfate, total (concentration)
pH
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
pH
load (kg/day)
450
400
350
300
250
200
150
100
50
0
Zn, total (load)
δ, ‰, per mil
-15.6
-15.8
-16.0
-16.2
-16.4
-16.6
-16.8
-17.0
-17.2
δ 18O ‰
conductivity (µS/cm)
1,400
1,200
1,000
800
600
400
200
0
Conductivity

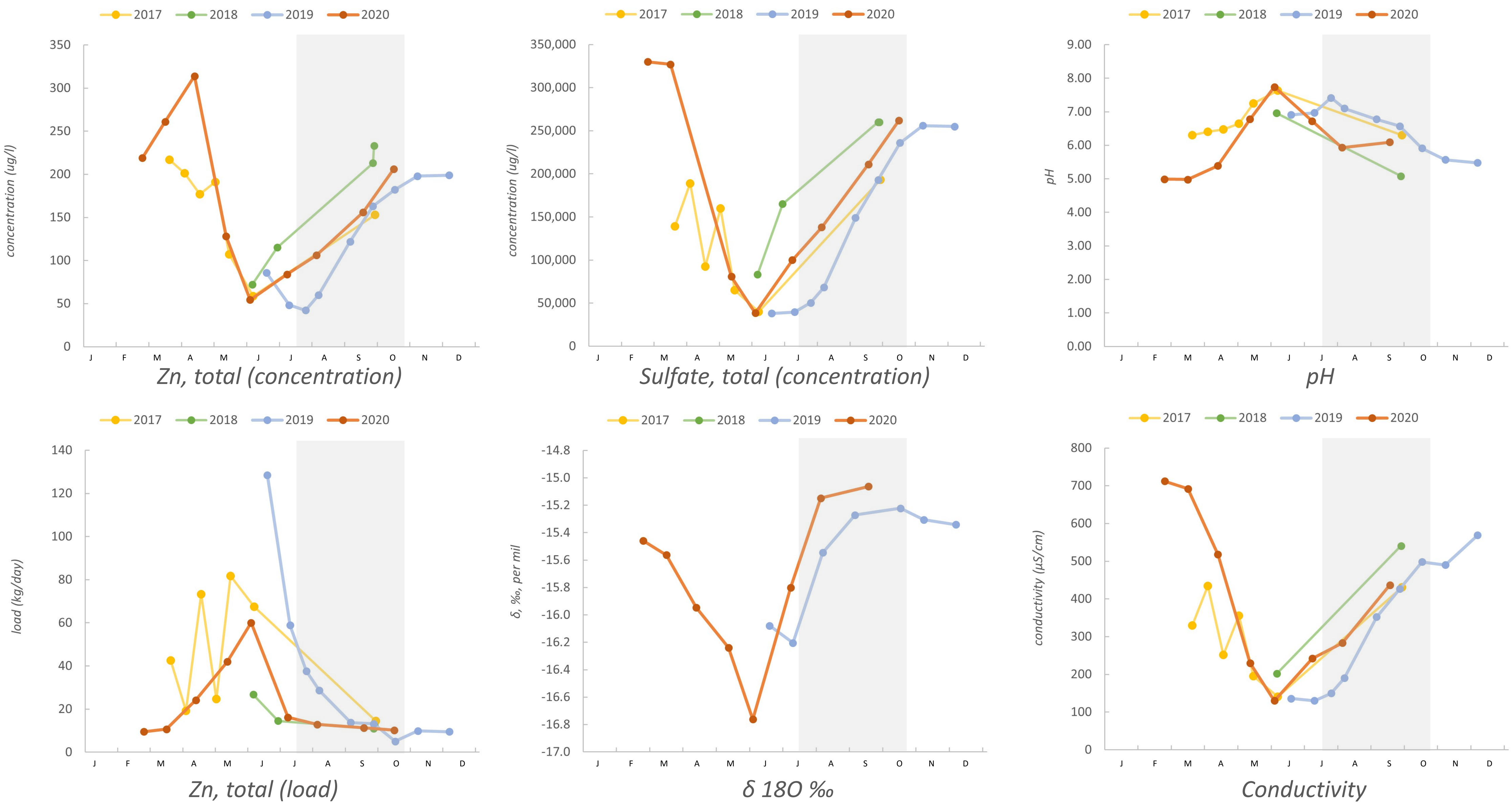
M34


2017
2018
2019
2020
concentration (ug/l)
load (kg/day)
J F M A M J J A S O N D
Al, total (concentration)
Cd, total (concentration)
Cu, total (concentration)
Al, total (load)
Cd, total (load)
Cu, total (load)

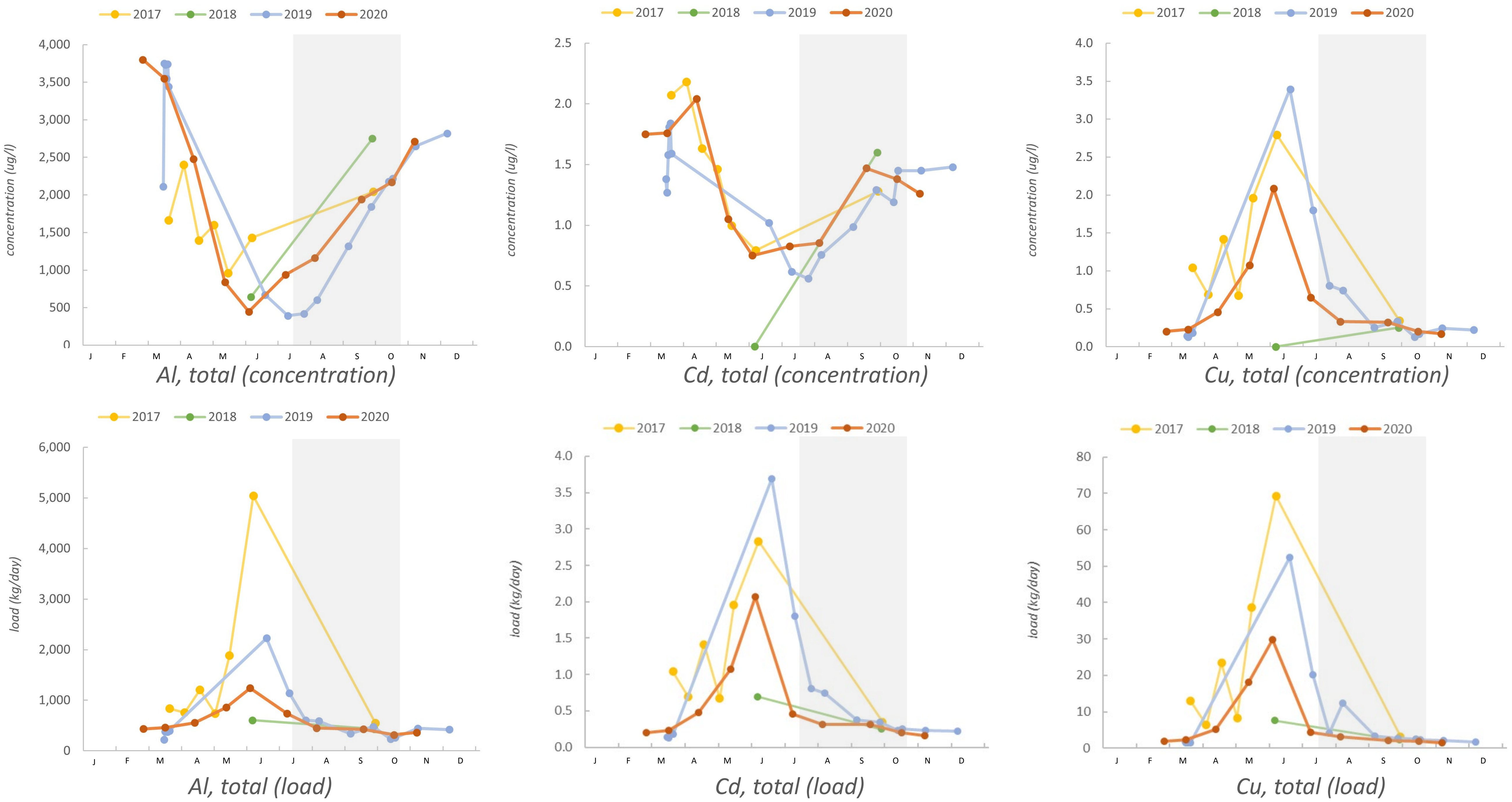
M34


2017
2018
2019
2020
concentration (ug/l)
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
J F M A M J J A S O N D
Fe, total (concentration)
14
12
10
8
6
4
2
0
Pb, total (concentration)
800
700
600
500
400
300
200
100
Mn, total (concentration)
load (kg/day)
2,500
2,000
1,500
1,000
500
Fe, total (load)
20
18
16
Pb, total (load)
400
350
300
250
200
150
100
50
Mn, total (load)

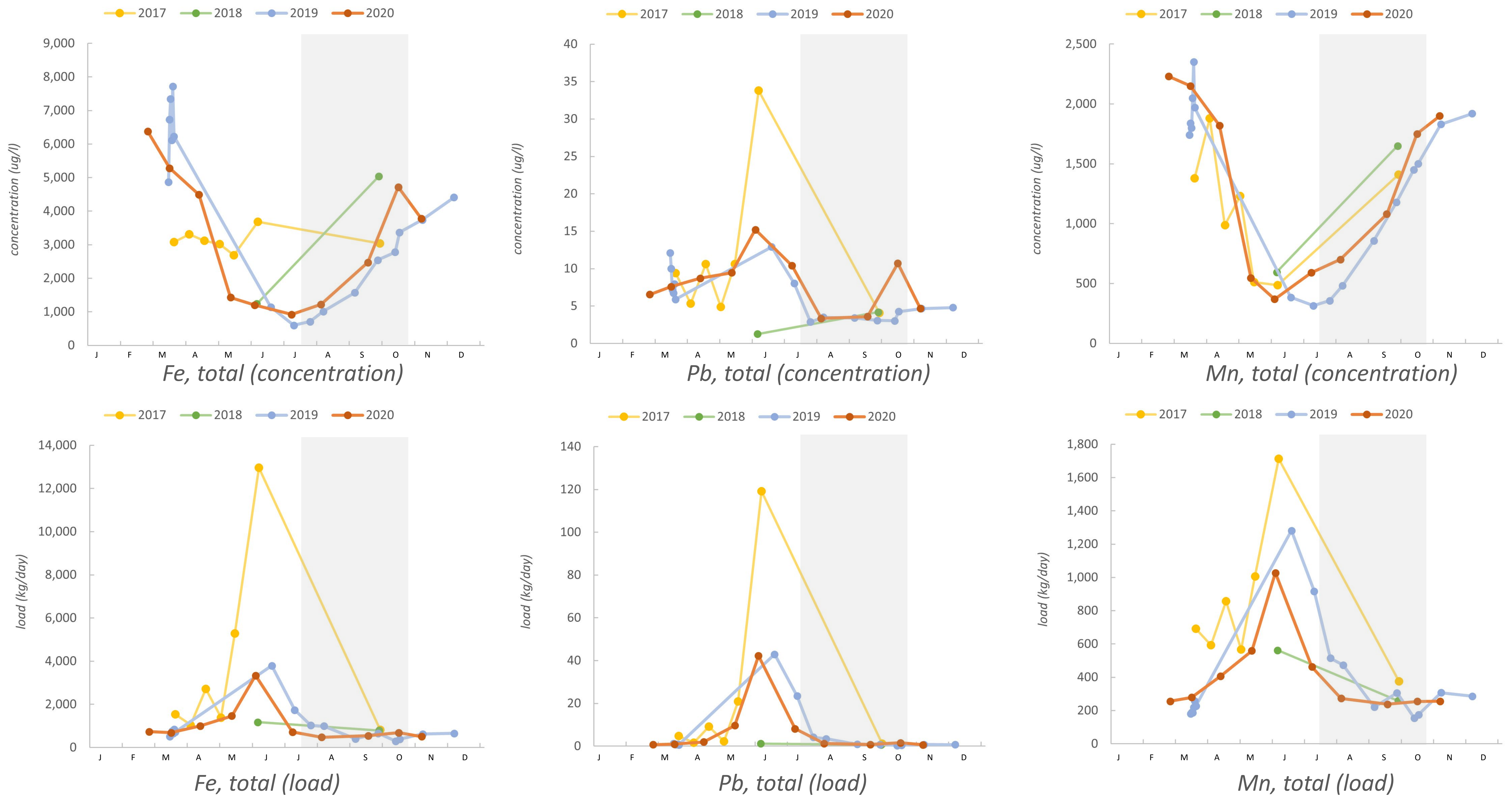
M34


2017
2018
2019
2020
concentration (ug/l)
Zn, total (concentration)
Sulfate, total (concentration)
pH
load (kg/day)
Zn, total (load)
δ, ‰, per mil
δ 18O ‰
conductivity (µS/cm)
Conductivity
J F M A M J J A S O N D

A72

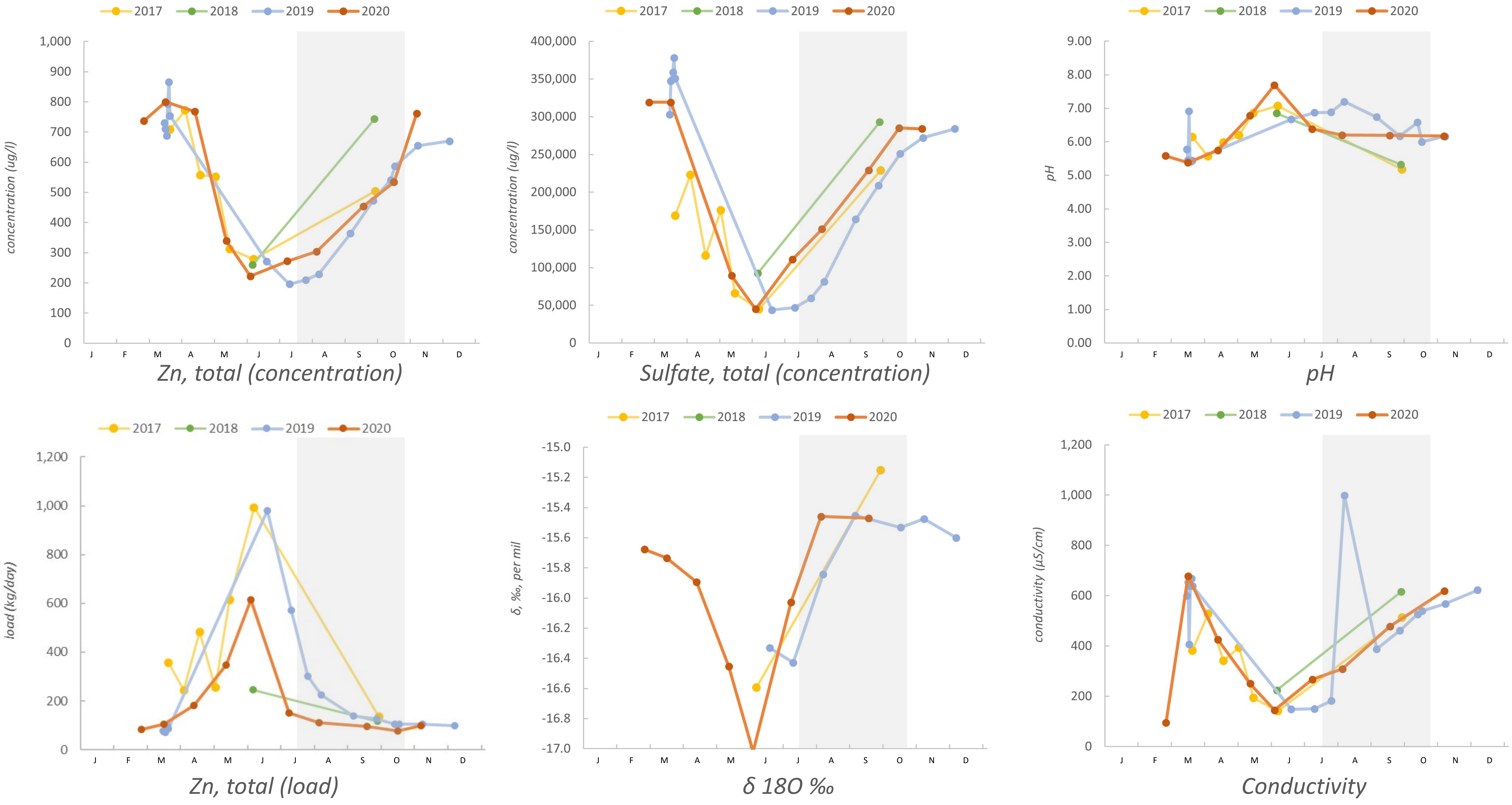

2017
2018
2019
2020
concentration (ug/l)
load (kg/day)
J F M A M J J A S O N D
Al, total (concentration)
Cd, total (concentration)
Cu, total (concentration)
Al, total (load)
Cd, total (load)
Cu, total (load)

A72

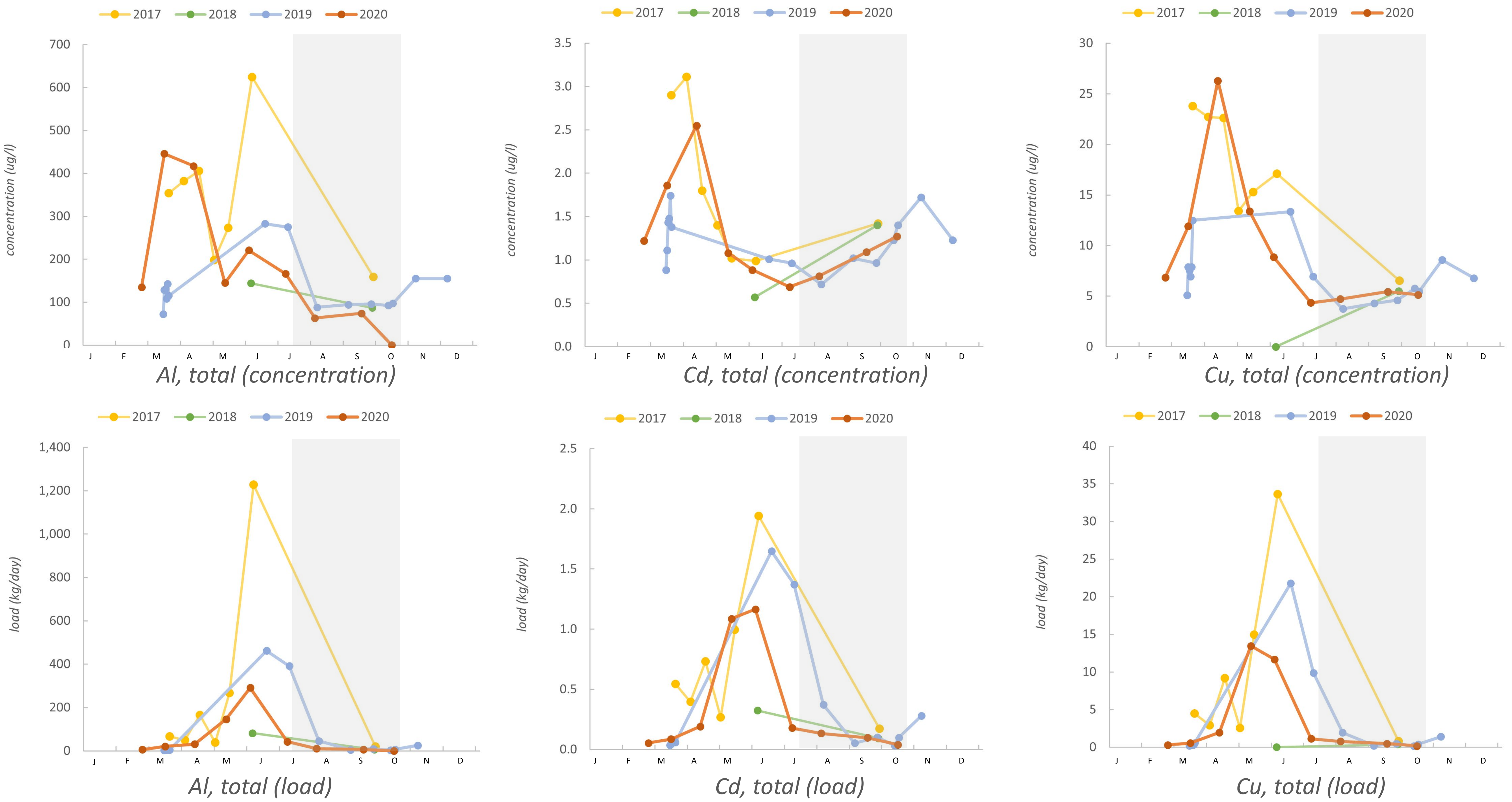


2017
2018
2019
2020
concentration (ug/l)
load (kg/day)
J F M A M J J A S O N D
Fe, total (concentration)
Pb, total (concentration)
Mn, total (concentration)
Fe, total (load)
Pb, total (load)
Mn, total (load)

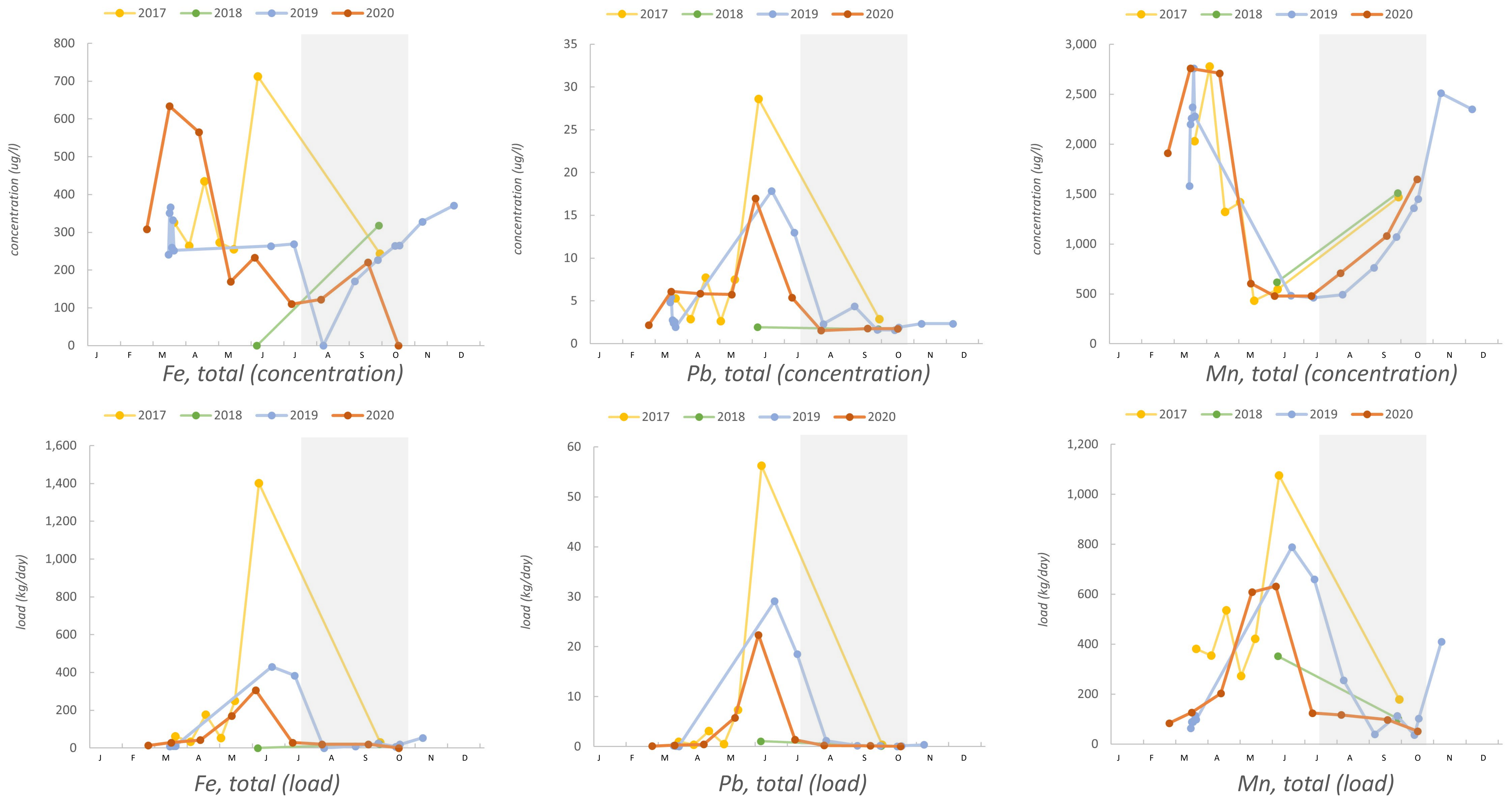
A72


Zn, total (concentration)
concentration (ug/l)
Sulfate, total (concentration)
concentration (ug/l)
pH
pH
Zn, total (load)
load (kg/day)
δ 18O ‰
δ, ‰, per mil
Conductivity
conductivity (µS/cm)
2017
2018
2019
2020
J F M A M J J A S O N D

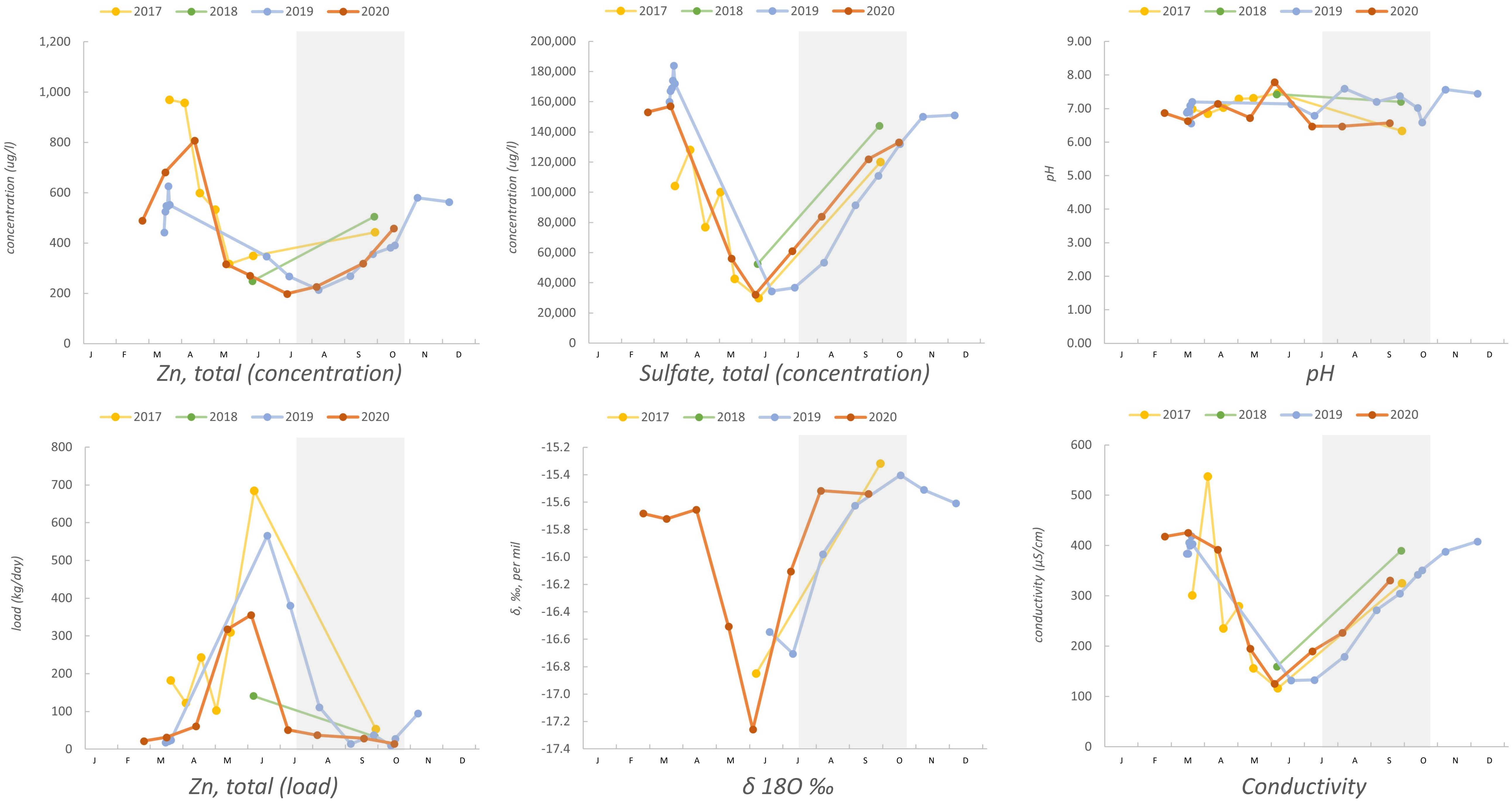
A68


2017 2018 2019 2020
concentration (ug/l)
Al, total (concentration)
Cd, total (concentration)
Cu, total (concentration)
load (kg/day)
Al, total (load)
Cd, total (load)
Cu, total (load)
J F M A M J J A S O N D

A68

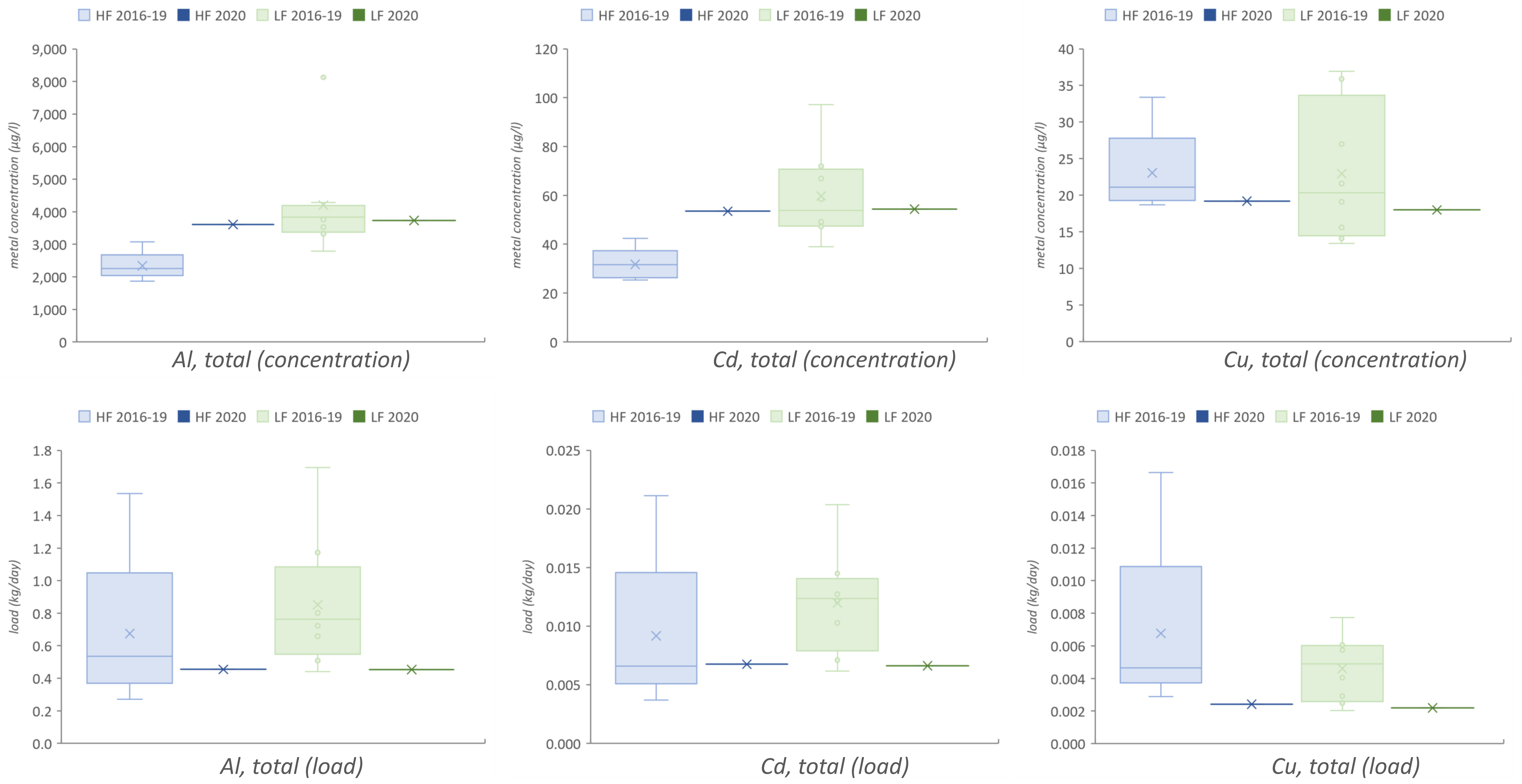

2017
2018
2019
2020
concentration (ug/l)
load (kg/day)
J F M A M J J A S O N D
Fe, total (concentration)
Pb, total (concentration)
Mn, total (concentration)
Fe, total (load)
Pb, total (load)
Mn, total (load)

A68

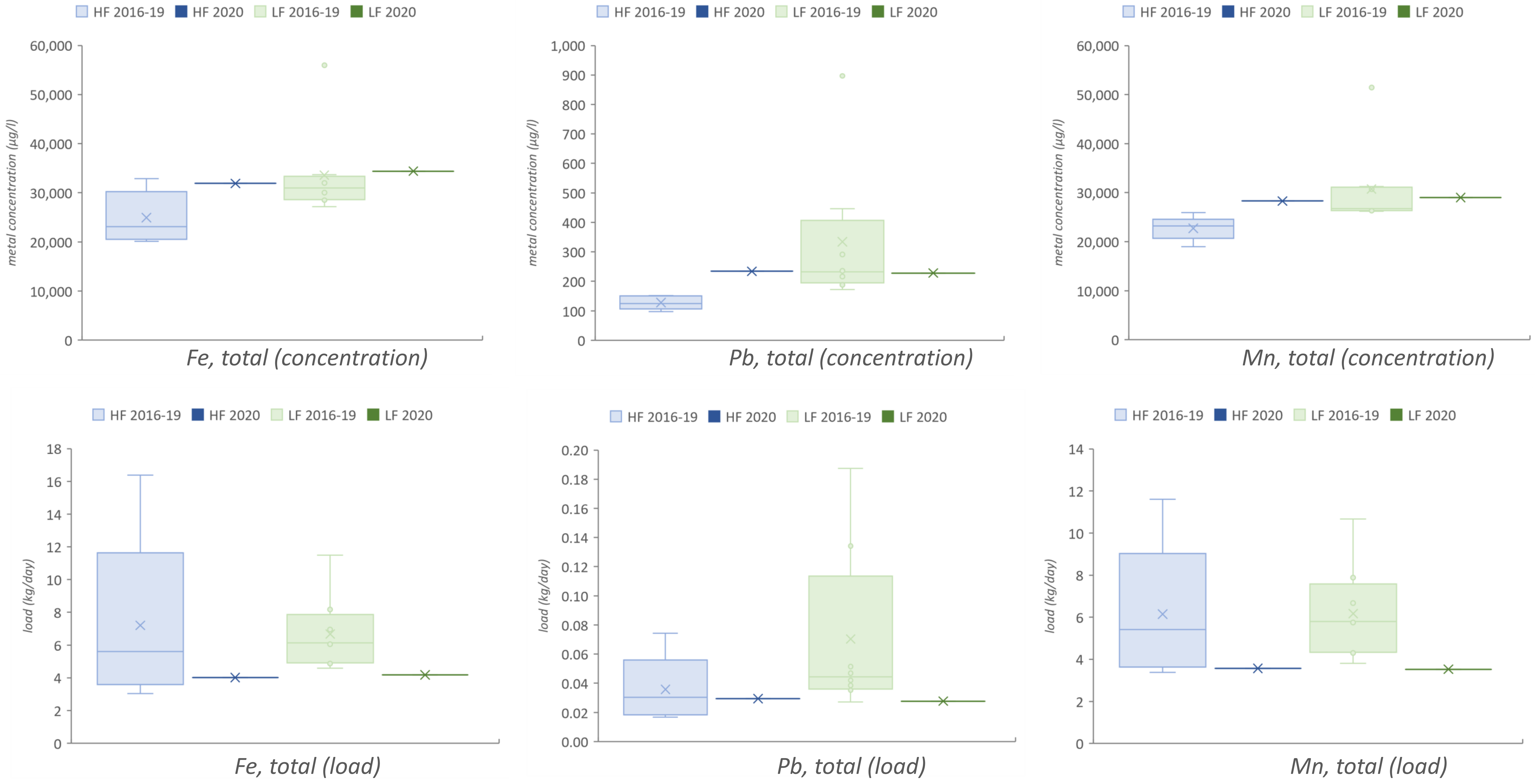

2017
2018
2019
2020
1,200
1,000
800
600
400
200
0
concentration (ug/l)
J F M A M J J A S O N D
Zn, total (concentration)
200,000
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
concentration (ug/l)
Sulfate, total (concentration)
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
pH
pH
800
700
600
500
400
300
200
100
0
load (kg/day)
Zn, total (load)
-15.2
-15.4
-15.6
-15.8
-16.0
-16.2
-16.4
-16.6
-16.8
-17.0
-17.2
-17.4
δ, ‰, per mil
δ 18O ‰
600
500
400
300
200
100
0
conductivity (µS/cm)
Conductivity

B. Comparison of 2020 water quality to 2016-19 water quality

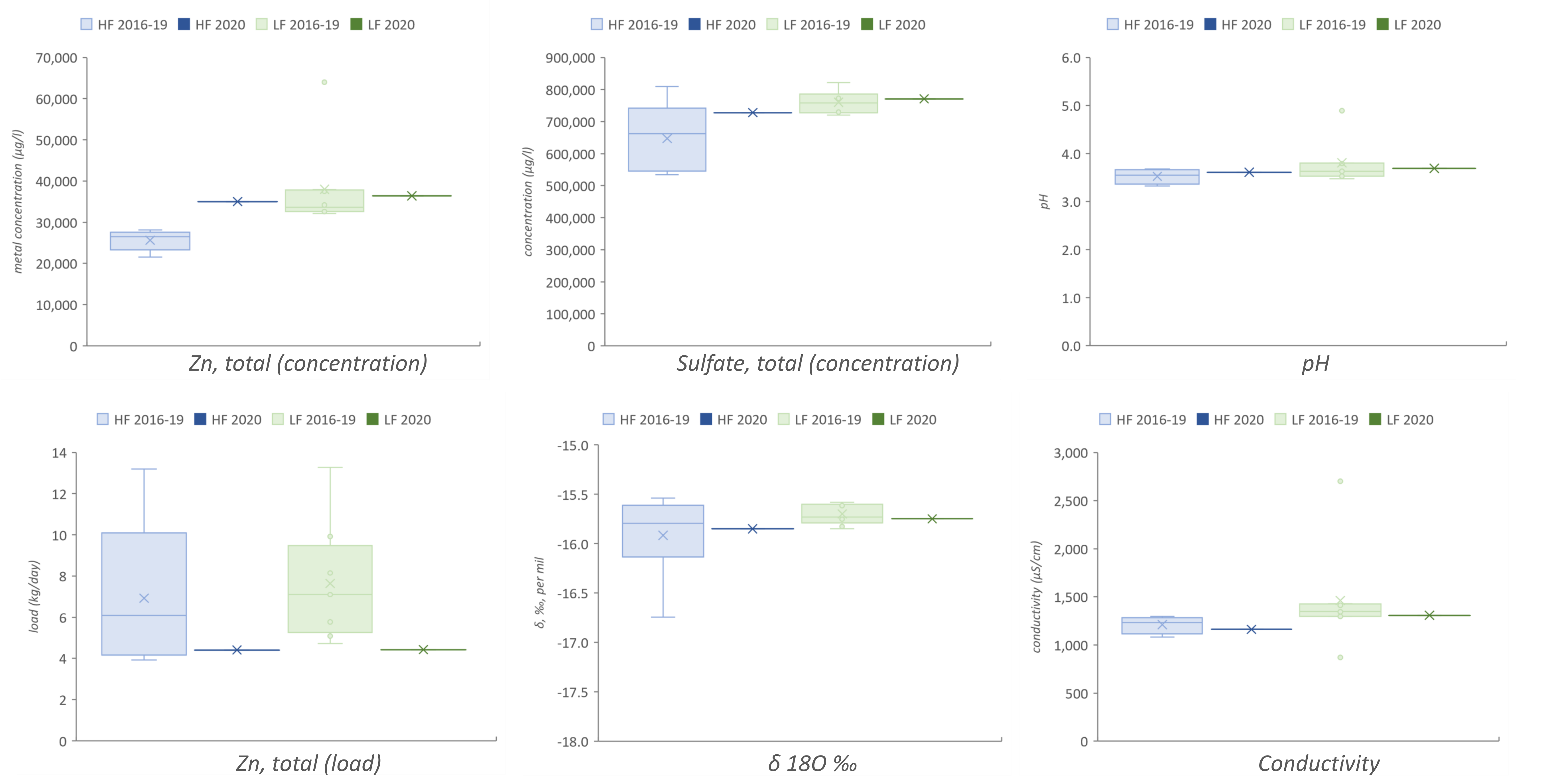
Mogul (CC01B)


HF 2016-19
HF 2020
LF 2016-19
LF 2020
metal concentration (µg/l)
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Al, total (concentration)
120
100
80
60
40
20
0
Cd, total (concentration)
40
35
30
25
20
15
10
5
0
Cu, total (concentration)
load (kg/day)
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Al, total (load)
0.025
0.020
0.015
0.010
0.005
0.000
Cd, total (load)
0.018
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
Cu, total (load)

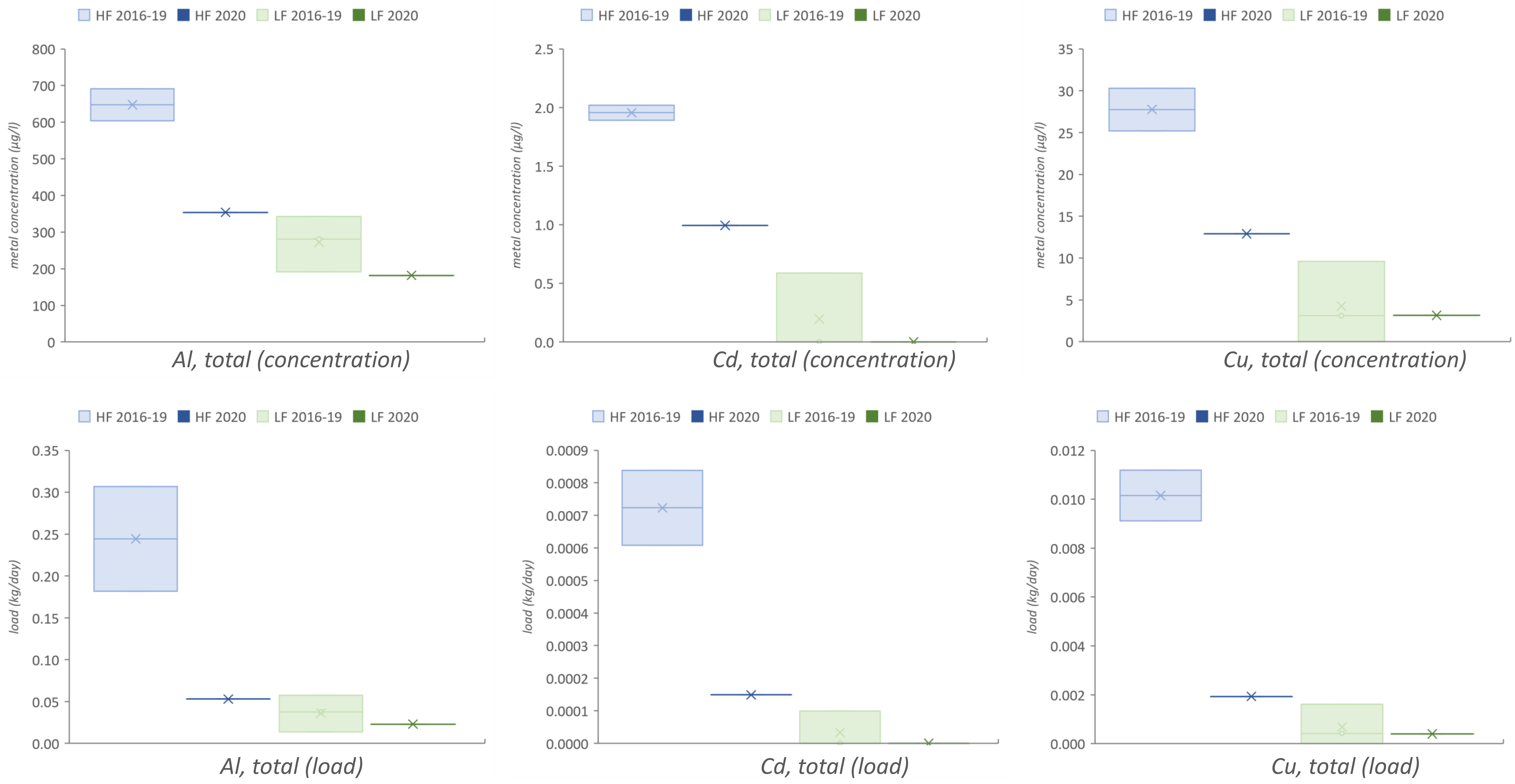
Mogul (CC01B)


HF 2016-19
HF 2020
LF 2016-19
LF 2020
metal concentration (µg/l)
Fe, total (concentration)
Pb, total (concentration)
Mn, total (concentration)
load (kg/day)
Fe, total (load)
Pb, total (load)
Mn, total (load)
0
10,000
20,000
30,000
40,000
50,000
60,000
100
200
300
400
500
600
700
800
900
1,000
2
4
6
8
10
12
14
16
18
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
0.20

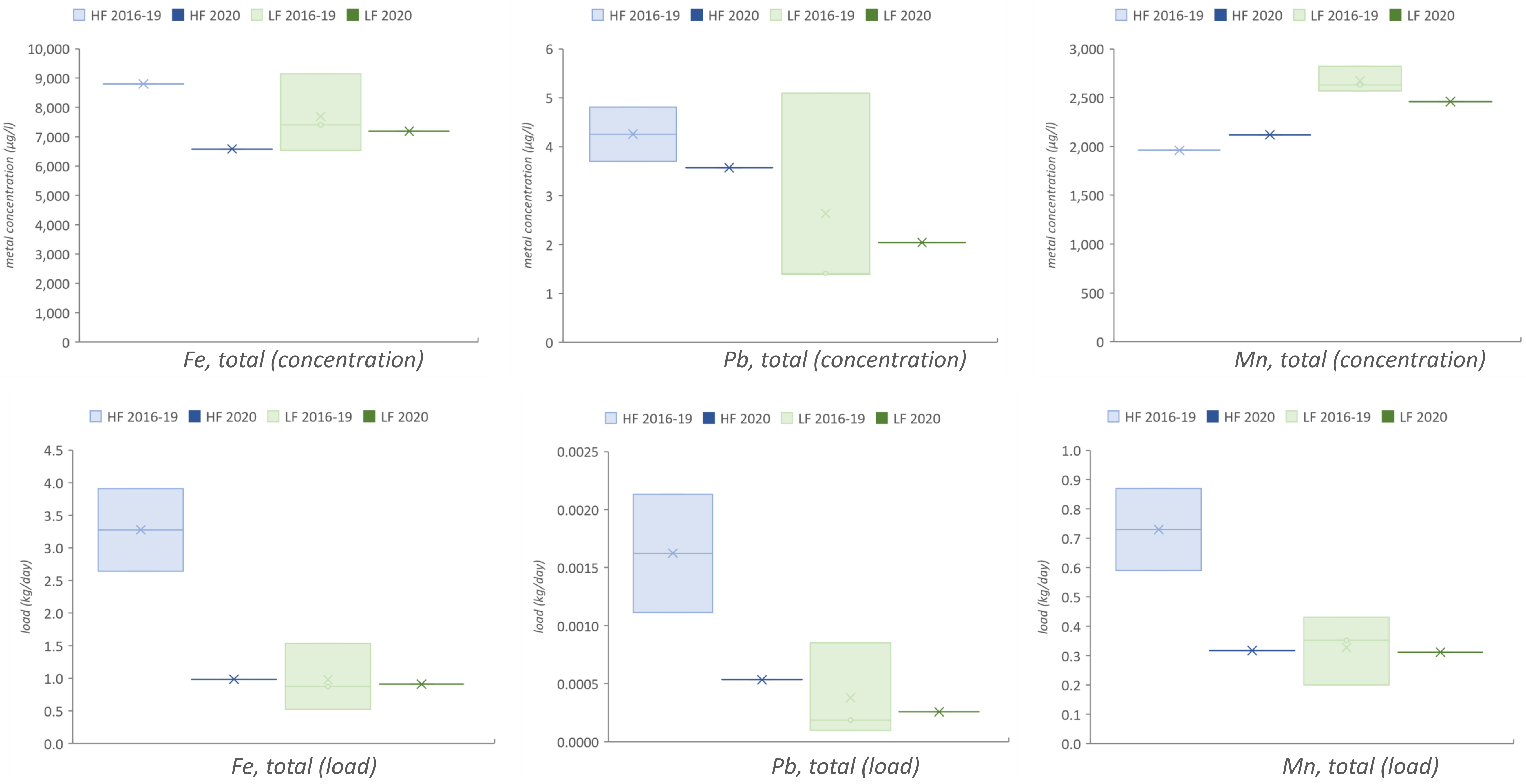
Mogul (CC01B)


HF 2016-19
HF 2020
LF 2016-19
LF 2020
metal concentration (µg/l)
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
Zn, total (concentration)
concentration (µg/l)
900,000
800,000
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
Sulfate, total (concentration)
pH
6.0
5.0
4.0
3.0
2.0
1.0
0.0
pH
load (kg/day)
14
12
10
8
6
4
2
0
Zn, total (load)
δ, ‰, per mil
-15.0
-15.5
-16.0
-16.5
-17.0
-17.5
-18.0
δ 18O ‰
conductivity (µS/cm)
3,000
2,500
2,000
1,500
1,000
500
0
Conductivity

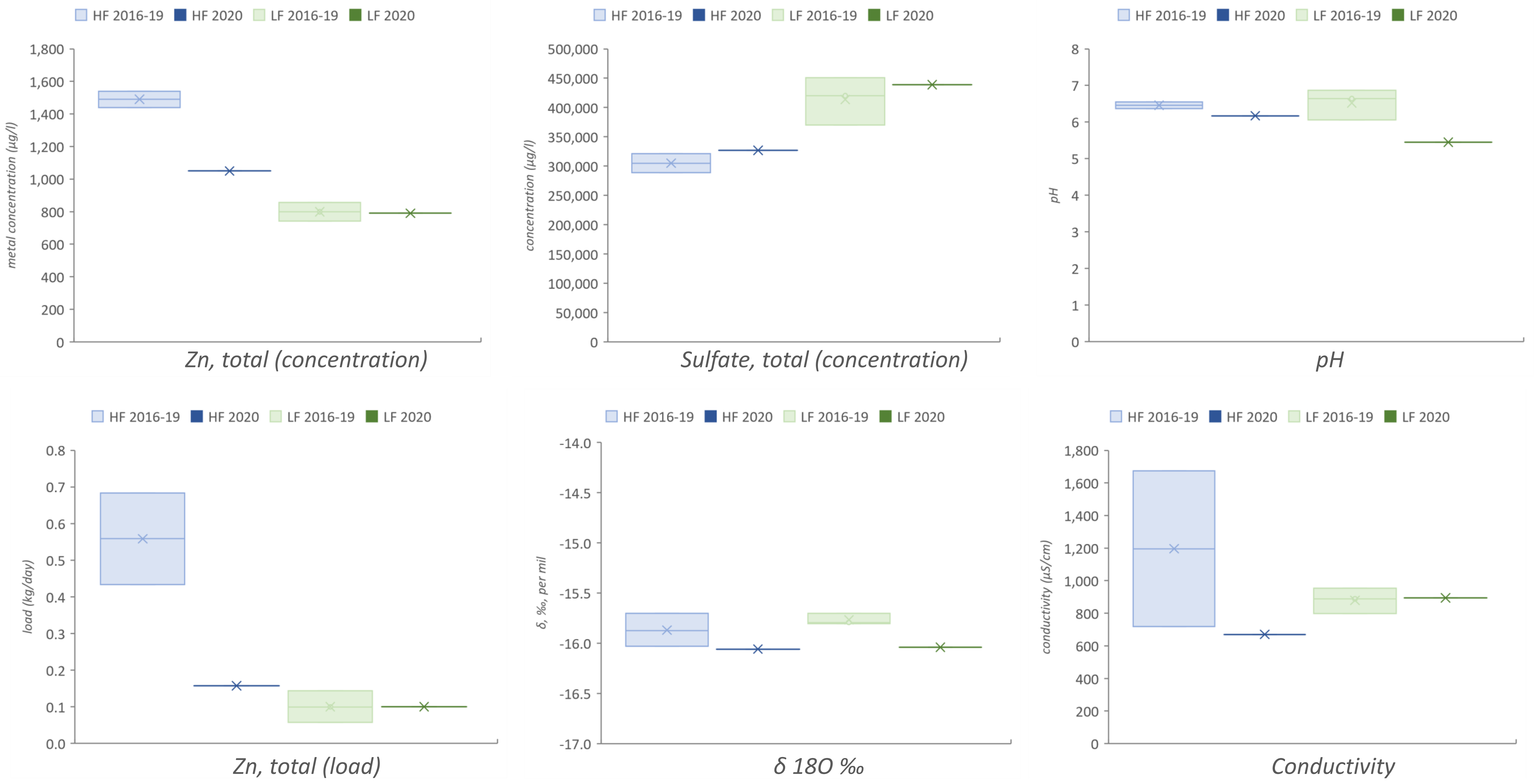
Mogul South (SS105)



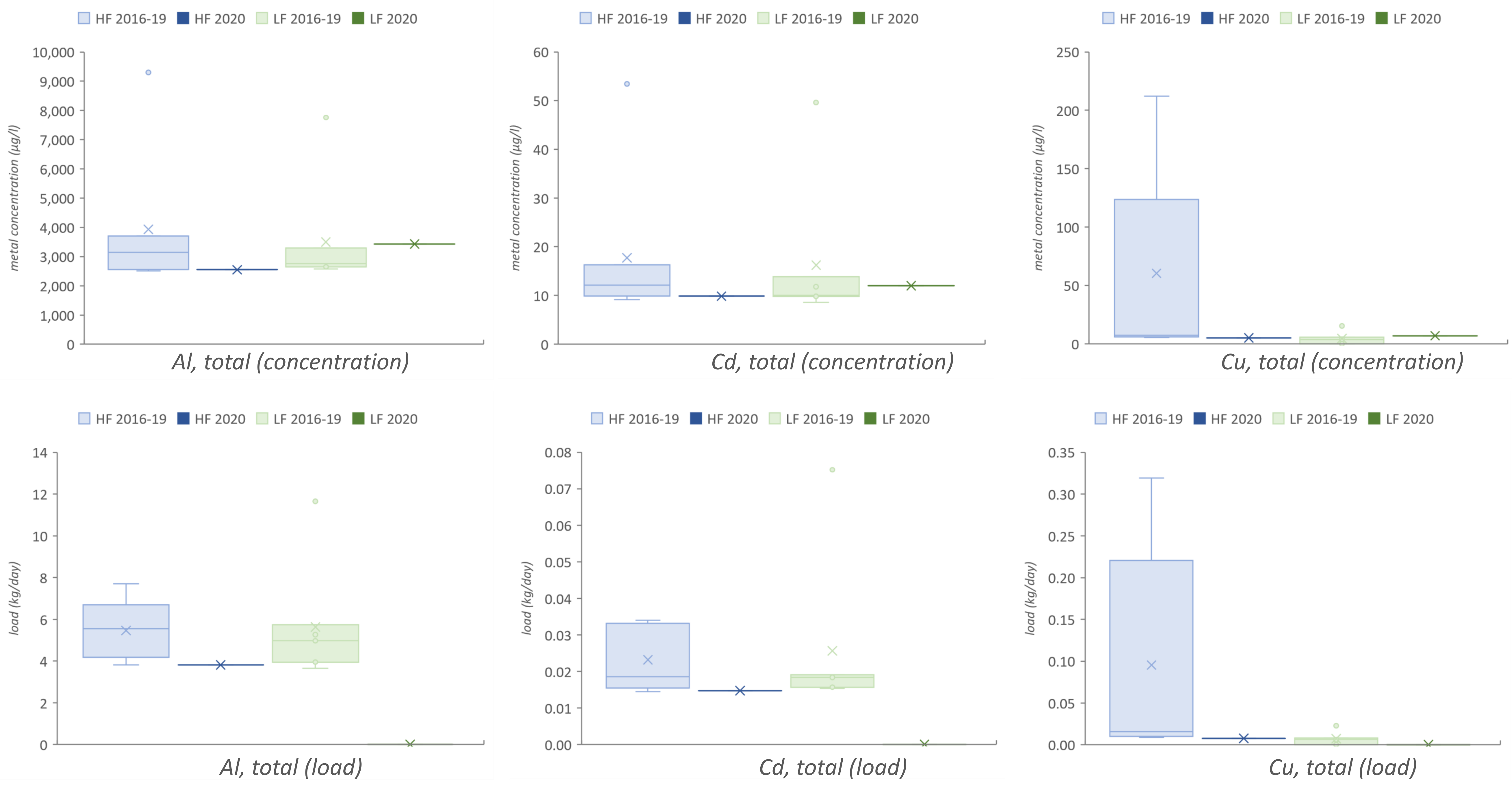
Mogul South (SS105)



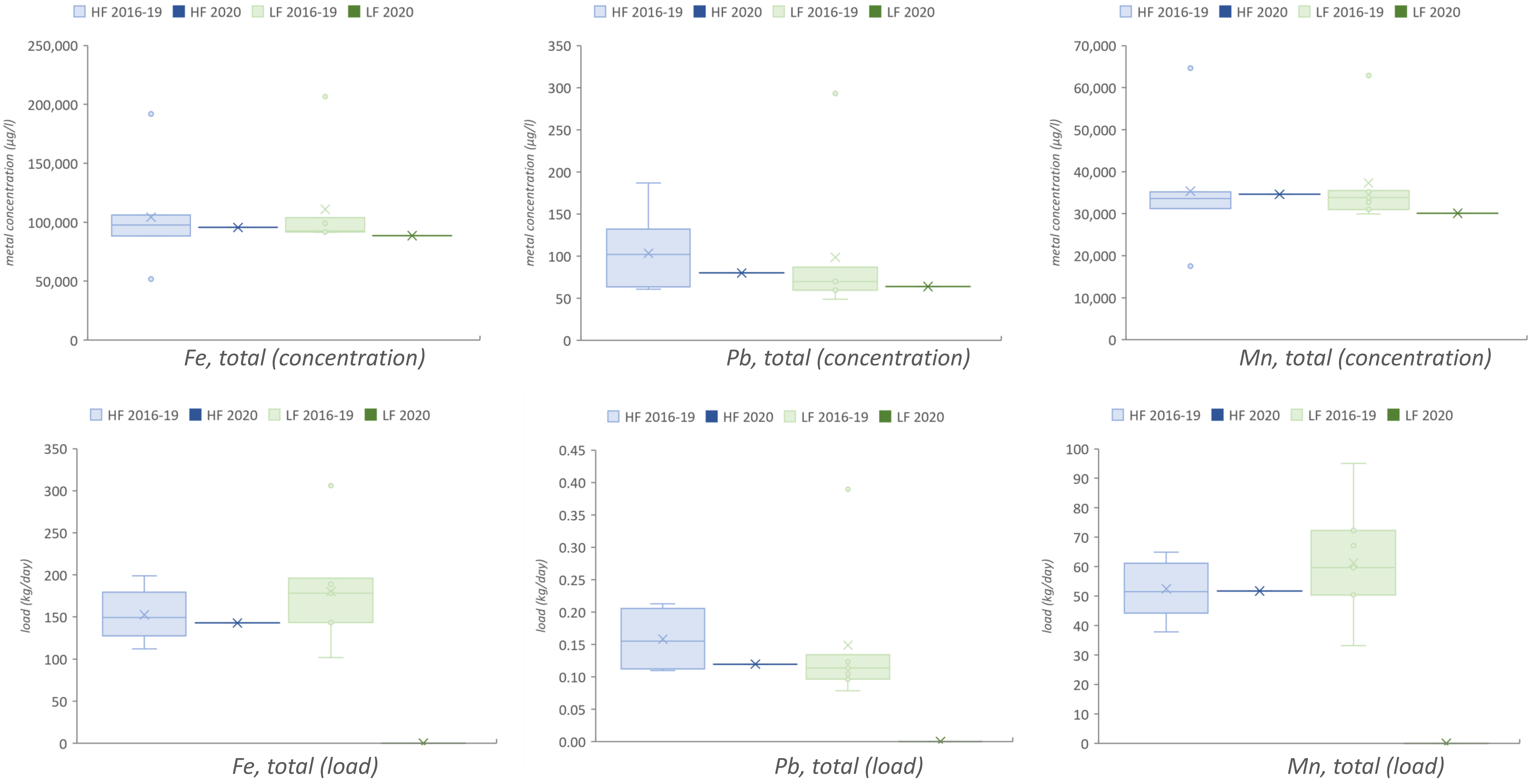
Mogul South (SS105)



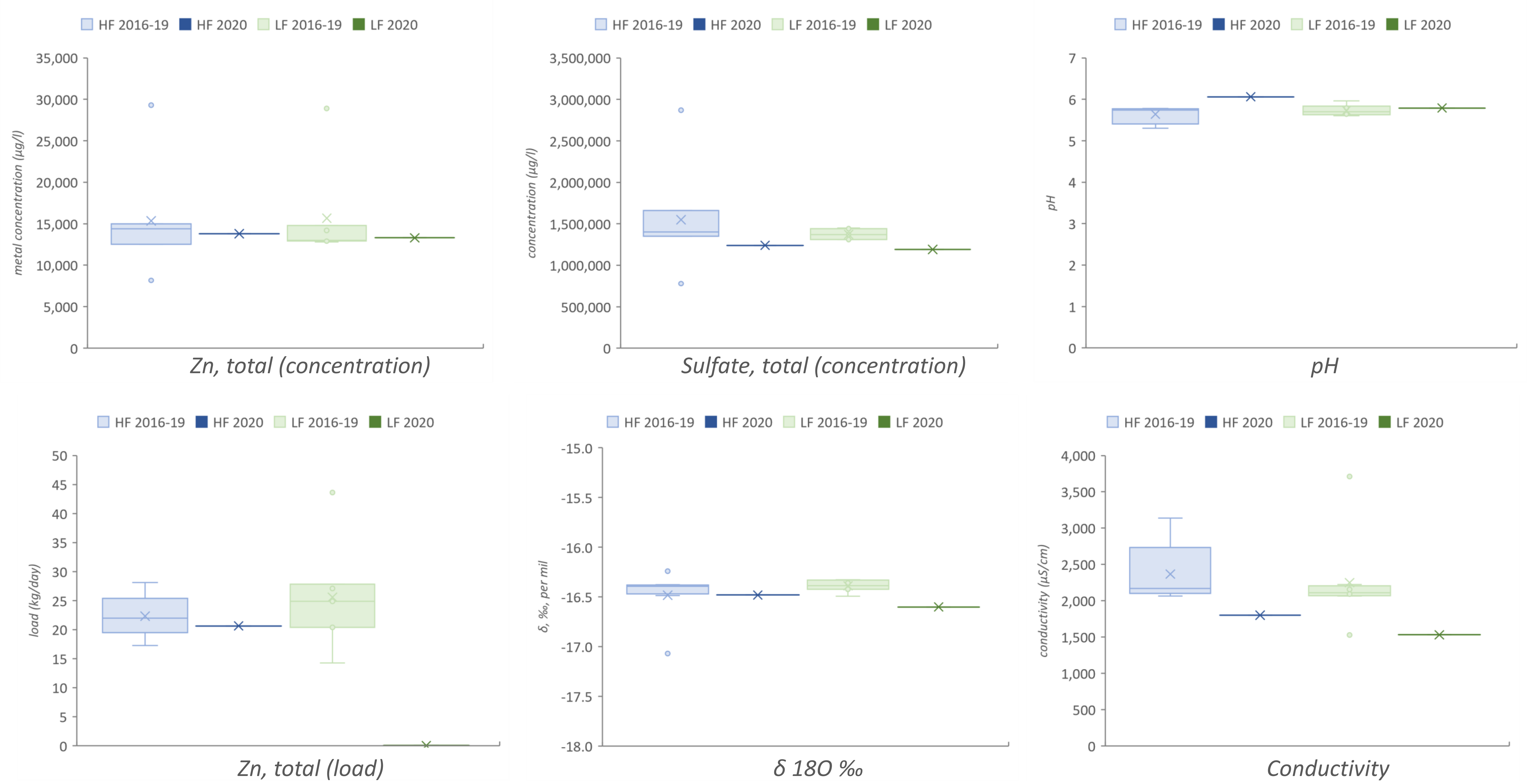
Red & Bonita (CC03C)



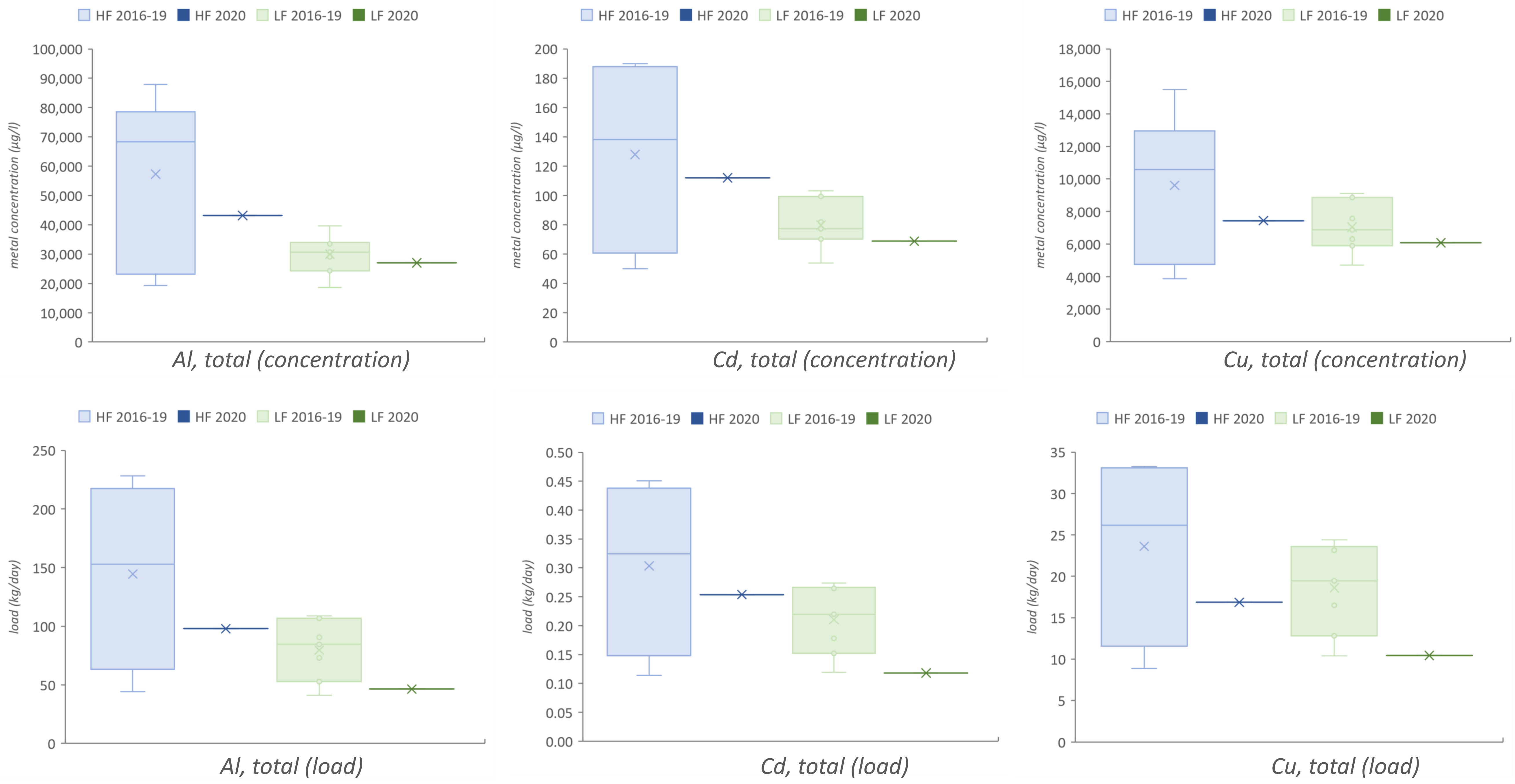
Red & Bonita (CC03C)



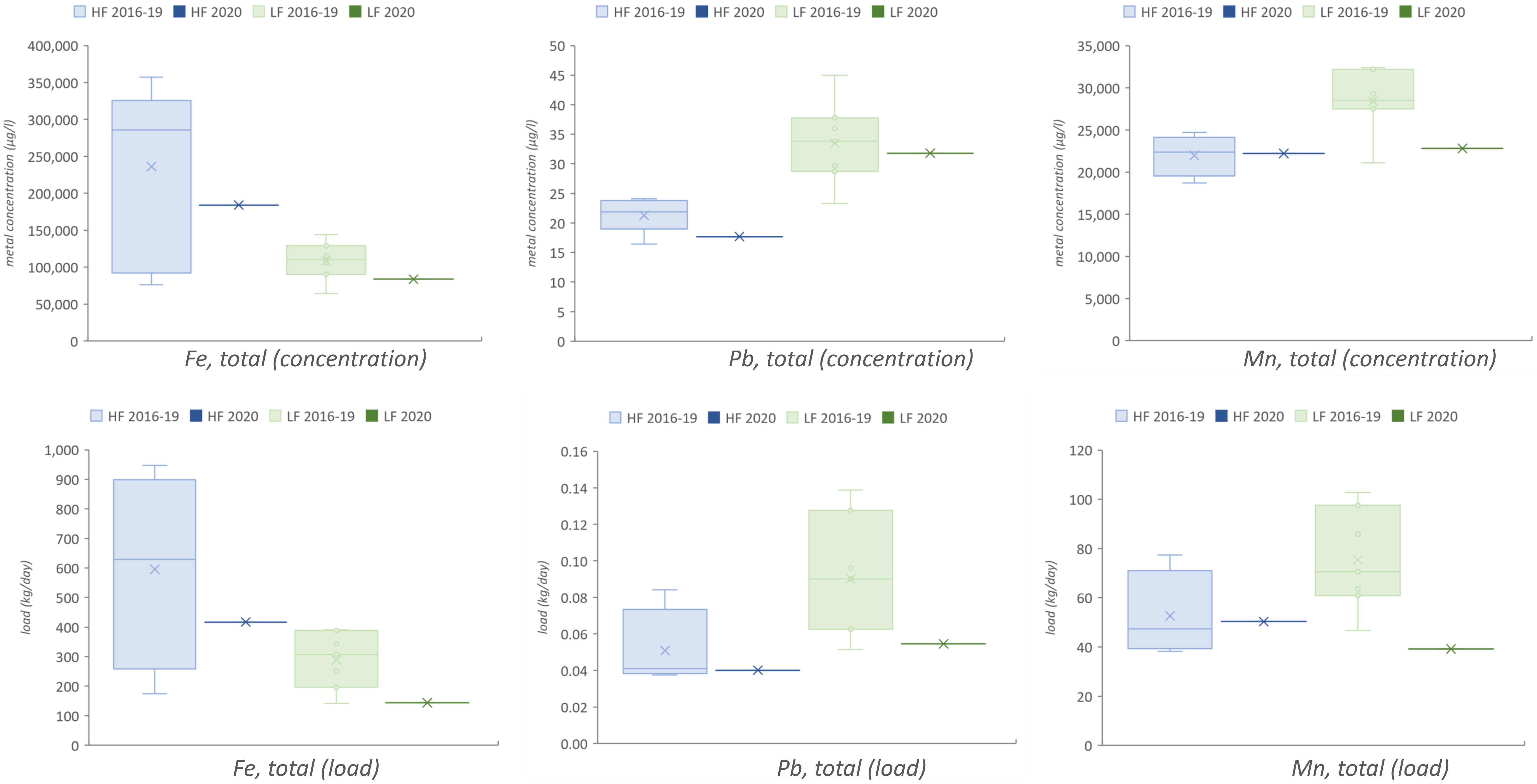
Red & Bonita (CC03C)



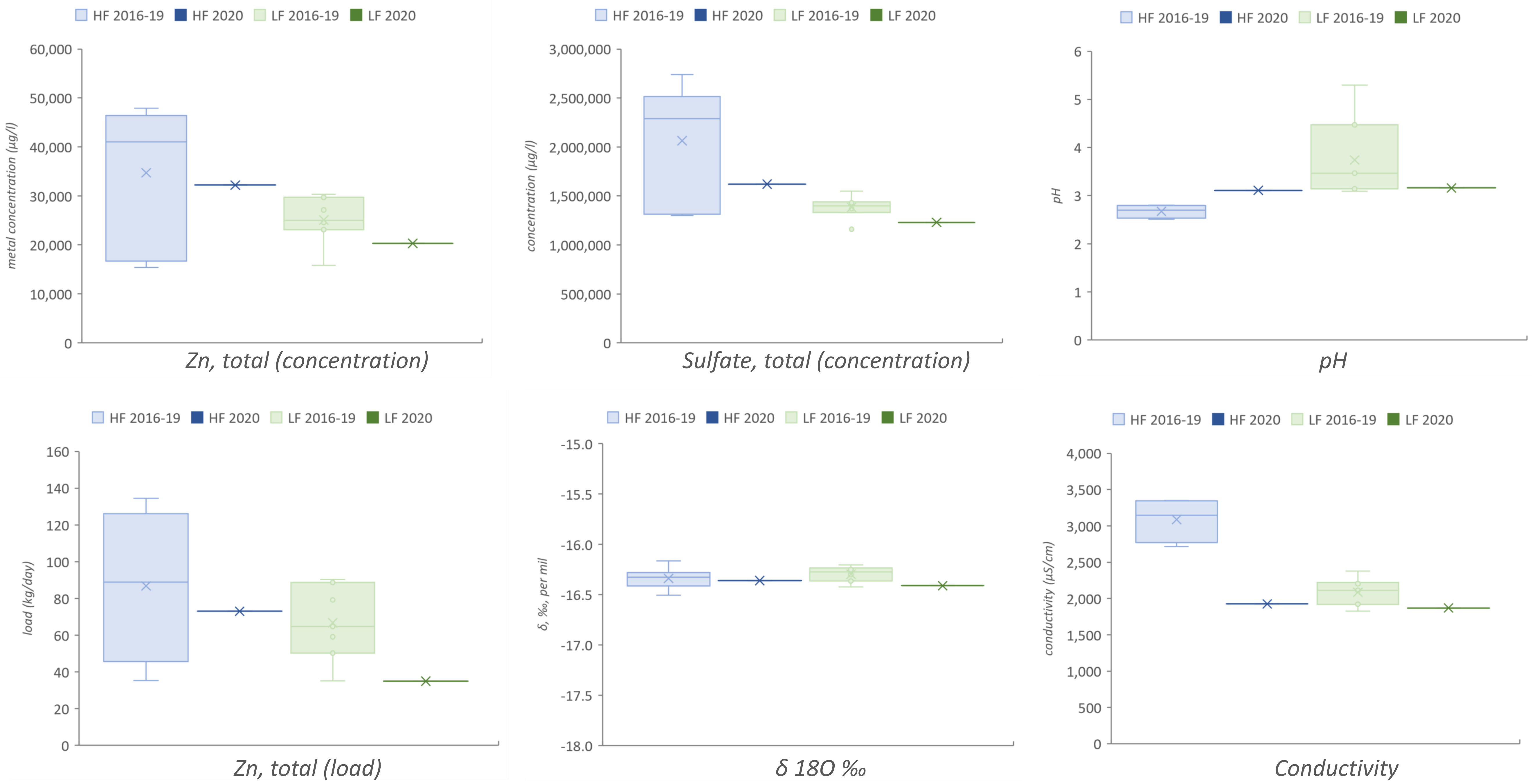
Gold King (CC06)



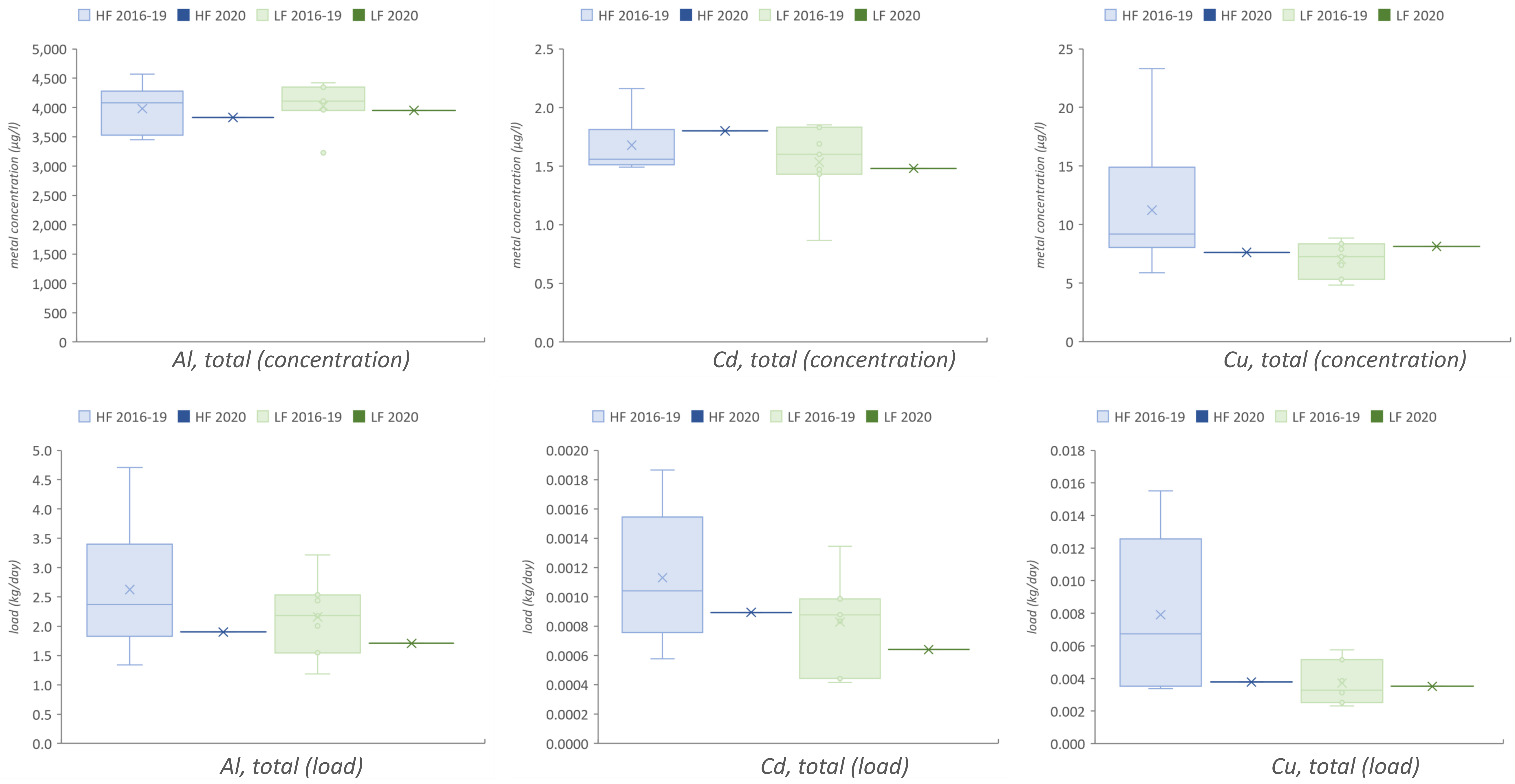
Gold King (CC06)



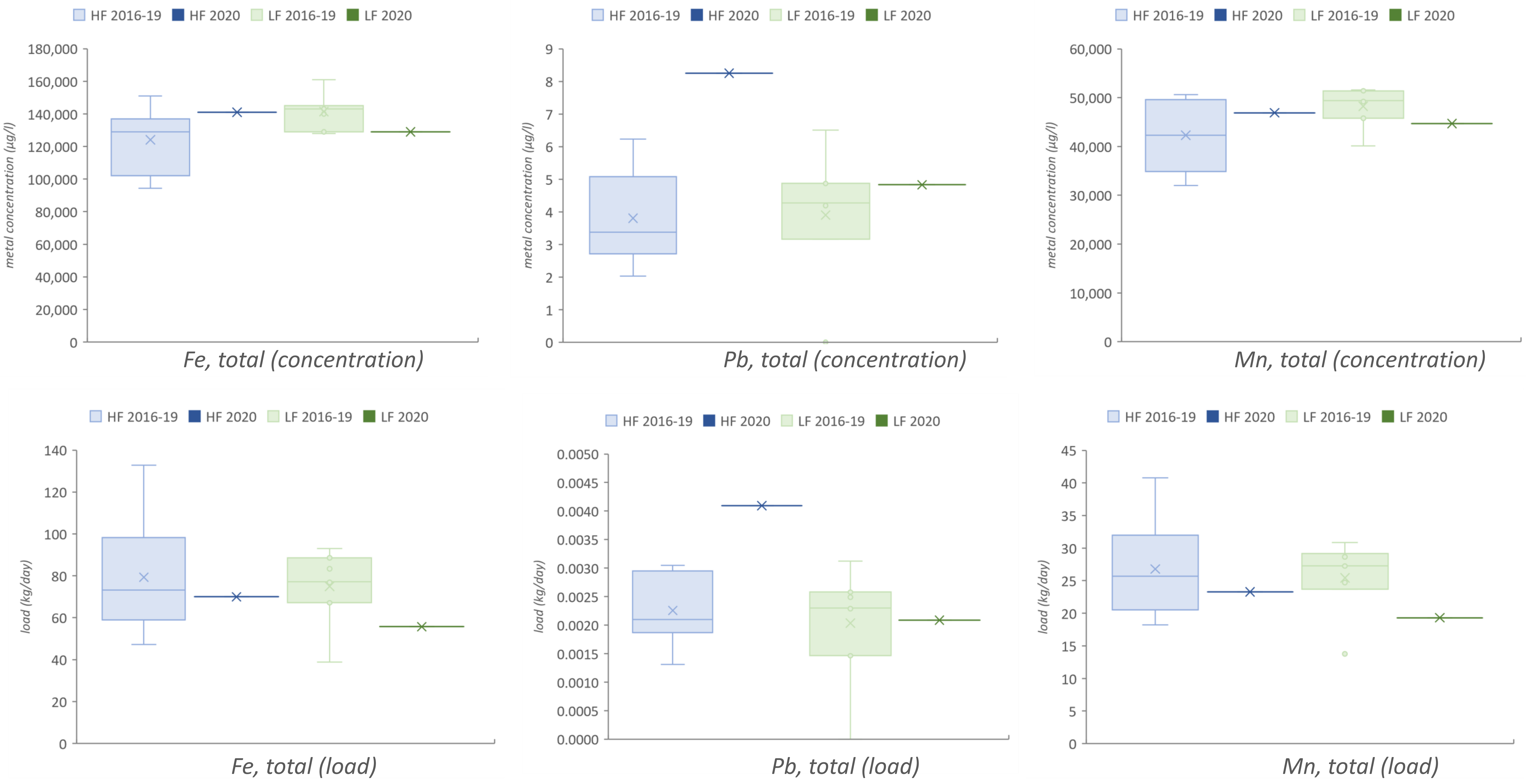
Gold King (CC06)



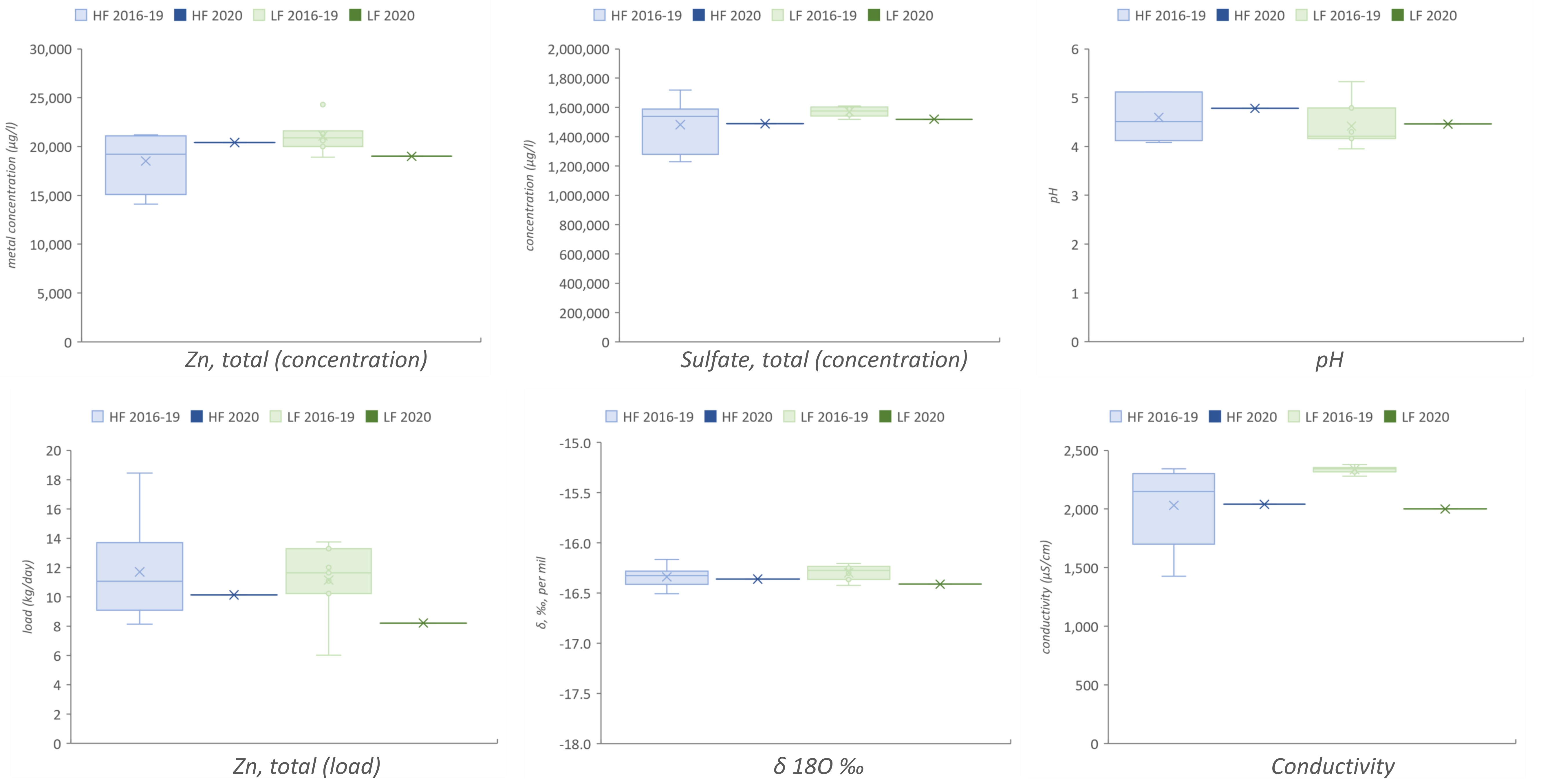
American Tunnel (CC19)



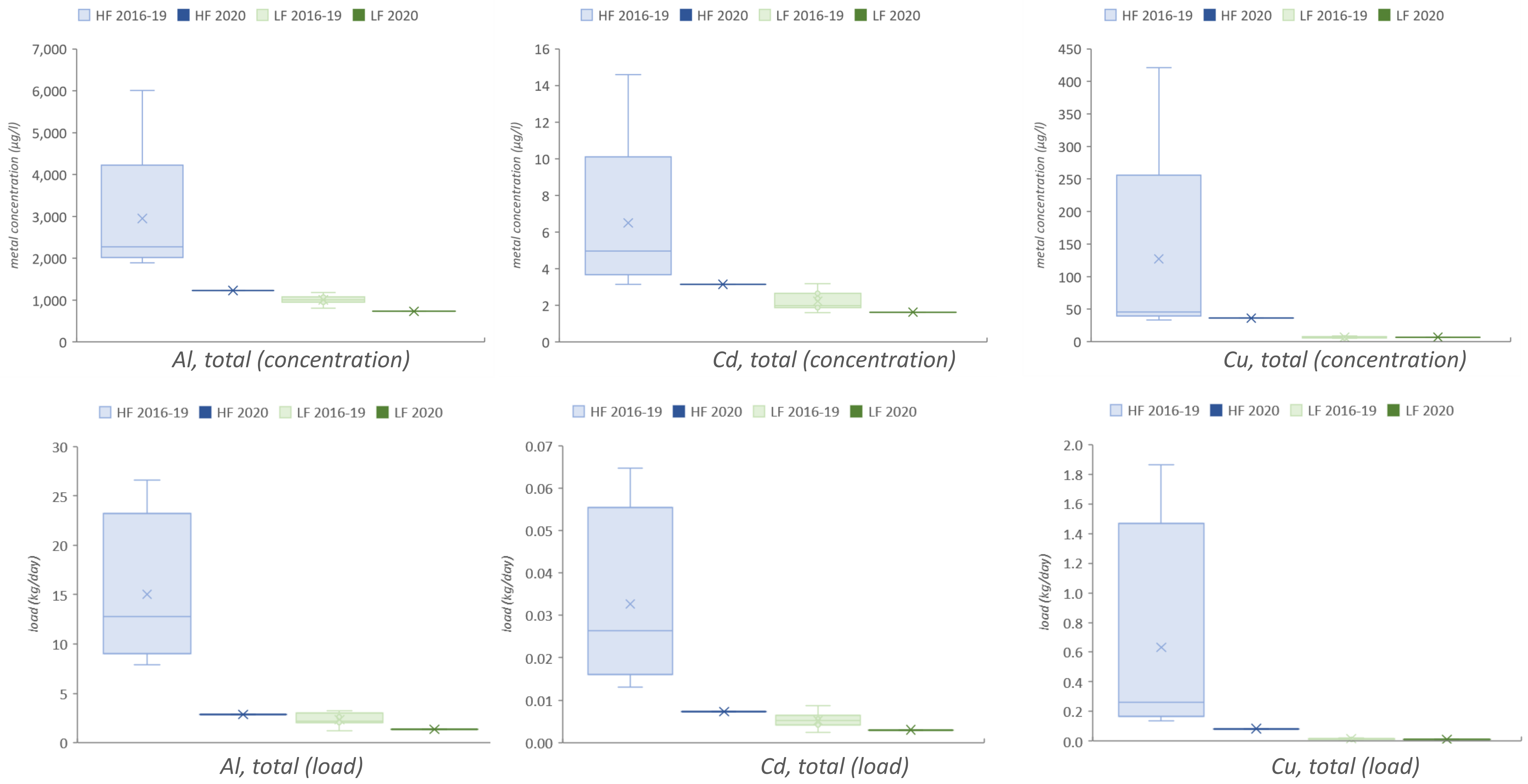
American Tunnel (CC19)



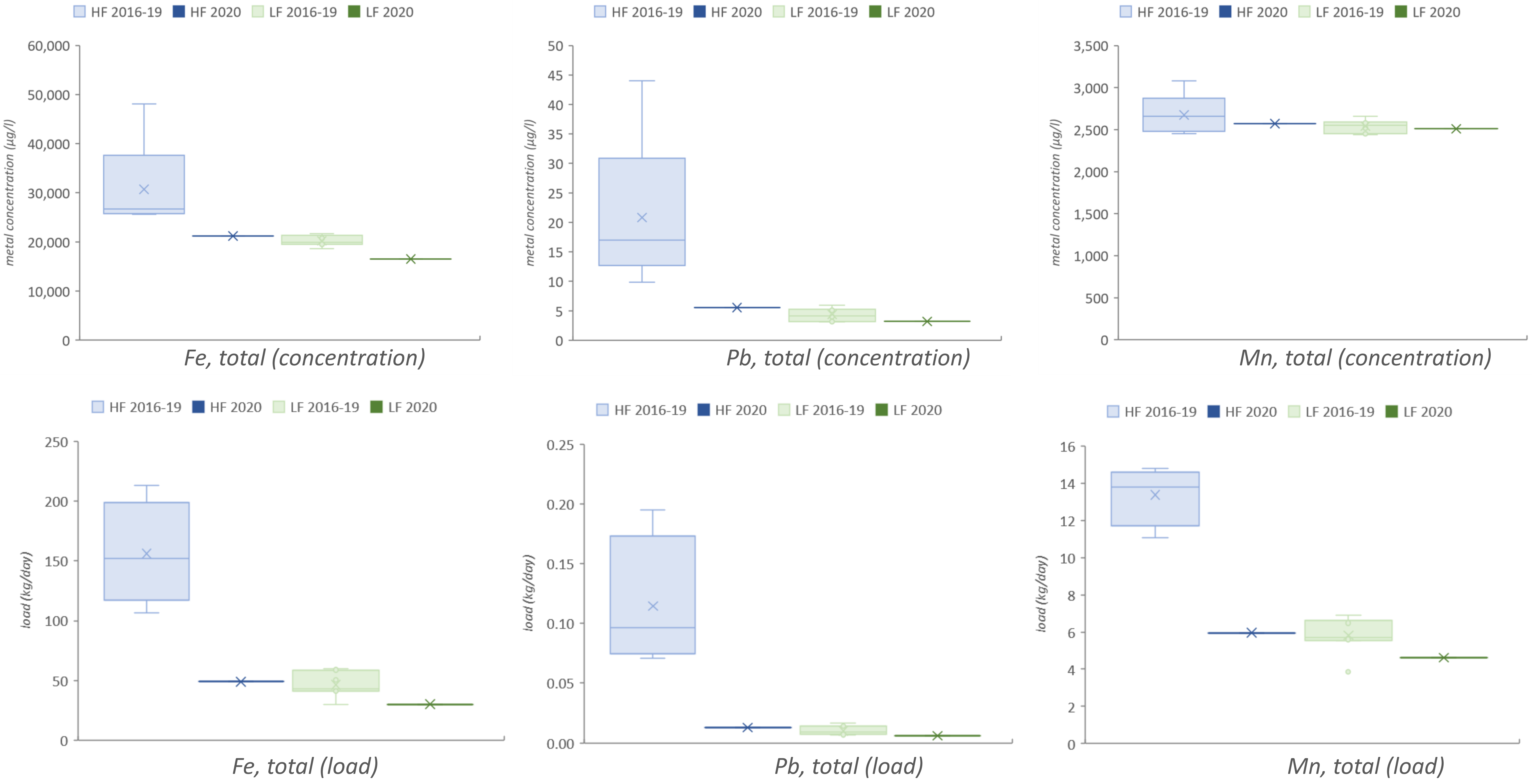
American Tunnel (CC19)



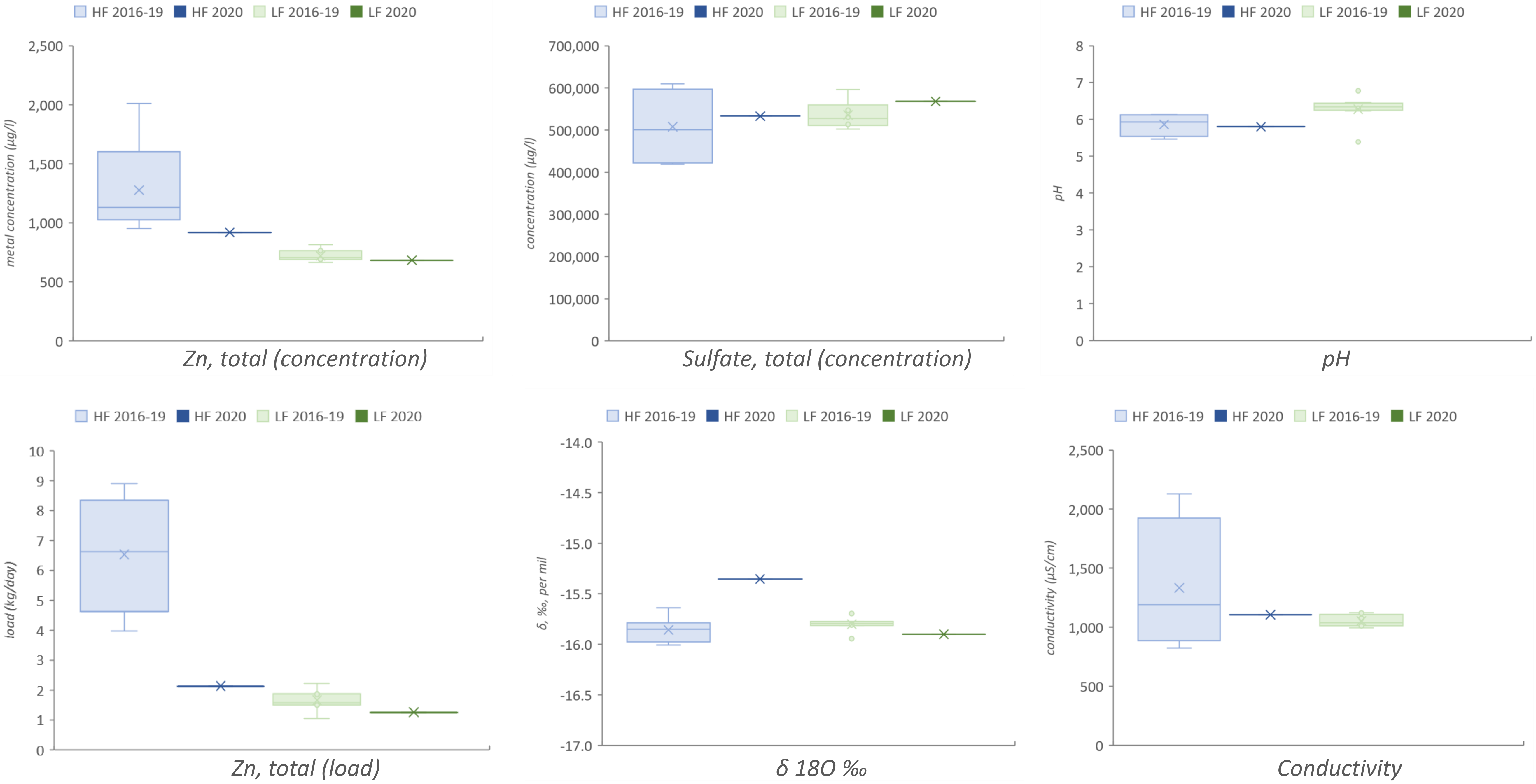
Natalie/Occidental (CC14)



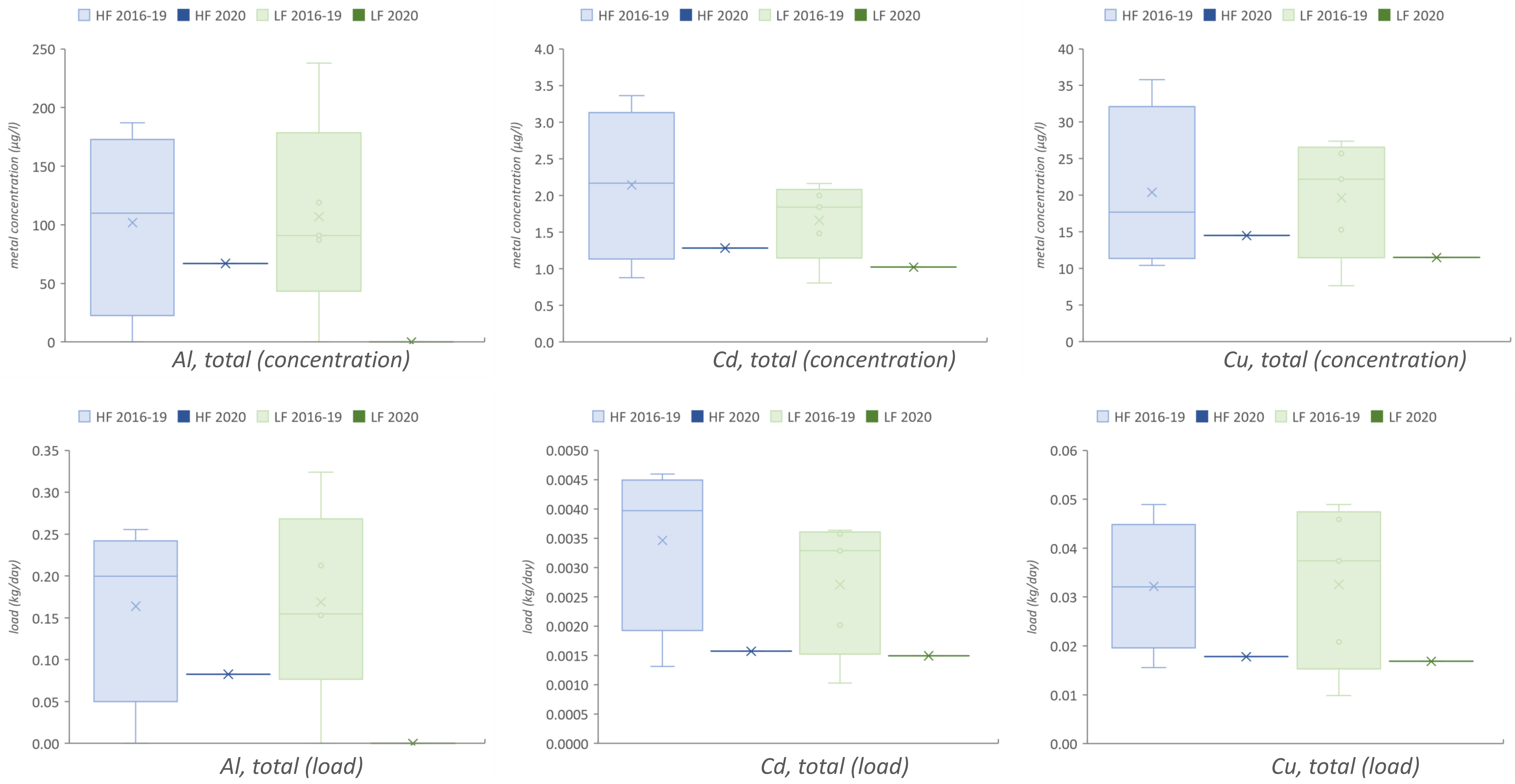
Natalie/Occidental (CC14)



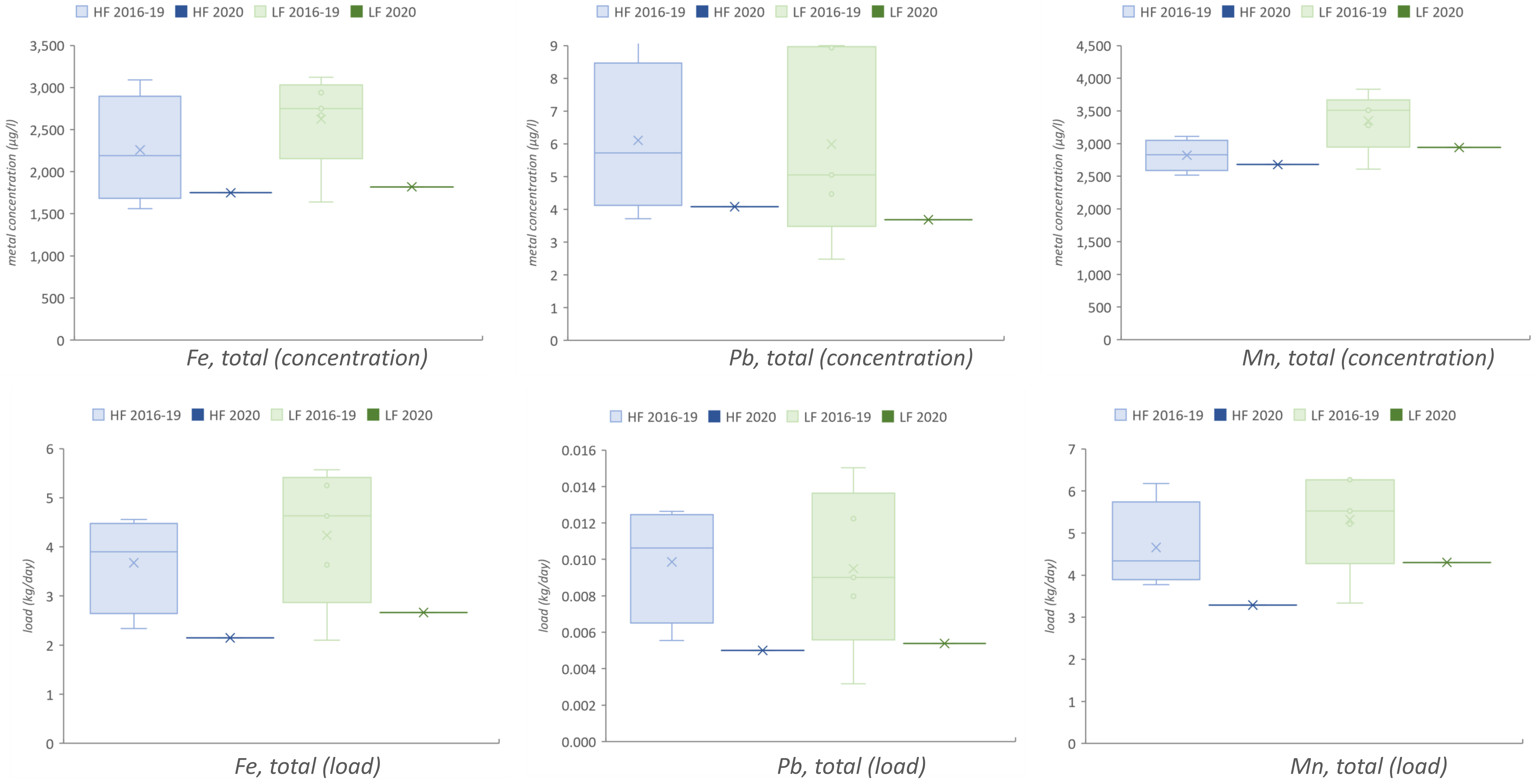
Natalie/Occidental (CC14)



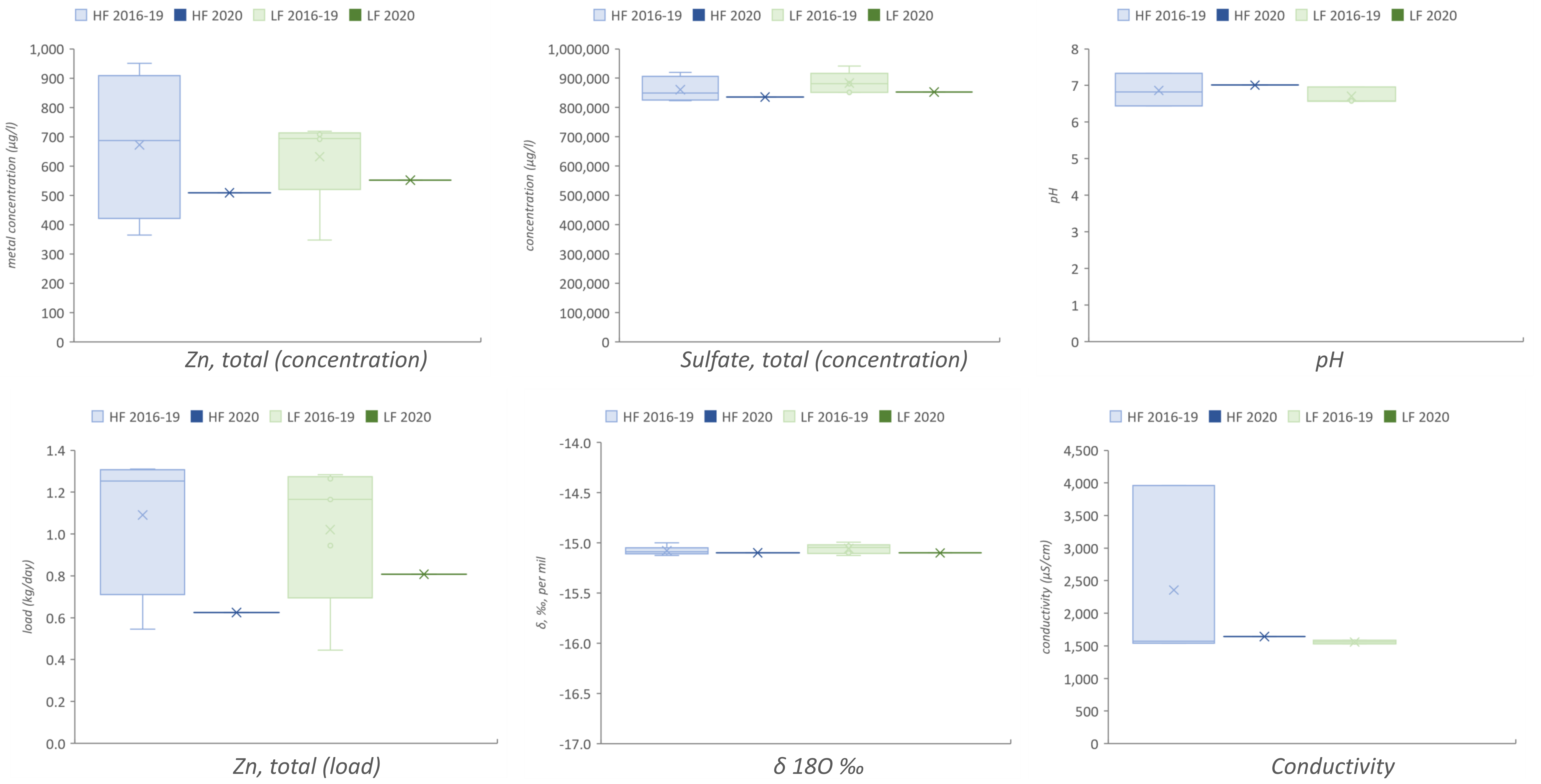
Blackhawk (CC50)



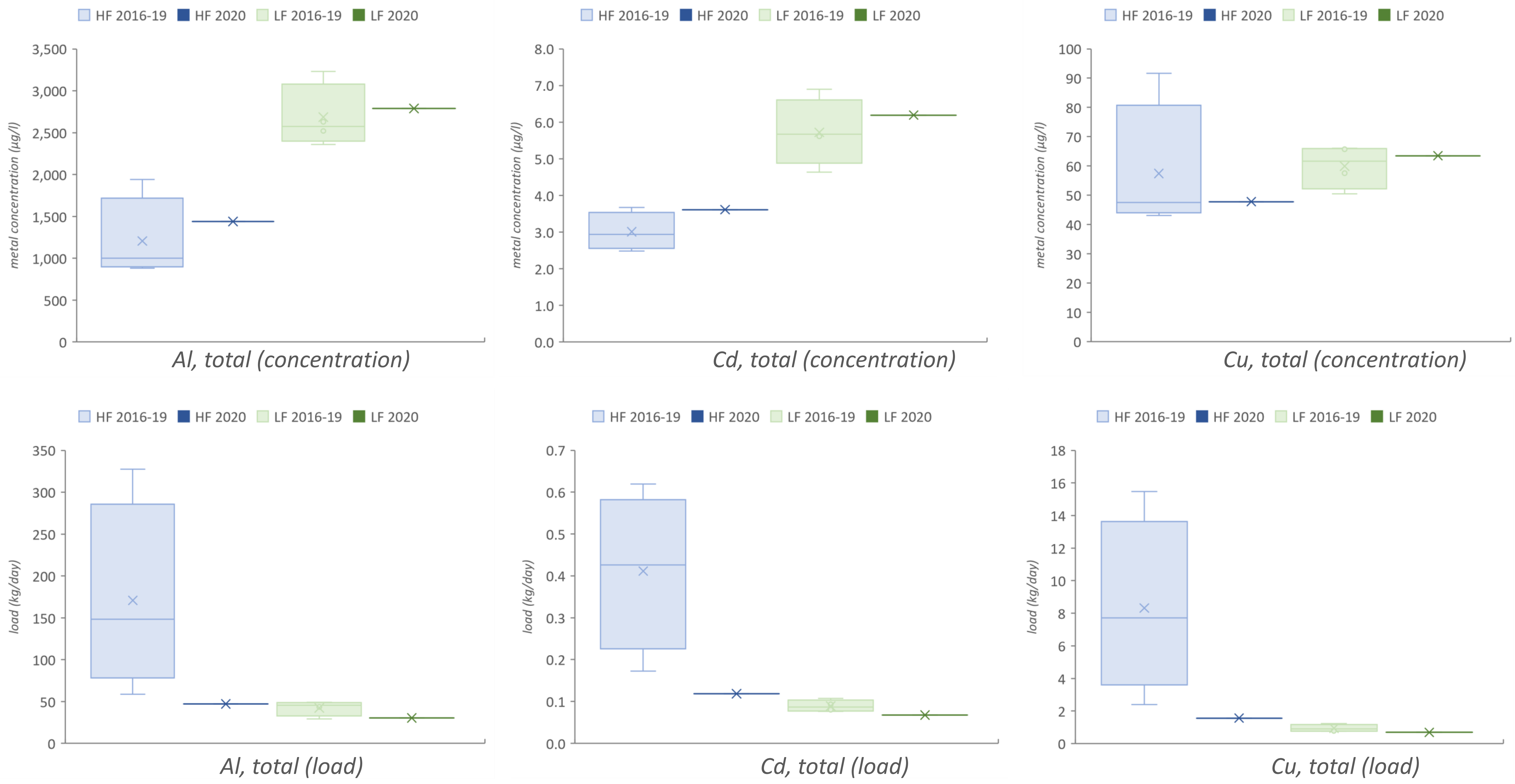
Blackhawk (CC50)



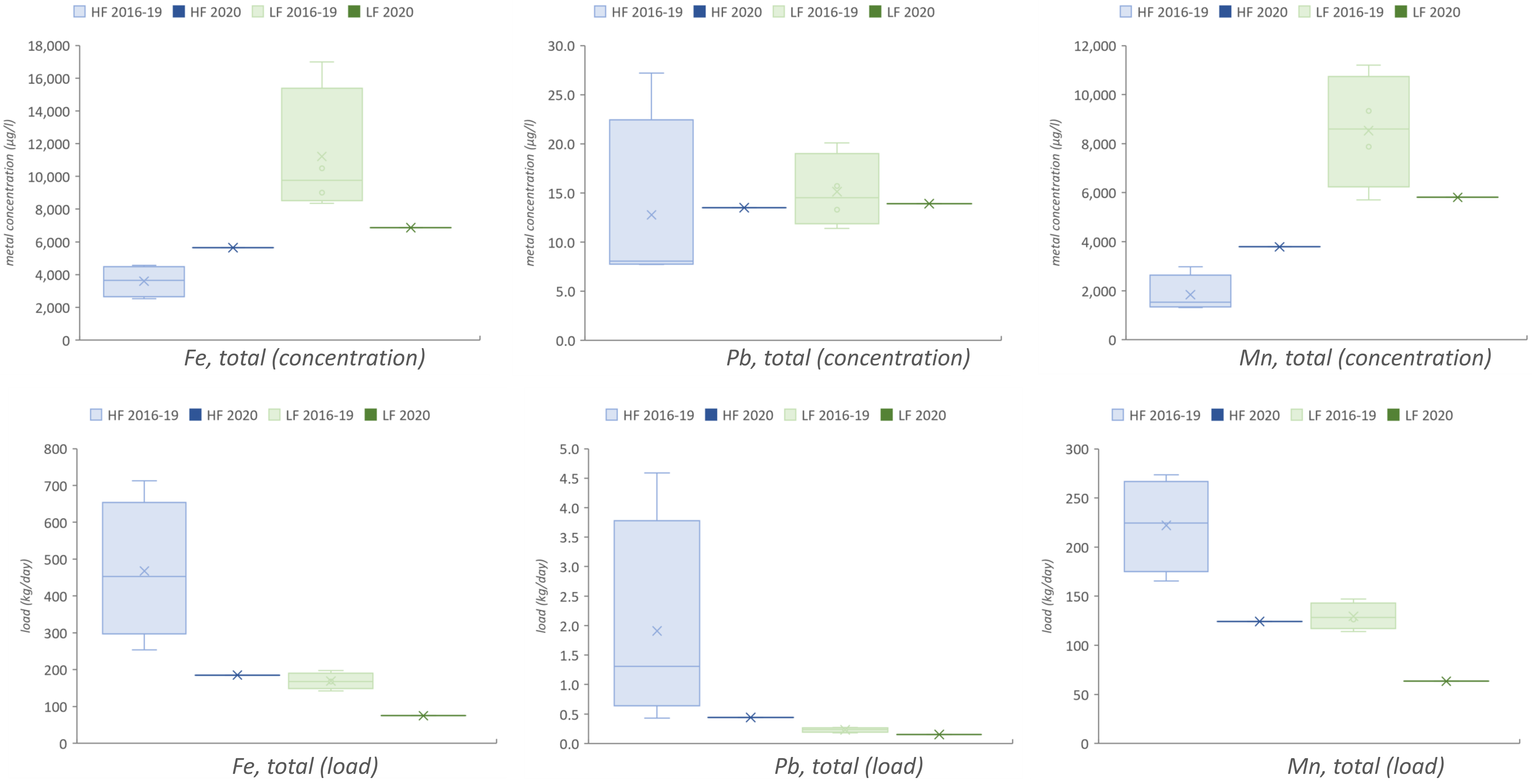
Blackhawk (CC50)



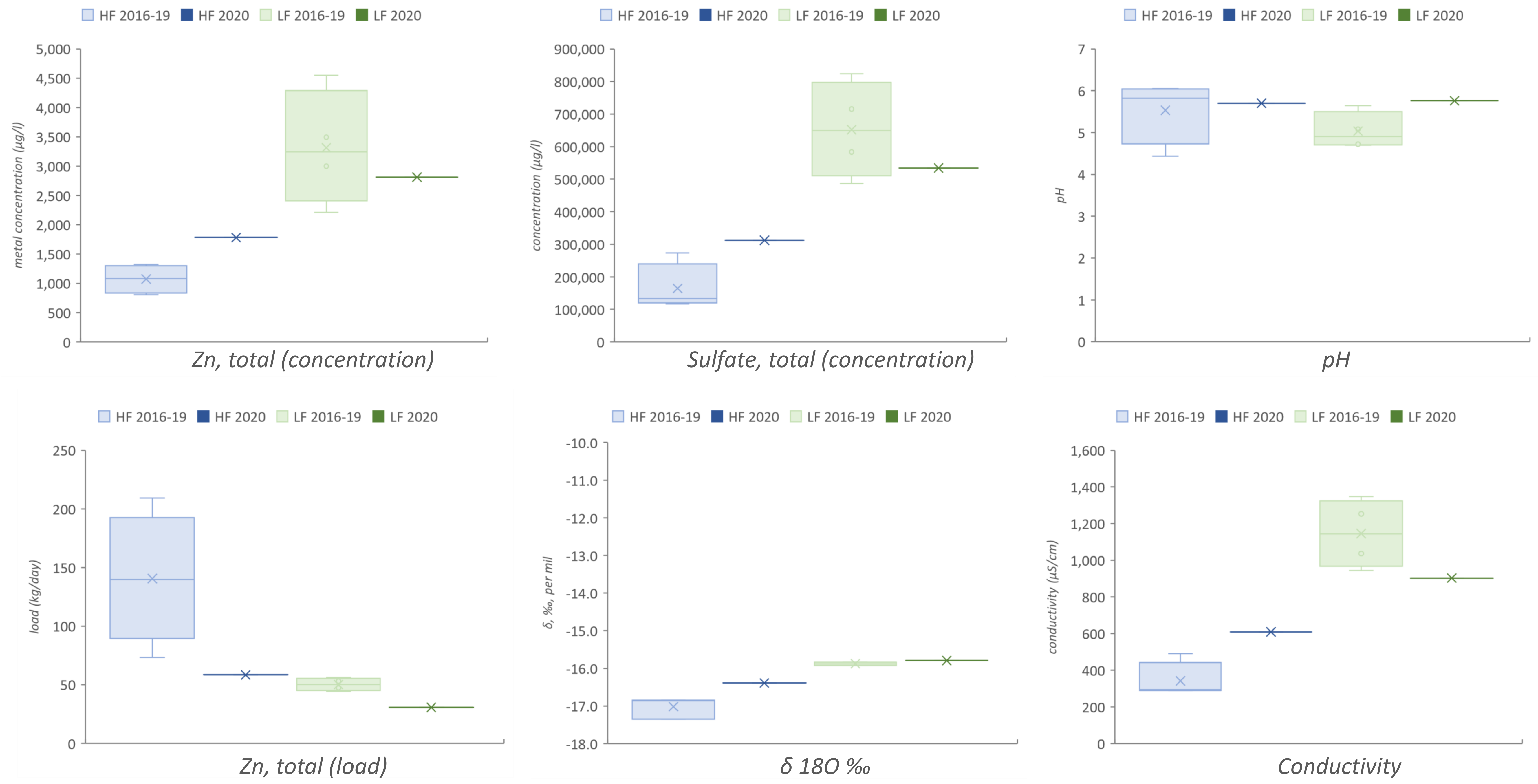
CCSG-1


HF 2016-19
HF 2020
LF 2016-19
LF 2020
metal concentration (µg/l)
3,500
3,000
2,500
2,000
1,500
1,000
500
0
Al, total (concentration)
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Cd, total (concentration)
100
90
80
70
60
50
40
30
20
10
0
Cu, total (concentration)
load (kg/day)
350
300
250
200
150
100
50
0
Al, total (load)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Cd, total (load)
18
16
14
12
10
8
6
4
2
0
Cu, total (load)

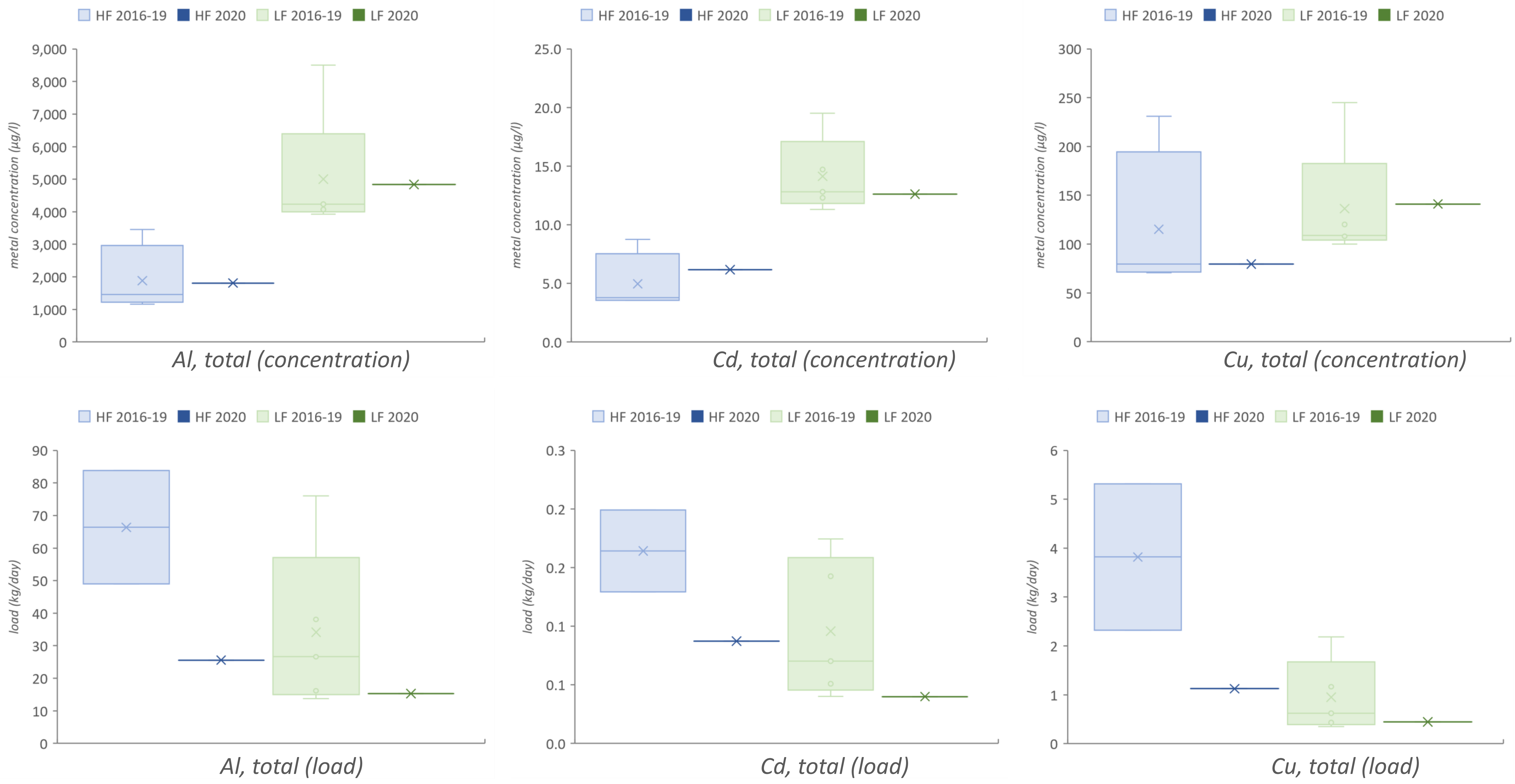
CCSG-1


HF 2016-19
HF 2020
LF 2016-19
LF 2020
metal concentration (µg/l)
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Fe, total (concentration)
30.0
25.0
20.0
15.0
10.0
5.0
0.0
Pb, total (concentration)
12,000
10,000
8,000
6,000
4,000
2,000
0
Mn, total (concentration)
load (kg/day)
800
700
600
500
400
300
200
100
0
Fe, total (load)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Pb, total (load)
300
250
200
150
100
50
0
Mn, total (load)

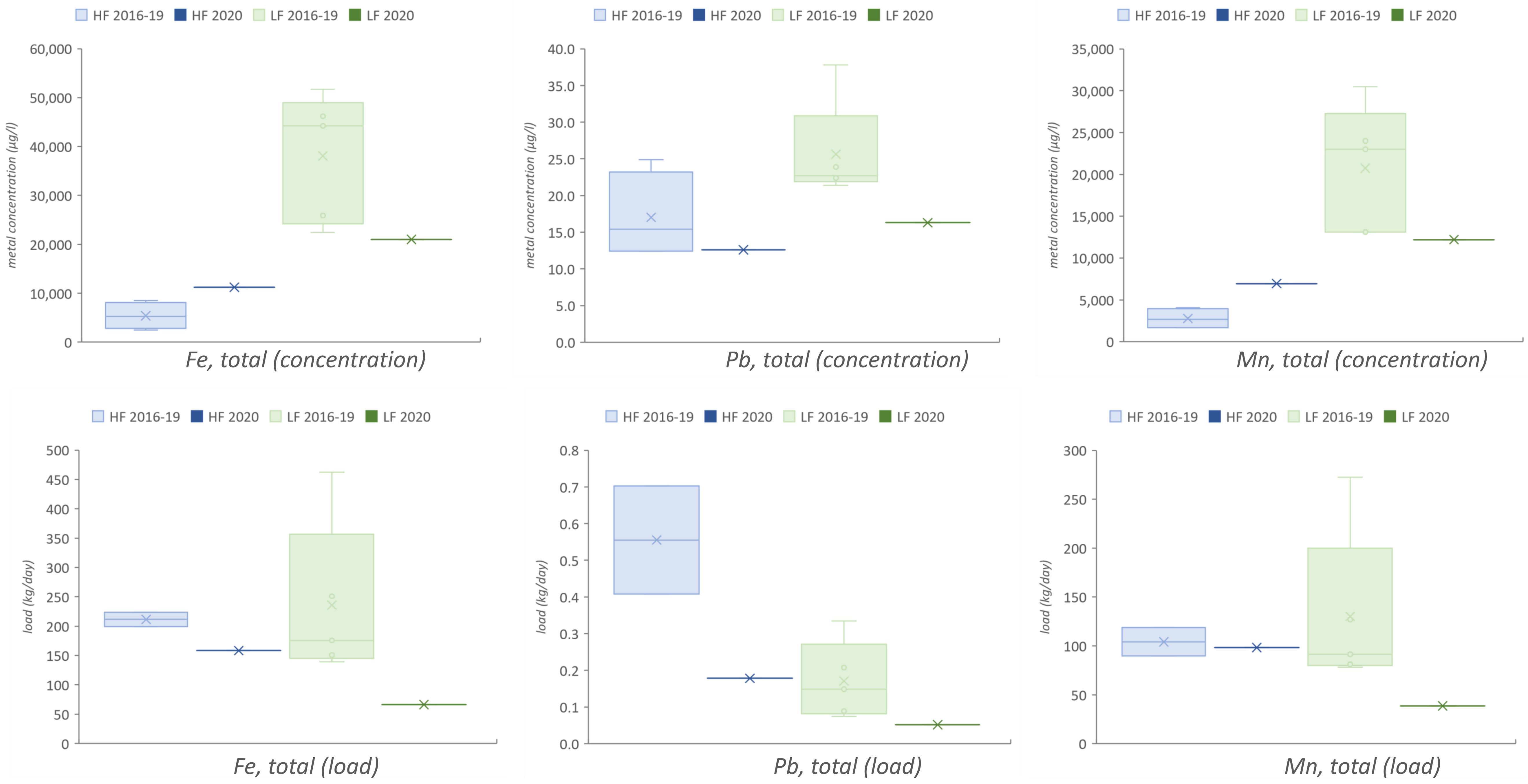
CCSG-1


HF 2016-19
HF 2020
LF 2016-19
LF 2020
metal concentration (µg/l)
Zn, total (concentration)
concentration (µg/l)
Sulfate, total (concentration)
pH
pH
load (kg/day)
Zn, total (load)
δ, ‰, per mil
δ 18O ‰
conductivity (µS/cm)
Conductivity

CCSG-3

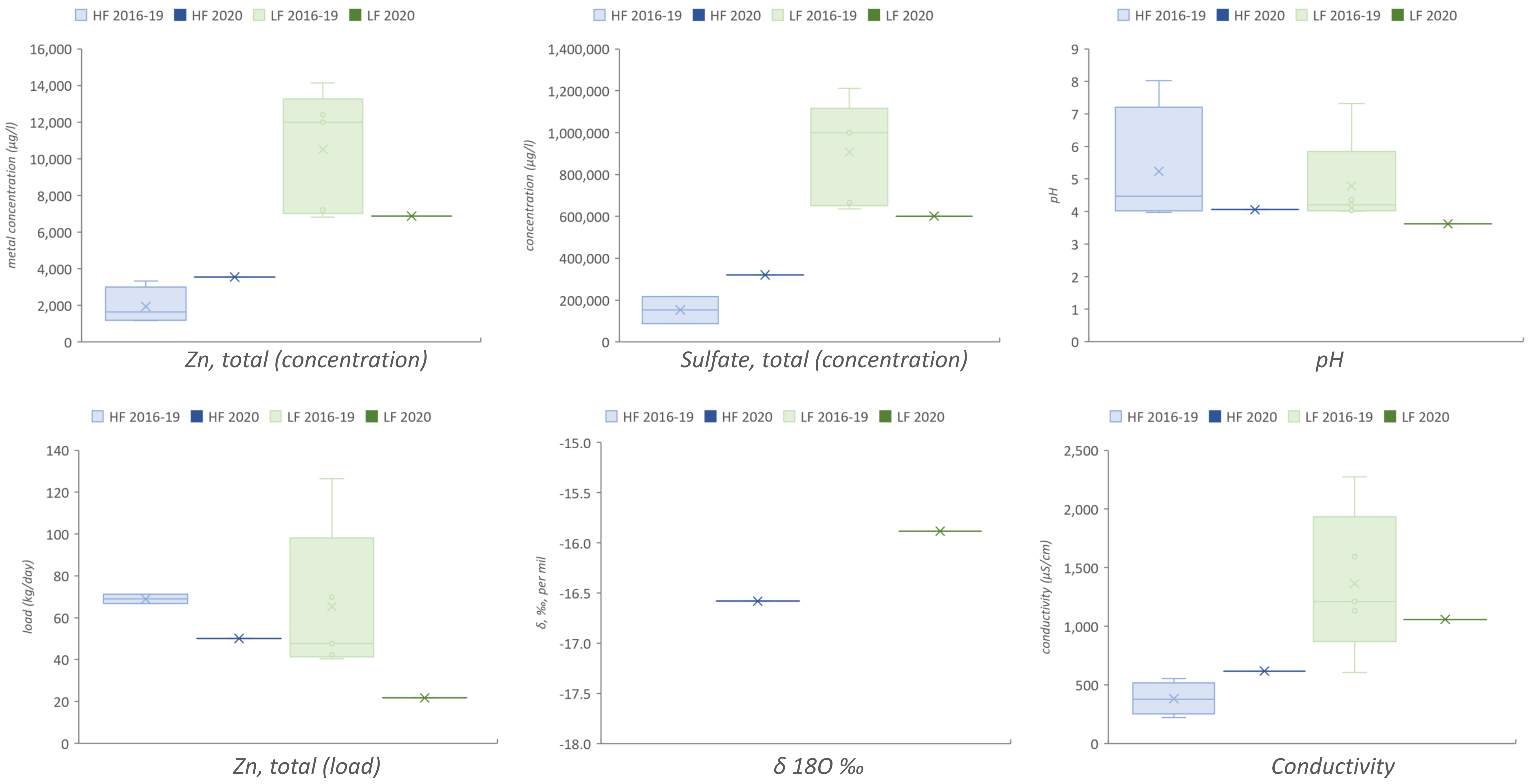

HF 2016-19
HF 2020
LF 2016-19
LF 2020
metal concentration (µg/l)
Al, total (concentration)
Cd, total (concentration)
Cu, total (concentration)
load (kg/day)
Al, total (load)
Cd, total (load)
Cu, total (load)
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
25.0
20.0
15.0
10.0
5.0
0.0
300
250
200
150
100
50
90
80
70
60
50
40
30
20
10
0.3
0.2
0.1
6
5
4
3
2
1

CCSG-3



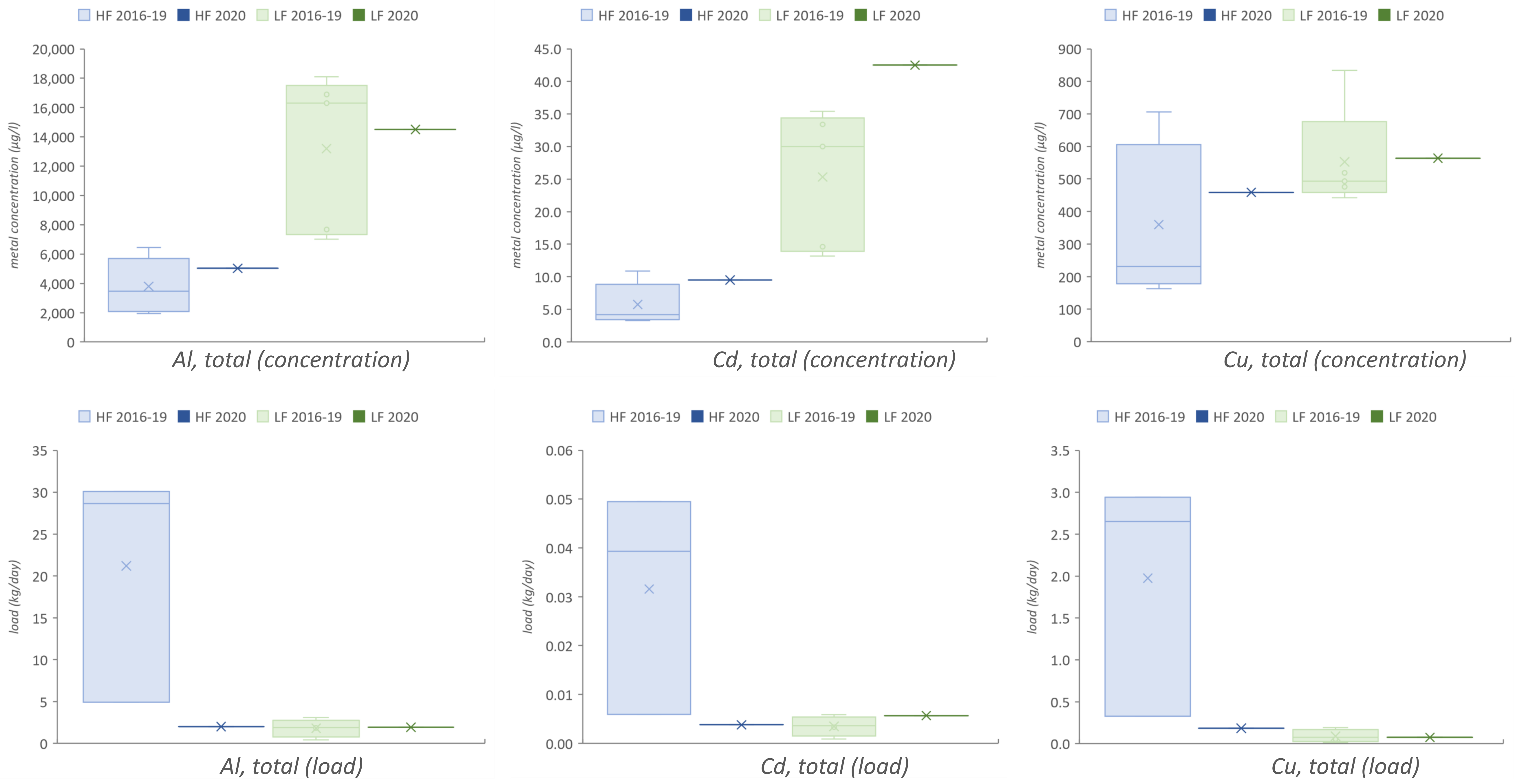
HF 2016-19
HF 2020
LF 2016-19
LF 2020
metal concentration (μg/l)
60,000
50,000
40,000
30,000
20,000
10,000
0
Fe, total (concentration)
HF 2016-19
HF 2020
LF 2016-19
LF 2020
metal concentration (μg/l)
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
Pb, total (concentration)
HF 2016-19
HF 2020
LF 2016-19
LF 2020
metal concentration (μg/l)
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
Mn, total (concentration)
HF 2016-19
HF 2020
LF 2016-19
LF 2020
load (kg/day)
500
450
400
350
300
250
200
150
100
50
0
Fe, total (load)
HF 2016-19
HF 2020
LF 2016-19
LF 2020
load (kg/day)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Pb, total (load)
HF 2016-19
HF 2020
LF 2016-19
LF 2020
load (kg/day)
300
250
200
150
100
50
0
Mn, total (load)

CCSG-3

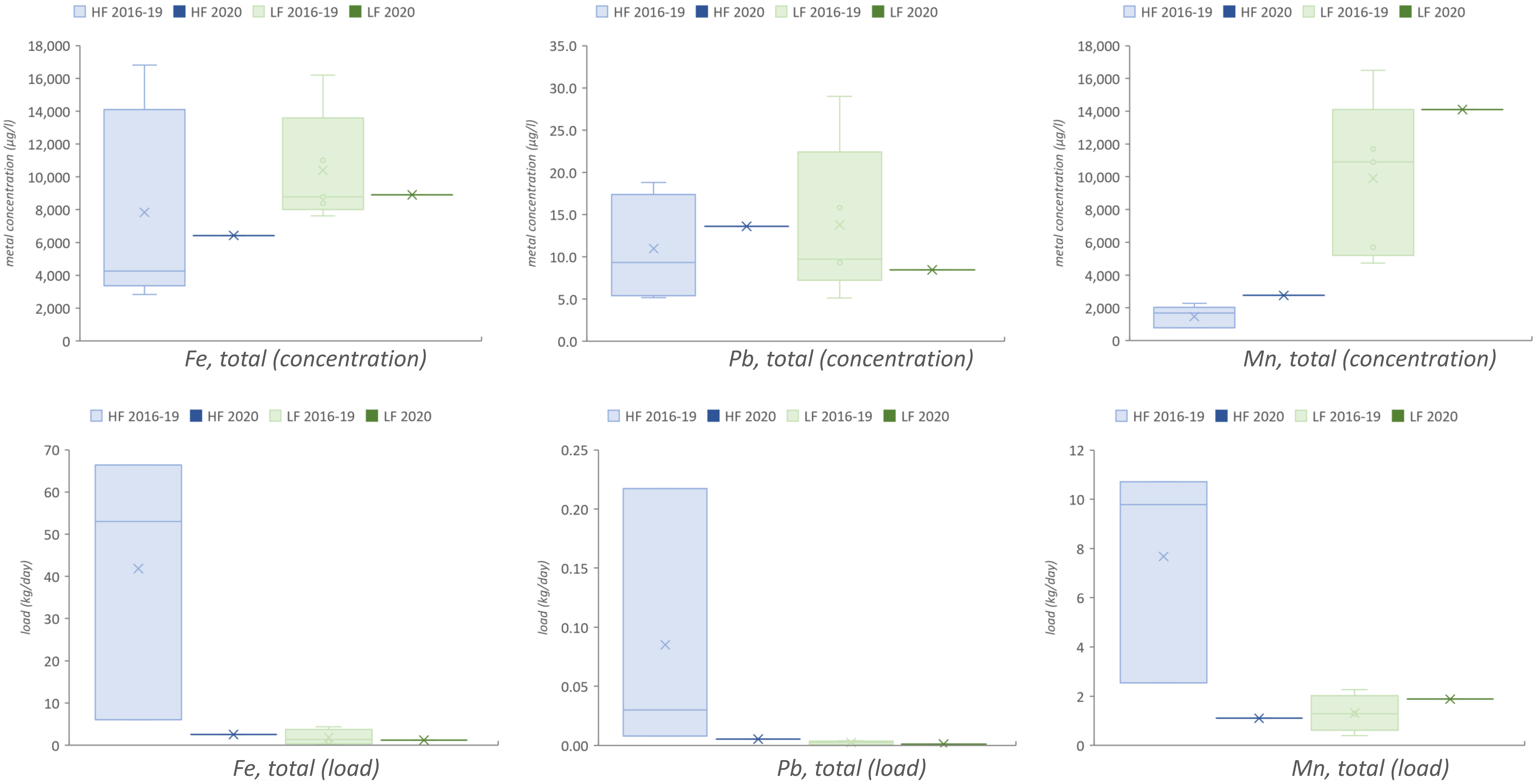


HF 2016-19
HF 2020
LF 2016-19
LF 2020
metal concentration (µg/l)
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Zn, total (concentration)
concentration (µg/l)
1,400,000
1,200,000
1,000,000
800,000
600,000
400,000
200,000
0
Sulfate, total (concentration)
pH
9
8
7
6
5
4
3
2
1
0
pH
load (kg/day)
140
120
100
80
60
40
20
0
Zn, total (load)
δ, ‰, per mil
-15.0
-15.5
-16.0
-16.5
-17.0
-17.5
-18.0
δ 18O ‰
conductivity (µS/cm)
2,500
2,000
1,500
1,000
500
0
Conductivity

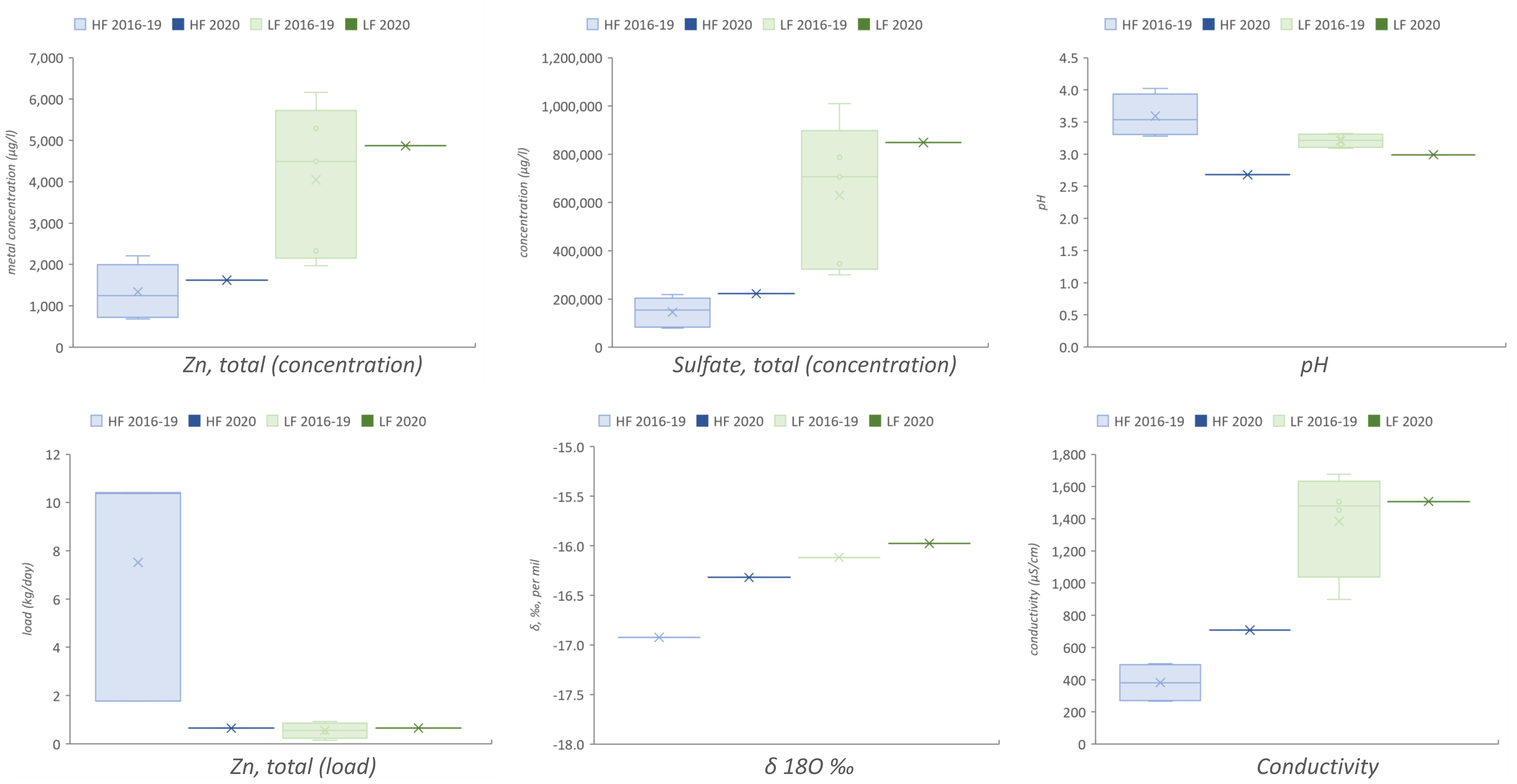
CCSG-5


HF 2016-19
HF 2020
LF 2016-19
LF 2020
metal concentration (µg/l)
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Al, total (concentration)
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
Cd, total (concentration)
900
800
700
600
500
400
300
200
100
0
Cu, total (concentration)
load (kg/day)
35
30
25
20
15
10
5
0
Al, total (load)
0.06
0.05
0.04
0.03
0.02
0.01
0.00
Cd, total (load)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Cu, total (load)

CCSG-5

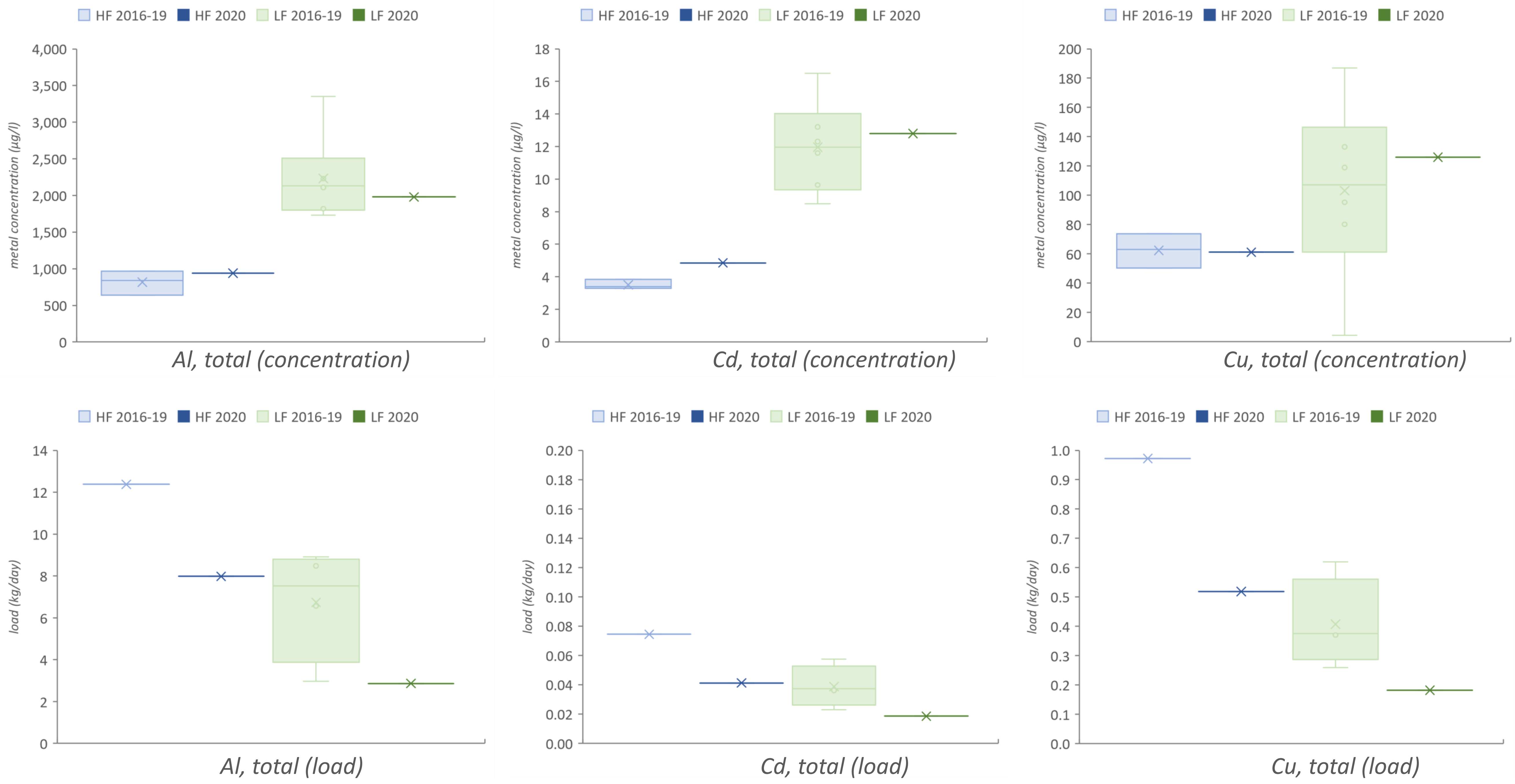

HF 2016-19
HF 2020
LF 2016-19
LF 2020
metal concentration (µg/l)
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Fe, total (concentration)
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
Pb, total (concentration)
Mn, total (concentration)
load (kg/day)
70
60
50
40
30
20
10
0
Fe, total (load)
0.25
0.20
0.15
0.10
0.05
0.00
Pb, total (load)
12
10
8
6
4
2
0
Mn, total (load)

CCSG-5

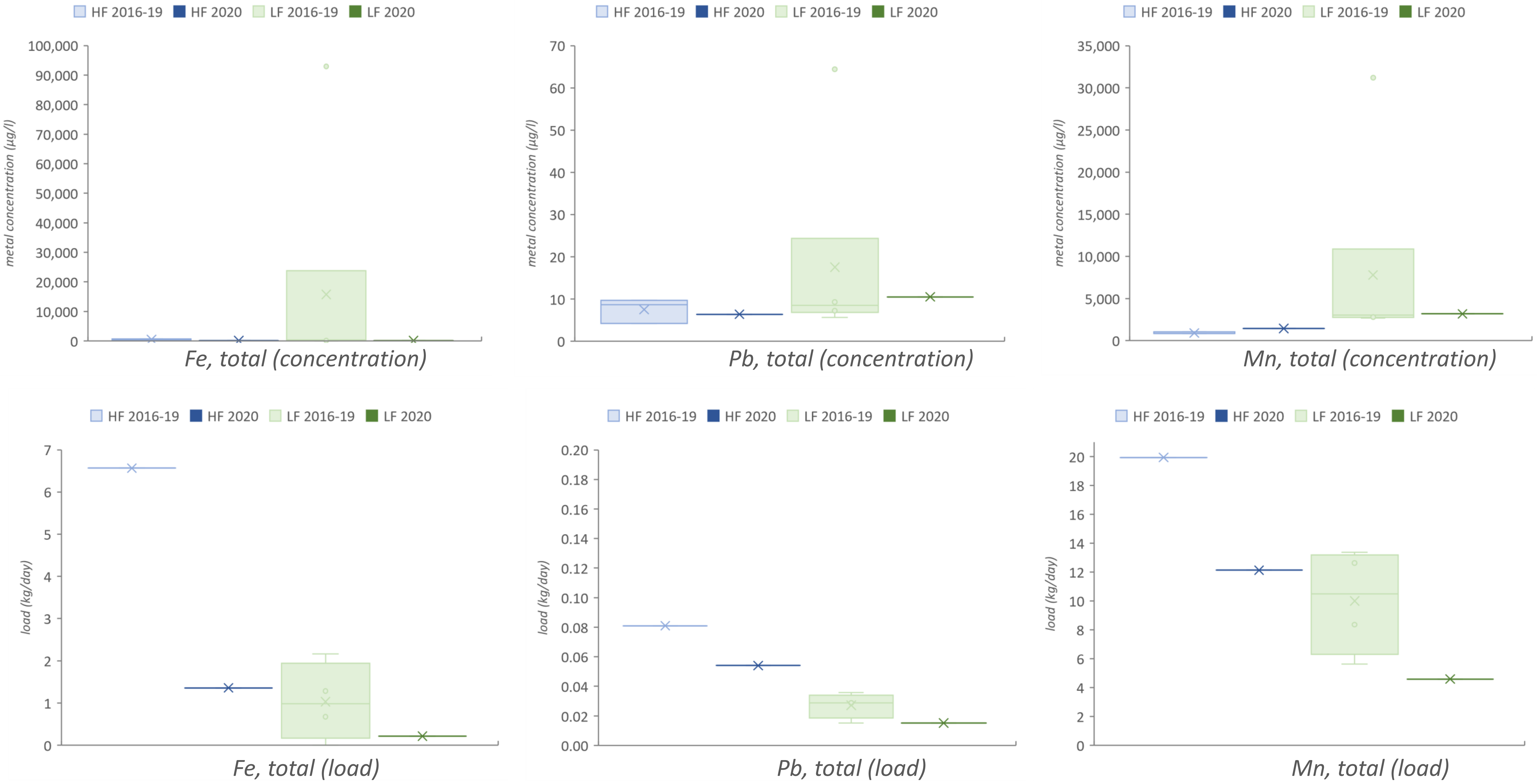


HF 2016-19
HF 2020
LF 2016-19
LF 2020
metal concentration (µg/l)
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Zn, total (concentration)
concentration (µg/l)
1,200,000
1,000,000
800,000
600,000
400,000
200,000
0
Sulfate, total (concentration)
pH
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
pH
load (kg/day)
12
10
8
6
4
2
0
Zn, total (load)
δ, ‰, per mil
-15.0
-15.5
-16.0
-16.5
-17.0
-17.5
-18.0
δ 18O ‰
conductivity (µS/cm)
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
Conductivity

CCSG-6

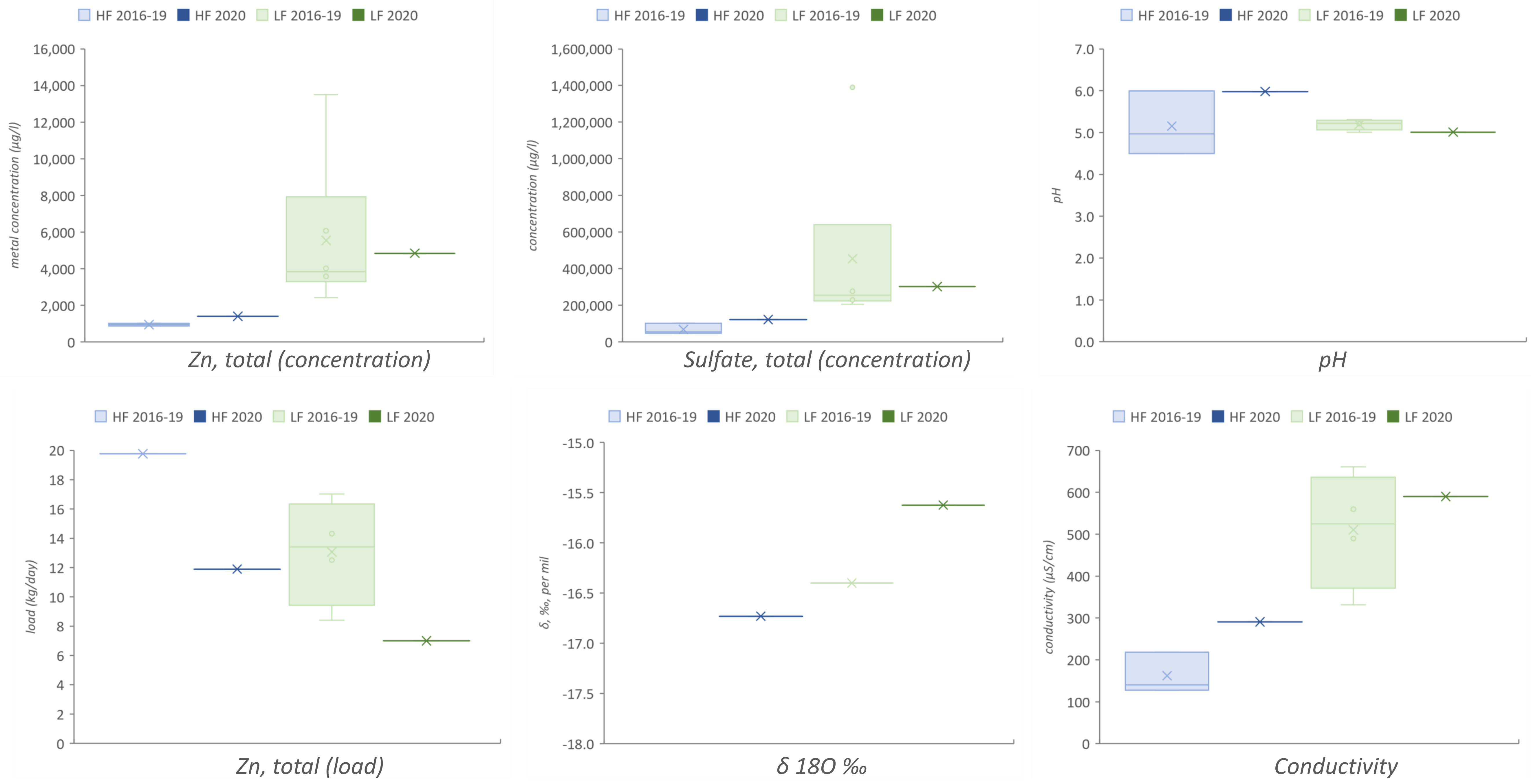

HF 2016-19
HF 2020
LF 2016-19
LF 2020
metal concentration (µg/l)
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
Al, total (concentration)
18
16
14
12
10
8
6
4
2
0
Cd, total (concentration)
200
180
160
140
120
100
80
60
40
20
0
Cu, total (concentration)
load (kg/day)
14
12
10
8
6
4
2
0
Al, total (load)
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
Cd, total (load)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Cu, total (load)

CCSG-6

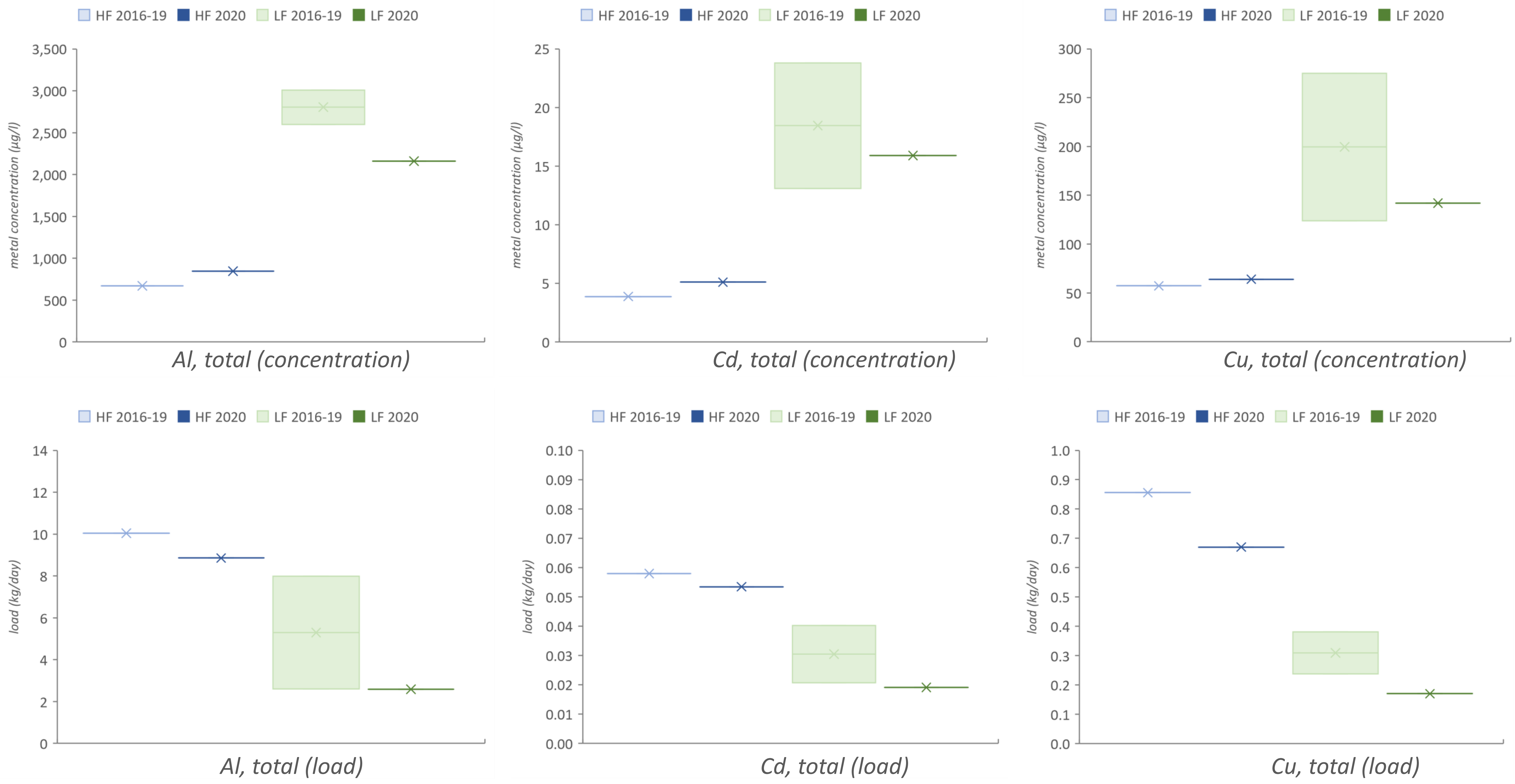


HF 2016-19
HF 2020
LF 2016-19
LF 2020
metal concentration (µg/l)
Fe, total (concentration)
Pb, total (concentration)
Mn, total (concentration)
load (kg/day)
Fe, total (load)
Pb, total (load)
Mn, total (load)

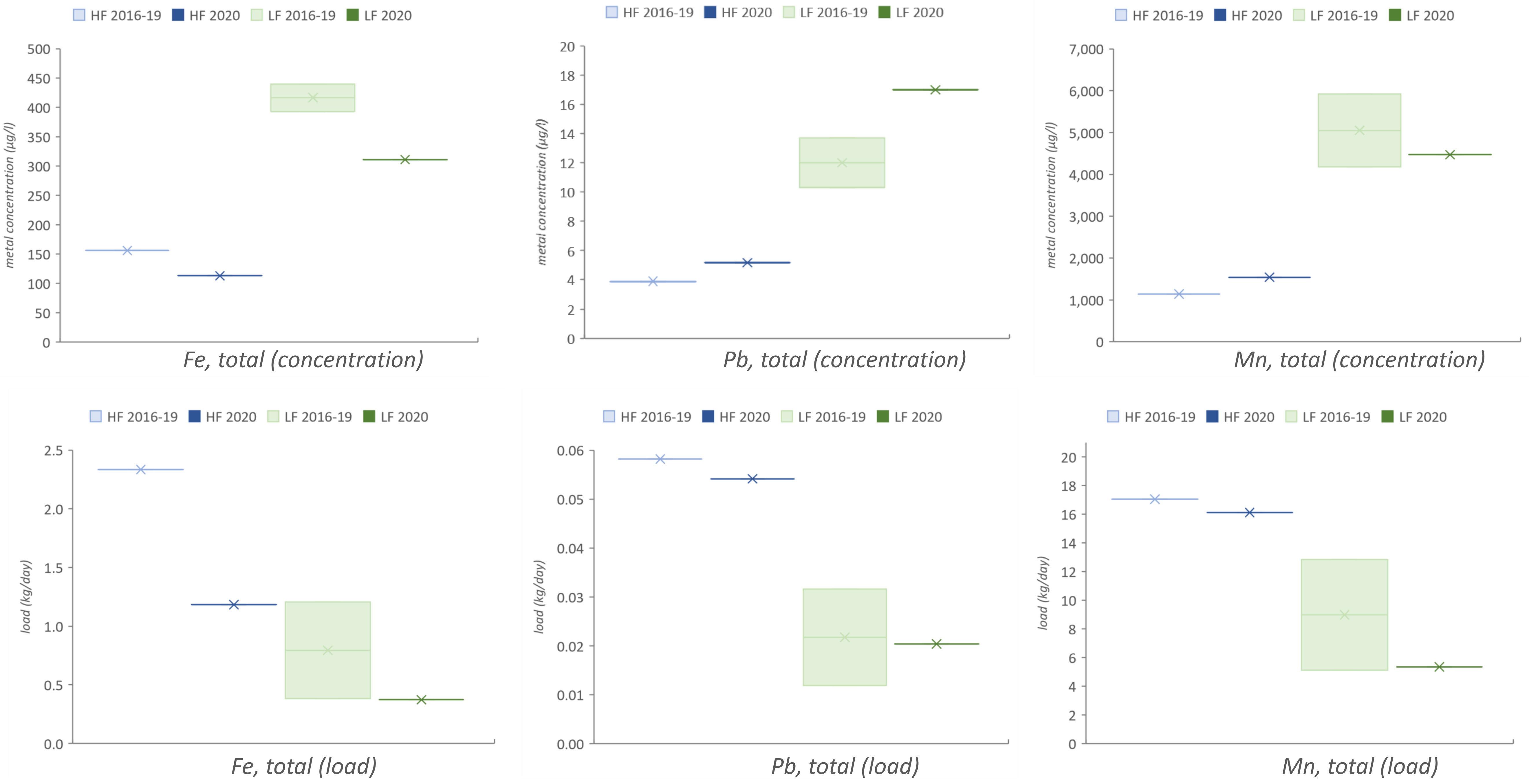
CCSG-6


HF 2016-19
HF 2020
LF 2016-19
LF 2020
metal concentration (µg/l)
Zn, total (concentration)
concentration (µg/l)
Sulfate, total (concentration)
pH
pH
load (kg/day)
Zn, total (load)
δ, ‰, per mil
δ 18O ‰
conductivity (µS/cm)
Conductivity

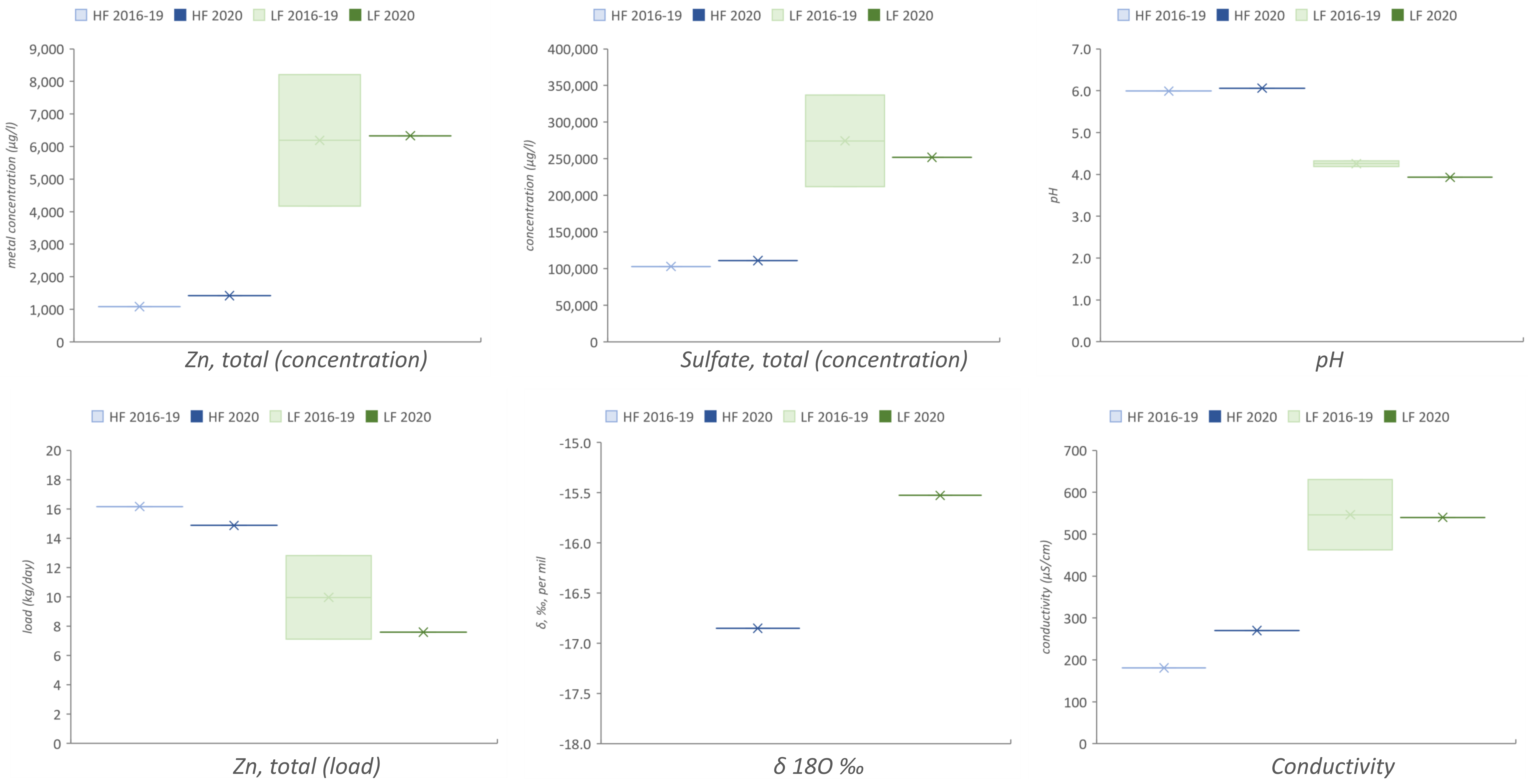
CCSG-7


HF 2016-19
HF 2020
LF 2016-19
LF 2020
metal concentration (µg/l)
Al, total (concentration)
Cd, total (concentration)
Cu, total (concentration)
load (kg/day)
Al, total (load)
Cd, total (load)
Cu, total (load)

CCSG-7

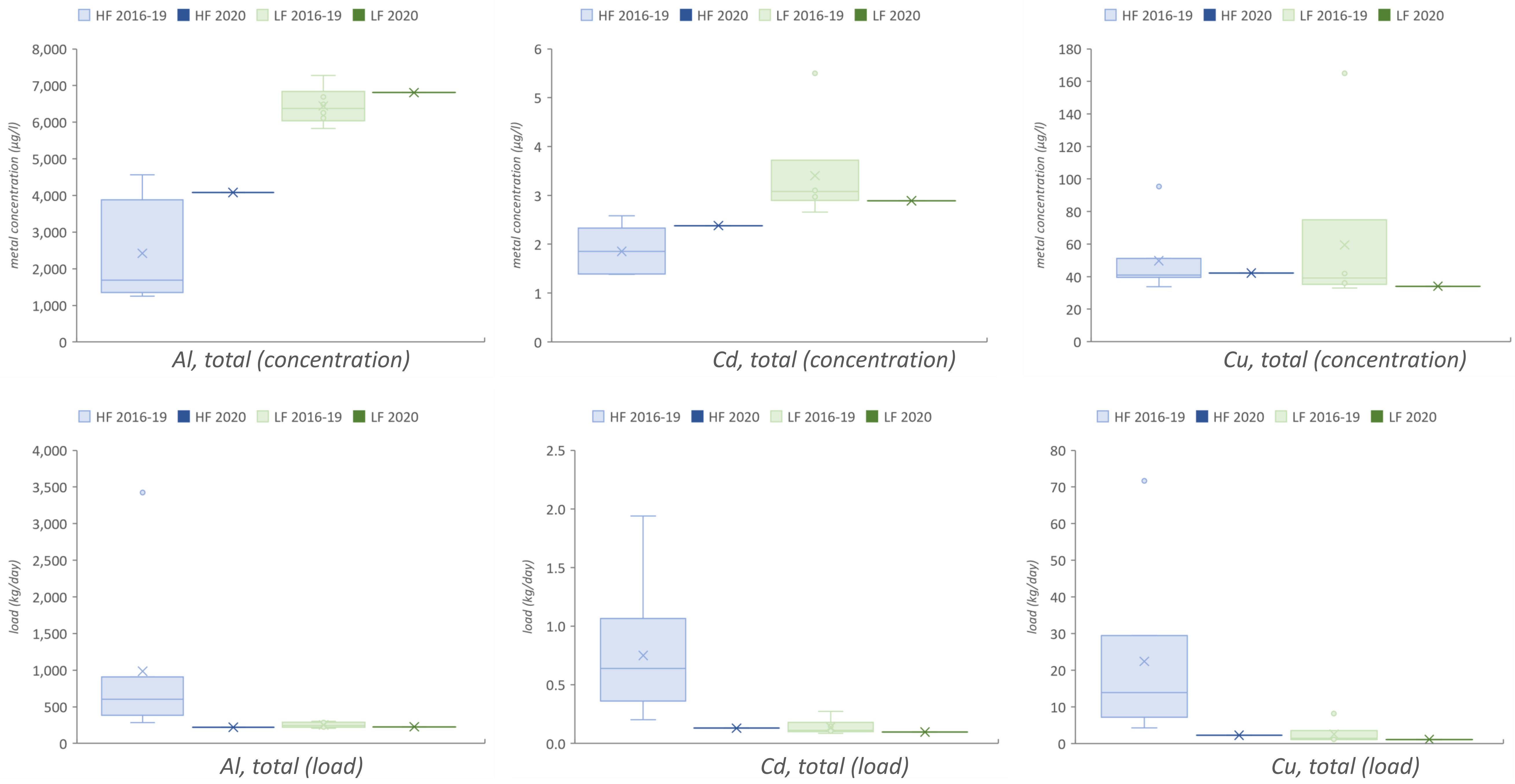

HF 2016-19
HF 2020
LF 2016-19
LF 2020
metal concentration (µg/l)
Fe, total (concentration)
Pb, total (concentration)
Mn, total (concentration)
load (kg/day)
Fe, total (load)
Pb, total (load)
Mn, total (load)

CCSG-7

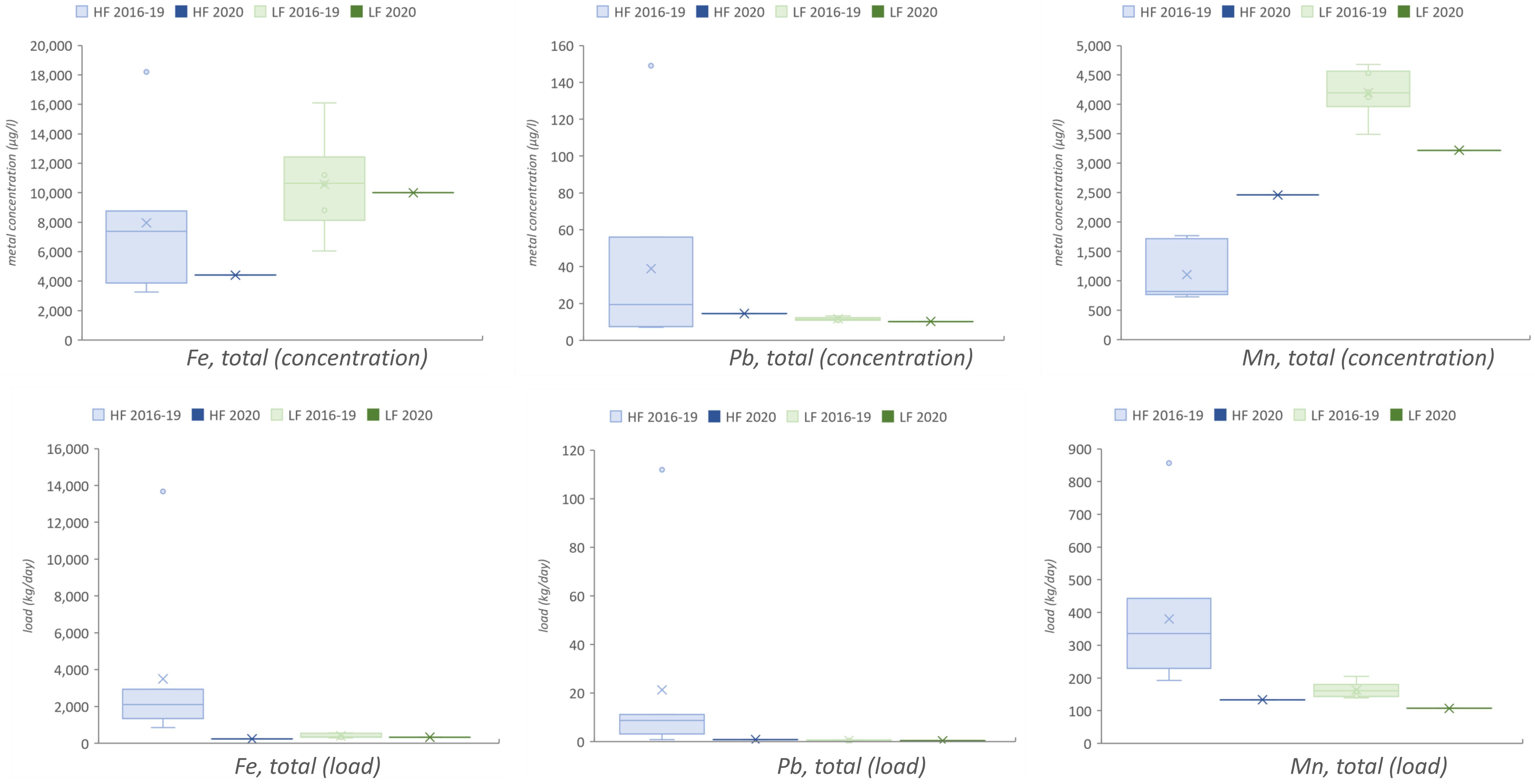


HF 2016-19
HF 2020
LF 2016-19
LF 2020
metal concentration (µg/l)
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Zn, total (concentration)
concentration (µg/l)
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
Sulfate, total (concentration)
pH
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
pH
load (kg/day)
20
18
16
14
12
10
8
6
4
2
0
Zn, total (load)
δ, ‰, per mil
-15.0
-15.5
-16.0
-16.5
-17.0
-17.5
-18.0
δ 18O ‰
conductivity (µS/cm)
700
600
500
400
300
200
100
0
Conductivity

CC48

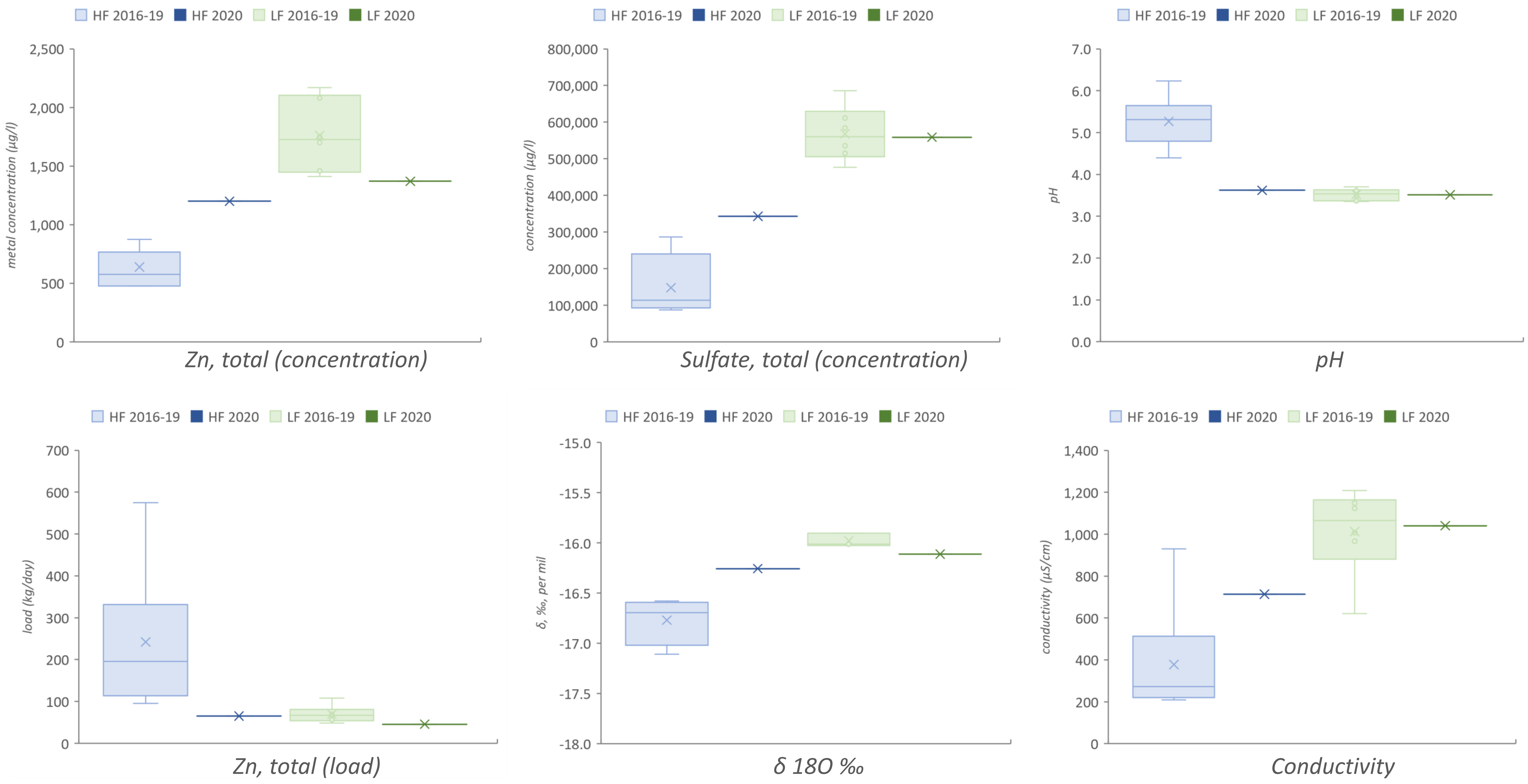

HF 2016-19
HF 2020
LF 2016-19
LF 2020
metal concentration (µg/l)
Al, total (concentration)
Cd, total (concentration)
Cu, total (concentration)
load (kg/day)
Al, total (load)
Cd, total (load)
Cu, total (load)

CC48



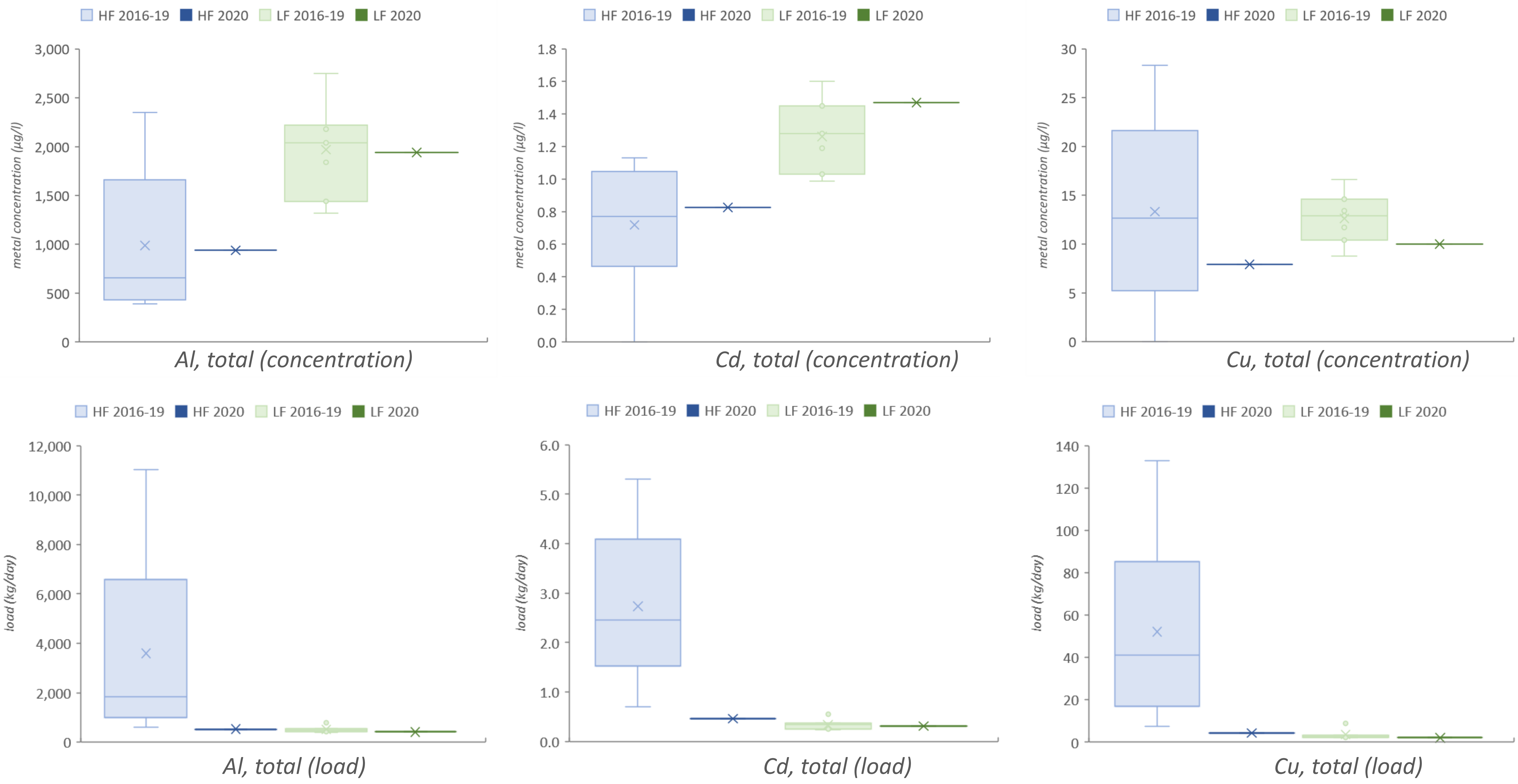
HF 2016-19
HF 2020
LF 2016-19
LF 2020
metal concentration (µg/l)
Fe, total (concentration)
Pb, total (concentration)
Mn, total (concentration)
load (kg/day)
Fe, total (load)
Pb, total (load)
Mn, total (load)

CC48

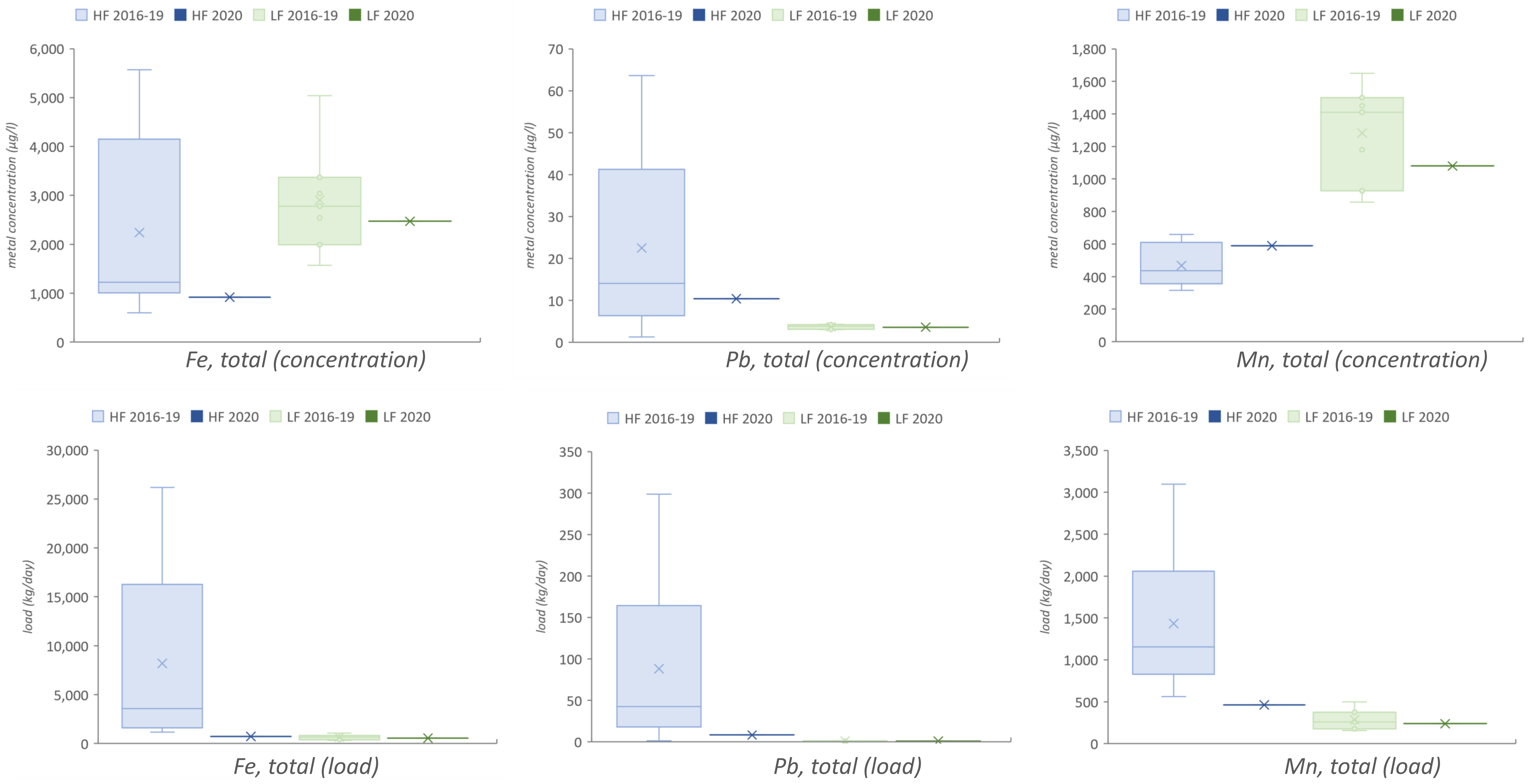


HF 2016-19
HF 2020
LF 2016-19
LF 2020
metal concentration (µg/l)
2,500
2,000
1,500
1,000
500
0
Zn, total (concentration)
concentration (µg/l)
800,000
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
Sulfate, total (concentration)
pH
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
pH
load (kg/day)
700
600
500
400
300
200
100
0
Zn, total (load)
δ, ‰, per mil
-15.0
-15.5
-16.0
-16.5
-17.0
-17.5
-18.0
δ 18O ‰
conductivity (µS/cm)
1,400
1,200
1,000
800
600
400
200
0
Conductivity

A72

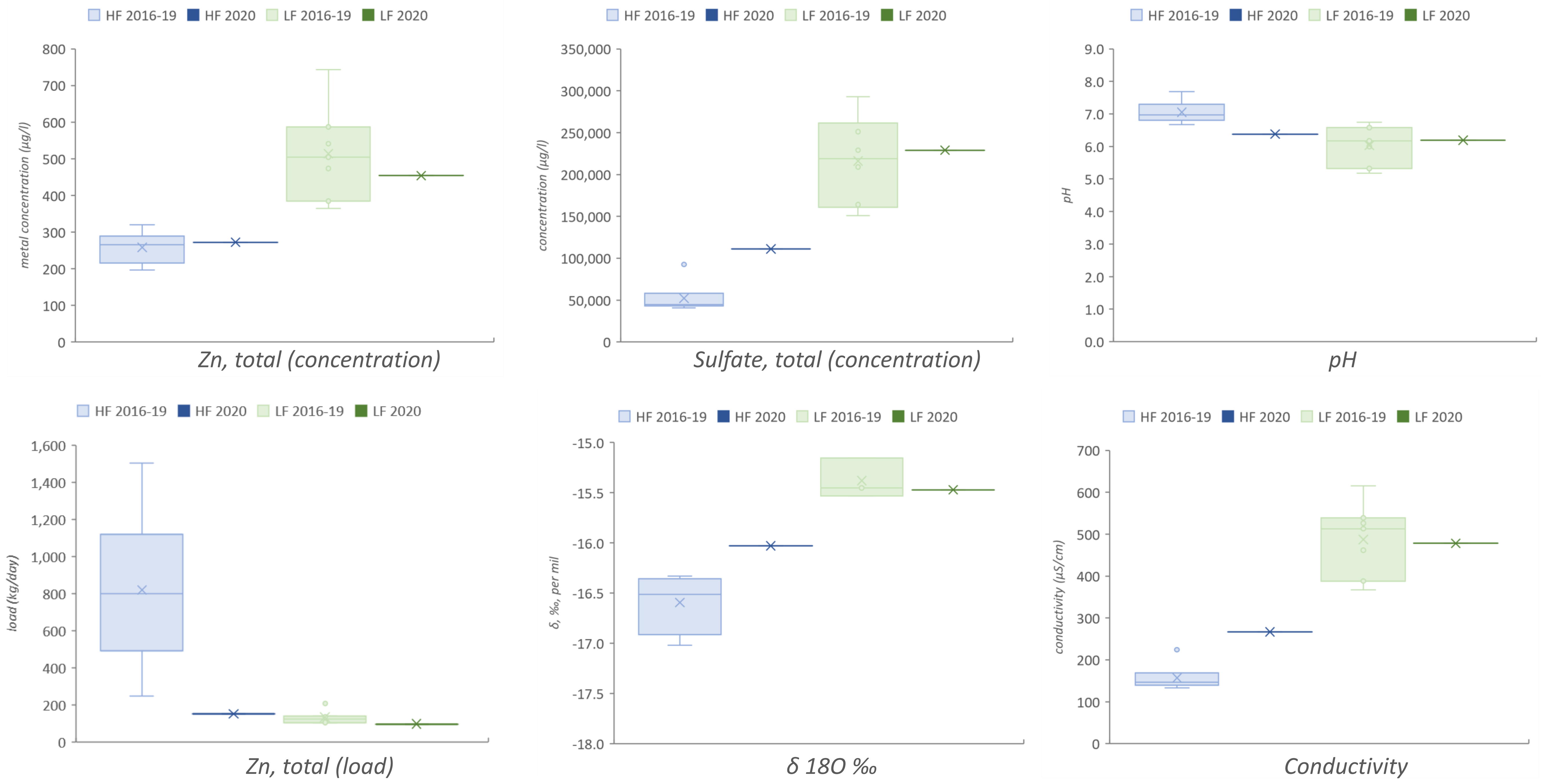

HF 2016-19
HF 2020
LF 2016-19
LF 2020
metal concentration (µg/l)
Al, total (concentration)
Cd, total (concentration)
Cu, total (concentration)
load (kg/day)
Al, total (load)
Cd, total (load)
Cu, total (load)

A72

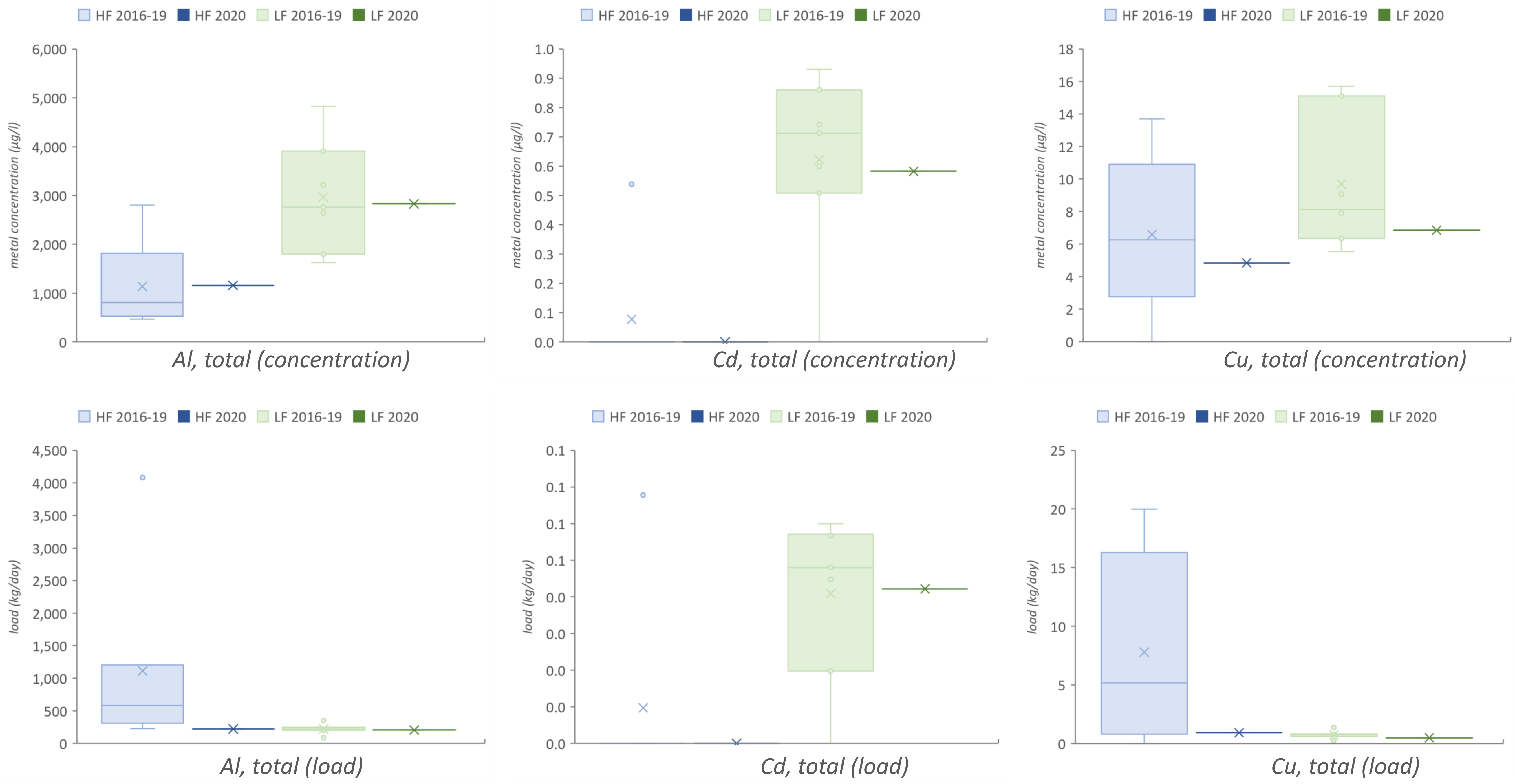


HF 2016-19
HF 2020
LF 2016-19
LF 2020
metal concentration (µg/l)
Fe, total (concentration)
Pb, total (concentration)
Mn, total (concentration)
load (kg/day)
Fe, total (load)
Pb, total (load)
Mn, total (load)

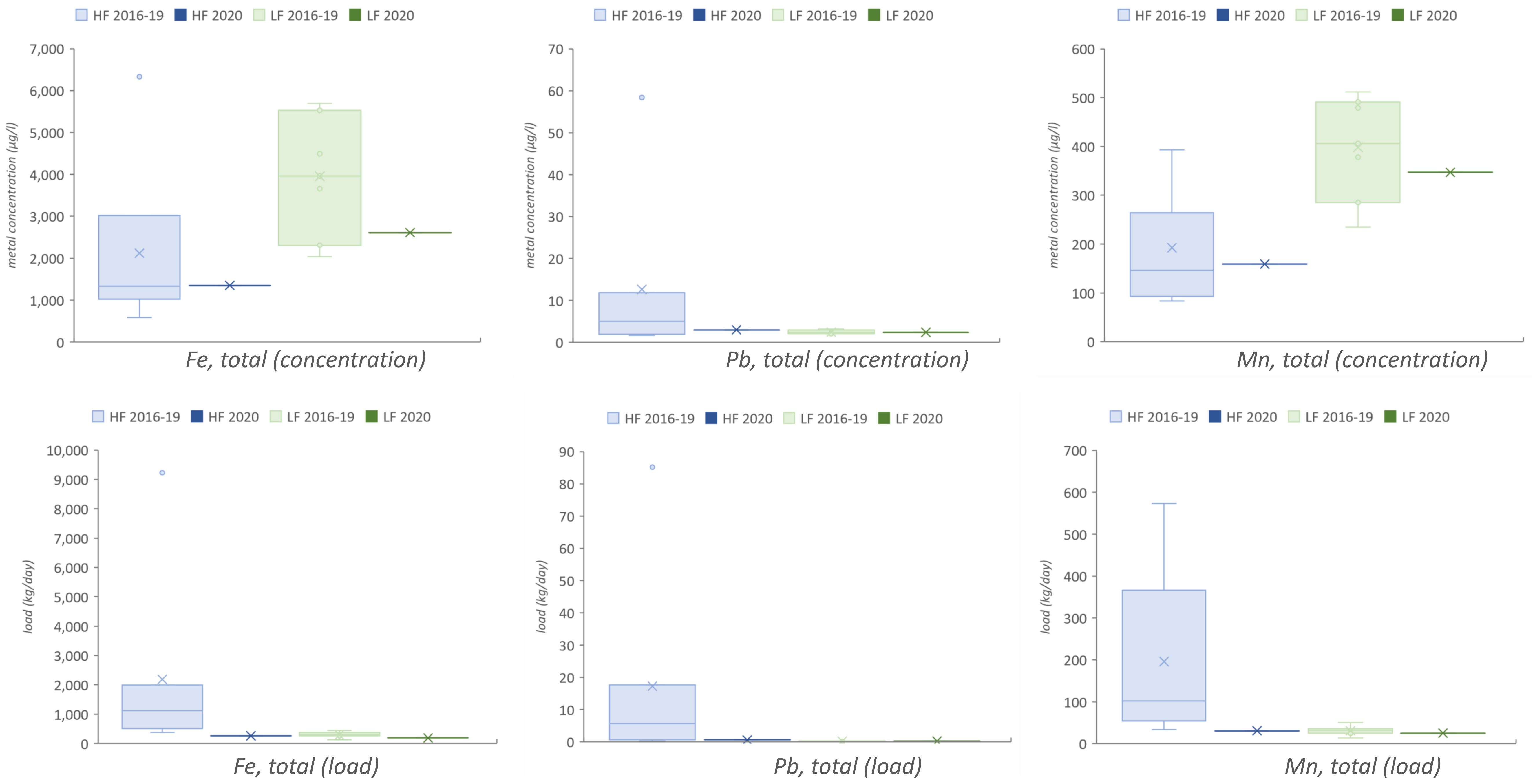
A72


HF 2016-19
HF 2020
LF 2016-19
LF 2020
metal concentration (µg/l)
0
100
200
300
400
500
600
700
800
Zn, total (concentration)
concentration (µg/l)
0
50,000
100,000
150,000
200,000
250,000
300,000
350,000
Sulfate, total (concentration)
pH
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
pH
load (kg/day)
0
200
400
600
800
1,000
1,200
1,400
1,600
Zn, total (load)
δ, ‰, per mil
-18.0
-17.5
-17.0
-16.5
-16.0
-15.5
-15.0
δ 18O ‰
conductivity (µS/cm)
0
100
200
300
400
500
600
700
Conductivity

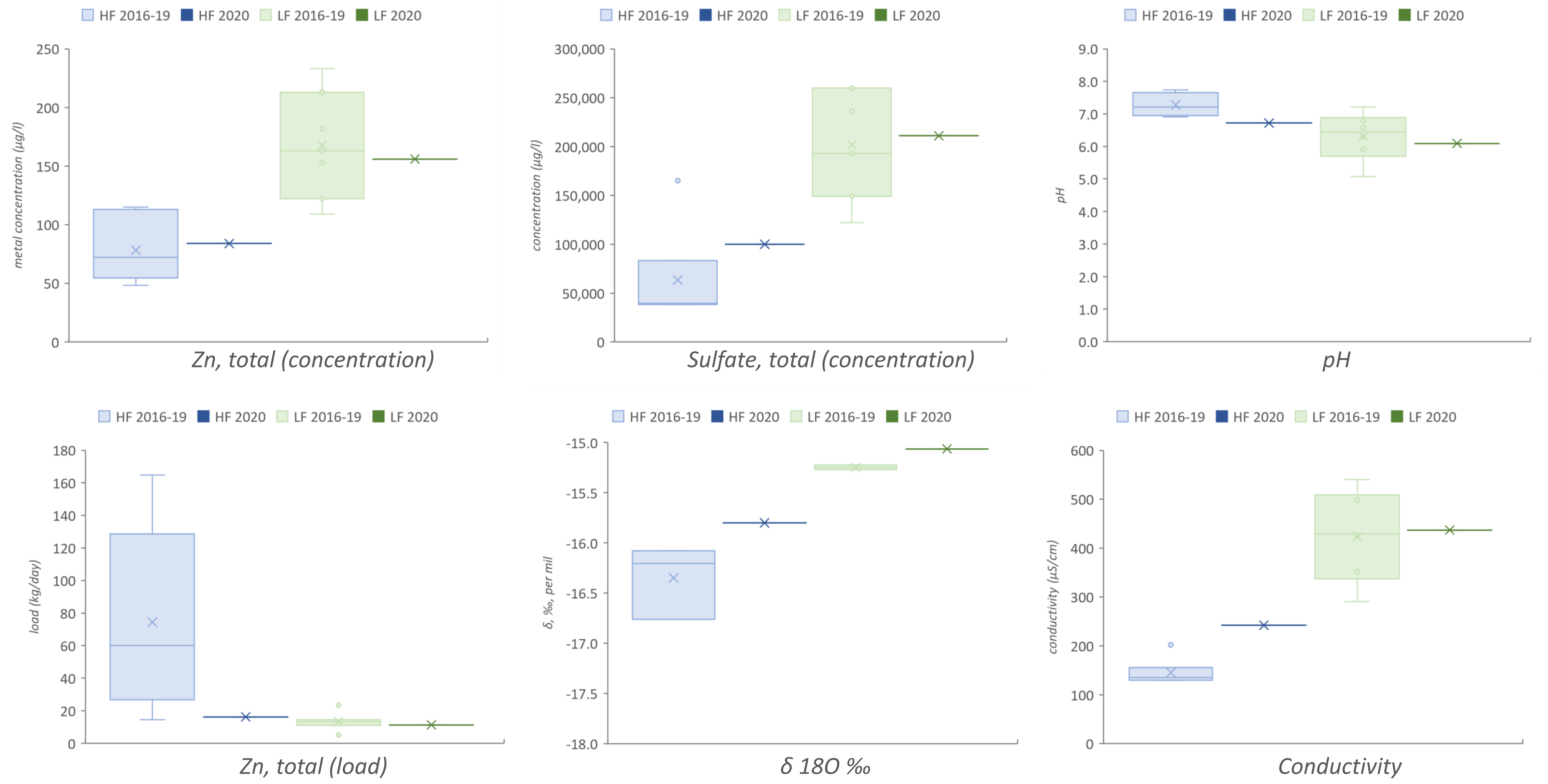
M34


HF 2016-19
HF 2020
LF 2016-19
LF 2020
metal concentration (µg/l)
6,000
5,000
4,000
3,000
2,000
1,000
0
Al, total (concentration)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Cd, total (concentration)
18
16
14
12
10
8
6
4
2
0
Cu, total (concentration)
load (kg/day)
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
Al, total (load)
Cd, total (load)
25
20
15
10
5
0
Cu, total (load)

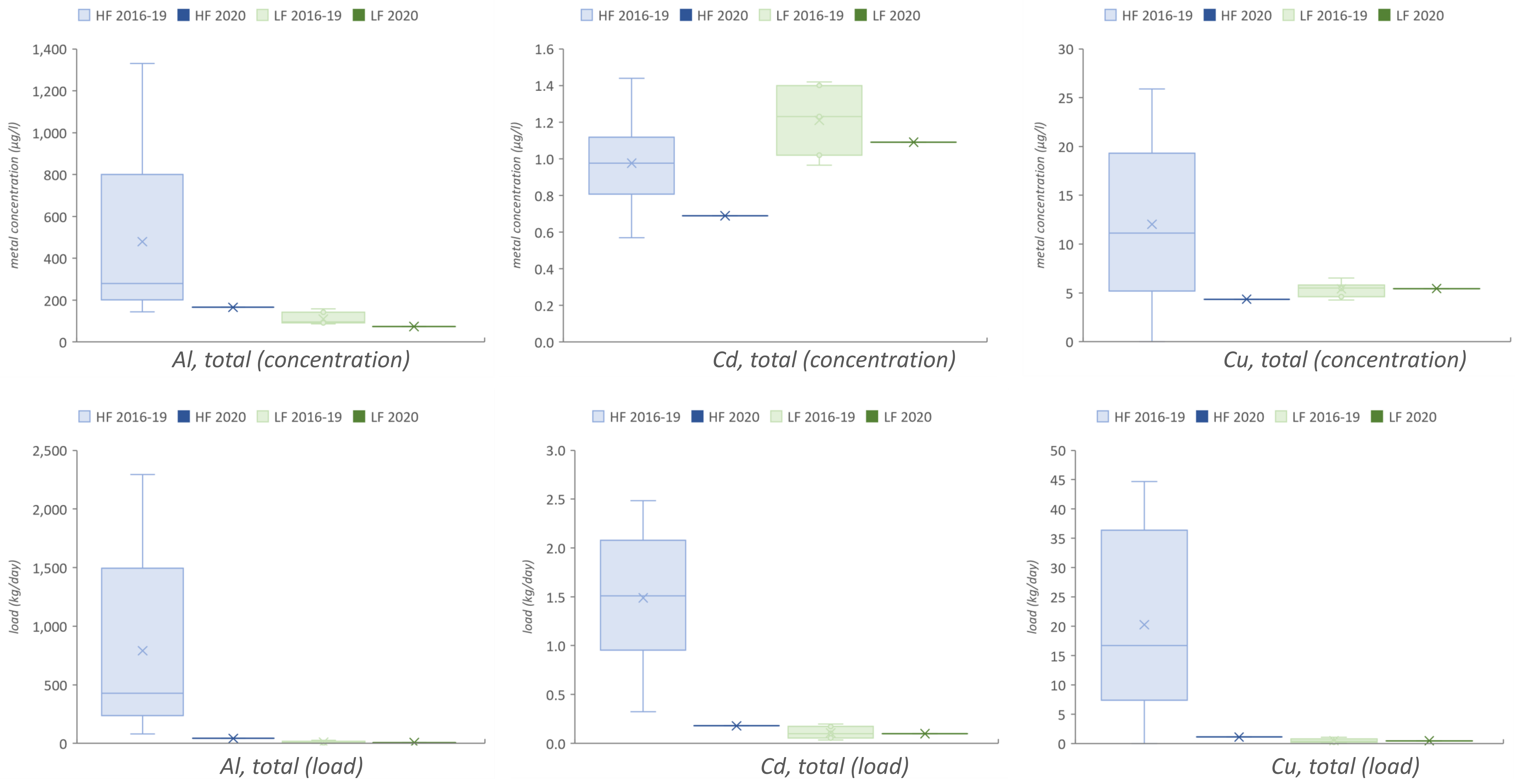
M34


HF 2016-19
HF 2020
LF 2016-19
LF 2020
metal concentration (µg/l)
Fe, total (concentration)
Pb, total (concentration)
Mn, total (concentration)
load (kg/day)
Fe, total (load)
Pb, total (load)
Mn, total (load)
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
70
60
50
40
30
20
10
600
500
400
300
200
100
10,000
9,000
8,000
90
80
700

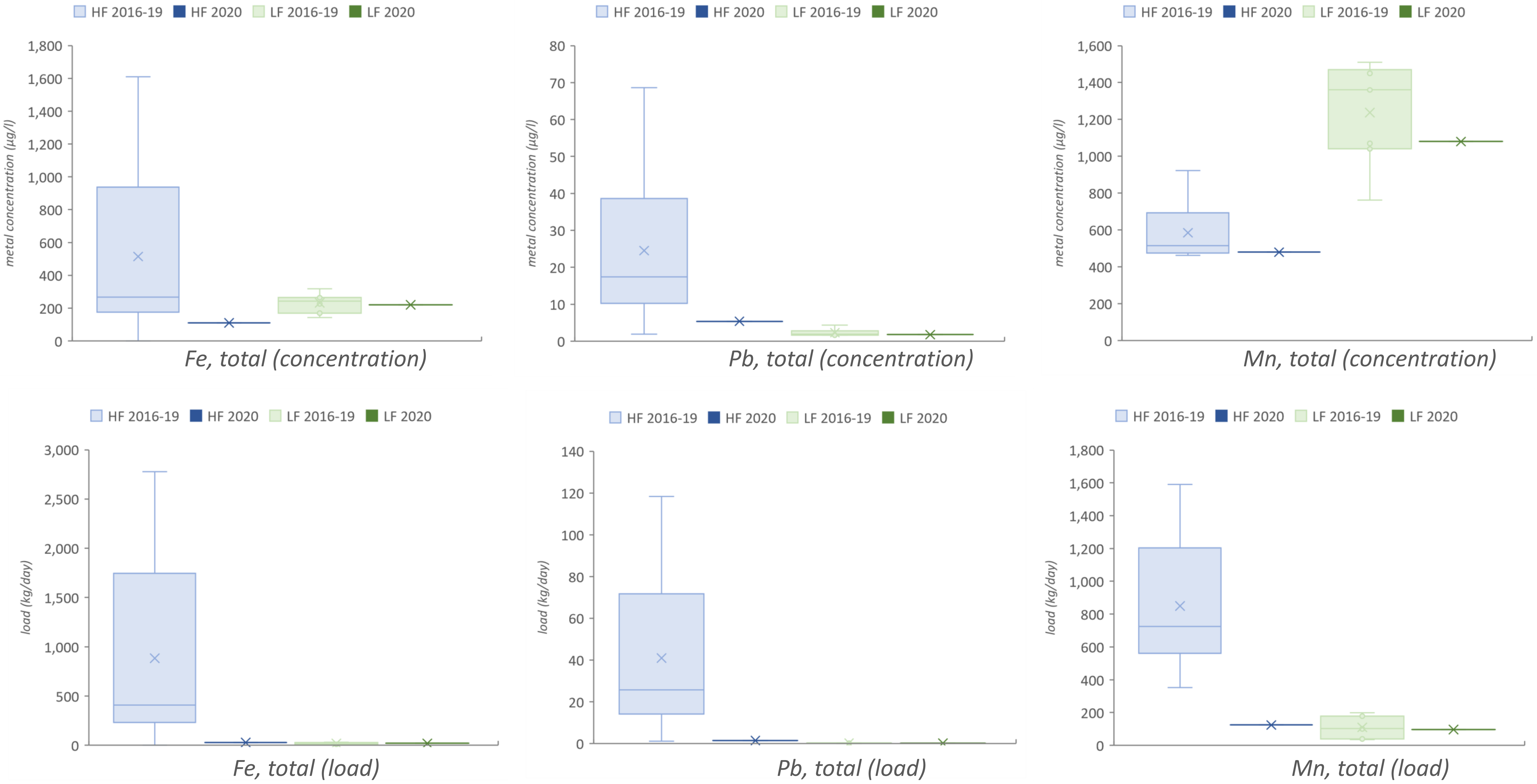
M34


HF 2016-19
HF 2020
LF 2016-19
LF 2020
metal concentration (µg/l)
Zn, total (concentration)
concentration (µg/l)
Sulfate, total (concentration)
pH
pH
load (kg/day)
Zn, total (load)
δ, ‰, per mil
δ 18O ‰
conductivity (µS/cm)
Conductivity

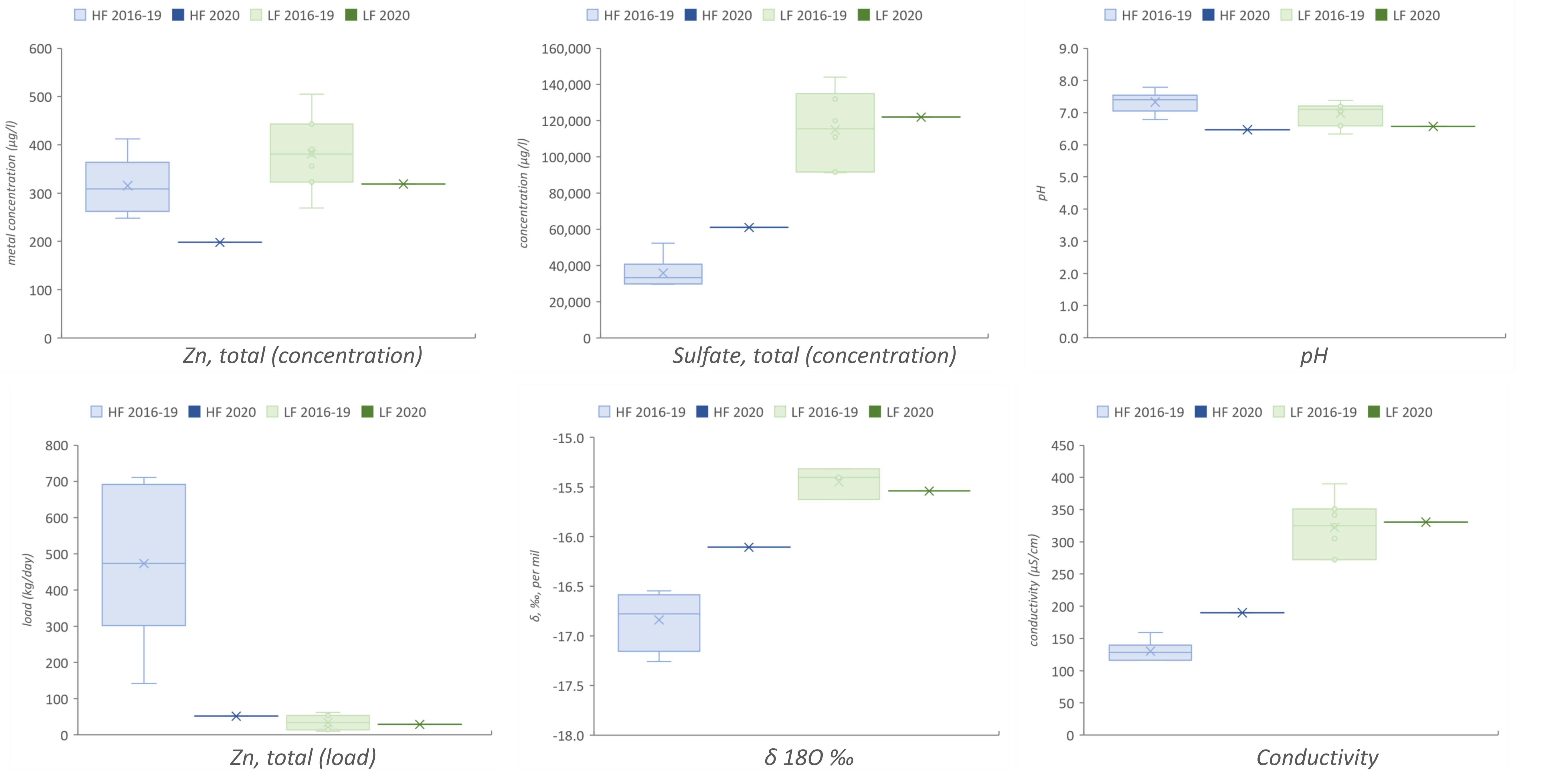
A68


HF 2016-19
HF 2020
LF 2016-19
LF 2020
metal concentration (µg/l)
1,400
1,200
1,000
800
600
400
200
0
Al, total (concentration)
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Cd, total (concentration)
30
25
20
15
10
5
0
Cu, total (concentration)
load (kg/day)
2,500
2,000
1,500
1,000
500
0
Al, total (load)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Cd, total (load)
50
45
40
35
30
25
20
15
10
5
0
Cu, total (load)

A68

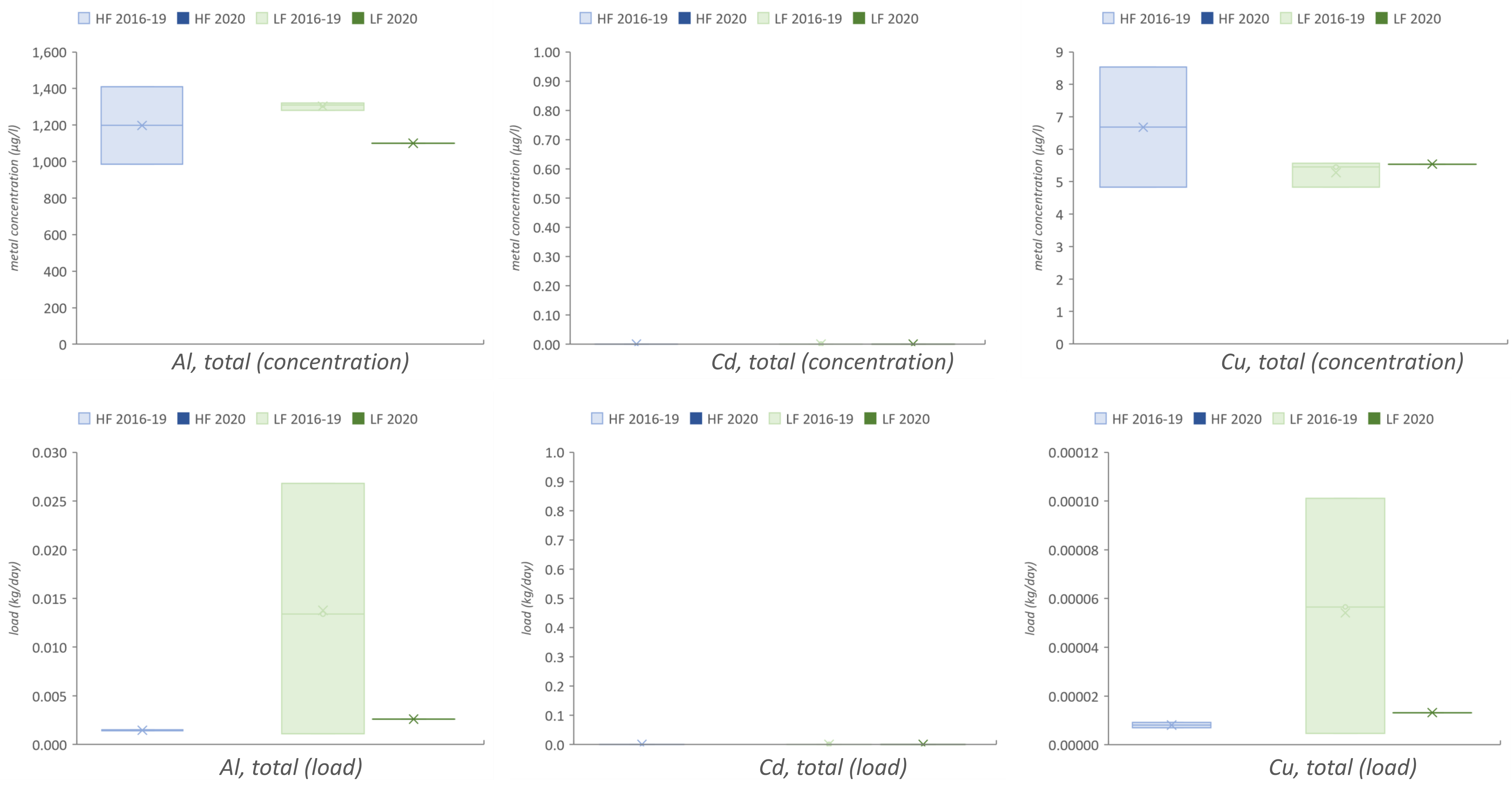

HF 2016-19
HF 2020
LF 2016-19
LF 2020
metal concentration (µg/l)
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
Fe, total (concentration)
80
70
60
50
40
30
20
10
Pb, total (concentration)
Mn, total (concentration)
load (kg/day)
3,000
2,500
2,000
1,500
1,000
500
Fe, total (load)
140
120
100
Pb, total (load)
Mn, total (load)

A68

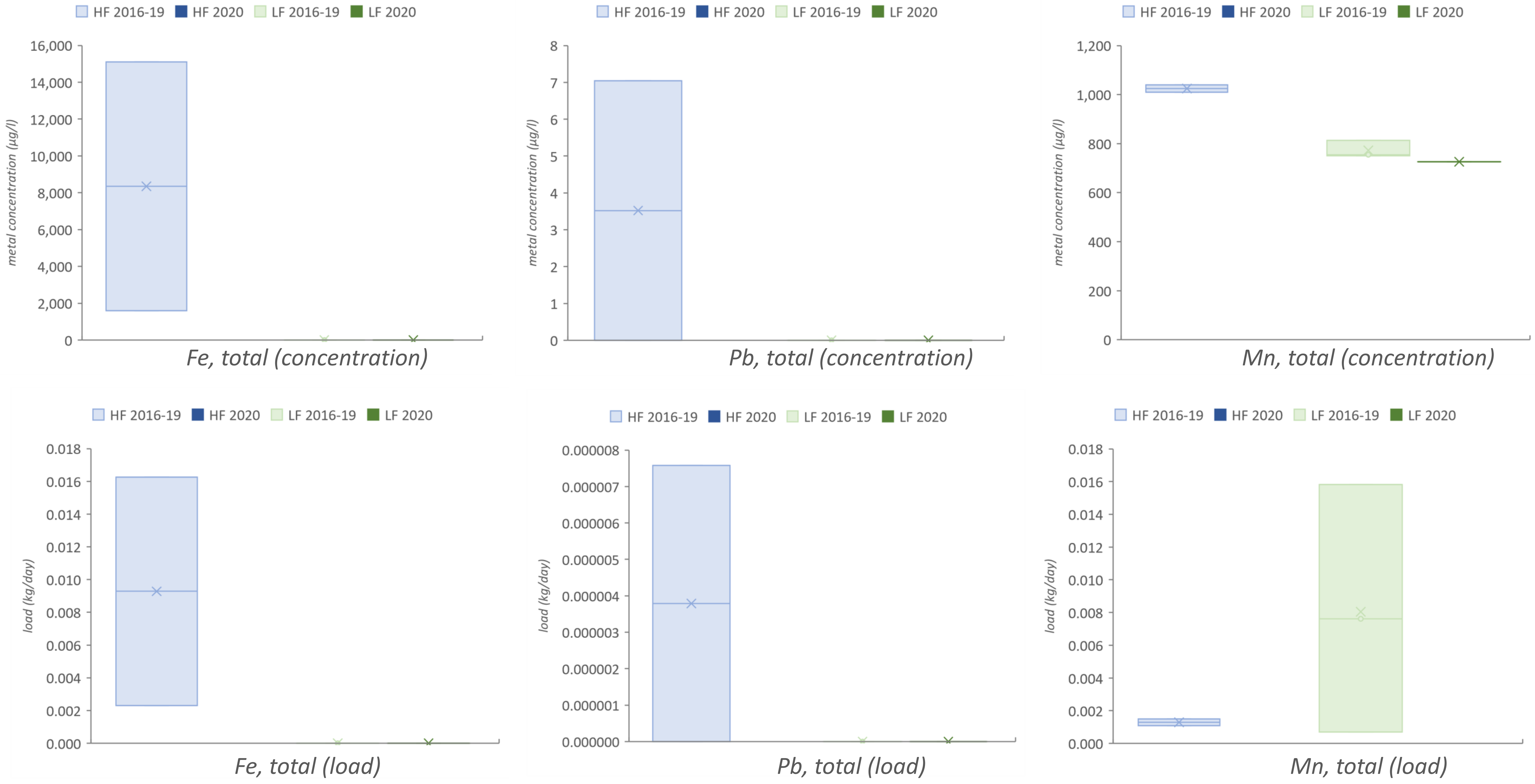


HF 2016-19
HF 2020
LF 2016-19
LF 2020
metal concentration (µg/l)
Zn, total (concentration)
concentration (µg/l)
Sulfate, total (concentration)
pH
pH
load (kg/day)
Zn, total (load)
δ, ‰, per mil
δ 18O ‰
conductivity (µS/cm)
Conductivity

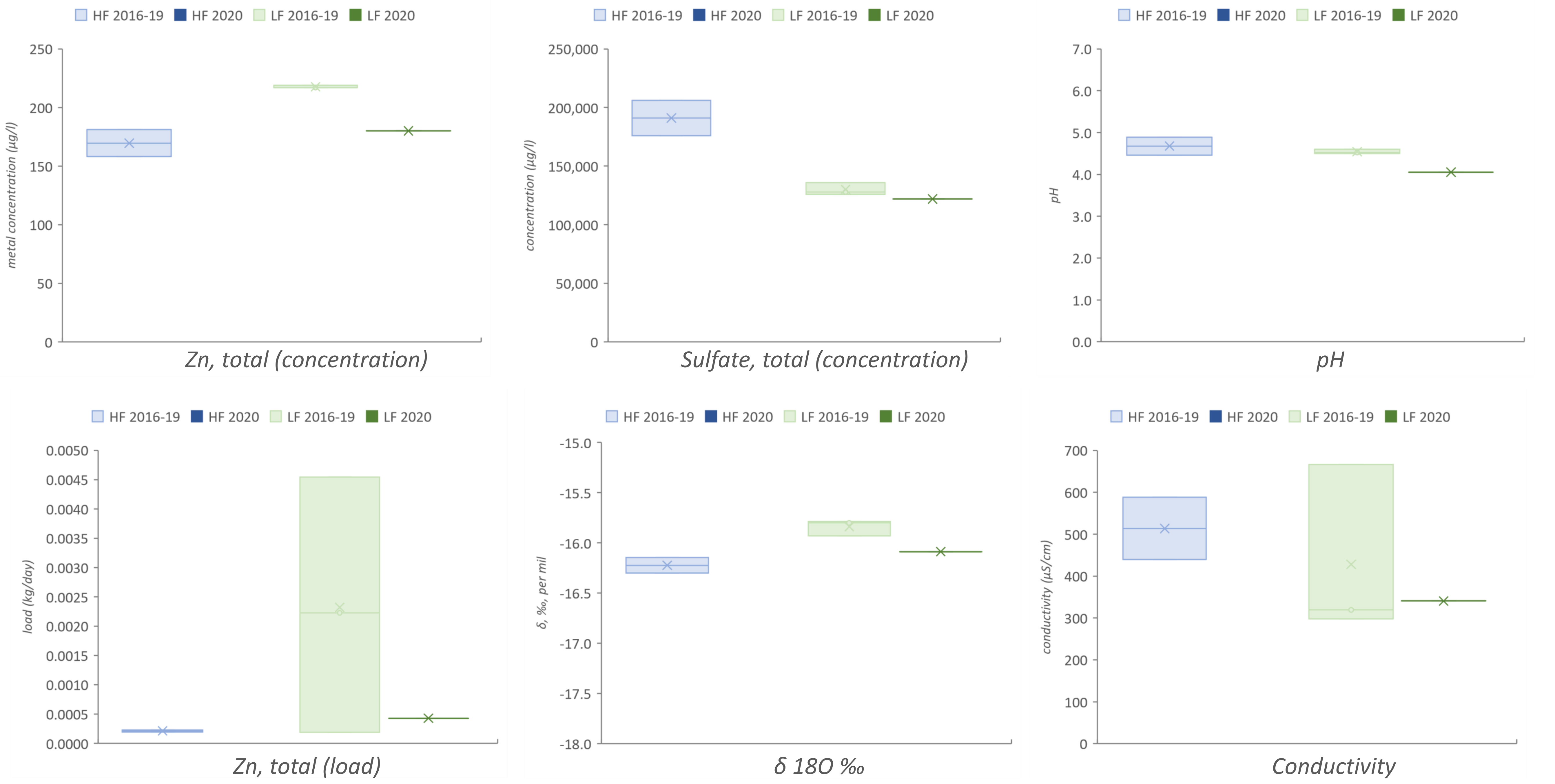
SS016


HF 2016-19
HF 2020
LF 2016-19
LF 2020
metal concentration (µg/l)
Al, total (concentration)
Cd, total (concentration)
Cu, total (concentration)
load (kg/day)
Al, total (load)
Cd, total (load)
Cu, total (load)

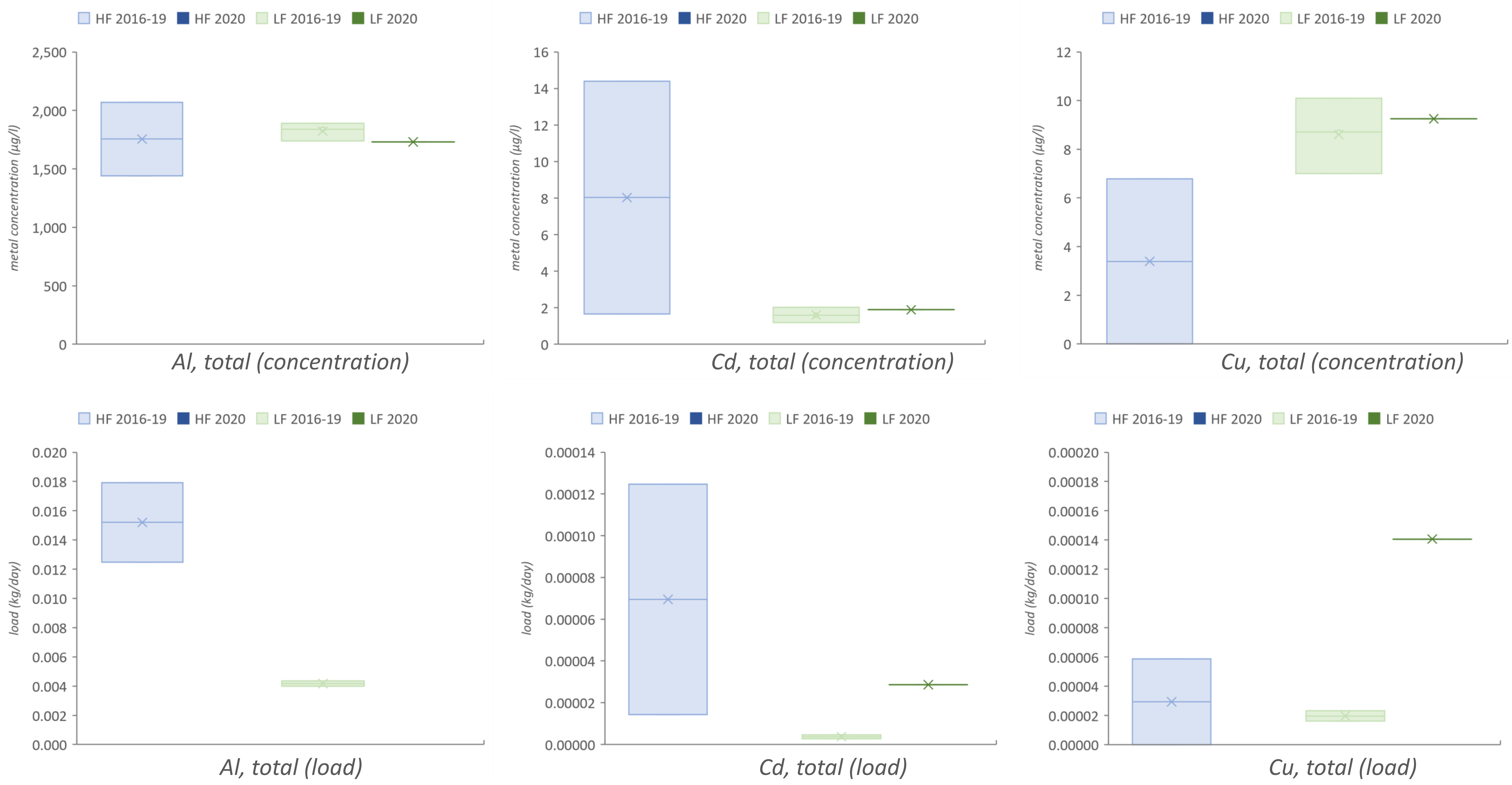
SS016


HF 2016-19
HF 2020
LF 2016-19
LF 2020
metal concentration (µg/l)
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Fe, total (concentration)
8
7
6
5
4
3
2
1
0
Pb, total (concentration)
1,200
1,000
800
600
400
200
Mn, total (concentration)
load (kg/day)
0.018
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
Fe, total (load)
0.000008
0.000007
0.000006
0.000005
0.000004
0.000003
0.000002
0.000001
0.000000
Pb, total (load)
Mn, total (load)

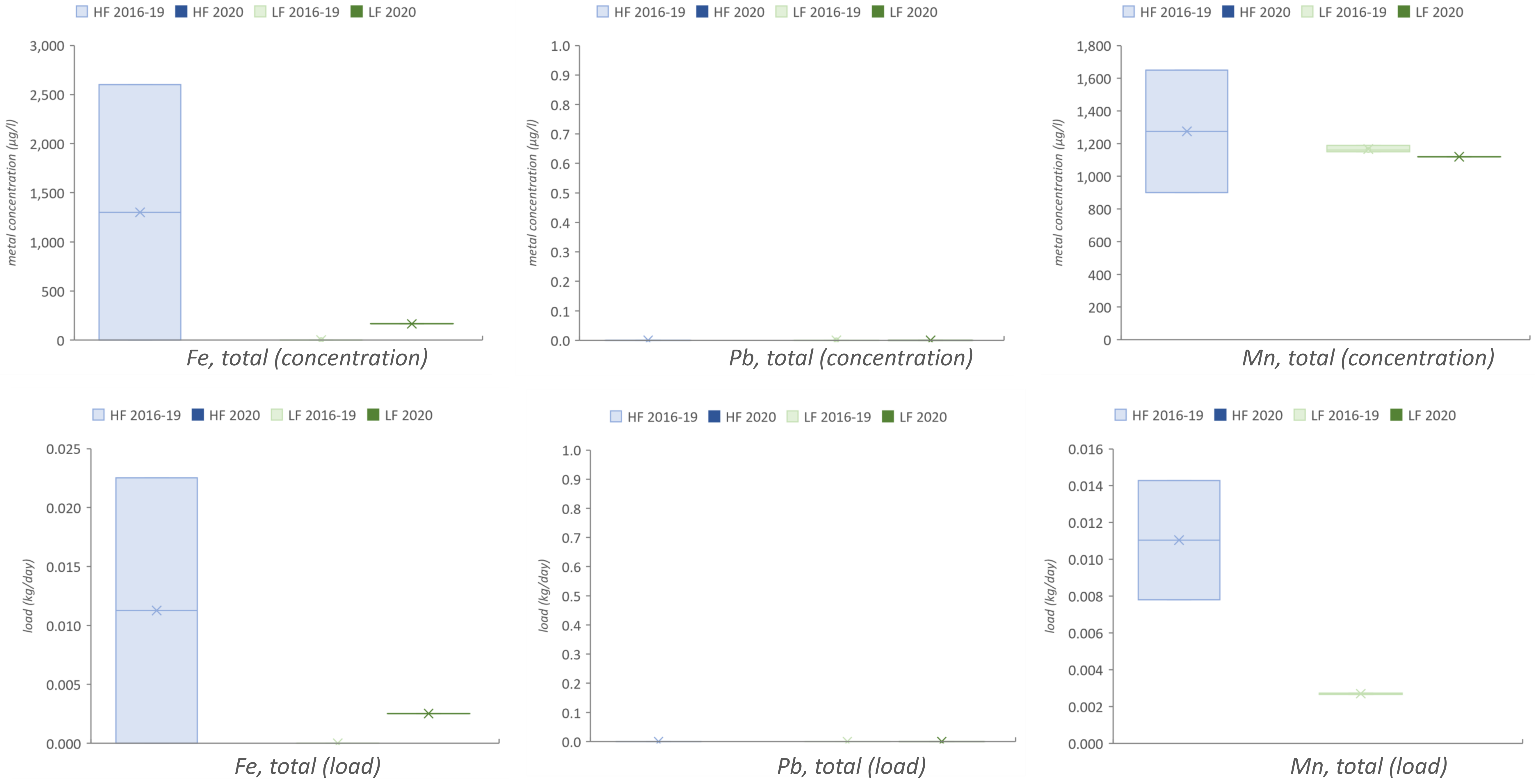
SS016


HF 2016-19
HF 2020
LF 2016-19
LF 2020
metal concentration (μg/l)
0
50
100
150
200
250
Zn, total (concentration)
concentration (μg/l)
0
50,000
100,000
150,000
200,000
250,000
Sulfate, total (concentration)
pH
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
pH
load (kg/day)
0.0000
0.0005
0.0010
0.0015
0.0020
0.0025
0.0030
0.0035
0.0040
0.0045
0.0050
Zn, total (load)
δ, ‰, per mil
-18.0
-17.5
-17.0
-16.5
-16.0
-15.5
-15.0
δ 18O ‰
conductivity (μS/cm)
0
100
200
300
400
500
600
700
Conductivity

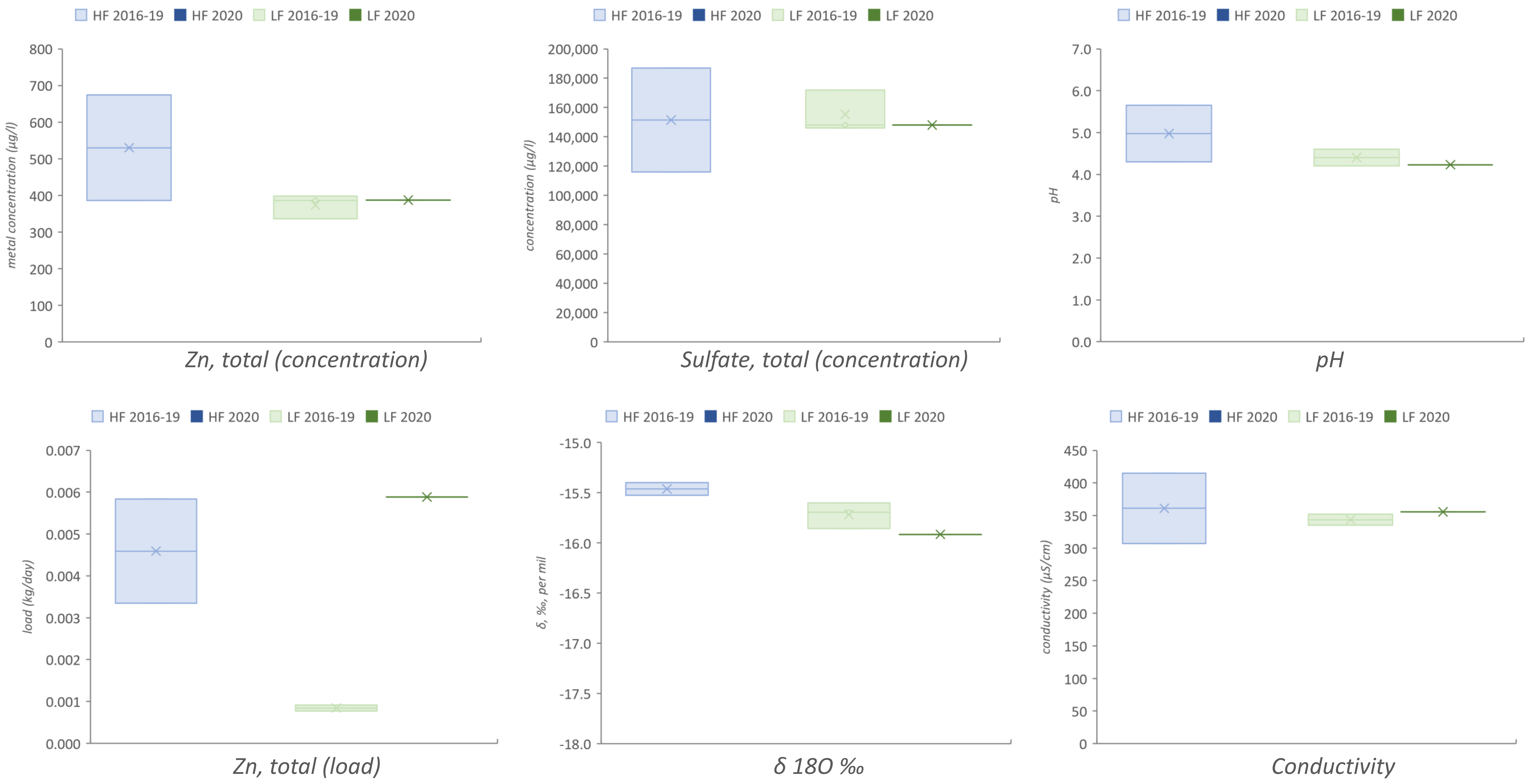
SS017


HF 2016-19
HF 2020
LF 2016-19
LF 2020
metal concentration (µg/l)
Al, total (concentration)
Cd, total (concentration)
Cu, total (concentration)
load (kg/day)
Al, total (load)
Cd, total (load)
Cu, total (load)
0
500
1,000
1,500
2,000
2,500
0
2
4
6
8
10
12
14
16
0
2
4
6
8
10
12
0.000
0.002
0.004
0.006
0.008
0.010
0.012
0.014
0.016
0.018
0.020
0.00000
0.00002
0.00004
0.00006
0.00008
0.00010
0.00012
0.00014
0.00000
0.00002
0.00004
0.00006
0.00008
0.00010
0.00012
0.00014
0.00016
0.00018
0.00020

SS017

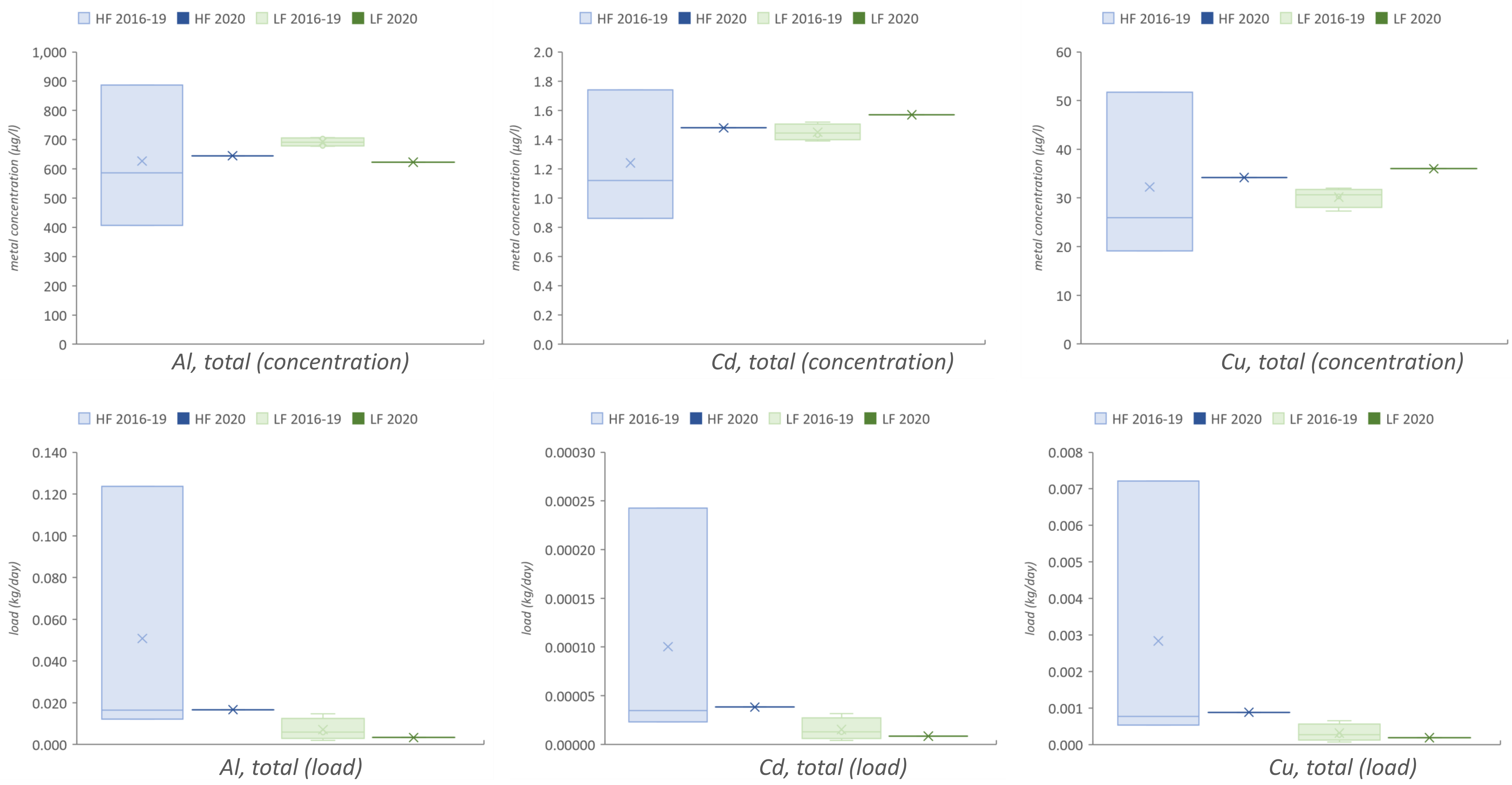

HF 2016-19
HF 2020
LF 2016-19
LF 2020
metal concentration (µg/l)
3,000
2,500
2,000
1,500
1,000
500
0
Fe, total (concentration)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Pb, total (concentration)
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
Mn, total (concentration)
load (kg/day)
0.025
0.020
0.015
0.010
0.005
0.000
Fe, total (load)
Pb, total (load)
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
Mn, total (load)

SS017

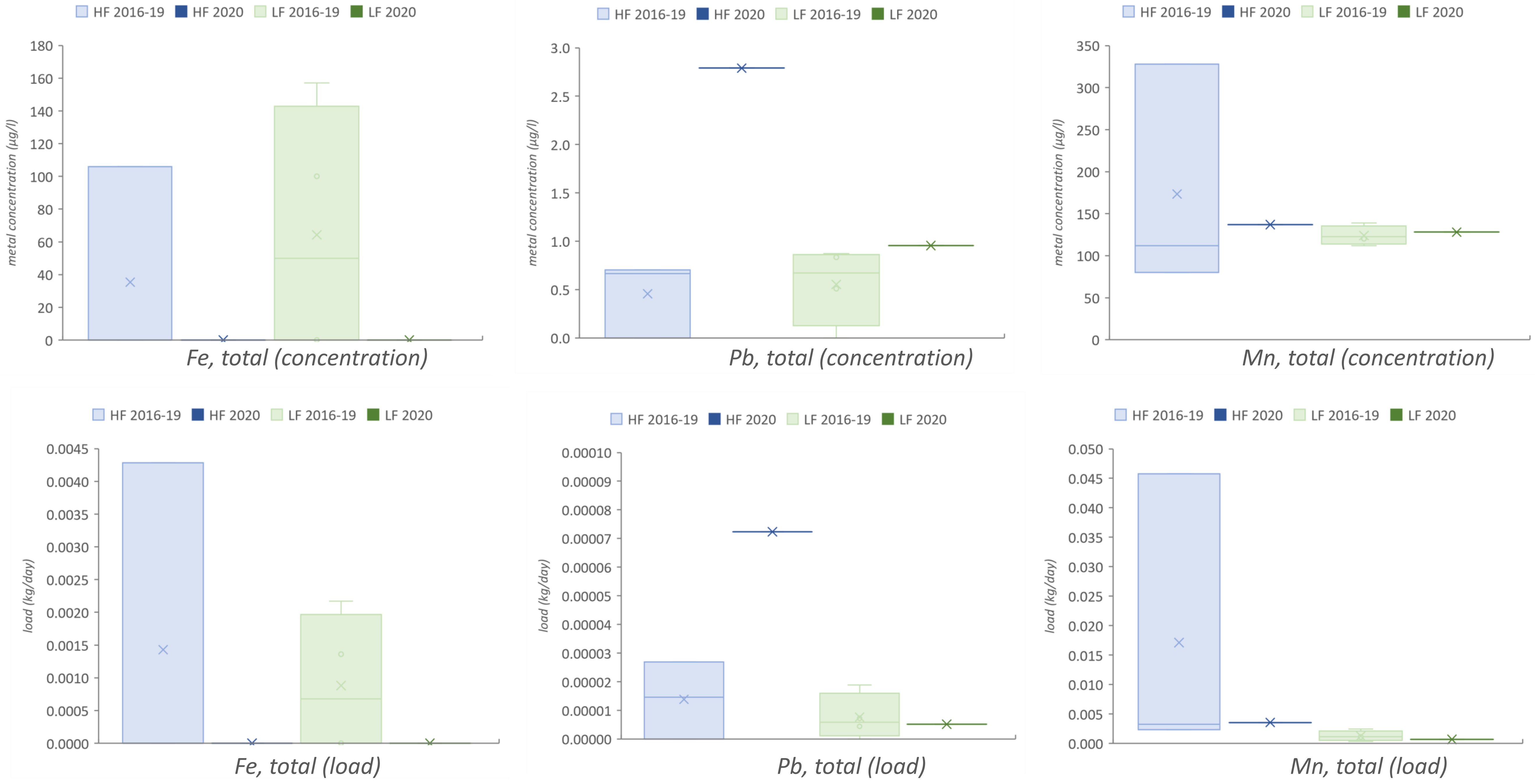


HF 2016-19
HF 2020
LF 2016-19
LF 2020
metal concentration (µg/l)
800
700
600
500
400
300
200
100
0
Zn, total (concentration)
concentration (µg/l)
200,000
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
Sulfate, total (concentration)
pH
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
pH
load (kg/day)
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0.000
Zn, total (load)
δ, ‰, per mil
-15.0
-15.5
-16.0
-16.5
-17.0
-17.5
-18.0
δ 18O ‰
conductivity (µS/cm)
450
400
350
300
250
200
150
100
50
0
Conductivity

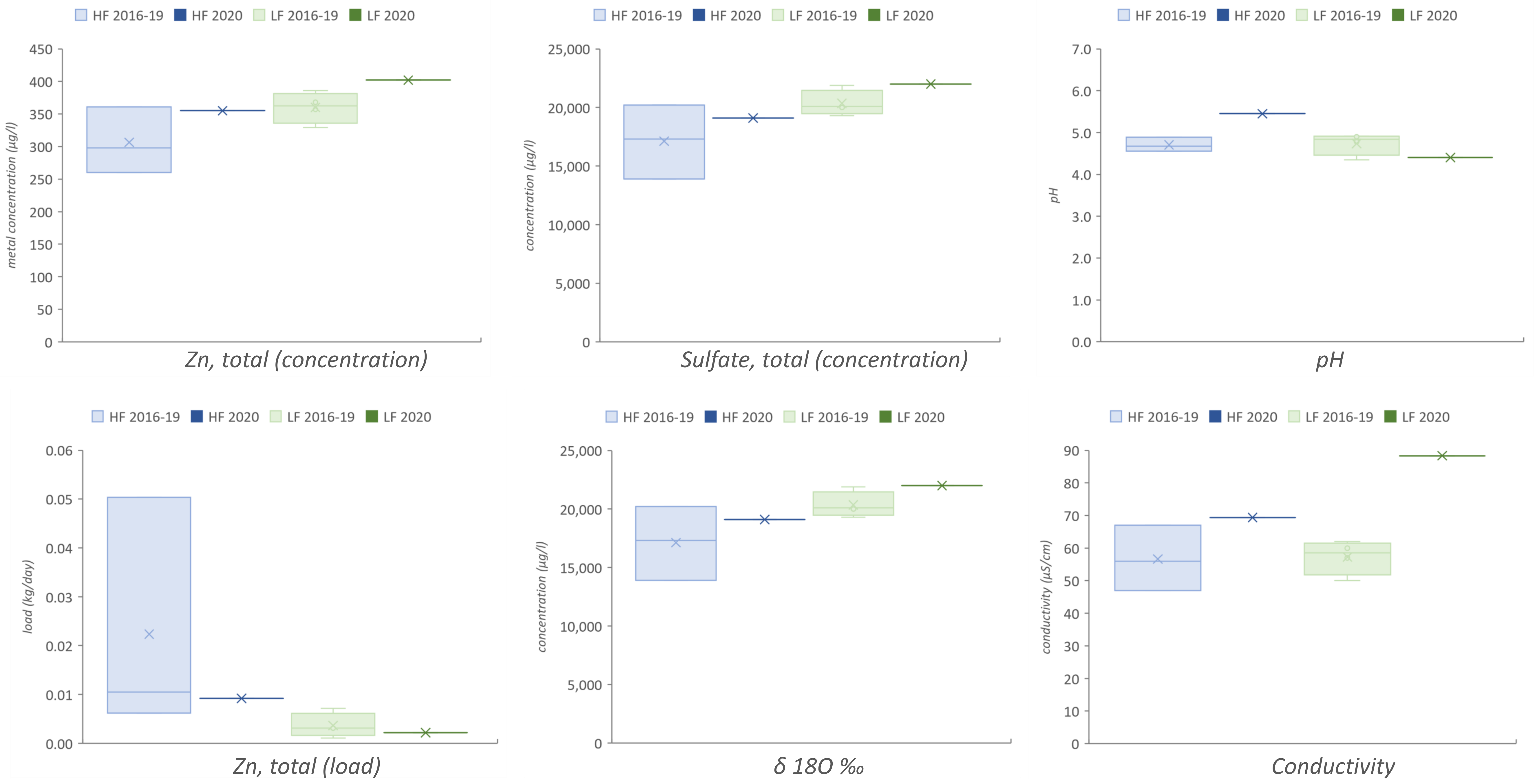
SS060


HF 2016-19
HF 2020
LF 2016-19
LF 2020
metal concentration (µg/l)
1,000
900
800
700
600
500
400
300
200
100
0
Al, total (concentration)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Cd, total (concentration)
60
50
40
30
20
10
0
Cu, total (concentration)
load (kg/day)
0.140
0.120
0.100
0.080
0.060
0.040
0.020
0.000
Al, total (load)
0.00030
0.00025
0.00020
0.00015
0.00010
0.00005
0.00000
Cd, total (load)
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0.000
Cu, total (load)

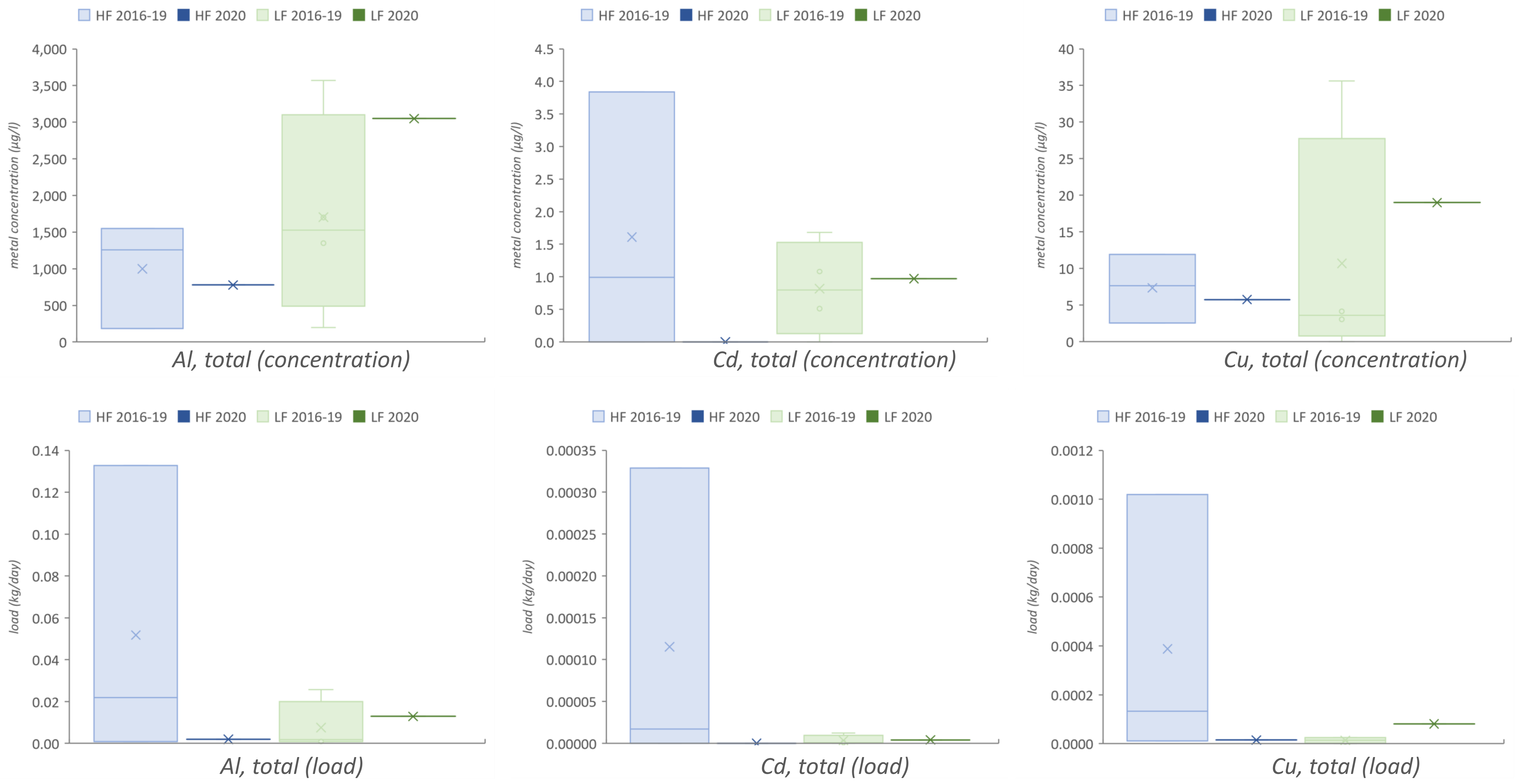
SS060


HF 2016-19
HF 2020
LF 2016-19
LF 2020
metal concentration (µg/l)
Fe, total (concentration)
Pb, total (concentration)
Mn, total (concentration)
load (kg/day)
Fe, total (load)
Pb, total (load)
Mn, total (load)

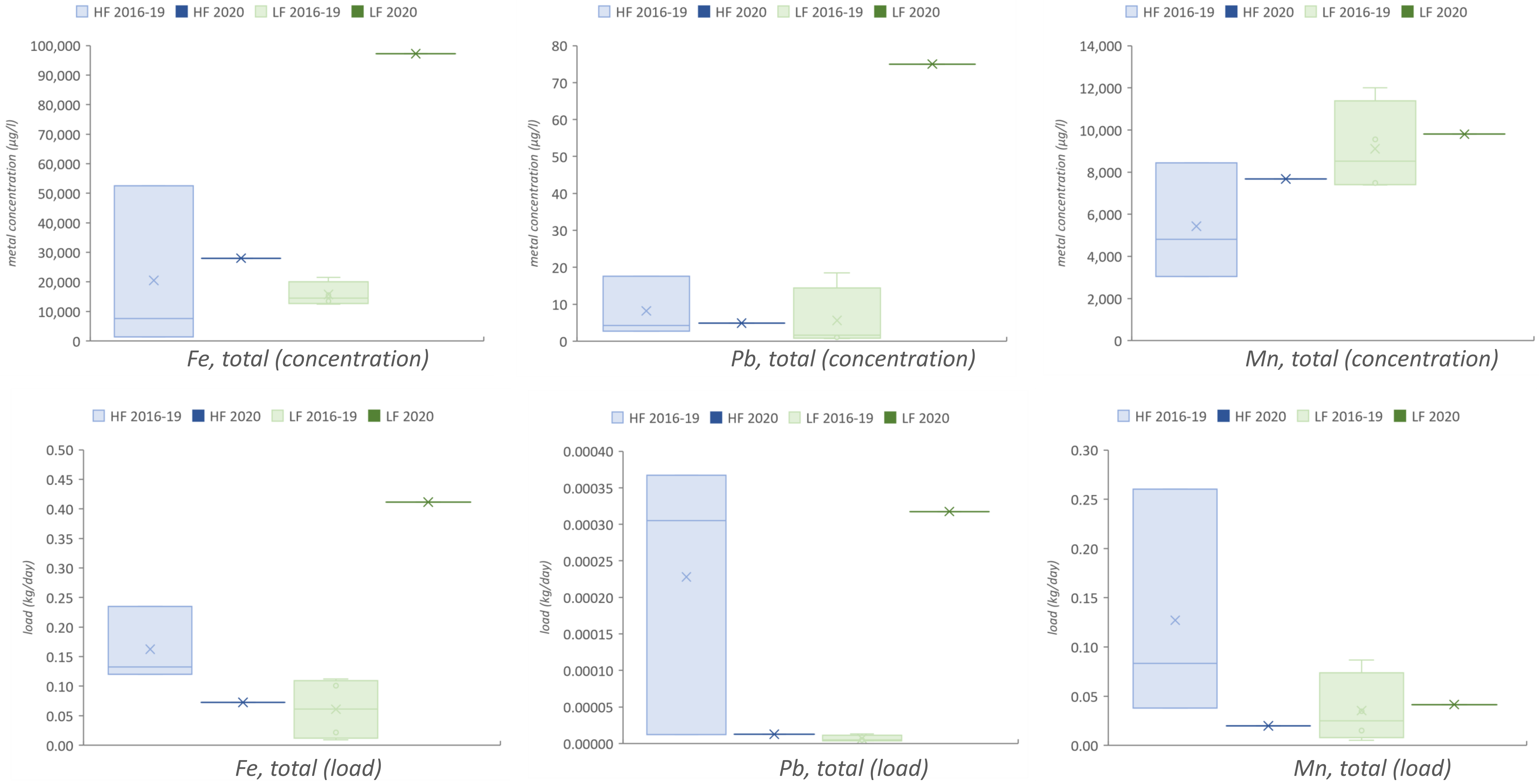
SS060


HF 2016-19
HF 2020
LF 2016-19
LF 2020
metal concentration (µg/l)
Zn, total (concentration)
concentration (µg/l)
Sulfate, total (concentration)
pH
pH
load (kg/day)
Zn, total (load)
concentration (µg/l)
δ 18O ‰
conductivity (µS/cm)
Conductivity

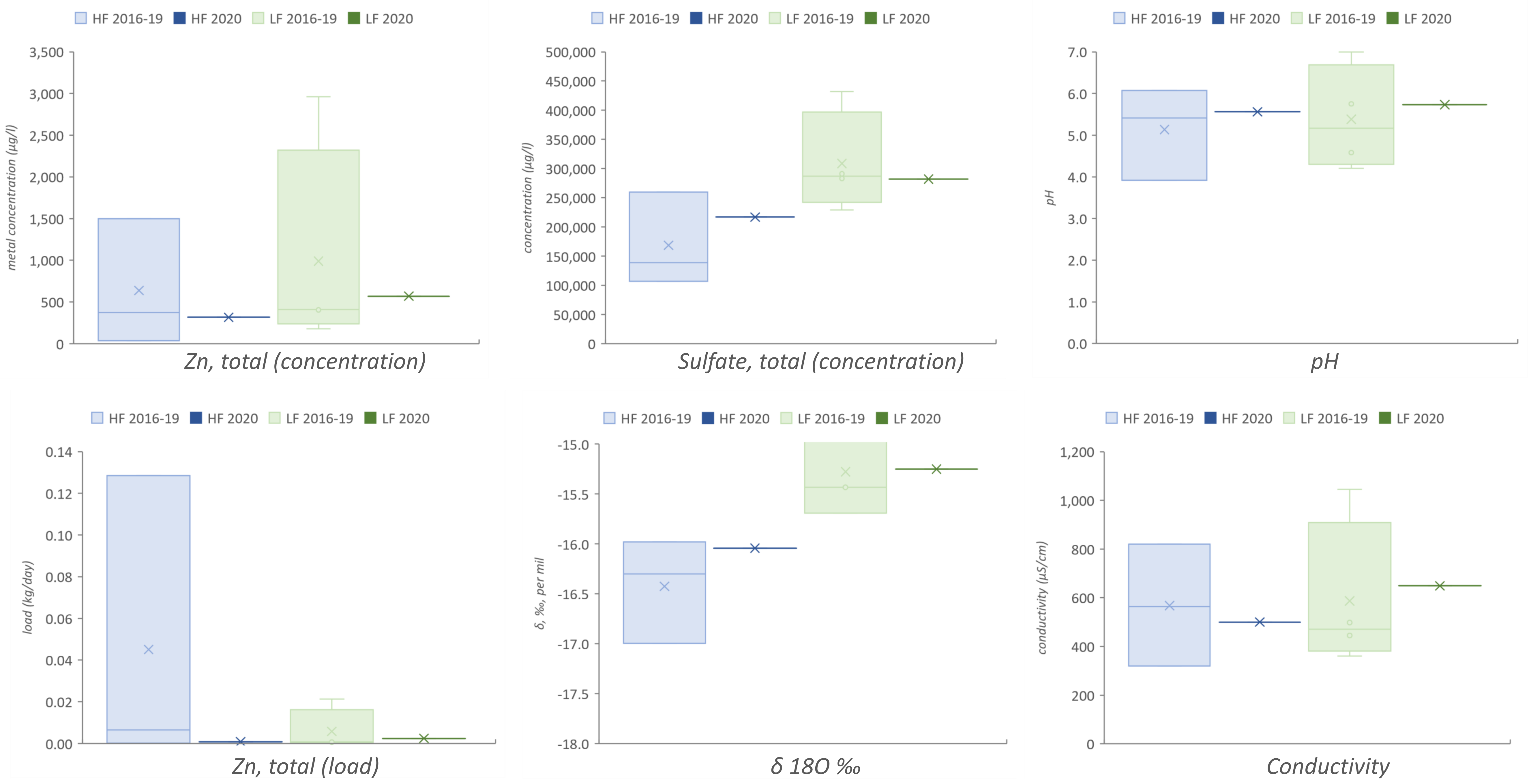
SS062


HF 2016-19
HF 2020
LF 2016-19
LF 2020
metal concentration (µg/l)
0
500
1,000
1,500
2,000
2,500
3,000
3,500
4,000
Al, total (concentration)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Cd, total (concentration)
0
5
10
15
20
25
30
35
40
Cu, total (concentration)
load (kg/day)
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
Al, total (load)
0.00000
0.00005
0.00010
0.00015
0.00020
0.00025
0.00030
0.00035
Cd, total (load)
0.0000
0.0002
0.0004
0.0006
0.0008
0.0010
0.0012
Cu, total (load)

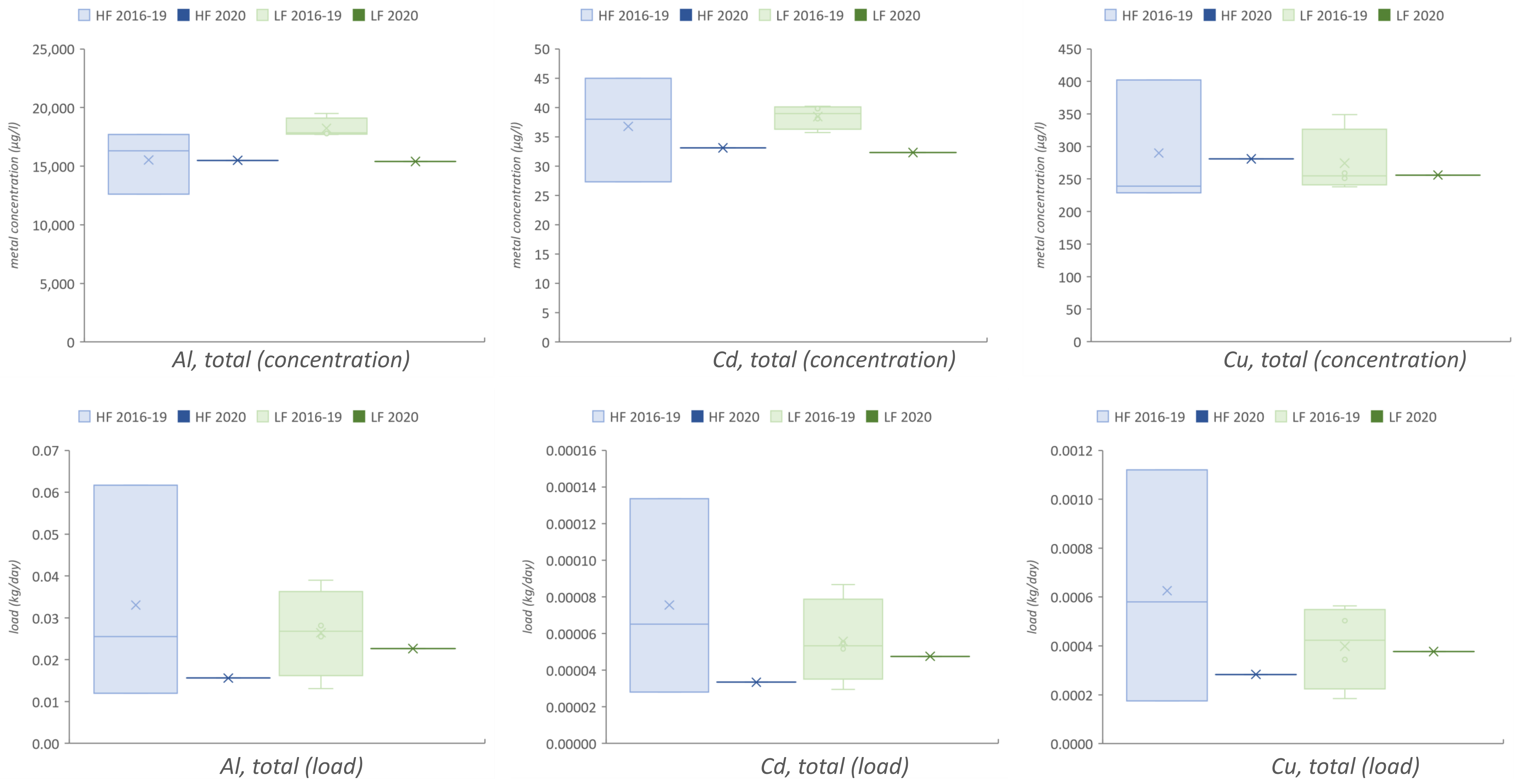
SS062


HF 2016-19
HF 2020
LF 2016-19
LF 2020
metal concentration (µg/l)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
Fe, total (concentration)
80
70
60
50
40
30
20
10
0
Pb, total (concentration)
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Mn, total (concentration)
load (kg/day)
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Fe, total (load)
0.00040
0.00035
0.00030
0.00025
0.00020
0.00015
0.00010
0.00005
0.00000
Pb, total (load)
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Mn, total (load)

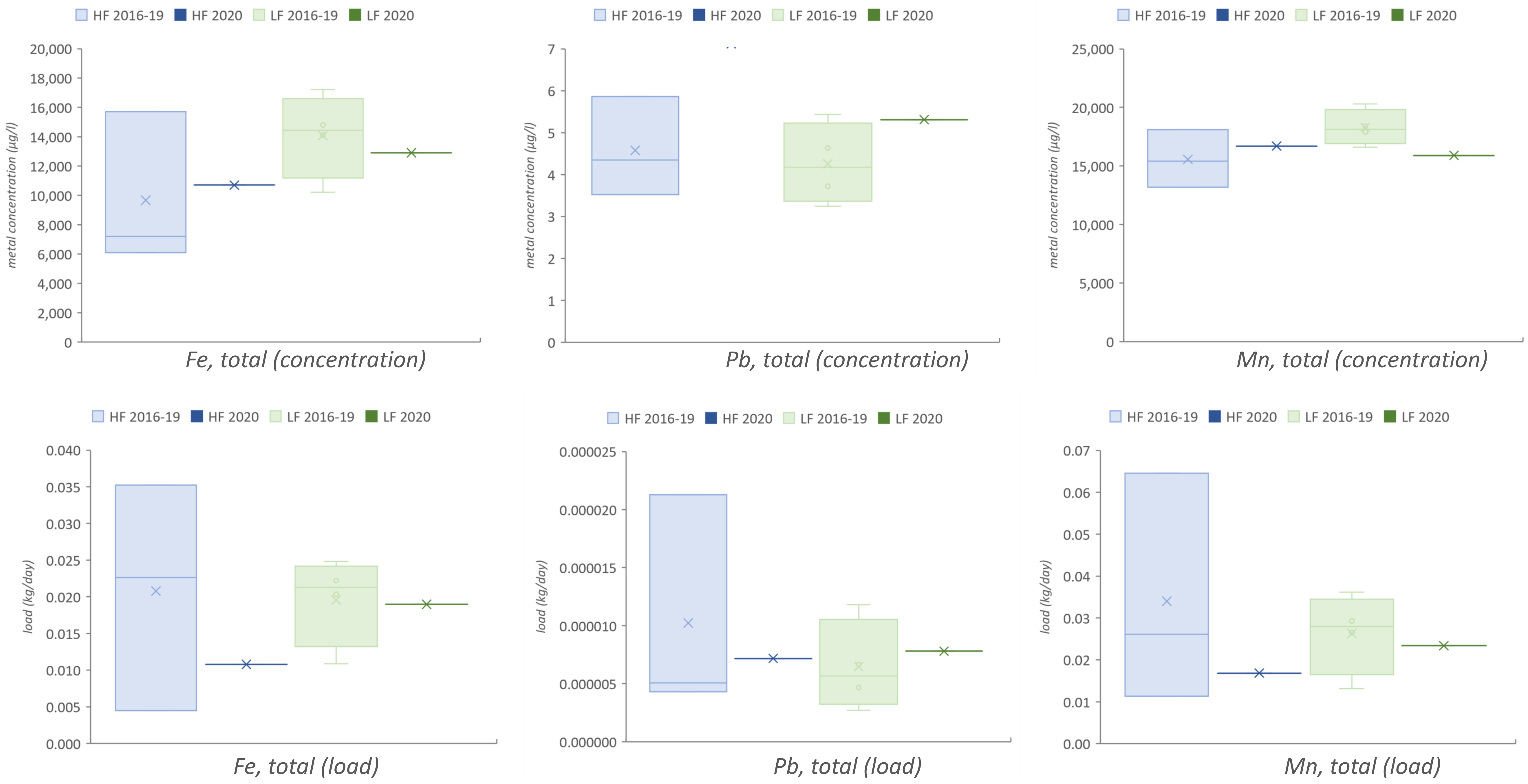
SS062


HF 2016-19
HF 2020
LF 2016-19
LF 2020
metal concentration (µg/l)
3,500
3,000
2,500
2,000
1,500
1,000
500
0
Zn, total (concentration)
concentration (µg/l)
500,000
450,000
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
Sulfate, total (concentration)
pH
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
pH
load (kg/day)
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
Zn, total (load)
δ, ‰, per mil
-15.0
-15.5
-16.0
-16.5
-17.0
-17.5
-18.0
δ 18O ‰
conductivity (µS/cm)
1,200
1,000
800
600
400
200
0
Conductivity

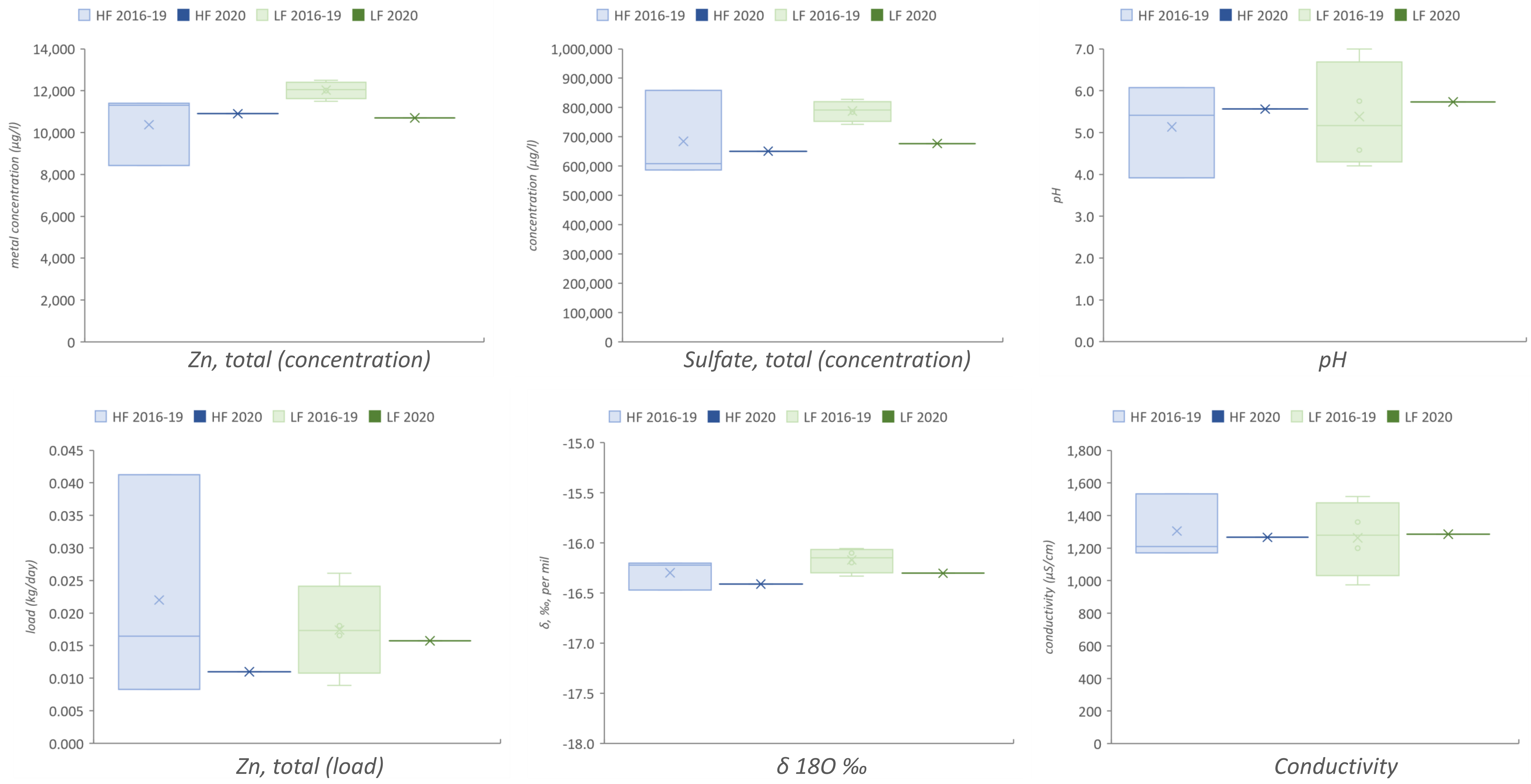
SS067


HF 2016-19
HF 2020
LF 2016-19
LF 2020
metal concentration (µg/l)
25,000
20,000
15,000
10,000
5,000
0
Al, total (concentration)
50
45
40
35
30
25
20
15
10
5
0
Cd, total (concentration)
450
400
350
300
250
200
150
100
50
0
Cu, total (concentration)
load (kg/day)
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
Al, total (load)
0.00016
0.00014
0.00012
0.00010
0.00008
0.00006
0.00004
0.00002
0.00000
Cd, total (load)
0.0012
0.0010
0.0008
0.0006
0.0004
0.0002
0.0000
Cu, total (load)

SS067

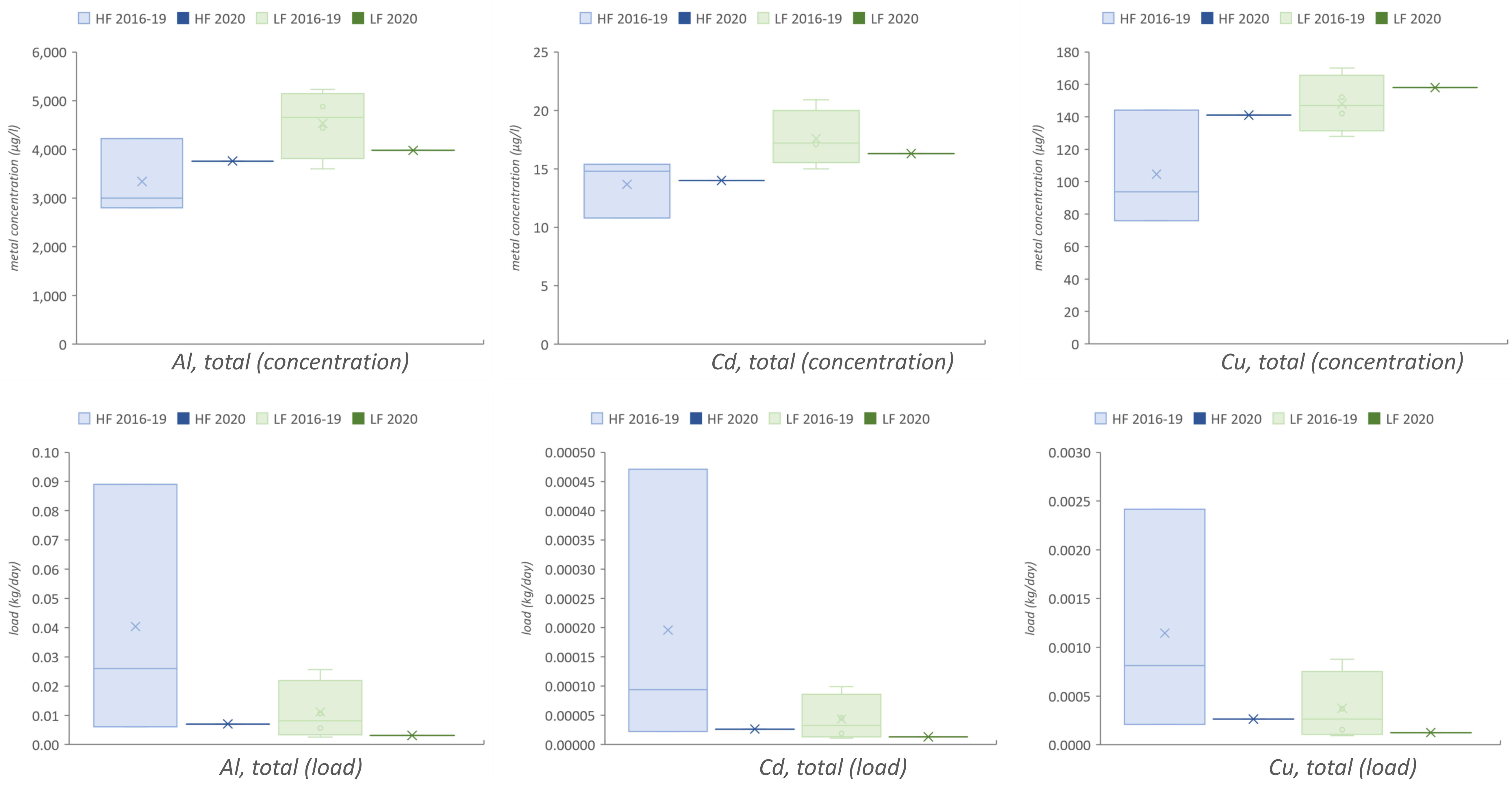

HF 2016-19
HF 2020
LF 2016-19
LF 2020
metal concentration (µg/l)
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Fe, total (concentration)
7
6
5
4
3
2
1
0
Pb, total (concentration)
25,000
20,000
15,000
10,000
5,000
Mn, total (concentration)
load (kg/day)
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
Fe, total (load)
0.000025
0.000020
0.000015
0.000010
0.000005
0.000000
Pb, total (load)
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
Mn, total (load)

SS067

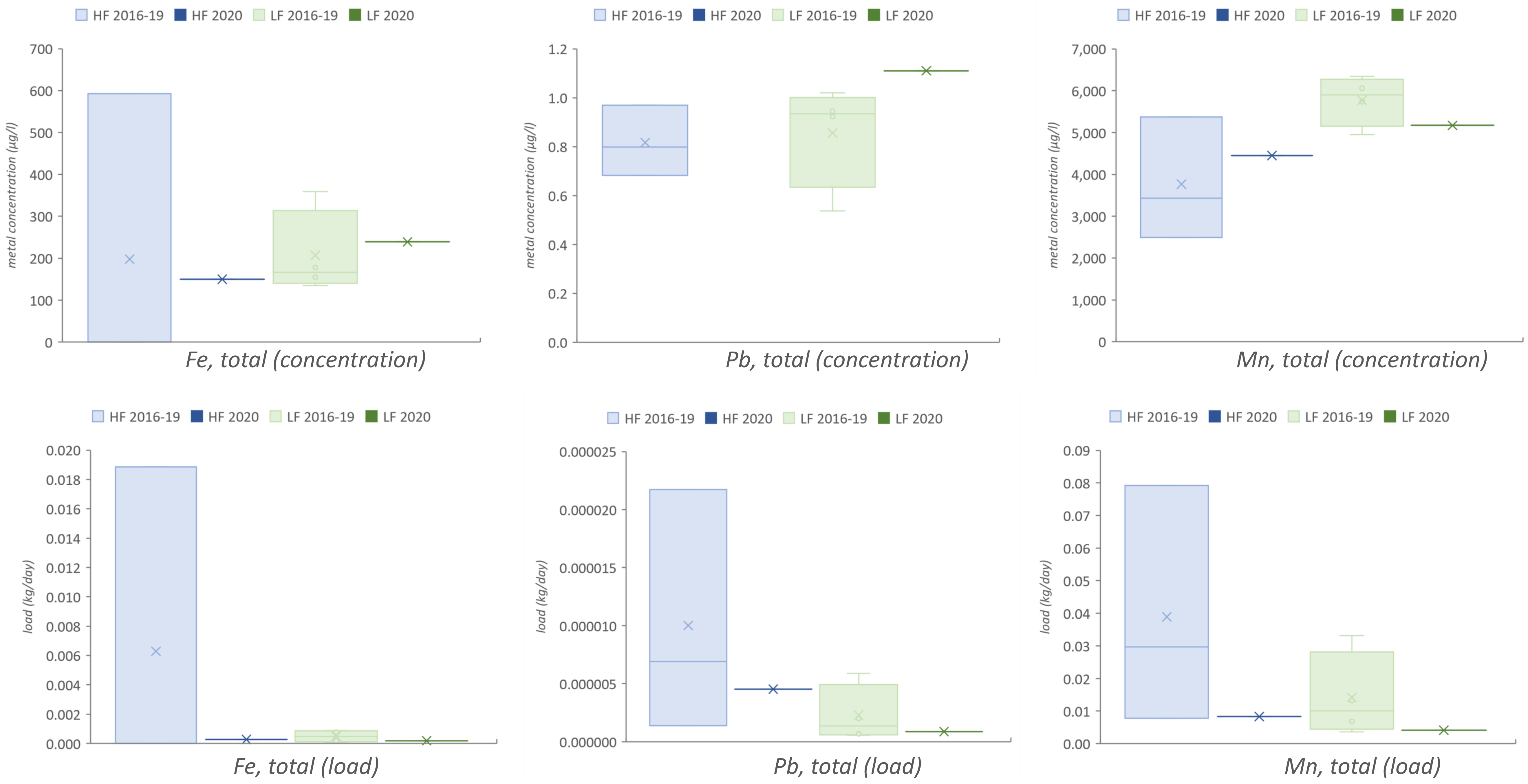


HF 2016-19
HF 2020
LF 2016-19
LF 2020
metal concentration (µg/l)
Zn, total (concentration)
concentration (µg/l)
Sulfate, total (concentration)
pH
load (kg/day)
Zn, total (load)
δ, ‰, per mil
δ 18O ‰
conductivity (µS/cm)
Conductivity

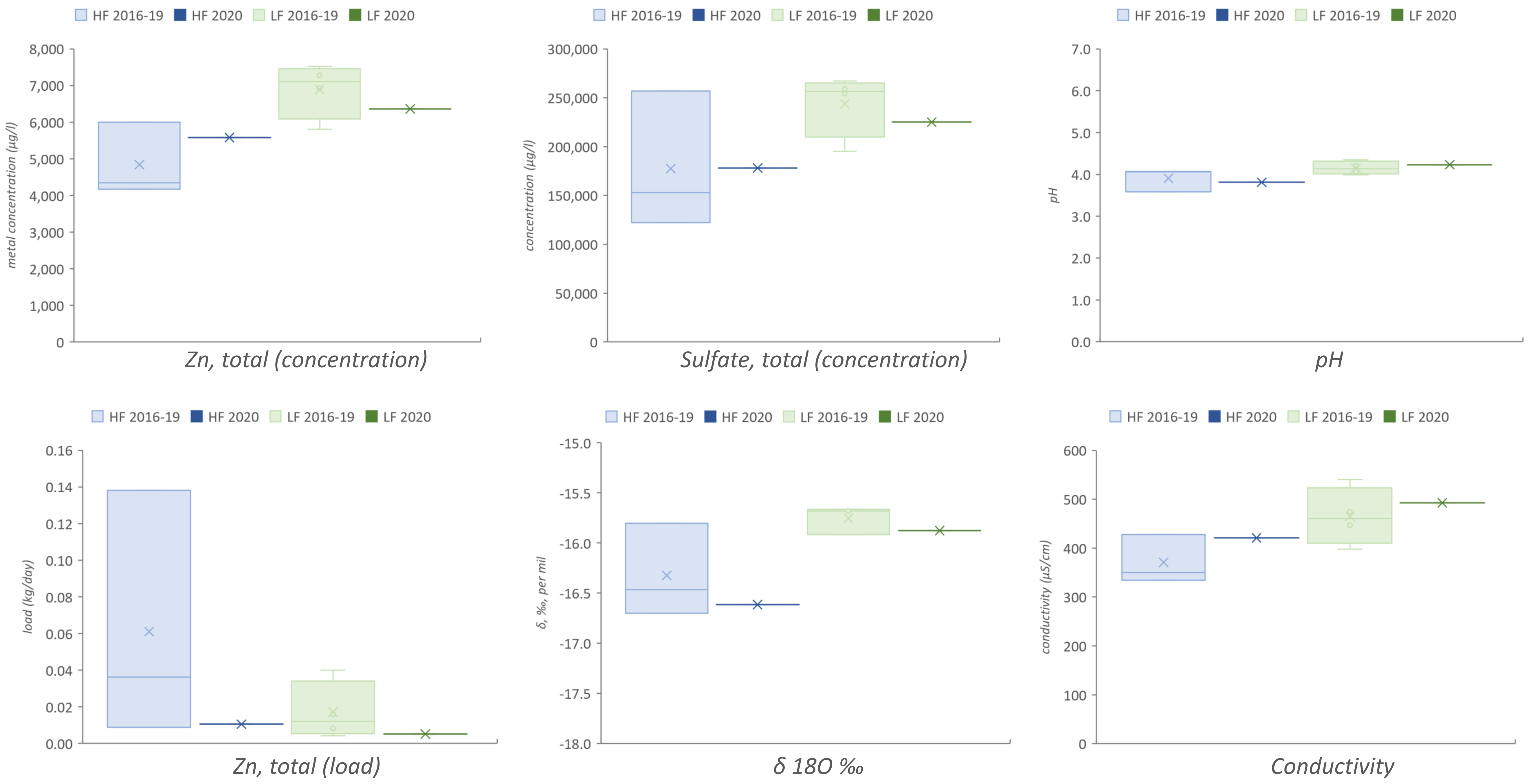
SS069


HF 2016-19
HF 2020
LF 2016-19
LF 2020
metal concentration (µg/l)
6,000
5,000
4,000
3,000
2,000
1,000
0
Al, total (concentration)
25
20
15
10
5
0
Cd, total (concentration)
180
160
140
120
100
80
60
40
20
0
Cu, total (concentration)
load (kg/day)
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
Al, total (load)
0.00050
0.00045
0.00040
0.00035
0.00030
0.00025
0.00020
0.00015
0.00010
0.00005
0.00000
Cd, total (load)
0.0030
0.0025
0.0020
0.0015
0.0010
0.0005
0.0000
Cu, total (load)

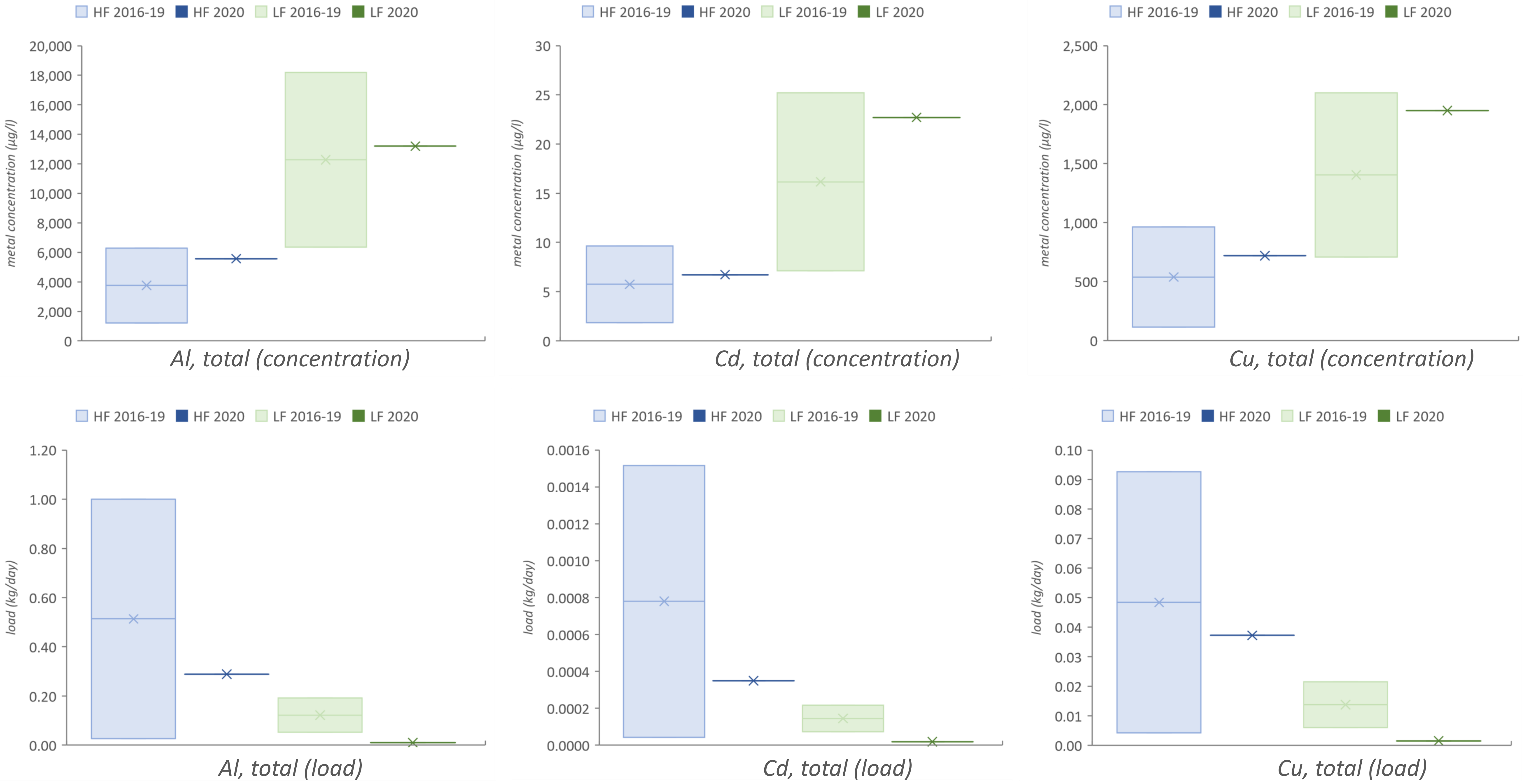
SS069


HF 2016-19
HF 2020
LF 2016-19
LF 2020
metal concentration (µg/l)
0
100
200
300
400
500
600
700
Fe, total (concentration)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
Pb, total (concentration)
0
1,000
2,000
3,000
4,000
5,000
6,000
7,000
Mn, total (concentration)
load (kg/day)
0.000
0.002
0.004
0.006
0.008
0.010
0.012
0.014
0.016
0.018
0.020
Fe, total (load)
0.000000
0.000005
0.000010
0.000015
0.000020
0.000025
Pb, total (load)
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
Mn, total (load)

SS069

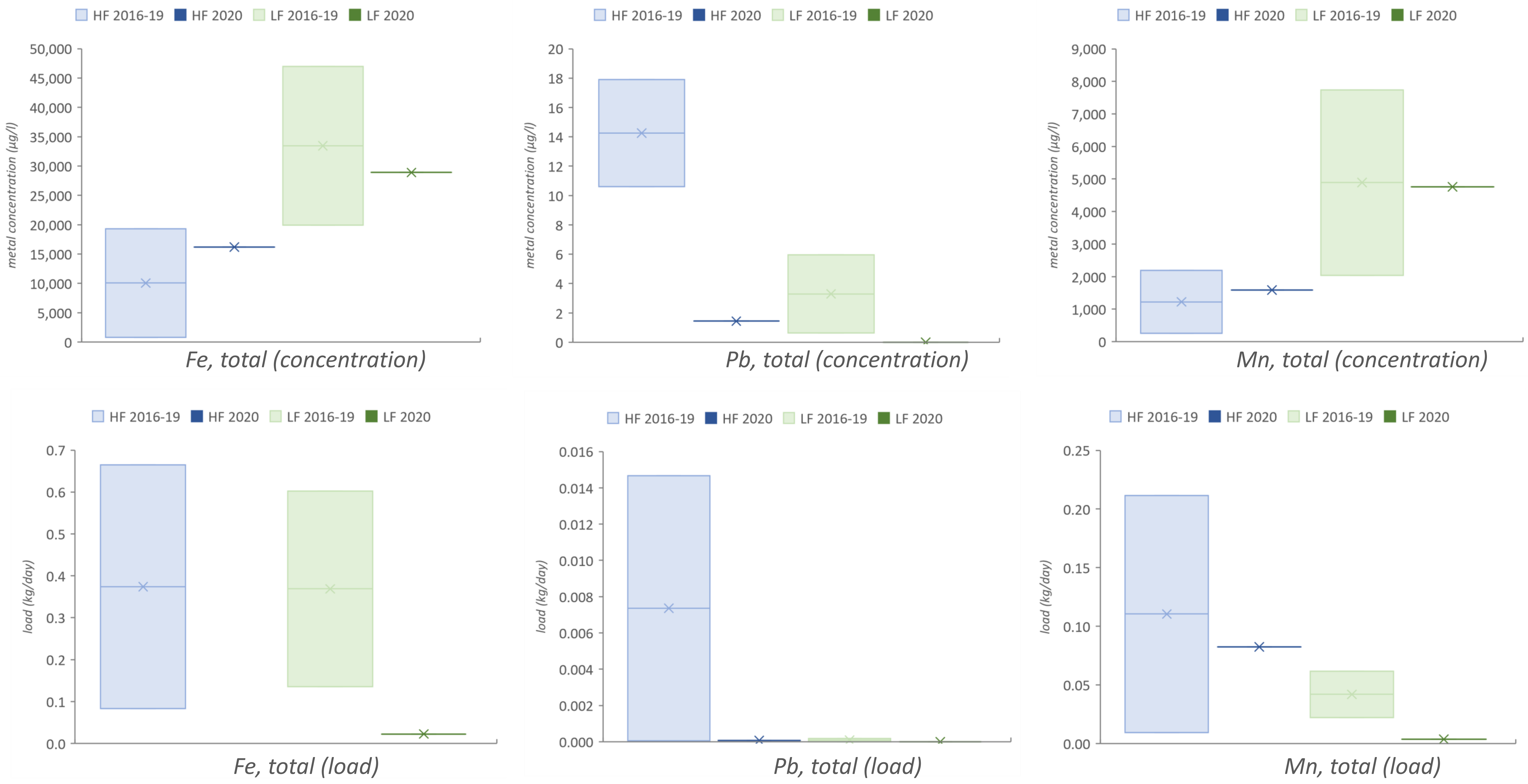

HF 2016-19
HF 2020
LF 2016-19
LF 2020
metal concentration (µg/l)
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Zn, total (concentration)
concentration (µg/l)
300,000
250,000
200,000
150,000
100,000
50,000
0
Sulfate, total (concentration)
pH
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
pH
load (kg/day)
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
Zn, total (load)
δ, ‰, per mil
-15.0
-15.5
-16.0
-16.5
-17.0
-17.5
-18.0
δ 18O ‰
conductivity (µS/cm)
600
500
400
300
200
100
0
Conductivity

SS084

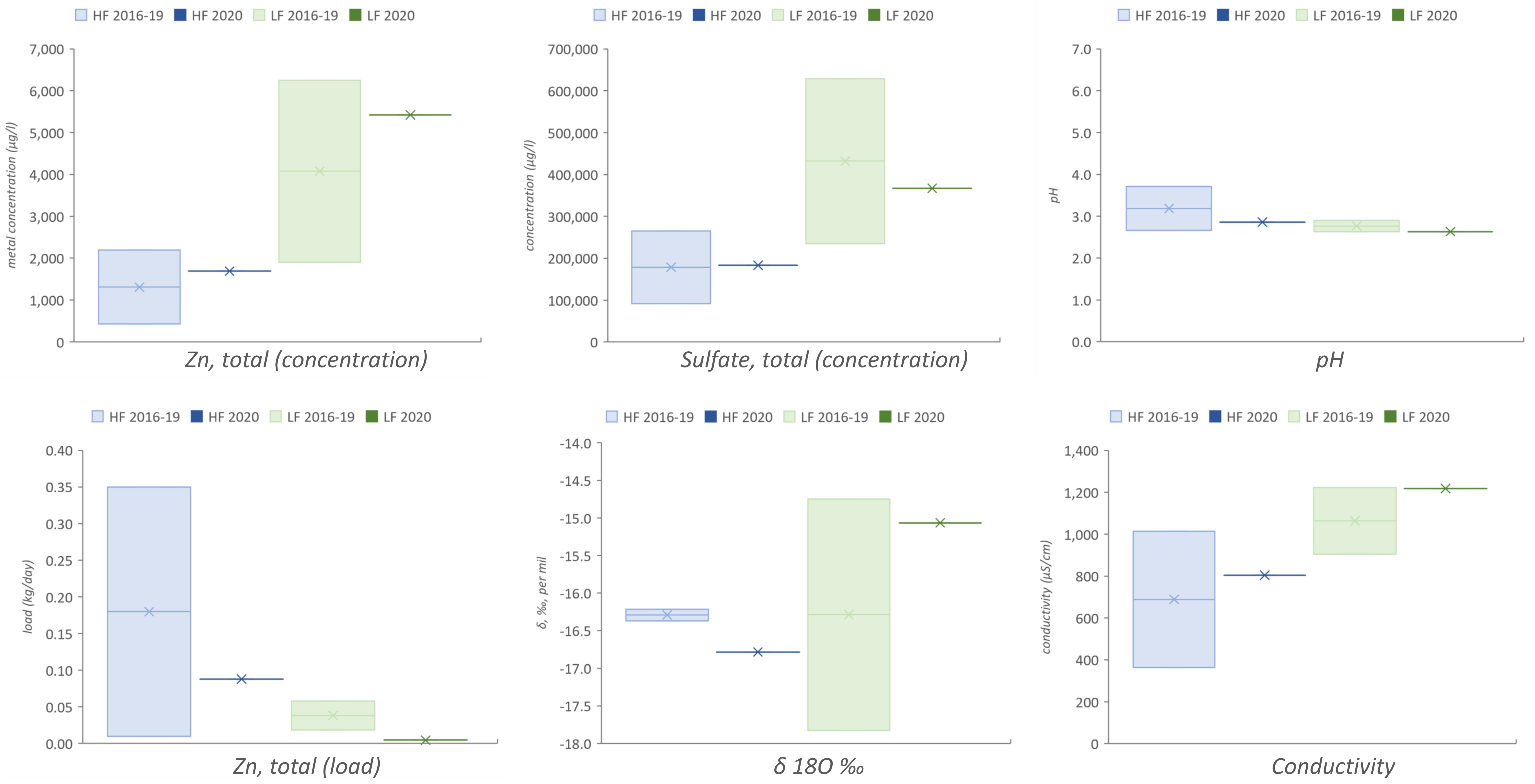


HF 2016-19
HF 2020
LF 2016-19
LF 2020
metal concentration (µg/l)
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Al, total (concentration)
30
25
20
15
10
5
0
Cd, total (concentration)
2,500
2,000
1,500
1,000
500
0
Cu, total (concentration)
load (kg/day)
1.20
1.00
0.80
0.60
0.40
0.20
0.00
Al, total (load)
0.0016
0.0014
0.0012
0.0010
0.0008
0.0006
0.0004
0.0002
0.0000
Cd, total (load)
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
Cu, total (load)

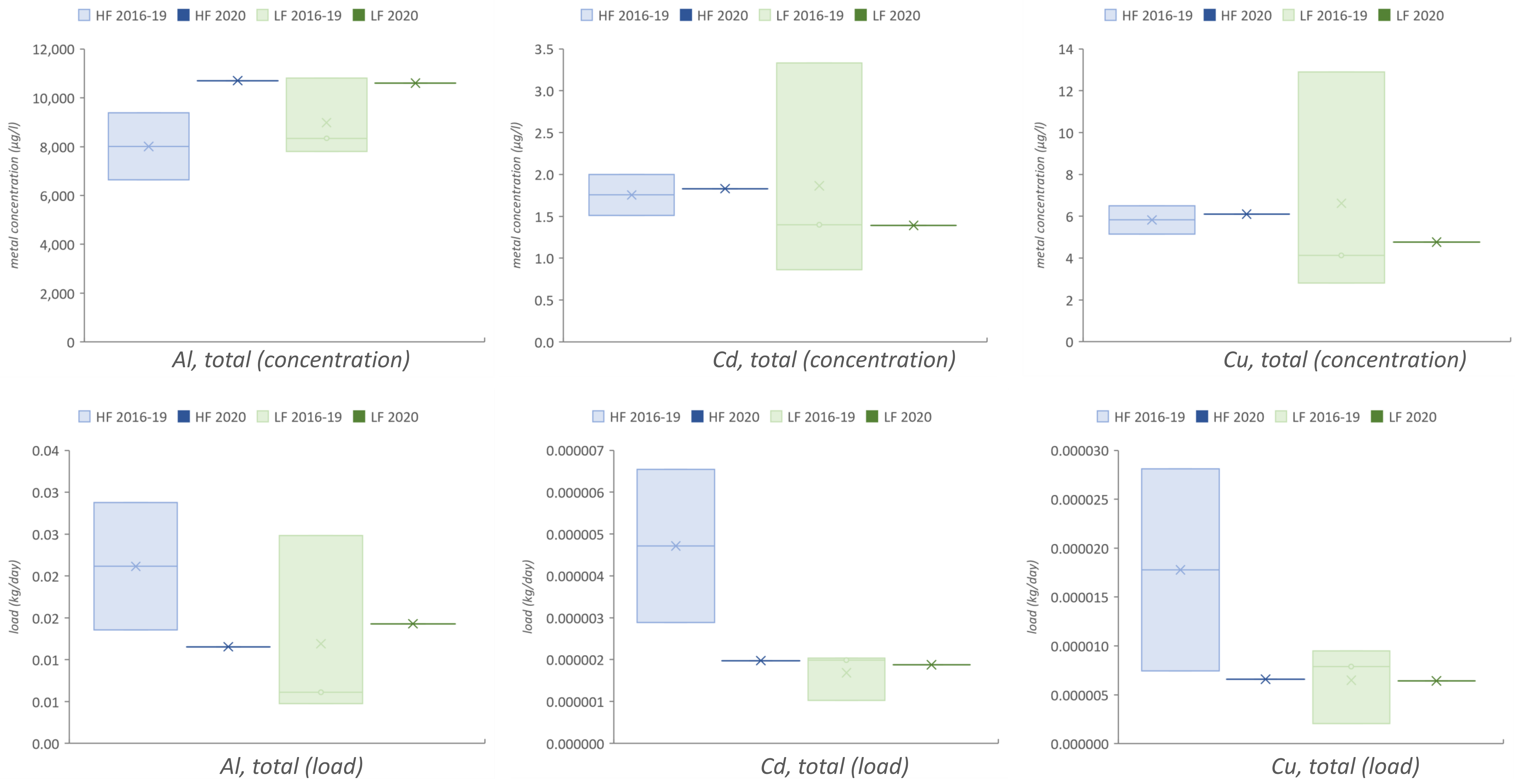
SS084


HF 2016-19
HF 2020
LF 2016-19
LF 2020
metal concentration (µg/l)
50,000
45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
Fe, total (concentration)
20
18
16
14
12
10
8
6
4
2
0
Pb, total (concentration)
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Mn, total (concentration)
load (kg/day)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Fe, total (load)
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
Pb, total (load)
0.25
0.20
0.15
0.10
0.05
0.00
Mn, total (load)

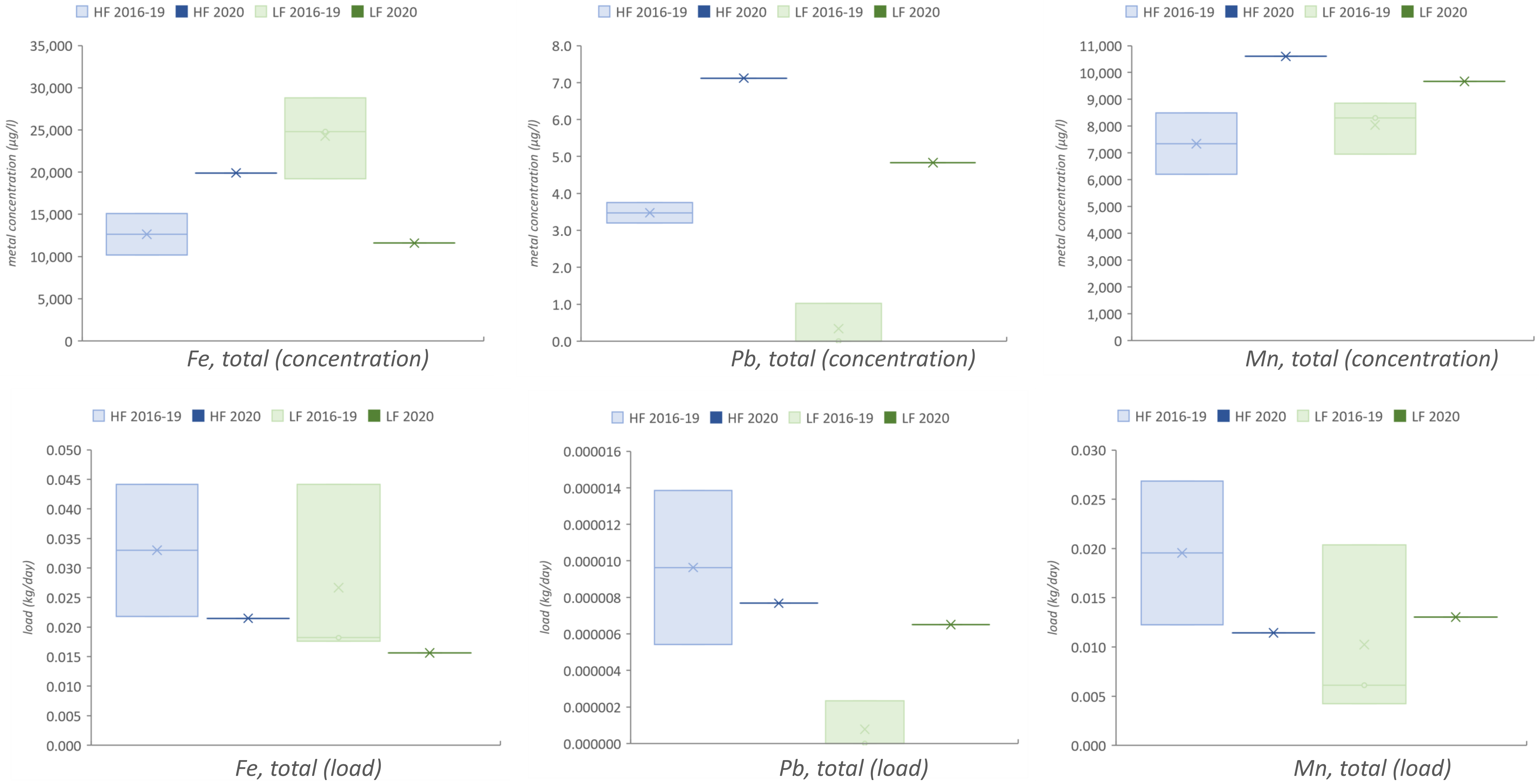
SS084


HF 2016-19
HF 2020
LF 2016-19
LF 2020
metal concentration (µg/l)
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Zn, total (concentration)
concentration (µg/l)
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
Sulfate, total (concentration)
pH
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
pH
load (kg/day)
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Zn, total (load)
δ, ‰, per mil
-14.0
-14.5
-15.0
-15.5
-16.0
-16.5
-17.0
-17.5
-18.0
δ 18O ‰
conductivity (µS/cm)
1,400
1,200
1,000
800
600
400
200
0
Conductivity

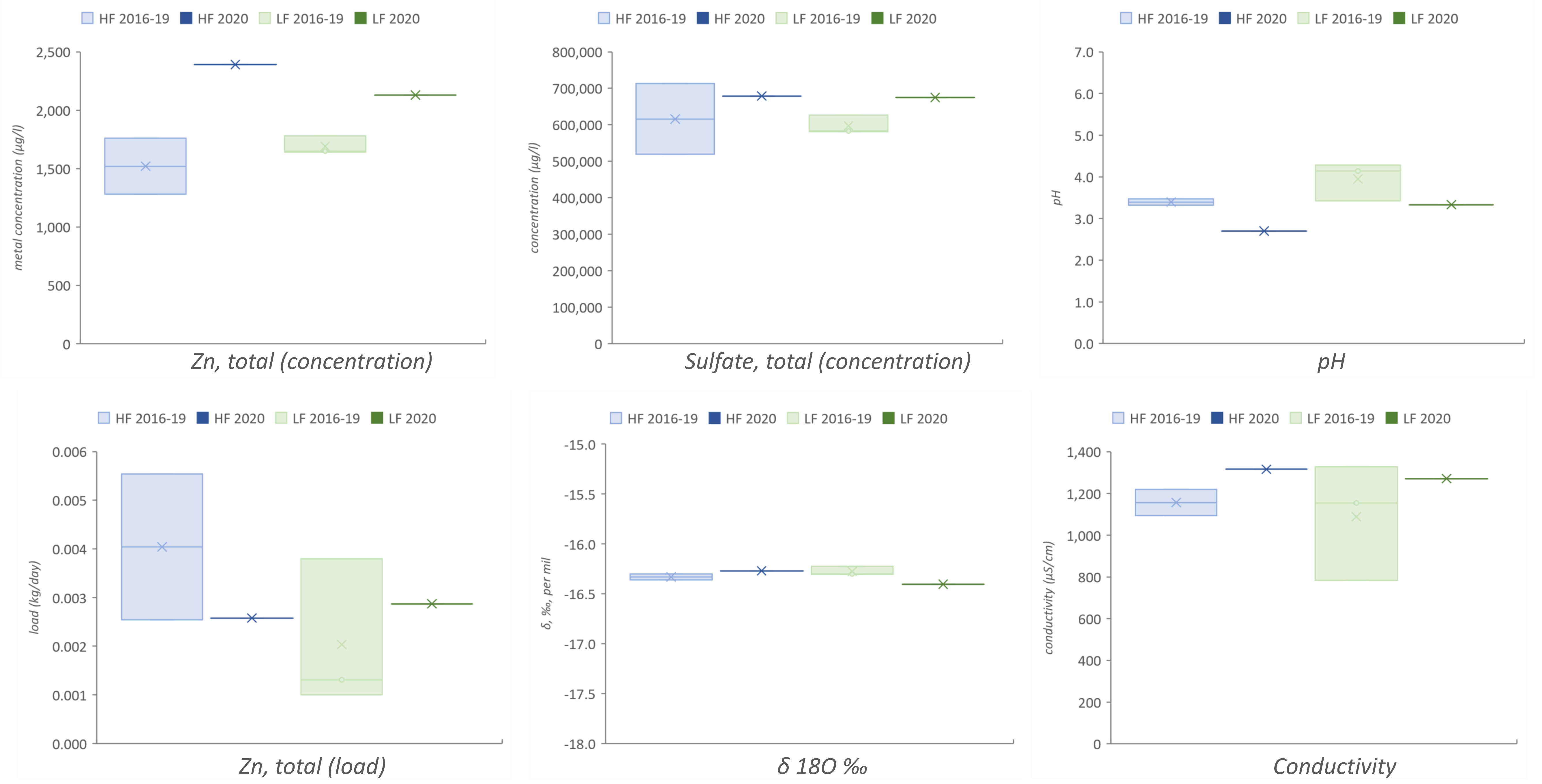
SS086


HF 2016-19
HF 2020
LF 2016-19
LF 2020
metal concentration (µg/l)
12,000
10,000
8,000
6,000
4,000
2,000
0
Al, total (concentration)
HF 2016-19
HF 2020
LF 2016-19
LF 2020
metal concentration (µg/l)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Cd, total (concentration)
HF 2016-19
HF 2020
LF 2016-19
LF 2020
metal concentration (µg/l)
14
12
10
8
6
4
2
0
Cu, total (concentration)
HF 2016-19
HF 2020
LF 2016-19
LF 2020
load (kg/day)
0.04
0.03
0.03
0.02
0.02
0.01
0.01
0.00
Al, total (load)
HF 2016-19
HF 2020
LF 2016-19
LF 2020
load (kg/day)
0.000007
0.000006
0.000005
0.000004
0.000003
0.000002
0.000001
0.000000
Cd, total (load)
HF 2016-19
HF 2020
LF 2016-19
LF 2020
load (kg/day)
0.000030
0.000025
0.000020
0.000015
0.000010
0.000005
0.000000
Cu, total (load)

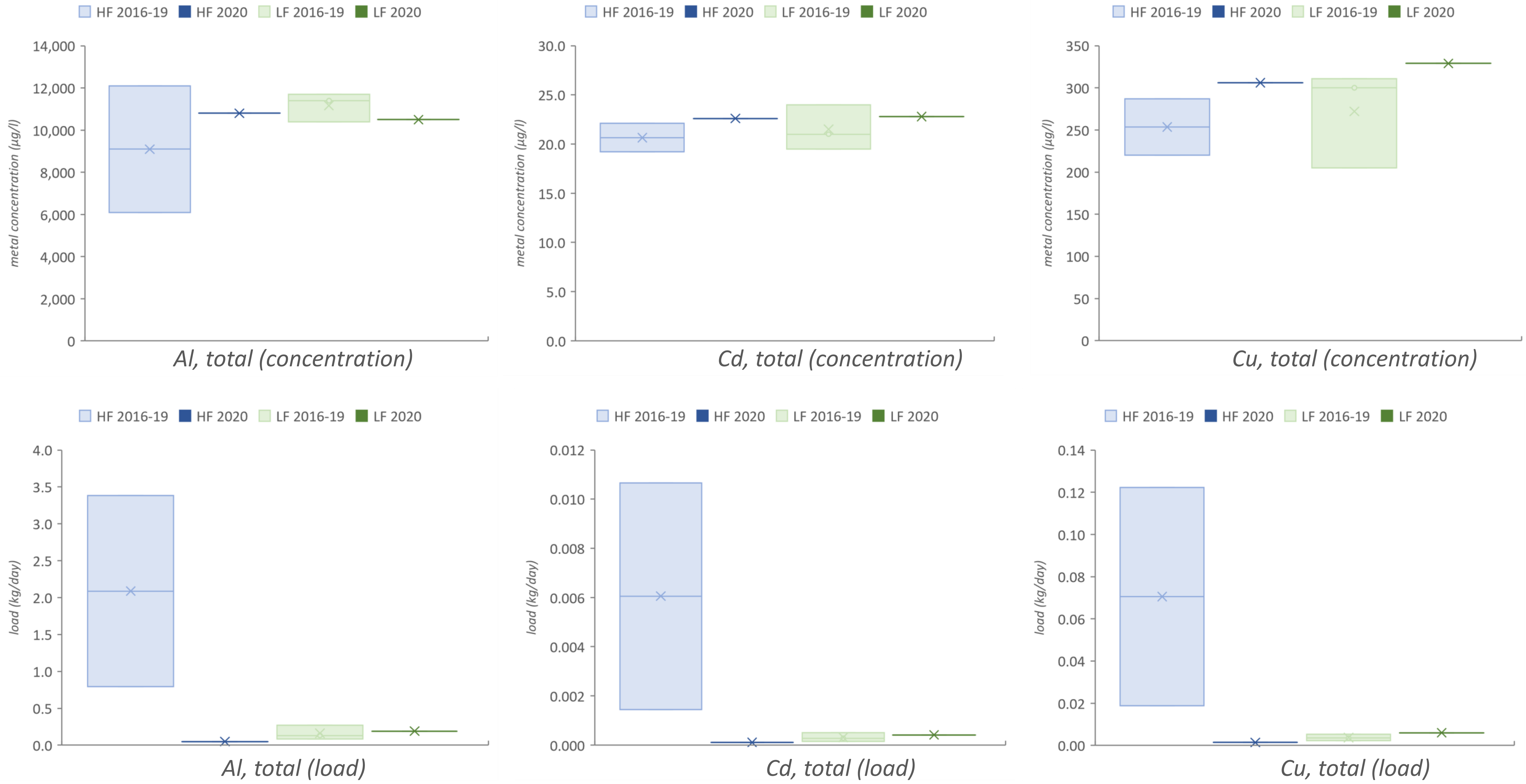
SS086


HF 2016-19
HF 2020
LF 2016-19
LF 2020
metal concentration (μg/l)
Fe, total (concentration)
Pb, total (concentration)
Mn, total (concentration)
load (kg/day)
Fe, total (load)
Pb, total (load)
Mn, total (load)

SS086

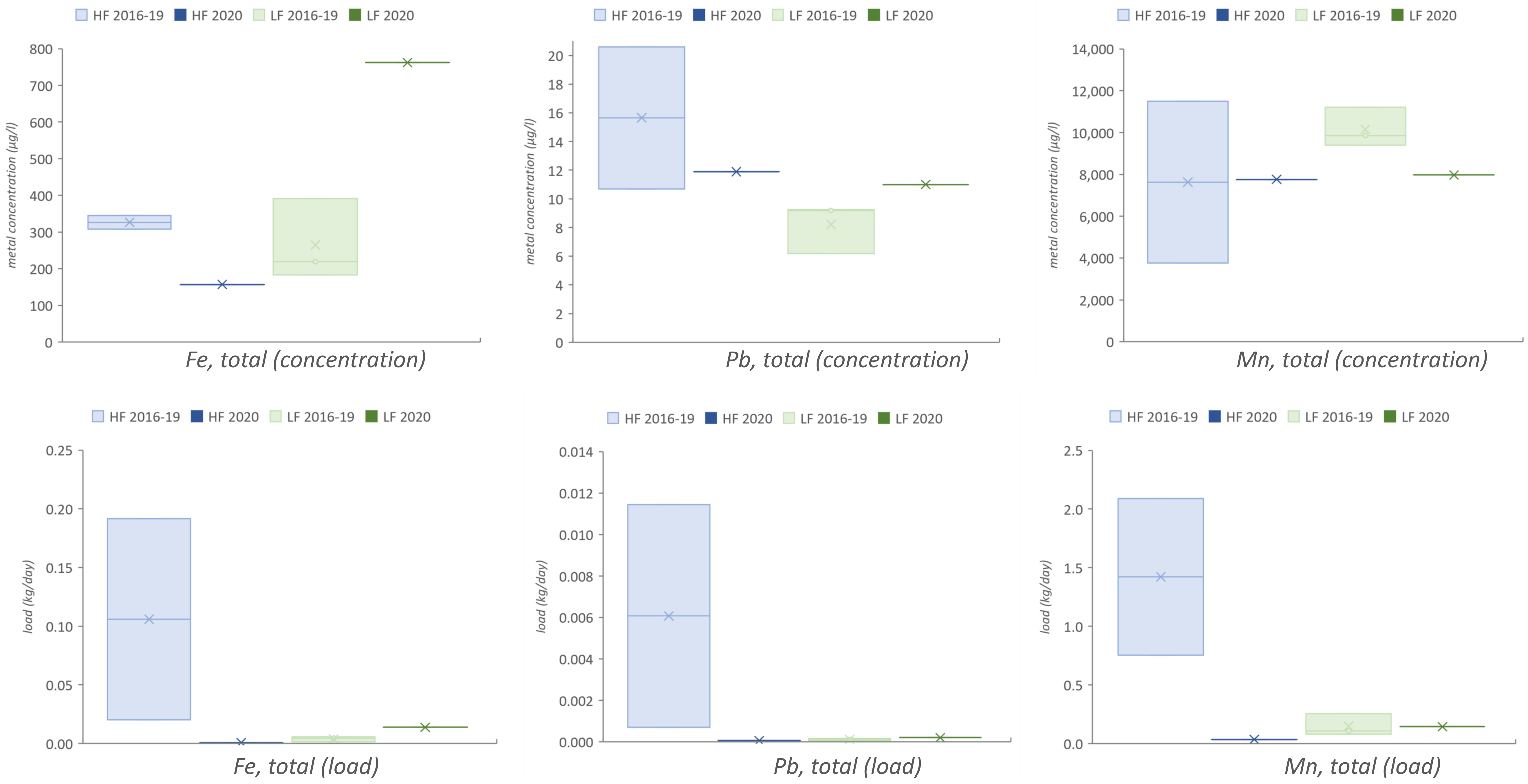

HF 2016-19
HF 2020
LF 2016-19
LF 2020
metal concentration (µg/l)
2,500
2,000
1,500
1,000
500
0
Zn, total (concentration)
concentration (µg/l)
800,000
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
Sulfate, total (concentration)
pH
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
pH
load (kg/day)
0.006
0.005
0.004
0.003
0.002
0.001
0.000
Zn, total (load)
δ, ‰, per mil
-15.0
-15.5
-16.0
-16.5
-17.0
-17.5
-18.0
δ 18O ‰
conductivity (µS/cm)
1,400
1,200
1,000
800
600
400
200
0
Conductivity

SS236



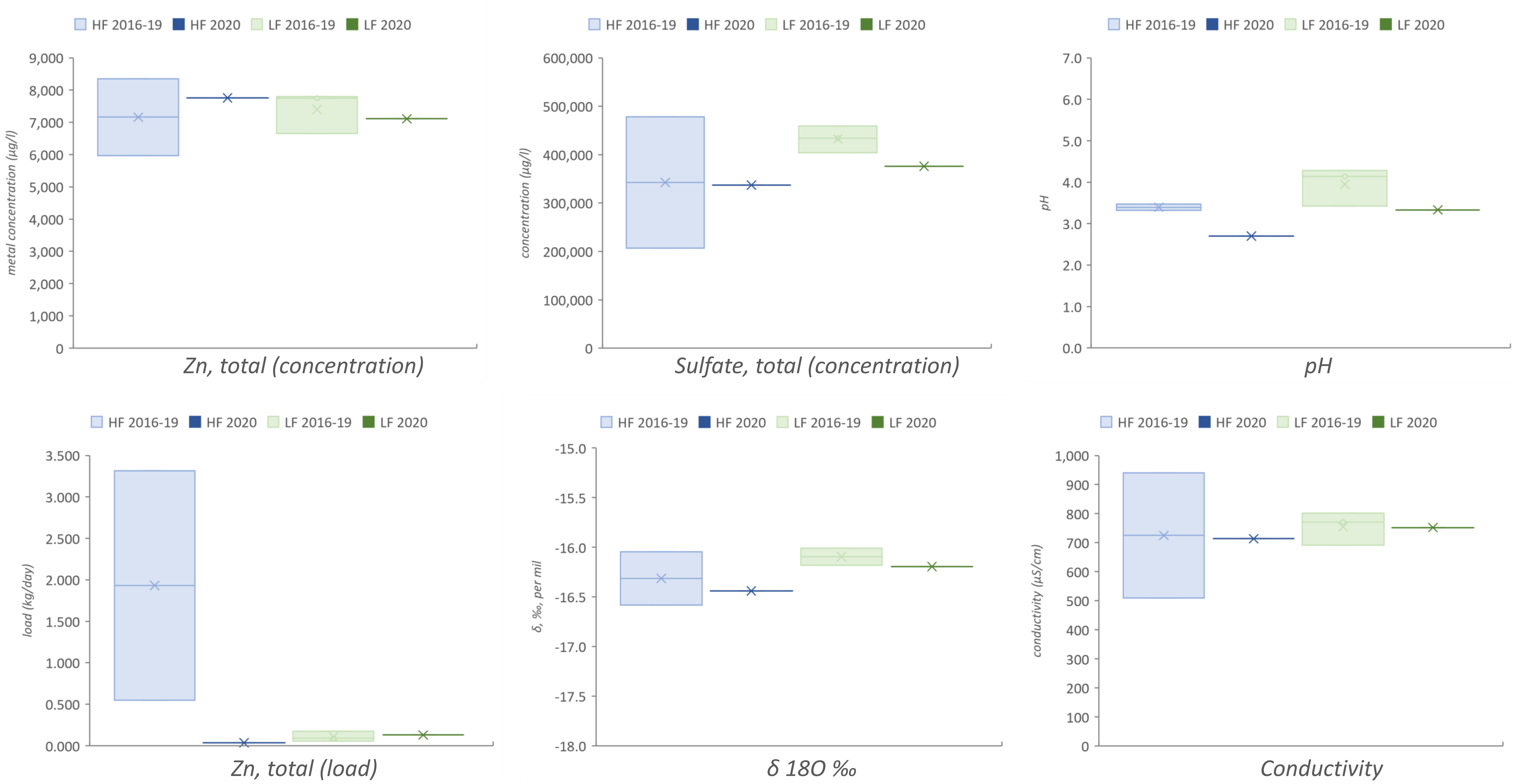
HF 2016-19
HF 2020
LF 2016-19
LF 2020
metal concentration (µg/l)
0
2,000
4,000
6,000
8,000
10,000
12,000
14,000
Al, total (concentration)
0.0
5.0
10.0
15.0
20.0
25.0
30.0
Cd, total (concentration)
0
50
100
150
200
250
300
350
Cu, total (concentration)
load (kg/day)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Al, total (load)
0.000
0.002
0.004
0.006
0.008
0.010
0.012
Cd, total (load)
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
Cu, total (load)

SS236

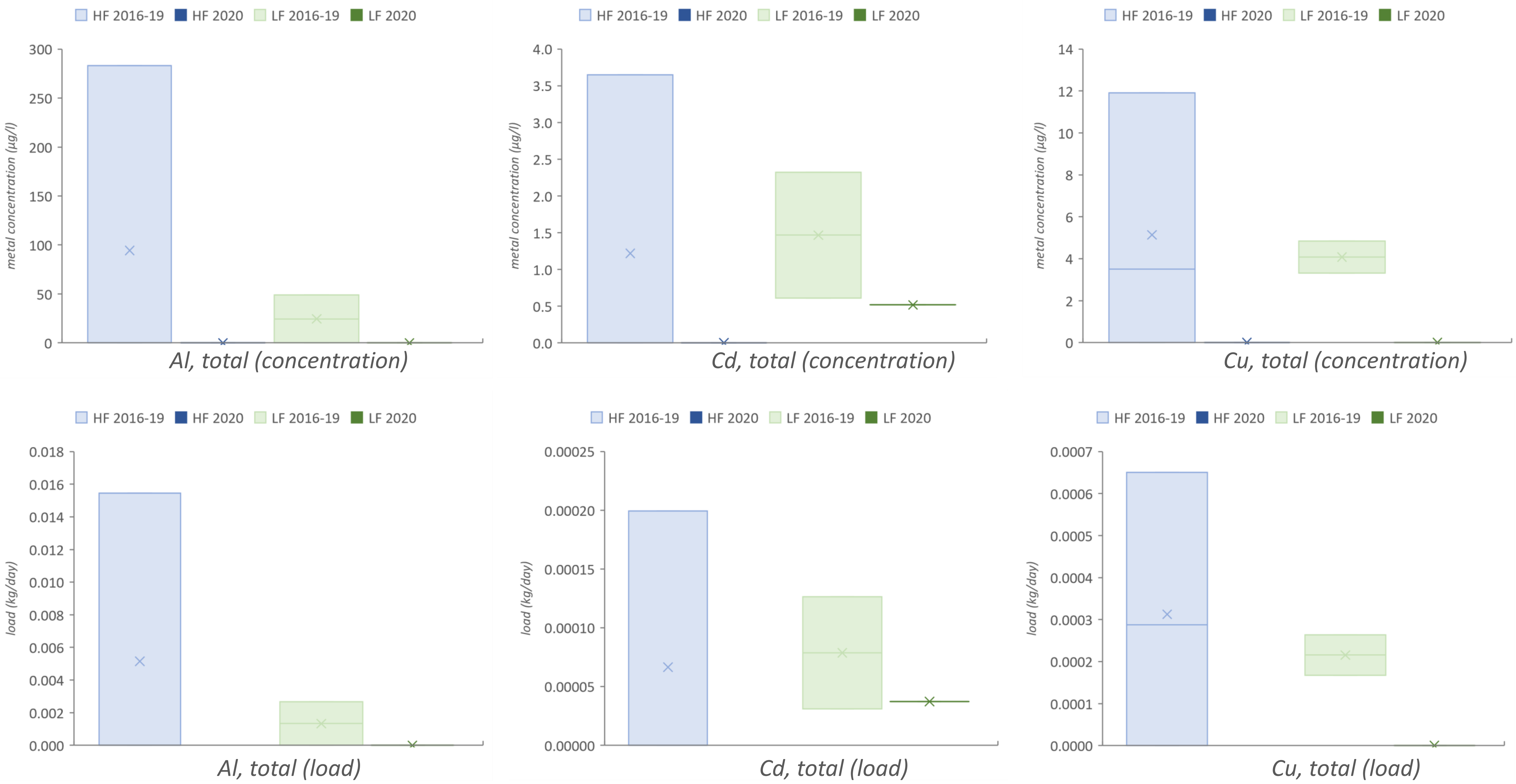


HF 2016-19
HF 2020
LF 2016-19
LF 2020
metal concentration (µg/l)
Fe, total (concentration)
Pb, total (concentration)
Mn, total (concentration)
load (kg/day)
Fe, total (load)
Pb, total (load)
Mn, total (load)

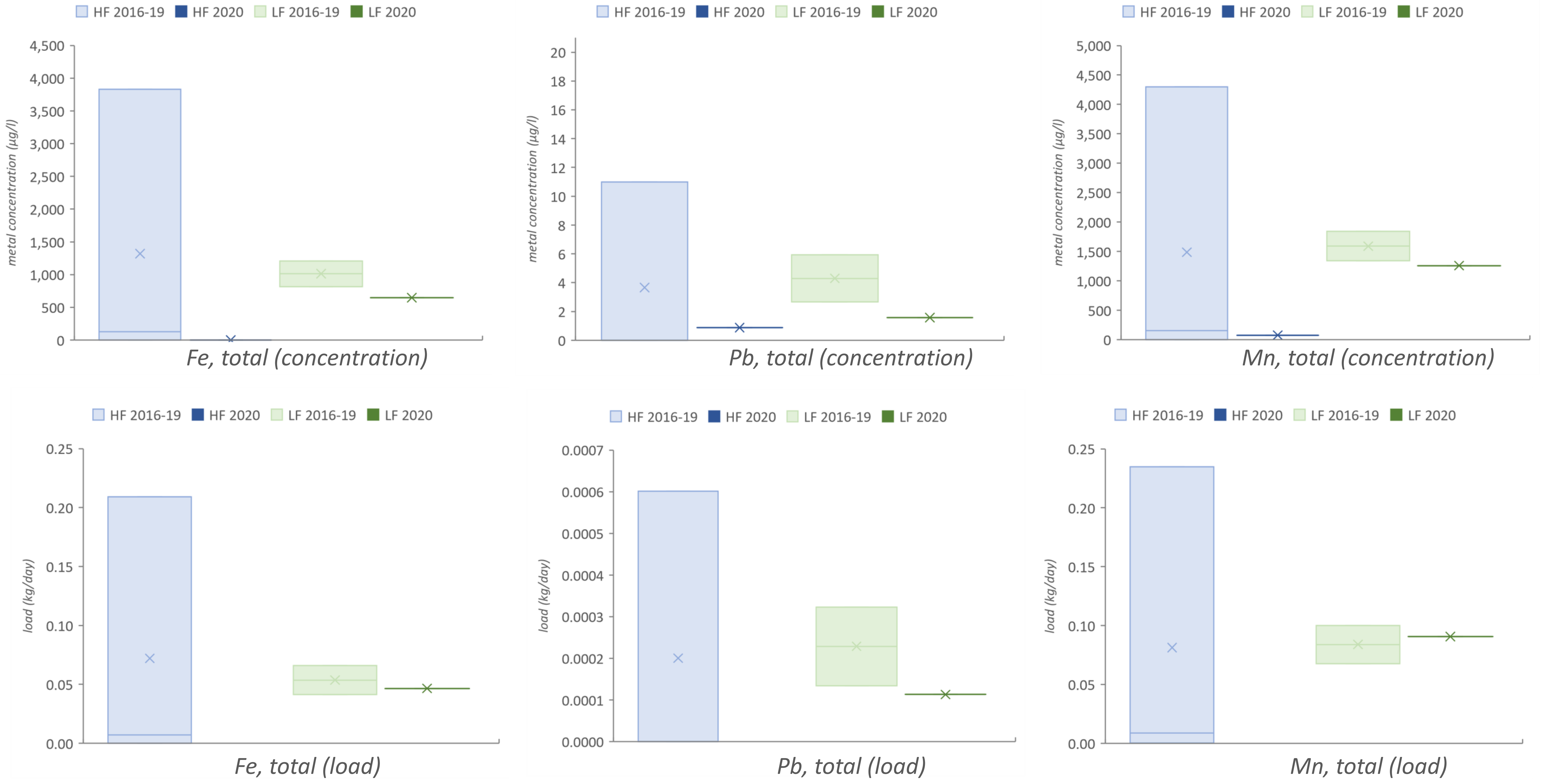
SS236


HF 2016-19
HF 2020
LF 2016-19
LF 2020
metal concentration (µg/l)
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Zn, total (concentration)
concentration (µg/l)
600,000
500,000
400,000
300,000
200,000
100,000
0
Sulfate, total (concentration)
pH
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
pH
load (kg/day)
3.500
3.000
2.500
2.000
1.500
1.000
0.500
0.000
Zn, total (load)
δ, ‰, per mil
-15.0
-15.5
-16.0
-16.5
-17.0
-17.5
-18.0
δ 18O ‰
conductivity (µS/cm)
1,000
900
800
700
600
500
400
300
200
100
0
Conductivity

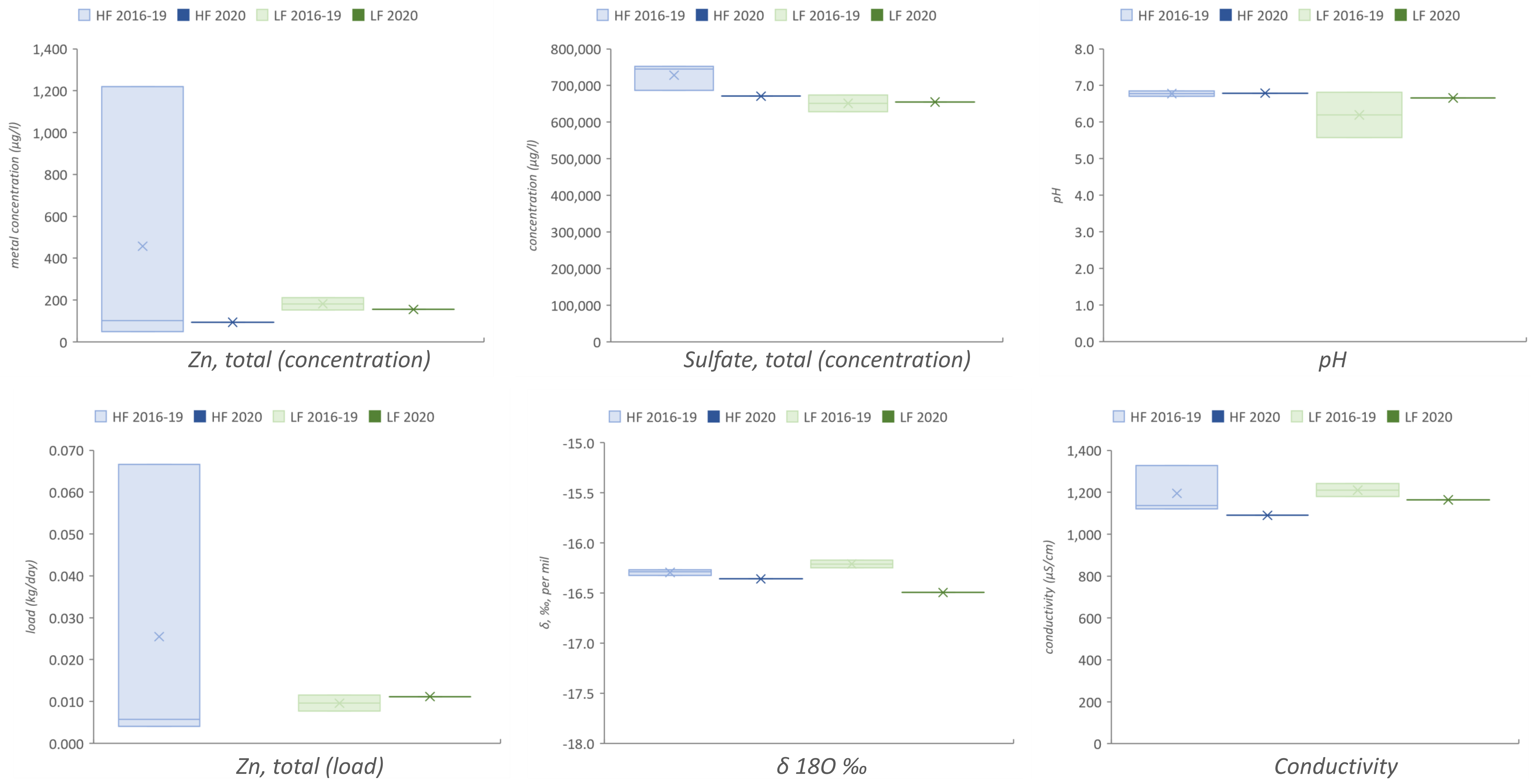
SS250

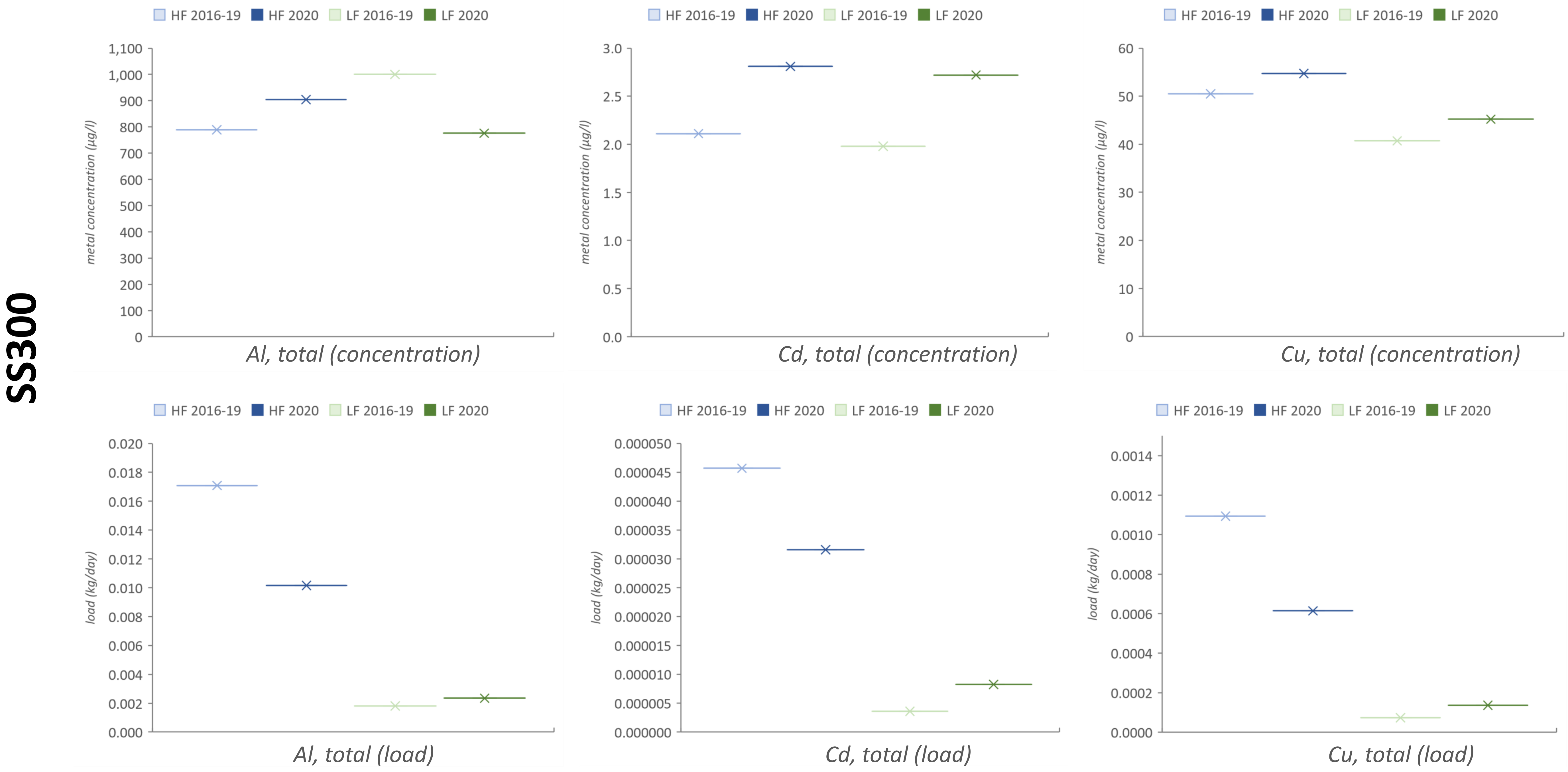

HF 2016-19
HF 2020
LF 2016-19
LF 2020
metal concentration (µg/l)
Al, total (concentration)
Cd, total (concentration)
Cu, total (concentration)
load (kg/day)
Al, total (load)
Cd, total (load)
Cu, total (load)

SS250

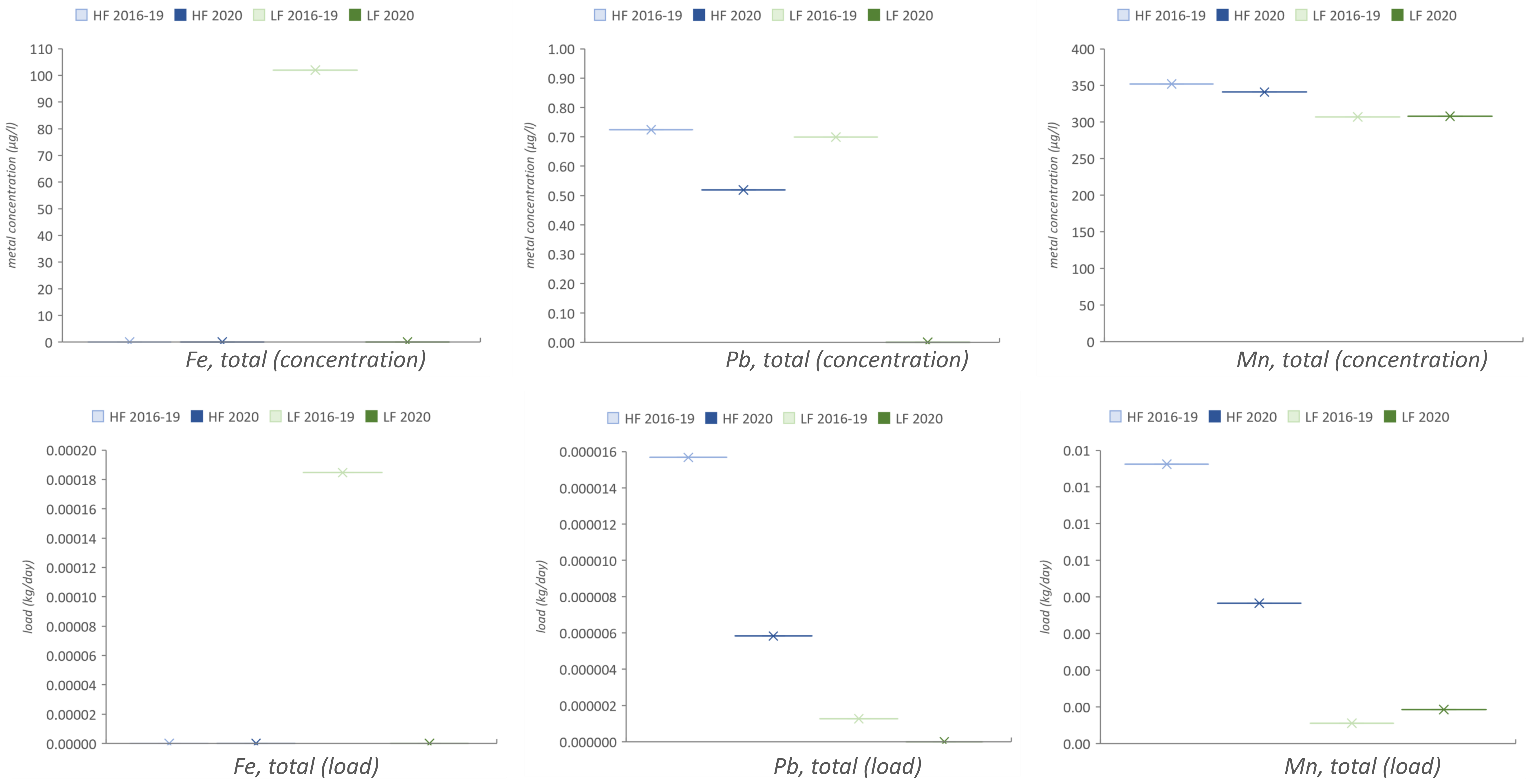

HF 2016-19
HF 2020
LF 2016-19
LF 2020
metal concentration (µg/l)
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
Fe, total (concentration)
HF 2016-19
HF 2020
LF 2016-19
LF 2020
metal concentration (µg/l)
20
18
16
14
12
10
8
6
4
2
0
Pb, total (concentration)
HF 2016-19
HF 2020
LF 2016-19
LF 2020
metal concentration (µg/l)
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
Mn, total (concentration)
HF 2016-19
HF 2020
LF 2016-19
LF 2020
load (kg/day)
0.25
0.20
0.15
0.10
0.05
0.00
Fe, total (load)
HF 2016-19
HF 2020
LF 2016-19
LF 2020
load (kg/day)
0.0007
0.0006
0.0005
0.0004
0.0003
0.0002
0.0001
0.0000
Pb, total (load)
HF 2016-19
HF 2020
LF 2016-19
LF 2020
load (kg/day)
0.25
0.20
0.15
0.10
0.05
0.00
Mn, total (load)

SS250

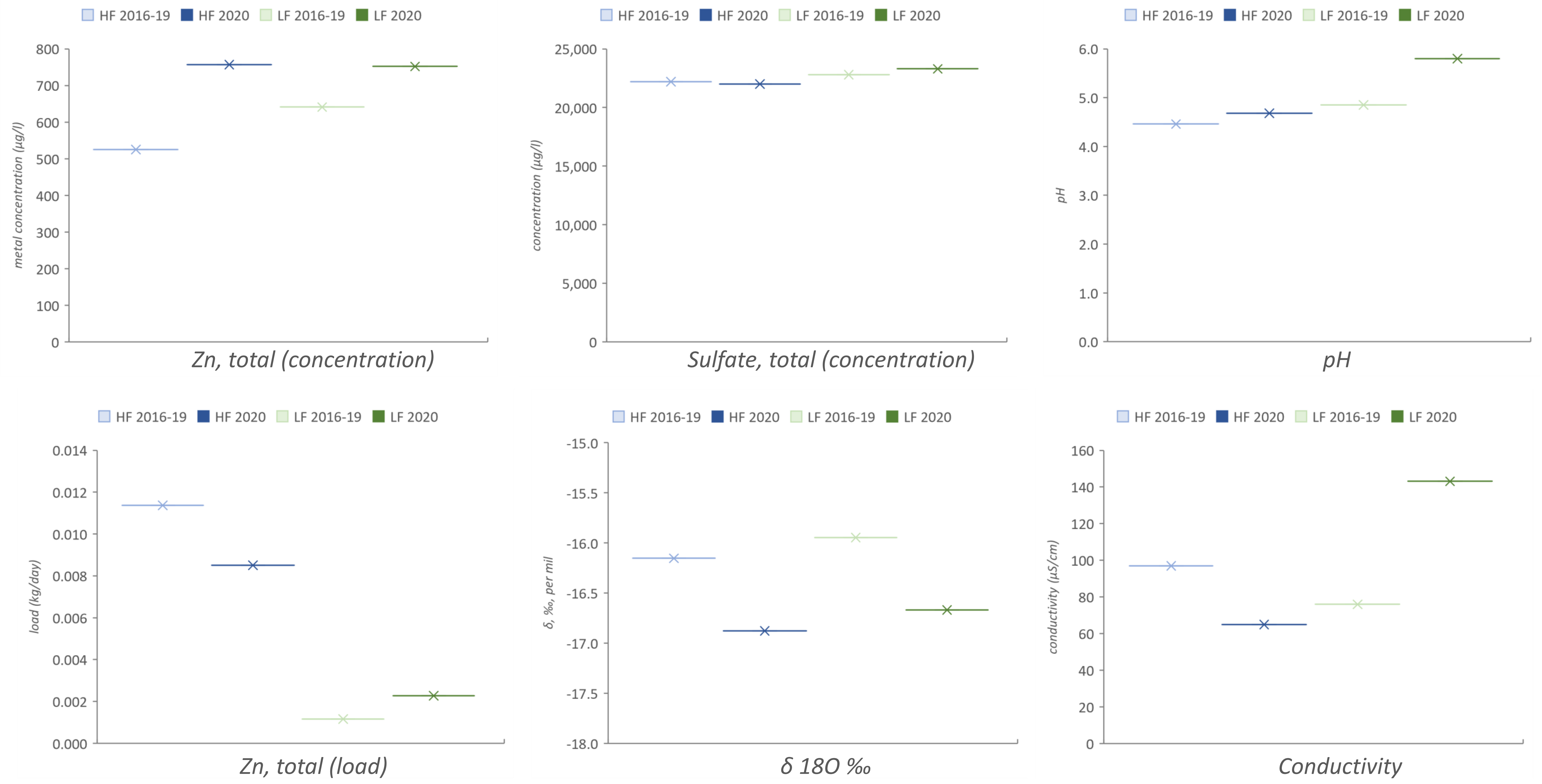

HF 2016-19
HF 2020
LF 2016-19
LF 2020
metal concentration (µg/l)
1,400
1,200
1,000
800
600
400
200
0
Zn, total (concentration)
concentration (µg/l)
800,000
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
Sulfate, total (concentration)
pH
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
pH
load (kg/day)
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
Zn, total (load)
δ, ‰, per mil
-15.0
-15.5
-16.0
-16.5
-17.0
-17.5
-18.0
δ 18O ‰
conductivity (µS/cm)
1,400
1,200
1,000
800
600
400
200
0
Conductivity


SS300
HF 2016-19
HF 2020
LF 2016-19
LF 2020
metal concentration (µg/l)
Al, total (concentration)
Cd, total (concentration)
Cu, total (concentration)
load (kg/day)
Al, total (load)
Cd, total (load)
Cu, total (load)

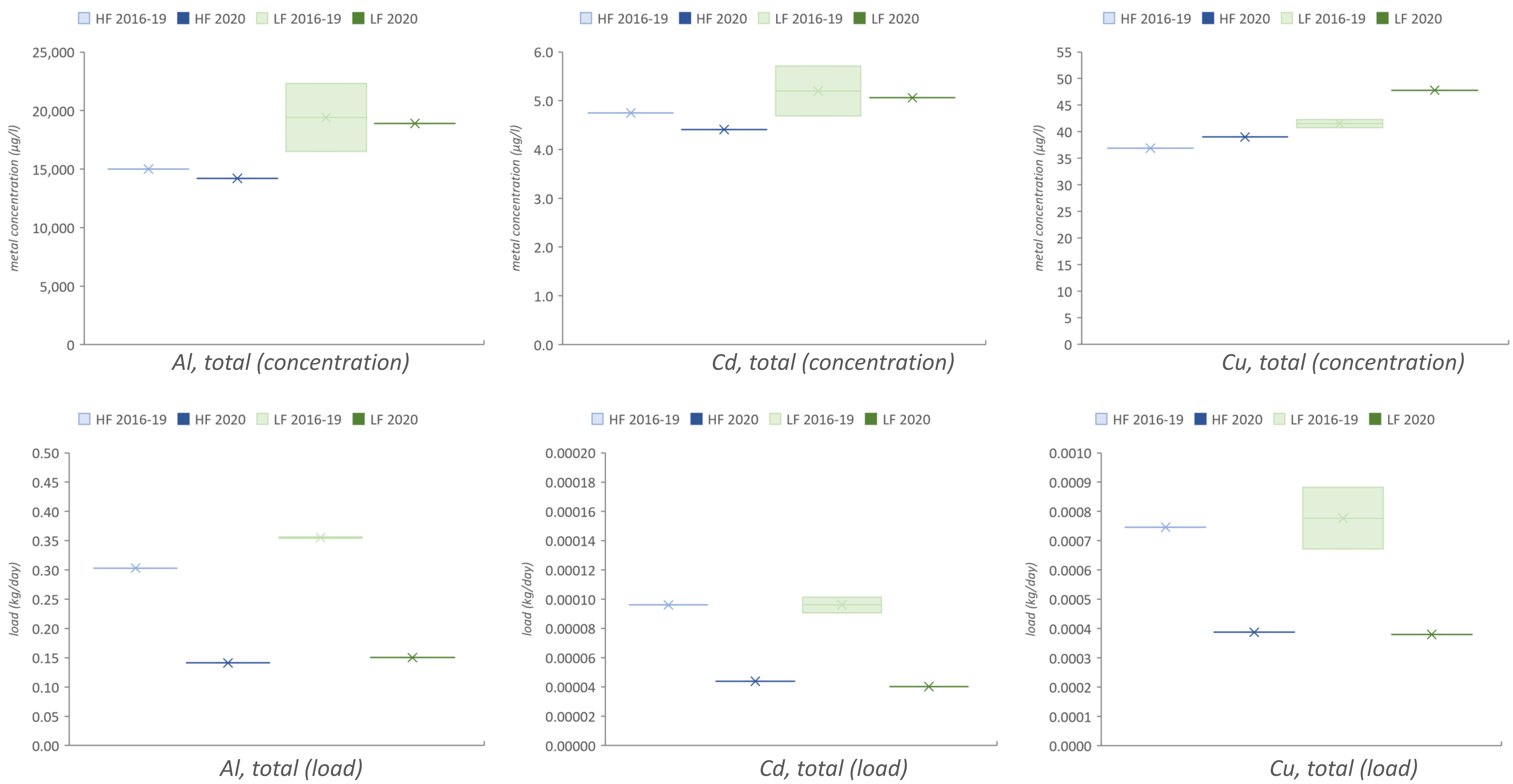
SS300


HF 2016-19
HF 2020
LF 2016-19
LF 2020
metal concentration (μg/l)
Fe, total (concentration)
Pb, total (concentration)
Mn, total (concentration)
load (kg/day)
Fe, total (load)
Pb, total (load)
Mn, total (load)

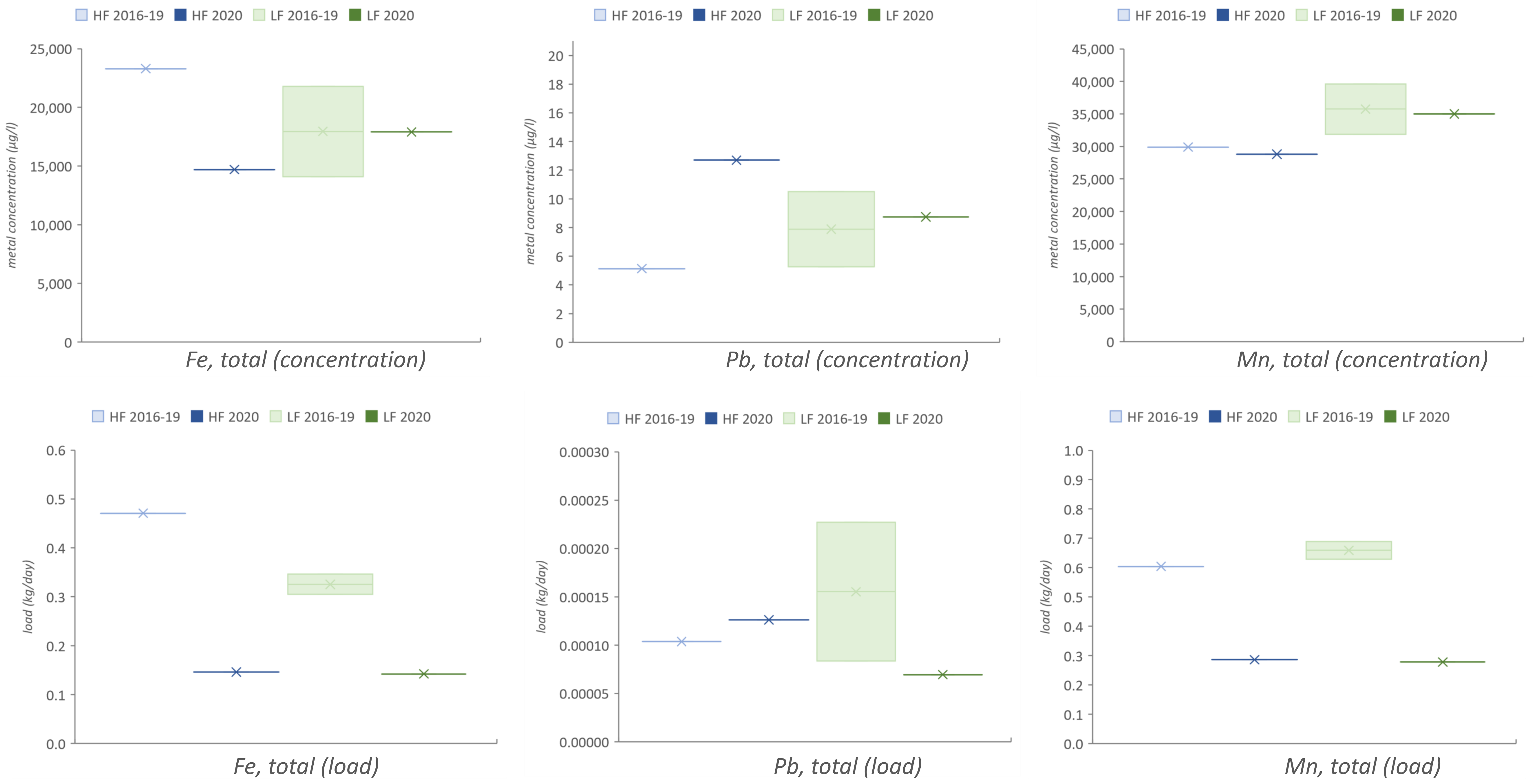
SS300


HF 2016-19
HF 2020
LF 2016-19
LF 2020
metal concentration (µg/l)
Zn, total (concentration)
concentration (µg/l)
Sulfate, total (concentration)
pH
load (kg/day)
Zn, total (load)
δ, ‰, per mil
δ 18O ‰
conductivity (µS/cm)
Conductivity

SS301

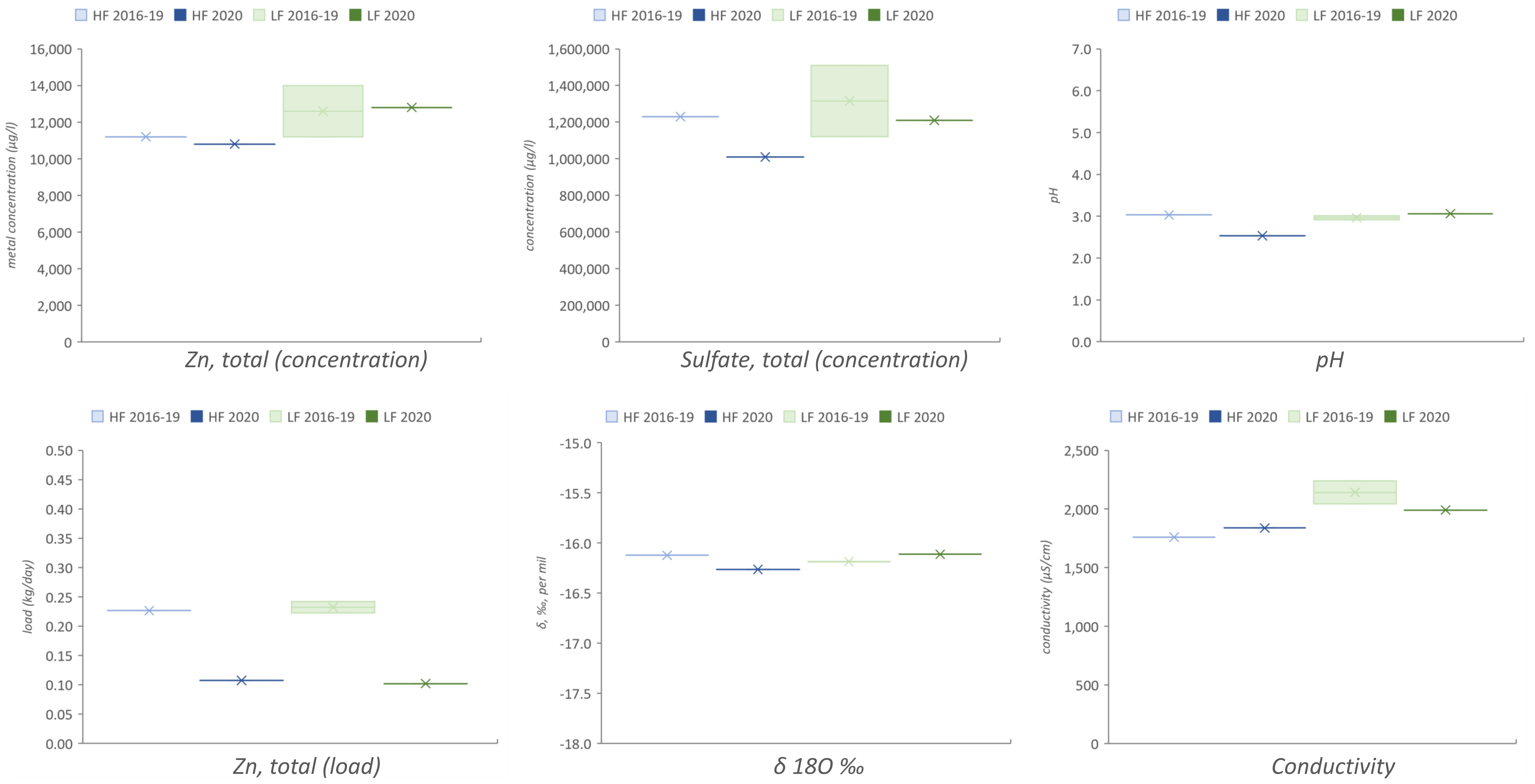

HF 2016-19
HF 2020
LF 2016-19
LF 2020
metal concentration (µg/l)
25,000
20,000
15,000
10,000
5,000
0
Al, total (concentration)
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Cd, total (concentration)
55
50
45
40
35
30
25
20
15
10
5
0
Cu, total (concentration)
load (kg/day)
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Al, total (load)
0.00020
0.00018
0.00016
0.00014
0.00012
0.00010
0.00008
0.00006
0.00004
0.00002
0.00000
Cd, total (load)
0.0010
0.0009
0.0008
0.0007
0.0006
0.0005
0.0004
0.0003
0.0002
0.0001
0.0000
Cu, total (load)

SS301



HF 2016-19
HF 2020
LF 2016-19
LF 2020
metal concentration (µg/l)
Fe, total (concentration)
Pb, total (concentration)
Mn, total (concentration)
load (kg/day)
Fe, total (load)
Pb, total (load)
Mn, total (load)

SS301


HF 2016-19
HF 2020
LF 2016-19
LF 2020
metal concentration (µg/l)
Zn, total (concentration)
concentration (µg/l)
Sulfate, total (concentration)
pH
pH
load (kg/day)
Zn, total (load)
δ, ‰, per mil
δ 18O ‰
conductivity (µS/cm)
Conductivity

C. Representative photos of newly documented surface water expressions

Photo 1: SS400 - 08/31/2020

Photo 2: SS401 - 08/31/2020

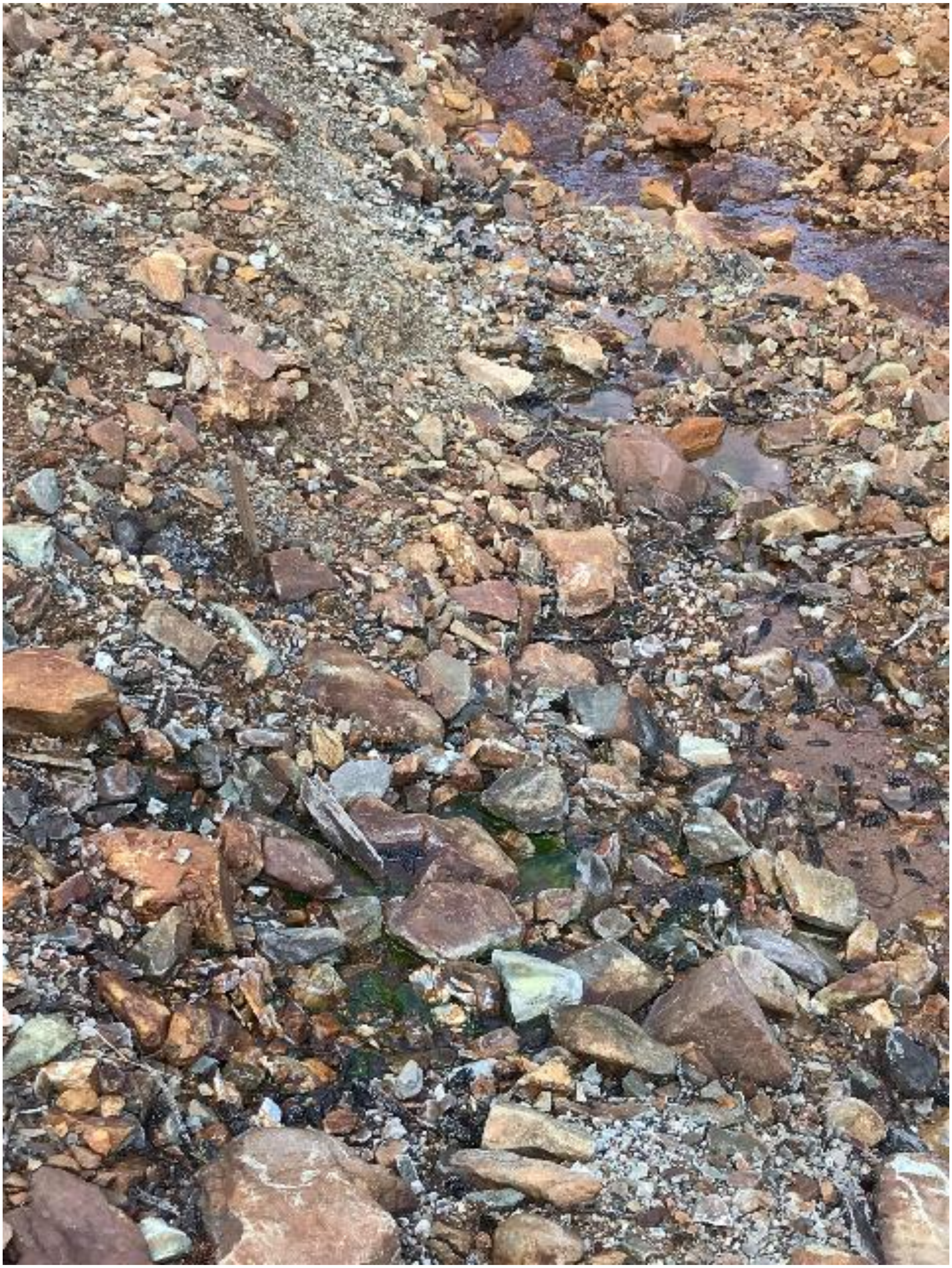


Photo 3: SS402 - 08/31/2020

Photo 4: SS403 - 08/31/2020

Photo 5: SS404 - 08/31/2020

Photo 6: SS405 - 08/31/2020

Photo 7: SS406 - 08/31/2020

Photo 8: SS407 - 09/14/2020

Photo 9: SS408 - 09/7/2020


Photo 10: SS409 - 10/20/2020

Photo 11: SS410 - 08/31/2020

Photo 12: SS411 - 08/31/2020

Photo 13: SS412 - 08/31/2020

Photo 14: SS413 - 08/31/2020


Photo 15: SS415 - 10/20/2020

Photo 16: SS416 - 08/31/2020

Photo 17: SS417 - 08/31/2020

Photo 18: SS418 - 08/31/2020

Photo 19: SS419 - 08/31/2020

Photo 20: SS420 - 10/20/2020

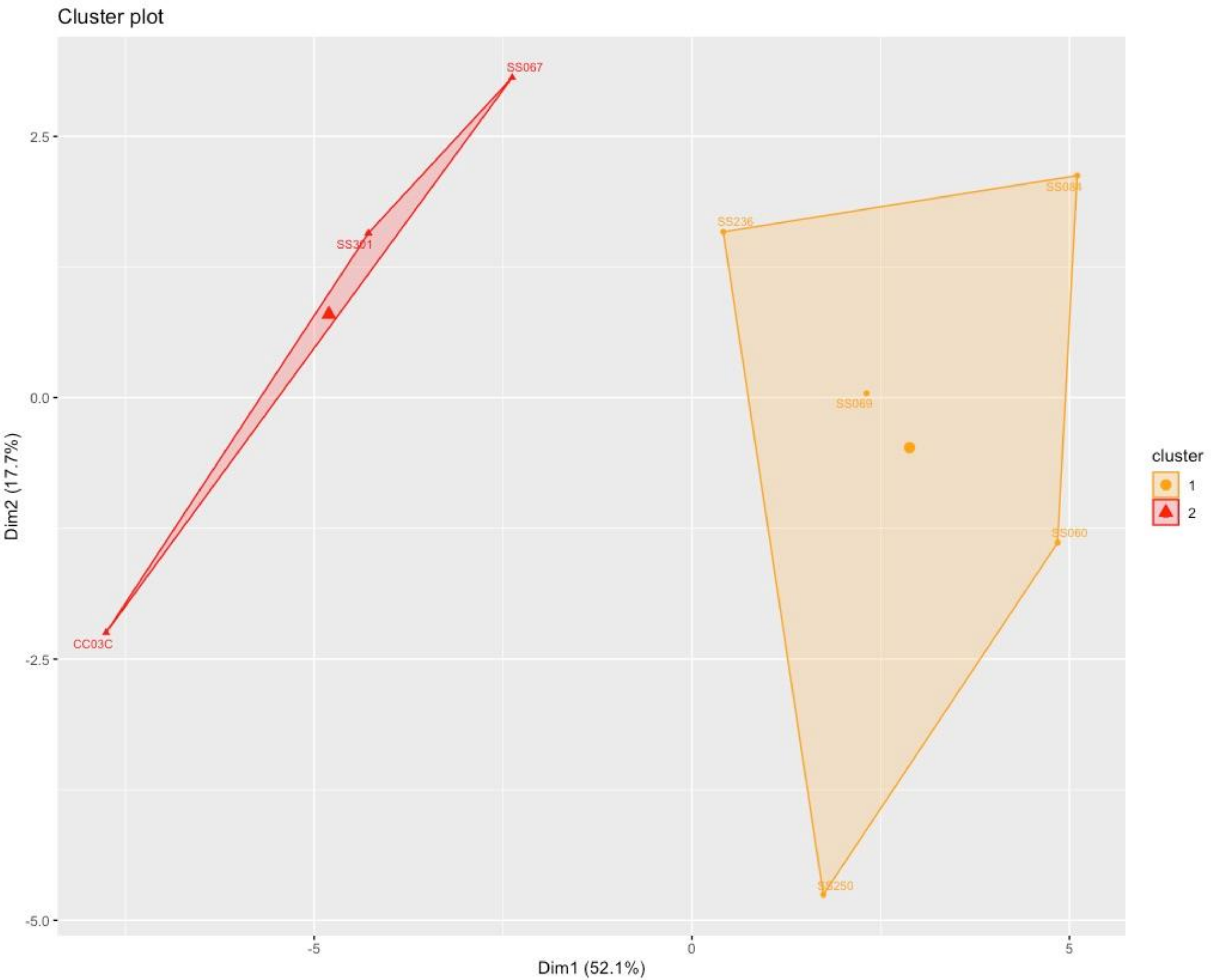

Photo 21: SS421 - 09/23/2020

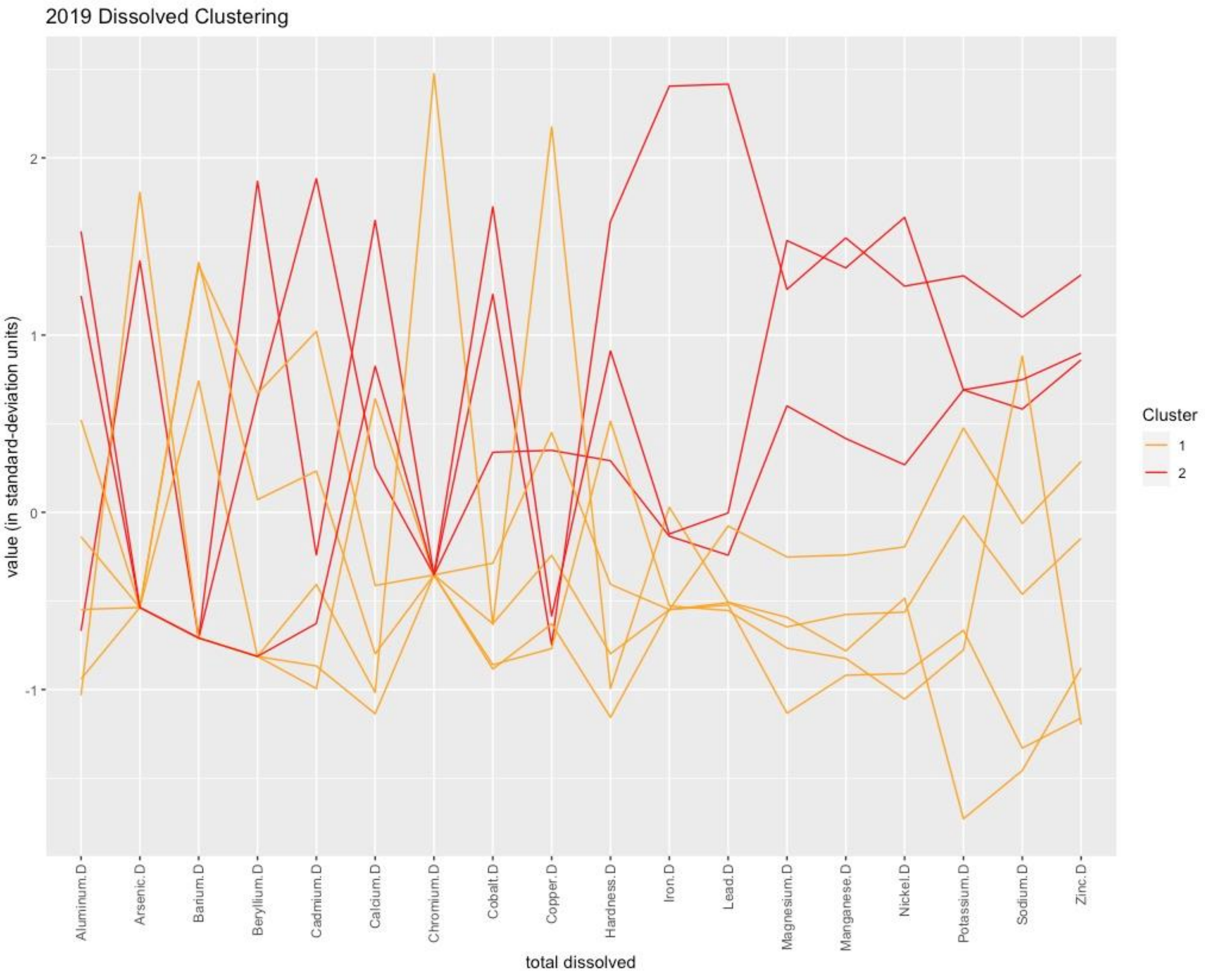
Photo 22: SS422 - 10/20/2020

Photo 23: SS423 - 10/20/2020

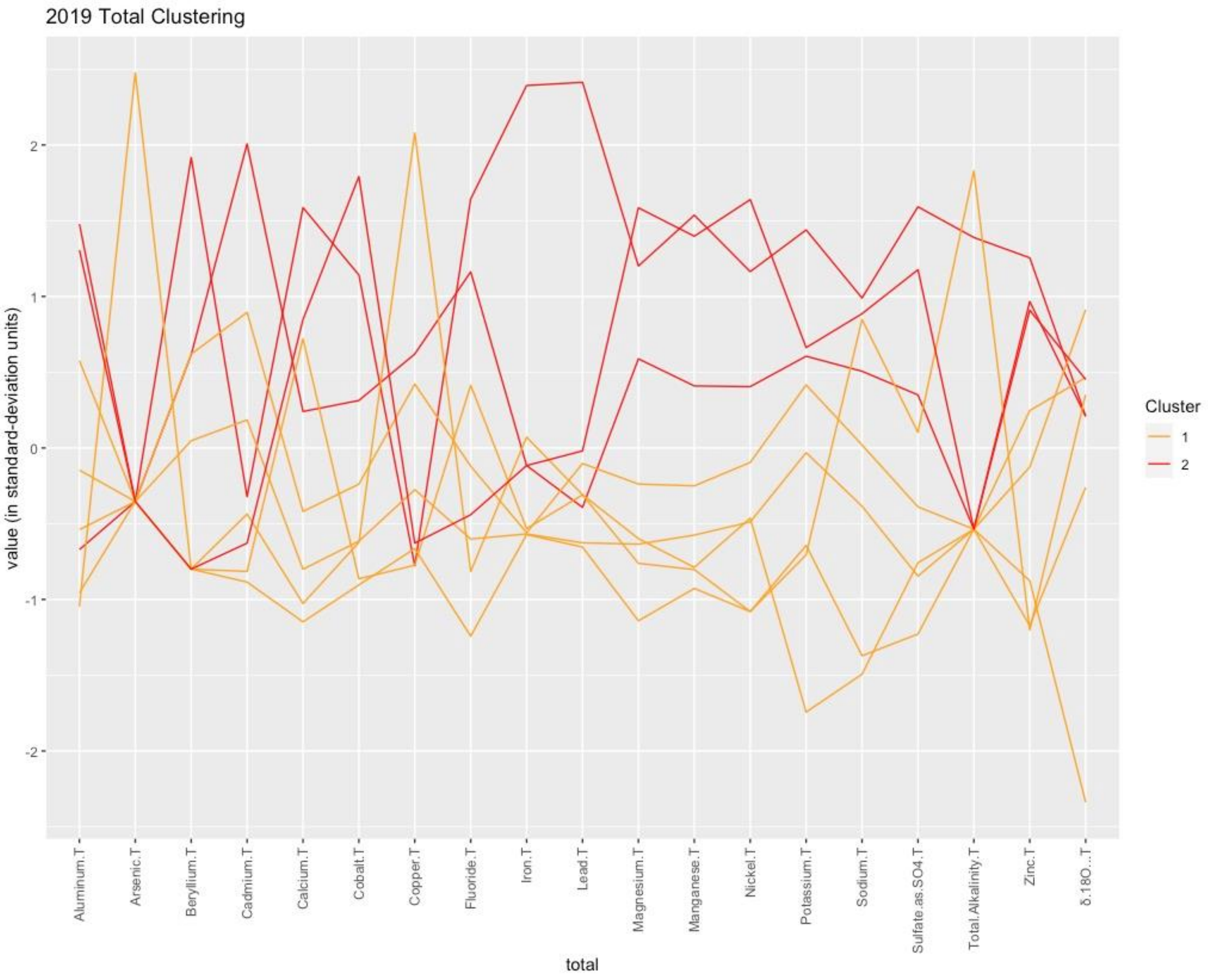
Photo 24: SS425 - 10/20/2020

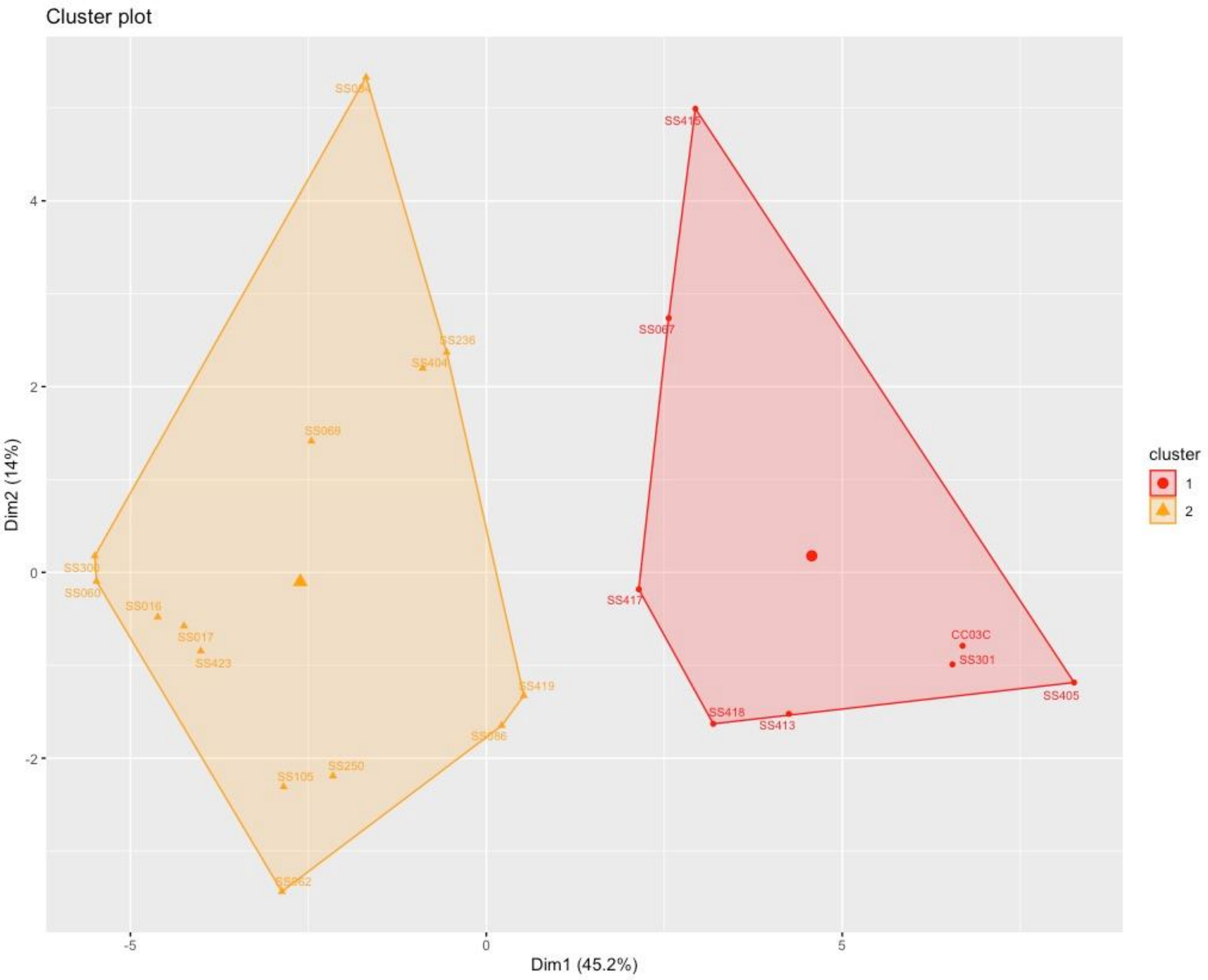
D. Statistical Analysis Plots: Cluster Analysis


Cluster plot
SS067
SS301
CC03C
SS236
SS084
SS069
SS060
SS250
2.5
0.0
-2.5
-5.0
-5
0
5
Dim1 (52.1%)
Dim2 (17.7%)
cluster
1
2

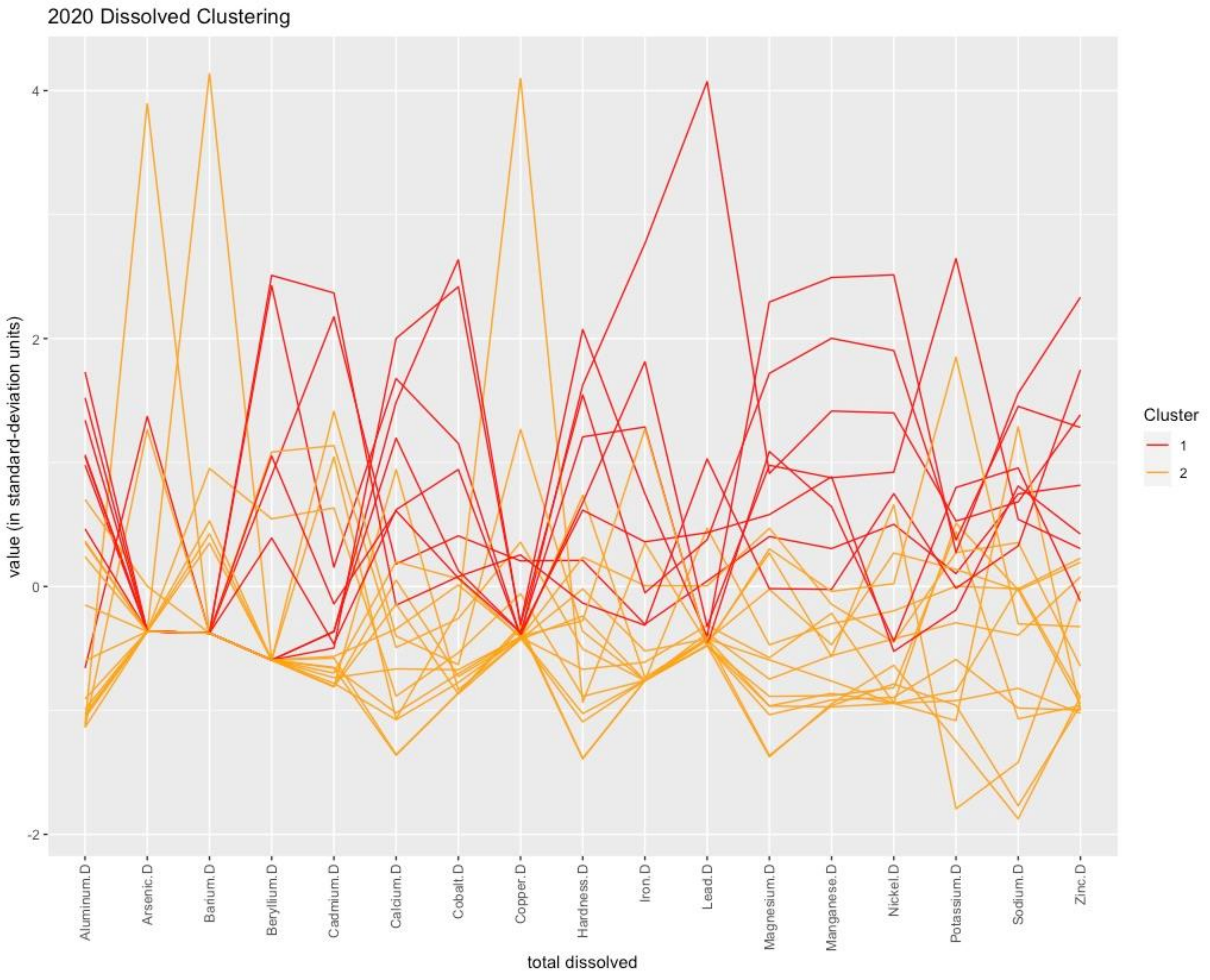


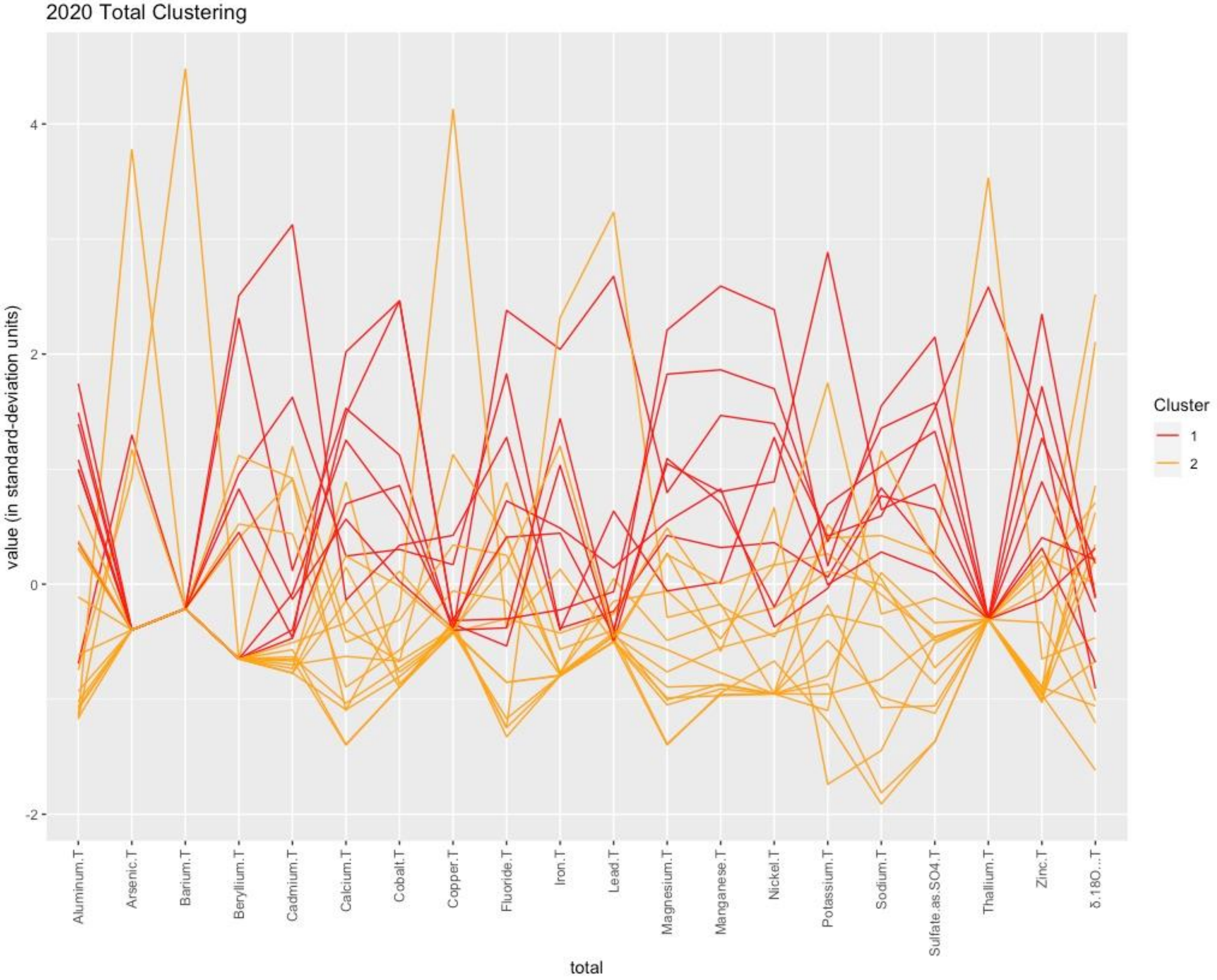
2019 Dissolved Clustering
value (in standard-deviation units)
2
1
0
-1
Aluminum.D
Arsenic.D
Barium.D
Beryllium.D
Cadmium.D
Calcium.D
Chromium.D
Cobalt.D
Copper.D
Hardness.D
Iron.D
Lead.D
Magnesium.D
Manganese.D
Nickel.D
Potassium.D
Sodium.D
Zinc.D
total dissolved
Cluster
1
2


2019 Total Clustering
value (in standard-deviation units)
2
1
0
-1
-2
Aluminum.T
Arsenic.T
Beryllium.T
Cadmium.T
Calcium.T
Cobalt.T
Copper.T
Fluoride.T
Iron.T
Lead.T
Magnesium.T
Manganese.T
Nickel.T
Potassium.T
Sodium.T
Sulfate.as.SO4.T
Total.Alkalinity.T
Zinc.T
δ.18O...T
total
Cluster
1
2



Cluster plot
SS034
SS415
SS067
SS236
SS404
SS069
SS300
SS060
SS016
SS017
SS423
SS419
SS086
SS250
SS105
SS262
SS417
CC03C
SS301
SS405
SS418
SS413
cluster
1
2
Dim2 (14%)
Dim1 (45.2%)
4
2
0
-2
-5
0
5


2020 Dissolved Clustering
value (in standard-deviation units)
4
2
0
-2
Aluminum.D
Arsenic.D
Barium.D
Beryllium.D
Cadmium.D
Calcium.D
Cobalt.D
Copper.D
Hardness.D
Iron.D
Lead.D
Magnesium.D
Manganese.D
Nickel.D
Potassium.D
Sodium.D
Zinc.D
total dissolved
Cluster
1
2


2020 Total Clustering
value (in standard-deviation units)
4
2
0
-2
Aluminum.T
Arsenic.T
Barium.T
Beryllium.T
Cadmium.T
Calcium.T
Cobalt.T
Copper.T
Fluoride.T
Iron.T
Lead.T
Magnesium.T
Manganese.T
Nickel.T
Potassium.T
Sodium.T
Sulfate.as.SO4.T
Thallium.T
Zinc.T
δ.18O...T
total
Cluster
1
2