Preliminary Analysis of Fall Fish Data Collected Under the Baseline and Remedial Action Monitoring Programs of the Hudson River PCBs Superfund Site from 2004 through 2009

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February 2010

Abstract: As part of its activities for the Hudson River PCBs Superfund Site, General Electric Company determined PCB levels in fish collected for five years preceding the initiation of dredging and during the first year of dredging to remove PCBs in 2009. Fish were collected in one reference section above the main source of PCBs and from four sections beginning with the most contaminated area of the river and proceeding downstream for approximately 45 miles from Fort Edward to Albany, New York. This report analyzes small pumpkinseed and forage fish collected in the fall of each year and compares contaminant levels in the 2009 fish, exposed for four months to elevated water column PCB concentrations due to dredging, with fish from the previous five years.

PCB levels in fish collected during the five baseline years showed high interannual variability in both forage fish and pumpkinseeds. PCB levels appear to have declined slightly over this baseline period but high variability prevented development of a valid model for any decline. PCB levels were significantly higher after dredging in both groups of fish when compared to the previous five years in the Thompson Island section, where the 2009 dredging occurred, and in the immediately downstream Northumberland – Fort Miller section; means increased by about 2.5 and 1.5 times in these sections, respectively. In contrast, no significant increase occurred in either the Stillwater section or at Albany. Thus, dredging was associated with a moderate, localized increase in PCB levels in small fish, but no discernible effect more than a few miles downstream.

Introduction

General Electric Company discharged PCBs into the Hudson River from its plants in Hudson Falls and Fort Edward, New York, from about 1947 until an agreement with the New York State Department of Environmental Conservation ended intentional releases in 1977. The 1973 removal of the Fort Edward Dam, below GE's operations, led to a downstream release of PCBs and PCB laden sediments, although PCBs were undoubtedly accumulating in downstream sediments even before the dam was taken out. Much of this remobilized PCB was deposited in a 40 mile stretch of the river beginning just below the removed dam and ending at the Federal Dam at Troy, with the bulk in the upper portion of this area. A major unintended release from the abandoned Allen Mill adjacent to GE's Hudson Falls plant site resulted in a further injection of PCBs into the river in 1991. Continuing control efforts have greatly reduced the amount of PCBs entering the river.

These releases of PCBs caused widespread contamination of the river bottom sediments and a chronic elevation of water column PCB concentrations. Among the consequences of high ambient PCB levels in the Hudson are elevated concentrations of PCBs in a wide variety of fish and other biota (Sloan et al. 2002, 2005). Fishing was banned for a period of time and is currently restricted to catch and release on the upper Hudson River, and heightened fish consumption advisories are in effect downstream of the catch and release area for the remaining 153 miles of the river (NYSDOH 2009).

In 2002, the U.S. Environmental Protection Agency issued a Record of Decision to remove PCB contaminated sediments from the upper Hudson River by dredging (US EPA 2002). The portion of the site where dredging will occur is within the 40 miles of river from Fort Edward downstream to the Troy Dam. Subsequent agreements and plans developed by EPA and GE called for an intensive monitoring program, which would build upon long term sampling by the New York State Department of Environmental Conservation, to monitor PCB levels in fish before, during and after dredging. The Baseline Monitoring Program (BMP) was designed to document pre-dredging conditions as a basis for evaluating the effects of PCB removal and took place from 2004 through 2008. The succeeding Remedial Action Monitoring Program (RAMP), which began after the initiation of dredging in 2009, was designed to detect and evaluate any effects during dredging. The monitoring programs had spring and fall fish sampling components. The spring collections were targeted at larger sportfish in size classes that might be eaten by humans while the fall collections were targeted at smaller fish that might be eaten by predacious fish and wildlife.

The Hudson River is divided by dams into eight pools over the length of the PCB remediation site. PCB removal is expected to proceed from upstream to downstream. Fish collection locations were chosen to include a reference area upstream of General Electric's plants, the three principal sections of the remediation site, and a location downstream of the remediation site. The three sections in the remediation site each had multiple sampling areas as part of an effort to look at spatial variation and determine an average concentration for the river reach.

Dredging began in 2009 in the pool formed by the Thompson Island Dam. Dredging occurred in the two channels around Rogers Island, six miles from the dam, and in the east channel around Griffin Island, about 1.5 miles from the dam. As expected, dredging and associated activities mobilized PCBs and resulted in a rise in water column PCB concentrations (US EPA 2010). While the monitoring programs had spring and fall fish collection protocols, the spring collection in 2009 occurred less than a month after dredging began, probably too soon to expect detectable effects on PCB levels in fish.

This report analyzes the fall fish collections to characterize PCB levels in fish during the baseline monitoring period and to compare fish exposed to higher levels of PCBs during the dredging season to the baseline fish. It reports only on data collected under the Baseline and Remedial Action Monitoring Programs. Although longer time series of data are available for some locations, the BMP and RAMP data form a coherent, spatially intensive body of information collected in a consistent way with few deviations from the designed protocol.

Materials and Methods

Fish sampling was divided into two periods or programs. Baseline or pre-dredging sampling was conducted as part of the Baseline Monitoring Program (BMP) from 2004 through 2008. Sampling in 2009 took place while dredging was underway as part of the Remedial Action Monitoring Program (RAMP). Detailed protocols can be found in the project plans for the monitoring programs (QEA and ESI 2004, Anchor QEA 2009). Sampling protocols under the two programs were as similar as possible; the program designation serves mainly to distinguish the pre-dredging baseline from the samples taken during dredging. Fall fish were typically collected in late August through the middle of September. Collections usually occurred over a generally contiguous three to five day period except in 2007 when sampling was split between the middle of September and early October due to equipment problems.

Fish were sampled in five sections of the Hudson River. The Feeder Dam section is located above the Glens Falls Feeder Dam, upstream of General Electric's Fort Edward and Hudson Falls plant sites, and functioned to provide background levels of PCBs. The Thompson Island section, equivalent to River Section 1 in remediation program documents, extends six miles downstream from the former Fort Edward Dam to the Thompson Island Dam. This section contains many of the most contaminated sediments and was the location where dredging took place in 2009. The Northumberland – Fort Miller section, which corresponds to River Section 2 of the remediation program, extends downstream for five miles from the Thompson Island Dam. It comprises pools formed by the Fort Miller Dam and the Northumberland Dam. The Stillwater section extends about 15 miles downstream from the Northumberland Dam to the Stillwater Dam and forms the upstream part of River Section 3 of the remediation program. The Albany section is below the Federal Dam at Troy, downstream of the confluence of the Mohawk River with the Hudson, in the tidal portion of the Hudson River.

Each section had one or more sampling areas. These were localities within which fish were sought. Although fairly small, these sampling areas were not rigorously bounded or fixed in location. Rather, they would be more or less extensive and might even be in slightly different locations from year to year, depending upon where fish could be obtained. The Feeder Dam section was sampled as a single area covering the entire pool (FD1). The Thompson Island section was sampled in five areas (TD1 – TD5). The Northumberland – Fort Miller section was sampled in four areas (ND1 and ND2 in the pool formed by the Fort Miller Dam, and ND3 and ND5 in the pool formed by the Northumberland Dam). An additional area (ND4) had been planned for the pool formed by the Northumberland Dam. When it failed to yield fish in 2004, it was dropped and its samples were apportioned to ND3 and ND5. Problems with access prevented sampling in areas ND1 and ND2 in the Fort Miller pool from 2006 through 2008. Samples scheduled for those two areas were taken instead in the two areas in the Northumberland pool, ND3 and ND5. The Stillwater section was sampled in five areas (SW1 – SW5). The Albany section had a single designated area (AT1). The fall location for AT1 was initially established at the south turning basin opposite the Port of Albany, ten miles downstream from the Troy Dam but was later expanded to two other locations due to difficulty in obtaining fish. A second location 2.0 miles upstream was added for 2007 and 2008 while a third location 3.4 miles upstream of the turning basin was needed for pumpkinseeds in 2009. The flexible nature of the sampling areas needs to be kept in mind when considering differences among years and areas.

Sampling targeted small pumpkinseeds (*Lepomis gibbosus*) and medium sized "forage fish." Sample size goals were 20 pumpkinseeds at the Feeder Dam and at Albany, 30 pumpkinseeds in the Thompson Island and Stillwater sections, 25 pumpkinseeds in the Northumberland – Fort Miller section, and 10 forage fish composites in each section. Pumpkinseeds were targeted by size in an attempt to obtain yearling fish, with 90% of the fish between 77 mm (3 inches) and 127 mm (5 inches) in length. Ages were determined by examination of scales in 2004, 2006 and 2009. Although yearling fish were targeted, in practice somewhat more than half the fish were yearlings. Most of the rest were two years old but a small number of three and four year old fish were also collected. Forage fish comprised a miscellaneous collection of small minnows (Cyprinidae) that depended upon availability. Spottail shiner (*Notropis hudsonius*) was the preferred species and accounted for nearly half the samples. The other species, listed in order of sample numbers, were golden shiner (*Notemigonus crysoleucas*) with about a quarter of the samples, unidentified small minnows, spotfin shiner (*Notropis spilopterus*), bluntnose minnow (*Pimephales notatus*), common shiner (*Notropis cornutus*), mimic shiner (*Notropis volucellus*), fallfish (*Semotilus corporalis*), and rosyface shiner (*Notropis rubellus*). Species composition differed among years (Chi-square = 48.7, df = 10, $P < 0.0001$). Approximately 90% of the forage fish were between 55 mm (2 inches) and 119 mm (4½ inches) in length.

Fish were collected by electroshocking. Forage fish were sought opportunistically without regard to species. Fish were stunned, collected with a net, and placed in a live well. Fish were then sorted on shore. Each pumpkinseed was weighed, measured for length and given an individual identifying number. Forage fish were sorted by species and approximately by size. Forage fish were measured individually for length and weight, and then combined into composites of between 2 and 25 fish (most often 2 to 10 fish) for analysis. Each composite was given an individual identifying number. Fish were placed on ice after processing and shipped within 24 hours to an analytical laboratory for analysis.

PCB results were reported as Aroclor concentrations on a whole body, wet weight basis. Percent lipid was also reported. Total wet weight PCB was obtained by summing the individual Aroclor values. Non-detect results were handled as follows: Aroclors were divided into two groups. The lower group consisted of Aroclors 1016, 1221, 1242 and 1248. The upper group consisted of Aroclors 1254 and 1260. If at least one detection occurred in one Aroclor from each of the lower and upper groups, all detected values were summed and no correction was made for non-detects. If a value was reported for at least one Aroclor in one group but not the other, half a detection limit was added to the sum of the reported values. If all Aroclor results were non-detect in both groups, total wet weight PCB was assigned the value of one detection limit. Lipid adjusted PCB values were derived by dividing the wet weight value by the percent lipid.

Data were collected by contractors to General Electric Company and provided to the New York State Department of Environmental Conservation by General Electric under the terms of agreements with the United States Environmental Protection Agency. Statistical analysis was performed using the R statistical software program (R Development Core Team 2009). Exponential regressions were fit using non-linear least squares after scaling the year of data collection by subtracting 2000.

Results

Correlations between wet weight PCB levels and lipid adjusted PCB levels were high for both forage fish and pumpkinseeds (Table 1; forage fish: $r = 0.904$; pumpkinseeds: $r = 0.974$; both $P < 0.001$). Nearly all statistical tests reported below gave equivalent results for both wet weight PCB and lipid adjusted PCB; figures are shown only for wet weight levels because patterns were similar. Correlations among other variables were generally low except for that between weight and length (Table 1, Figure 1). With such generally low correlations, attempts to adjust PCB values to other characteristics of the fish such as size are likely to be counterproductive and were not performed. BMP and RAMP fish generally showed little differences in other measured characteristics. No significant differences were found in either forage fish or pumpkinseeds for length, weight or percent lipid with the exception of pumpkinseed weight in the Thompson Island section (BMP mean = 19.7 g, RAMP mean = 15.95 g; $P = 0.022$).

The BMP fish showed a weak and generally inconsistent trend of declining PCB concentrations over the five year monitoring program (Figure 2). Plausible models for any decline are linear (constant reduction) and exponential (reduction proportional to the amount present). Models were fit to each of the four river sections for wet weight and lipid adjusted PCBs. Of the 32 model fits (2 model types, 2 species, 2 response variables, 4 sections) all were significant ($P < 0.05$) except for the forage fish lipid adjusted linear regression at Stillwater and exponential regression at Thompson Island. An examination of regression residuals (Figure 2) shows, however, that almost none of the models provided a good fit to the data. All linear regressions have at least one, and most have two, annual means that are outside the 95% confidence limits for the regression (Figure 2). Similarly, the individual data values, and hence the residuals from the regression, from one or two years cluster heavily on one side of the fitted regression line in every case (Figure 2). Thus, neither type of model provides an adequate description of the data. Given this inadequacy, it would be inadvisable to adjust BMP levels for any trend when comparing them to RAMP levels. Comparisons between BMP and RAMP fish were therefore made using unadjusted data from each program.

Feeder Dam PCB levels for both forage fish and pumpkinseeds were consistently low during the BMP period and remained low in 2009 (Table 2); medians are reported because of the substantial number of results below the detection limit. The BMP and RAMP forage fish were significantly different, with higher levels in RAMP fish for wet weight and lipid adjusted PCBs, while pumpkinseeds did not differ on either variable (Table 3).

PCB levels at the Thompson Island section were considerably higher than at the Feeder Dam, averaging 4.46 ppm for forage fish and 5.94 ppm for pumpkinseeds during the BMP period (Figure 3). Levels decreased downstream from the Thompson Island section to attain averages for the BMP fish of 0.96 ppm and 0.80 ppm for forage fish and pumpkinseeds, respectively, in the Albany section. Year to year variation was considerable for both species during the BMP (Table 4, Figure 4).

Dredging was associated with a substantial increase in PCB levels in fish from the Thompson Island section, a smaller increase in the Northumberland – Fort Miller section, and little, if any change in the Stillwater and Albany sections (Figure 5). Because PCB levels clearly differed among sections, the effect of dredging was first analyzed as a two way analysis of variance with factors of program (BMP versus RAMP) and section. The interaction term of the ANOVA was significant ($P < 0.001$) in both forage fish and pumpkinseeds for both wet weight and lipid adjusted PCB levels (Figure 6). This significant interaction means that the effect of dredging on PCB levels in fish differs among the sections. Consequently, examination of the effect of dredging over all sections combined (a main effect of program) would be meaningless. Instead, differences between the BMP and RAMP fish were tested for each section.

The ANOVAs for the Thompson Island and Northumberland – Fort Miller sections were significant for both forage fish (all $P < 0.04$ for wet weight and lipid adjusted PCBs) and pumpkinseeds (all $P < 0.03$) (Table 5). RAMP PCB levels increased about 2.5 times in the Thompson Island section and about 1.5 times in the Northumberland – Fort Miller section over BMP levels. In contrast, no ANOVA was significant for either the Stillwater or Albany sections for forage fish (all $P > 0.20$) or pumpkinseeds (all $P > 0.15$) (Table 5).

PCB levels in the BMP fish appear to differ among the sampling areas within a section and some areas had more change between the BMP and RAMP fish than others (Figure 7). The two-way ANOVA interaction term for sampling area and program was significant ($P < 0.001$) for forage fish and pumpkinseeds for both wet weight and lipid adjusted PCB levels. Given the small numbers of RAMP samples, two for forage fish and five for pumpkinseeds from all but one sampling area, and the large number of sampling areas, an attempt to test for differences between sampling programs for each area is inadvisable as it would be plagued by incorrect rejections and acceptances of the null hypothesis of no difference. Given this limitation, no reliable conclusions can be drawn as to whether the patterns evident in Figure 7 reflect real differences among the sampling areas or are merely the result of a relatively small number of samples.

Discussion

Dredging to remove PCBs was associated with a fairly rapid and substantial, but local, increase in PCB levels in small fish. After about four months of dredging and associated work, three of which were at a high rate of activity, RAMP fish collected from the Thompson Island section, in which dredging occurred, had average wet weight and lipid adjusted PCB levels that increased about 150% over the average of the BMP fish from the previous five years. Levels were elevated by about 50% in the Northumberland – Fort Miller section. This section, comprising two pools formed by dams, extends for five miles immediately downstream from the Thompson Island section.

In contrast, the data do not support a conclusion that PCB levels increased further downstream. Although the average RAMP wet weight PCB levels in the Stillwater section increased by 0.76 ppm and 0.42 ppm for forage fish and pumpkinseeds, respectively, the difference was not significant. In the Albany section, RAMP averages were actually less than the BMP averages and were again not significantly different. Thus, beyond about eight miles from the downstream limit of dredging, any effect of dredging on PCB levels in young fish is at most questionable and small in magnitude.

PCB levels in these fish reflect both the sharp increase in PCB concentrations in the river water in the vicinity of dredging and the attenuation of concentrations downstream due to loss of PCBs from the water column and dilution from tributaries. Water column PCB levels during the BMP period were similar at all monitoring stations between the Thompson Island Dam and the Troy Dam and typically ranged between 20 and 80 ng/L during the summer months (US EPA 2010). Concentrations at Albany averaged roughly half those in the upper three sections (US EPA 2010), reflecting the influence of the inflow from the Mohawk River. Water column PCB monitoring during dredging showed a considerable increase over baseline just below the Thompson Island Dam, with an average through October 27 of 200 ng/L (US EPA 2010), roughly a five-fold increase. The average at Lock 5, at the head of the Stillwater section, was 155 ng/L (US EPA 2010), a roughly four-fold increase, while the 59 ng/L average at Albany was about double the BMP average (US EPA 2010). The increase in PCB levels in RAMP fish relative to BMP fish was thus considerably smaller than the increase in PCB water concentrations. Whether these fish had attained steady-state levels of PCB concentrations by the time of sampling and how the limited duration of increased water column PCB concentration during and shortly following PCB removal activities will affect fish concentrations over the long term cannot yet be determined.

Over five years, the BMP fish showed considerable interannual variability in PCB levels amidst what is probably a slight decline (Figure 2). This interannual variability is a far more salient feature of the data than any trend. The consequent failure to fit regression models embodying plausible mechanisms of change over time to the BMP data precludes valid projection of temporal trends. Because the decline is too erratic to be modeled reliably, the most that can be concluded is that a slight decline has probably occurred; useful prediction or extrapolation into the future is impossible. Extrapolation based on a purely descriptive model with no causal mechanism would be even less advisable. Such a model would merely fit the data with no reason to believe that it encapsulates any decay process. Moreover, with only five years of data, model overfitting would be a real danger.

Although a temporal association between dredging PCB laden sediments and higher PCB levels in fish has been demonstrated, the high interannual variability suggests that caution is appropriate before assigning a causal relationship. When, as in the Thompson Island section, the mean in 2009 was well beyond the range of means of the preceding five years (Table 4), a conclusion of dredging induced effects on fish PCB levels is well supported. In the Northumberland – Fort Miller section, the 2009 wet weight PCB means were slightly higher than all of the means for the preceding five years whereas the lipid adjusted means in 2009 were less than the means in 2006 for both forage fish and pumpkinseeds. A causal relationship between dredging and the higher 2009 levels in Northumberland – Fort Miller therefore seems likely but is less certain. The 2009 means at Stillwater and Albany are well within the range of the means of the preceding five years, further reinforcing the conclusion that dredging had little influence on fish PCB levels in these river sections. The significantly higher 2009 PCB levels in forage fish at the Feeder Dam, which could not have been caused by dredging, emphasizes this caution as well as the need to look at magnitude of any difference along with statistical significance when drawing conclusions about the effect of dredging on fish.

Sample sizes at individual areas were too small to determine whether the apparent differences among areas (Figure 7) are meaningful. As remedial dredging progresses, it may be useful to reliably distinguish among these areas, an analysis that will require larger sample sizes.

In conclusion, small fish in the vicinity of dredging showed an increase in PCB levels that was smaller than might be expected given the increase in water concentration. The effect of dredging diminished rapidly with distance. As with past events such as the Allen Mill release of PCBs in 1991 and subsequent control, it is likely that the effect will also diminish with time so that fish sampled within a few years following dredging can be expected to no longer exceed pre-dredging levels. Of great interest will be how rapidly PCB concentrations decline below the pre-dredging levels following the removal of a portion of the PCB laden sediments.

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Table 1. Correlations among measured variables; upper diagonal has the correlation coefficient and the lower diagonal has the P value. WW PCB and L PCB are wet weight and lipid adjusted PCB, respectively.

	WW PCB	L PCB	Length	Weight	Percent Lipid
Forage fish (n = 294)					
Wet weight PCB	–	0.90	0.18	0.12	0.40
Lipid adjusted PCB	<0.0001	–	0.19	0.14	0.13
Length (mm)	0.0019	0.0014	–	0.94	0.20
Weight (grams)	0.0466	0.0149	<0.0001	–	0.12
Percent lipid	<0.0001	0.0292	0.0006	0.0434	–
Pumpkinseeds (n = 738)					
Wet weight PCB	–	0.97	0.03	0.04	0.20
Lipid adjusted PCB	<0.0001	–	0.01	0.01	0.07
Length (mm)	0.3612	0.7709	–	0.95	0.01
Weight (grams)	0.2811	0.7539	<0.0001	–	0.06
Percent lipid	<0.0001	0.0575	0.6985	0.1059	–

Table 2. Median PCB levels at the Feeder Dam.

	2004	2005	2006	2007	2008	2009
Wet weight (ppm)						
Forage fish	0.06	0.05	0.06	0.03	0.01	0.09
Pumpkinseeds	0.05	0.07	0.06	0.05	0.01	0.05
Lipid adjusted (ppm)						
Forage fish	1.55	2.62	2.60	1.21	0.34	3.71
Pumpkinseeds	1.99	2.72	2.30	2.56	0.41	1.91

Table 3: Comparisons of PCB concentrations between BMP and RAMP fish at the Feeder Dam (K-W is the Kruskal-Wallis test statistic).

	BMP	RAMP	K-W	df	P
	Median				
Wet weight (ppm)					
Forage fish	0.04	0.09	6.7547	1	0.0094
Pumpkinseeds	0.05	0.05	0.0299	1	0.8628
Lipid adjusted (ppm)					
Forage fish	1.40	3.71	10.3321	1	0.0013
Pumpkinseeds	2.16	1.91	0.2643	1	0.6072

Table 4. Mean PCB levels by section and year.

	2004	2005	2006	2007	2008	2009
Wet weight (ppm)						
Forage fish						
Thompson Island	4.72	7.15	7.06	1.52	1.85	10.57
Northumberland – FM	5.75	4.81	6.20	1.81	1.63	6.27
Stillwater	3.68	3.36	3.05	0.98	1.78	3.33
Albany	2.11	0.56	1.21	0.52	0.56	0.90
Pumpkinseeds						
Thompson Island	9.47	5.53	8.61	3.44	2.17	14.80
Northumberland – FM	7.52	5.64	6.82	1.34	3.57	7.83
Stillwater	3.52	3.02	2.71	1.40	1.77	2.90
Albany	1.05	1.12	0.79	0.59	0.55	0.79
Lipid adjusted (ppm)						
Forage fish						
Thompson Island	121.79	242.06	183.84	69.89	50.41	267.08
Northumberland – FM	107.07	106.24	142.37	46.19	53.17	129.84
Stillwater	81.54	75.92	72.56	39.80	69.36	74.97
Albany	33.15	34.21	37.57	26.47	19.58	32.25
Pumpkinseeds						
Thompson Island	305.37	205.87	308.49	130.70	84.64	520.93
Northumberland – FM	208.34	149.30	225.37	64.33	130.20	216.99
Stillwater	119.69	92.83	94.57	55.36	66.49	104.56
Albany	38.25	39.00	37.33	15.78	22.63	26.44

Table 5: Comparisons of PCB concentrations between BMP and RAMP fish at the Thompson Island, Northumberland – Fort Miller, Stillwater and Albany sections.

	BMP		RAMP		F	df	P
	Mean	SE	Mean	SE			
Wet weight (ppm)							
Forage fish							
Thompson Island	4.46	0.53	10.57	2.37	14.98	1, 58	0.0003
Northumberland – FM	4.04	0.43	6.27	0.82	41.54	1, 58	0.0348
Stillwater	2.57	0.24	3.33	0.65	1.61	1, 58	0.2095
Albany	0.96	0.11	0.90	0.17	0.06	1, 51	0.8007
Pumpkinseeds							
Thompson Island	5.94	0.65	14.80	2.41	23.68	1, 182	<0.0001
Northumberland – FM	4.93	0.38	7.83	0.94	9.54	1, 140	0.0024
Stillwater	2.48	0.17	2.90	0.56	0.83	1, 177	0.3639
Albany	0.80	0.03	0.79	0.05	0.02	1, 111	0.8983
Lipid adjusted (ppm)							
Forage fish							
Thompson Island	133.60	17.13	267.08	45.46	9.51	1, 58	0.0031
Northumberland – FM	91.01	7.70	129.84	17.62	4.21	1, 58	0.0448
Stillwater	67.84	4.69	74.97	11.93	0.37	1, 58	0.5457
Albany	29.00	1.52	32.25	2.26	0.95	1, 51	0.3351
Pumpkinseeds							
Thompson Island	209.57	19.69	520.93	82.33	29.48	1, 182	<0.0001
Northumberland – FM	155.93	11.50	216.99	21.96	5.16	1, 140	0.0247
Stillwater	85.56	5.03	104.56	19.98	1.76	1, 177	0.1861
Albany	30.02	1.49	26.44	1.44	1.18	1, 111	0.2789

Figure Legends

Figure 1: Pairwise scatterplots for forage fish (a) and pumpkinseeds (b). The variables involved in each plot are given by the intersection of the variable names found on the main diagonal.

Figure 2. Linear and exponential regressions of wet weight PCB concentration on year over the five years of the BMP program for each section for forage fish (a) and pumpkinseeds (b). Open circles are individual sample results, large filled circles are annual means, red line is linear fit, blue line is exponential fit, and dotted lines are 95% confidence intervals for the linear fit.

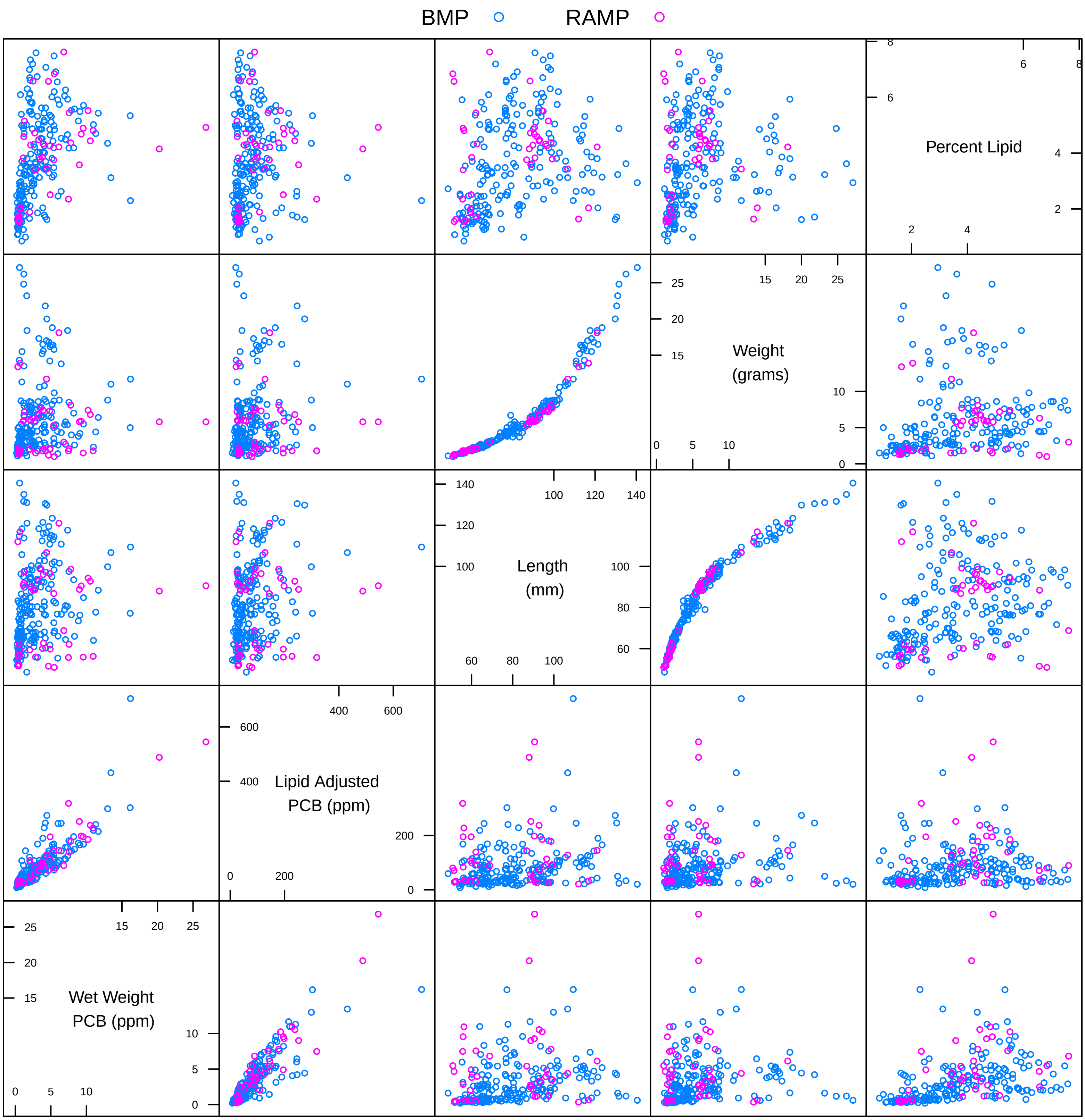
Figure 3. Wet weight PCB levels of BMP fish from 2004 through 2008 by section. Individual observations are offset horizontally to minimize overlap. Violin plots (the symmetric wavy lines) show the approximate density of sample results at the concentration given by the Y axis value. The large dot is the median.

Figure 4. Wet weight PCB levels for each year by section and species; individual observations (small circles) are offset horizontally to minimize overlap.

Figure 5. BMP and RAMP fish wet weight PCB concentrations for each section. Individual observations are offset horizontally to minimize overlap. Violin plots (the symmetric wavy lines) show the approximate density of sample results at the concentration given by the Y axis value. The large dot is the median.

Figure 6. Interaction plots showing mean wet weight PCB levels by section and monitoring program for forage fish (left) and pumpkinseeds (right).

Figure 7. Wet weight PCB levels of BMP and RAMP fish by sampling area. Individual observations (small dots) are offset horizontally to minimize overlap. Violin plots (the symmetric wavy lines) show the approximate density of sample results at the concentration given by the Y axis value..



BMP
RAMP
Percent Lipid
Weight
(grams)
Length
(mm)
Lipid Adjusted
PCB (ppm)
Wet Weight
PCB (ppm)

Figure 1a

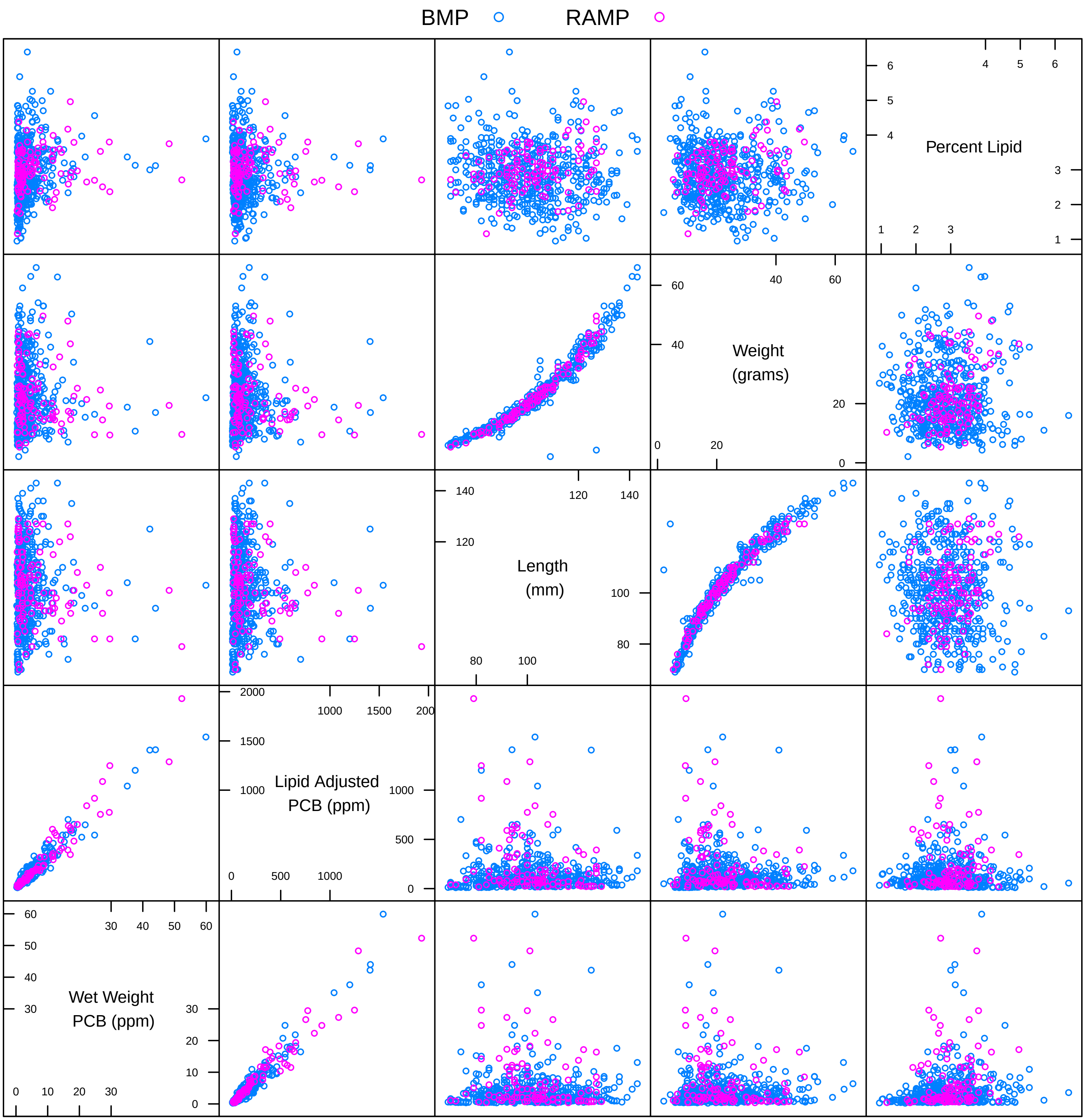

BMP
RAMP
Percent Lipid
Weight
(grams)
Length
(mm)
Lipid Adjusted
PCB (ppm)
Wet Weight
PCB (ppm)

Figure 1b

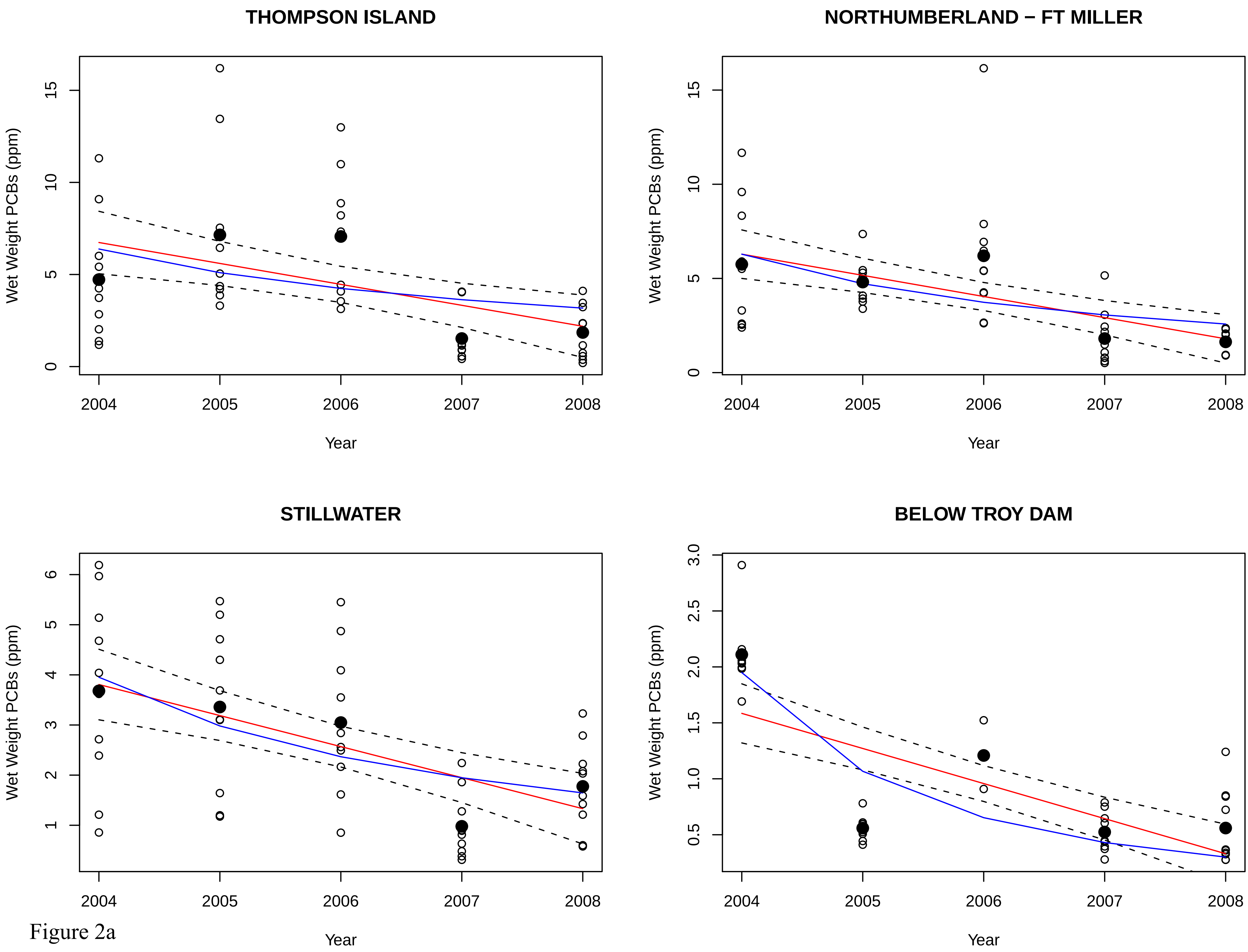

THOMPSON ISLAND
NORTHUMBERLAND − FT MILLER
STILLWATER
BELOW TROY DAM
Wet Weight PCBs (ppm)
Year
2004
2005
2006
2007
2008

Figure 2a

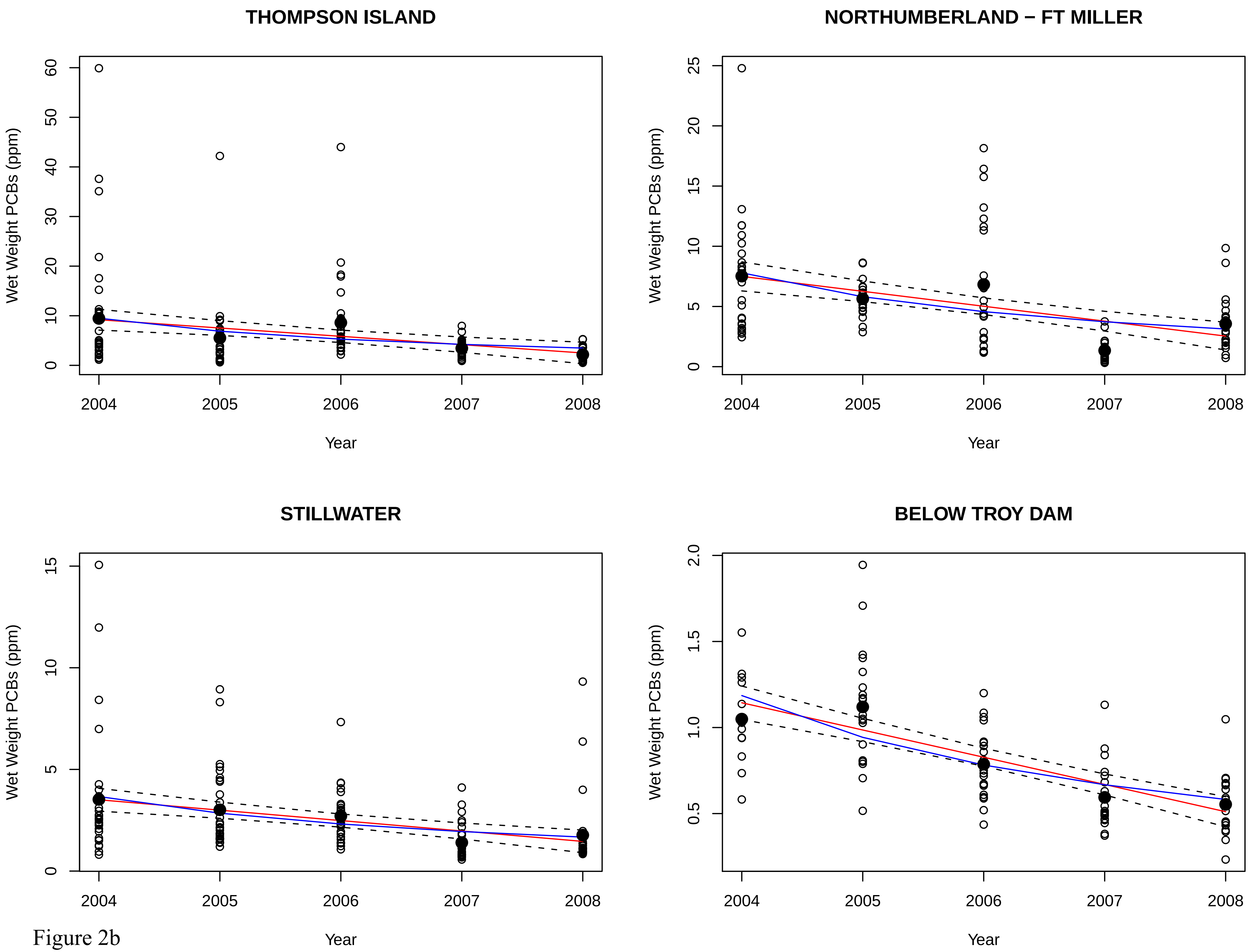

THOMPSON ISLAND
NORTHUMBERLAND – FT MILLER
STILLWATER
BELOW TROY DAM
Wet Weight PCBs (ppm)
Year
2004
2005
2006
2007
2008

Figure 2b

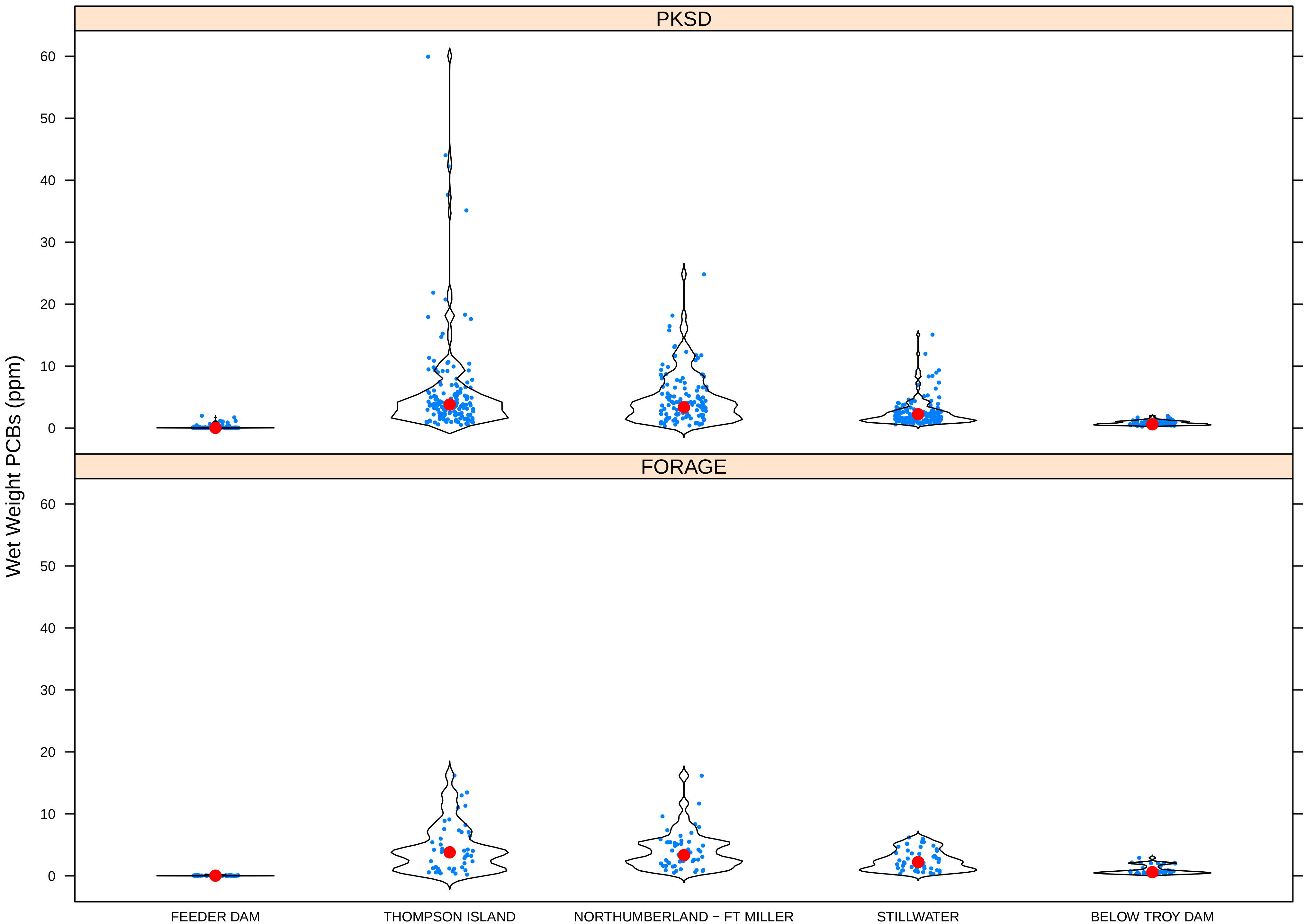

PKSD
FORAGE
Wet Weight PCBs (ppm)
0
10
20
30
40
50
60
FEEDER DAM
THOMPSON ISLAND
NORTHUMBERLAND – FT MILLER
STILLWATER
BELOW TROY DAM

Figure 3

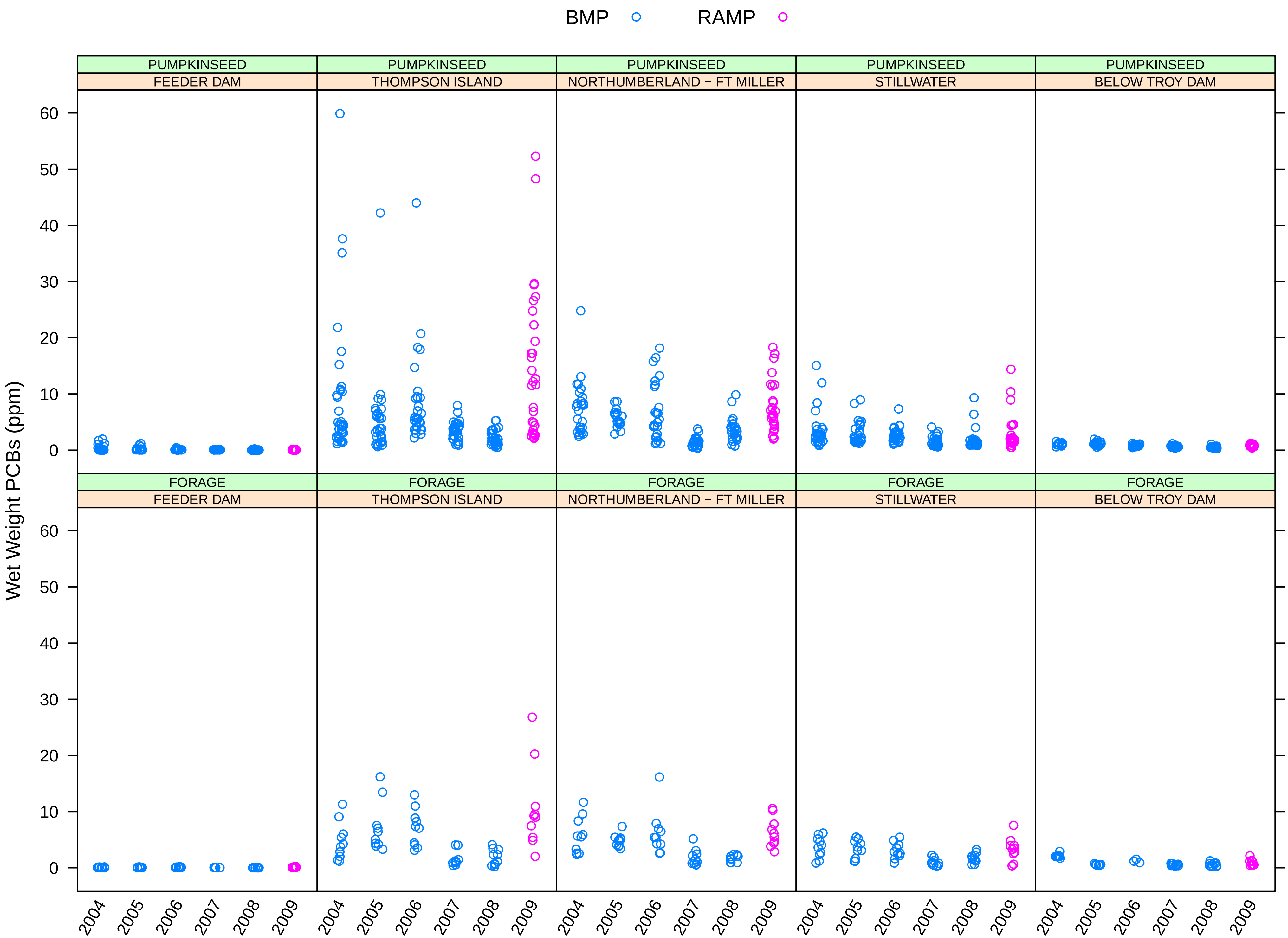
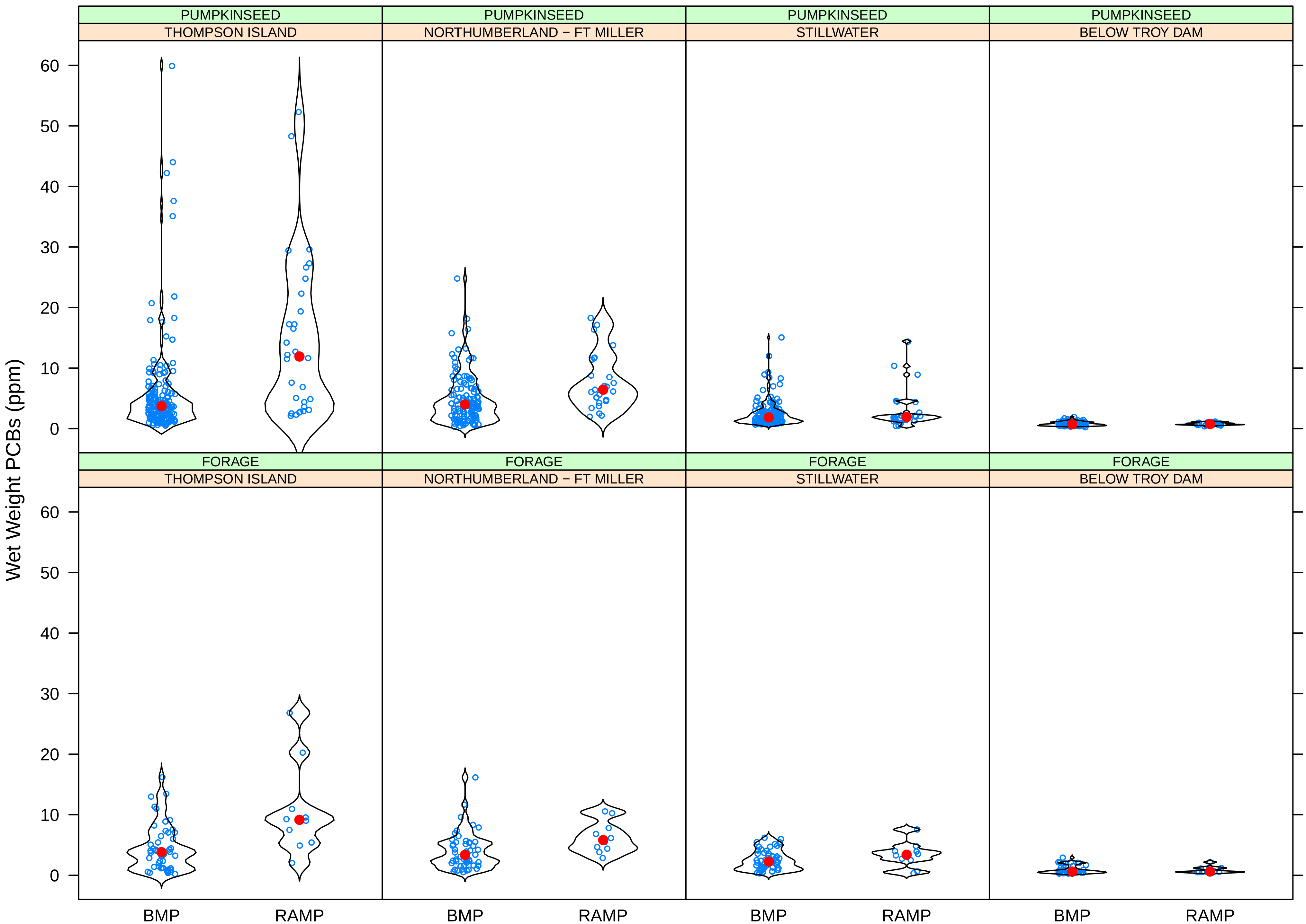

BMP
RAMP
PUMPKINSEED
FEEDER DAM
PUMPKINSEED
THOMPSON ISLAND
PUMPKINSEED
NORTHUMBERLAND – FT MILLER
PUMPKINSEED
STILLWATER
PUMPKINSEED
BELOW TROY DAM
FORAGE
FEEDER DAM
FORAGE
THOMPSON ISLAND
FORAGE
NORTHUMBERLAND – FT MILLER
FORAGE
STILLWATER
FORAGE
BELOW TROY DAM
Wet Weight PCBs (ppm)
0
10
20
30
40
50
60
2004
2005
2006
2007
2008
2009

Figure 4



PUMPKINSEED
THOMPSON ISLAND
PUMPKINSEED
NORTHUMBERLAND – FT MILLER
PUMPKINSEED
STILLWATER
PUMPKINSEED
BELOW TROY DAM
FORAGE
THOMPSON ISLAND
FORAGE
NORTHUMBERLAND – FT MILLER
FORAGE
STILLWATER
FORAGE
BELOW TROY DAM
Wet Weight PCBs (ppm)
0
10
20
30
40
50
60
BMP
RAMP

Figure 5

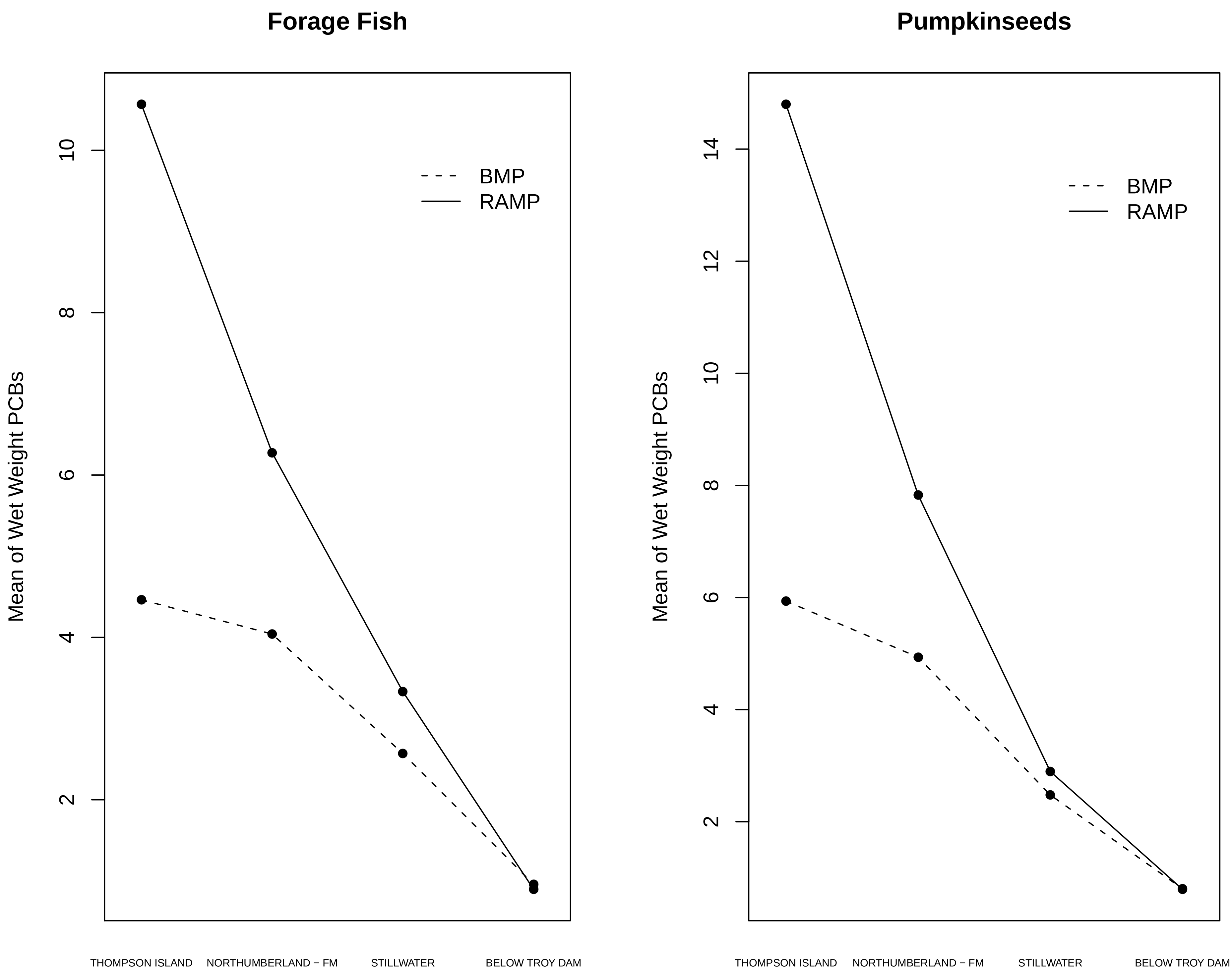

Forage Fish
Mean of Wet Weight PCBs
2
4
6
8
10
BMP
RAMP
THOMPSON ISLAND
NORTHUMBERLAND − FM
STILLWATER
BELOW TROY DAM
Pumpkinseeds
Mean of Wet Weight PCBs
2
4
6
8
10
12
14
BMP
RAMP
THOMPSON ISLAND
NORTHUMBERLAND − FM
STILLWATER
BELOW TROY DAM

Figure 6

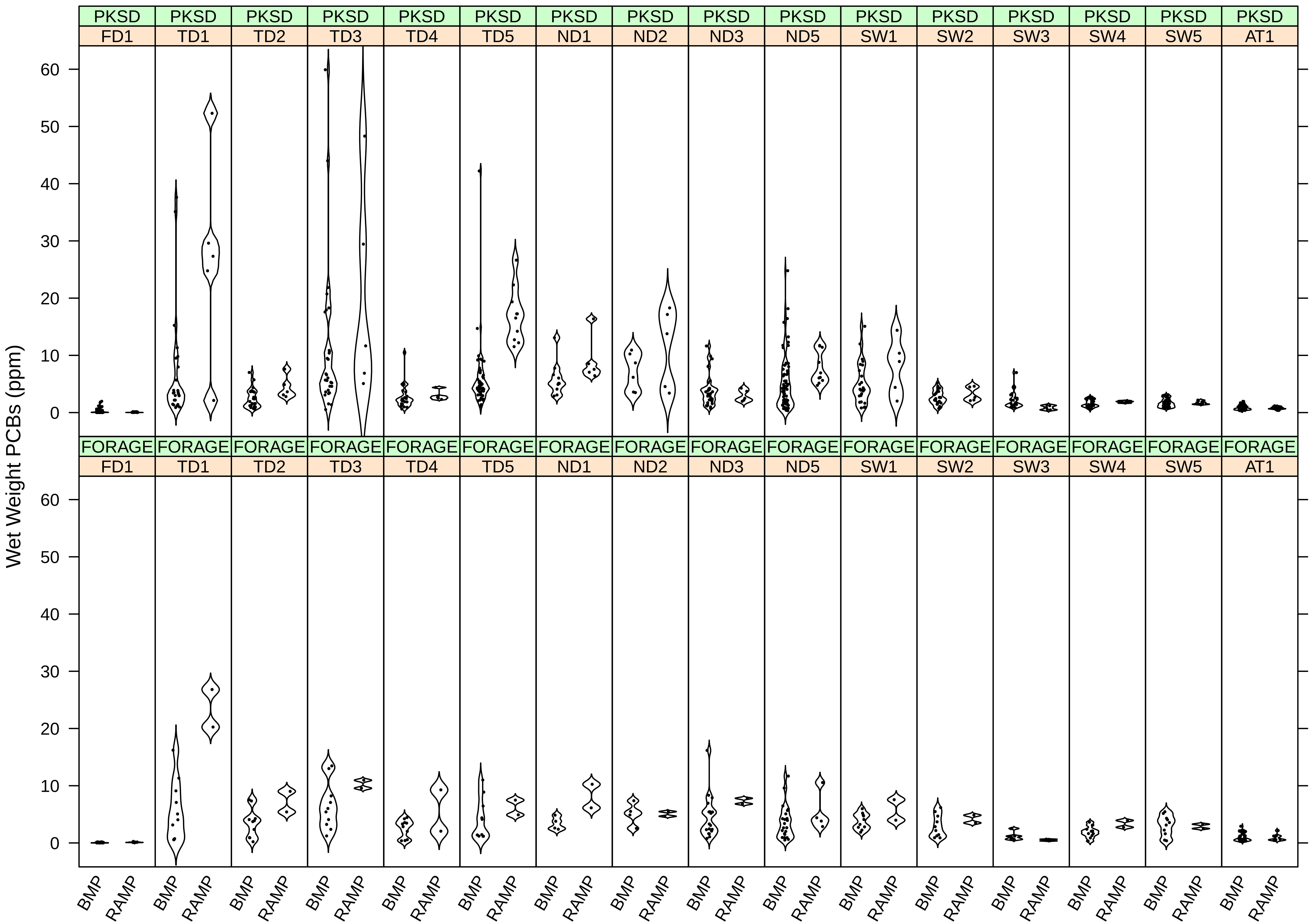

Wet Weight PCBs (ppm)
PKSD
FORAGE
FD1
TD1
TD2
TD3
TD4
TD5
ND1
ND2
ND3
ND5
SW1
SW2
SW3
SW4
SW5
AT1
BMP
RAMP
0
10
20
30
40
50
60

Figure 7