Report on maintenance, cleaning and *in situ* calibration of the BBFL2 instrument aboard the BC Ferries, Queen of Alberni

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1. Background:

Ocean Networks Canada installed a SeaKeeper 1000 system aboard the BC Ferries vessel, the Queen of Alberni, in May 2012. The ferry transits the Strait of Georgia between Duke Point (Vancouver Island) and Tsawwassen (mainland BC) ferry terminals up to 8 times daily. Surface seawater is pumped from an opening in the hull and through instruments housed in the SeaKeeper instrument box in the Boson's room. Instruments include an SBE Thermosalinograph (conductivity, temperature), Aanderaa oxygen optode, and a Wetlabs BBFL2 triplet (Chlorophyll fluorescence, CDOM fluorescence, and turbidity).

To date, at least 27 ferry maintenance trips have been documented by ONC staff (http://venus.uvic.ca/data/about-the-data/about-ferry-data/ferry-maintenance-information/). The first 18 trips, however, were not carried out on a regular basis. More recently (starting March 14, 2014), we have started a regular program of maintenance trips every 2 weeks (occasionally 3 weeks). We initiated this regular program in response to results of a report compiled by Chuning Wang (UBC) and Rich Pawlowicz (UBC) which documented a suite of instrument issues that in some instances appear to be related to bio-fouling of instruments and/or sedimentation within instrument housing. Of particular concern is the BBFL2 triplet which appears to be sensitive to both bio-fouling and sedimentation within its housing.

This report deals specifically with BBFL2 measurements from January 1, 2014 to July 18, 2014. An additional report outlining ONC actions/responses to all other instrument issues identified by Wang & Pawlowicz is in preparation. Here we: 1) address specific issues in the 2014 BBFL2 time series; 2) assess the value of regular instrument cleaning; and 3) address the potential application of *in situ* "calibrations" for correcting data for signal decay.

2. Methods:

A schedule of regular maintenance trips to the Queen of Alberni was initiated on March 14, 2014. The three instruments (SBE, Aanderaa optode, and BBFL2) are removed from the instrument box (Figure 1). All connections and tubing connecting instruments to the pump via the manifold are inspected for leaks or signs of corrosion. The housing for each instrument is dis-assembled in preparation for cleaning. We typically take photographs of the condition of the instrument box and each instrument prior to cleaning and these pictures are included in the maintenance report posted online a few days following each trip (http://venus.uvic.ca/data/about-the-data/about-ferry-data/ferry-maintenance-information/).

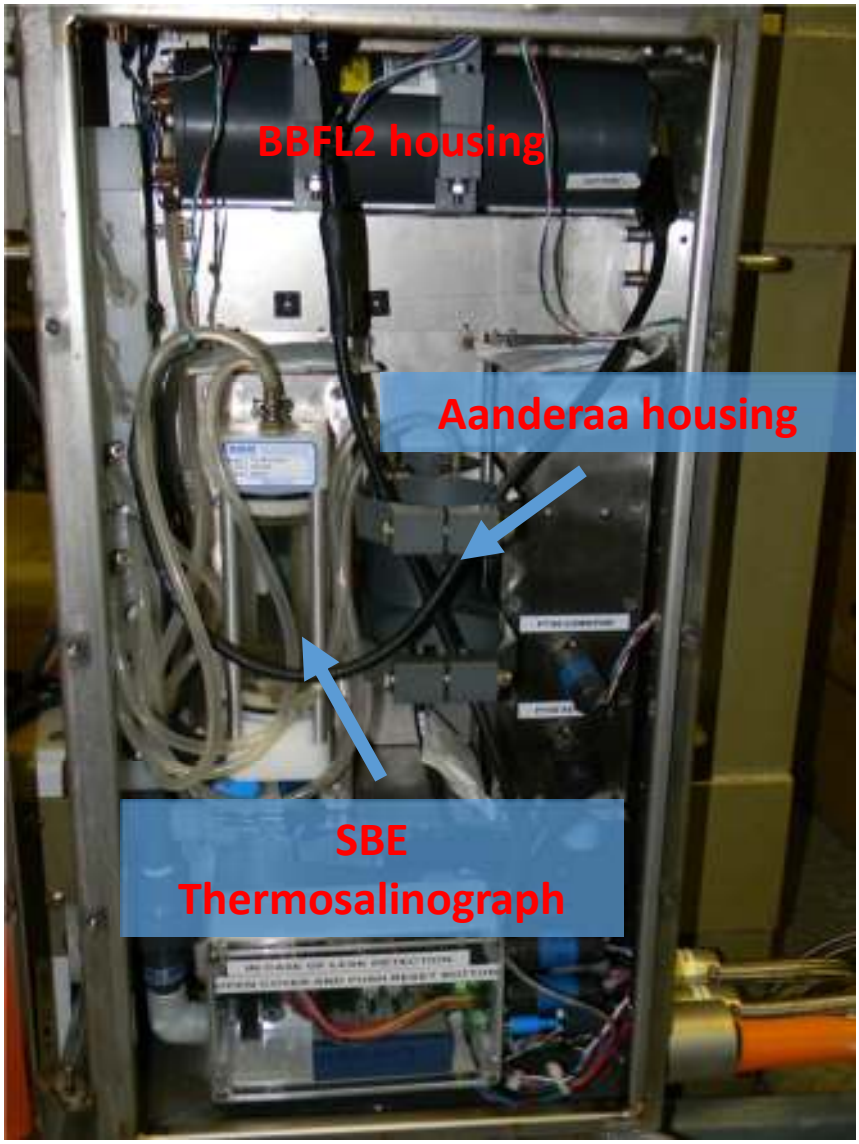

Figure 1. SeaKeeper 1000 instrument housing box in the Boson's room aboard the Queen of Alberni. The manifold leading from the pump to the three instruments is positioned vertically alongside the SBE Thermosalinograph. Tubing from the manifold to each instrument is replaced periodically (~every 6-8 weeks) depending on the degree of fouling.

Figure 2. Pictures of each instrument: A) SBE Thermosalinograph; B) Aanderaa optode and housing; and C) view looking down the BBFL2 housing; note that the instrument measuring face is the bottom surface. These photographs were taken on the most recent maintenance trip (July 18, 2014) and clearly indicate the potential for sediment accumulation and bio-fouling taking place in just 2 weeks following the previous cleaning (July 4, 2014).

We began a suite of pre- and post-cleaning BBFL2 measurements using a variety of solutions and solid standards starting on the March 27, 2014 maintenance trip (see Table 1). Our objective was to identify a means of calculating correction factors which could be applied retrospectively to the BBFL2 time series. We targeted both Coloured (or Chromophoric) Dissolved Organic Matter (CDOM) and Chlorophyll fluorescence (Chl). We are not aware of any turbidity standards that can be routinely used for this purpose. Our initial tests consisted of measurements of the Chl fluorescence of flattened Diet Coke and the CDOM fluorescence of flattened diluted tonic water. Solutions were poured into the BBFL2 housing and filled to 2 cm below the mouth. The end cap was replaced, and fluorescent measurements were made offline for a minimum of 60 seconds. We generally waited for a stable signal before recording raw counts, however, in some instances the recorded signal did not stabilize but decayed slowly. We have since realized that this decay is largely caused by the sedimentation of materials re-suspended in the housing by the solution. Later trips included 1 or 2 initial gentle rinses with distilled water before measuring the fluorescence of each standard solution. This initial rinse appears to have limited the signal decay and yielded a less variable measurement (See Tables 2,3, and 6); however, in some cases, materials were continuously sloughed off of the inside of the housing wall and the effects of sinking material were unavoidable. Over time we expanded our measurements to include fluorescent sticks specific to Chl (pink) and CDOM (blue). A specialized bracket was built to fit onto the housing end cap and holds the fluorescent sticks into place (see Figure 3). We have recently started to test Sprite Zero (CDOM) as a standard solution. All measurements are made offline before (Pre-) and after (Post-) cleaning.

Figure 3. Photographs of pink (left; appears orange with camera flash) and blue fluorescent sticks held in place on the end-cap bracket. The relative location along the bracket and position of the end cap was kept constant and corresponds to a mid-range fluorescent reading.

3. Results:

3.1. *CDOM fluorescence*: see Figure captions.

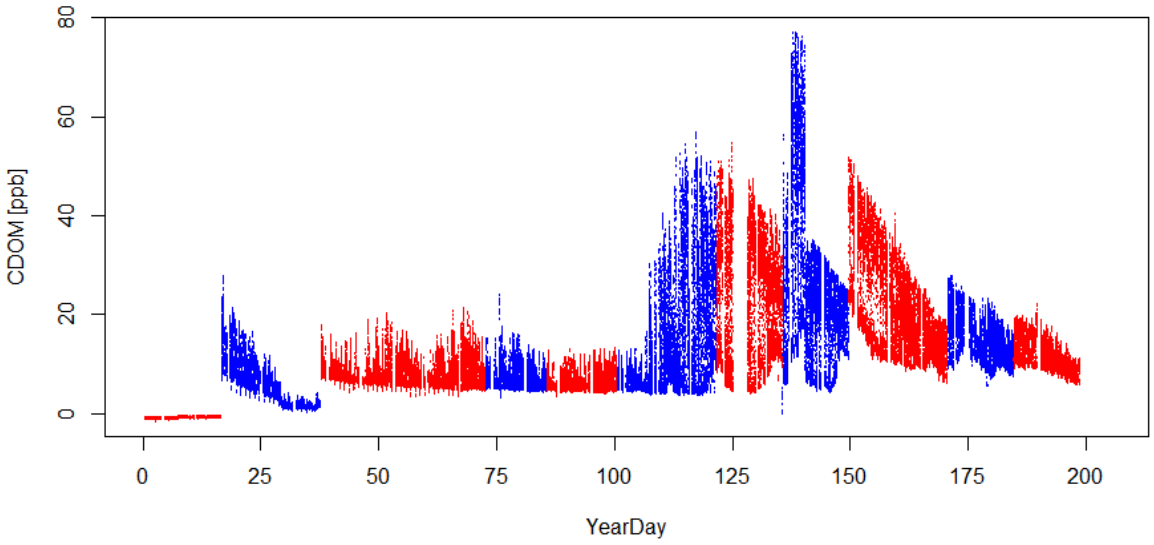

Figure 4. Temporal pattern of CDOM [ppb] (1 minute averaged) measured with the BBFL2 CDOM fluorescent sensor housed in the SeaKeeper 1000 system aboard the BC Ferries vessel, the Queen of Alberni. The periods between maintenance trips are distinguished by alternating red and blue symbols. No corrections have been applied to the measurements illustrated above. Notable activities or events are listed in Table 1. Of particular note are 3 events: 1) the BBFL2 was repositioned from a vertical (i.e. measuring surface facing up within housing) to a horizontal attitude (Day 37; note signal decay leading up to this day); 2) CPU temperature increased to out of range values resulting in the noticeable spike in values starting immediately following instrument cleaning (Day 135); and 3) although CPU temperatures returned to a normal range; the instrument (BBFL2-786) was replaced (BBFL2-787) and resulted in an increased sensitivity of CDOM measurements. Note also the change in baseline following the instrument swap. Cleaning of the instrument was carried out on a nearly 2-week basis following Day 37. The day 37-149 period is characterized by little indication of signal decay. Following installation of BBFL2-787, CDOM values tend to show marked improvement between cleanings; suggesting a period of rapid sediment accumulation and bio-fouling.

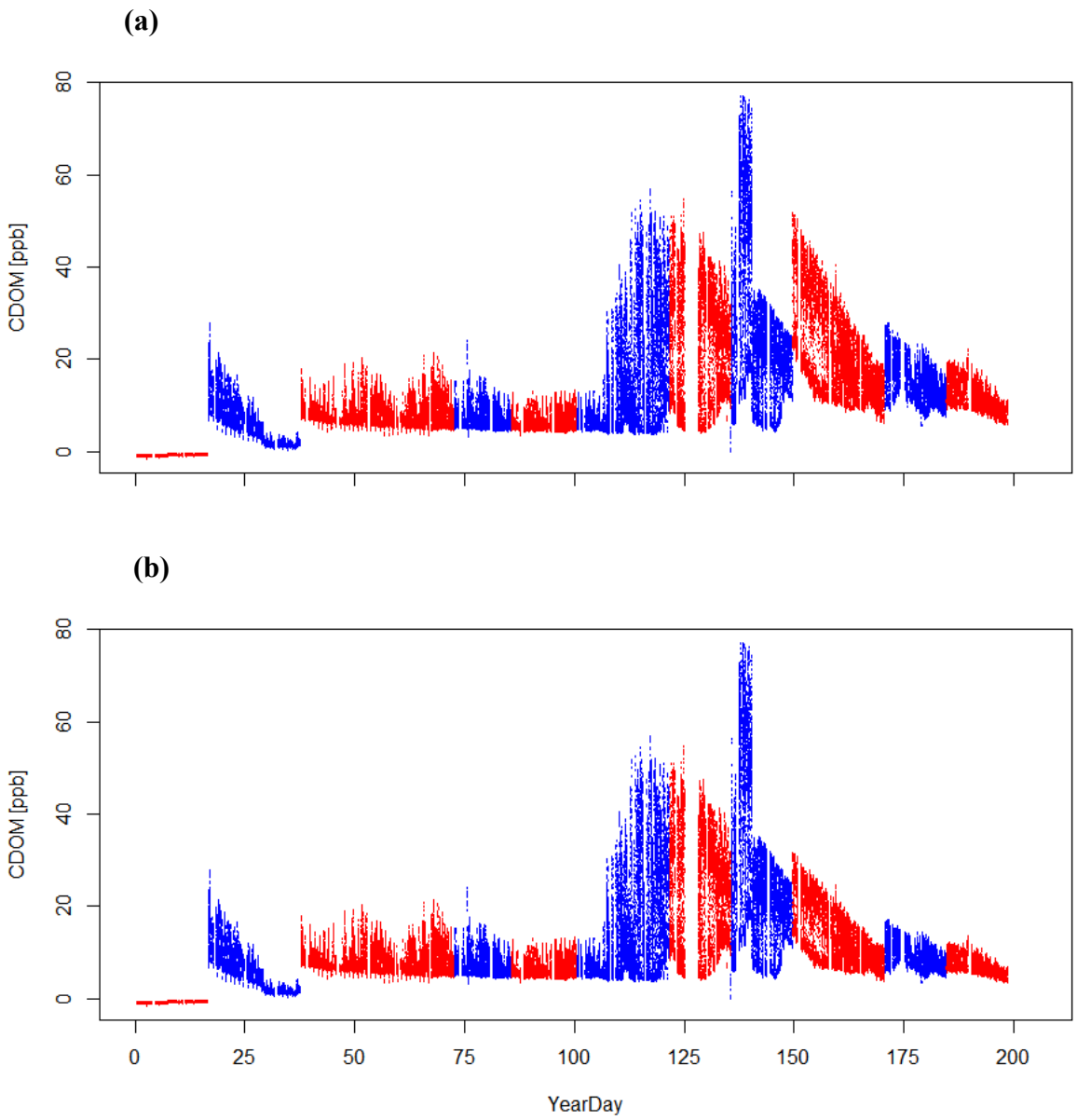

Figure 5. a) CDOM no correction (as in Figure 4) b) CDOM with all BBFL2-787 1 minute averaged values multiplied by a correction factor (CF) of 0.608. The CF was calculated as the ratio of the raw CDOM fluorescence of Sprite Zero measured by the BBFL2-786 and BBFL2-787 with the same solution and within 24 hours. The BBFL2 was swapped out on day 149, and the increased sensitivity is evident in (a). The correspondence between the two instruments is improved after applying the CF to the post-swap time series (b). Note, that the baseline measurements following the instrument swap were elevated and are improved following correction. The CF was applied to the BBFL2-787 time series arbitrarily, and the choice of which instrument time series to correct needs to be more fully explored.

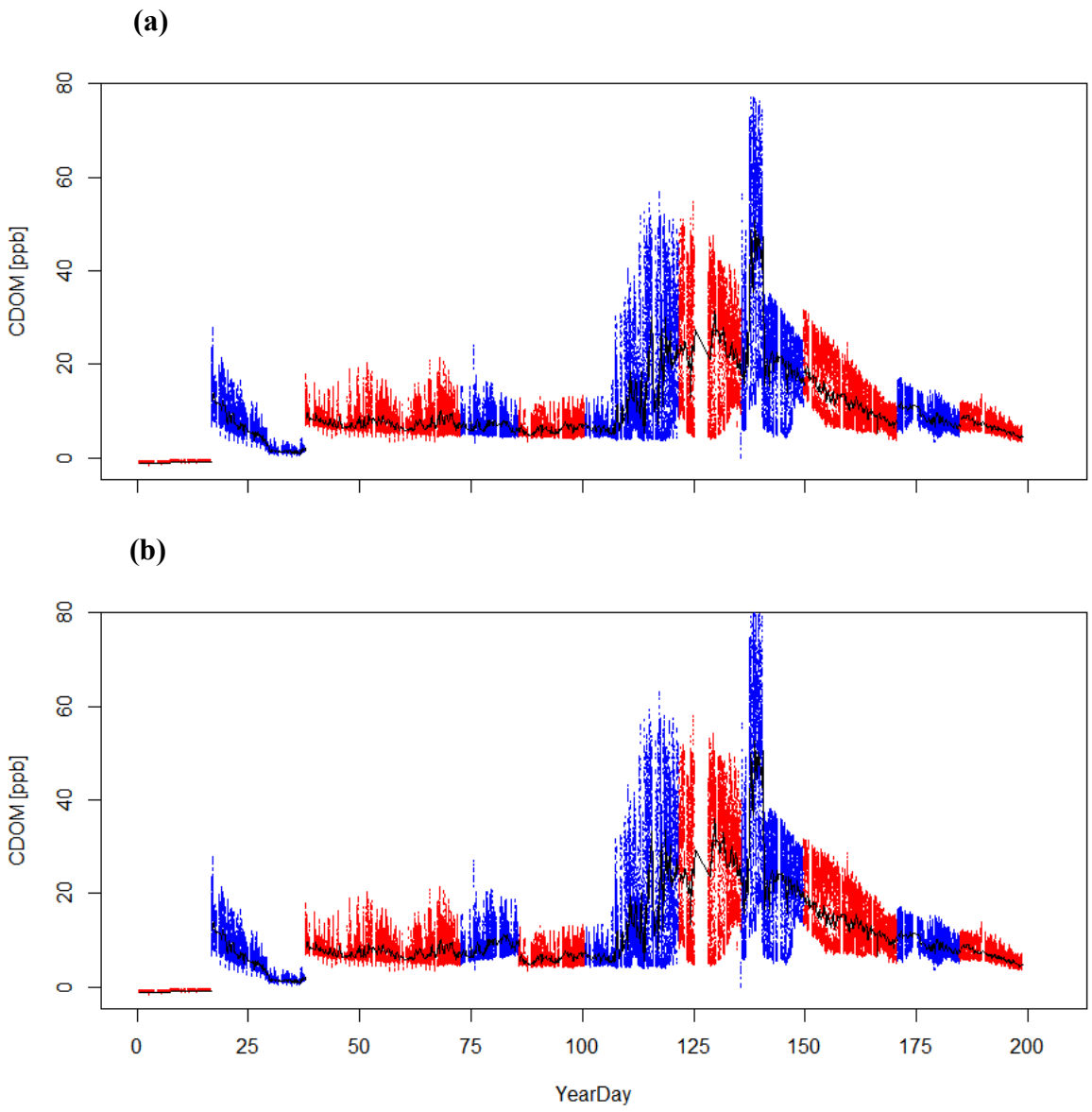

Figure 6. Time series of CDOM fluorescence measurements before (a) and after (b) correction for the relative (%) change in pre- and post-cleaning fluorescence of diluted tonic water. Red and blue symbols used to identify periods between successive maintenance trips. The black line represents the mean values for each ferry crossing. CDOM values across the time series have been normalized for differences in instrument sensitivity (see Figure 5). No other correction has been applied to panel (a); whereas, panel (b) represents the time series where the % change (see Table 2) has been applied retrospectively as a linear correction going back to the start of the first ferry transit following instrument cleaning. The tonic water correction appears to work well. This is particularly evident for the last three periods where signal decay between cleaning is evident. It is not clear, however, why the first measurements with diluted tonic water (applied retrospectively from day 85) were too extreme.

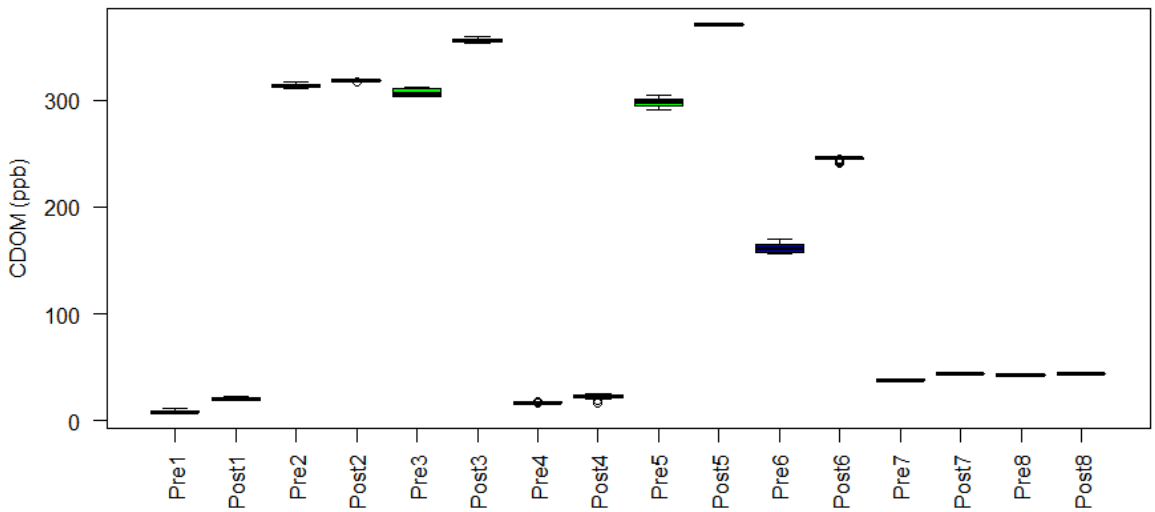

Figure 7. Box-plots of mean pre- and post- cleaning measurements (see Table 1 for specific dates) of CDOM fluorescence diluted tonic water. Mean values, standard errors and the % change between pre- and post- cleaning measurements are listed in Table 2. The difference between pre- and post-cleaning measurements was always positive (i.e. cleaning improved the signal). Lack of consistency between post-cleaning values is due to differences in the dilution of tonic water used.

3.2.*Chl fluorescence and turbidity backscatter*: see Figure captions.

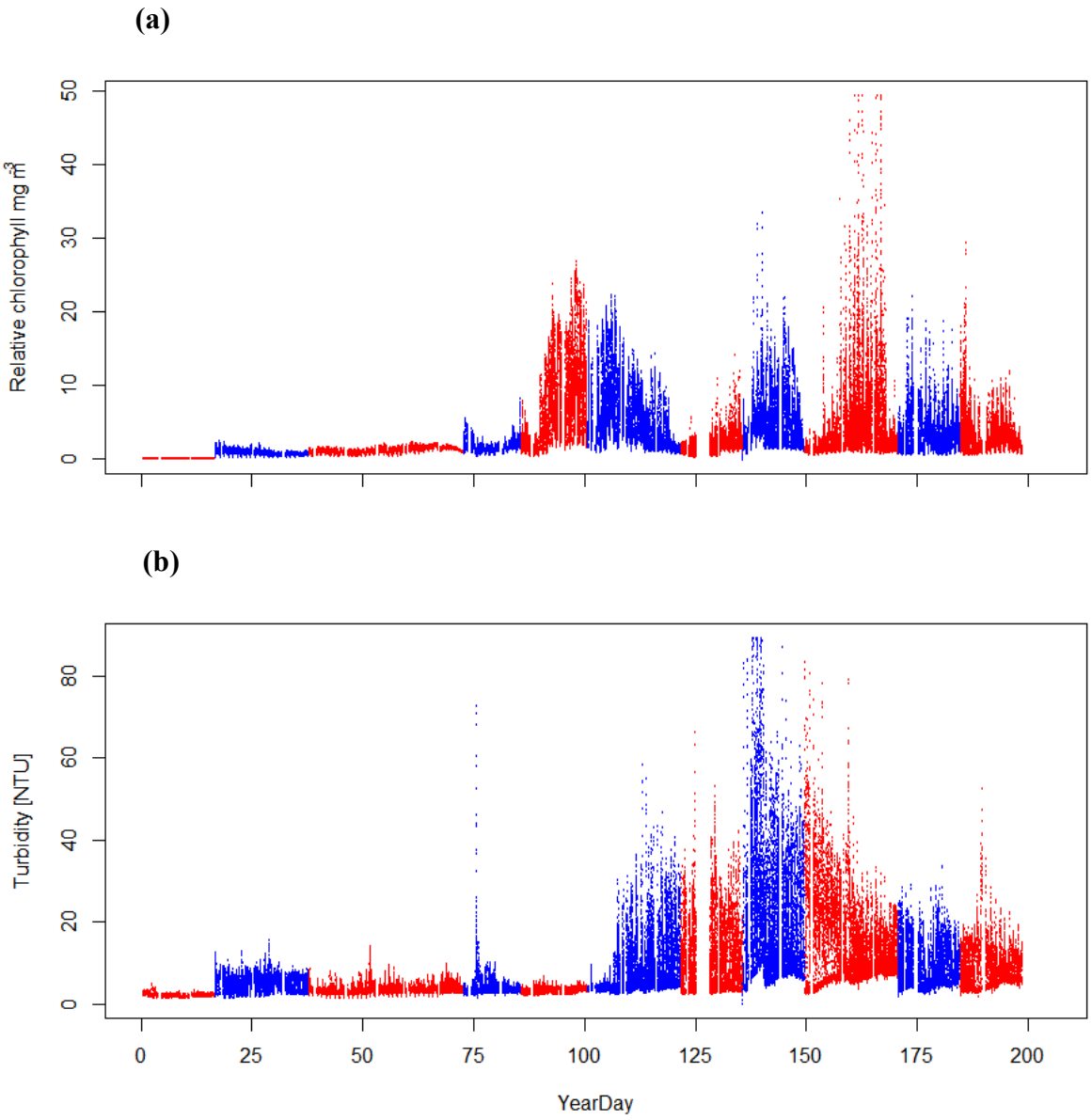

Figure 8. Temporal patterns of a) chlorophyll [mg m^{-3}] and b) turbidity [NTU] values measured with BBFL2 fluorescence and backscatter sensors housed in the SeaKeeper 1000 system aboard the BC Ferries vessel, the Queen of Alberni. The periods between maintenance trips are distinguished by alternating red and blue symbols. No corrections have been applied to either of the time series illustrated above. No obvious Chl fluorescence response to cleaning following the start of our regular maintenance time series (post Day 35). Clear jump in Chl fluorescence signal following re-orientation of the instrument, however the signal clearly decays over the following 35 days. There is some indication that the CPU temperature problem starting day 149 inflated Chl values. The CPU temperature issue is more apparent for turbidity (see below for specific discussion of CPU temperature issues). Baseline turbidity values clearly increase with time

between cleanings following instrument swap. This pattern is similar (but opposite) to the same period for CDOM, indicative of increased sediment accumulation and the negative influence of sediment on CDOM fluorescence values.

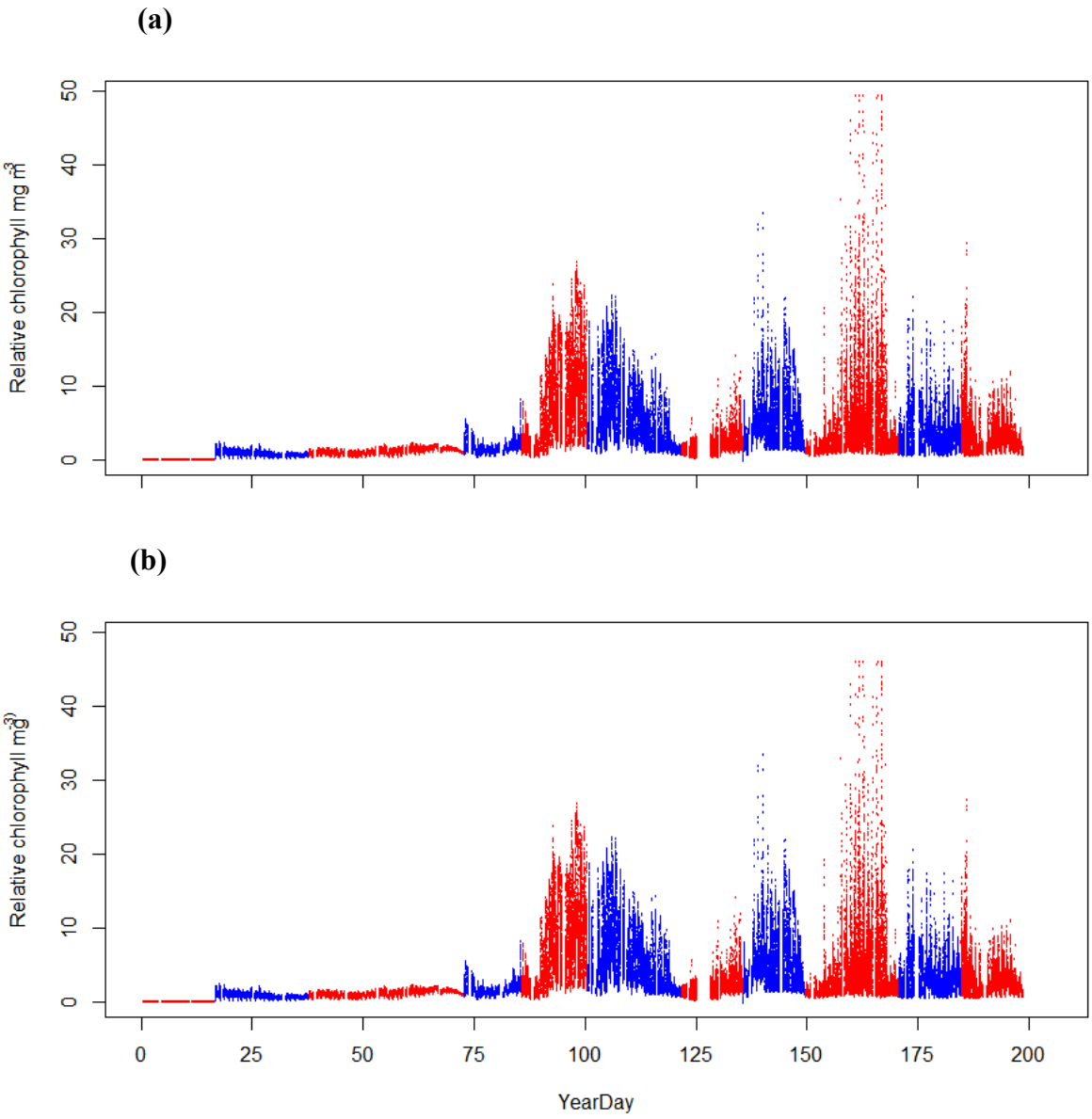

Figure 9. a) Chl time series with no correction (as in Figure 8a) b) Chl with all BBFL2-787 1 minute averaged values multiplied by a correction factor (CF) of 0.931. The CF was calculated as the ratio of the raw Chl fluorescence of Diet Coke measured by the BBFL2-786 and BBFL2-787 with the same solution and within 24 hours. The BBFL2 was swapped out on day 149, and no obvious change in sensitivity is evident in (a). The modest CF has little impact on the differences between post-swap time series with and without the CF. The CF was applied to the

BBFL2-787 time series arbitrarily, and the choice of which instrument time series to correct needs to be more fully explored.

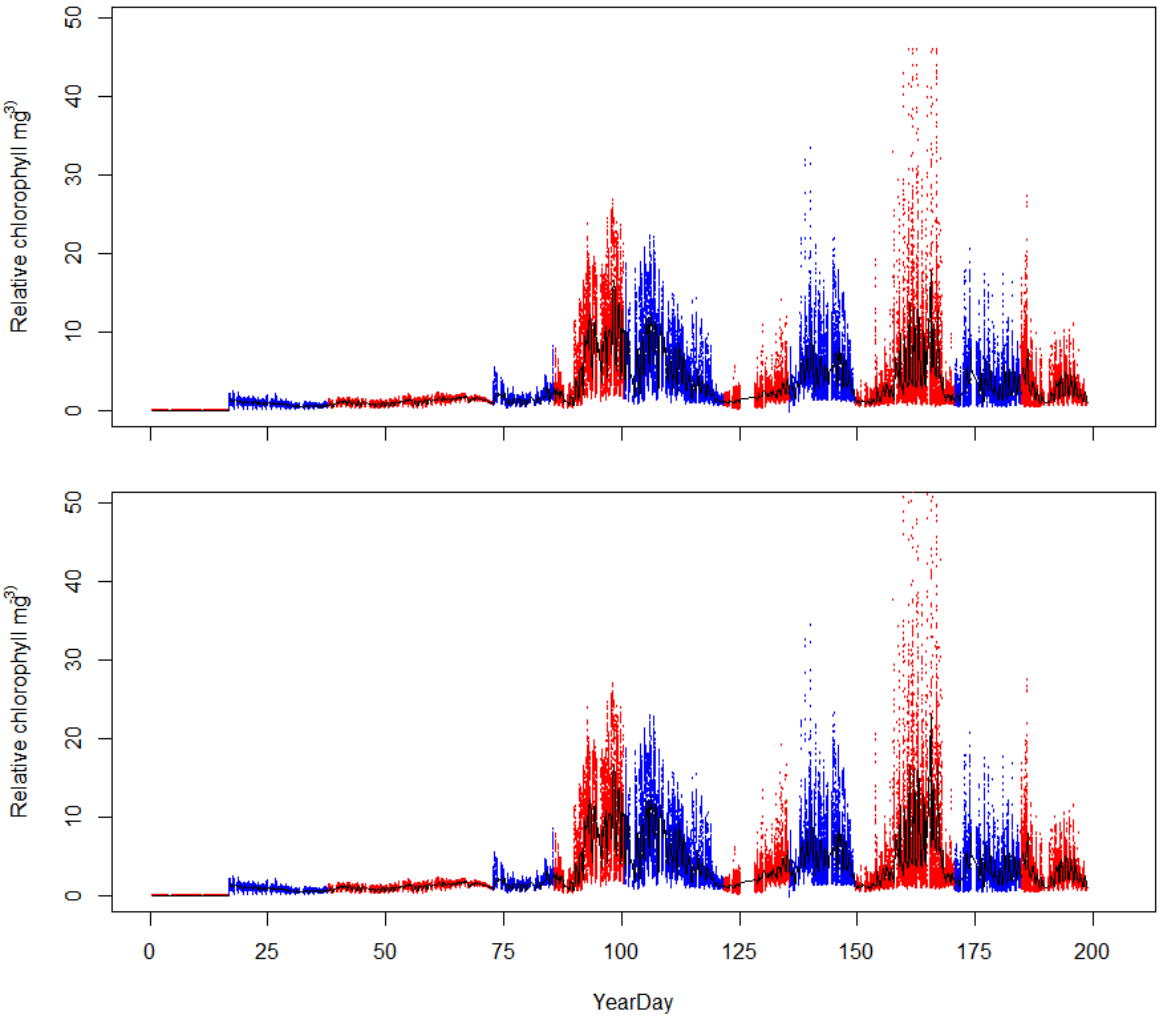

Figure 10. Time series of Chl fluorescence measurements before (a) and after (b) correction for the relative (%) change in pre- and post-cleaning fluorescence of Diet Coke. Red and blue symbols used to identify periods between successive maintenance trips. The black line represents the mean values for each ferry crossing. Chl values across the time series have been normalized for differences in instrument sensitivity (see Figure 9). No other correction has been applied to panel (a); whereas, panel (b) represents the time series where the % change (see Table 3) has been applied retrospectively as a linear correction to the first ferry transit following instrument cleaning. The relative change in diet coke fluorescence pre- and post- cleaning was typically moderate (see Table 3 and Figure 11) and yields little difference between the two time series illustrated above.

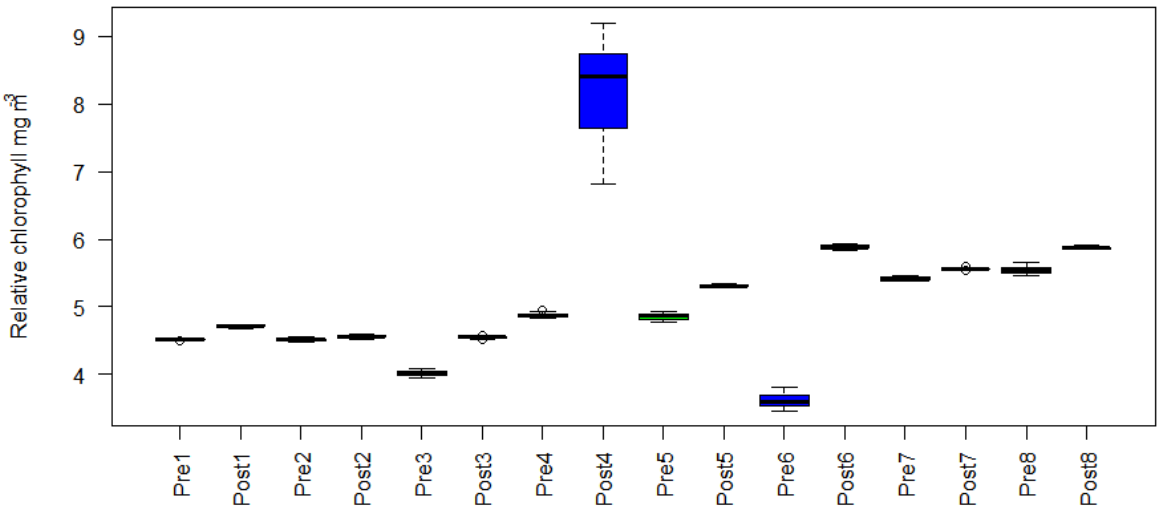

Figure 11. Box-plots of mean pre- and post- cleaning measurements (see Table 1 for specific dates) of Chl fluorescence of Diet Coke. Mean values, standard errors and the % change between pre- and post- cleaning measurements are listed in Table 3. The difference between pre- and post-cleaning measurements was always positive (i.e. cleaning improved the signal). In contrast to tonic water, no dlution of Diet Coke was necessary. Post-cleaning values are fairly consistent. The exceptionally high value post-cleaning 4, represents the CPU temperature malfunction and the resulting CF should not be used. Elevated (>5 mg m^{-3}) post-cleaning values begin on the date of instrument swap. Indicating a moderate difference the sensitivity of the Chl fluorometers in the BBFL2 786 and BBFL2 787 units.

3.3 *Additional measurements*: see Figure captions.

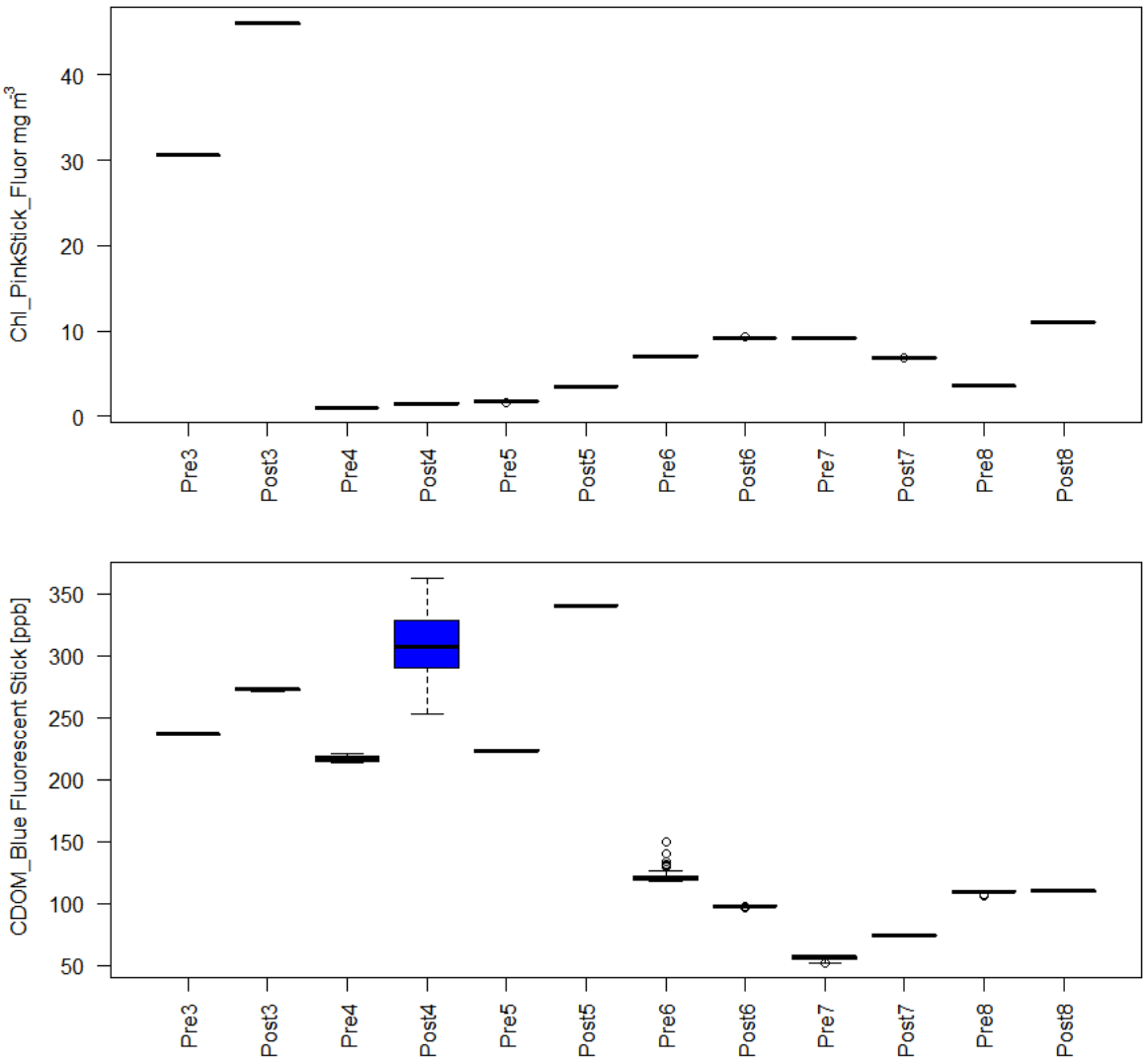

Figure 12. Box-plots of mean pre- and post- cleaning measurements (see Table 1 for specific dates) of Chl fluorescence pink fluorescent stick and CDOM fluorescence blue fluorescent stick. Mean values, standard errors and the % change between pre- and post- cleaning measurements are listed in Tables 4 and 5. The difference between pre- and post-cleaning measurements is typically positive for both measurements. However, a negative response was measured once for both instruments (different dates). The pink fluorescent stick apears to perform better than the blue stick. The temporal pattern for the pink stick is similar to that of Diet Coke. The blue stick on the other hand, is not especially consistent. Some (or perhaps much) of this lack of consistency can attributed to the very sensitive reposnse of the instrument to even substle changes in the rotation of the end-cap holding the fluorescent stick.

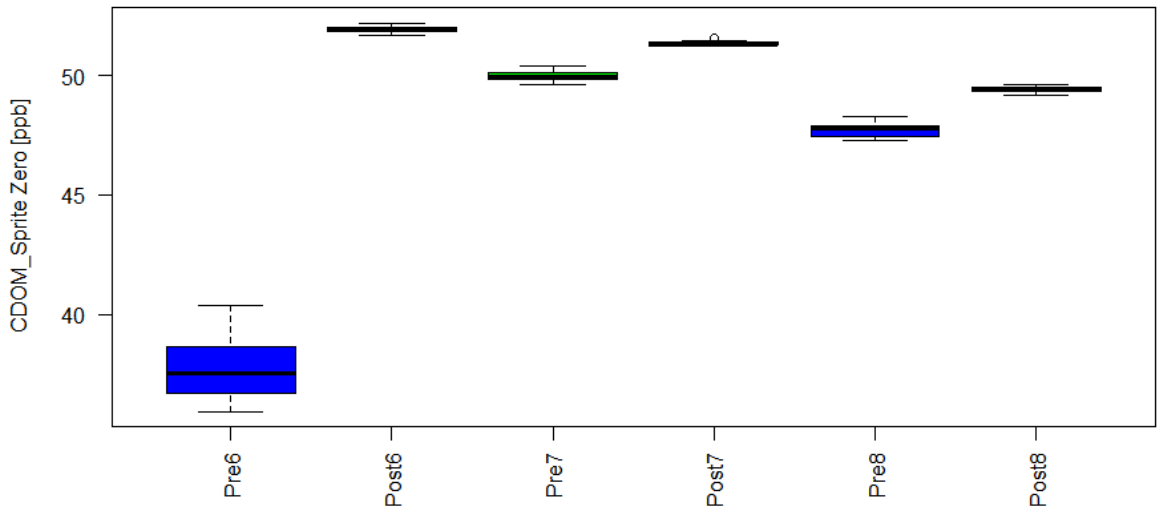

Figure 13. Box-plots of mean pre- and post- cleaning measurements (see Table 1 for specific dates) of CDOM fluorescence of Sprite Zero. Mean values, standard errors and the % change between pre- and post- cleaning measurements are listed in Table 6. The difference between pre- and post-cleaning measurements is positive for this time series. We have recently started to use this solution in order test its potential as a replacement for tonic water. The major advantage being, that Sprite Zero does not require diltuion and may serve as a useful measure (similar to Diet Coke) of long term instrument calibration.

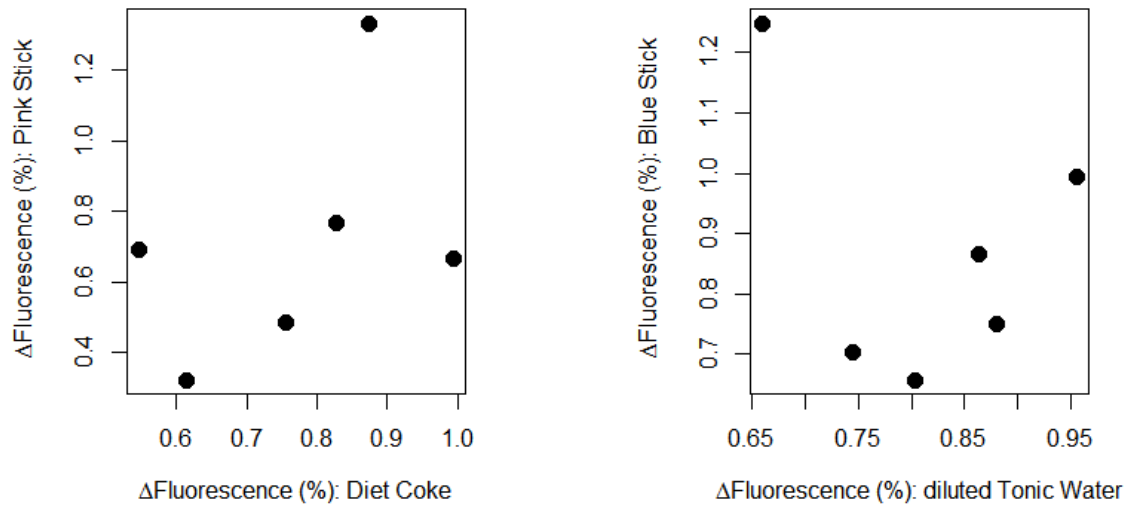

Figure 14. Comparisons of the relative difference between pre- and post-cleaning fluorescence for, a) the pink fluorescent stick and Diet Coke (Chl fluorescence); and b) the blue fluorescent stick and diluted Tonic Water (CDOM fluorescence). The relationship for Chl fluorescence (a) is positive but not significant. The relationship for CDOM fluorescence (b) is neither positive nor significant. This relationship does become positive by dropping the single D blue stick point >1, however, the relationship remains non-significant. The positive relationships indicate a generally similar response of sticks and solutions (as depicted in their respective boxplots), however, as discussed earlier, the fluorescent stick values suffer from logistical issues.

Date	YearDay	Days since last visit	Major Actions	Pre/Post designation
1/17/14	16	38	Cleaning	
2/7/14	37	21	BBFL2: Vertical to horizontal orientation; Cleaning	
3/14/14	72	35	Cleaning	
3/27/14	85	13	Initiated Diet Coke&Tonic water time series; Cleaning	Pre/Post1
4/11/14	100	15	Cleaning	Pre/Post2
5/2/14	121	21	Initiated Pink and Blue Fluorescent Stick time series; Cleaning	Pre/Post3
5/16/14	135*	14	CPU temp problems post; Cleaning	Pre/Post4
5/30/14	149**	14	BBFL2 unit swap; Cleaning	Pre/Post5
6/20/14	170	21	Initiated Sprite Zero time series; Cleaning	Pre/Post6
7/4/14	184	14	Cleaning	Pre/Post7
7/18/14	198	14	Cleaning	Pre/Post8

Table 1.

Date	YearDay	Days since last visit	Pre-cleaning flour (CDOM [ppb]; mean±SEM)	Post-cleaning flour (CDOM [ppb]; mean±SEM)	Δ fluor (%)
3/27/14	85	13	8.72±0.13	20.62±0.078	0.58
4/11/14	100	15	313.6±0.199	317.99±0.015	0.01
5/2/14	121	21	307.08±0.46	355.44±0.176	0.14
5/16/14	135*	14	17.29±0.016	23.22±0.156	0.26
5/30/14	149**	14	297.86±0.551	370.87±0	0.20
6/20/14	170	21	161.73±0.508	245.05±0.118	0.34
7/4/14	184	14	38.45±0.029	43.7±0.015	0.12
7/18/14	198	14	42.62±0.023	44.58±0.013	0.04

Table 2. CDOM fluorescence; diluted tonic water

Date	YearDay	Days since last visit	Pre-cleaning flour (Chl μg L^{-1}; mean±SEM)	Post-cleaning flour (Chl μg L-1; mean±SEM)	Δ fluor (%)
3/27/14	85	13	4.51±0.002	4.72±0.001	0.04
4/11/14	100	15	4.52±0.002	4.56±0.002	0.01
5/2/14	121	21	4.01±0.004	4.55±0.002	0.12
5/16/14	135*	14	4.87±0.003	8.26±0.064	0.41
5/30/14	149**	14	4.86±0.005	5.31±0.002	0.08
6/20/14	170	21	3.61±0.012	5.88±0.002	0.39
7/4/14	184	14	5.42±0.003	5.56±0.002	0.03
7/18/14	198	14	5.54±0.006	5.87±0.002	0.06

Table 3. Chlorophyll fluorescence; Diet Coke

Date	YearDay	Days since last visit	Pre-cleaning flour (Chl μg L^{-1}]; mean±SEM)	Post-cleaning flour (Chl μg L^{-1} mean±SEM)	Δ fluor (%)
5/2/14	121	21	30.58±0.013	46±0.009	0.34
5/16/14	135*	14	1.02±0.002	1.48±0.008	0.31
5/30/14	149**	14	1.68±0.002	3.47±0.008	0.52
6/20/14	170	21	7.06±0.008	9.19±0.003	0.23
7/4/14	184	14	9.18±0.003	6.89±0.003	-0.33
7/18/14	198	14	3.53±0.01	10.98±0.002	0.68

Table 4. Chlorophyll fluorescence; pink fluorescent stick

Date	YearDay	Days since last visit	Pre-cleaning flour (CDOM [ppb]; mean±SEM)	Post-cleaning flour (CDOM [ppb]; mean±SEM)	Δ fluor (%)
5/2/14	121	21	236.52±0.035	272.85±0.094	0.13
5/16/14	135*	14	216.8±0.276	308.07±2.014	0.30
5/30/14	149**	14	223.63±0.06	340.39±0.082	0.34
6/20/14	170	21	122.24±0.666	98.02±0.04	-0.25
7/4/14	184	14	55.91±0.253	74.47±0.026	0.25
7/18/14	198	14	109.32±0.131	109.97±0.036	0.01

Table 5. CDOM fluorescence; blue fluorescent stick

Date	YearDay	Days since last visit	Pre-cleaning flour (CDOM [ppb]; mean±SEM)	Post-cleaning flour (CDOM [ppb]; mean±SEM)	Δ fluor (%)
6/20/14	170	21	37.72±0.154	51.95±0.015	0.27
7/4/14	184	14	49.97±0.026	51.35±0.014	0.03
7/18/14	198	14	47.74±0.036	49.41±0.013	0.08

Table 6. CDOM fluorescence; Sprite Zero

4. BBFL2 CPU temperature malfunction (May 16th – 22nd May 2014):

After a routine cleaning visit on May 16th 2014 the BBFL2 triplet began giving elevated and highly suspicious data readings for a still unknown reason. It was noticed that a non-data channel that had previously given consistent reading of ~530 had jumped to well over 1000. WetLabs was contacted and advised that this data stream was "CPU Temp Counts" and that values in this range were indeed anomalies and the instrument should be replaced. Plans were made to replace the instrument on the next visit planned for May 30th but by May 22nd the "CPU Temp Counts" had returned to its previous value of ~530 and the data seemed reasonable again. Regardless of this change the instrument was replaced with a new one on the May 30th cleaning trip.

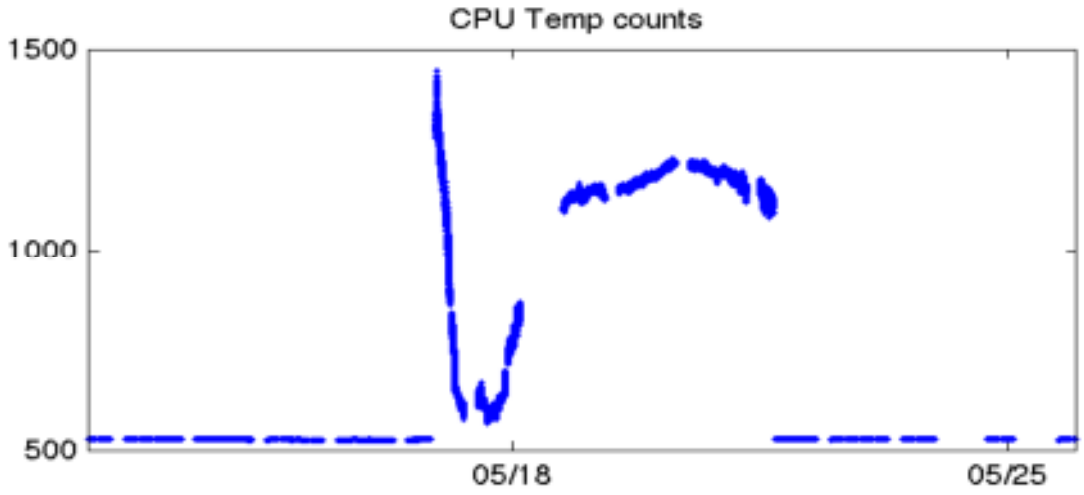

Figure 15. Very steady "CPU Temp Counts" until the cleaning trip occurring on May 16th and the return to steady values after May 20th.

Between May 16th and May 22nd the data should be treated with extreme caution as the instrument was known to be malfunctioning (overheating?). Between the dates of May 22nd to May 30th the data appears to be okay but should still be treated with some caution as the instrument may have been damaged and the data from this period does not seamlessly match with that of the new instrument.

To help fill the data gap caused by the malfunction a simple linear correction model was developed that to bring the data back into reasonable ranges.

$$CorrectedData = RawData * \frac{530}{CPU\ Temp}$$

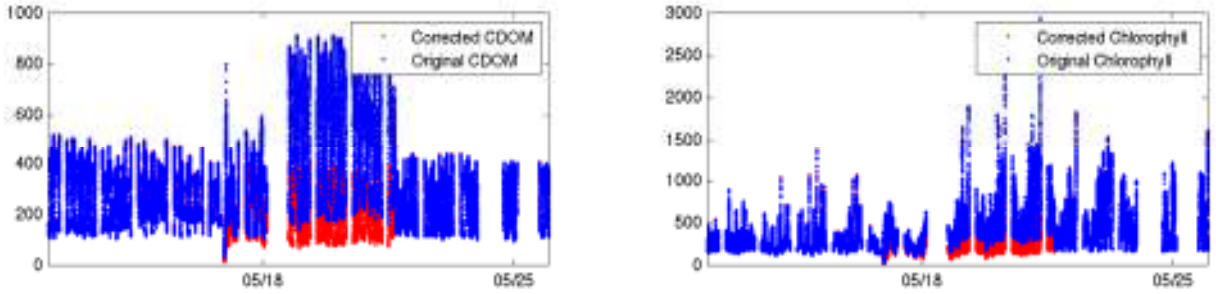

Figure 16. The effect of the correction equation brings chlorophyll, CDOM, and turbidity back into reasonable ranges but the effect is largest for chlorophyll and CDOM.

The usefulness of the equation can also be seen in scatter plots of CDOM vs salinity and chlorophyll vs oxygen. Both scatters show much more linearity and less spread after the correction which is to be expected and a good indication that: 1) the values observed are indeed incorrect and 2) the linear correction does not introduce any new significant errors.

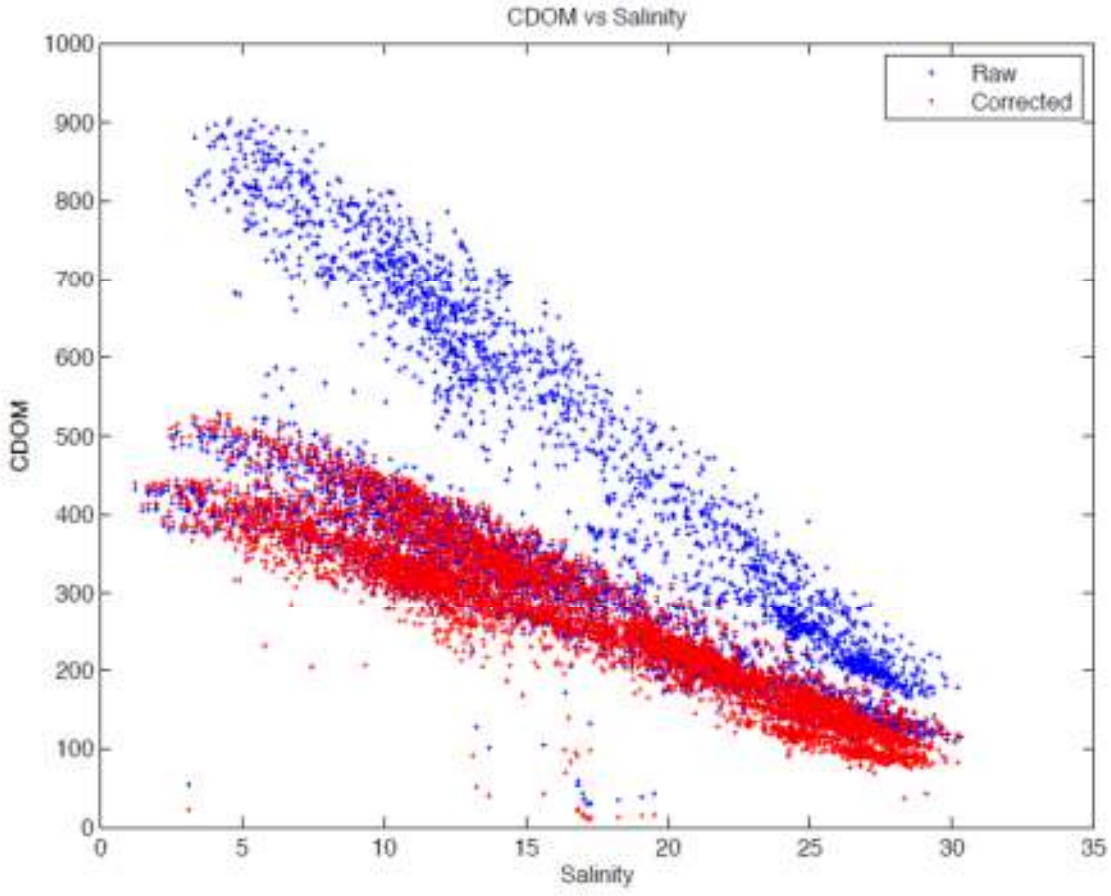

Figure 17. The strong linear fit of CDOM and salinity is largely restored by applying the linear correction.

5. Summary & Recommendations:

1) A useful time-series of BBFL2-based data demands regular cleaning of the instrument. A period of 2 weeks appears to be effective. Despite this relatively short window, we still observe periods (e.g. late June 2014 to the present) where sediment accumulation and possible bio-fouling impacts on signal quality is high. It may be possible to extend the time between maintenance trips during periods characterised by low productivity and river flow; however, this is as yet to be determined and may have to be assessed as seasonal conditions develop and change. Note, however, that significant signal decay was observed over a 21 day period occurring during a period (January 17, 2014 through February 7, 2014) of low productivity and river flow.

2) Standardized measurements represent a useful means of assessing the degree of instrument signal decay for both Chl and CDOM. This is particularly important for the more sensitive CDOM fluorescence measurement. We have now standardized our approach with standard solutions and corrections (particularly for CDOM) appear to produce good results. We have had more success with the liquid solutions; Diet Coke (Chl) and diluted tonic water (CDOM) relative to the solid standards (pink and blue fluorescent sticks). The orientation of the fluorescent stick within the instrument housing relative to the location of each sensor may make these measurements too sensitive to subtle orientation changes and therefore difficult to employ on a routine basis. We have also started a time-series of Sprite Zero (CDOM) measurements which we hope will replace the tonic water measurements. The advantage is that we do not need to dilute Sprite Zero and can use a time series of post-cleaning values as a regular check on the calibration of the sensor.

3) Standardized measurements are also useful (necessary?) when swapping instruments. We found a significant difference in the sensitivity of two instruments which share similar factory calibrations.

4) We do not have a standardized means of correcting for decay in the turbidity signal due to sediment accumulation and/or microbial growth on the instrument surface. It may be possible to address the relative decay in data quality when the baseline NTU increases over time. Likewise, the CDOM baseline tends to drop in a linear manner when sediment loading into the BBFL2 increases.

5) QA/QC flagging is currently only applied to the calibrated data made available online. We discovered a significant instrument malfunction (CPU temperature elevation) because we are making our measurements using the raw data output. The QA/QC process is important, but should also consider raw data stream.