MONTICELLO BASIN STREET SWEEPING WATER QUALITY TREND ANALYSIS

Prepared for
City of Redmond

Prepared by
Herrera Environmental Consultants, Inc.

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Prepared for
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King County

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INTRODUCTION

The City of Redmond (City) retained Herrera Environmental Consultants (Herrera) to perform analyses on water quality grab sample data that have been collected in the Monticello basin in Redmond, Washington from Water Year (WY) 2016 through WY2019 as part of the Redmond Paired Watershed Project (Herrera 2015). During this time period street sweeping in the basin increased from quarterly to monthly to biweekly. The objective of the analysis was to determine if there were any trends in water quality during this time period which might be attributed to the increased street sweeping frequency.

During the study period, water quality grab samples were collected from three sites in the basin (Figure 1). The downstream station (MONM) is located near the confluence of Monticello and Bear Creek. The two upstream sites are located on the north (MONMN) and south (MONMS) forks of the creek, respectively (Figure 1). In total, 44 storm samples and 16 base flow samples were collected from each of the three sites and analyzed for a suite of parameters. Previous studies on street sweeping have indicated that the programs are primarily effective at reducing total suspended solids, particulate metals, and potentially total phosphorus (SPU 2018). Consequently, of the 12 parameters collected for the Redmond Paired Watershed Study (RPWS) the following four parameters were included for analysis in this study:

- Total suspended solids (TSS)
- Total phosphorus (TP)
- Particulate copper
- Particulate zinc

This memorandum first presents a detailed description of the study basin followed by a discussion of the water quality trend analysis methods. Analysis results and conclusions are then provided in concluding sections.

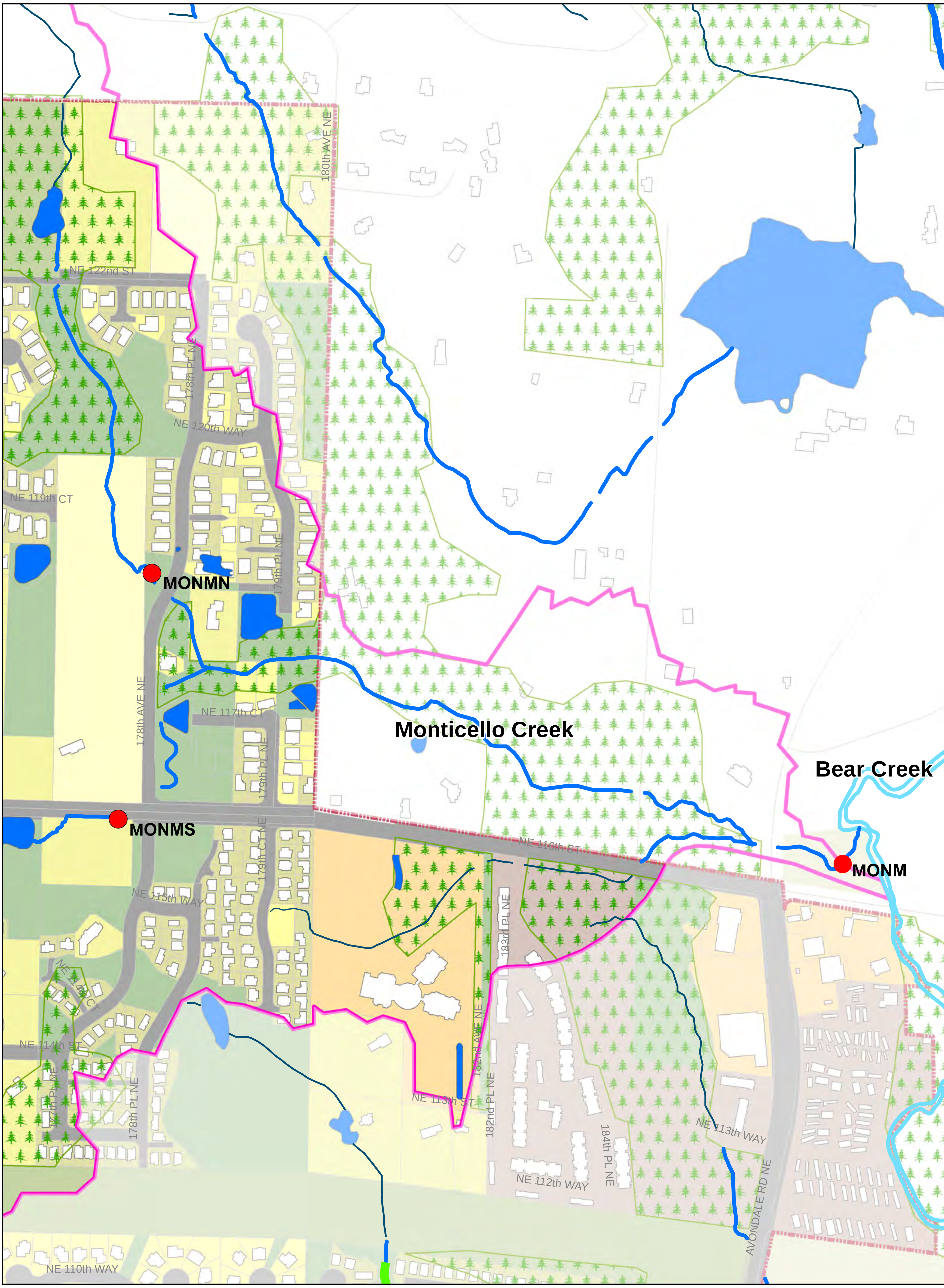


Figure 1. Monticello Creek Paired Watershed Study Monitoring Locations.

City of Redmond, Washington

6/25/2015

0 0.0375 0.075 0.15 Miles

N

City of Redmond WASHINGTON

Disclaimer: This map is created and maintained by the Natural Resources Division of the City of Redmond, Washington, for reference purposes only. The City makes no guarantee as to the accuracy or completeness of the features shown on this map.

Legend

- Class I Stream
- Class II Stream
- Class III Stream
- Class IV Stream
- Ponds
- City Limits
- Watershed Boundary
- Commercial
- Industrial
- Multifamily
- Park / Undeveloped
- Public ROW
- Single Family HighDensity
- Single Family Low Density
- Single Family Medium Density
- Single Family Rural Density
- Flow & WQ Monitoring

STUDY SITE DESCRIPTION

Monticello Creek is a right bank tributary of Bear Creek. The main stem originates in King County, north of the City boundary and flows south and east (Figure 1). A right bank tributary joins the main stem from the west within the City, and another right bank tributary enters the stream from the south in King County. The headwaters of Monticello Creek are in King County and are dominated by large residential lots and pastures. The northernmost reach within the City limits flows through Smith Woods, a 10-acre wooded parcel. The mouth of the creek is located in the Middle Bear Creek Natural Area. The total stream length is 9,878 linear feet; 6,125 linear feet are within the City, of which 3,170 linear feet are designated as a Class II stream. An average of 3.5 stormwater outfalls can be found per 1,000 feet along the creek (Herrera 2015).

The Monticello Creek watershed is 345 acres; 264 acres are within the City limits. Land use is predominantly single-family residential, parks and undeveloped land (Figure 1). There is a relatively low effective impervious surface (EIS) area within the City portion of the watershed (23 percent) (Herrera 2015). Land cover is mostly landscaping (Figure 1). The watershed is experiencing significant redevelopment, converting low density (1- to 5-acre lots) to high density residential development (less than 0.25-acre lots). Most of the development is occurring adjacent to or upstream of MONMN and MONMS.

Benthic Index of Biotic Integrity (B-IBI) scores for Monticello Creek calculated from data collected through the RPWS from five stations (MONT-1, MONT-2, MONT-3, MONT-4, and MONT-5) over the period from 2016 through 2018 range from 5.9 to 74.0. The median score (41.5) from these data indicate habitat conditions in Monticello Creek are generally "fair" (PSSB 2020).

The City has recently initiated development of the Monticello Creek Watershed Restoration Plan. This plan will provide engineering analysis to identify a comprehensive rehabilitation strategy for Monticello Creek. After its completion in 2020, the plan will identify all projects required to fully rehabilitate the creek and provide preliminary designs for the three highest ranked projects in terms of their overall benefit. It is anticipated that these projects will not be constructed and operational in the Monticello watershed until 2021 or beyond. Because the benefits of these structural stormwater controls will not be realized in the watershed for some time, the City has targeted this watershed for nonstructural stormwater controls (e.g., increased street sweeping, public outreach, business inspections, municipal best management practices, etc.) in the near-term. Specifically, the City has focused on increasing the frequency of street sweeping in the basin over the past four years from quarterly, to monthly, to now bi-weekly. This study is being implemented to quantify the water quality benefit of this increase in street sweeping frequency.

ANALYSIS METHODS

The first step in the data analysis involved the compilation of water quality data and information on development and sweeping activity in the basin. The Washington State Department of Ecology's Environmental Information Management (EIM) database was queried to obtain data for TSS, TP, total and dissolved copper, and total and dissolved zinc that were collected from the three monitoring sites described above (MONM, MONMN, and MONMS) over the period from March 18, 2016 to September 22, 2019 through the RPWS. During this time period 16 base flow samples and 44 storm event samples were collected.

Prior to conducting any analyses, dissolved metal concentrations for each sample were subtracted from total metal concentrations to derive an estimate of the particulate metal concentration. When both the total metal and dissolved metal concentrations were below reporting limits for a sample, the particulate metal concentration was reported as a zero. When a dissolved metal concentration was below the reporting limit but the total metal concentration was detected, one half the value of the reporting limit for the dissolved metal concentration was subtracted from the total metal concentration to estimate the particulate metal concentration for that sample. For all other parameters (i.e., TSS and TP) if a result was at or below the reporting limit a value of one half the reporting limit was used prior to running any statistical analyses.

After performing these computations and adjusting non-detected values, all the data were imported into the R statistical package for further analysis. The following summary statistics were computed for each combination of monitoring site, sample type (storm and base), and pollutant:

- Number of samples
- Percent censored (i.e., or non-detect)
- 25th Percentile
- Mean
- Median
- 75th Percentile
- Interquartile Range

Next, two different trend analysis methods (Helsel and Hirsch 2002) were used to determine if water quality in Monticello Creek may be changing as a result of increased sweeping in the basin.

1. **Method 1 – Kendall's Tau trend**
   In this method, pollutant concentrations were plotted versus sample collection time and a LOWESS regression was used to visually model the temporal trend. A Kendall's Tau correlation analysis was performed on these data to test for statistically significant ($\alpha = 0.1$) trends. Separate tests were performed on the pollutant concentrations from storm event samples, base flow samples, and all samples pooled.

2. **Method 2 – Kruskal-Wallis and a Bonferroni/Dunn post-hoc test**
   In this method, pollutant concentrations in samples from periods with 'quarterly sweeping', 'monthly sweeping', and bi-weekly sweeping (twice per month) were separately grouped and a Kruskal-Wallis test was applied to determine if one data population was significantly different ($\alpha = 0.1$) from another. Next a Bonferroni/Dunn post-hoc test was performed to determine if a significant a difference was present between each possible combination of groups (i.e., quarterly versus monthly, quarterly versus biweekly, and biweekly versus monthly). Separate tests were performed on the pollutant concentrations from storm event samples, base flow samples, and all samples pooled.

For trend analysis method 1, the null (Ho) and alternate (Ha) hypotheses for the associated statistical tests are as follows:

Ho: pollutant concentrations remained constant over the study period.

Ha: pollutant concentrations increased or decreased over the study period.

For trend analysis method 2, the null and alternate hypotheses for the associated statistical tests are as follows:

Ho: pollutant concentrations were equal for periods with 'quarterly sweeping', 'monthly sweeping', and 'biweekly sweeping'.

Ha: pollutant concentrations were not equal for periods with 'quarterly sweeping' and 'monthly sweeping', and 'biweekly sweeping'.

RESULTS AND DISCUSSION

This section presents the results from the analyses described above. The raw data used in the analyses for each parameter can be accessed and viewed via the following links to interactive temporal graphs:

TSS: <https://herrerainc-my.sharepoint.com/:u:/p/dahearn/ESwivfZcbMBAv48n1HmOvHYBAjdQVAJOM6JkilW9BaHl8w?e=uVtv6Z>.

TP: <https://herrerainc-my.sharepoint.com/:u:/p/dahearn/EdkqVFmCP1lDjKq9fL9zfmQBOobtAnjoz5Ah_1oTWqx7aw?e=An179f>.

Particulate Copper: <https://herrerainc-my.sharepoint.com/:u:/p/dahearn/EUjnoXmwavtliGdt510teKMB4RUO2y0m0r_jWIVZAIopjg?e=rqH1vj>.

Particulate Zinc: <https://herrerainc-my.sharepoint.com/:u:/p/dahearn/ESOKi77XD0pOizQCcFwsqnsB72zHGXFh2HmS0Ag5KAdkEw?e=nGhPKP>.

Separate sections below discuss the summary statistics that were computed from these data and summarize results from the trend analyses and hypothesis testing.

Summary Statistics

TSS concentrations in storm event samples were higher than concentrations in base flow samples at all three sites (Table 1). There were no non-detected values from samples collected during storm events, while 6.3 percent of the samples collected during base flow had TSS concentrations below the reporting limit. TSS concentrations increased in the downstream direction with samples from MONM exhibiting greater concentrations (median 11.0 mg/L) when compared with samples from MONMN (median 8.5 mg/L) and MONMS (median 4.7 mg/L) (Table 1). There was no clear pattern of decreasing TSS concentrations in samples collected after the increase in sweeping frequency relative to before (Table 1).

TP concentrations were lowest in samples from MONMS (median 0.036 mg/L) while samples from MONM and MONMN exhibited slightly higher median concentrations at 0.051 and 0.053 mg/L, respectively (Table 2). Median TP concentrations in storm event samples were slightly higher than concentrations in base flow samples; and concentrations in nearly all samples were at or above reporting limits (except for 6.3 percent of base flow events at MONM). No clear pattern developed when comparing median TP concentrations before and after the increase in sweeping frequency (Table 2).

Particulate copper concentrations in samples from MONM, MONMN, and MONMS were generally similar with median values of 0.9, 0.5, and 0.6 ug/L, respectively. Particulate copper concentrations in base flow samples were between 50.0 and 87.5 percent not detected, while between 9.1 and 11.4 percent of the concentrations in storm event samples were below the reporting limit, depending on the site. When comparing particulate copper concentrations in storm event samples before and after the change in sweeping frequency, concentrations tended to decrease; this was especially the case for MONMS which had median concentrations of 1.5 ug/L during the quarterly sweeping period and 0.4 ug/L during the biweekly sweeping period (Table 3).

There were no undetected particulate zinc concentration observed at MONM, but 28.3 and 48.3 percent of the samples collected from MONMN and MONMS, respectively were undetected. (Table 4). Concentrations in storm event samples were generally higher than concentrations in base flow samples. When comparing the particulate zinc data in events sampled before and after the change in sweeping frequency, there was not clear trend in median concentrations (Table 4).

It should be noted that particulate metals concentrations for copper and zinc were relatively low, with many values either below the reporting limit or within 5 times the reporting limit. When concentrations are near the reporting limit, laboratory precision is decreased; this caveat should be considered when interpreting the analyses presented in subsequent sections.

Table 1. Total Suspened Solids Summary Statistics								
All Data (2016-03-18 through 2019-09-22)								
Site	**Event type**	**Number of samples**	**Percent censored**	**25th percentile**	**Mean**	**Median**	**75th percentile**	**Inter-quartile range**
MONM	All Events	60	1.7%	3.8	19.0	11.0	25.0	21.2
MONMN	All Events	60	1.7%	4.1	19.6	8.5	25.0	21.0
MONMS	All Events	60	1.7%	2.6	6.2	4.7	8.1	5.5
MONM	Base Events	16	6.3%	1.6	3.7	2.0	3.9	2.3
MONMN	Base Events	16	6.3%	2.0	6.2	2.2	4.9	2.9
MONMS	Base Events	16	6.3%	1.4	3.4	2.1	3.9	2.5
MONM	Storm events	44	0.0%	10.0	24.5	17.5	33.0	23.0
MONMN	Storm events	44	0.0%	6.8	24.4	14.5	25.0	18.3
MONMS	Storm events	44	0.0%	3.8	7.2	5.4	9.2	5.4
Quarterly Sweeping (2016-03-18 through 2017-12-19)								
MONM	All Events	26	3.8%	3.8	16.1	10.5	21.3	17.5
MONMN	All Events	26	3.8%	3.3	15.3	8.0	19.8	16.5
MONMS	All Events	26	3.8%	1.9	6.4	5.0	8.7	6.9
MONM	Base Events	8	12.5%	1.4	3.0	2.3	3.9	2.5
MONMN	Base Events	8	12.5%	1.9	3.5	2.3	4.1	2.2
MONMS	Base Events	8	12.5%	1.4	2.3	1.4	1.9	0.5
MONM	Storm events	18	0.0%	10.3	21.9	17.0	33.3	23.0
MONMN	Storm events	18	0.0%	7.7	20.6	12.5	24.3	16.6
MONMS	Storm events	18	0.0%	4.6	8.2	7.0	9.8	5.2
Monthly Sweeping (2018-01-11 through 2018-08-08)								
MONM	All Events	16	0.0%	8.1	18.1	12.0	27.0	19.0
MONMN	All Events	16	0.0%	4.5	18.8	6.9	25.3	20.8
MONMS	All Events	16	0.0%	2.4	7.3	5.1	11.3	8.9
MONM	Base Events	4	0.0%	2.2	7.0	6.7	11.5	9.3
MONMN	Base Events	4	0.0%	1.8	8.3	3.1	9.7	7.9
MONMS	Base Events	4	0.0%	2.2	2.2	2.2	2.3	0.1
MONM	Storm events	12	0.0%	9.8	21.9	20.0	33.0	23.2
MONMN	Storm events	12	0.0%	6.2	22.2	12.0	29.5	23.3
MONMS	Storm events	12	0.0%	4.9	9.0	6.0	12.3	7.4
Biweekly Sweeping (2018-10-16 through 2019-09-22)								
MONM	All Events	18	0.0%	4.0	23.9	11.0	24.3	20.3
MONMN	All Events	18	0.0%	4.8	26.4	14.5	28.3	23.5
MONMS	All Events	18	0.0%	2.7	4.8	4.4	6.4	3.7
MONM	Base Events	4	0.0%	1.6	1.7	1.6	1.8	0.2
MONMN	Base Events	4	0.0%	2.1	9.6	2.2	9.7	7.6
MONMS	Base Events	4	0.0%	5.5	6.8	8.0	9.3	3.8
MONM	Storm events	14	0.0%	9.2	30.2	16.0	27.3	18.1
MONMN	Storm events	14	0.0%	9.2	31.2	18.0	28.3	19.1
MONMS	Storm events	14	0.0%	2.7	4.2	4.0	5.3	2.6

Note that statistics are calculated using one half the reporting limit for censored data

Units: mg/L

Table 2. Total Phosphorus Summary Statistics								
All Data (2016-03-18 through 2019-09-22)								
Site	**Event type**	**Number of samples**	**Percent censored**	**25th percentile**	**Mean**	**Median**	**75th percentile**	**Inter-quartile range**
MONM	All Events	60	1.7%	0.040	0.064	0.051	0.073	0.033
MONMN	All Events	60	0.0%	0.031	0.076	0.053	0.077	0.046
MONMS	All Events	60	0.0%	0.027	0.041	0.036	0.051	0.024
MONM	Base Events	16	6.3%	0.025	0.037	0.036	0.045	0.020
MONMN	Base Events	16	0.0%	0.022	0.053	0.035	0.070	0.048
MONMS	Base Events	16	0.0%	0.021	0.031	0.027	0.031	0.010
MONM	Storm events	44	0.0%	0.044	0.074	0.060	0.086	0.043
MONMN	Storm events	44	0.0%	0.037	0.085	0.059	0.082	0.045
MONMS	Storm events	44	0.0%	0.032	0.044	0.040	0.058	0.026
Quarterly Sweeping (2016-03-18 through 2017-12-19)								
MONM	All Events	26	0.0%	0.037	0.059	0.049	0.072	0.036
MONMN	All Events	26	0.0%	0.027	0.067	0.053	0.076	0.049
MONMS	All Events	26	0.0%	0.026	0.041	0.035	0.060	0.033
MONM	Base Events	8	0.0%	0.023	0.034	0.027	0.051	0.028
MONMN	Base Events	8	0.0%	0.019	0.042	0.025	0.064	0.045
MONMS	Base Events	8	0.0%	0.019	0.024	0.022	0.028	0.009
MONM	Storm events	18	0.0%	0.044	0.070	0.058	0.083	0.039
MONMN	Storm events	18	0.0%	0.046	0.078	0.060	0.085	0.039
MONMS	Storm events	18	0.0%	0.033	0.049	0.046	0.061	0.028
Monthly Sweeping (2018-01-11 through 2018-08-08)								
MONM	All Events	16	6.3%	0.035	0.049	0.043	0.054	0.020
MONMN	All Events	16	0.0%	0.026	0.061	0.039	0.069	0.043
MONMS	All Events	16	0.0%	0.026	0.033	0.030	0.038	0.012
MONM	Base Events	4	25.0%	0.033	0.045	0.043	0.054	0.022
MONMN	Base Events	4	0.0%	0.040	0.070	0.059	0.089	0.048
MONMS	Base Events	4	0.0%	0.026	0.027	0.028	0.029	0.003
MONM	Storm events	12	0.0%	0.035	0.051	0.043	0.054	0.020
MONMN	Storm events	12	0.0%	0.026	0.058	0.035	0.057	0.031
MONMS	Storm events	12	0.0%	0.026	0.034	0.032	0.043	0.017
Biweekly Sweeping (2018-10-16 through 2019-09-22)								
MONM	All Events	18	0.0%	0.047	0.084	0.066	0.084	0.037
MONMN	All Events	18	0.0%	0.049	0.103	0.072	0.085	0.036
MONMS	All Events	18	0.0%	0.035	0.047	0.041	0.055	0.020
MONM	Base Events	4	0.0%	0.029	0.035	0.036	0.041	0.012
MONMN	Base Events	4	0.0%	0.031	0.059	0.035	0.063	0.032
MONMS	Base Events	4	0.0%	0.023	0.051	0.041	0.069	0.046
MONM	Storm events	14	0.0%	0.058	0.098	0.072	0.092	0.033
MONMN	Storm events	14	0.0%	0.057	0.115	0.074	0.085	0.028
MONMS	Storm events	14	0.0%	0.037	0.046	0.041	0.054	0.017

Note that statistics are calculated using one half the reporting limit for censored data

Units: mg/L

Table 3. Particulate Copper Summary Statistics								
All Data (2016-03-18 through 2019-09-22)								
Site	Event type	Number of samples	Percent censored	25th percentile	Mean	Median	75th percentile	Inter-quartile range
MONM	All Events	60	31.7%	0.0	0.9	0.9	1.3	1.3
MONMN	All Events	60	31.7%	0.0	0.9	0.5	0.9	0.9
MONMS	All Events	60	20.0%	0.1	0.7	0.6	1.0	0.9
MONM	Base Events	16	87.5%	0.0	0.0	0.0	0.0	0.0
MONMN	Base Events	16	68.8%	0.0	0.2	0.0	0.0	0.0
MONMS	Base Events	16	50.0%	0.0	0.3	0.1	0.6	0.6
MONM	Storm events	44	11.4%	0.6	1.2	1.2	1.5	0.9
MONMN	Storm events	44	18.2%	0.2	1.1	0.8	1.0	0.9
MONMS	Storm events	44	9.1%	0.2	0.8	0.7	1.3	1.1
Quarterly Sweeping (2016-03-18 through 2017-12-19)								
MONM	All Events	26	38.5%	0.0	0.9	1.0	1.5	1.5
MONMN	All Events	26	46.2%	0.0	0.9	0.5	0.9	0.9
MONMS	All Events	26	26.9%	0.2	1.1	1.1	1.6	1.5
MONM	Base Events	8	87.5%	0.0	0.1	0.0	0.0	0.0
MONMN	Base Events	8	75.0%	0.0	0.1	0.0	0.1	0.1
MONMS	Base Events	8	62.5%	0.0	0.3	0.0	0.7	0.7
MONM	Storm events	18	16.7%	0.9	1.2	1.3	1.6	0.7
MONMN	Storm events	18	33.3%	0.0	1.3	0.8	1.1	1.1
MONMS	Storm events	18	11.1%	1.1	1.4	1.5	1.9	0.9
Monthly Sweeping (2018-01-11 through 2018-08-08)								
MONM	All Events	16	31.3%	0.0	0.8	1.0	1.3	1.3
MONMN	All Events	16	31.3%	0.0	0.6	0.3	0.8	0.8
MONMS	All Events	16	25.0%	0.0	0.4	0.5	0.6	0.6
MONM	Base Events	4	100.0%	0.0	0.0	0.0	0.0	0.0
MONMN	Base Events	4	100.0%	0.0	0.0	0.0	0.0	0.0
MONMS	Base Events	4	75.0%	0.0	0.2	0.0	0.2	0.2
MONM	Storm events	12	8.3%	0.8	1.1	1.1	1.4	0.5
MONMN	Storm events	12	8.3%	0.1	0.7	0.6	0.9	0.8
MONMS	Storm events	12	8.3%	0.1	0.5	0.6	0.7	0.6
Biweekly Sweeping (2018-10-16 through 2019-09-22)								
MONM	All Events	18	22.2%	0.1	1.0	0.7	1.2	1.2
MONMN	All Events	18	11.1%	0.2	1.1	0.8	1.2	1.0
MONMS	All Events	18	5.6%	0.1	0.4	0.4	0.6	0.5
MONM	Base Events	4	75.0%	0.0	0.0	0.0	0.0	0.0
MONMN	Base Events	4	25.0%	0.0	0.4	0.0	0.4	0.4
MONMS	Base Events	4	0.0%	0.4	0.5	0.5	0.5	0.1
MONM	Storm events	14	7.1%	0.6	1.3	1.1	1.3	0.7
MONMN	Storm events	14	7.1%	0.3	1.3	0.9	1.2	0.9
MONMS	Storm events	14	7.1%	0.1	0.4	0.4	0.7	0.6

Note that statistics are calculated using one half the reporting limit for censored data

Units: ug/L

Table 4. Particulate Zinc Summary Statistics								
All Data (2016-03-18 through 2019-09-22)								
Site	**Event type**	**Number of samples**	**Percent censored**	**25th percentile**	**Mean**	**Median**	**75th percentile**	**Inter-quartile range**
MONM	All Events	60	0.0%	4.2	11.0	7.8	12.6	8.4
MONMN	All Events	60	28.3%	0.0	8.3	3.5	8.0	8.0
MONMS	All Events	60	48.3%	0.0	2.4	0.5	3.9	3.9
MONM	Base Events	16	0.0%	0.7	3.4	3.3	4.9	4.3
MONMN	Base Events	16	68.8%	0.0	2.5	0.0	2.9	2.9
MONMS	Base Events	16	75.0%	0.0	0.5	0.0	0.0	0.0
MONM	Storm events	44	0.0%	6.3	13.8	9.4	15.5	9.2
MONMN	Storm events	44	13.6%	2.8	10.3	5.2	9.8	7.0
MONMS	Storm events	44	38.6%	0.0	3.1	3.3	4.5	4.5
Quarterly Sweeping (2016-03-18 through 2017-12-19)								
MONM	All Events	26	0.0%	4.1	11.1	7.5	14.9	10.8
MONMN	All Events	26	38.5%	0.0	7.8	3.2	7.4	7.4
MONMS	All Events	26	38.5%	0.0	3.3	3.4	4.6	4.6
MONM	Base Events	8	0.0%	0.6	3.6	3.8	5.7	5.1
MONMN	Base Events	8	87.5%	0.0	0.4	0.0	0.0	0.0
MONMS	Base Events	8	75.0%	0.0	0.5	0.0	0.0	0.0
MONM	Storm events	18	0.0%	6.0	14.4	9.6	17.5	11.5
MONMN	Storm events	18	16.7%	2.8	11.0	5.7	7.5	4.7
MONMS	Storm events	18	22.2%	3.1	4.6	4.3	6.8	3.7
Monthly Sweeping (2018-01-11 through 2018-08-08)								
MONM	All Events	16	0.0%	3.0	7.9	7.6	9.8	6.8
MONMN	All Events	16	25.0%	0.0	5.0	2.9	6.1	6.1
MONMS	All Events	16	68.8%	0.0	1.2	0.0	3.3	3.3
MONM	Base Events	4	0.0%	1.3	3.6	2.5	4.9	3.6
MONMN	Base Events	4	50.0%	0.0	3.7	1.7	5.4	5.4
MONMS	Base Events	4	100.0%	0.0	0.0	0.0	0.0	0.0
MONM	Storm events	12	0.0%	6.3	9.3	7.9	11.0	4.8
MONMN	Storm events	12	16.7%	1.1	5.5	2.9	6.1	4.9
MONMS	Storm events	12	58.3%	0.0	1.6	0.0	3.4	3.4
Biweekly Sweeping (2018-10-16 through 2019-09-22)								
MONM	All Events	18	0.0%	5.1	13.6	8.5	13.0	7.9
MONMN	All Events	18	16.7%	3.0	11.8	6.0	12.4	9.4
MONMS	All Events	18	44.4%	0.0	2.2	1.0	3.4	3.4
MONM	Base Events	4	0.0%	1.7	2.7	2.8	3.7	2.0
MONMN	Base Events	4	50.0%	0.0	5.6	1.4	7.0	7.0
MONMS	Base Events	4	50.0%	0.0	1.1	0.5	1.6	1.6
MONM	Storm events	14	0.0%	7.1	16.7	10.3	13.4	6.3
MONMN	Storm events	14	7.1%	4.3	13.6	7.0	12.4	8.2
MONMS	Storm events	14	42.9%	0.0	2.5	1.0	3.7	3.7

Note that statistics are calculated using one half the reporting limit for censored data

Units: ug/L

Kendall's Tau Trend Analysis Results

Kendall's Tau correlation analyses performed on pollutant concentrations and sample collection times detected statistically significant ($\alpha = 0.1$) negative trends for particulate copper concentrations measured in storm event samples from MONMS (Figure 2), particulate copper concentrations measured in all event samples from MONMS (Figure 3), and TSS concentrations measured in storm event samples from MONMS (Figure 4). Figures presenting results for the parameters and flow conditions which did not exhibit statistically significant Kendall's Tau trends can be found in Appendix A.

The consistency of the decreasing trends at MONMS may indicate that this site is more sensitive to street sweeping activities in the basin. There were no statistically significant trends detected for any of the pollutants measured in base flow samples. Statistically significant trends were also not detected for particulate zinc or TP measured under any flow conditions (Table 5). Graphical representations of the trends and associated statistical results for all parameters are presented in Appendix A and summarized in Table 5 for all tested relationships.

Kruskal-Wallis Hypothesis Test Results

Results from the Kruskal-Wallis tests were similar to those from the proceeding subsection. Specifically, MONMS particulate copper concentrations measured in all events (Figure 2) and storm events (Figure 3), and MONMS TSS concentrations measured in storm events (Figure 4) were lower during the periods of increased sweeping frequency. This test indicated that increasing sweeping from quarterly to monthly resulted in reduced particulate copper concentrations at MONMS, but further increasing sweeping from monthly to biweekly did not further improve reductions (Figures 2 and 3). A slightly different pattern developed at MONMS for storm event TSS. Figure 4 shows that TSS concentrations did not significantly decrease until sweeping increased to biweekly. Note that in Figures 2 through 4, letters positioned above each boxplot indicate which datasets are significantly different from the others. If two or more boxplots share a letter they are not statistically significantly different ($\alpha = 0.1$).

Unlike with the Kendall's Tau test which is designed to detect a trend across the entire dataset, the Kruskal-Wallis test required separating the data into three groups (quarterly, monthly, and biweekly sweeping periods) and comparing the data across each of these groups. This means that, for example, if concentrations of TSS went down by a statistically significant amount during monthly sweeping, but then back up during biweekly sweeping, that a significant difference would still be detected among the three groups. This even though there would not be an overall significant downward trend across the whole dataset. This "down and back up" trend was common for TP in this dataset (Table 5, Appendix A), and was also observed for particulate zinc storm events at MONMS (Table 5, Appendix A). Additional years of data may be necessary to see if an overall trend develops for these parameters.

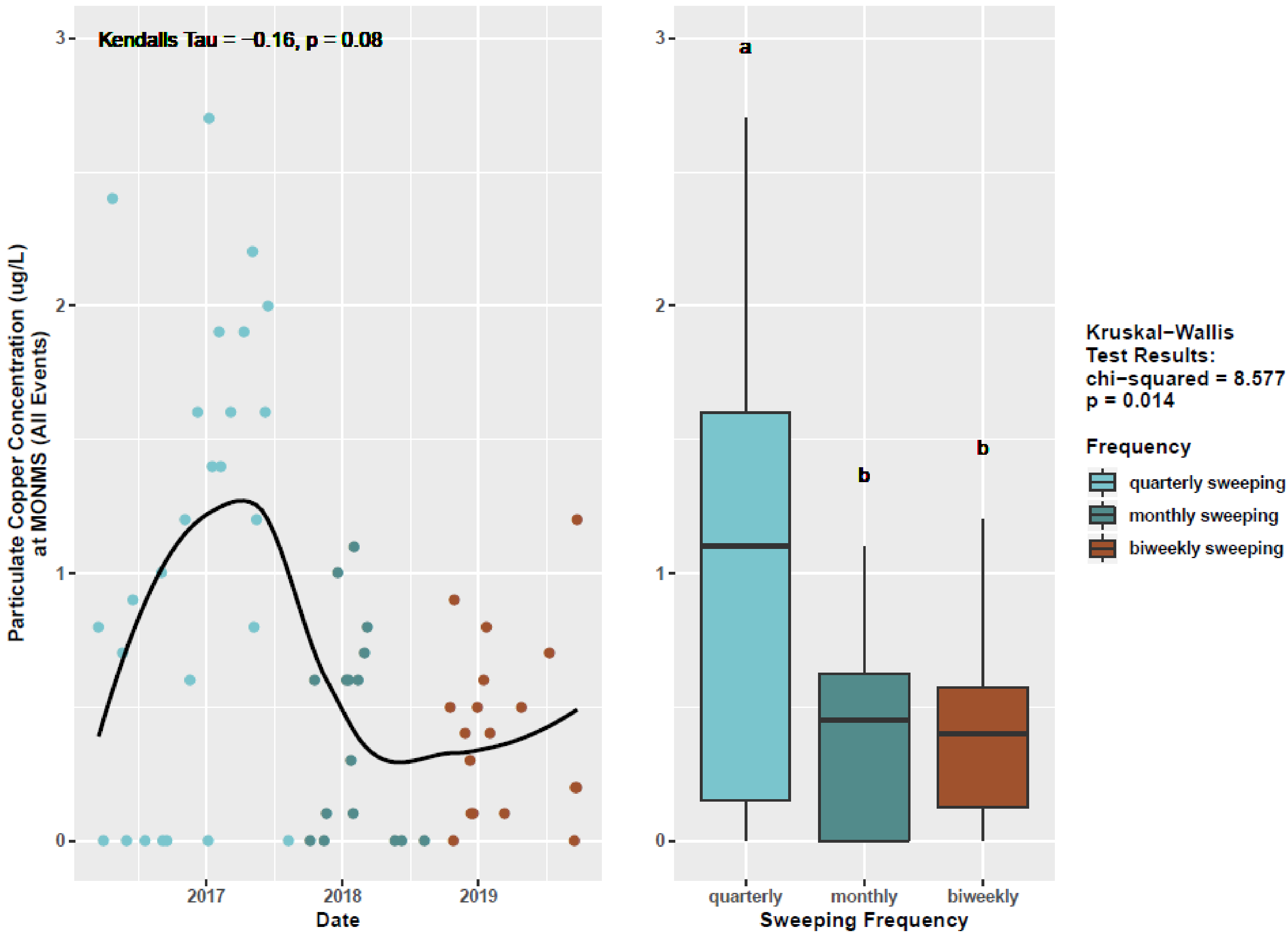


Figure 2. MONMS All Event Particulate Copper Trend and Hypothesis Test Results.

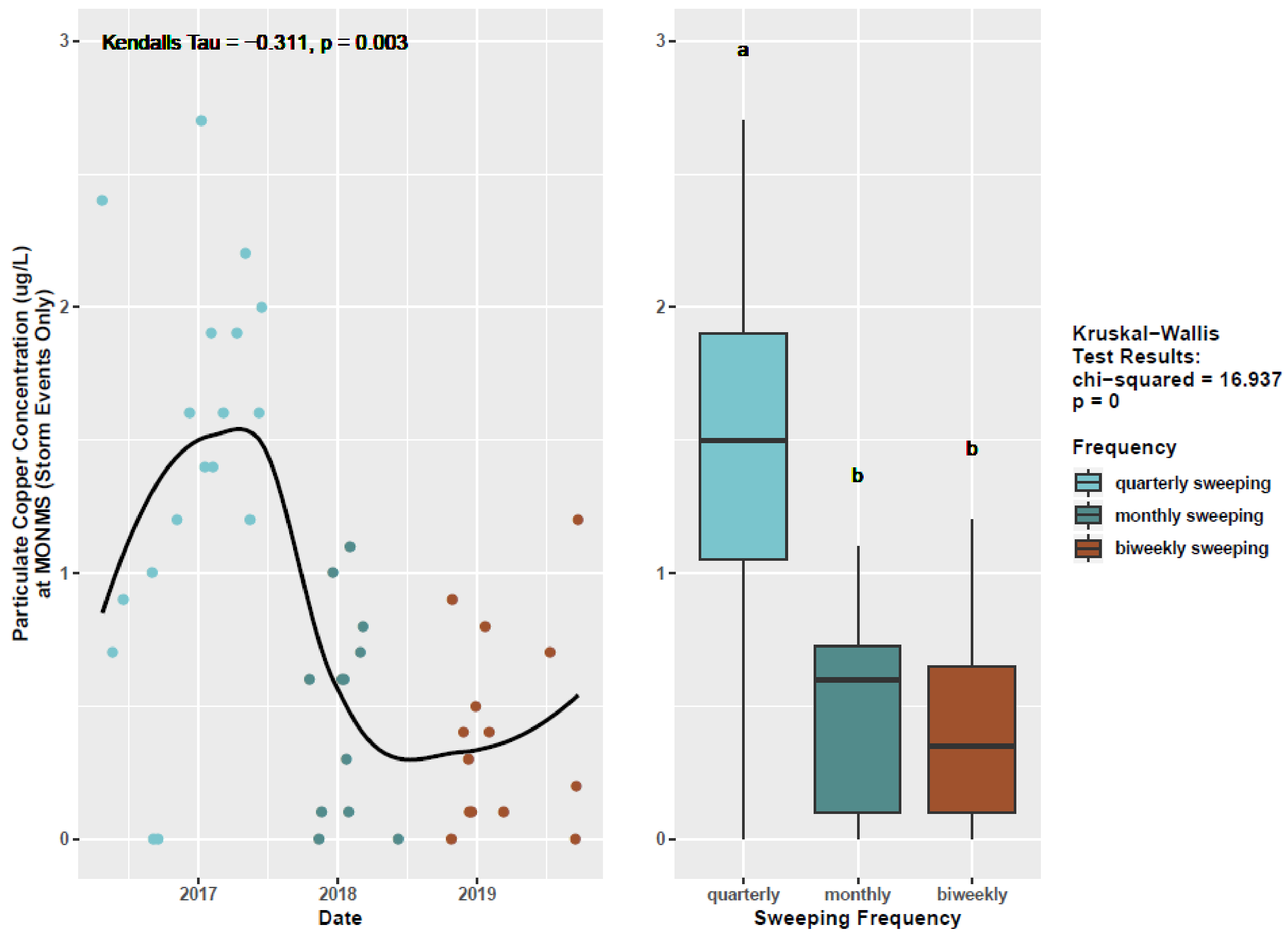


Figure 3. MONMS Storm Event Particulate Copper Trend and Hypothesis Test Results.

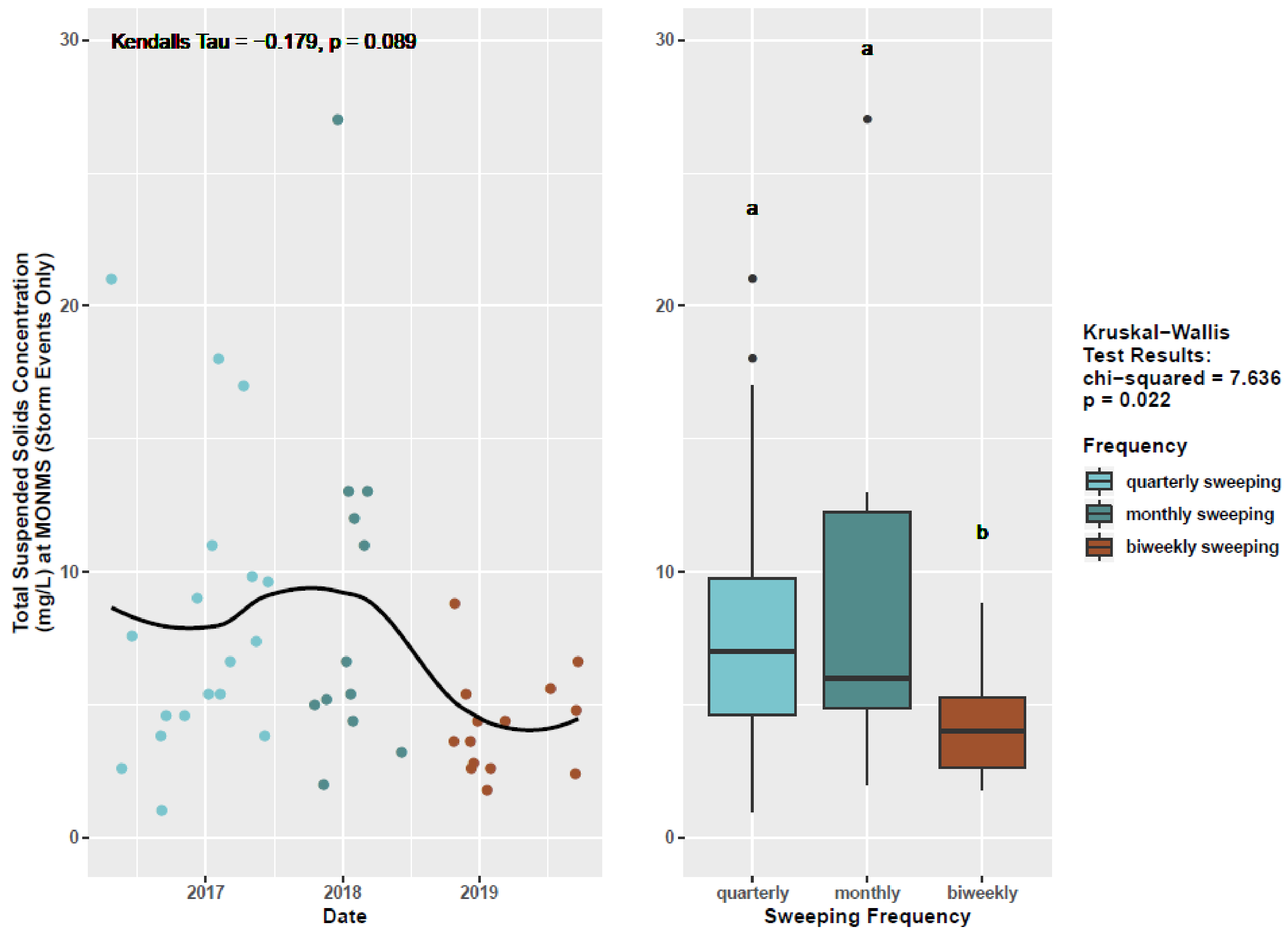


Figure 4. MONMS Storm Event Total Suspended Solids Trend and Hypothesis Test Results.

Table 5. Results of the Kendall's Tau Trend Test on All Data and the Kruskal-Wallis Test for Data Collected under each of the Three Sweeping Conditions.

Parameter	Site	Event type	Significance of Kendall's Tau Trend Test (α = 0.1)	Significance of Kruskal-Wallis Test (α = 0.1)
Particulate Copper	MONM	All Events	not significant	not significant
Particulate Copper	MONM	Storm Events	not significant	not significant
Particulate Copper	MONM	Base Events	not significant	not significant
Particulate Copper	MONMN	All Events	not significant	not significant
Particulate Copper	MONMN	Storm Events	not significant	not significant
Particulate Copper	MONMN	Base Events	not significant	not significant
Particulate Copper	MONMS	All Events	**significant**	**significant**
Particulate Copper	MONMS	Storm Events	**significant**	**significant**
Particulate Copper	MONMS	Base Events	not significant	not significant
Particulate Zinc	MONM	All Events	not significant	not significant
Particulate Zinc	MONM	Storm Events	not significant	not significant
Particulate Zinc	MONM	Base Events	not significant	not significant
Particulate Zinc	MONMN	All Events	not significant	not significant
Particulate Zinc	MONMN	Storm Events	not significant	not significant
Particulate Zinc	MONMN	Base Events	not significant	not significant
Particulate Zinc	MONMS	All Events	not significant	not significant
Particulate Zinc	MONMS	Storm Events	not significant	**significant**
Particulate Zinc	MONMS	Base Events	not significant	not significant
Total Phosphorus	MONM	All Events	not significant	**significant**
Total Phosphorus	MONM	Storm Events	not significant	**significant**
Total Phosphorus	MONM	Base Events	not significant	not significant
Total Phosphorus	MONMN	All Events	not significant	not significant
Total Phosphorus	MONMN	Storm Events	not significant	**significant**
Total Phosphorus	MONMN	Base Events	not significant	not significant
Total Phosphorus	MONMS	All Events	not significant	**significant**
Total Phosphorus	MONMS	Storm Events	not significant	**significant**
Total Phosphorus	MONMS	Base Events	not significant	not significant
Total Suspended Solids	MONM	All Events	not significant	not significant
Total Suspended Solids	MONM	Storm Events	not significant	not significant
Total Suspended Solids	MONM	Base Events	not significant	not significant
Total Suspended Solids	MONMN	All Events	not significant	not significant
Total Suspended Solids	MONMN	Storm Events	not significant	not significant
Total Suspended Solids	MONMN	Base Events	not significant	not significant
Total Suspended Solids	MONMS	All Events	not significant	not significant
Total Suspended Solids	MONMS	Storm Events	**significant**	**significant**
Total Suspended Solids	MONMS	Base Events	not significant	not significant

Shaded/bold cells indicate a significant difference.

INTERPRETATION AND CONCLUSIONS

This study was conducted to detect potential water quality improvements in Monticello Creek that could be attributed to changes in the City's street sweeping program that were implemented in the basin over the period from WY2016 to WY2019. There are many factors that can influence water quality results that are obtained from grab samples collected in an urbanized watershed including the timing of sample collection during the event (Bertrand-Krajewski et al. 1998), when the event occurs during the year (Lee et al. 2002), the land use and land cover in the basin (Hatt et al. 2004), and the existence of structural and non-structural best management practices (BMPs) (Selbig et al. 2008).

With so many confounding variables, it can be difficult to detect a trend of interest while also confirming its independence from other potential influences. For this reason, investigations of water quality improvement efforts often use a paired basin study design that involves the collection of data in a manner that limits the influence of potential confounding variables. For example, to examine the potential benefits of street sweeping, sampling would occur simultaneously in two basins, one where street sweeping is increased and one where no street sweeping is occurring; all other factors would be held constant to the extent possible. This is the approach employed by the City of Seattle in their 2018 street sweeping study along Martin Luther King Ave in Seattle, Washington (SPU 2018). That study found a significant relationship between sweeping and decreased pollutant concentrations in stormwater for two parameters: particulate copper and coarse sediment above 250 microns. Unlike the study discussed herein that examines potential water quality improvements in the receiving water from street sweeping, the SPU study was examining potential water quality improvements in the catch basin directly adjacent to the road being swept; hence, there were likely fewer confounding variables to contend with in the SPU study. Though these studies had very different designs they both came to a similar conclusion, and that is street sweeping appears to have an effect on particulate copper and TSS is stormwater.

Another confounding variable of this study was the fact that street sweeping was not the only action in the basin which may have been impacting water quality in the creek. The Monticello Creek basin has been rapidly developing; during the study 5.64 acres of impervious surface was added to the basin. The figures in Appendix B present concentrations of the four pollutants evaluated in this study against the estimated times that the additional impervious was added to the basin. The addition of impervious surfaces could, in theory, have the opposite effect on water quality that increased sweeping may have, resulting in a masking off any potential trends.

The low particulate metal concentrations (all within 5 times the reporting limit) that were observed in samples collected for this study are an additional confounding factor. Because there is more uncertainty in results that are obtained this close to the reporting limit, the particulate metal trends reported herein should be considered in this context.

Overall the clearest trend was observed in the particulate copper and TSS concentrations from MONMS samples collected during storm events. There appeared to be a significant decrease in storm event TP concentrations at all the sites after sweeping was increased from quarterly to monthly, but then the concentrations went back up during the biweekly sweeping period, so overall there was no significant TP trend. It is recommended that more data be collected over time to assure that these trends continue as high frequency sweeping in the basin continues. Furthermore, data from other creeks that are being sampled through the RPWS should be analyzed to confirm this trend is related to street sweeping in the Monticello Creek basin and is not related to some larger, unrelated factor that is occurring in multiple basins.

REFERENCES

Bertrand-Krajewski, J.L., G. Chebbo, and A. Saget. 1998. Distribution of Pollutant Mass Vs Volume in Stormwater Discharges and the First Flush Phenomenon. Water Research 32(8):2341-2356.

Hatt, B.E., T.D. Fletcher, C.J. Walsh, and S.L. Taylor. 2004. The Influence of Urban Density and Drainage Infrastructure on the Concentrations and Loads of Pollutants in Small Streams. Environmental Management 34(1):112-124.

Helsel, D.R., and R.M. Hirsch. 2002. Statistical Methods in Water Resources. Elsevier, Amsterdam.

Herrera. 2015. Redmond Paired Watershed Study: Experimental Design Summary Report. Prepared for the City of Redmond by Herrera Environmental Consultants, Inc., Seattle, Washington.

Lee, J.H., K.W. Bang, L.H. Ketchum, J.S. Choe, and M.J. Yu. 2002. First Flush Analysis of Urban Storm Runoff. Science of the Total Environment 293(1-3):163-175.

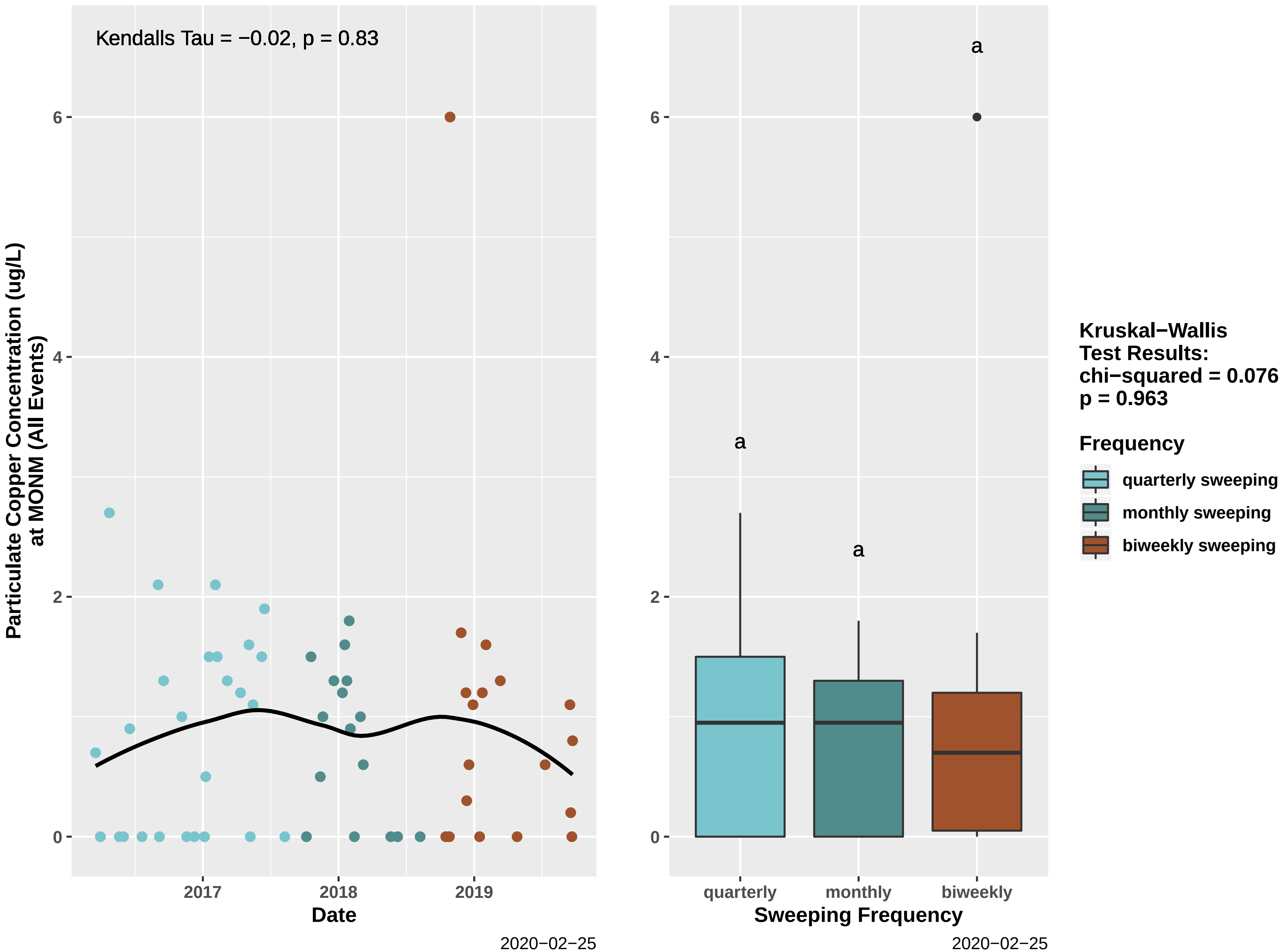
PSSB. 2020. Benthic Index of Biotic Integrity (B-IBI) scores for Washington Streams. Puget Sound Stream Benthos (PSSB). <http://pugetsoundstreambenthos.org/default.aspx>. (accessed February 18, 2020).

Selbig, W.R., R.T. Bannerman, Wisconsin. Dept. of Natural Resources., and Geological Survey (U.S.). 2008. A Comparison of Runoff Quantity and Quality from Two Small Basins Undergoing Implementation of Conventional and Low-Impact-Development (LID) Strategies : Cross Plains, Wisconsin, Water Years 1999-2005. Scientific Investigations Report 2008–5008, U. S. Geological Survey, Reston, Virginia.

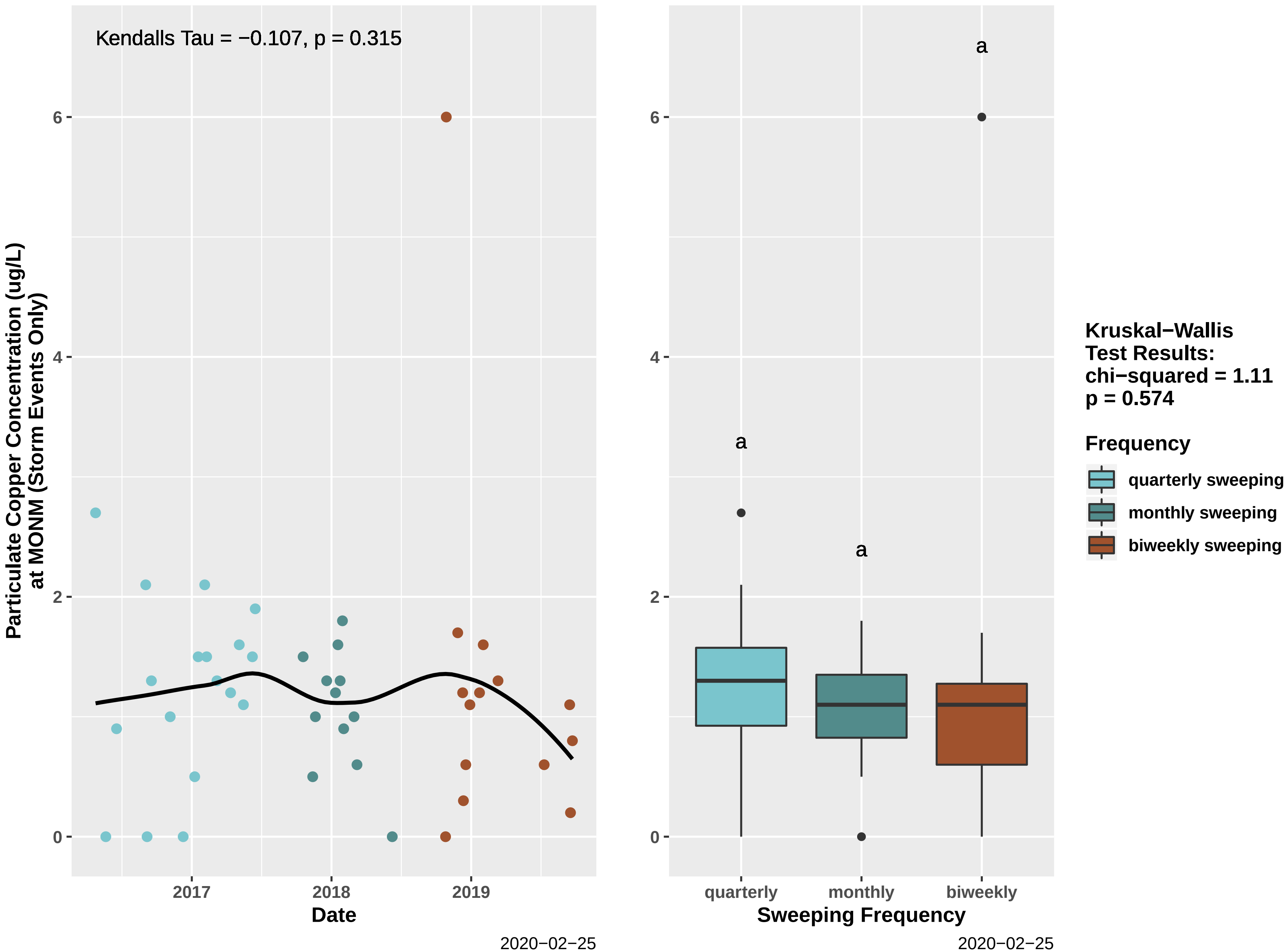
SPU. 2018. NPDES Phase I Municipal Stormwater Permit: Street Sweeping Water Quality Effectiveness Study Final Report. Seattle Public Utilities, Seattle, Washington.

APPENDIX A

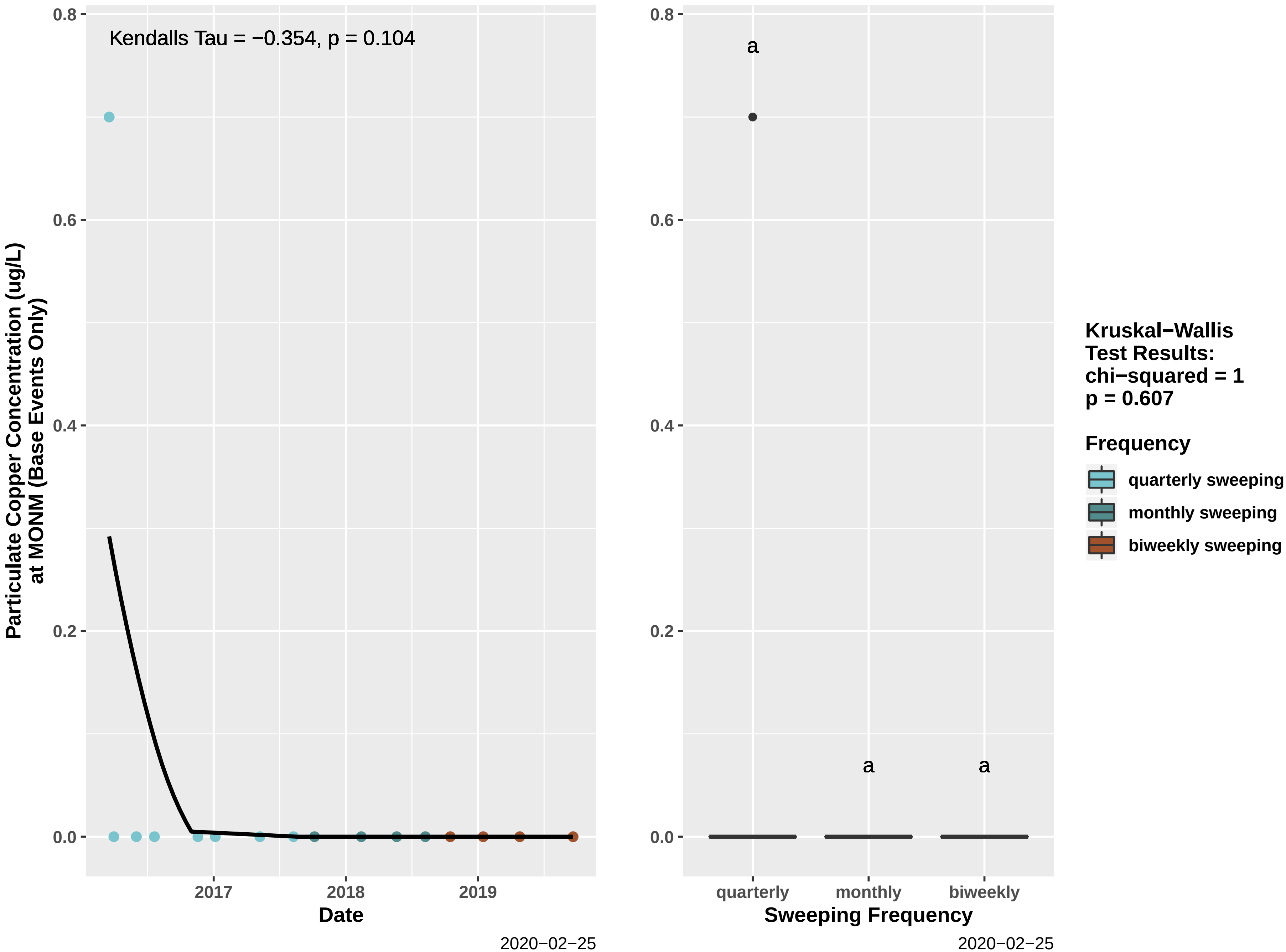
Kendall's Tau and Mann-Whitney Result Plots

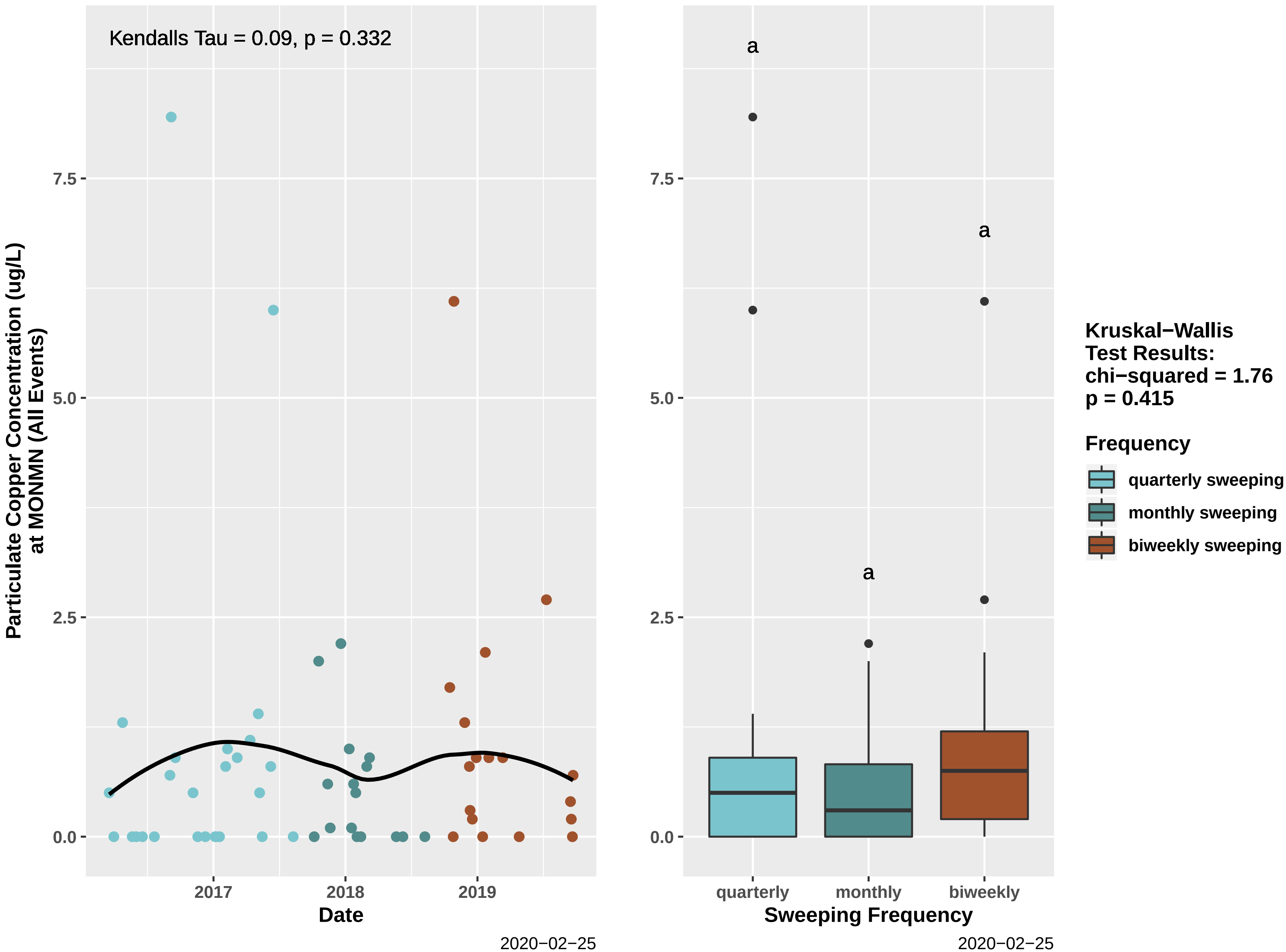


Kendalls Tau = −0.02, p = 0.83
Particulate Copper Concentration (ug/L)
at MONM (All Events)
0
2
4
6
2017
2018
2019
Date
2020−02−25
a
a
a
quarterly
monthly
biweekly
Sweeping Frequency
2020−02−25
Kruskal−Wallis
Test Results:
chi−squared = 0.076
p = 0.963
Frequency
quarterly sweeping
monthly sweeping
biweekly sweeping

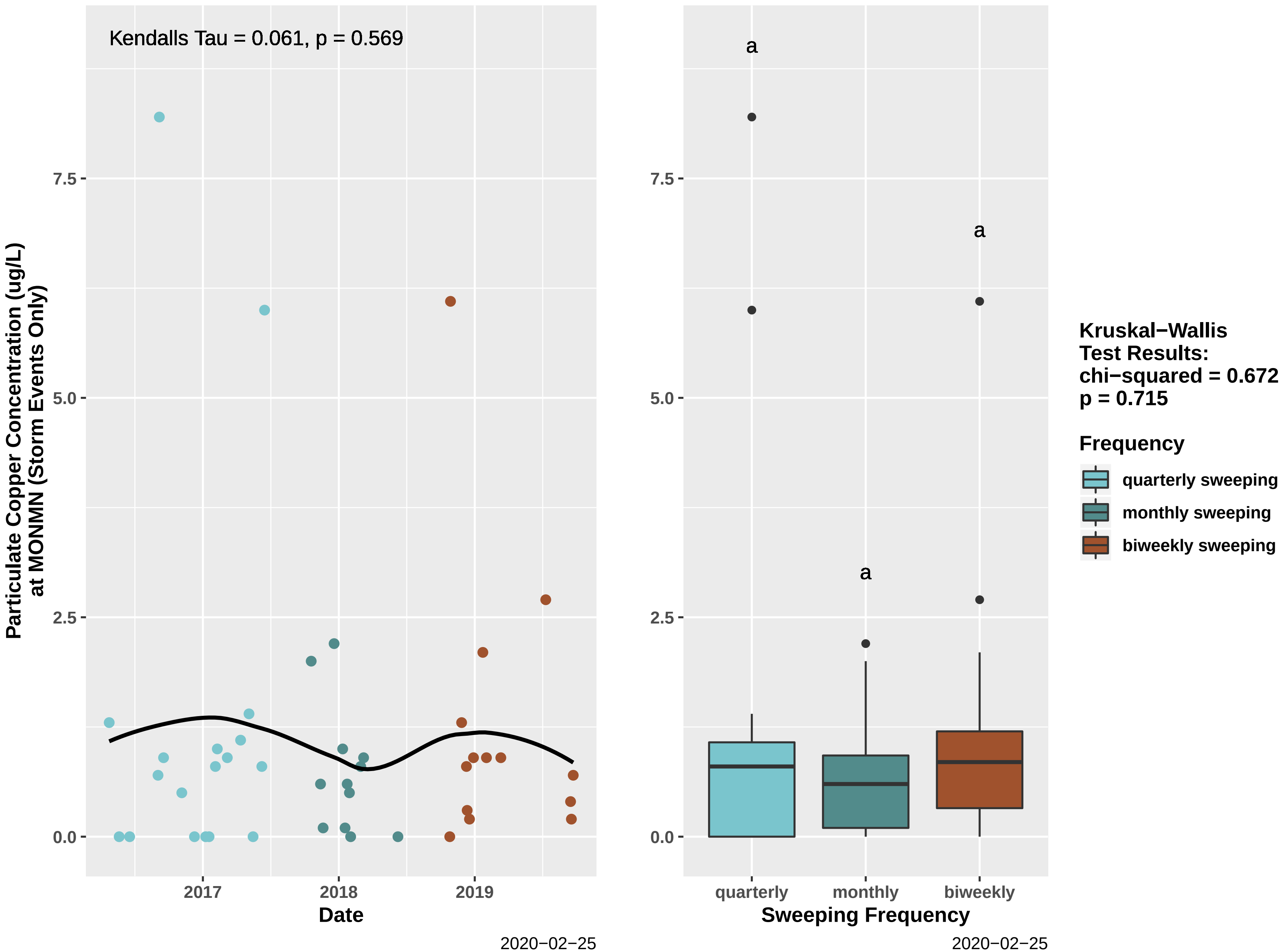


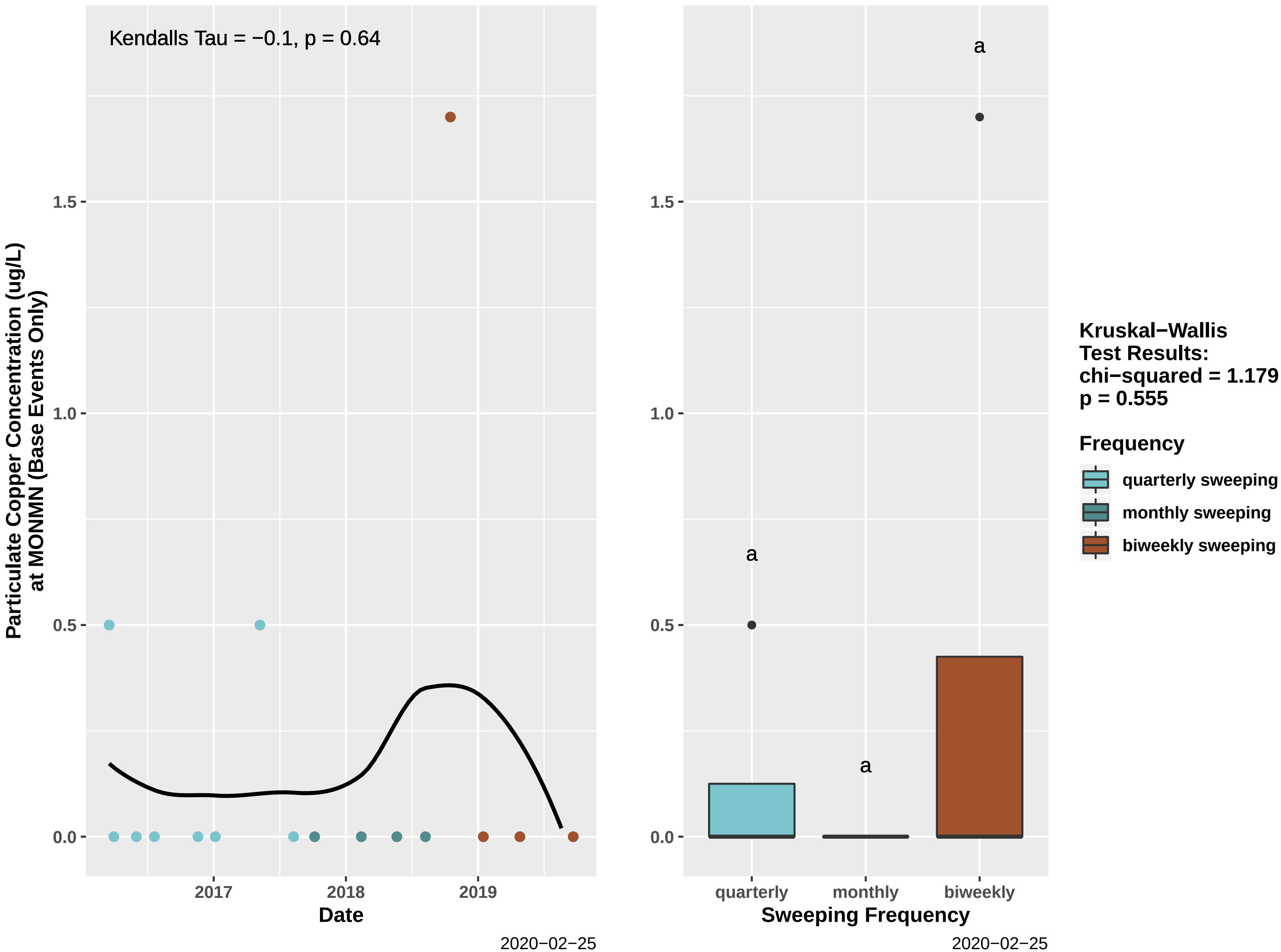
Kendalls Tau = −0.107, p = 0.315
Particulate Copper Concentration (ug/L)
at MONM (Storm Events Only)
0
2
4
6
2017
2018
2019
Date
2020−02−25
a
a
a
quarterly
monthly
biweekly
Sweeping Frequency
2020−02−25
Kruskal−Wallis
Test Results:
chi−squared = 1.11
p = 0.574
Frequency
quarterly sweeping
monthly sweeping
biweekly sweeping

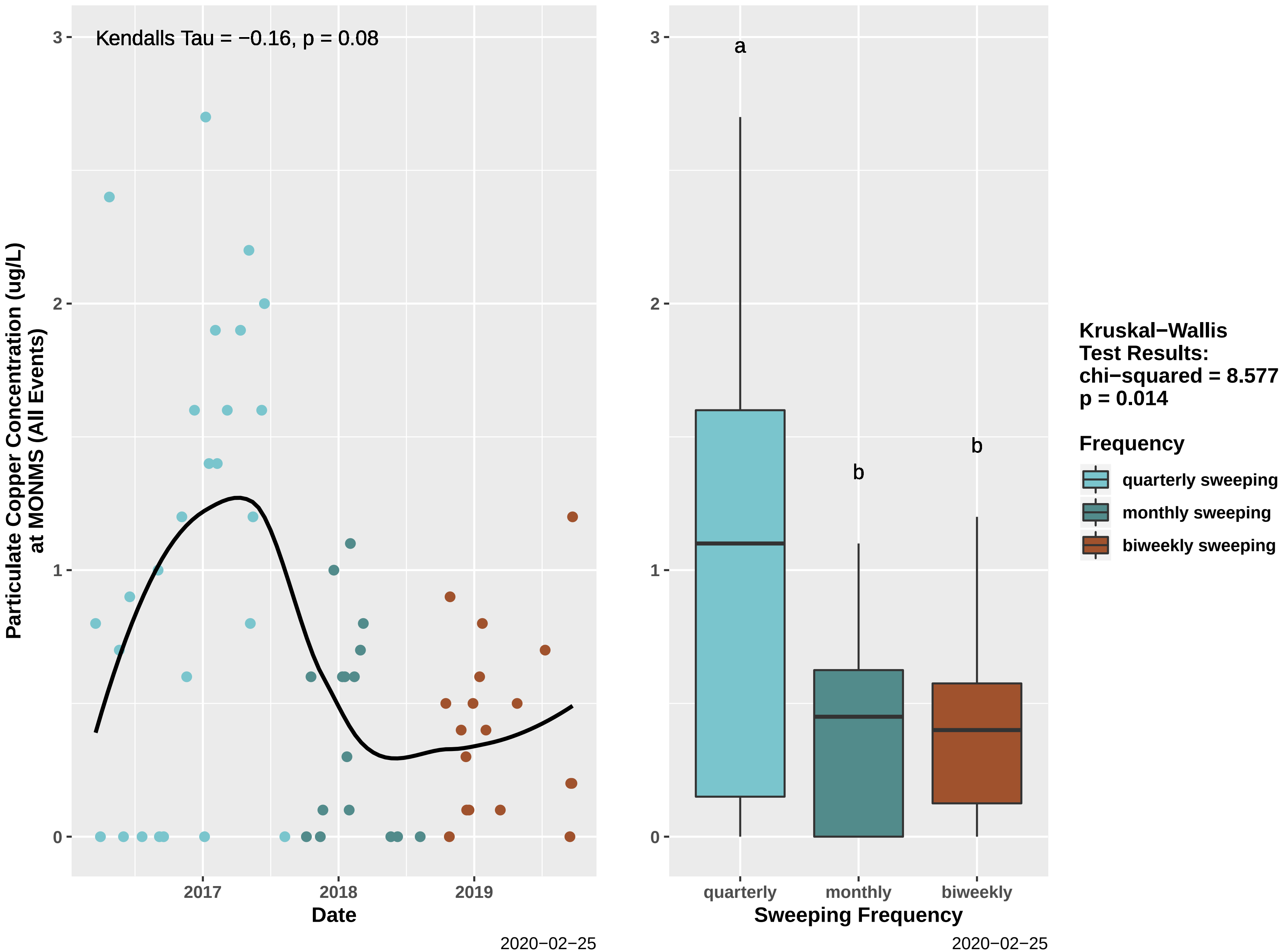

Kendalls Tau = −0.354, p = 0.104
Particulate Copper Concentration (ug/L) at MONM (Base Events Only)
0.8
0.6
0.4
0.2
0.0
2017
2018
2019
Date
2020−02−25
a
a
a
quarterly
monthly
biweekly
Sweeping Frequency
2020−02−25
Kruskal−Wallis Test Results:
chi−squared = 1
p = 0.607
Frequency
quarterly sweeping
monthly sweeping
biweekly sweeping

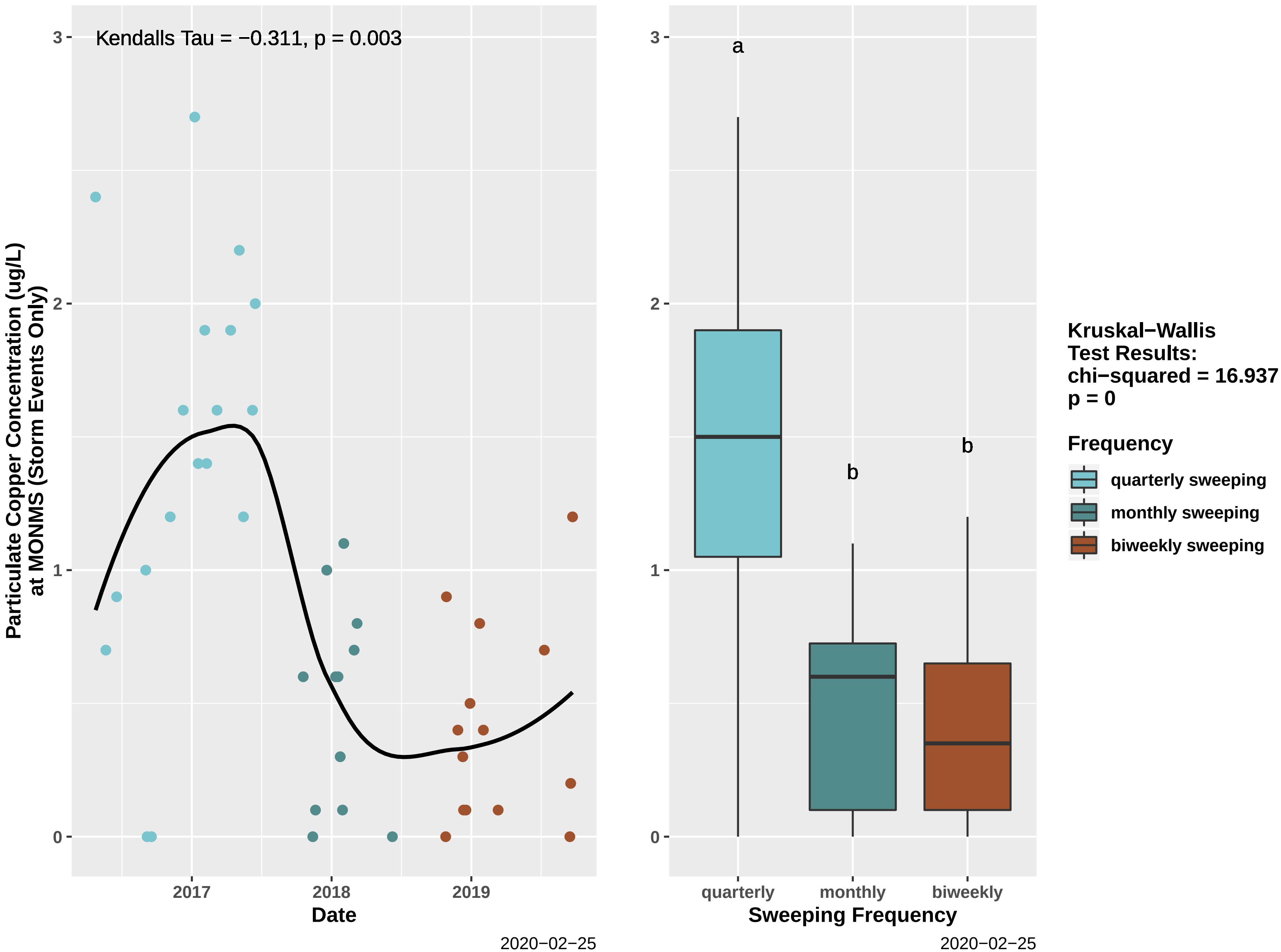


Kendalls Tau = 0.09, p = 0.332
Particulate Copper Concentration (ug/L) at MONMN (All Events)
7.5
5.0
2.5
0.0
2017
2018
2019
Date
2020−02−25
a
a
a
quarterly
monthly
biweekly
Sweeping Frequency
2020−02−25
Kruskal−Wallis Test Results:
chi−squared = 1.76
p = 0.415
Frequency
quarterly sweeping
monthly sweeping
biweekly sweeping

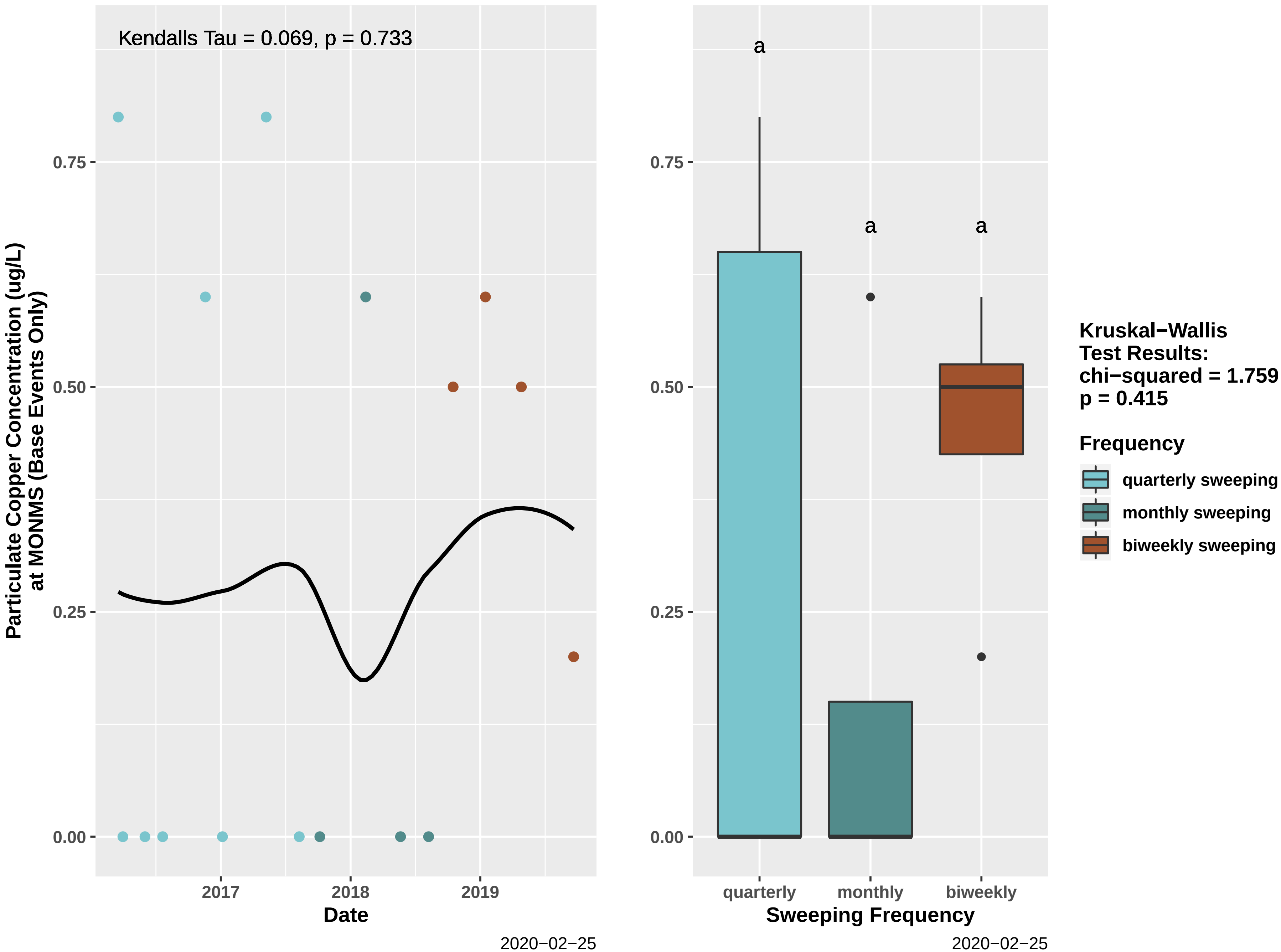

Kendalls Tau = 0.061, p = 0.569
Particulate Copper Concentration (ug/L) at MONMN (Storm Events Only)
7.5
5.0
2.5
0.0
2017
2018
2019
Date
2020−02−25
a
a
a
quarterly
monthly
biweekly
Sweeping Frequency
2020−02−25
Kruskal−Wallis Test Results:
chi−squared = 0.672
p = 0.715
Frequency
quarterly sweeping
monthly sweeping
biweekly sweeping

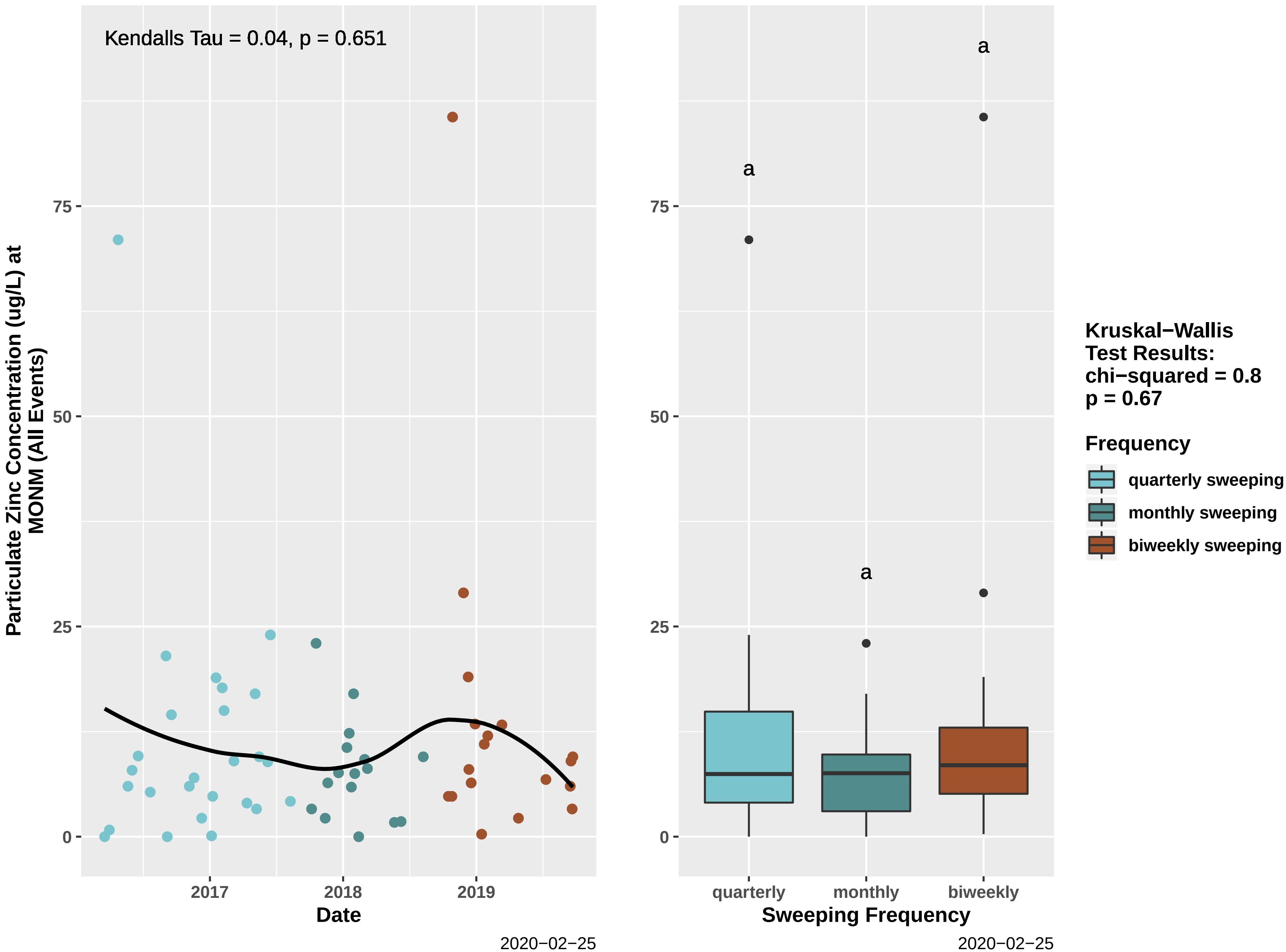

Kendalls Tau = −0.1, p = 0.64
Particulate Copper Concentration (ug/L)
at MONMN (Base Events Only)
1.5
1.0
0.5
0.0
2017
2018
2019
Date
2020−02−25
a
a
a
quarterly
monthly
biweekly
Sweeping Frequency
2020−02−25
Kruskal−Wallis
Test Results:
chi−squared = 1.179
p = 0.555
Frequency
quarterly sweeping
monthly sweeping
biweekly sweeping


Kendalls Tau = −0.16, p = 0.08
Particulate Copper Concentration (ug/L) at MONMS (All Events)
Date
2017
2018
2019
2020−02−25
a
b
b
quarterly
monthly
biweekly
Sweeping Frequency
2020−02−25
Kruskal−Wallis Test Results:
chi−squared = 8.577
p = 0.014
Frequency
quarterly sweeping
monthly sweeping
biweekly sweeping

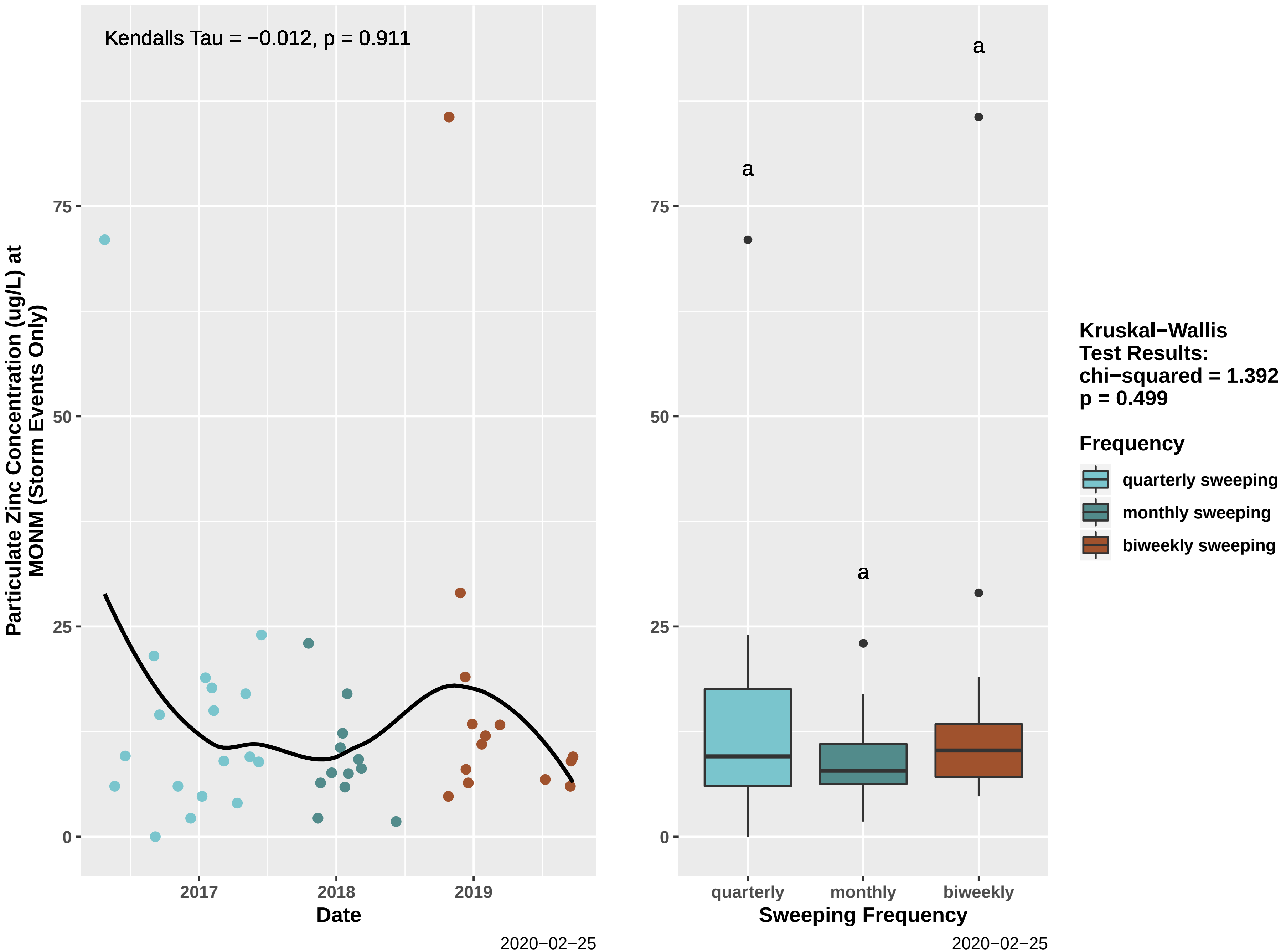


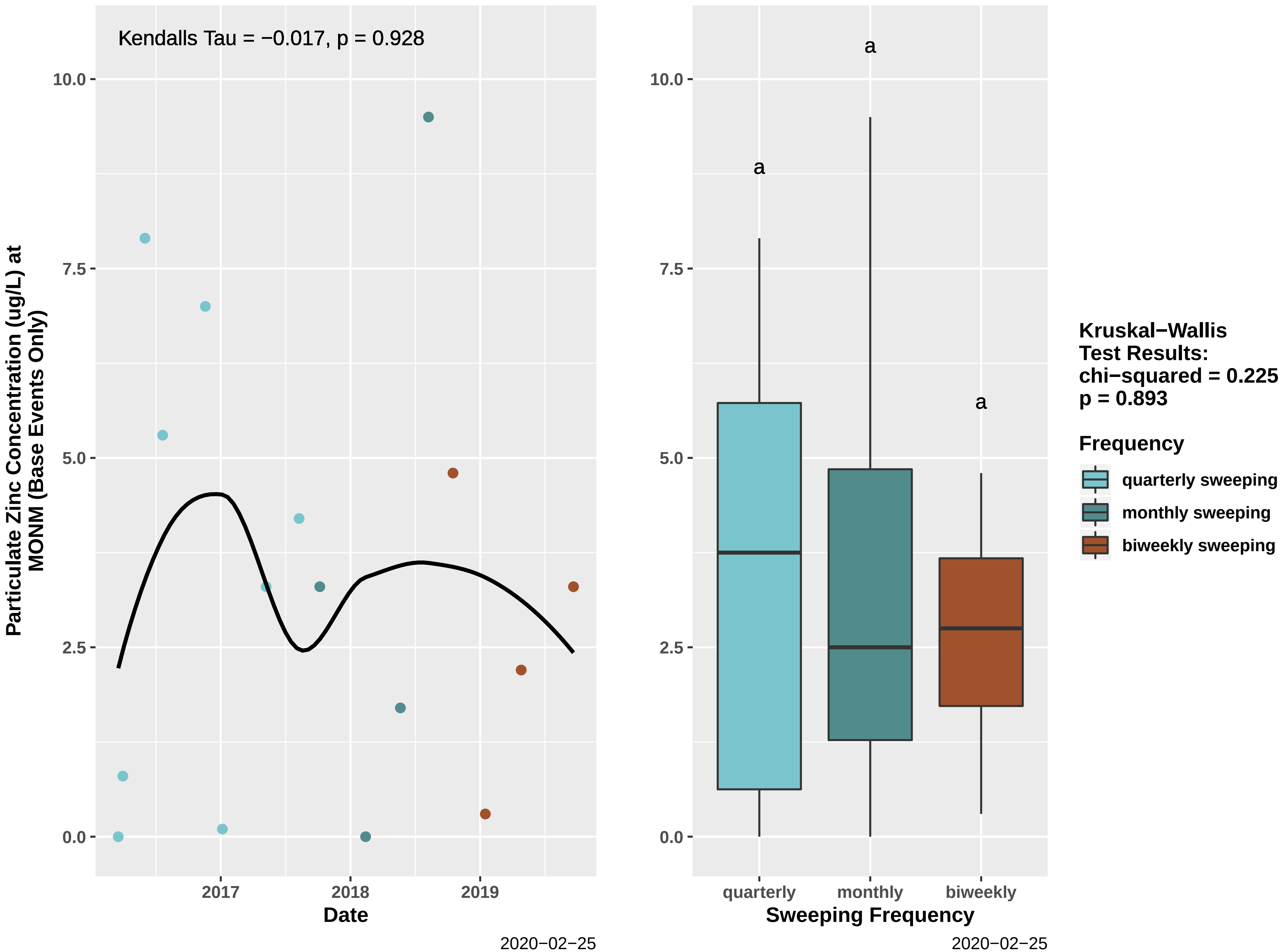
Kendalls Tau = −0.311, p = 0.003
Particulate Copper Concentration (ug/L) at MONMS (Storm Events Only)
3
2
1
0
2017
2018
2019
Date
2020−02−25
a
b
b
quarterly
monthly
biweekly
Sweeping Frequency
2020−02−25
Kruskal−Wallis Test Results:
chi−squared = 16.937
p = 0
Frequency
quarterly sweeping
monthly sweeping
biweekly sweeping

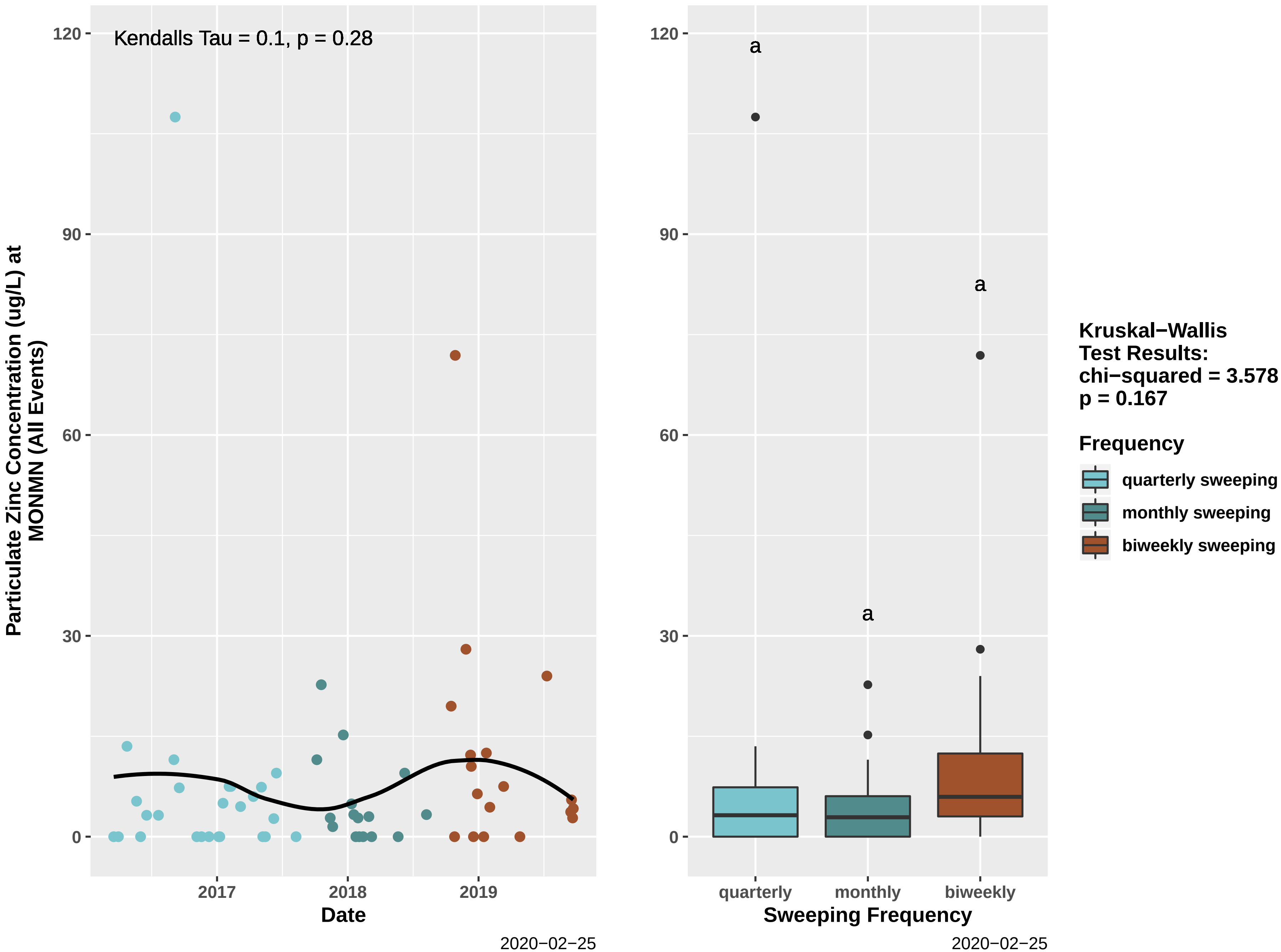

Kendalls Tau = 0.069, p = 0.733
Particulate Copper Concentration (ug/L) at MONMS (Base Events Only)
0.00
0.25
0.50
0.75
2017
2018
2019
Date
2020−02−25
a
a
a
quarterly
monthly
biweekly
Sweeping Frequency
2020−02−25
Kruskal−Wallis Test Results:
chi−squared = 1.759
p = 0.415
Frequency
quarterly sweeping
monthly sweeping
biweekly sweeping

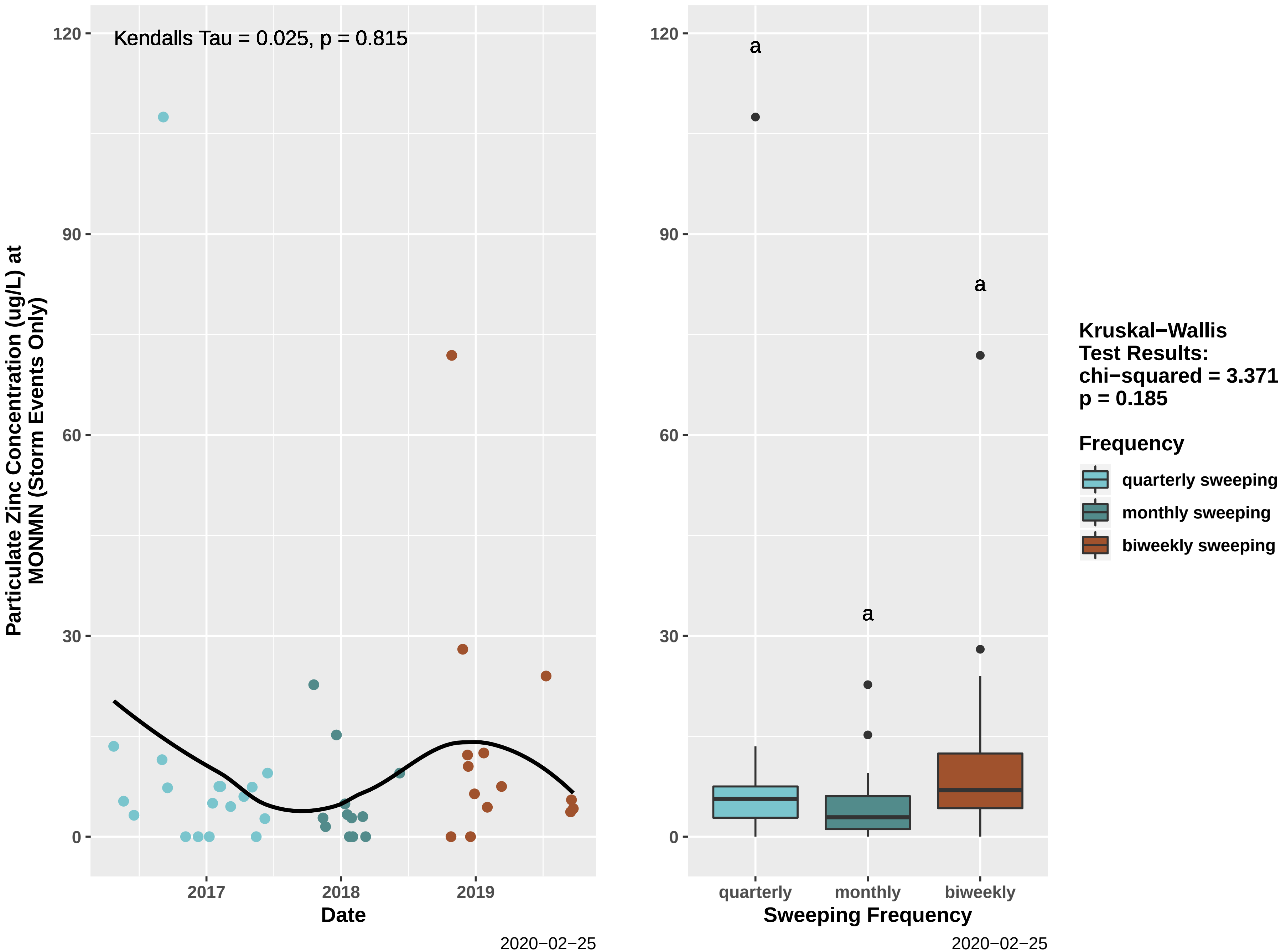


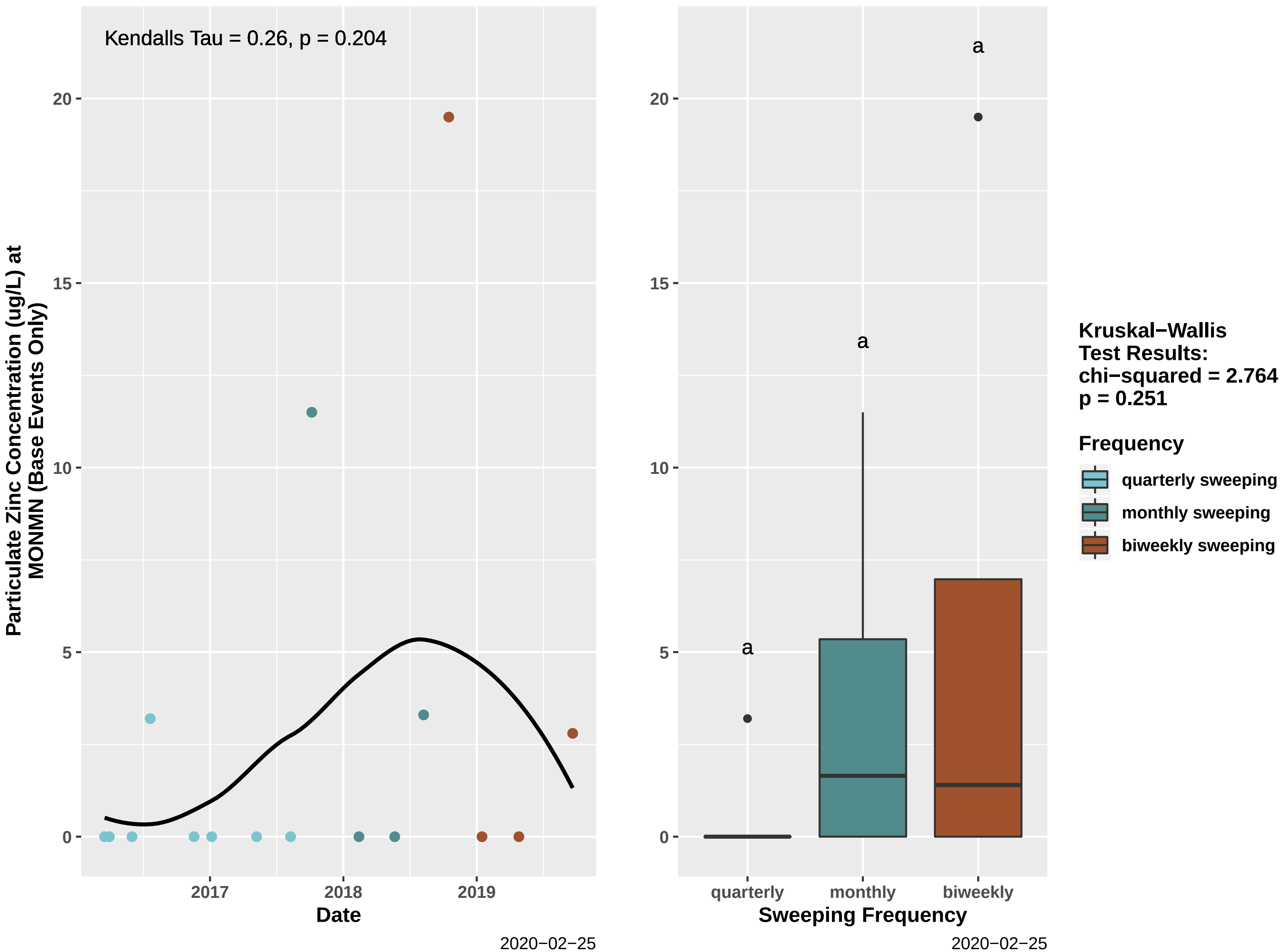
Kendalls Tau = 0.04, p = 0.651
Particulate Zinc Concentration (ug/L) at MONM (All Events)
75
50
25
0
2017
2018
2019
Date
2020−02−25
a
a
a
75
50
25
0
quarterly
monthly
biweekly
Sweeping Frequency
2020−02−25
Kruskal−Wallis Test Results:
chi−squared = 0.8
p = 0.67
Frequency
quarterly sweeping
monthly sweeping
biweekly sweeping


Kendalls Tau = −0.012, p = 0.911
Particulate Zinc Concentration (ug/L) at MONM (Storm Events Only)
75
50
25
0
2017
2018
2019
Date
2020−02−25
a
a
a
quarterly
monthly
biweekly
Sweeping Frequency
2020−02−25
Kruskal−Wallis Test Results:
chi−squared = 1.392
p = 0.499
Frequency
quarterly sweeping
monthly sweeping
biweekly sweeping

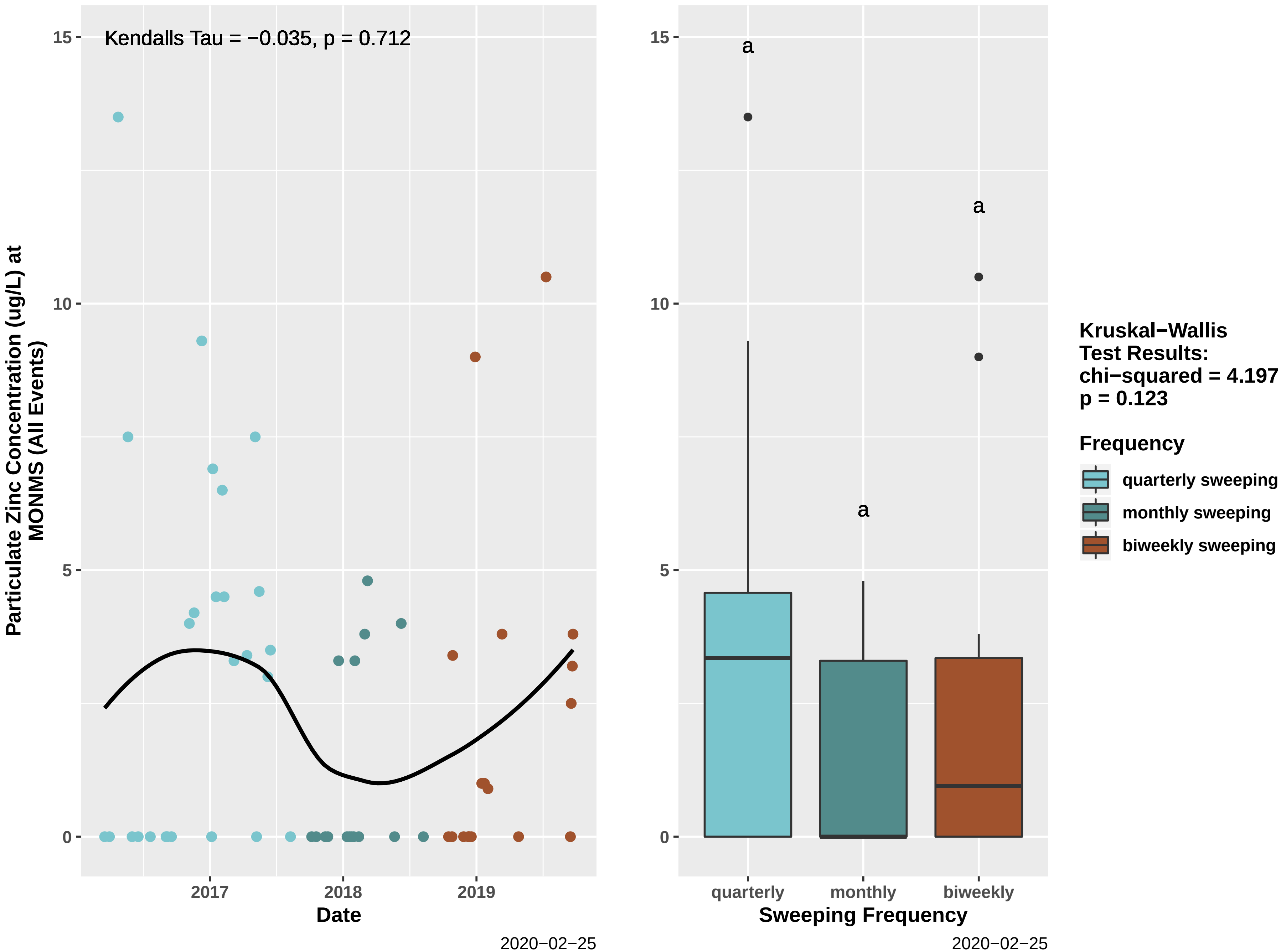

Kendalls Tau = −0.017, p = 0.928
Particulate Zinc Concentration (ug/L) at
MONM (Base Events Only)
10.0
7.5
5.0
2.5
0.0
2017
2018
2019
Date
2020−02−25
a
a
a
quarterly
monthly
biweekly
Sweeping Frequency
2020−02−25
Kruskal−Wallis
Test Results:
chi−squared = 0.225
p = 0.893
Frequency
quarterly sweeping
monthly sweeping
biweekly sweeping

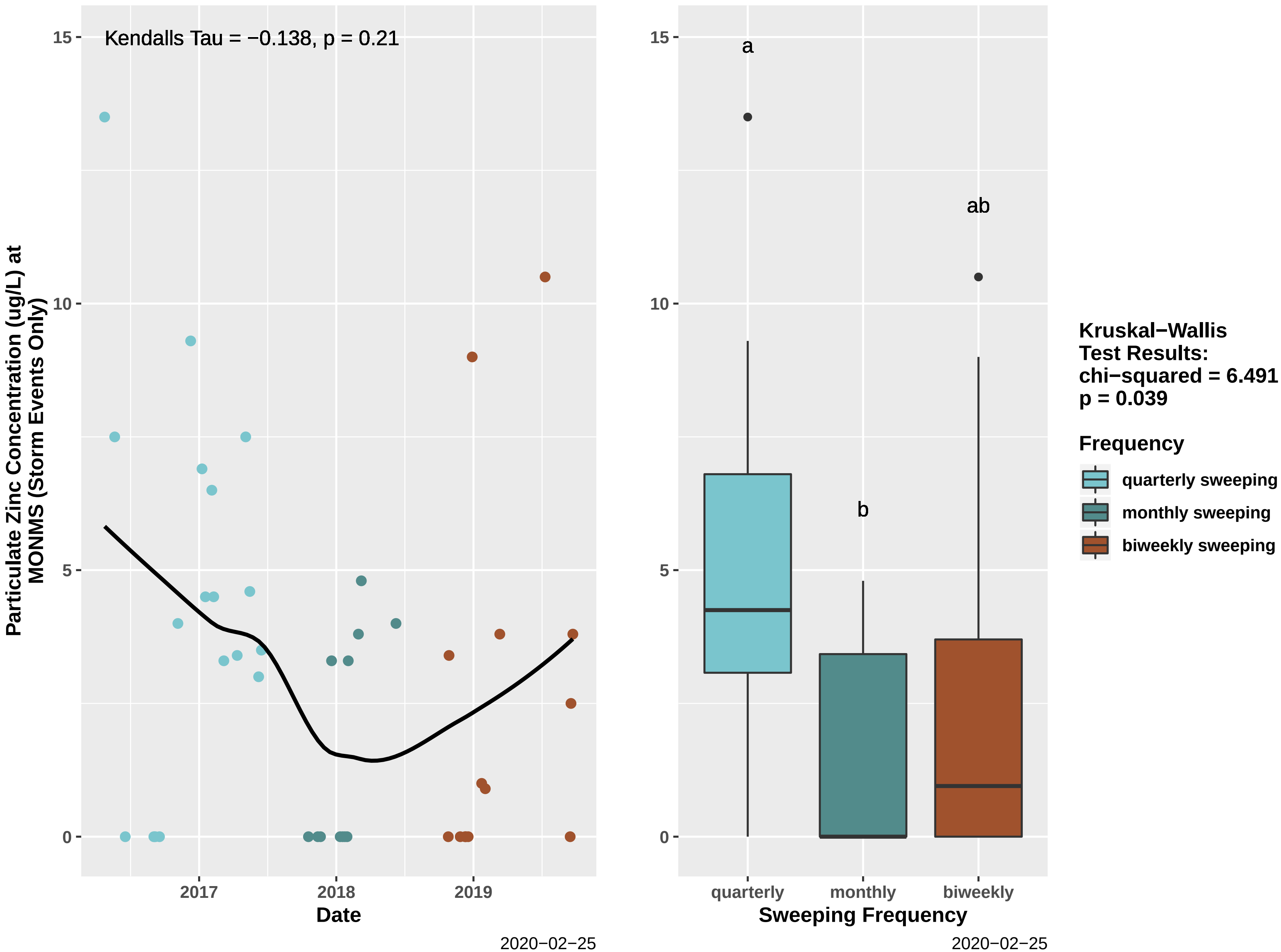

Kendalls Tau = 0.1, p = 0.28
Particulate Zinc Concentration (ug/L) at MONMN (All Events)
120
90
60
30
0
2017
2018
2019
Date
2020−02−25
a
a
a
quarterly
monthly
biweekly
Sweeping Frequency
2020−02−25
Kruskal−Wallis Test Results:
chi−squared = 3.578
p = 0.167
Frequency
quarterly sweeping
monthly sweeping
biweekly sweeping

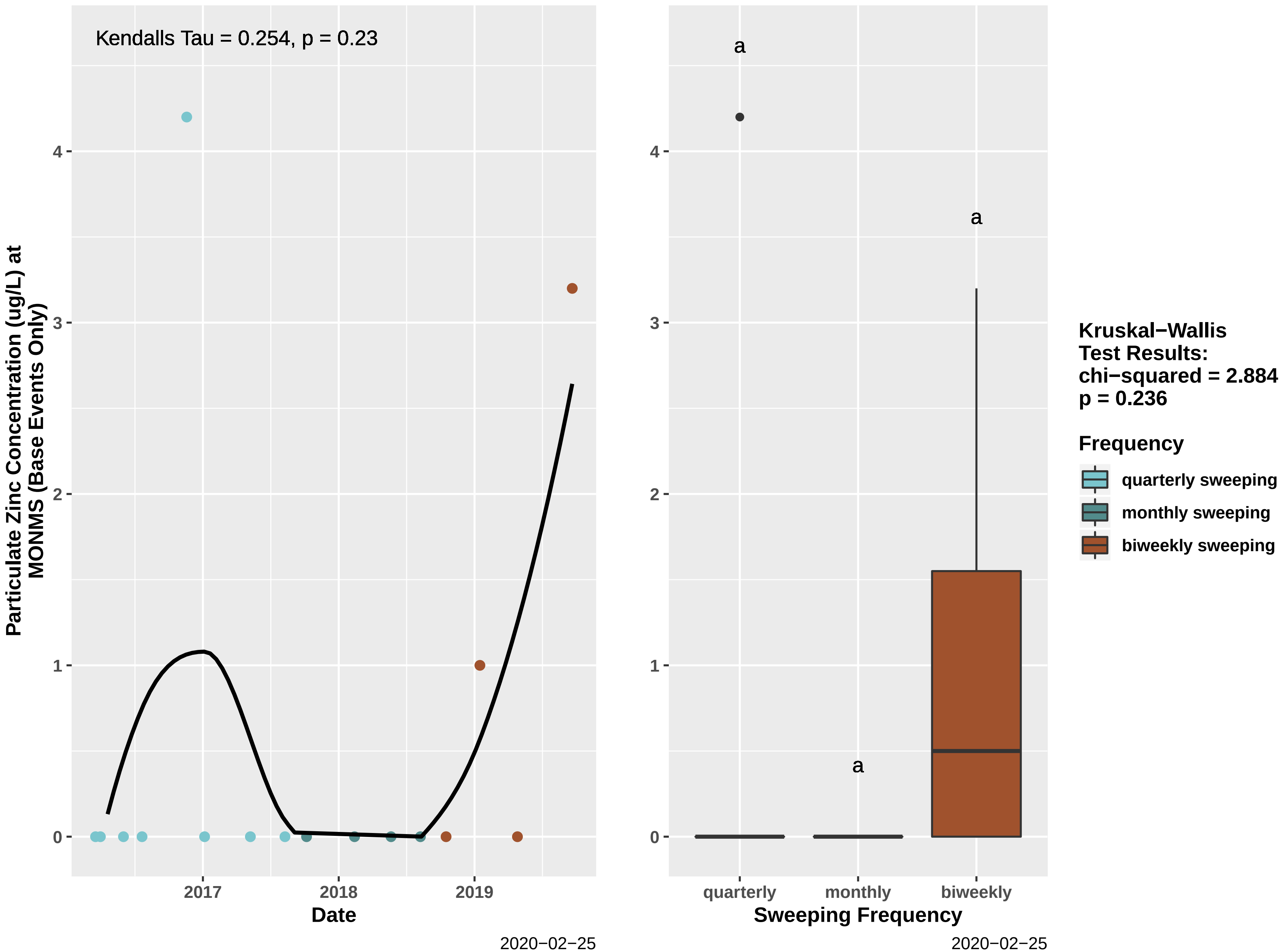

Kendalls Tau = 0.025, p = 0.815
Particulate Zinc Concentration (ug/L) at MONMN (Storm Events Only)
120
90
60
30
0
2017
2018
2019
Date
2020−02−25
a
a
a
quarterly
monthly
biweekly
Sweeping Frequency
2020−02−25
Kruskal−Wallis Test Results:
chi−squared = 3.371
p = 0.185
Frequency
quarterly sweeping
monthly sweeping
biweekly sweeping

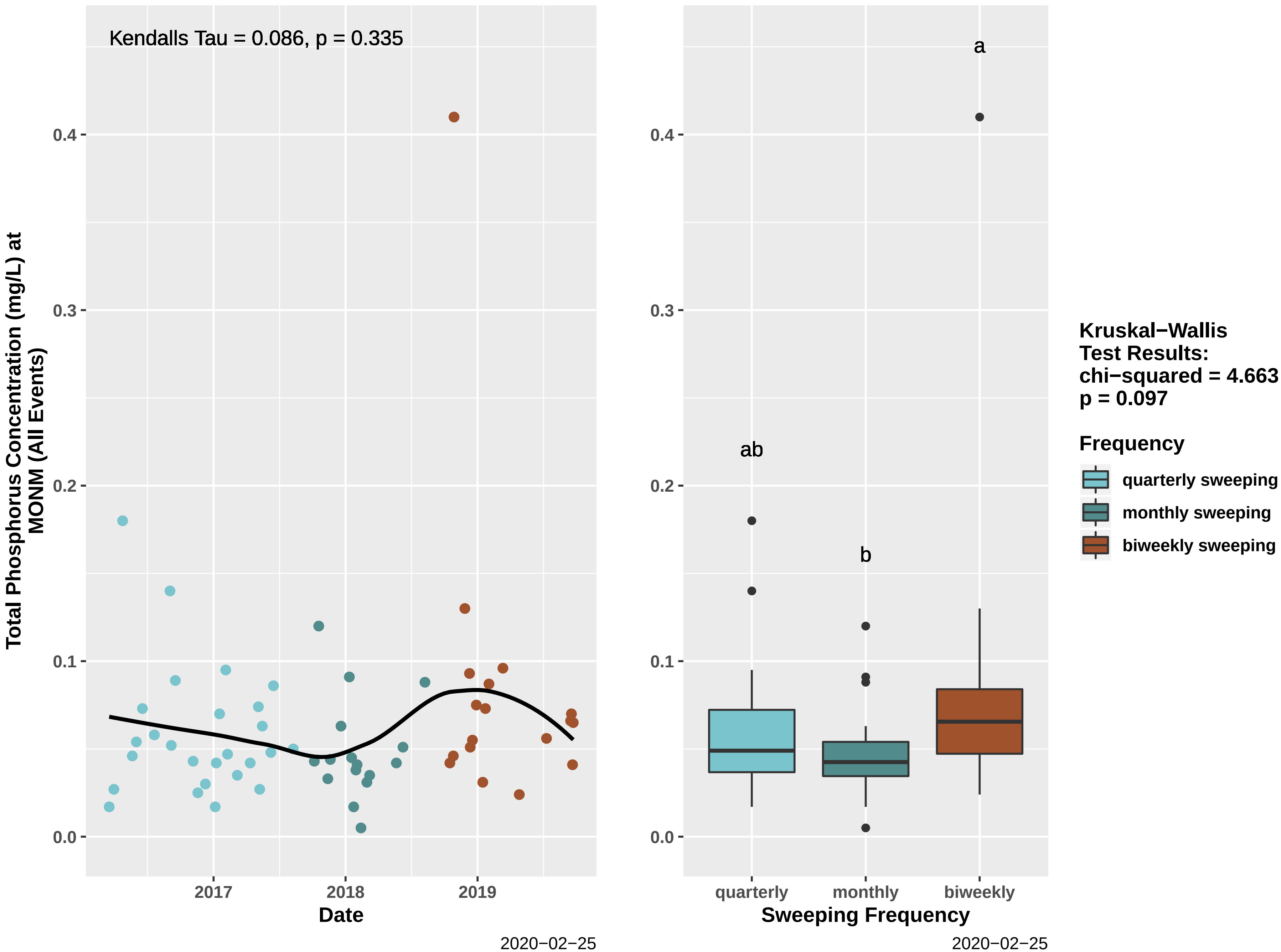


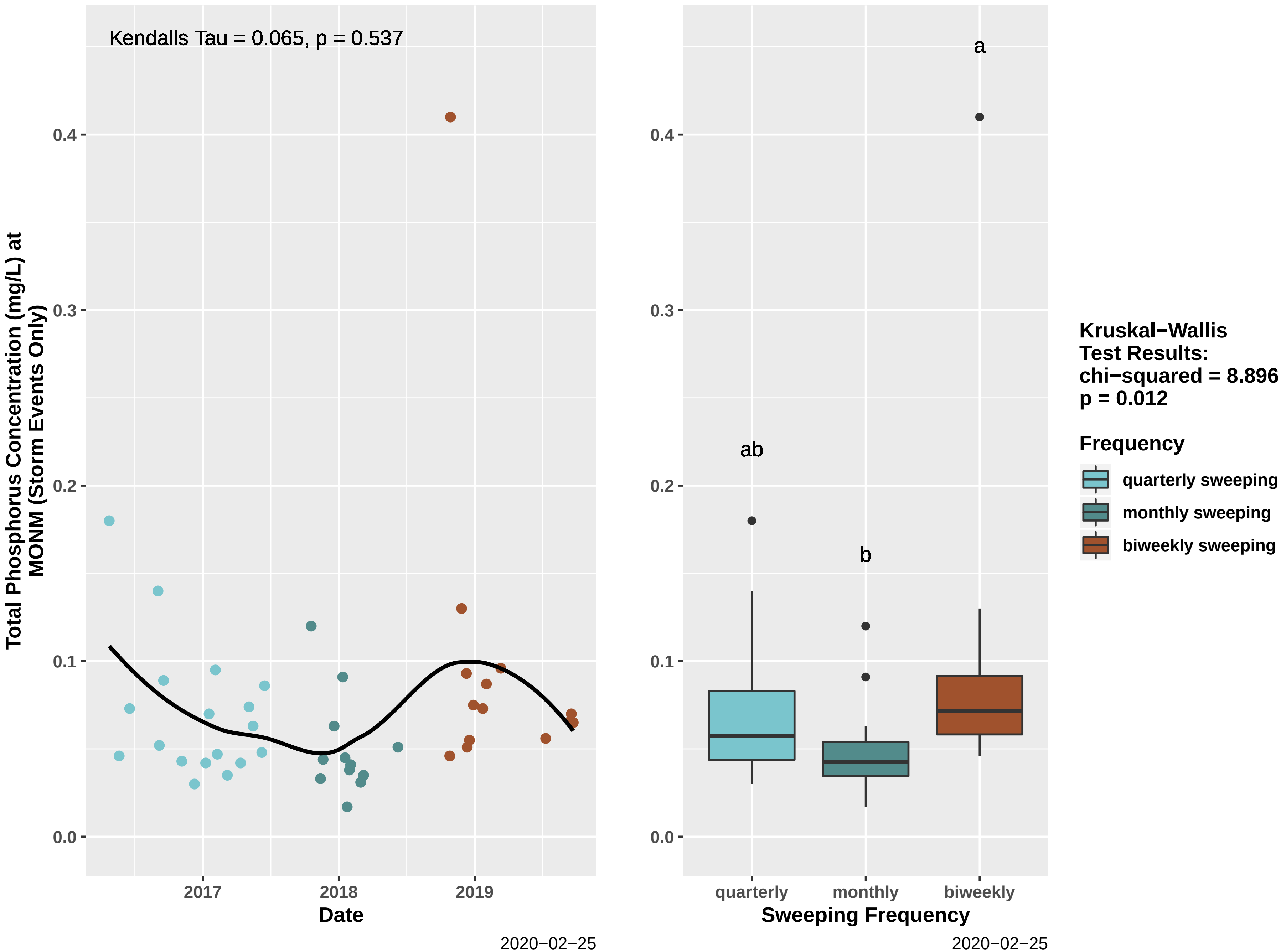
Kendalls Tau = 0.26, p = 0.204
Particulate Zinc Concentration (ug/L) at MONMN (Base Events Only)
20
15
10
5
0
2017
2018
2019
Date
2020−02−25
a
a
a
quarterly
monthly
biweekly
Sweeping Frequency
2020−02−25
Kruskal−Wallis Test Results:
chi−squared = 2.764
p = 0.251
Frequency
quarterly sweeping
monthly sweeping
biweekly sweeping

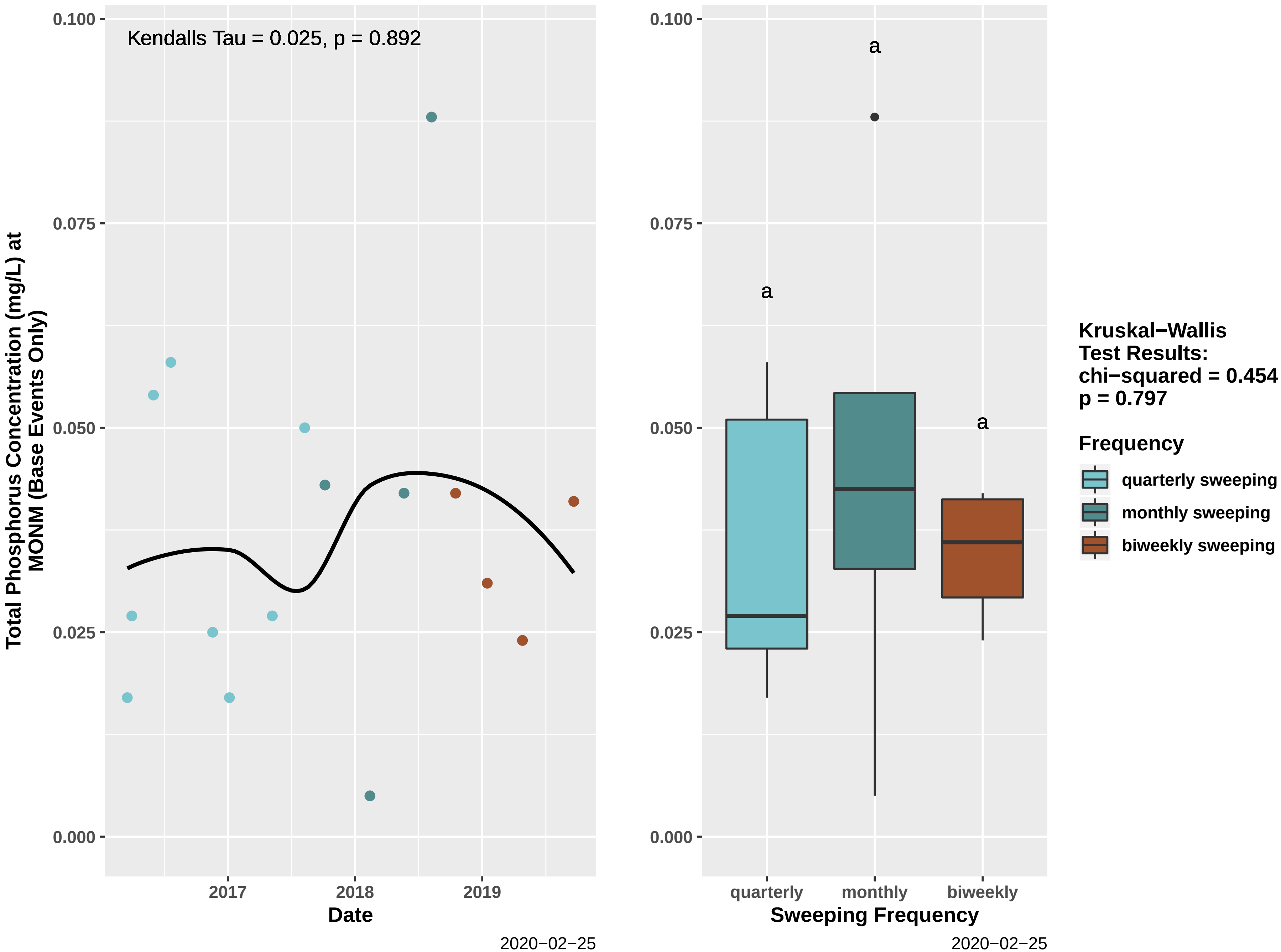

Kendalls Tau = −0.035, p = 0.712
Particulate Zinc Concentration (ug/L) at MONMS (All Events)
15
10
5
0
2017
2018
2019
Date
2020−02−25
a
a
a
quarterly
monthly
biweekly
Sweeping Frequency
2020−02−25
Kruskal−Wallis Test Results:
chi−squared = 4.197
p = 0.123
Frequency
quarterly sweeping
monthly sweeping
biweekly sweeping


Kendalls Tau = −0.138, p = 0.21
Particulate Zinc Concentration (ug/L) at MONMS (Storm Events Only)
15
10
5
0
2017
2018
2019
Date
2020−02−25
a
ab
b
quarterly
monthly
biweekly
Sweeping Frequency
2020−02−25
Kruskal−Wallis Test Results:
chi−squared = 6.491
p = 0.039
Frequency
quarterly sweeping
monthly sweeping
biweekly sweeping

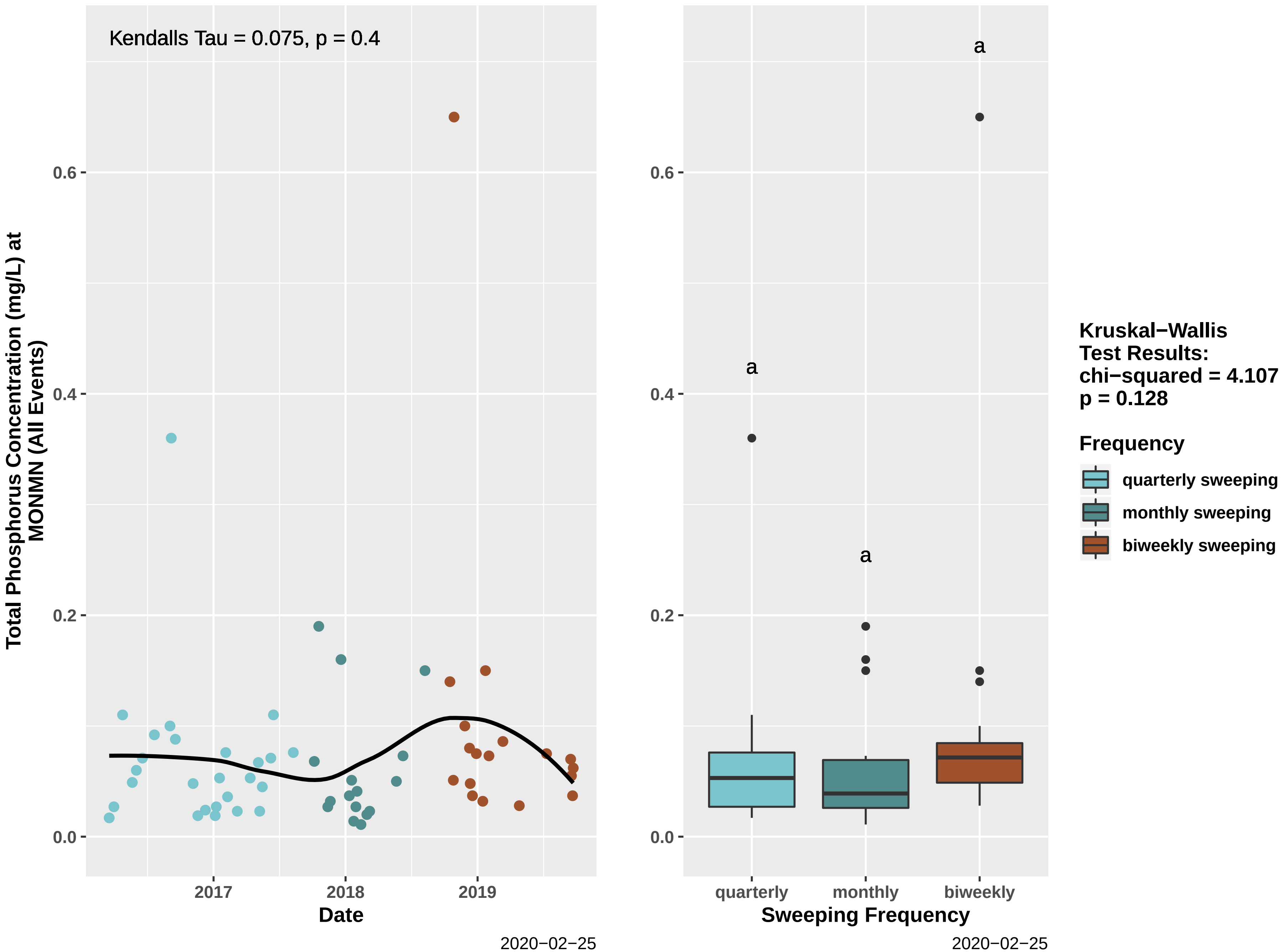

Kendalls Tau = 0.254, p = 0.23
Particulate Zinc Concentration (ug/L) at MONMS (Base Events Only)
0
1
2
3
4
2017
2018
2019
Date
2020−02−25
a
a
a
quarterly
monthly
biweekly
Sweeping Frequency
2020−02−25
Kruskal−Wallis Test Results:
chi−squared = 2.884
p = 0.236
Frequency
quarterly sweeping
monthly sweeping
biweekly sweeping


Kendalls Tau = 0.086, p = 0.335
Total Phosphorus Concentration (mg/L) at
MONM (All Events)
0.0
0.1
0.2
0.3
0.4
2017
2018
2019
Date
2020−02−25
a
ab
b
quarterly
monthly
biweekly
Sweeping Frequency
2020−02−25
Kruskal−Wallis
Test Results:
chi−squared = 4.663
p = 0.097
Frequency
quarterly sweeping
monthly sweeping
biweekly sweeping

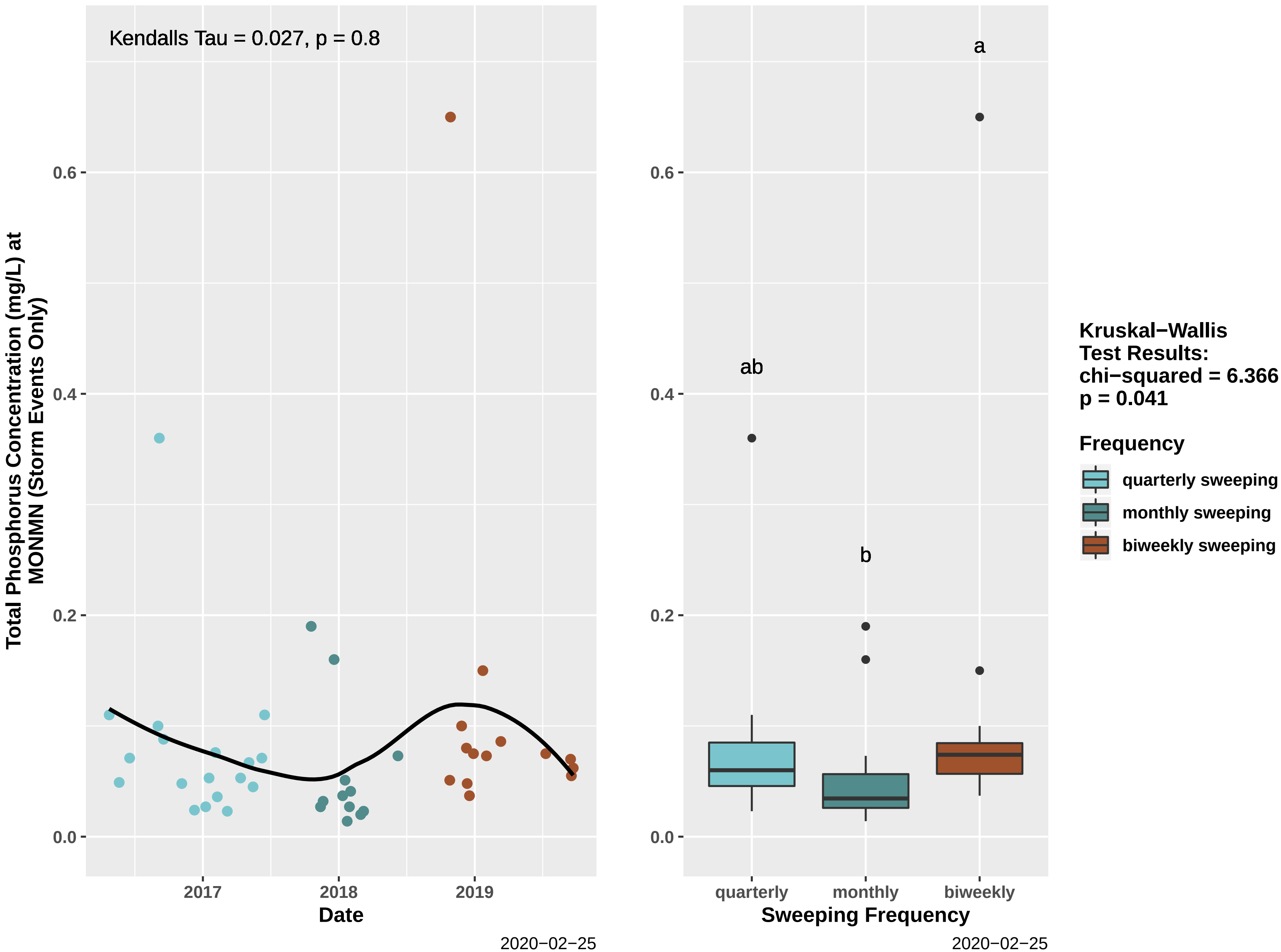

Kendalls Tau = 0.065, p = 0.537
Total Phosphorus Concentration (mg/L) at MONM (Storm Events Only)
0.4
0.3
0.2
0.1
0.0
2017
2018
2019
Date
2020−02−25
a
ab
b
quarterly
monthly
biweekly
Sweeping Frequency
2020−02−25
Kruskal−Wallis Test Results:
chi−squared = 8.896
p = 0.012
Frequency
quarterly sweeping
monthly sweeping
biweekly sweeping

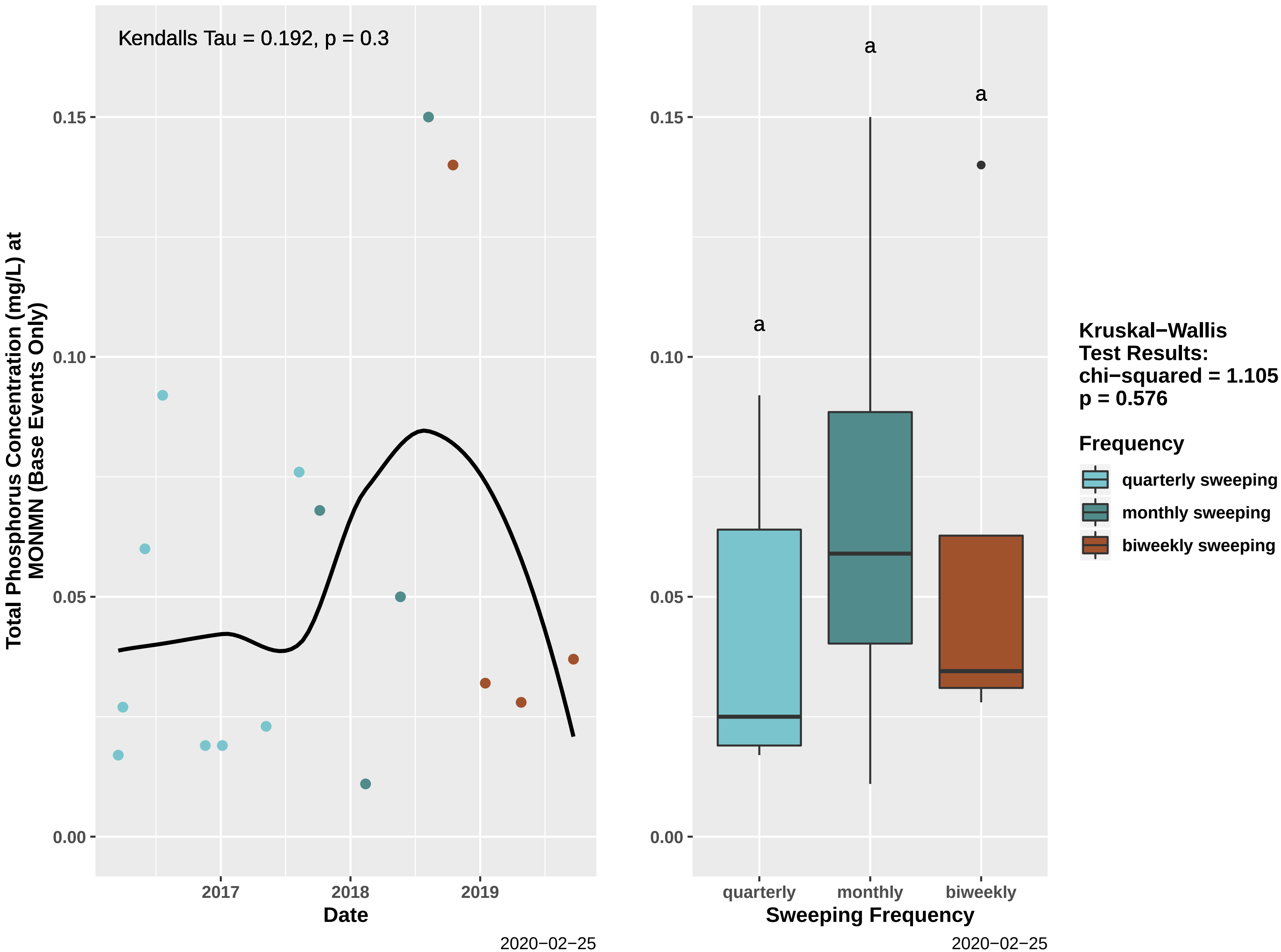


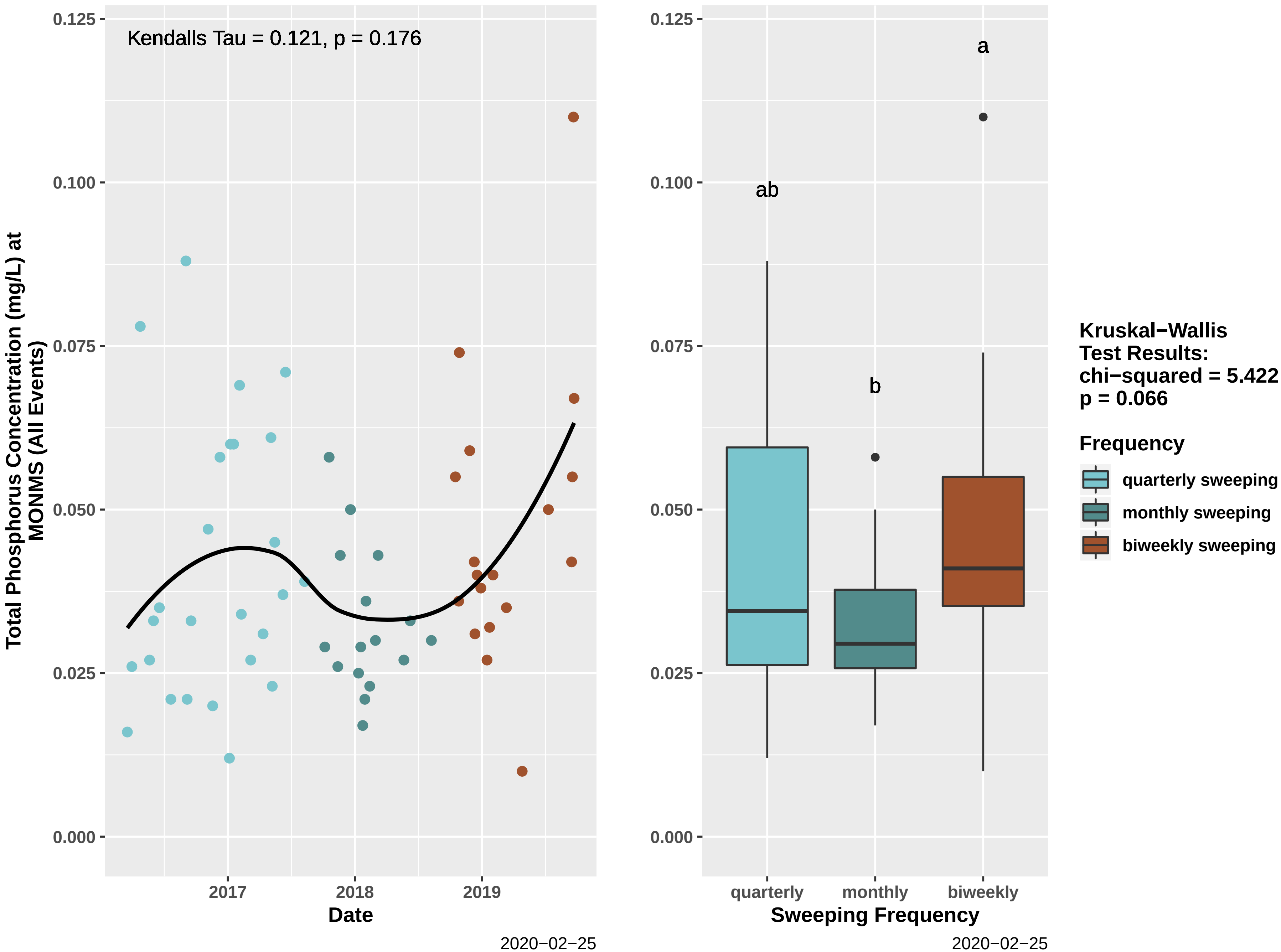
Kendalls Tau = 0.025, p = 0.892
Total Phosphorus Concentration (mg/L) at MONM (Base Events Only)
0.100
0.075
0.050
0.025
0.000
2017
2018
2019
Date
2020−02−25
a
a
a
quarterly
monthly
biweekly
Sweeping Frequency
2020−02−25
Kruskal−Wallis Test Results:
chi−squared = 0.454
p = 0.797
Frequency
quarterly sweeping
monthly sweeping
biweekly sweeping

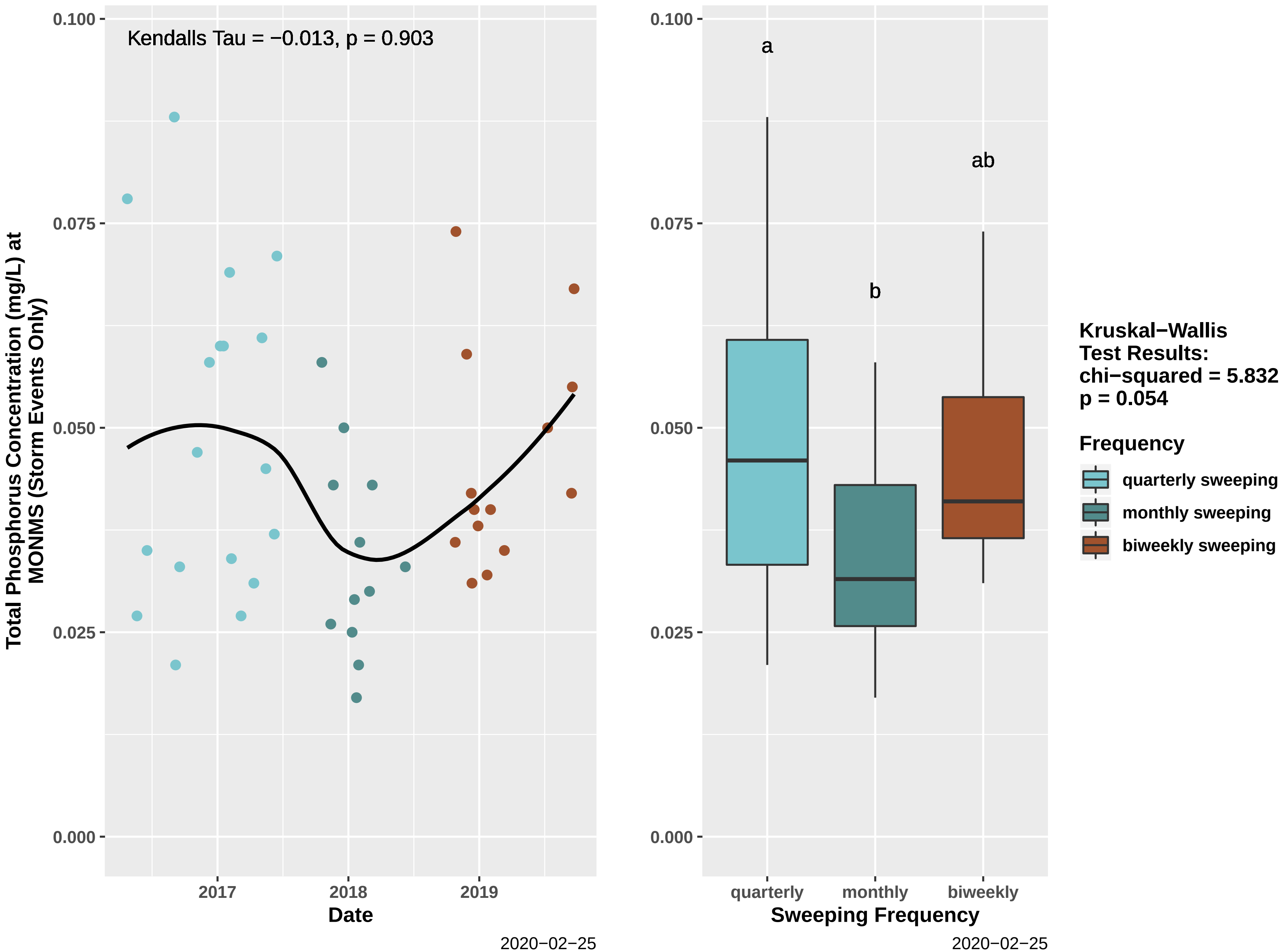


Kendalls Tau = 0.075, p = 0.4
Total Phosphorus Concentration (mg/L) at MONMN (All Events)
0.0
0.2
0.4
0.6
2017
2018
2019
Date
2020−02−25
a
a
a
quarterly
monthly
biweekly
Sweeping Frequency
2020−02−25
Kruskal−Wallis Test Results:
chi−squared = 4.107
p = 0.128
Frequency
quarterly sweeping
monthly sweeping
biweekly sweeping

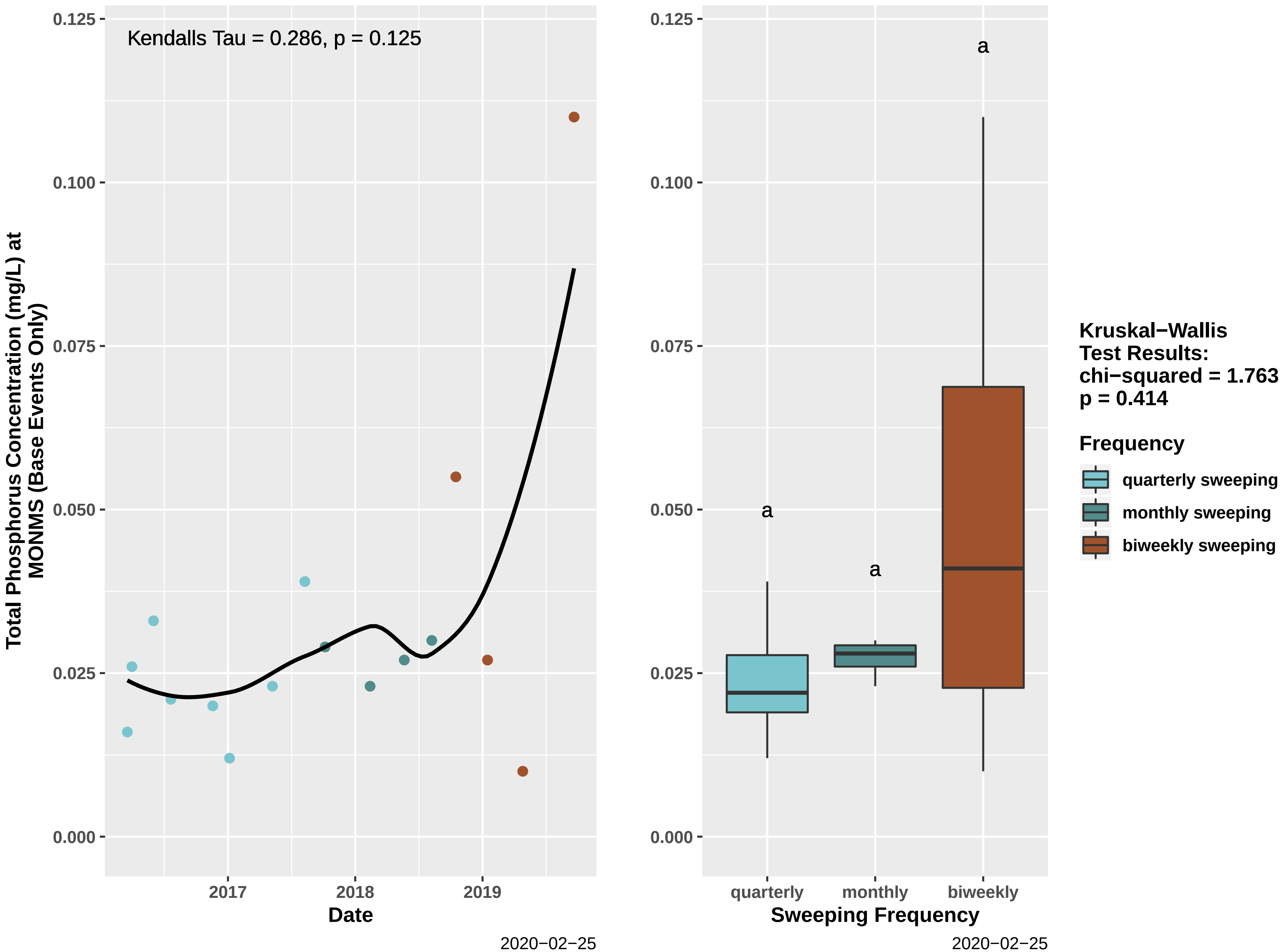

Kendalls Tau = 0.027, p = 0.8
Total Phosphorus Concentration (mg/L) at MONMN (Storm Events Only)
0.0
0.2
0.4
0.6
2017
2018
2019
Date
2020−02−25
a
ab
b
quarterly
monthly
biweekly
Sweeping Frequency
2020−02−25
Kruskal−Wallis Test Results:
chi−squared = 6.366
p = 0.041
Frequency
quarterly sweeping
monthly sweeping
biweekly sweeping

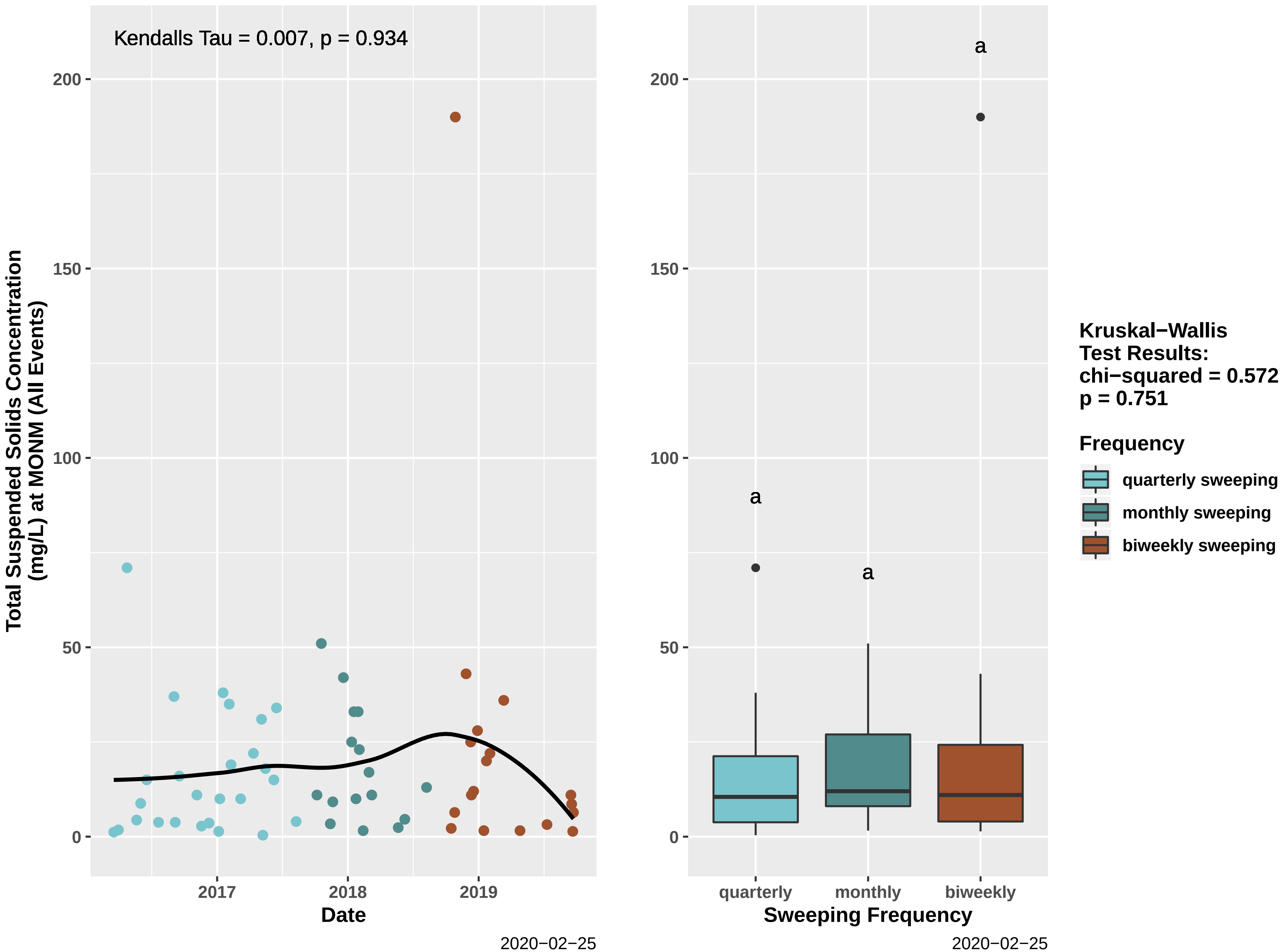

Kendalls Tau = 0.192, p = 0.3
Total Phosphorus Concentration (mg/L) at MONMN (Base Events Only)
0.15
0.10
0.05
0.00
2017
2018
2019
Date
2020−02−25
a
a
a
quarterly
monthly
biweekly
Sweeping Frequency
2020−02−25
Kruskal−Wallis Test Results: chi−squared = 1.105 p = 0.576
Frequency
quarterly sweeping
monthly sweeping
biweekly sweeping

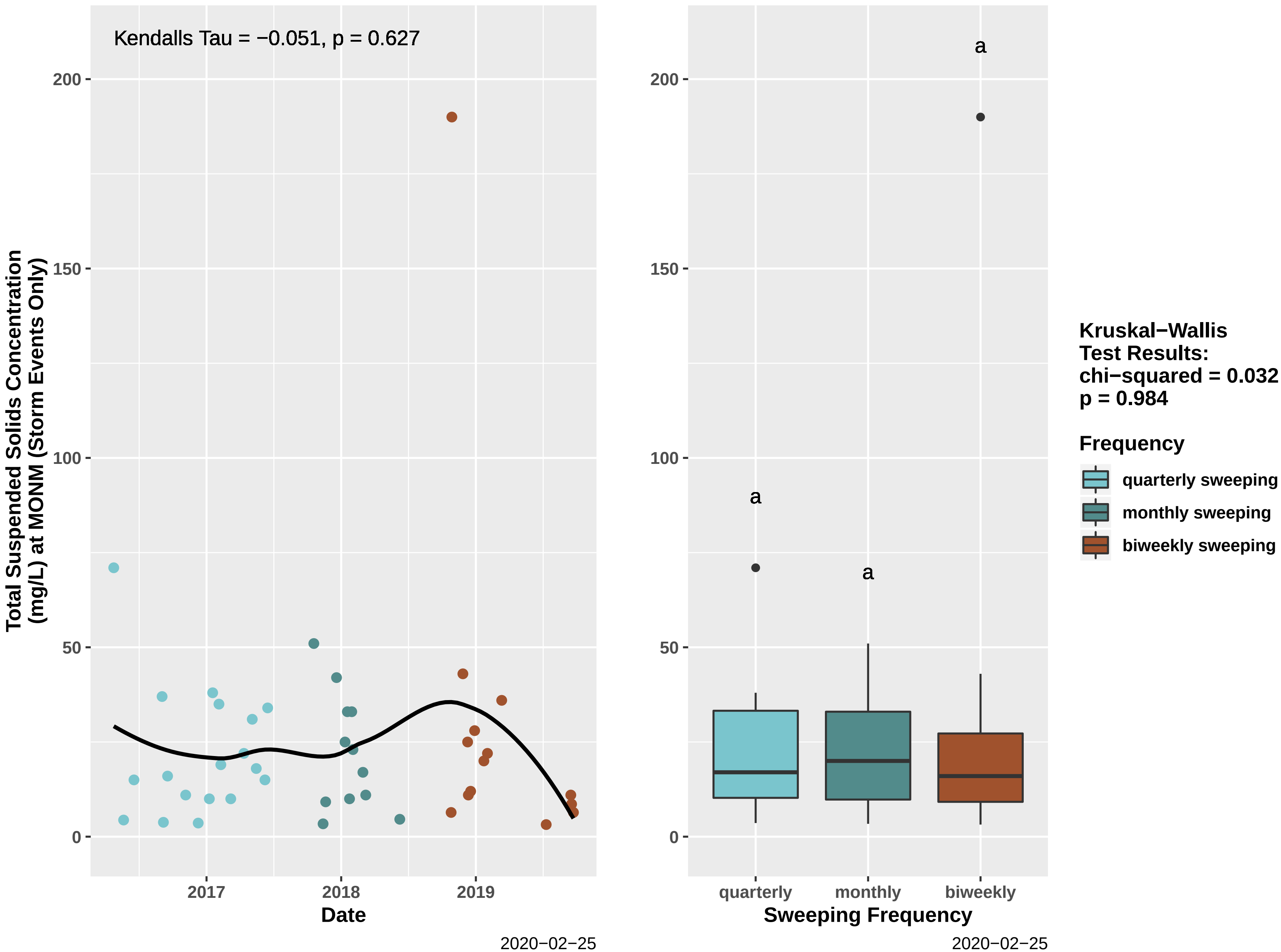

Kendalls Tau = 0.121, p = 0.176
Total Phosphorus Concentration (mg/L) at MONMS (All Events)
0.125
0.100
0.075
0.050
0.025
0.000
2017
2018
2019
Date
2020−02−25
ab
b
a
quarterly
monthly
biweekly
Sweeping Frequency
2020−02−25
Kruskal−Wallis Test Results:
chi−squared = 5.422
p = 0.066
Frequency
quarterly sweeping
monthly sweeping
biweekly sweeping



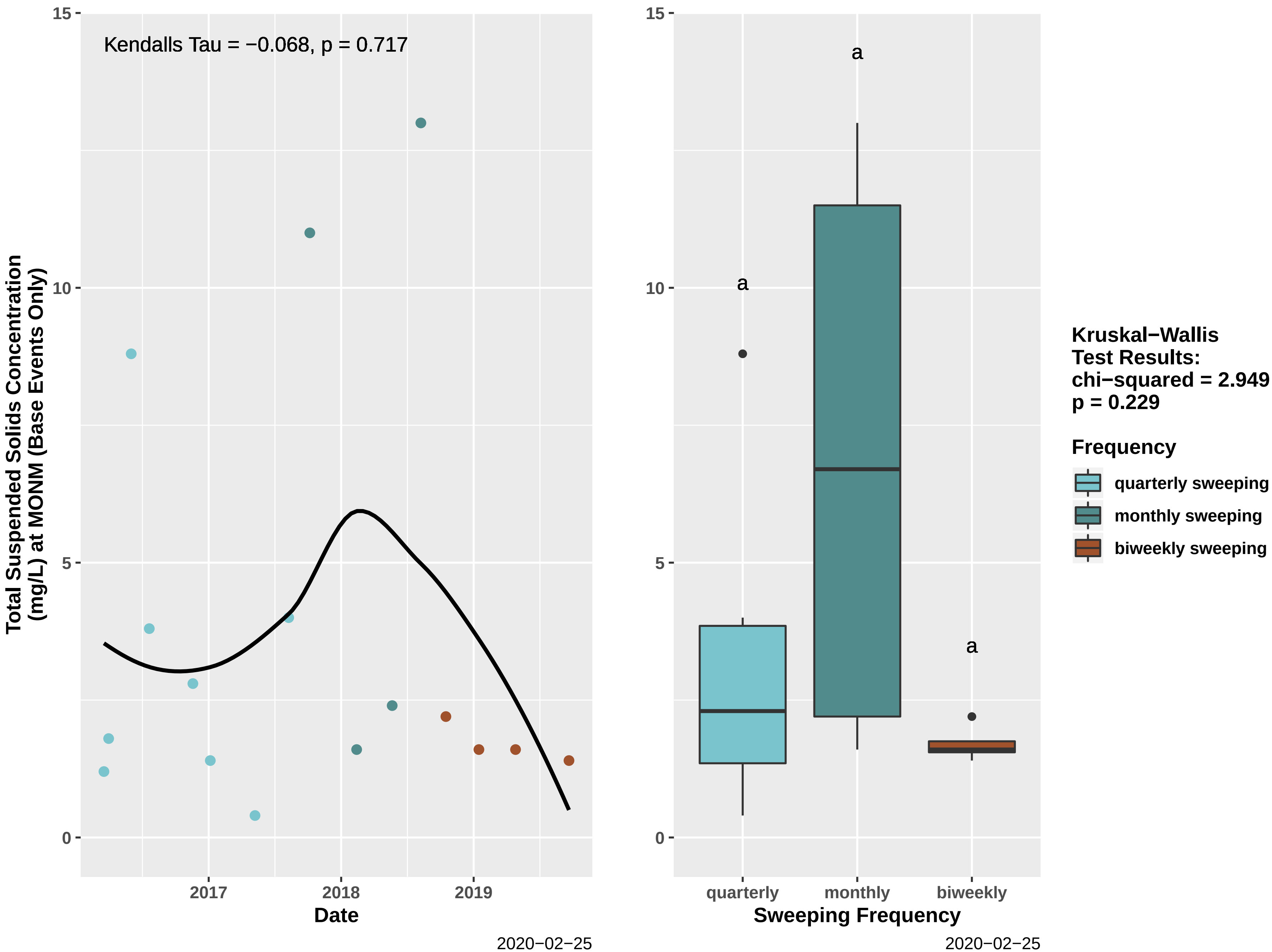
Kendalls Tau = −0.013, p = 0.903
Total Phosphorus Concentration (mg/L) at MONMS (Storm Events Only)
0.100
0.075
0.050
0.025
0.000
2017
2018
2019
Date
2020−02−25
a
b
ab
quarterly
monthly
biweekly
Sweeping Frequency
2020−02−25
Kruskal−Wallis Test Results:
chi−squared = 5.832
p = 0.054
Frequency
quarterly sweeping
monthly sweeping
biweekly sweeping

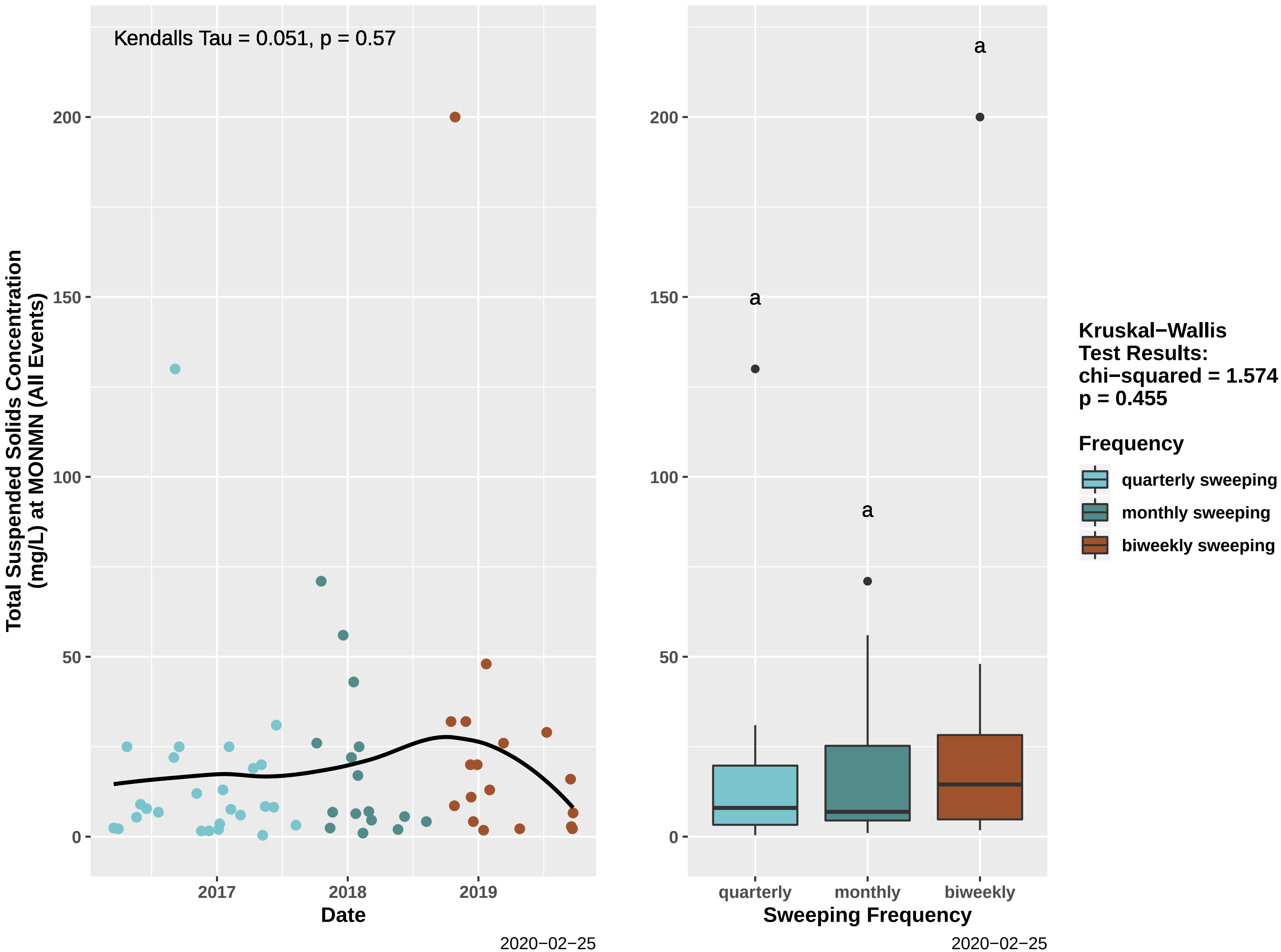

Kendalls Tau = 0.286, p = 0.125
Total Phosphorus Concentration (mg/L) at
MONMS (Base Events Only)
0.125
0.100
0.075
0.050
0.025
0.000
2017
2018
2019
Date
2020−02−25
a
a
a
quarterly
monthly
biweekly
Sweeping Frequency
2020−02−25
Kruskal−Wallis
Test Results:
chi−squared = 1.763
p = 0.414
Frequency
quarterly sweeping
monthly sweeping
biweekly sweeping

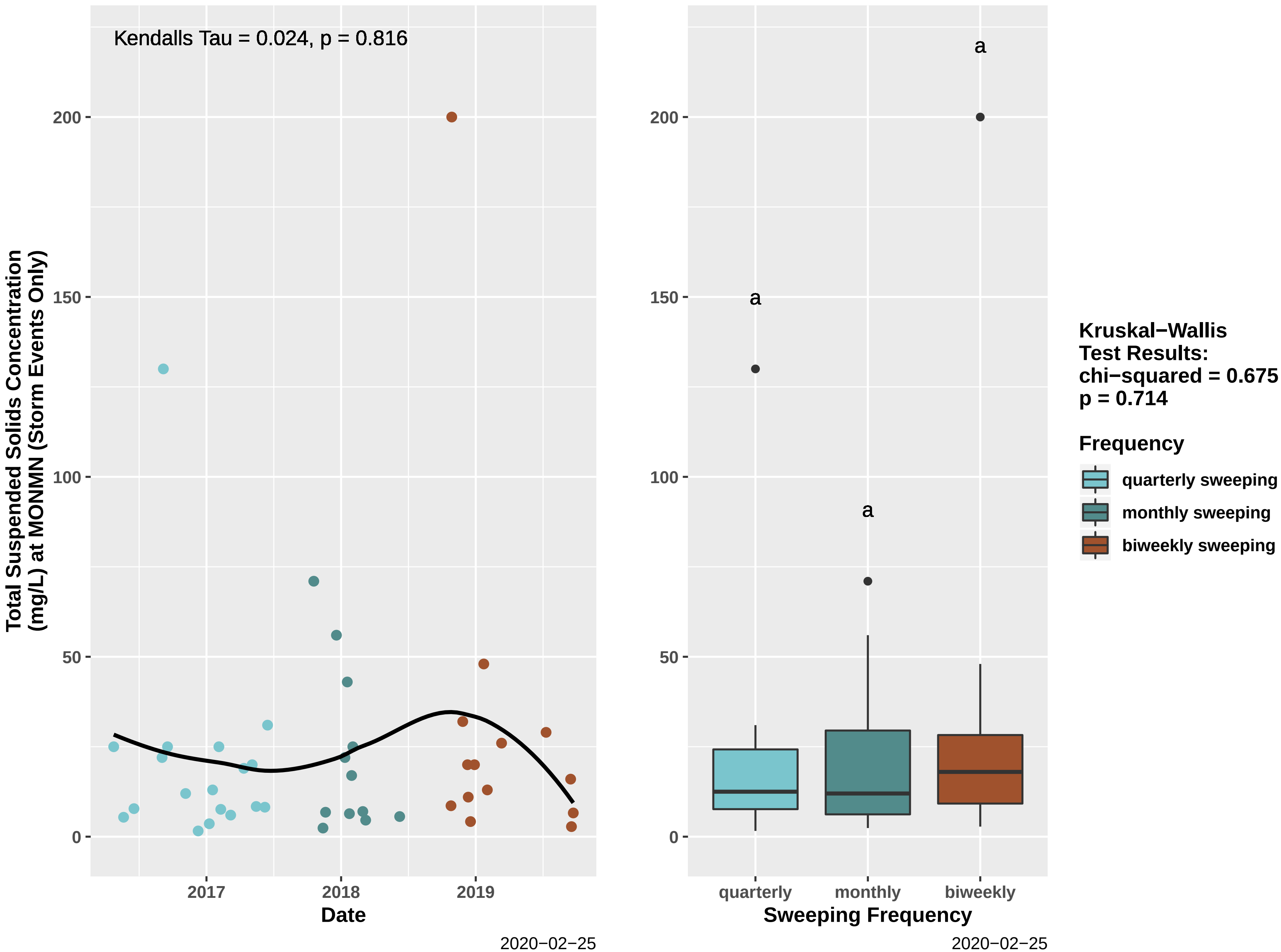

Kendalls Tau = 0.007, p = 0.934
Total Suspended Solids Concentration (mg/L) at MONM (All Events)
200
150
100
50
0
2017
2018
2019
Date
2020−02−25
a
a
a
quarterly
monthly
biweekly
Sweeping Frequency
2020−02−25
Kruskal−Wallis Test Results:
chi−squared = 0.572
p = 0.751
Frequency
quarterly sweeping
monthly sweeping
biweekly sweeping



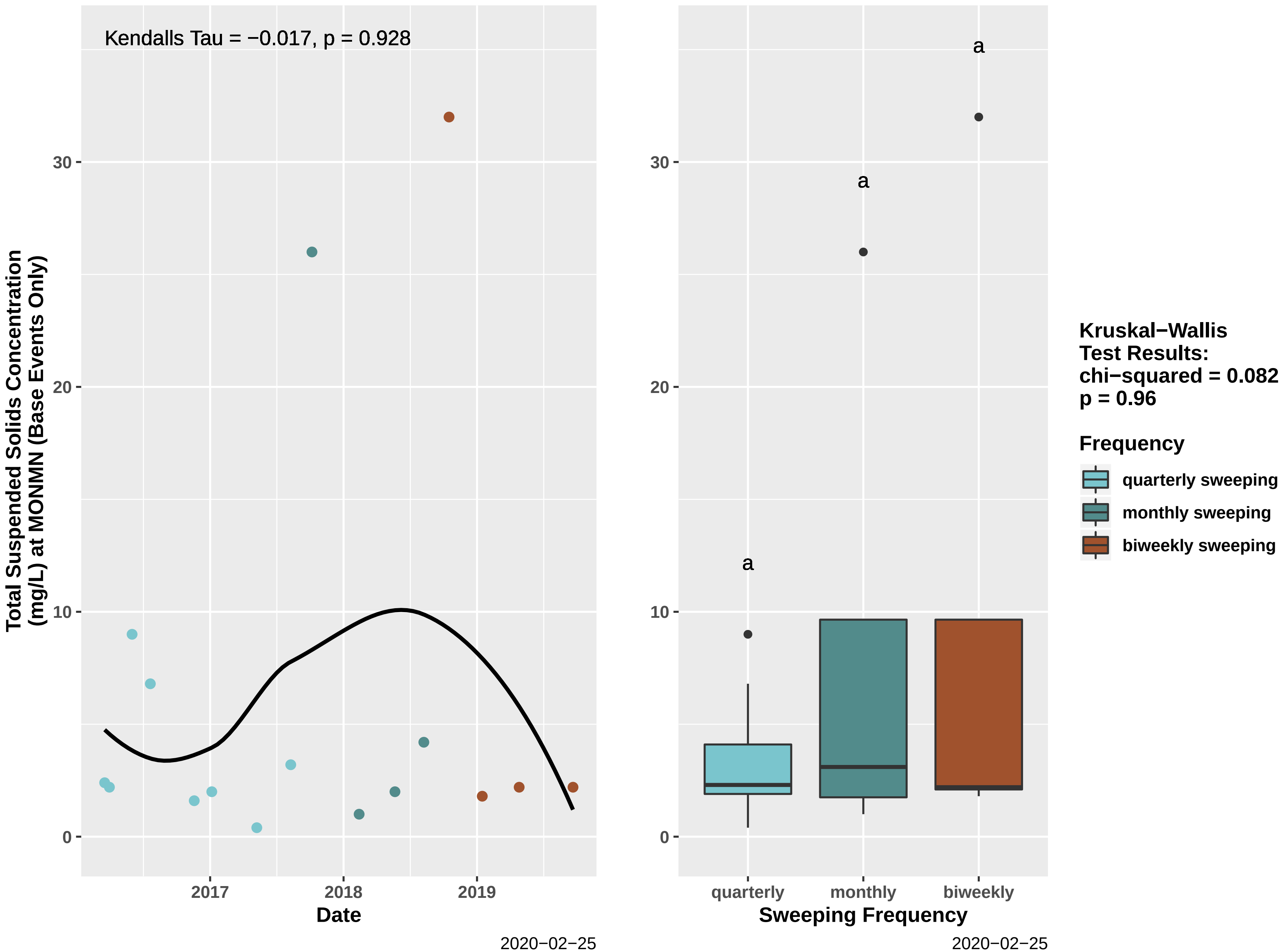
Kendalls Tau = −0.051, p = 0.627
Total Suspended Solids Concentration
(mg/L) at MONM (Storm Events Only)
200
150
100
50
0
2017
2018
2019
Date
2020−02−25
a
a
a
quarterly
monthly
biweekly
Sweeping Frequency
2020−02−25
Kruskal−Wallis
Test Results:
chi−squared = 0.032
p = 0.984
Frequency
quarterly sweeping
monthly sweeping
biweekly sweeping


Kendalls Tau = −0.068, p = 0.717
Total Suspended Solids Concentration
(mg/L) at MONM (Base Events Only)
15
10
5
0
2017
2018
2019
Date
2020−02−25
a
a
a
quarterly
monthly
biweekly
Sweeping Frequency
2020−02−25
Kruskal−Wallis
Test Results:
chi−squared = 2.949
p = 0.229
Frequency
quarterly sweeping
monthly sweeping
biweekly sweeping

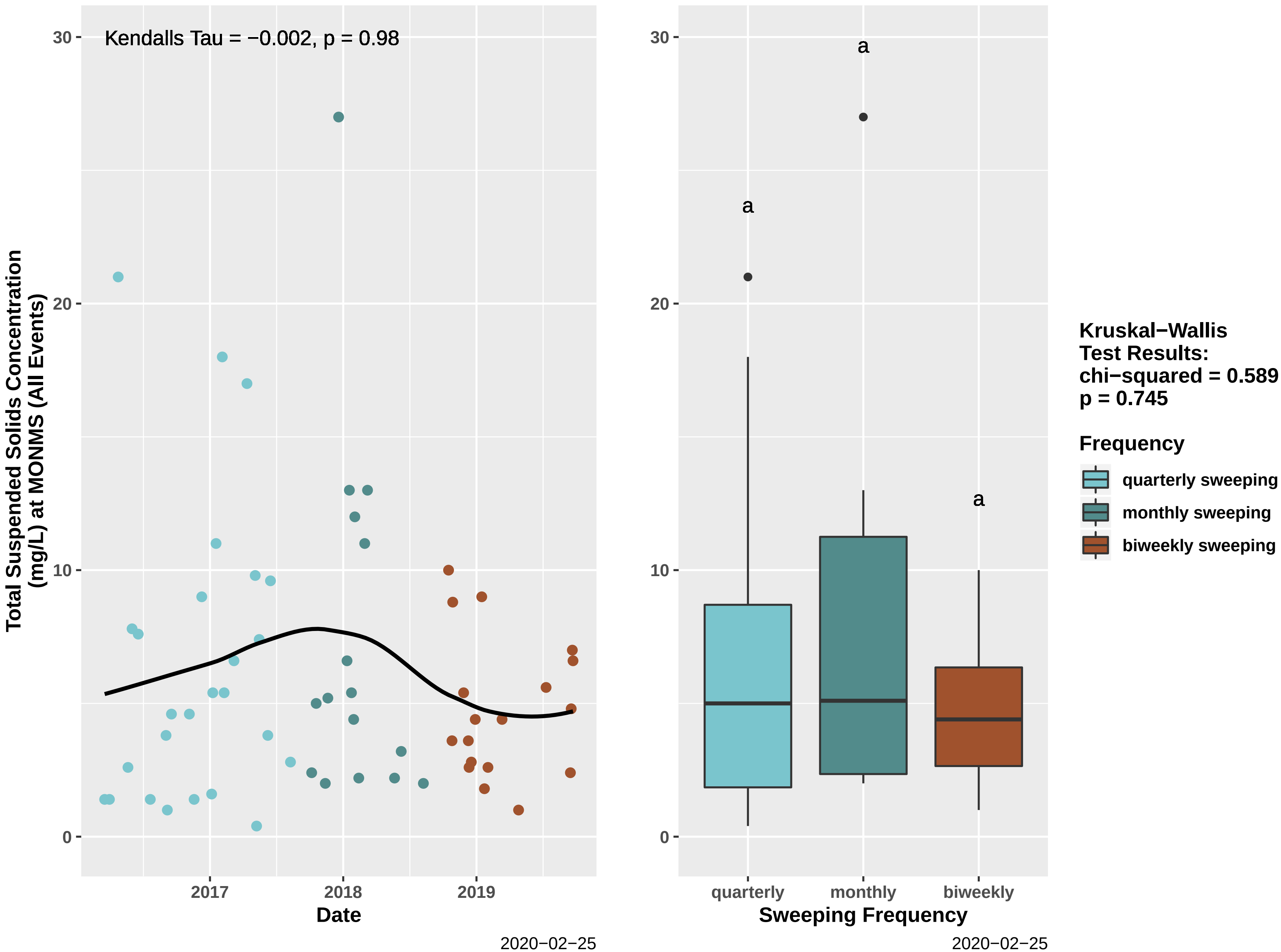

Kendalls Tau = 0.051, p = 0.57
Total Suspended Solids Concentration (mg/L) at MONMN (All Events)
0
50
100
150
200
2017
2018
2019
Date
2020−02−25
a
a
a
quarterly
monthly
biweekly
Sweeping Frequency
2020−02−25
Kruskal−Wallis Test Results:
chi−squared = 1.574
p = 0.455
Frequency
quarterly sweeping
monthly sweeping
biweekly sweeping



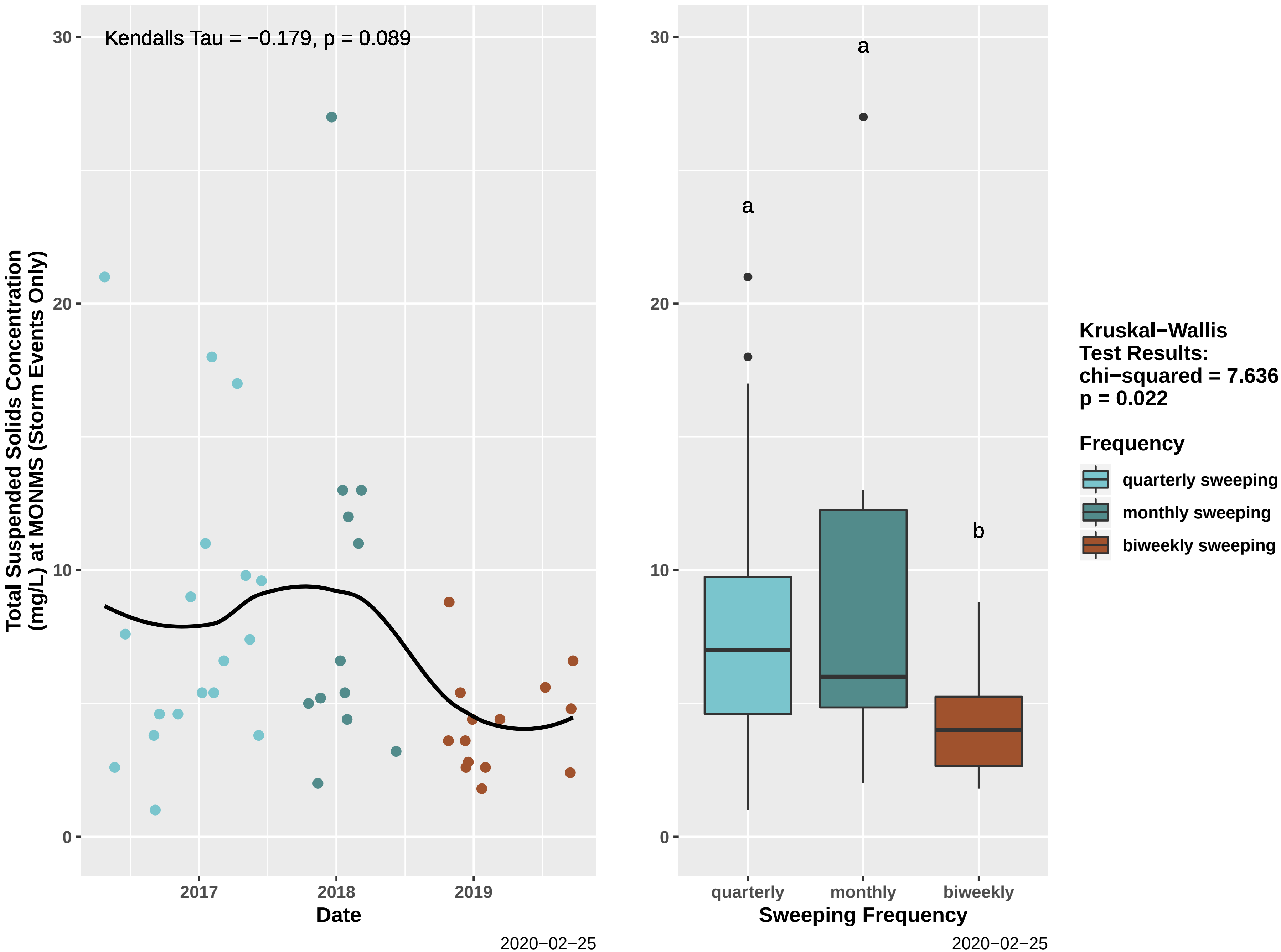
Kendalls Tau = 0.024, p = 0.816
Total Suspended Solids Concentration (mg/L) at MONMN (Storm Events Only)
200
150
100
50
0
2017
2018
2019
Date
2020−02−25
a
a
a
quarterly
monthly
biweekly
Sweeping Frequency
2020−02−25
Kruskal−Wallis Test Results:
chi−squared = 0.675
p = 0.714
Frequency
quarterly sweeping
monthly sweeping
biweekly sweeping



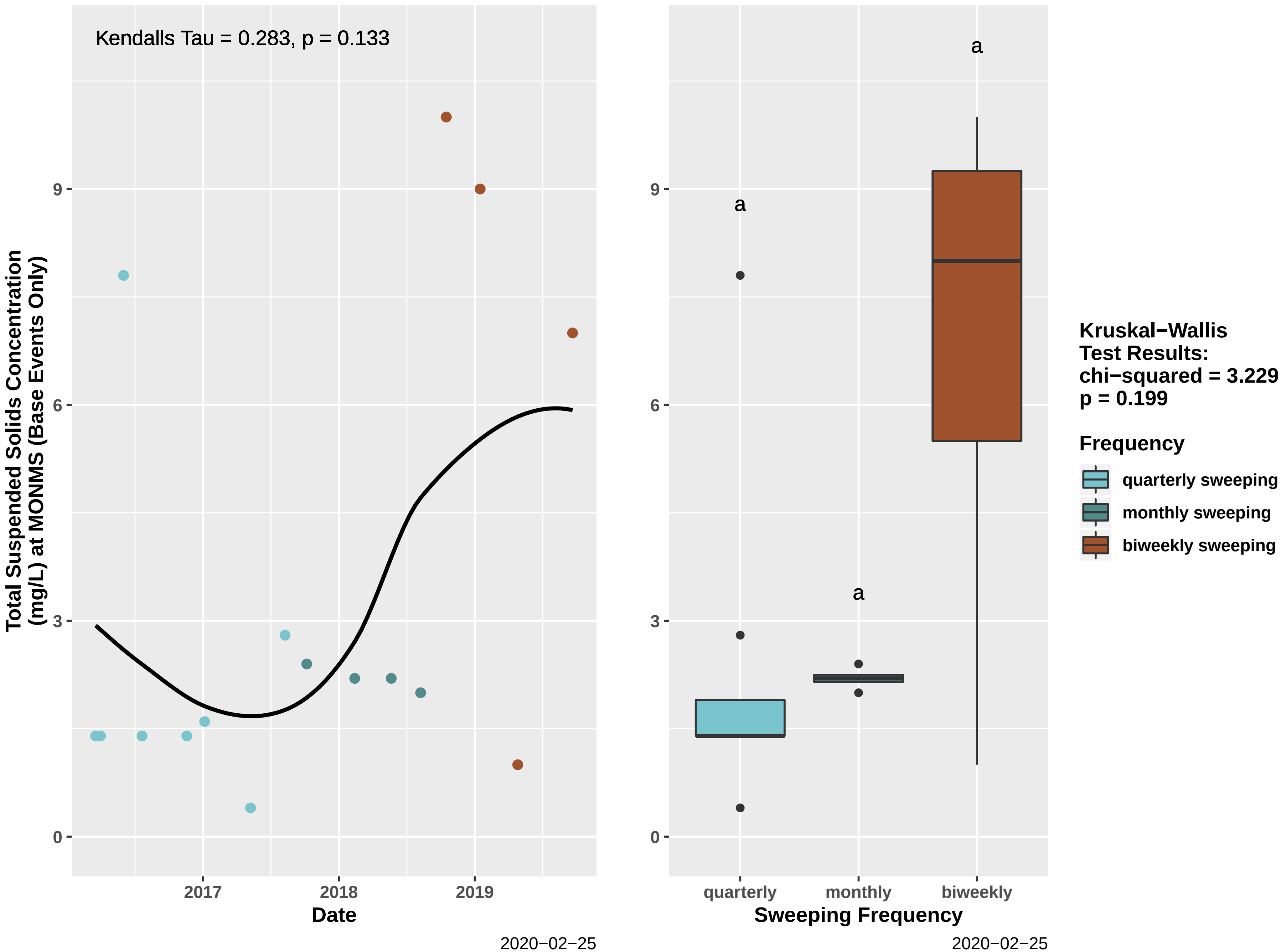
Kendalls Tau = −0.017, p = 0.928
Total Suspended Solids Concentration (mg/L) at MONMN (Base Events Only)
0
10
20
30
2017
2018
2019
Date
2020−02−25
a
a
a
quarterly
monthly
biweekly
Sweeping Frequency
2020−02−25
Kruskal−Wallis Test Results:
chi−squared = 0.082
p = 0.96
Frequency
quarterly sweeping
monthly sweeping
biweekly sweeping



Kendalls Tau = −0.002, p = 0.98
Total Suspended Solids Concentration
(mg/L) at MONMS (All Events)
30
20
10
0
2017
2018
2019
Date
2020−02−25
a
a
a
quarterly
monthly
biweekly
Sweeping Frequency
2020−02−25
Kruskal−Wallis
Test Results:
chi−squared = 0.589
p = 0.745
Frequency
quarterly sweeping
monthly sweeping
biweekly sweeping



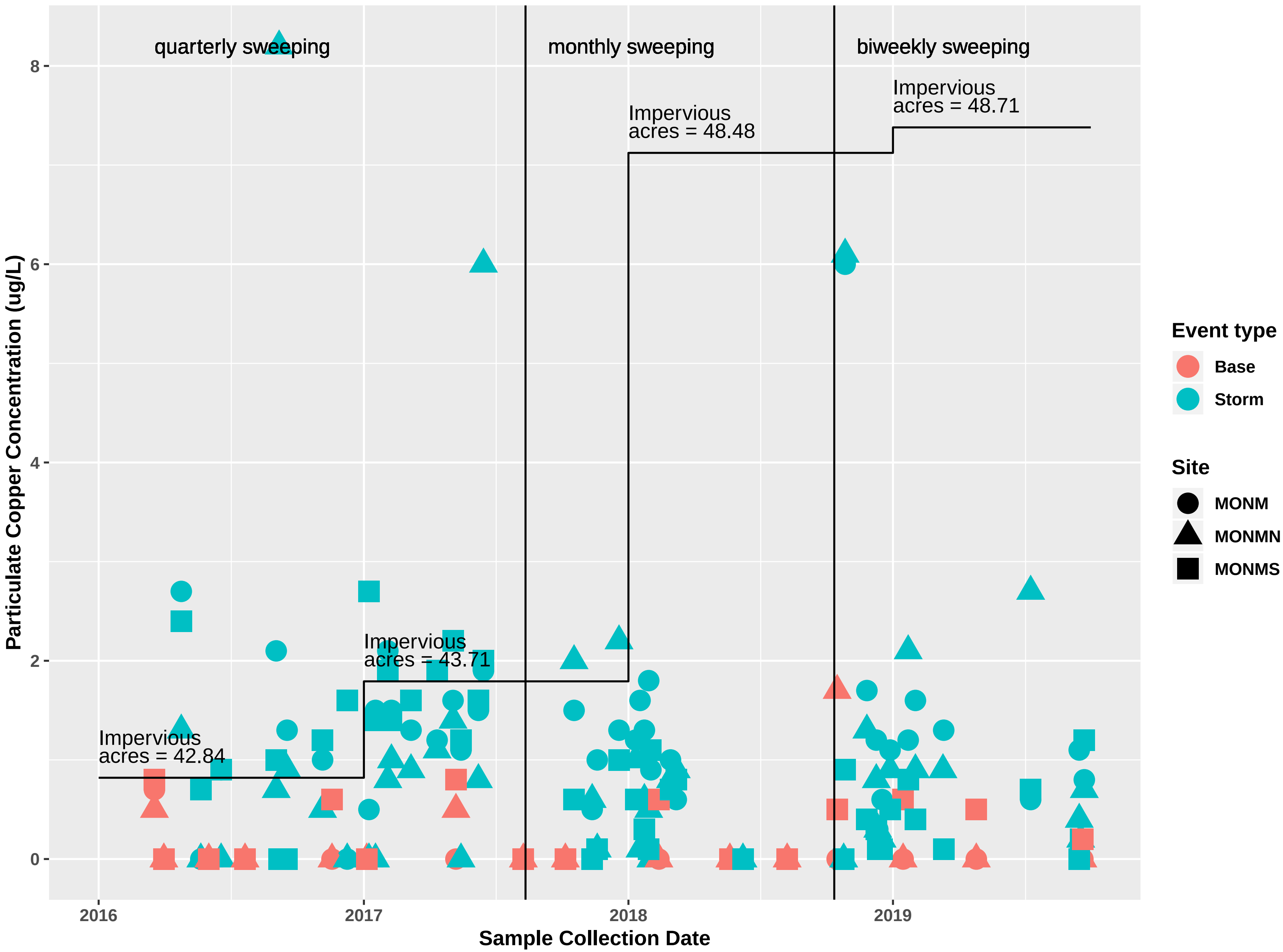
Kendalls Tau = −0.179, p = 0.089
30
20
10
0
Total Suspended Solids Concentration
(mg/L) at MONMS (Storm Events Only)
2017
2018
2019
Date
2020−02−25
a
a
b
quarterly
monthly
biweekly
Sweeping Frequency
2020−02−25
Kruskal−Wallis
Test Results:
chi−squared = 7.636
p = 0.022
Frequency
quarterly sweeping
monthly sweeping
biweekly sweeping

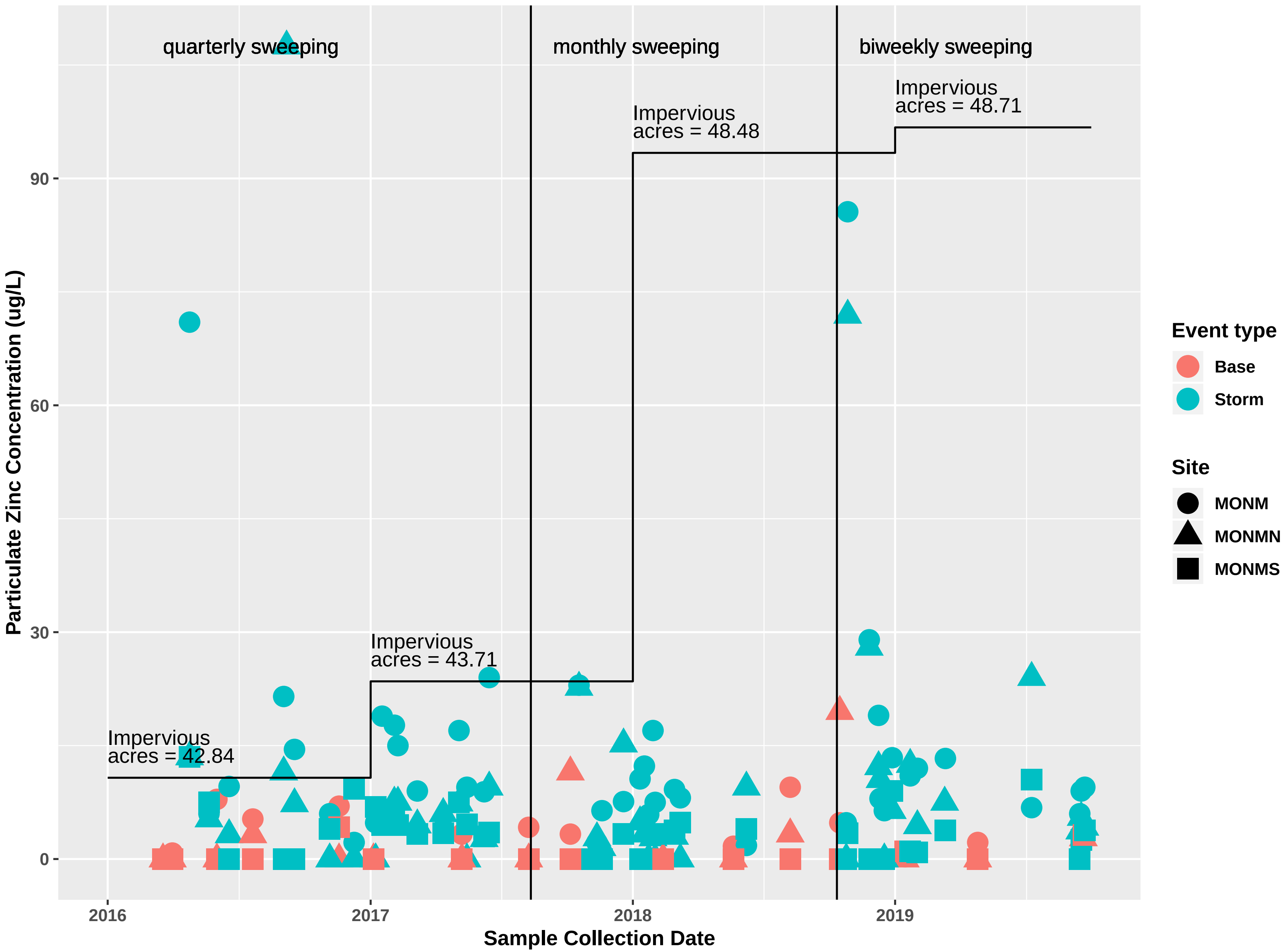


Kendalls Tau = 0.283, p = 0.133
Total Suspended Solids Concentration
(mg/L) at MONMS (Base Events Only)
0
3
6
9
2017
2018
2019
Date
2020−02−25
a
a
a
quarterly
monthly
biweekly
Sweeping Frequency
2020−02−25
Kruskal−Wallis
Test Results:
chi−squared = 3.229
p = 0.199
Frequency
quarterly sweeping
monthly sweeping
biweekly sweeping

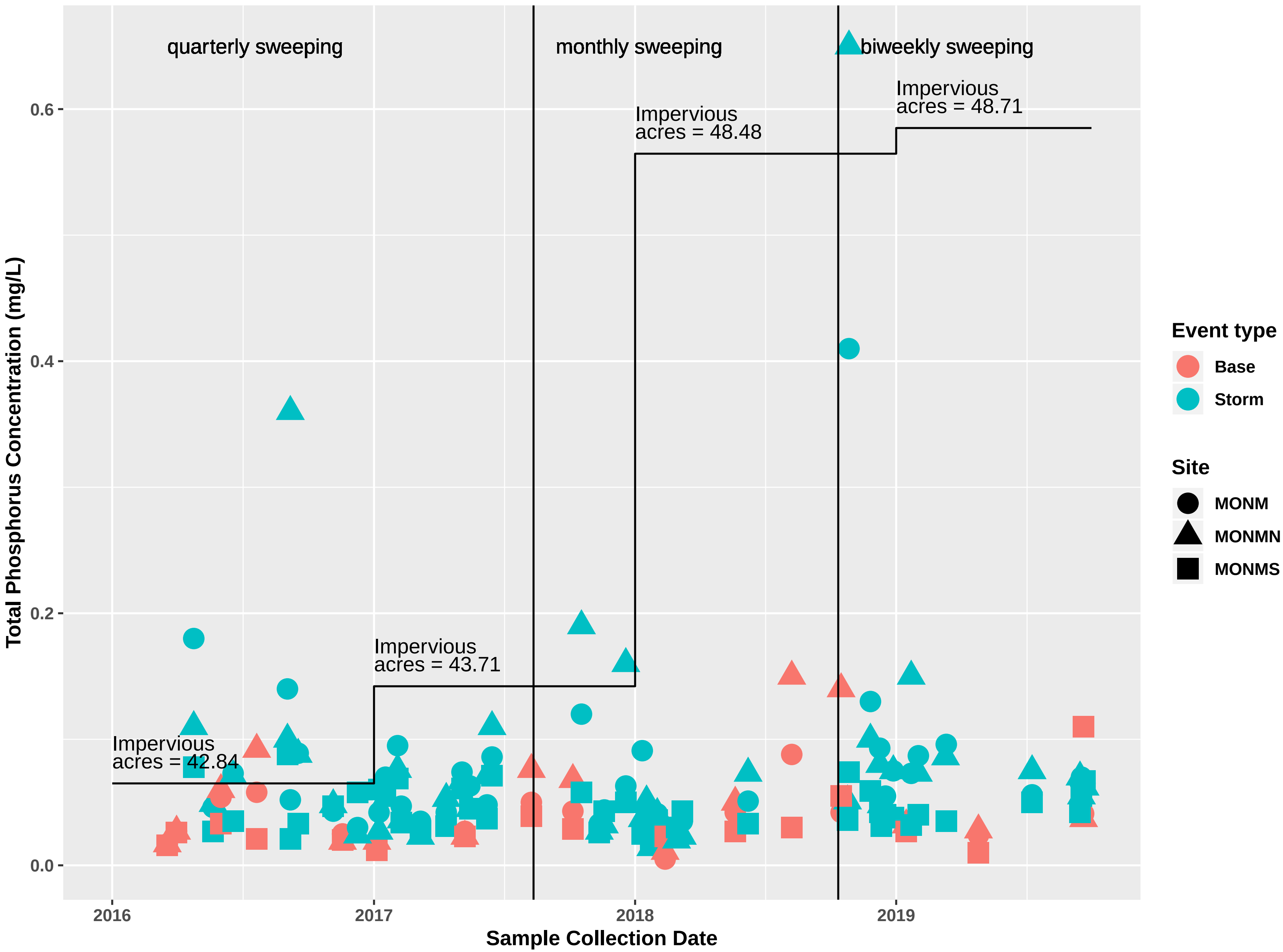
APPENDIX B

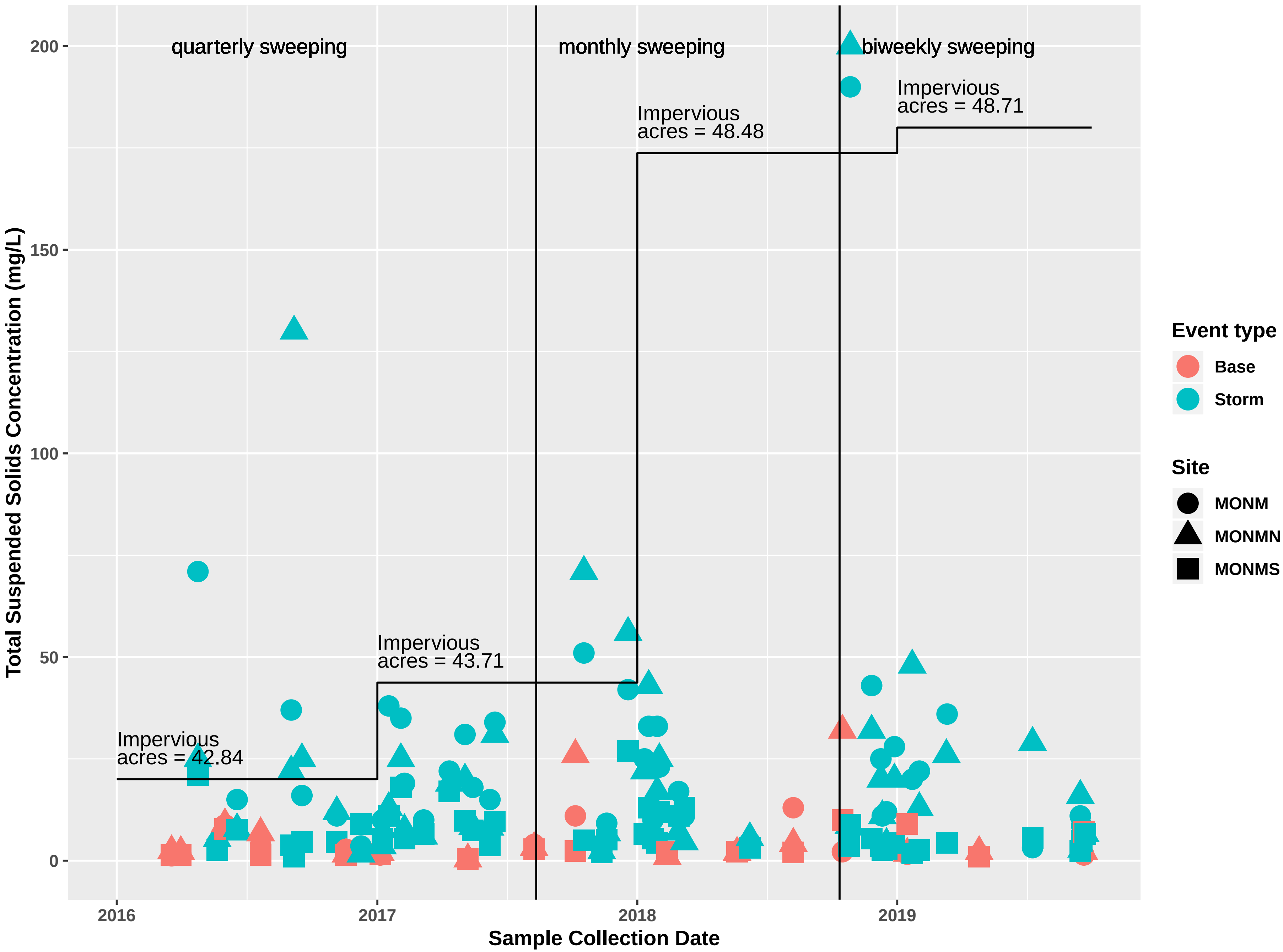
Temporal Plots


quarterly sweeping
monthly sweeping
biweekly sweeping
Impervious acres = 42.84
Impervious acres = 43.71
Impervious acres = 48.48
Impervious acres = 48.71
Particulate Copper Concentration (ug/L)
0
2
4
6
8
2016
2017
2018
2019
Sample Collection Date
Event type
Base
Storm
Site
MONM
MONMN
MONMS



quarterly sweeping
monthly sweeping
biweekly sweeping
Impervious acres = 42.84
Impervious acres = 43.71
Impervious acres = 48.48
Impervious acres = 48.71
Particulate Zinc Concentration (ug/L)
0
30
60
90
2016
2017
2018
2019
Sample Collection Date
Event type
Base
Storm
Site
MONM
MONMN
MONMS


quarterly sweeping
monthly sweeping
biweekly sweeping
Impervious acres = 42.84
Impervious acres = 43.71
Impervious acres = 48.48
Impervious acres = 48.71
Total Phosphorus Concentration (mg/L)
0.0
0.2
0.4
0.6
Sample Collection Date
2016
2017
2018
2019
Event type
Base
Storm
Site
MONM
MONMN
MONMS



quarterly sweeping
monthly sweeping
biweekly sweeping
Impervious acres = 42.84
Impervious acres = 43.71
Impervious acres = 48.48
Impervious acres = 48.71
Total Suspended Solids Concentration (mg/L)
0
50
100
150
200
2016
2017
2018
2019
Sample Collection Date
Event type
Base
Storm
Site
MONM
MONMN
MONMS