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EFFECTS OF FLOW RELEASES ON MACROINVERTEBRATE ASSEMBLAGES IN THE INDIAN AND HUDSON RIVERS IN THE ADIRONDACK MOUNTAINS OF NORTHERN NEW YORK

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ABSTRACT

The effects of flow releases (daily during spring and four times weekly during summer) from a small impoundment on macroinvertebrate assemblages in the lower Indian River and upper Hudson River of northern New York were assessed during the summers of 2005 and 2006. Community indices, feeding guilds, dominant species and Bray–Curtis similarities at three sites on the Indian River, below a regulated impoundment, were compared with those at four control sites on the Cedar River, below a run-of-the-river impoundment of comparable size. The same indices at four less-likely affected sites on the Hudson River, below the mouth of the Indian River, were compared with those at an upstream control site on the Hudson River. Results show that the function and apparent health of macroinvertebrate communities were generally unaffected by atypical flow regimes and/or altered water quality at study reaches downstream from both dams in the Indian, Cedar and Hudson Rivers. The lentic nature of releases from both impoundments, however, produced significant changes in the structure of assemblages at Indian and Cedar River sites immediately downstream from both dams, moderate effects at two Indian River sites 2.4 and 4.0 km downstream from its dam, little or no effect at three Cedar River sites 7.2–34.2 km downstream from its dam, and no effect at any Hudson River site. Bray–Curtis similarities indicate that assemblages did not differ significantly among sites within similar impact categories. The paucity of scrapers at all Indian River sites, and the predominance of filter-feeding *Simulium gouldingi* and *Pisidium compressum* immediately below Abanakee dam, show that only minor differences in dominant species and trophic structure of macroinvertebrate communities occurred at affected sites in the Indian River compared to the Cedar River. Thus, flow releases had only a small, localized effect on macroinvertebrate communities in the Indian River. Copyright © 2011 John Wiley & Sons, Ltd.

KEY WORDS: recreational releases; pulse flows; macroinvertebrate communities; impoundment effects; dam; flow regulation

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INTRODUCTION

Dams can adversely affect downstream flow regimes, stream-channel geomorphology, water quality, aquatic habitat, resident- and migratory-species populations and entire aquatic ecosystems (Williams and Wolman, 1985; Vinson, 2001; Gillette *et al.*, 2005; Kocovsky *et al.*, 2009). The impoundments created by dams also can provide benefits such as recreation, generation of electricity and protection against floods (Lessard and Hayes, 2003). The effects of dams on undisturbed habitats tend to be greatest within the impoundment, but are also evident in downstream reaches (Ward and Stanford, 1979; Kanehl *et al.*, 1997), where they can affect aquatic species assemblages as well as hamper nutrient, water and sediment flux, and thereby alter many of the processes critical to healthy river ecosystems (Ligon *et al.*, 1995; Thomson *et al.*, 2005).

The general effects of decreased or moderated flows on downstream biological communities in riverine systems have been well documented (Ward and Stanford, 1979; Walker, 1985; Williams and Wolman, 1985; Drinkwater and Frank, 1994; Ligon *et al.*, 1995; Wood and Armitage, 1997; Nilsson and Berggren, 2000; Lessard and Hayes, 2003; Agostinho *et al.*, 2004). For example, altered flows can lower the diversity of downstream benthic macroinvertebrate communities, and increased stability of flows, and a surplus of fine, particulate organic matter, can modify the trophic structure of resident communities (Cortes *et al.*, 1998, 2002). Also, indices of biotic integrity, taxa richness (including Ephemeroptera, Plecoptera and Trichoptera richness) and the percentage of clingers (Santucci *et al.*, 2005), are typically higher in unregulated river sections than in regulated sections downstream from impoundments. Most of the effects of regulation on downstream macroinvertebrate communities result from dam-related alterations in riverine habitat or from changes in the quality of water stored and released from the impoundments (Lessard and Hayes, 2003; Tiemann *et al.*, 2004).

Periodic flow releases from a small impoundment on the lower Indian River in the Adirondack Mountains of

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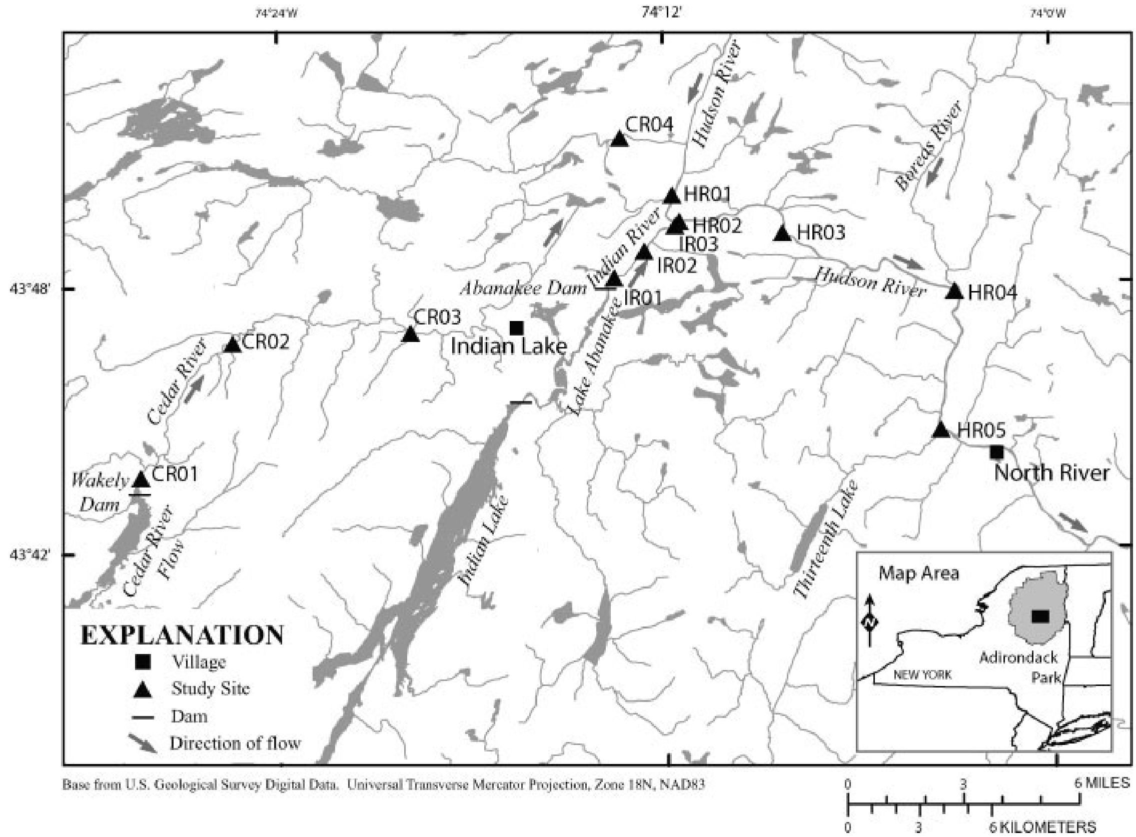

Figure 1. Principal geographic features and locations of monitoring sites on Cedar, Indian and Hudson Rivers, Essex and Hamilton Counties, NY, 2005–06.

northeastern New York (Figure 1) potentially affect downstream ecosystems and have led to disagreements over the best use of local water resources. The town of Indian Lake releases top water for 1.5–2 h daily from a dam on Lake Abanakee (Figure 1), from April to May and four times weekly from June to October, to increase river stage in a 27 km reach of the lower Indian and upper Hudson Rivers. These recreational flow releases (referred to as 'releases' from here on) are vital to the local economy, specifically the rafting industry, because they augment river stage during summer, when flows would normally be too low for rafting. These frequent releases, however, could also potentially affect the health and survival of stocked trout by adversely affecting the benthic macroinvertebrate assemblages that constitute much of their diet. Though natural and man-made impoundments often produce dramatic changes in benthic invertebrate communities in affected downstream reaches (Ward and Stanford, 1979; Walker, 1985; Lessard and Hayes, 2003) the effects that infrequent (peaking) flows have on the health of local macroinvertebrate communities or individual species populations are not well documented. Infrequent high-flow pulses could affect macroinvertebrate communities by (a) increasing thermal stresses or physical injuries, (b) creating higher drift rates, (c) altering the source, quantity or quality of their food or (d) decreasing the quality and quantity of preferred benthic habitat. These changes in turn could potentially affect the food web and alter entire aquatic ecosystems in parts of the Indian and Hudson Rivers below the Abanakee Dam.

In 2004, the US Geological Survey (USGS), in cooperation with the New York State Department of Environmental Conservation (NYSDEC) and Cornell University, began a 4 year study to evaluate the effects that the releases from Lake Abanakee have on benthic macroinvertebrate communities in a 27 km reach of the Indian and Hudson Rivers in the Adirondack Mountains of northern New York (Figure 1). Data on the flow regime, water temperatures and macroinvertebrate assemblages were collected to provide a basis to evaluate the effects that the releases from Lake Abanakee may have on downstream aquatic communities in the lower Indian River and parts of the upper Hudson River. Potential biological effects of the releases were assessed through comparisons of macroinvertebrate indices (metrics), dominant species and the percentages of selected functional feeding groups at affected reaches with those at (1) four control sites in a run-of-the-river system (Cedar River; impounded by Wakely Dam but unaffected by any flow releases) or (2) one site on

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the Hudson River upstream from the mouth of the Indian River and thus unaffected by any flow releases from Lake Abanakee (Figure 1). Adverse effects were hypothesized to be most evident at sites nearest the two impoundments and to become less evident with distance downstream as inflows from tributaries (and the mainstem Hudson River) potentially attenuate variations in flow caused by the releases (Munn and Brusven, 1991). Increased knowledge of the actual and potential effects of impoundment-management strategies will help regulatory agencies to balance the demands of political and economic interests (currently competing for the finite amounts of stream flow) against the requirements for sustained health of riverine ecosystems. Striking a better balance will ensure that these aquatic ecosystems are protected while the economies of local communities are not harmed.

METHODS

Three study sites were established in the Indian River, four in the Cedar River and five in the Hudson River during fall 2004 and spring 2005 (Figure 1). Site identifiers, USGS station numbers, site names, drainage areas and location of each site are given in Table I. Macroinvertebrate communities were surveyed at most study sites during August 2005 and at all study sites during 2006. The results from 2006 are preferentially interpreted because data collected at the same sites in 2005 and 2006 were similar and because the 2006 survey included three additional control sites in the Cedar River that were not sampled during 2005. The procedures for monitoring and assessing river discharge, stage, temperature and macroinvertebrate assemblages are summarized below and provided in greater detail by Baldigo *et al.* (2010).

Discharge, stage and water temperature

A near real-time discharge-gaging station (Indian River below Lake Abanakee near Indian Lake, USGS station 01315081) was installed on the Indian River 150 m downstream from the Lake Abanakee dam (IR01, Figure 1). This streamgage logged and transmitted near-real-time data on stage, discharge and water temperature during the study period (November 2004–September 2006). Discharge was computed from a new stage-to-discharge relation (rating curve) developed from flow and stage measurements through standard USGS methods (Rantz, 1982). Supplemental temporary stage and temperature transducers were installed at two other Indian River sites (IR02 and IR03) and at the five Hudson River sites (HR01–HR05) during spring 2005. Data from the temporary streamgages were stored by an internal logger and periodically downloaded manually during the study period. The streamgage at HR03 was not reactivated in 2006 due to access limitations and two other

Table I. Station number, name, location, distance downstream from impoundment and drainage area for each site in the Indian River, Hudson River and Cedar River study area, Essex and Hamilton Counties, NY, 2005–06

Site code	USGS station number	Site name	Distance below dam (km)	Drainage area (km^2)	Drainage area (mi^2)	Latitude (° ″ ′)	Longitude (° ″ ′)
IR01	01315081	Indian River below Lake Abanakee near Indian Lake	0.1	505	195	43 47 55.4	74 13 46.3
IR02	01315083	Indian River above Mouth near Indian Lake	2.4	513	198	43 48 47.6	74 12 37.5
IR03	0131508505	Indian River at Mouth near Indian Lake	4.0	518	200	43 49 21.4	74 11 40.0
HR01	01314000	Hudson River at Gooley, Near Indian Lake	na	1085	419	43 50 03.0	74 11 45.1
HR02	0131508508	Hudson River below Indian River near Indian Lake	4.6	1627	628	43 49 25.8	74 11 31.8
HR03	01315095	Hudson River near North River	9.5	1655	639	43 49 10.0	74 08 18.1
HR04	0131511503	Hudson River above Boreas River near North River	17.8	1691	653	43 47 50.6	74 03 00.1
HR05	01315340	Hudson River at, North River	24.4	1968	760	43 44 40.5	74 03 30.8
CR01	01312710	Cedar River below Wakely Dam near Indian Lake	0.1	117	45	43 43 38.9	74 28 18.5
CR02	01312790	Cedar River above Brown's Brook near Indian Lake	7.2	150	58	43 46 46	74 25 25
CR03	01312925	Cedar River above Bear, Trap Brook near Indian Lake	15.2	212	82	43 46 59	74 19 55
CR04	01313600	Cedar River above mouth near Indian Lake	34.2	425	164	43 51 21	74 13 22

Site locations are shown in Figure 1; na, not applicable.

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Hudson River streamgages that failed (HR02 and HR05) during summer 2006 were not repaired or replaced. All data loggers were programmed to measure stage and temperature at 15 min intervals.

All stage and water temperature data collected during the summers (June–September) of 2005 and 2006 were analysed to determine if significant changes in stage and water temperature occurred during dam releases. At each study site, water temperature and stage at the start and peak of each release were identified and the total change in both during each release was calculated. The same calculation was made for comparable time periods on non-release days. Mean changes in stage and temperature were calculated for both release and non-release days and *t*-tests were used to determine if the changes in stage and temperature on release days were significantly different ($p \leq 0.05$) from the changes in stage or temperature on non-release days for each month during the 4 month (summer) study periods and for each of the pooled 4-month periods each year. Thus, hypotheses test whether average (mean) monthly increases or decreases in stage and temperature (during releases) on release days is significantly different than the changes observed (during the comparable period) on non-release days. Additional comparisons of post-release stage decreases at IR01 were made in a similar manner.

Macroinvertebrate assemblages

Macroinvertebrates and debris were collected from nine sites (CR01, IR01–03 and HR01–05) in early August 2005 (Figure 1) by the standard travelling kick method (Bode *et al.*, 2002). These same sites were also sampled during August 2006 along with three new sites on the Cedar River (CR02–CR04). These additional sites were included to characterize the longitudinal extent of any reservoir effect on macroinvertebrate communities and potential recovery in the Cedar River. At each site, single 5-min samples were collected in riffles over a distance of about 5 m. Collection nets were rectangular and measured 23 cm × 46 cm, with a mesh size of 0.8 mm × 0.9 mm. Samples were rinsed in a 500 μm mesh sieve and preserved in 95% ethanol. At the laboratory, 100 specimens were randomly sorted from the debris three times and identified to the lowest possible taxonomic level (generally genus or species) and enumerated. Twenty-seven 100-specimen (organism) count samples were generated from the nine sites surveyed by this method during 2005, and 36 such samples were generated from the 12 sites surveyed during 2006.

Four general macroinvertebrate-community indices were calculated from each 100-organism sub-sample; the four indices were defined by Novak and Bode (1992) as follows:

- *Total community richness* denotes the total number of macroinvertebrate taxa (generally species) found at each site.
- *EPT richness* (Lenat, 1988) denotes the number of mayfly (Ephemeroptera), stonefly (Plecoptera) and caddisfly (Trichoptera) taxa found at each site. Species in these three orders are widely distributed, generally abundant and tend to be sensitive to variations in water quality.
- *Hilsenhoff's biotic index (HBI)* (Hilsenhoff, 1987) denotes degree of tolerance to organic enrichment. Sensitive taxa have low HBI values and tolerant taxa have high HBI values.
- *Percent model affinity (PMA)* (Novak and Bode, 1992) denotes the degree to which taxa from the benthic macroinvertebrate community at a given site matches that of an ideal or 'model' benthic macroinvertebrate community. It is based on the premise that the biological effects of pollutants can be quantified through a comparison of the makeup of a given macroinvertebrate community with that of an ideal community. The ideal model in riffles of New York streams consists of 20% Chironomidae, 10% Trichoptera, 40% Ephemeroptera, 5% Plecoptera, 10% Coleoptera, 5% Oligocheata and 10% 'other'.

The four indices described above were combined into the NYSDEC standard multimetric water quality-assessment score, the Biological Assessment Profile (NYSBAP), using methods described in Bode *et al.* (2002). All taxa were also categorized according to their functional feeding group using materials and methods from Merritt and Cummins (1996), Bode *et al.* (2002) and Barbour *et al.* (1999).

The potential effects of the releases on macroinvertebrate communities were assessed by comparing the five indices, dominant species and the proportions of various functional feeding groups at affected reaches with those from (1) control reaches in a run-of-the-river system (the Cedar River; impounded by Wakely Dam, but unaffected by releases) and (2) one control reach in the Hudson River located upstream of its confluence with the Indian River. Adverse effects were hypothesized to be most evident at the Indian River sites and Hudson River sites downstream and closest to Lake Abanakee and progressively less evident at further downstream sites, where inflows from tributaries and from the mainstem Hudson River attenuate flow variations caused by the releases. The relations among macroinvertebrate indices, the NYSBAP and the percentage for the various functional feeding groups at each site were evaluated through graphic and multi-parametric (ANOVA) analyses to qualify and quantify site-to-site differences or similarities, and to characterize possible shifts in community function and overall ecosystem processes that might be caused by the releases from Lake Abanakee. The dominant-taxa data were evaluated to identify obvious differences among sites. Further analyses of spatial patterns in macroinvertebrate-community composition and classifications (groupings of sites with similar assemblages) were done through multidimensional

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scaling (MDS) ordination of taxa relative-abundance data (square-root transformed; Shepard, 1962; Kruskal, 1964). The MDS ordination generates an arrangement of samples in 'species-space' according to the non-parametric ranks of their Bray–Curtis similarities (Clarke and Warwick, 2001). Bray–Curtis similarities were estimated from the same data metrics through hierarchical cluster (group-average linking) analysis and permutation tests of similarity profiles ($p \leq 0.05$; Clarke and Warwick, 2001).

Community indices, similarity of species assemblages, functional feeding groups and the dominant species at 12 study sites sampled during 2006 were assessed to test hypotheses that: (1) macroinvertebrate communities at all Indian River sites were adversely affected by releases from the Abanakee dam and (2) macroinvertebrate communities at the four sites on the Hudson River (below the mouth of the Indian River) were also partly affected by the same releases. Because sites in the upper Cedar were affected by a run-of-the-river impoundment, comparisons of macroinvertebrate indices between Indian River and Cedar River sites illustrate the relative effects of the releases on benthic invertebrate communities in the Indian River (they help adjust data for normal impoundment effects). Because macroinvertebrate communities in the Cedar River were not affected by recreational releases, the effects that the releases from Lake Abanakee had on macroinvertebrate communities at the three Indian River sites were evaluated by comparing community indices from IR01–04 to those from the Cedar River sites. Similarly, community indices from the four downstream Hudson River sites (HR02–HR05) were compared with those from HR01 (upstream of the study reach) to define effects and possibly quantify diminishing downstream effects related to the impoundment and the releases. Since analyses showed that the releases had (see results) minor effects on macroinvertebrate communities in the four Hudson River study sites, the community indices at these sites were also compared with those at Indian River sites to help define the combined effects of the impoundment and the releases on benthic macroinvertebrate communities at the three Indian River sites. All four study sites in the Cedar River and HR01 in the Hudson River (upstream of its confluence with the Indian River) were primarily used as controls. All statistical tests assign significance where $p \leq 0.05$ unless otherwise noted.

RESULTS AND DISCUSSION

Discharge, stage and water temperature

Indian and Hudson River discharge. Increases in discharge at IR01 and in river stage at all three Indian River sites, and all four Hudson River sites below the confluence with the Indian River, were significant during releases. Daily stage, discharge and water temperature data for IR01 (USGS station number 01315081) are available at, http://nwis.waterdata.usgs.gov/. Instantaneous maximum and minimum discharges, daily mean discharges for IR01 and water temperatures for most study sites are summarized in annual (2005 and 2006) USGS Water-Data Reports for Eastern New York excluding Long Island (http://ny.water.-usgs.gov/htmls/pub/data.html). Analysis of unit (15 min) values from the Indian River at Lake Abanakee streamgage (IR01) show that discharges were usually higher during summer 2006 than during summer 2005; daily mean flows averaged 259 and 443 $ft^3 s^{-1}$ during summer 2005 and 2006, respectively. During summer 2005, discharge averaged 180 $ft^3 s^{-1}$ immediately before each release, peaked at an average of 1387 $ft^3 s^{-1}$ during releases and decreased on average to 127 $ft^3 s^{-1}$ after the spillway gate was closed. During summer 2006, discharge averaged 349 $ft^3 s^{-1}$ immediately before each release, peaked at an average of 1410 $ft^3 s^{-1}$ during releases and decreased on average to 263 $ft^3 s^{-1}$ after the spillway gate was closed. During each release cycle, discharge at the this site typically increased to peak flows within 30 min, remained at peak flows for 90–120 min and decreased below original flows within 30 min. Discharge after the gates were closed decreased on average by 65–70 $ft^3 s^{-1}$ (mean 66 $ft^3 s^{-1}$) and by 63–96 $ft^3 s^{-1}$ (mean 80 $ft^3 s^{-1}$) below flows that occurred prior to releases during the summers of 2005 and 2006, respectively.

Indian and Hudson River stage. Monthly mean increases in stage at the three Indian River sites during releases were greater in 2005 than in 2006 and ranged from 1.18 to 2.14 ft during summer 2005 and from 0.79 to 1.94 ft during summer 2006 (Baldigo *et al.*, 2010). Monthly mean changes in stage at Hudson River sites (further downstream) during releases ranged from 1.14 to 3.15 ft during summer 2005 and from 0.67 to 1.31 ft during summer 2006 (Baldigo *et al.*, 2010). The mean and median changes in river stages recorded at all study sites between the start and the peak of releases on release days (rel) and for the same time intervals on non-release days (no rel) from July 1 to August 1, 2005 and 2006 are depicted in Figure 2A and B. Increases in stage during releases were comparable among all seven sites except IR01, which was directly below the dam and HR03, which was in a narrow section of the Hudson River gorge (Figure 2A). These increases were statistically significant at all seven sites downstream from Abanakee dam; stage at the Hudson River control site (HR01), upstream from the mouth of the Indian River, was unaffected by the releases, thus, changes in stage over the same periods on release and non-release days were not significant (Figure 2A).

River-stage and discharge data revealed one unanticipated aspect of the releases that could possibly affect local benthic macroinvertebrate communities. Stage and discharge at the Indian River gage below the Abanakee dam (IR01) usually dropped below the prerelease levels after the gate was closed and generally took at least 24 h to return to those same levels.

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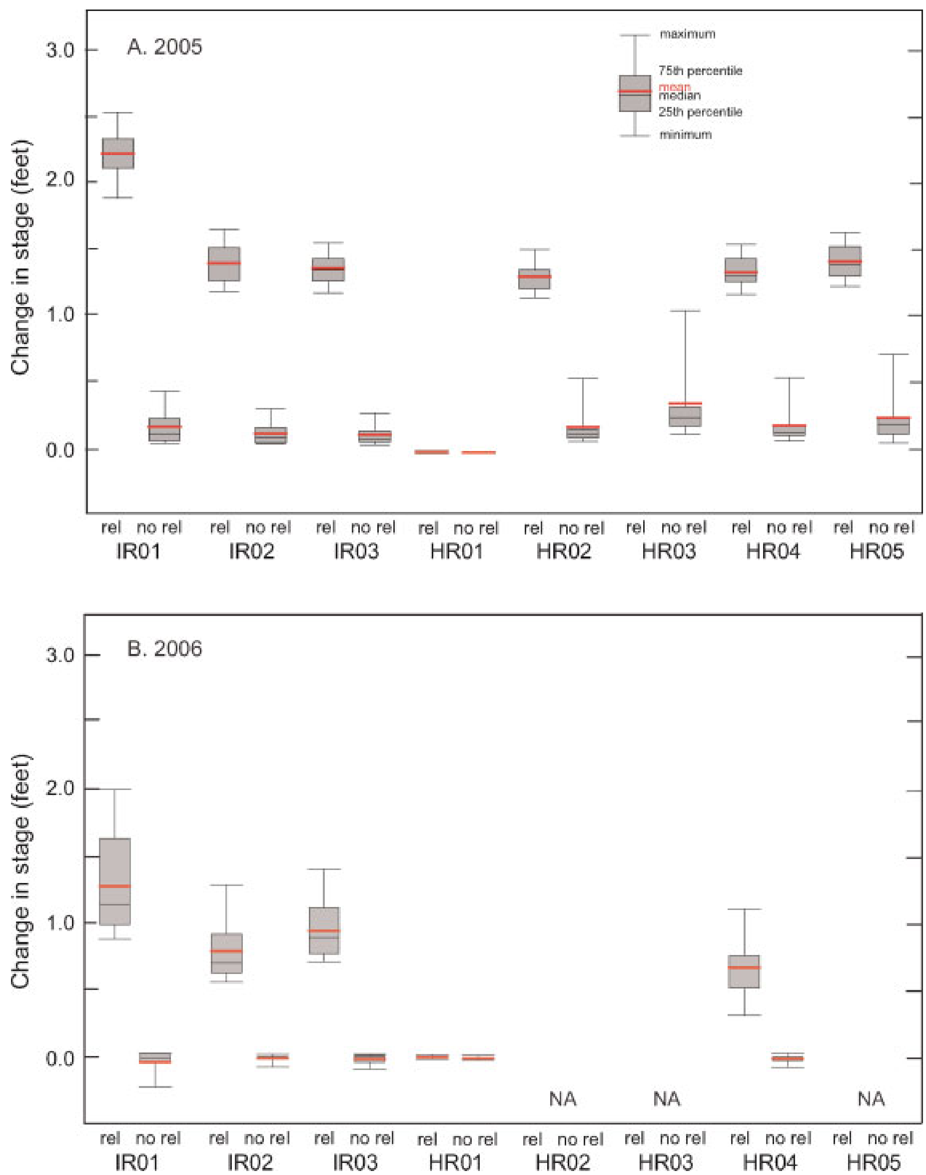

Figure 2. Change in river stage between the start and the peak of releases at three sites below an impoundment on the Indian River, at a control site on the Hudson River and at four affected sites on the Hudson River below the mouth of the Indian River on release days (rel) and for comparable intervals at the same sites on days of no release (no rel) during July 1 to August 1 of 2005 (A) and 2006 (B). Site locations are shown in Figure 1. This figure is available in colour online at wileyonlinelibrary.com

The mean decrease in river stage at this site following gate closures at Abanakee Dam ranged from 0.23 to 0.27 ft (mean 0.25 ft) below prerelease levels during summer months in 2005 and from 0.13 to 0.33 ft (mean 0.23 ft) during summer months in 2006 (Baldigo *et al.*, 2010). These prolonged decreases in river stage following releases indicate that wetted width, mean depth and total area of affected river segments were generally smaller after each release than before. Although not directly assessed by our study, the overall amount of stream habitat (and primary production) could be measurably reduced within affected reaches, especially at sites close to the dam.

River temperatures. Temperature data from the three sites on the Indian River and the five sites on the Hudson River indicate that the releases from Lake Abanakee either had no affect, or caused only minor decreases, in summertime water temperatures. Baldigo *et al.* (2010) assessed mean changes in river temperatures from the start of each release to its peak with mean changes during comparable periods on non-release days during the summer months (June–September) of 2005 and 2006 and determined that the releases generally caused: (a) significant ($p \leq 0.05$), but small (-0.04 to -0.60°C) decreases in temperature at the uppermost Indian River site IR01, (b) sometimes

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significant, but small positive and negative (−0.61–0.54°C) changes at IR02 and IR03, (c) non-significant and small increases at HR01 (0.14–0.50°C) and (d) sometimes significant, mostly positive and small changes (−0.05–0.64°C) at Hudson River sites HR02, HR03, HR04 and HR05.

Analysis of mean and median water temperatures (all data collected over 30-day periods) on release and on non-release days during each summer month (May–July and September) generally support the findings from the release-period comparisons (above). For example, Baldigo *et al.* (2010) reports that mean and median water temperatures during July 2005 were generally lower on release days compared to non-release days at all sites (Figure 3A). They also found that temperature differences between release and non-release days were often smaller during 2006 (Figure 3B) than during 2005 and were significant only at IR01 (−0.08°C), IR02 (0.05°C) and HR04 (0.11°C). Temperature data were not available at the control site (HR01) for July 2005, but differences in mean and median values between release and non-release days were not significant during 2006. All temperature differences related to the releases were either not significant or significant and small (negative or less than 0.61°C in 2005 and less than 0.25°C in 2006), which suggests that the releases did not alter overall temperatures sufficiently to affect biological communities at study sites in both rivers.

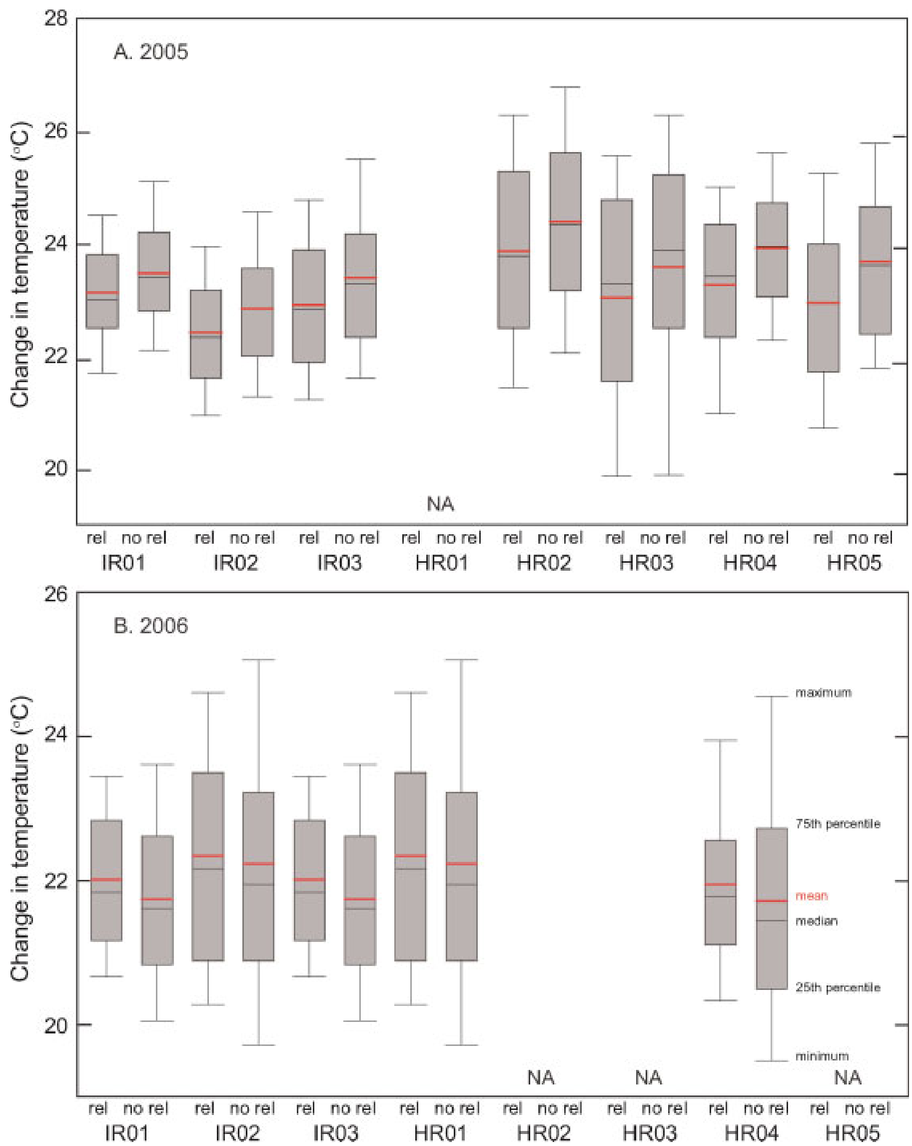

Figure 3. Change in river temperatures between the start and the peak of releases at three sites below an impoundment on the Indian River, at a control site on the Hudson River and at four affected sites on the Hudson River below the mouth of the Indian River on release days (rel) and for comparable intervals at the same sites on days of no release (no rel) during July 1 to August 1 of 2005 (A) and 2006 (B). Site locations are shown in Figure 1. This figure is available in colour online at wileyonlinelibrary.com

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In general, river water temperatures at all sites were slightly higher during summer 2005 than during summer 2006 (Baldigo *et al.*, 2010). Monthly mean temperatures were 1.1, 1.6 and 2.8°C greater in July, August and September of 2005 than during the same months in 2006. Maximum water temperatures for the period of record at Indian River below Lake Abanakee were 26.5°C on July 18, August 9 and August 10, 2005 (http://ny.water.usgs.gov/htmls/pub/data.html). Daily mean temperature records for 2005 and 2006 are available for the other temporary gages at: http://ny.water.usgs.gov/htmls/pub/data.html, during respective periods of operation.

Macroinvertebrate assemblages

Community indices. Mean community indices and the NYSBAP for macroinvertebrates from sites sampled during 2005 and 2006 are summarized in Table II. Community richness fell at or below the non-impacted to slightly impacted (category) threshold of 26 species (Smith and Bode, 2004) at CR01 and the three Indian River sites during 2005 and 2006, and at two additional Cedar River sites (CR03 and CR04) and three Hudson River sites (HR04 and HR05) during 2006. The HBI threshold of 4.51 for slight impact (Smith and Bode, 2004) was also surpassed only at sites CR01 and IR01 during 2005 and 2006. Estimates of EPT richness were below the non-impacted to slightly impacted threshold of 10 species (Smith and Bode, 2004) at IR01 in 2005, at all three Indian River sites, and at CR01 and CR04 during 2006. PMA was below the non-impacted to slightly impacted threshold of 64 (Smith and Bode, 2004) at CR01, IR01 and IR02 in 2005 and at these same sites plus CR04 and HR04 during 2006. Three of four individual indices (PMA, community richness and EPT richness) also categorized the impacts at IR01 and CR01 as moderate during 2006 (Table II). The average NYSBAP scores (derived from the four base indices) fell below 7.5 and indicate that macroinvertebrate communities were slightly impacted only at CR01 and IR01 during 2005 (Table II) and at all three Indian River sites (IR01–03) and at two Cedar River sites (CR01 and CR04) during 2006 (Table II, Figure 4).

Table II. Mean estimates of macroinvertebrate community richness (number of species), Hilsenhoff's biotic index (HBI), Ephemeroptera–Plecoptera–Trichoptera (EPT) richness, percent model affinity (PMA) and New York State Bioassessment Profile (NYSBAP) for samples collected in riffles at 12 study sites of the Cedar River, Indian River and Hudson River during summer 2005 and 2006

Site	Species richness	HBI	EPT richness	PMA	NYS BAP
2005 Survey					
CR01	**25.3**	**4.6**	11.3	**59.3**	**7.3**
IR01	**20.0**	**4.7**	**9.0**	**48.0***	**6.1**
IR02	**26.0**	4.4	13.0	**58.7**	7.6
IR03	**25.3**	4.3	14.0	70.0	8.1
HR01	28.3	4.3	15.0	69.3	8.4
HR02	31.0	3.7	18.3	65.0	8.7
HR03	27.3	4.2	12.0	72.0	8.1
HR04	33.7	3.4	17.3	77.3	9.1
HR05	35.0	4.2	14.0	82.0	9.1
2006 Survey					
CR01	**15.3***	**5.5**	**7.3**	**46.0***	**5.2**
CR02	29.3	4.3	13.0	75.0	8.4
CR03	**23.0**	4.2	12.7	78.3	8.0
CR04	**23.7**	4.0	**6.7**	**49.3**	**6.4**
IR01	**18.3***	**5.3**	**5.3***	**44.0***	**5.2**
IR02	**18.7***	4.3	**10.0**	**59.0**	**6.7**
IR03	**20.3**	3.7	**9.7**	71.3	**7.3**
HR01	**24.3**	3.7	16.7	69.3	8.3
HR02	29.7	3.6	15.7	66.7	8.5
HR03	32.3	3.8	16.0	76.7	9.0
HR04	**20.0**	3.1	12.7	**62.7**	7.6
HR05	**24.7**	3.6	14.0	74.3	8.3

Bold values denote scores in the slightly impacted category; asterisks indicate scores in the moderately impacted category. Site locations are shown in Figure 1.

The various community indices help define site-to-site differences and similarities, however, they cannot easily separate potential release effects from impoundment effects (Bode *et al.*, 2002) which are normally caused by altered water quality, hydrology, food supplies, nutrient and suspended-sediment loads and temperature regimes (Lessard and Hayes, 2003; Tiemann *et al.*, 2004; Santucci *et al.*, 2005). The slight and moderate community effects found at Indian and Cedar River sites may be caused by both the releases and the impoundment. In fact, macroinvertebrate indices at sites downstream of impoundments are usually corrected by shifting the impact-category cutoffs down one category (Bode *et al.*, 2002). Thus, the NYSBAP lower limit for the non-impacted classification would shift from 7.5 to 5.0, and the communities at all study sites would be reclassified as non-impacted. On the other hand, the 95% least significant differences (LSD) confidence intervals (Figure 4), and comparisons of homogeneous groups (Table III) for mean 2006 NYSBAP scores (and most of the other indices) suggest that communities at sites IR01–03 and Cedar River sites CR01 and CR04 are relatively alike and significantly different from most of the Hudson River sites (including the control site—HR01). Similarly, mean NYSBAP scores for 2005 and 2006 indicate that only sites CR01 and IR01 were slightly impacted (Table II); and these scores were significantly lower than those at all other sites in 2006 (Table III). The mean 2006 NYSBAP scores at sites IR03, CR03 and HR04 are also not significantly different from each other (Table III), which may be related to a diminishing impoundment effect at IR03 and possibly a weak impoundment effect at CR03 and HR04. Both CR04

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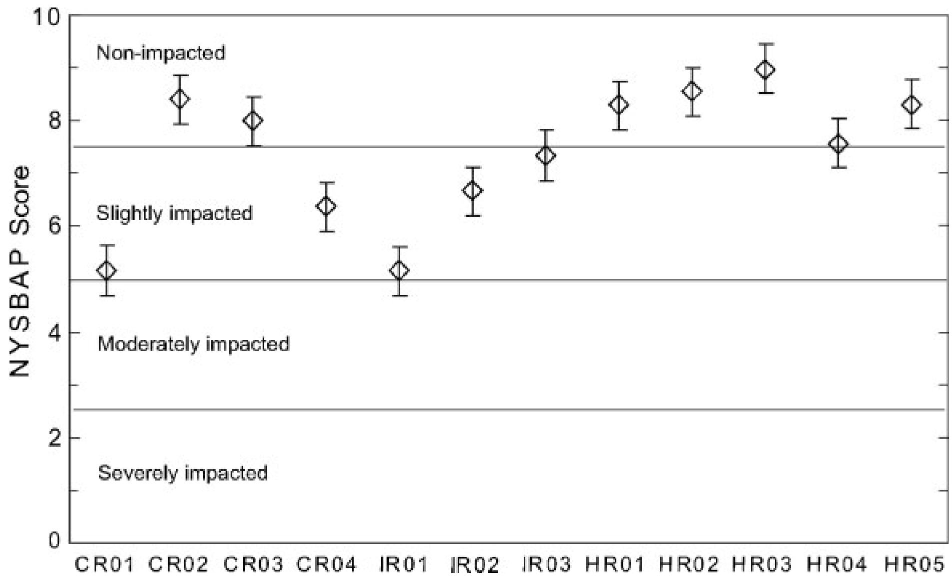

Figure 4. Mean New York State Bioassessment Profile (NYSBAP) scores and Fisher's LSD 95% confidence intervals in relation to impact categories at the 12 study sites in the Indian River, Hudson River and Cedar River, August 2006. Site locations are shown in Figure 1.

and HR04 are situated downstream of extensive riverine pools, which in the case of CR04 resembles a large marsh and may make it quite similar to IR02 (Table III).

The lack of significantly different mean NYSBAP scores and other indices between HR01 and the four other Hudson River sites located downstream of its confluence with the Indian River during 2006 (Table III, Figure 4) and 2005 (not shown), and the fact that all Hudson River sites were classified as non-impacted during both 2005 and 2006 (Table II), suggest that the releases (and the impoundment) had little or no negative effect on benthic invertebrate communities in the Hudson River. This is not surprising because the drainage area (and thus the discharge) of the Hudson River is approximately twice as large as the Indian River at their confluence (Table I), thus, any physical and biological effects at Hudson River sites should be diluted and relatively small. The similarity in NYSBAP scores between IR01 and CR01, the two sites located immediately downstream of the two impoundments, suggests that both communities responded to analogous stresses and were

Table III. Mean estimates for macroinvertebrate community richness, Hilsenhoff's biotic index (HBI), Ephemeroptera–Plecoptera–Trichoptera (EPT) richness, percent model affinity (PMA) and the New York State Bioassessment Profile (NYSBAP), and similarities among 12 study sites in the Cedar River, Indian River and Hudson River, Essex and Hamilton Counties, NY, 2006

Study site	Richness		HBI		EPT		PMA		NYSBAP	
	Mean value	Similar sites	Mean value	Similar sites	Mean value	Similar sites	Mean value	Similar sites	Mean value	Similar sites
CR01	15.3	*	5.5	*	7.3	***	46.0	*	5.2	*
CR02	29.3	***	4.3	*	13.0	***	75.0	***	8.4	**
CR03	23.0	***	4.2	**	12.7	***	78.3	*	8.0	**
CR04	23.7	**	4.0	**	6.7	**	49.3	*	6.4	*
IR01	18.3	**	5.3	*	5.3	*	44.0	*	5.2	*
IR02	18.7	***	4.3	*	10.0	***	59.0	*	6.7	**
IR03	20.3	****	3.7	*	9.7	***	71.3	***	7.3	**
HR01	24.3	**	3.7	*	16.7	*	69.3	***	8.3	*
HR02	29.7	**	3.6	*	15.7	***	66.7	***	8.5	**
HR03	32.3	*	3.8	**	16.0	**	76.7	**	9.0	*
HR04	20.0	****	3.1	*	12.7	***	62.7	**	7.6	*
HR05	24.7	**	3.6		14.0	***	74.3	***	8.3	**

The sites containing asterisk's within each column form a group of means which do not differ significantly ($p \leq 0.05$) based on Fisher's least significant difference (LSD) procedures. Site locations are shown in Figure 1.

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affected more by the impoundment than by releases. The releases did not appear to strongly affect macroinvertebrate communities in the Indian River given that the communities at most Indian River sites were comparable those occurring at Cedar River sites downstream from its run-of-the-river impoundment. In addition, potential impoundment (and release) effects did not extend to any study sites in the Hudson River. The lack of strong or significant effects on community indices, however, does not entirely eliminate the possibility that the releases adversely affected individual species and that ensuing species replacements fundamentally altered local food webs and riverine ecosystems at one or more Indian River and Hudson River sites.

Functional feeding groups. Further analyses of feeding guilds or groups at all study sites and of differences in the dominant macroinvertebrate species (taxa) among these sites generally confirmed an effect from the impoundment and also helped illustrate subtle effects that the releases had on different trophic levels and species populations. Mean percentages for each of five functional feeding groups at all 12 sites sampled in 2005 and 2006 (Table IV) show that spatial trends were generally comparable during both years. The three sites affected by impoundments (IR01, IR02 and CR01) generally had much lower percentages of collector-gathers and scrapers, and much higher percentages of filterers than most of the sites far downstream from both impoundments (Figure 5). The percentage of collector-filterers at the upper two sites in the Indian River (IR01 and IR02) was generally comparable to that at CR01 and was much higher than those at all Hudson River sites during 2006 (Table IV). The percentages of predators at all sites on the Indian River were slightly lower than at several sites on the Hudson River and at CR01 and CR02, but these differences were typically not significant (Table V). The percentages of scrapers at the three Indian River sites and CR01 were exceedingly low—slightly lower than at CR02 and significantly lower than at the five Hudson River sites (Table V). The scrapers at the three Indian River sites constituted less than 2% of the community assemblage but ranged from 5 to 18% at the four Cedar River sites and from 18 to 25% at the five Hudson River sites. The percentages of shredders differed minimally among all sites, whereas the percentages of collector-gatherers at IR01, CR01 and CR04 were significantly lower than at most other sites. No major differences were observed between the percentages of all feeding guilds at HR01 and their percentages at the other four Hudson River sites.

The feeding groups at CR01 and IR01, and generally at IR02 and IR03, like community indices, provide strong evidence that the impoundments alter food webs and the normal succession (continuum) of macroinvertebrate feeding groups at sites immediately downstream from both

Table IV. Mean percentage of macroinvertebrates within each of five functional feeding groups in samples collected from 12 sites in Cedar, Indian and Hudson River study area during summers of 2005 and 2006

Study site	Collector-filterer	Predator	Scraper	Shredder	Collector-gatherer
2005 Survey					
CR01	17.7	51.3	19.8	3.1	8.1
IR01	51.5	33.2	2.7	1.0	11.5
IR02	46.0	19.3	2.3	5.7	26.7
IR03	34.6	23.2	3.8	2.8	35.7
HR01	31.3	26.3	17.7	4.7	20.0
HR02	24.4	29.1	20.4	6.4	19.7
HR03	25.0	32.8	19.8	1.3	21.1
HR04	19.8	30.2	21.1	8.7	20.1
HR05	12.8	24.6	19.6	7.1	36.0
2006 Survey					
CR01	66.7	21.3	5.0	3.3	3.7
CR02	9.7	25.7	14.3	6.7	43.7
CR03	14.0	16.0	9.7	2.0	58.3
CR04	56.7	15.3	17.7	3.0	7.3
IR01	66.9	20.9	1.4	2.0	8.8
IR02	47.3	17.3	0.3	5.3	29.7
IR03	33.8	16.5	1.7	0.3	47.6
HR01	28.3	25.3	23.3	1.7	21.3
HR02	29.0	28.3	18.3	2.0	22.3
HR03	19.1	34.8	18.4	3.3	24.4
HR04	22.0	20.0	25.0	2.0	31.0
HR05	21.4	28.4	18.4	2.0	29.8

CR, Cedar River, IR, Indian River, HR, Hudson River. Site locations are shown in Figure 1.

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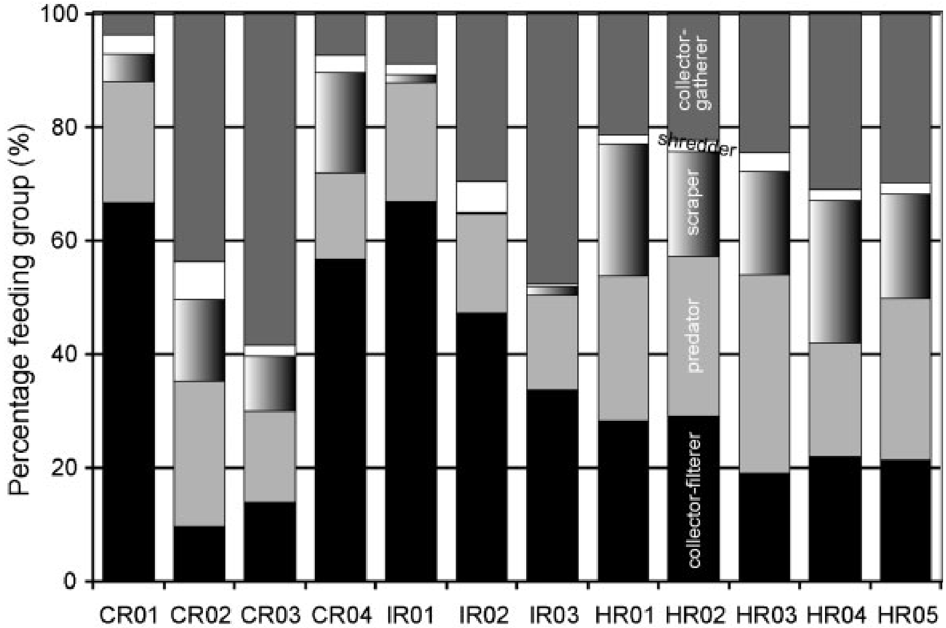

Figure 5. Percentage of total macroinvertebrates represented by each of five functional feeding groups at 12 study sites in the Indian River, Hudson River and Cedar River, August 2006. Site locations are shown in Figure 1.

dams. The scarcity of scrapers (grazers) and the abundance of filterers, at all three Indian River sites and at sites downstream from both dams (IR01 and CR01) indicate low primary productivity and a paucity of coarse organic material which is generally expected in large rivers or lentic habitats according to the river continuum concept (Vannote *et al.*, 1980). The river-continuum concept also predicts that macroinvertebrate communities (specifically the proportion of selected feeding groups) change sequentially as one proceeds further downstream due to normal succession in the physical environment, the size of particulate organic matter and the relationship between production and respiration. Minor differences in communities between both sites, therefore, might be also attributed to differences in drainage areas, which are about four times larger in the Indian River downstream of Lake Abanakee (IR01) than in the Cedar River downstream of Wakely Dam (CR01). The total length of stream channel upstream of IR01 is much

Table V. Mean percentage of macroinvertebrate community feeding groups and similarities among 12 study sites in the Cedar River, Indian River and Hudson River, Essex and Hamilton Counties, NY, 2006

Study site	Collector-filterer		Predator		Scraper		Shredder		Collector-gatherer	
	Mean value	Similar sites	Mean value	Similar sites	Mean value	Similar sites	Mean value	Similar sites	Mean value	Similar sites
CR01	66.7	*	21.3	***	5.0	*	3.3	**	3.7	*
CR02	9.7	*	25.7	***	14.3	*	6.7	*	43.7	*
CR03	14.0	**	16.0	**	9.7	*	2.0	**	58.3	*
CR04	56.7	*	15.3	*	17.7	*	3.0	***	7.3	*
IR01	66.9	*	20.9	***	1.4	**	2.0	**	8.8	*
IR02	47.3	*	17.3	**	0.3	*	5.3	**	29.7	*
IR03	33.8	*	16.5	**	1.7	**	0.3	*	47.6	*
HR01	28.3	**	25.3	****	23.3	*	1.7	**	21.3	*
HR02	29.0	*	28.3	**	18.3	*	2.0	**	22.3	***
HR03	19.1	**	34.8	*	18.4	*	3.3	**	24.4	***
HR04	22.0	**	20.0	***	25.0	*	2.0	**	31.0	*
HR05	21.4	*	28.4	**	18.4	*	2.0	**	29.8	*

The sites containing asterisk's within each column form a group of means which do not differ significantly ($p \leq 0.05$) based on Fisher's least significant difference (LSD) procedures. Site locations are shown in Figure 1.

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longer than that upstream of CR01 which also places IR01 relatively lower in its river system than CR01. The communities at CR01 and IR01 (immediately downstream of both impoundments), however, are basically alike and more representative of lower, rather than mid-basin river reaches. This suggests that both impoundments prevent the normal community succession and site-to-site differences, which would be predicted due to differences in drainage areas. The only obvious difference between macroinvertebrate assemblages in the Cedar River and those in the Indian River was the lower percentage of scrapers at all Indian River sites than found at most Cedar River sites. Otherwise, site-to site differences in feeding guilds provide limited evidence that the releases had a discernible effect (that was unique and distinguishable from the impoundment effect) at the three Indian River sites or at any of the Hudson River sites downstream from its confluence with the Indian River.

Dominant taxa. The dominant and subdominant macroinvertebrate species (the two to four species with the highest sample counts at each site) differed somewhat between affected (or impacted) and non-affected sites and reflect the unique physical conditions and food sources within riffles just downstream from both impoundments. Benthic macroinvertebrate communities at non-affected sites HR01–HR03 were dominated by collector-gatherers (e.g. swimming mayflies—*Ameletus* spp. and *Acentrella* spp.), scrapers (e.g. baetid mayflies such as *Heterocloeon* sp. and beetle larvae—*Oulimnius* spp. and *Stenelmis* spp.), predators (e.g. Acariformes and Megalopterans such as *Climacia* sp. and collector-filterers such as fingernail and pea clams (*Musculium transversum* and *Pisidium compressum*) and *Hydropsyche* spp., even though streamflows at HR02 and HR03 fluctuated moderately with the releases. In contrast, local communities at sites affected sites CR01, IR01 and to some extent at CR04, were dominated by collector-filterers like the pea clam (*P. compressum*) and blackflies (*Simulium gouldingi*), and net-building chiromonids (*Microspectra polita*) and caddisflies (e.g. *Hydropsyche* spp. and *Nyctiophylax* sp.); whereas scrapers and collector-filterers were generally rare (Figure 5). Two species (*P. compressum* and *S. gouldingi*), however, were abundant at IR01 and almost entirely absent at CR01. In addition, scrapers such as *Stenelmis* spp., *Oulimnius* spp., *Phaenopsectra* sp., *Heterocloeon* sp. and *Stenonema* spp., were present at both sites, but they constituted 5–18% of the total counts at CR01 and less than 2% of the counts at IR01 during 2006 (Table V) and 2005 (not shown). Communities at the other Indian River and Cedar River sites (IR02, IR03, CR02 and CR03) were generally similar to each other and more comparable to those at most Hudson River sites than to those at affected sites within the same rivers. The predominance of collector-filterers solely at CR01 and IR01 confirms that any effects are spatially limited and directly related to conditions normally encountered below impoundments (Bode *et al.*, 2002). The comparable effects on macroinvertebrate communities in both the Indian River and Cedar River (at sites within the first few 100 m downstream of respective dams) and the relative similarity in communities at IR02–03, CR02–03 and among all Hudson River sites, indicate that releases did not seriously impair communities in much of the lower Indian River nor at any study site in the Hudson River. The larger percentage of scrapers at CR01 than at the three Indian River sites, and the presence of two collector-filterer species (blackflies and pea clams) only at IR01 suggest that the releases did have a negligible effect on macroinvertebrate assemblages in the Indian River, however, the effect was limited mainly to sites close to the Abanakee dam.

Community similarity. A cluster analysis of Bray–Curtis similarities (Figure 6) for 2006 data generally supported the findings from prior feeding-guild and dominant-species analyses. The macroinvertebrate assemblages at sites IR01

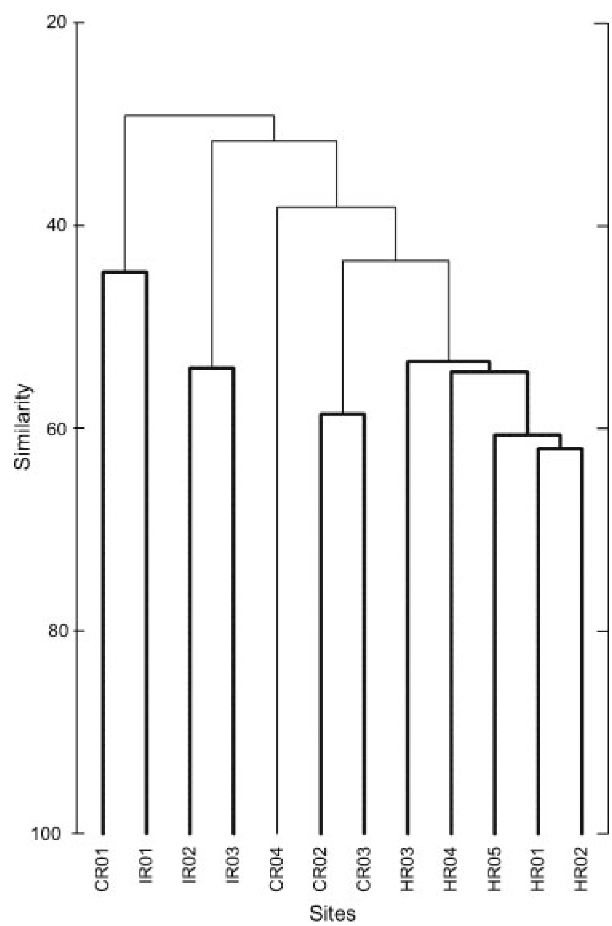

Figure 6. Cluster analysis of Bray–Curtis similarities for macroinvertebrate assemblages, based on square-root-transformed relative abundance data from combined replicate samples collected at 12 study sites in the Indian River, Hudson River and Cedar River, August 2006. The dark bold links identify site assemblages that do not differ significantly ($p \leq 0.05$) from each other. Site locations are shown in Figure 1.

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and CR01 did not differ from one another significantly ($p < 0.05$) and were more similar to each other (about 45% similar) than to assemblages at all other study sites (about 29% similar). Macroinvertebrate assemblages at IR02 and IR03 were about 54% similar to each other and were 29% similar to those at CR01 and IR01, and about 32% similar to those at all other sites. Assemblages at CR02–CR04 were from 38 to 58% similar to each other and 43% similar to those at all Hudson River sites. Macroinvertebrate assemblages at all Hudson River sites were 53–65% similar to each other and did not differ significantly from one another.

The 40% similarity bubbles in the two-dimentional ordination plot (Figure 7) help illustrate how well species assemblages from affected, partly affected and unaffected sites segregated into groups. These groupings did not identify any effects in the Indian River that were attributable only to the releases, but indicated: (a) a strong and similar impoundment effect only at the two sites immediately downstream from both dams (IR01 and CR01), (b) an undefined effect at CR04 (possibly related to boggy upstream conditions), (c) diminished impoundment effects at downstream sites IR02 and IR03 in the Indian River (1.4–2.5 mi below the dam) and (d) no distinguishable effects at any Hudson River sites (HR01–HR05) nor at downstream Cedar River sites CR02 and CR03, located 5.0–33.5 mi below its dam.

Study implications

Our ever increasing demand for finite water resources will require a thorough and thoughtful evaluation of competing needs for multiple users and the associated environmental and monetary costs. Accurate and up-to-date information on aquatic ecosystems and on local and regional water resources will be necessary to evaluate the interconnected effects of each use and for responsible allocation of limited supplies. Findings from this study indicate that the function and integrity (health) of benthic macroinvertebrate communities were generally not affected by the altered hydrologic regimes, nor by degraded water quality, at all study reaches located downstream from both dams in the Indian, Cedar and Hudson Rivers. The strong effects on the structure of macroinvertebrate communities at sites immediately downstream from both dams could be attributed primarily to the lentic nature of waters found downstream from impoundments. The lack of significant differences between the NYSBAP scores and other indices for control site HR01 and those for the four Hudson River sites downstream from the mouth of the Indian River during the summers of 2005 and 2006, together with the classification of all five Hudson River sites as non-impacted during both years, indicate that neither the releases nor the impoundments themselves had any adverse effects on macroinvertebrate communities in the Hudson River. The near absence of scrapers at all Indian River sites and the presence of two distinctive species (blackflies and pea clams) only at IR01 (closest to the dam), suggests that the releases affected macroinvertebrate assemblages within the lower Indian River, but to only a negligible degree. The effects that the observed differences in macroinvertebrate assemblages might have on organisms at higher trophic levels in the lower Indian River are unknown but could possibly be important on the scale of 1–2 km. Whether those small effects would extend to intermediate trophic levels and top consumers in the Indian River would require more intensive studies of local fish communities and food web interactions.

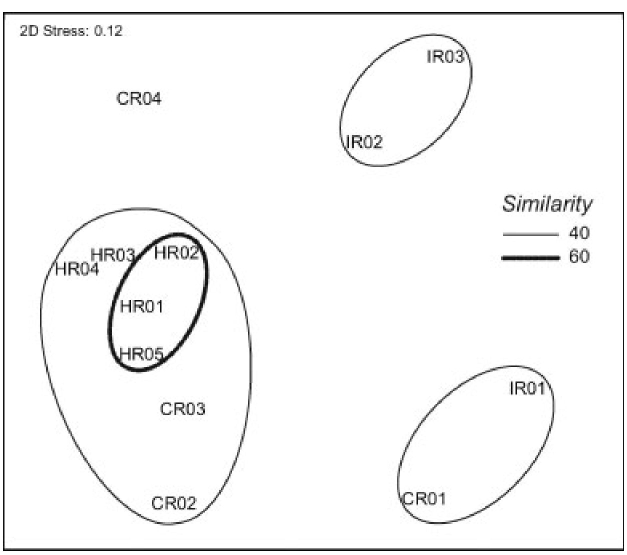

Figure 7. Ordination plot of macroinvertebrate assemblages, based on square-root-transformed relative abundance data from combined replicates collected at the 12 study sites in the Indian River, Hudson River and Cedar River, August 2006. The bubbles denote group membership (40 and 60 percent Bray–Curtis similarity; $p \leq 0.05$) based on group-averaged cluster analysis. Site locations are shown in Figure 1.

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