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RESEARCH ARTICLE

Effects of extreme floods on macroinvertebrate assemblages in tributaries to the Mohawk River, New York, USA

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Abstract

Climate change is forecast to bring more frequent and intense precipitation to New York which has motivated research into the effects of floods on stream ecosystems. Macroinvertebrate assemblages were sampled at 13 sites in the Mohawk River basin during August 2011, and again in October 2011, following historic floods caused by remnants of Hurricane Irene and Tropical Storm Lee. The annual exceedance probabilities of floods at regional flow-monitoring sites ranged from 0.5 to 0.001. Data from the first 2 surveys, and from additional surveys done during July and October 2014, were assessed to characterize the severity of flood impacts, effect of seasonality, and recovery. Indices of total taxa richness; Ephemeroptera, Plecoptera, and Trichoptera (EPT) richness; Hilsenhoff's biotic index; per cent model affinity; and nutrient biotic index-phosphorus were combined to calculate New York State Biological Assessment Profile scores. Analysis of variance tests were used to determine if the Biological Assessment Profile, its component metrics, relative abundance, and diversity differed significantly ($p \le .05$) among the four surveys. Only total taxa richness and Shannon–Wiener diversity increased significantly, and abundance decreased significantly, following the floods. No metrics differed significantly between the July and August 2014 surveys which indicates that the differences denoted between the August and October 2011 surveys were caused by the floods. Changes in taxa richness, EPT richness, and diversity were significantly correlated with flood annual exceedance probabilities. This study increased our understanding of the resistance and resilience of benthic macroinvertebrate communities by showing that their assemblages were relatively impervious to extreme floods across the region.

KEYWORDS

Biological Assessment Profile, climate change, EPT richness, extreme floods, hurricane Irene, Mohawk River, resilience, resistance

1 | INTRODUCTION

Climate change is forecasted to increase annual precipitation amounts, reduce winter snow cover, increase the intensity of warm season extreme rainfall, and shift the seasonality of runoff across New York State (Rosenzweig et al., 2011). Extreme precipitation is projected to increase worldwide (Kundzewicz et al., 2008); rates of precipitation are predicted to increase by 20% within 100 km of tropical cyclone storm centres (Knutson et al., 2010). The resulting intensification of the global water cycle is predicted to increase flood risk in many regions (Milly, Wetherald, Dunne, & Delworth, 2002). Changes in the predictability, frequency, magnitude, and duration of flooding are of concern to hydrologists, managers, and policy makers because these changes increase the threat to human welfare as well as to public and private infrastructure. Just as important, more extreme, longer, and frequent low and high flows in lotic systems will subject resident biota to increased stresses caused by larger temporal variations in hydrologic and thermal regimes (Rosenzweig et al., 2011).

Floods are considered one of the principal structuring forces on stream macroinvertebrate populations and assemblages (Resh et al., 1988). Flooding events severely modify stream habitats, directly or indirectly affecting species abundance, altering assemblage composition (Franssen et al., 2006) as well as changing entire ecosystems (Bunn & Arthington, 2002). Macroinvertebrate density, biomass, and diversity are typically reduced by flood events (Robinson, Uehlinger, & Monaghan, 2003) because of (a) increased catastrophic drift conveying the macroinvertebrates downstream (Gibbins, Scott, Soulsby, & McEwan, 2005), (b) increased shear stress on the streambed disturbing their habitat (Bond & Downes, 2003), and/or (c) increased metabolic costs associated with reconstruction activities (Beveridge & Lancaster, 2007). Despite the evolution of morphological and behavioural characteristics of benthic macroinvertebrates to sustain their position in high velocities/flows, many assemblages have low resistance to floods (Death, 2008). Community metrics that reflect the health of macroinvertebrate assemblages generally decrease with increases in the magnitude of flow alteration (Poff & Zimmerman, 2010). Once benthic macroinvertebrate assemblages are impacted by severe floods, recovery may vary from days to years depending on flood magnitude, disturbance history, effects of the flood on riparian vegetation, food sources, the size of the remaining population, and antecedent conditions (Death, 2008). Given the complexity of macroinvertebrate responses to floods relative to specific watershed and channel attributes, regional studies are useful in building a predictive understanding of the relationship between macroinvertebrate assemblages and floods.

Tropical Storm Irene entered New York on August 28th (NOAA, 2012) and caused record flooding at 60 U. S. Geological Survey (USGS) streamgages (gages) in New York (Lumia, Firda, & Smith, 2014). Flood peaks at 25 gages equaled or exceeded the 0.01 flood annual exceedance probability (flood AEP), while they exceeded the 0.002 AEP at nine sites (Lumia et al., 2014). A flood AEP of 0.002 is equal to the 500-year recurrence interval (Holmes & Dinicola, 2010). Tropical Storm Lee entered the state on September 7 and dropped more than 30 cm of rain which caused major flooding in south-central, east-central, and southeast New York (Lumia et al., 2014). Record floods, some exceeding the 0.01 AEP, were recorded at 10 gages in the Susquehanna River basin (Brown, 2011) and two gages in the Cayuga Lake Basin (Lumia et al., 2014).

Macroinvertebrate assemblages at 13 stream study sites on tributaries to the Mohawk River were surveyed in August 2011 just before floods (caused by tropical storms Irene and Lee) as part of a long-term New York Department of Environmental Conservation (NYSDEC) water-quality monitoring program. The same 13 sites were resampled by the NYSDEC in October 2011, less than 2 months after the historic floods. Additional samples were collected from these sites by the lead author in July and October 2014, about 3 years after the floods. The primary objective of this study was to increase our understanding of the resistance and resilience of macroinvertebrate communities to extreme floods in streams of the region. Specific goals of this effort were to document the impact of the 2011 floods on the benthic macroinvertebrate communities, the potential effects of seasonality on community indices, and the likely recovery that took place between 2011 and 2014.

2 | METHODS

2.1 | Sampling regime

The NYSDEC collected macroinvertebrate samples from 13 sites in the Mohawk River basin (Figure 1, Table 1) in August 2011 as part of their Rotating Integrated Basin Studies program. A second set of samples was collected at the same 13 sites during October 2011, 6 weeks after floods associated with the two storms occurred. These datasets permitted us to evaluate the effects of the floods on benthic macroinvertebrate communities. Resident assemblages and stream physical–chemical parameters were resampled by the lead author again in July and October 2014 to help separate the potential effects of season from the effects of the floods between the two 2011 surveys. The 13 study sites (Table 1) were broadly distributed across the watershed (Figure 1) and represent a range of watershed areas, land use cover, altitude, and geographic location in the Mohawk River basin.

2.2 | Flood magnitude

The peak flows (discharge) during the floods of August and September 2011 were estimated for each ungaged study site by scaling USGS reference stations reported peak discharge magnitude or the AEP of that discharge, using a USGS watershed characteristics database called StreamStats. StreamStats was used to delineate the ungaged drainage–basin boundary and estimate the peak flows associated with standard flood AEP (Ries, Guthrie, Rea, Steeves, & Stewart, 2008) using regional regression equations devised between basin characteristics and long-term USGS discharge records, by hydro-physiographic region (Lumia, Freehafer, & Smith, 2006). The flood discharge and AEP associated with the Irene and Lee storms at each ungaged site were estimated using two methods, and the most extreme values (i.e., largest discharge, smallest AEP) were used to assess relationships with changes in macroinvertebrate metrics following the floods. The first method estimated ungaged peak discharge, $Q_{u\text{-}P}$, as the product of the ratio of watershed areas, A_u/A_g and the observed peak discharge, $Q_{g\text{-}P}$, where A_u is the ungaged watershed area and A_g is the gaged watershed area (Lumia et al., 2006). Then the $Q_{u\text{-}P}$ was used in StreamStats to interpolate between the regional regression flood discharge values and identify the associated $AEP_{u\text{-}P}$ for the ungaged peak flood. The second method simply used the USGS reported $AEP_{g\text{-}P}$ associated with the $Q_{g\text{-}P}$, (Lumia et al., 2014) to approximate the flood $Q_{u\text{-}P}$ for the ungaged site. The USGS gage reference sites used for each study site were selected based on the following characteristics: (a) the drainage area ratio A_u/A_g were within 0.5–1.5 of the ungaged site (Ries et al., 2008); (b) the precipitation during the storms had to be comparable to that in the ungaged watershed; (c) if there were more than one candidate gage, the one closest to the ungaged site was used; (d) the mean annual runoff had to be comparable to that of the ungaged site (as estimated for both reaches by StreamStats); and (e) the per cent of forested area had to be comparable to that of the ungaged site (as estimated for both reaches by StreamStats). For Mathew Creek (MATT), the A_u/A_g was 0.3 but otherwise met all other criteria. The reference peak flood flows, $Q_{g\text{-}P}$, were obtained from the USGS report on tropical storms Irene and Lee (Lumia et al., 2014), confirmed using records of peak flows at active gages.

2.3 | Rainfall magnitude

Precipitation (rainfall) amounts should also characterize the relative stress or potential harm to macroinvertebrate assemblages at all study sites. Like the flow-based AEP, rainfall-based AEP estimates

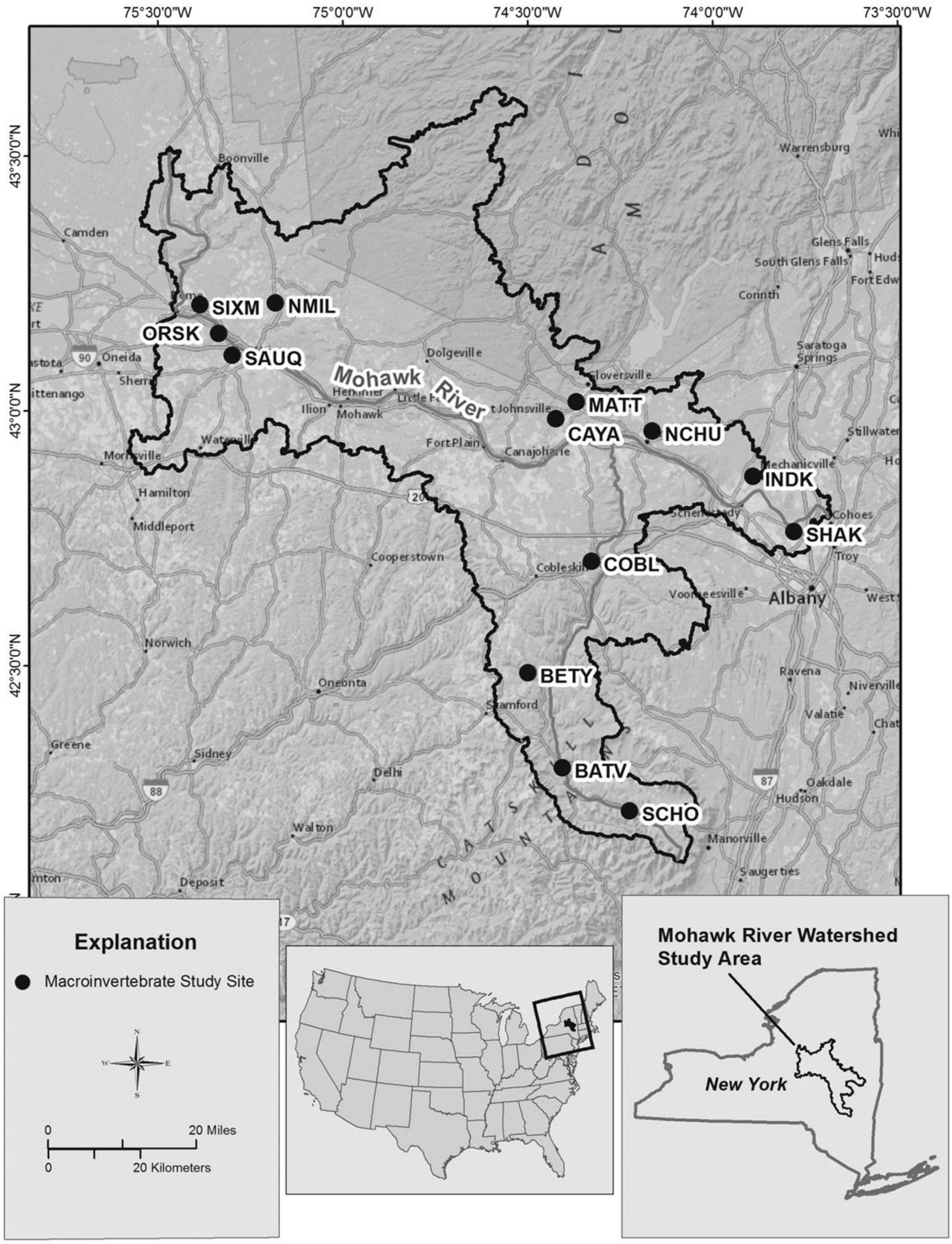

FIGURE 1 The locations of 13 study sites in the Mohawk River basin, New York where macroinvertebrate assemblages were sampled during August 2011, October 2011, July 2014, and October 2014. Stream names are listed in Table 1

characterize storm severity, but in this study, they were measured and had an advantage over flow-based AEP because they need not assume that conditions at ungaged study sites and gaged reference sites were comparable. They also had an important disadvantage in that rainfall AEP estimates—under some circumstances—might not reflect the actual severity of flooding as well as the potential stress and resulting harm to benthic macroinvertebrate assemblages. Rainfall quantities (1 to 24-hr time steps) and rainfall-based AEPs were determined using NEXRAD digital precipitation array data in subbasins upstream from each study and reference site. Both the 1- and 24-hr rainfall AEPs, and time of concentration (t_c), were used as predictor variables. The "time of concentration" is the time required for runoff to travel from the hydraulically most distant point in the watershed to the outlet or specific site (Fang, Thompson, Cleveland, Pradhan, & Malla, 2008); it was calculated by using methods described by Kirpich (1940). This method uses channel length and average slope of the watercourse to estimate the time of concentration in hours. For each of the 13 study (and 9 reference)

TABLE 1 Identification codes, stream names, latitude, longitude, and county for 13 study sites in the Mohawk River basin where macroinvertebrate assemblages were sampled in August 2011, October 2011, July 2014, and October 2014

Study site identification code	Stream name	Latitude, Longitude[a]	County
BATV	Batavia Kill	42.30264, −74.4198	Greene
BETY	Betty Brook	42.48900, −74.5090	Schoharie
SHAK	Shakers Creek	42.76056, −73.7992	Albany
INDK	Indian Kill	42.87028, −73.9064	Schenectady
SCHO	Schoharie Creek	42.21639, −74.2428	Greene
COBL	Cobleskill Creek	42.70722, −74.3383	Schoharie
NMIL	Ninemile Creek	43.2159, −75.1794	Oneida
ORSK	Oriskany Creek	43.15556, −75.3317	Oneida
SIXM	Sixmile Creek	43.21139, −75.3825	Oneida
CAYA	Cayadutta Creek	42.98667, −74.4303	Fulton
MATT	Mathew Creek	43.02028, −74.3753	Fulton
NCHU	North Chuctanunda	42.96167, −74.1733	Montgomery
SAUQ	Sauquoit Creek	43.11306, −75.2944	Oneida

[a]Datum is NAD83.

sites, the watershed (upstream drainage area) polygon file was used to download the NEXRAD rainfall time series for both storms using the USGS Geo Data Portal website (Blodgett, Booth, Kunicki, Walker, & Lucido, 2012). For each site's watershed, the estimated rainfall quantities at 1- and 24-hr durations and t_c were compared with extreme rainfall data (downloaded from the Northeast Climate Center Extreme Precipitation in New York and New England using the map interface tool) to estimate 1- and 24-hr rainfall-based AEPs following the same methods used to derive the flow-based AEPs. The NEXRAD rainfall data for the watersheds of reference sites were also retrieved and analysed to confirm that storm rainfalls at each reference site (used to estimate flow-based AEPs) and at its paired ungaged study site were comparable.

2.4 | Macroinvertebrate surveys

All benthic macroinvertebrate surveys followed standard sampling methods (NYSDEC, 2012), using a travelling kick net to disturb bottom substrate and capture dislodged organisms floating downstream with a 22.8 × 45.7 cm net, with mesh opening size 0.8 × 0.9 mm. All samples were collected in riffles with a combination of rock, rubble, gravel, and sand substrate, at depths less than 1 m. All sediment, organic debris and specimens were preserved with 95% ethyl alcohol. All samples were processed in the laboratory following standard procedures outlined in NYSDEC (2012). In general, each sample (debris and macroinvertebrates) were transferred to an enamel pan and a random subsample was removed with a spatula. This portion was examined under a stereo-microscope to locate, count, and sort individual specimens into major taxonomic groups. Sorting continued until at least a 100-organism subsample had been removed. The weight of the subsampled material was compared to the total weight of the entire unpicked sample material to calculate the per cent of the original sample that was processed to obtain 100 specimens. All sorted organisms, including Chironomidae and Oligochaeta, were identified to lowest possible taxonomic level, usually genus or species, using standard keys (NYSDEC, 2012).

2.5 | Macroinvertebrate community metrics

New York State Biological Assessment Profile (BAP) scores for macroinvertebrate communities in riffle habitats were calculated for all samples collected at each of the 13 study sites. The BAP is the standard multimetric index for assessing water quality impacts on benthic macroinvertebrate communities (NYSDEC, 2012). The five component indices used to calculate BAP scores were total taxa richness; Ephemeroptera, Plecoptera, and Trichoptera (EPT) richness; Hilsenhoff biotic index (HBI; Hilsenhoff, 1987); per cent model affinity (PMA; Novak & Bode, 1992); and nutrient biotic index–phosphorus (NBI-P; Smith, Bode, & Kleppel, 2007). The Shannon–Wiener index (D) was also assessed to gauge the potential impacts of the 2011 floods on community diversity.

2.6 | Data analysis

The effects of the 2011 floods were assessed by comparing BAP scores, its component metrics, per cent sorted, and diversity from August 2011 to the same metrics from October 2011, while potential seasonal changes (unaffected by any flood) were assessed by comparing the metrics from July 2014 to those from October 2014. Differences in metrics from the October 2011 and October 2014 surveys were used to both confirm the effects of the flood (like the 2011 comparisons), as well as the degree of recovery. The significance of differences in BAP scores and other metrics were analysed by using a parametric block design analysis of variance (ANOVA) test and a non-parametric Kruskal–Wallis test of differences in means, as well as Tukey–Kramer honest significant difference comparison tests, using a significance level of $\alpha = .05$. The relationships between flood magnitude (AEP) and the per cent change in BAP scores, component metrics (total richness, EPT richness, PMA, HBI, and NBI-P), and Shannon–Wiener diversity (D) were assessed using Spearman rank correlations. The relative abundance (per cent) of individual taxa in all samples were also analysed by using non-metric multidimensional scaling to describe similarities in the composition of assemblages across the four survey periods (Clarke & Warwick, 2001). Abundance data were square root transformed and similarities in taxonomic composition between surveys were analysed by using Bray–Curtis distances.

3 | RESULTS

3.1 | Macroinvertebrate community metrics

Five thousand one hundred organisms were counted and identified from all samples collected during the four surveys done at 13 study sites in 2011 and 2014. These data are available from the primary author or from the NYSDEC Biomonitoring Unit in Troy, New York. Differences between the total numbers of taxa (richness) were higher between samples collected at the same sites in August and October 2011 than between samples collected at the same sites in July and October 2014 (Figure 2, Table 2). The response and recovery of total richness (Figure 3b) and diversity (Figure 3e) to the floods were analogous. Shannon–Wiener diversity and total taxa richness at all sites were significantly lower after the floods (October 2011) than before the floods (August 2011) based on Kruskal–Wallis rank sum tests (Figure 3b,e). The Tukey tests confirmed that mean total richness in August 2011 (20.9) was significantly higher than it was during October 2011 (15.1). Mean total richness in October 2014 (17.8) was also significantly higher than it was in October 2011 (16.5) and indicates that taxa richness fully recovered during the 3 years since the floods. The lack of significant differences in mean total richness between samples collected in July 2014 (16.5) and October 2014 (17.8; Figure 3b) indicates that seasonality has little or no effect during the interval and did not bias the interpretation of impacts attributed to the floods during 2011.

The mean per cent of the sample sorted (a surrogate for relative abundance) at all sites was significantly larger during the October 2011 surveys (mean 56%, range 26%–100%) than during the August 2011 surveys (mean 19%, range 5%–36%) based on the ANOVA and Tukey comparison tests (Figure 3d, Table 2). The average per cent of sample sorted during the July 2014 surveys (34%, range 18%–58%) did not differ significantly from the mean during the October 2014 surveys (36%, range 14%–85%) (Figure 3d), which further supports the finding that the floods, not seasonality, produced the differences noted between the August and October 2011 surveys.

There were no significant differences between the mean EPT richness and the BAP scores from any survey period when pooled data were analysed by using a blocked ANOVA design or a non-parametric Kruskal–Wallis rank sums test (Figure 3a,c). The other component metrics used to calculate BAP (EPT richness, HBI, PMA, and NBI-P) (Table 2) also did not differ significantly between the August and October 2011 surveys.

3.2 | Magnitude of peak discharge and precipitation

Nine reference stream gages were identified and served as surrogates to the 13 ungaged sites, using the gage peak discharge, $Q_{g\text{-}P}$, and $AEP_{g\text{-}P}$ to estimate the ungaged study reach $Q_{u\text{-}P}$ and $AEP_{u\text{-}P}$ (Table 3). For 10 ungaged sites the most extreme discharge $AEP_{u\text{-}P}$ was based on estimation method 2, using the gage reported $AEP_{g\text{-}P}$ to interpolate $Q_{u\text{-}P}$ in StreamStats. For the other three ungaged sites (BATV, BETY, and SCHO), the most extreme $AEP_{u\text{-}P}$ was based on estimation method 1, using the product of area ratio and $Q_{g\text{-}P}$ to obtain $Q_{u\text{-}P}$, used to interpolate $AEP_{u\text{-}P}$ in StreamStats. Estimates of peak flood flows and AEP for all study sites are summarized in Table 3. Estimates of the rainfall AEPs for 1- and 24-hr rainfalls and for t_c that occurred at all study sites during the floods are summarized in Table 4. The flood AEP was not significantly correlated with 24-hr rainfall AEP (r = .23), 1-hr rainfall AEP (r = .38), or t_c (r = .35).

3.3 | Relationships between community metrics and flood magnitude

The changes in BAP scores between the August and October 2011 surveys were not significantly correlated with the (a) flood AEP (r = −.19), (b) 24-hr rainfall AEP (r = .12), (c) 1-hr rainfall AEP (r = .21), or (d) t_c (r = .10). The change in taxa richness between the August and October 2011 surveys was moderately correlated (p < .10) with flood AEP (r = −.48) but not significantly correlated with 24-hr rainfall AEP (r = .16), 1-hr rainfall AEP (r = .17), or t_c (r < .07). Like taxa richness, changes in diversity between the August and October 2011 surveys were moderately correlated with flood AEP (r = −.50, p < .01), and changes in EPT richness were significantly correlated with flood AEP (r = −.55). The changes in diversity or EPT richness between the August and October 2011 surveys were not significantly correlated with 24-hr rainfall AEP, 1-hr rainfall AEP, or t_c. Changes in PMA, HBI, NBI-P, and the per cent of sample sorted between the August and October 2011

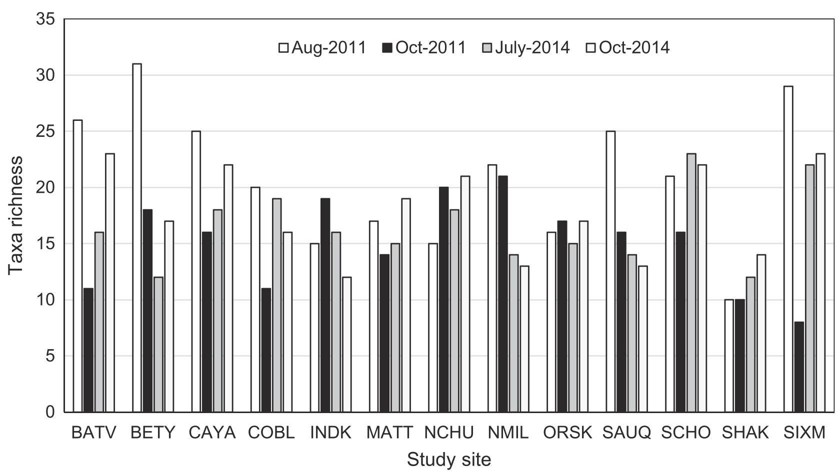

FIGURE 2 The total number of macroinvertebrate taxa (richness) for samples collected at 13 study sites in the Mohawk River basin during August 2011, October 2011, July 2014, and October 2014

TABLE 2 Macroinvertebrate community metrics from samples collected in riffles at each of 13 study sites in the Mohawk River basin during surveys done in August 2011, October 2011, July 2014, and October 2014

Community metric	Site ID												
	BATV	BETY	SHAK	INDK	SCHO	COBL	NMIL	ORSK	SIXM	CAYA	MATT	NCHU	SAUQ
August 2011													
Taxa richness	26	31	10	15	21	20	22	16	29	25	17	15	25
Per cent picked	14.2	22.0	14.8	9.7	30.0	28.4	31.3	5.2	36.0	16.3	7.1	21.8	6.2
EPT richness	16	19	4	2	11	11	6	9	4	7	5	8	7
HBI	4.15	3.26	5.45	5.19	4.06	4.35	4.12	4.70	5.20	5.21	4.17	3.64	5.11
PMA	75	54	47	36	73	48	52	43	51	52	40	61	65
NBI-P	5.72	4.42	6.87	7.19	6.28	5.01	6.24	7.12	6.77	7.15	6.14	5.11	6.56
BAP	7.89	8.30	4.04	5.66	6.90	6.69	5.88	4.90	8.50	5.44	5.04	6.57	6.18
Diversity	4.02	4.51	2.53	2.67	3.89	3.19	3.30	3.33	4.09	3.45	3.52	2.82	4.12
October 2011													
Taxa richness	11	18	10	19	16	11	21	17	8	16	14	20	16
Per cent picked	100	42.0	48.3	44.0	25.7	47.7	52.0	58.8	87.0	36.0	38.4	41.0	100
EPT richness	7	14	4	8	12	10	11	9	3	10	4	12	8
HBI	4.47	3.59	5.58	4.78	2.73	3.63	3.61	4.83	5.52	4.53	3.53	3.37	4.79
PMA	43	41	29	34	63	59	75	39	23	49	34	74	40
NBI-P	5.82	4.26	6.57	6.73	4.33	5.88	5.98	7.04	6.76	7.10	5.36	5.24	6.23
BAP	5.13	6.93	3.54	8.51	7.49	6.07	7.17	4.83	4.47	5.23	5.06	7.62	5.13
Diversity	3.06	3.70	2.26	3.39	2.62	2.97	3.60	3.25	1.51	3.31	2.92	3.49	3.36
July 2014													
Taxa richness	16	12	12	16	23	19	14	15	22	18	15	18	14
Per cent picked	58.0	28.3	23.0	56.0	20.2	22.0	39.0	32.0	18.0	25.3	27.6	47.0	51.0
EPT richness	10	9	6	3	17	12	9	9	5	9	5	10	5
HBI	4.33	5.14	5.53	5.38	2.74	4.61	4.78	5.22	4.39	4.90	3.56	4.34	5.39
PMA	65	66	32	55	68	53	65	45	31	46	34	73	79
NBI-P	5.26	6.38	6.41	6.29	3.66	5.95	6.12	5.99	6.53	6.33	5.88	5.51	6.39
BAP	6.73	5.67	4.16	6.37	8.49	6.38	5.99	5.34	8.59	5.45	4.97	6.88	5.55
Diversity	3.24	2.82	2.94	3.41	3.87	3.72	3.17	3.19	3.41	3.55	2.99	3.34	2.91
October 2014													
Taxa richness	23	17	14	12	22	16	13	17	23	22	19	21	13
Per cent picked	47.3	31.0	26.3	48.0	24.0	23.0	37.0	14.3	35.0	33.0	20.0	45.8	85.0
EPT richness	17	10	5	3	16	11	8	9	8	12	9	11	8
HBI	3.88	2.21	5.96	5.76	2.67	4.62	3.93	4.37	5.72	4.34	3.01	3.27	5.17
PMA	54	49	35	27	60	56	74	51	32	50	55	77	58
NBI-P	5.61	5.08	6.90	7.41	3.59	6.12	6.54	6.05	6.66	5.98	5.27	5.13	6.04
BAP	7.28	6.77	3.90	5.45	8.24	6.09	5.98	5.84	8.66	6.51	6.78	7.71	5.55
Diversity	3.92	3.54	3.06	2.39	3.91	3.53	3.34	3.62	3.19	3.86	3.28	3.76	3.26

Notes. BAP = New York State Biological Assessment Profile; Diversity = Shannon–Wiener index (D); EPT = Ephemeroptera, Plecoptera, and Trichoptera richness; HBI = Hilsenhoff biotic index; NBI-P = nutrient biotic index; Per cent picked = per cent of sample sorted to obtain 100 specimens; PMA = per cent model affinity. The names of study sites are listed in Table 1.

surveys were also not significantly correlated with any flood or precipitation metric.

3.4 | Community composition

The high 2D stress (0.25) and substantial overlap in the non-metric multidimensional scaling ordinations (Figure 4) indicate that the composition of macroinvertebrate communities at the 13 sites was highly variable and that assemblages did not change substantially across the four survey periods. More important, the distribution of August 2011 sites did not diverge noticeably from that of the others. This indicates that there were no shifts in community composition which might have been associated with flooding caused by tropical storms Irene or Lee or with seasonal shifts related to emergence of mature instars during late summer or early fall.

4 | DISCUSSION

The number of macroinvertebrate taxa (richness) found at most study sites in the Mohawk River basin was significantly affected by the 2011 floods, thus, it was not surprising that changes in taxa richness

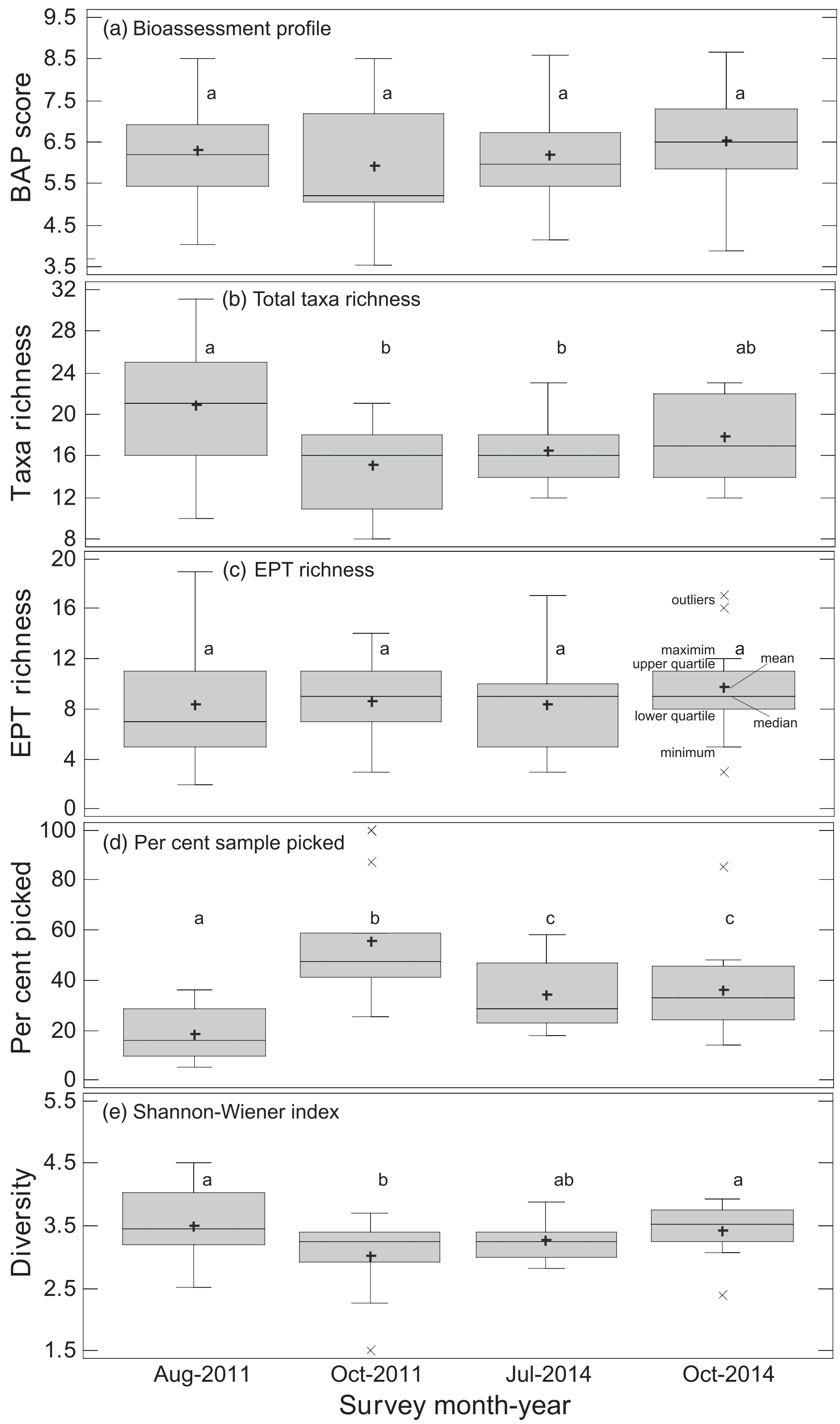

FIGURE 3 Boxplots depicting the mean, median, 25th and 75th quartiles (shaded boxes), the largest and smallest values, and outliers (data more than 1.5 times above or below the interquartile range) for (a) Biological Assessment Profile (BAP) scores, (b) total number of taxa, (c) number of Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa, (d) per cent of sample sorted to obtain 100 organisms, and (e) Shannon–Wiener diversity from macroinvertebrate samples collected at 13 study sites in the Mohawk River basin during August 2011, October 2011, July 2014, and October 2014. Boxes that share a letter do not differ significantly using Tukey tests and α = .05

after the floods were at least moderately correlated with flood magnitude. Taxa richness was the bioassessment metric most sensitive to the floods; it decreased on average by 28% after the floods, which was consistent with observations from other investigations (Fritz & Dodds, 2004; Gray & Fisher, 1981; Poff & Zimmerman, 2010; Quinn & Hickey, 1990; Rader, Voelz, & Ward, 2008). For example, Fritz and Dodds (2004) reported that more than 95% of taxa were lost after larger than 0.02 AEP floods occurred in streams in northeastern Kansas. Flood magnitudes at our 13 study sites were highly variable, with a moderate flood (0.033 AEP) at site SIXM causing a 72% decrease in taxa richness, while several sites with a similar or larger floods, such as at NMIL and MATT, did not markedly affect taxa richness (Figure 2, Table 3). With few exceptions, the loss of taxa observed at most sites following the 2011 floods had been erased by July and October 2014.

As expected, relative abundance of macroinvertebrates decreased markedly after the 2011 floods at most study sites. The mean per cent of sample sorted tripled after the floods and fell almost to pre-disturbance levels (20%–40% of sample) by 2014. A number of other studies documented changes in the abundance of benthic macroinvertebrates following floods (Bond & Downes, 2003; Fritz & Dodds, 2004; Lake, 2000; Molles, 1985; Robinson et al., 2003), with many reporting significant declines (Fisher, Gray, Grimm, & Busch, 1982; Gray & Fisher, 1981). In a review of flood studies, Death (2008) noted that the abundance of stream invertebrates can be reduced by 70%–95% after

TABLE 3 The drainage areas, estimates of peak discharge and annual exceedance probabilities (AEP), and the 2011 storm that caused the highest flows at 13 ungaged sites (and 9 reference sites) in the Mohawk River basin where macroinvertebrate assemblages were sampled in August 2011, October 2011, July 2014, and October 2014. The largest flood estimates (bold values) were used for assessing relations with macroinvertebrate metrics

		Drainage area (DA)			Reference site		Estimated peak discharge and AEP at ungaged study sites (based on)				
Ungaged site ID	Reference site ID	Ungaged site (km^2)	Reference site (km^2)	DA ratio	Peak flow (cms)	Flood AEP	Product of reference site peak × DA ratio Peak (cms)	Estimated peak and flow-AEP relation at ungaged site AEP	Reference AEP and flow-AEP relation at ungaged site Peak (cms)	Equal to AEP of reference site AEP	Storm
BATV	1349950	187.1	175.6	1.1	1251	<0.002	**1,334**	**0.001**	612	<0.002	Irene
BETY	1421618	21.6	36.6	0.6	70	0.111	**41**	**0.026**	25	0.111	Irene
CAYA	1330000	105.5	66.6	1.6	42	0.050	66	0.588	**159**	**0.050**	Irene
COBL	1359528	355.8	430.1	0.8	374	0.022	**309**	0.103	157	**0.022**	Irene
INDK	1360640	22.5	24.3	0.9	26	0.067	24	0.123	**28**	**0.067**	Irene
MATT	1348420	4.9	16.7	0.3	51	<0.002	15	0.005	**17**	**<0.002**	Irene
NCHU	1330000	91.1	66.6	1.4	42	0.050	57	0.397	**114**	**0.050**	Irene
NMIL	1503980	49.2	62.2	0.8	31	0.033	25	0.920	**90**	**0.033**	Lee
ORSK	4243500	373.8	289.3	1.3	181	0.100	233	0.227	**306**	**0.100**	Lee
SAUQ	4243500	153.9	289.3	0.5	181	0.100	96	0.267	**138**	**0.100**	Lee
SCHO	1349705	114.9	247.8	0.5	1147	0.500	**532**	**0.003**	92	0.500	Irene
SHAK	1360640	19.7	24.3	0.8	26	0.067	21	0.242	**32**	**0.067**	Irene
SIXM	1503980	30.7	62.2	0.5	31	0.033	15	1.399	**88**	**0.033**	Lee

Note. cms = cubic metres per second. Stream names for site IDs are listed in Table 1.

flooding. Many of these comparative surveys, however, were done within 2 weeks of the flood. Our post-flood survey was completed 6 weeks after the storm, which may have permitted some level of recolonization from upstream source areas or recruitment from normal late summer reproduction events. This may partly account for the relatively small decreases in abundance observed in our study sites between the August 2011 and October 2011 surveys. Given their potential for rapid recovery (Death, 2008), an earlier post-flood survey might have been able to detect some relations between flood-magnitude and community metrics.

The summer and fall 2014 surveys provided critical information needed to interpret the effects of the 2011 floods. The absence of a seasonal effect during the 2014 surveys indicates that floods were the primary cause for the significant decrease in richness and

TABLE 4 The storm that yielded the highest annual exceedance probabilities for 24- and 1-hr rainfalls, and the time of concentration (t_c) in the upstream drainages for 13 study sites in the Mohawk River basin where macroinvertebrate assemblages were sampled in August 2011, October 2011, July 2014, and October 2014 (stream names are listed in Table 1)

	Annual exceedance probabilities			
Site ID	24-hr rainfall	1-hr rainfall	t_c rainfall	Storm
BATV	0.002	0.15	0.004	Irene
BETY	0.014	0.91	0.28	Irene
SHAK	0.015	0.77	0.21	Irene
INDK	0.007	0.28	0.09	Irene
SCHO	0.004	0.18	0.02	Irene
COBL	0.013	0.71	0.01	Irene
NMIL	0.080	2.50	0.63	Lee
ORSK	0.030	2.50	1.10	Lee
SIXM	0.200	3.33	2.00	Lee
CAYA	0.040	0.83	0.36	Irene
MATT	0.050	1.25	1.25	Irene
NCHU	0.010	0.25	0.03	Irene
SAUQ	0.036	2.50	1.10	Lee

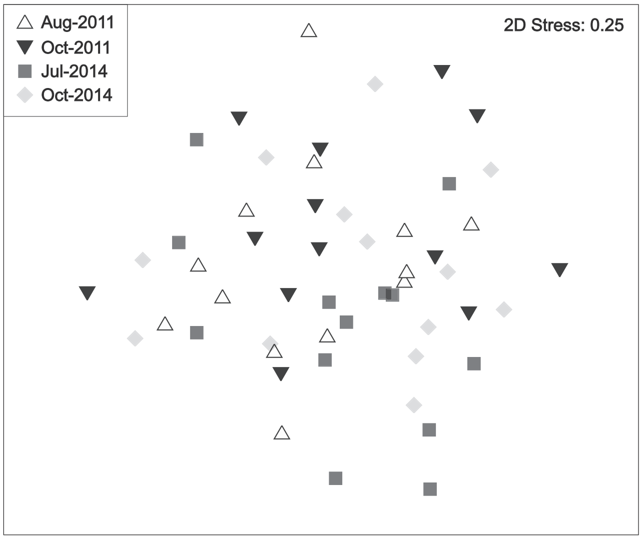

FIGURE 4 Non-metric multidimensional scaling ordination based on a matrix of abundance data for all taxa collected from 13 study sites in the Mohawk River basin during four surveys: August 2011, October 2011, July 2014, and October 2014

abundance between the August 2011 and October 2011 surveys. In aquatic systems, seasonality is often a result of the normal progression or changes in precipitation and insolation which affect stream parameters such as flow, depth, width, and velocity. These changes, along with shifts in temperature, alter habitat conditions and provide cues that regulate growth and development, and ultimately the emergence, mating, and reproduction of many univoltine and multivoltine macroinvertebrate species; all of which can cause replacement of dominant taxa (Beche, Mcelravy, & Resh, 2006).

The lack of response in BAP scores and several of its component metrics was not entirely unexpected because the component metrics were not designed to measure the effects of floods. The NYSDEC BAP is a standardized score designed to characterize water quality that is potentially impaired by organic enrichment, eutrophication, low dissolved oxygen, and industrial pollutants (Smith et al., 2007). For example, one component of the BAP, the HBI, was designed as an indicator of organic pollution and low dissolved oxygen (Hilsenhoff, 1987), while another, the NBI-P, was designed as an indicator of phosphorus enrichment (Smith et al., 2007). The BAP was not designed to detect changes in macroinvertebrate assemblages caused by increases in shear stress and bed mobilization or sedimentation, thus, it should not be overly responsive to flood disturbance.

There are several reasons, however, why the BAP might be expected to react to and reflect the severity of flood impacts on macroinvertebrate communities. Total taxa richness was responsive to flood magnitude and used to compute the BAP, thus, BAP scores could potentially reflect flood impacts if richness were more heavily weighted. Peak discharge itself, however, may not be the best gauge of flood-disturbance potential and impacts to benthic invertebrate communities (Townsend, Scarsbrook, & Dolédec, 1997). There is some evidence that any increase in discharge can have dissimilar biological effects in different streams (Death, 2008) or different effects in the same stream at different times of the year (Boulton, Peterson, Grimm, & Fisher, 1992). Different biological responses may result from wide variations in resistance among species populations (Scarsbrook & Townsend, 1993), the condition of assemblages before floods, the remnant assemblages remaining after floods (Death, 2008), and site-to-site differences in stream morphology and hydraulic forces during the floods. The relatively wide range in flood magnitude (i.e., flood AEP) at our 13 study sites means that benthic assemblages were subject to different stresses; thus, they should have responded inconsistently to peak flows resulting from tropical storms Irene and Lee. Perhaps another index that relies on total richness, diversity, abundance, and (or) some other metrics is needed to better characterize the impacts of extreme hydrologic events on macroinvertebrate assemblages in streams of the region.

The magnitude, duration, and frequency of extreme hydrologic events (floods and droughts) in the northeastern US are expected to change further with ongoing shifts in climatic conditions and increasingly threaten local macroinvertebrate assemblages; they might, however, remain relatively unaffected for several reasons. First, the lack of significant changes in most biotic metrics indicate that the function of most macroinvertebrate communities were not seriously impaired by the floods caused by tropical storms Irene and Lee. Though richness, diversity, and relative abundance at our study sites decreased, changes in community composition or structure (Figure 4) were minor and suggest that resident populations and communities were fairly resilient to the 2011 floods. Second, several investigators report that macroinvertebrate assemblages can recover from extreme floods in a few days, weeks, or months (Fritz & Dodds, 2004; Matthaei, Uehlinger, Meyer, & Frutiger, 1996; Molles, 1985), due mainly to re-colonization through drift or relocation of adults during emergence and egg deposition (Death, 2008). Gray and Fisher (1981) described four main re-colonization pathways for stream benthos including (a) aerial movements, (b) downstream drift, (c) upstream movement, and (d) vertical movement from deep substrates. Thus, whatever flood impacts were identified by the 2011 surveys, the macroinvertebrate assemblages at our study sites were probably beginning their recovery by the time of the October 2011 surveys. Third, the morphological and behavioural adaptations of many benthic species likely permitted them to resist displacement during flood flows. Although macroinvertebrates generally do not resist torrential flows well (Death, 2008), morphological adaptations such as dorsoventral flattening and holdfasts allow them to minimize drag, and withstand displacement by high velocities associated with large floods (Merritt & Cummins, 1996). Furthermore, habitat or substrate variability generally increases the availability of refugia into which individuals can escape large shear stresses during floods (Bond & Downes, 2003; Lake, 2000). Though not assessed, differences in refuge areas among the 13 study sites in the Mohawk River basin might help explain some inconsistent responses to the 2011 floods. Overall, the macroinvertebrate assemblages in streams of the region appear to be able to resist detrimental effects of extreme floods and (or) to recover rapidly from (or be resilient to) such events.

Our results do not closely track temporal succession or recovery from the 2011 floods, but suggest that richness, diversity, and abundance of assemblages were good indicators of flood impacts and recovery in benthic macroinvertebrate communities at our study sites. These metrics were significantly affected by the floods, yet are also relatively insensitive to nutrient enrichment, unlike NBI-P, PMA, and HBI. Thus, they appear to be most responsive (and good indicators) of flood effects. More frequent surveys would be needed to better qualify community resiliency, which could be characterized by how fast, and to what degree the three metrics recover from flood impacts across the region. The macroinvertebrate communities at five sites in the upper Esopus Creek (a tributary to the lower Hudson River), were also severely affected by floods during Irene, yet five surveys in 12 months detected some recovery by November 2011; and recovery was essentially complete by August 2012 (Data on file, New York State Department of Environmental Conservation). Richness remained lower in July and October of 2014 than it was in August and October of 2011 (before and after the floods) at several Mohawk River basin sites (e.g., NMIL and SAUQ: Figure 2), which suggests the assemblages did not fully recover or that other non-climatic factors changed at these sites and continue to limit community richness. For example, specific conductance at NMIL and SAUQ increased 10 fold between the 2011 and 2014 surveys which suggests that water quality, suspended-sediment concentrations, or habitat suitability changed permanently after the flood. Although community recovery after flooding can be rapid (Lake, 2000), not all metrics recover at the same rate, and different taxa groups recover at different rates (Molles, 1985). Though recovery from floods typically varies from 1 month for a 0.2 AEP flood (Matthaei, Uehlinger, & Frutiger, 1997) to almost 3 years for a 0.02 AEP flood (Giller, Sangpradub, & Twomey, 1991), Death (2008) noted that full recovery may take more than 5 years after severe floods. Thus, although apparently resilient, the macroinvertebrate communities at several study sites on tributaries to the Mohawk River may still be healing from the effects of the floods caused by tropical storms Irene and Lee.

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