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Effects of Recreational Flow Releases on Natural Resources of the Indian and Hudson Rivers in the Central Adirondack Mountains, New York, 2004–06

Scientific Investigations Report 2010–5223

U.S. Department of the Interior
U.S. Geological Survey

Cover. Main photograph—Hudson River near the Blue Ledges, October 2004.
Inset photograph—Rafters at the confluence of the Indian and Hudson Rivers, July 2005.

Effects of Recreational Flow Releases on Natural Resources of the Indian and Hudson Rivers in the Central Adirondack Mountains, New York, 2004–06

By B.P. Baldigo, C.I. Mulvihill, A.G. Ernst, and B.A. Biosvert

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Conversion Factors, Datums, and Acronyms

SI to Inch/Pound

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	Area	
hectare (ha)	0.003861	square mile (mi^2)
square kilometer (km^2)	0.3861	square mile (mi^2)
	Volume	
cubic meter (m^3)	35.31	cubic foot (ft^3)
	Flow rate	
cubic meter per second (m^3/s)	35.31	cubic foot per second (ft^3/s)

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
cubic foot (ft^3)	0.02832	cubic meter (m^3)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F = (1.8 \times °C) + 32$$

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

°C= (°F-32)/1.8

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).
Mesh sizes of sieves are given in micrometers (µm).

Coordinates for trout telemetry data are rcorded in Universal Transverse Mercator Zone (U18) coordinates.

List of Acronyms

CI	Confidence intervals
EPT	Ephemeroptera-Plecoptera-Trichoptera
GCU	Geomorphic channel units
HBI	Hilsenhoff's Biotic Index
MDS	Multidimensional scaling
NYSBAP	New York State Biological Assessment Profile
NYSDEC	New York State Department of Environmental Conservation
PMA	Percent model affinity
RIT	Rochester Institute of Technology
TD	Temperature differences
USGS	U.S. Geological Survey
UWNY	United Water New York
WSA	Water Supply Application

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Executive Summary

The U.S. Geological Survey (USGS), New York State Department of Environmental Conservation (NYSDEC), and Cornell University completed a cooperative 2-year study from late 2004 to 2006 to characterize the potential hydrologic, physical, and biological effects of the releases from Lake Abanakee on the Indian, Cedar, and Hudson Rivers in the Adirondack Mountains of New York. Researchers gathered baseline information on hydrology, temperature, habitat, wetlands, and communities of resident fish (brown trout) and macroinvertebrates. Collaborators with the Rochester Institute of Technology measured surface river-water temperatures in August 2005 through remote (aerial) infrared imaging during base and high (release) flows.

This report summarizes important natural resources and evaluates differences in (1) selected physical (hydrology and temperature) conditions in a 17-mile-long[1] reach of the Indian and Hudson Rivers downstream from the Abanakee Dam; (2) the frequency, duration, magnitude, and spatial extent of variations in hydrology and temperature related to the releases; (3) macroinvertebrate and fish communities, riparian wetlands, and instream-habitat data from most of the same sites (and from four control sites in the Cedar River); (4) the potential effects of flow releases on the biological resources of the Indian and Hudson Rivers; (5) the quality and quantity of thermal refuges in the three rivers under normal base flows and the effects of flow releases on thermal refuges in the Indian and Hudson Rivers; (6) the normal use of thermal refuges by brown trout during base flows in the three rivers and the potential effects of releases on trout behavior, survival, and use of thermal refuges in the Indian and Hudson Rivers; and (7) the level of drawdown (change in stage) in Lake Abanakee caused by the releases.

The effects of the releases were assessed by comparing data from affected reaches with information from (1) the same reaches during nonrelease days, (2) control reaches in a nearby run-of-the-river system (the Cedar River), and (3) one reach in the Hudson River upstream from the confluence with the Indian River.

River Discharge and Stage — Discharge for the Indian River at Lake Abanakee (site IR01) was usually higher in summer 2006 than in summer 2005; daily mean flows averaged 259 and 443 cubic feet per second (ft^3/s) during June, July, August, and September 2005 and 2006, respectively. The average base flow before releases in June, July, August, and September 2006 was 349 ft^3/s, which was nearly double the flow observed during the same period in 2005 (180 ft^3/s); however, the average peak discharges during releases in 2005 and 2006 (1,387 and 1,410 ft^3/s, respectively) were nearly equivalent. Discharge during the releases increased on average by 1,207 ft^3/s and 1,061 ft^3/s in the summer (June, July, August, and September) of 2005 and 2006, respectively.

Mean increases in stage during releases in June, July, August, and September at the three Indian River sites ranged from 1.18 to 2.14 feet (ft) during 2005 and from 0.79 to 1.94 ft during 2006. Mean monthly changes in stage during releases for study sites in the Hudson River ranged from 1.14 to 3.15 ft during 2005 and from 0.67 to 1.31 ft during 2006. Increases were smaller in 2006 than in 2005 because base flows were generally higher during the summer of 2006.

[1] Unit conversions are shown in the conversion tables at the front of the report.

In 2005, mean river stage and discharge during June, July, August, and September at IR01 decreased by 0.23 to 0.27 ft (mean 0.25 ft) and 65 to 70 ft (mean 66 ft), respectively, below values prior to the release and after the gate was closed; river stage and flow did not fully rebound until the next release about 60 percent of the time. In 2006, mean river stage and discharge during June, July, August, and September at IR01 decreased by 0.13 to 0.33 ft (mean 0.23 ft) and 63 to 96 ft (mean 80 ft), respectively, below mean values prior to the release, after the gate was closed; river stage and flow did not fully rebound until the next release about 46 percent of the time.

Lake Abanakee Stage — The releases caused the Lake Abanakee stage to consistently decrease by 0.30 ft on release days during June, July, August, and September of 2005 and 2006. Lake stage between releases fully rebounded to the stage before the release 50 percent of the time in 2005 and 58 percent of the time in 2006. The average recovery prior to the next release was 91 percent of the prerelease stage in 2005 and 98 percent of the prerelease stage in 2006. Lake levels dropped more than 0.30 ft only during gate malfunctions or when the gate was left open to alleviate risk of flooding around the shores of Lake Abanakee.

River Temperatures — The recreational flow releases appeared to cause no biologically relevant change in water temperatures at all study sites in the Indian and Hudson Rivers, even though mean and median temperatures on release days were significantly lower than mean and median temperatures on nonrelease days. Regardless of releases, water temperatures at all study sites commonly exceeded a threshold (20°C) known to be stressful to brown trout. The maximum water temperature for the period of record at Indian River below Lake Abanakee (IR01) was 26.5°C on July 18, August 9, and August 10, 2005. Water temperatures were higher at all sites in summer 2005 than in summer 2006; mean daily temperatures were 1.1, 1.6, and 2.8°C greater in July, August, and September of 2005, respectively, than in the same months during 2006. The mean daily maximum temperatures at all study sites did not differ significantly on days with releases and days without releases. The releases caused no significant short-term increase in river temperature at any study site, but they produced small (less than 0.5°C) significant decreases in water temperatures at three sites.

Stream Habitat — Short riffles dominated habitat at most Indian and Hudson River study sites during base flows, and fewer but larger habitat units were evident during the releases. Higher water velocities during releases increased the amount of fast-water habitat (rapid, riffle, run) and decreased the amount of slow-water habitat (pool, glide, backwater, side channel) at all study reaches. Habitat alterations were more pronounced in reaches nearer the dam; rapids were a dominant habitat unit in the Indian and upper Hudson reaches during release flows, but glides were a dominant habitat unit in the lower Hudson reaches during both release and base flows. Changes in water velocities and habitat during flow releases might force fish species to alter behaviors or be displaced from preferred habitat and (or) positions in the river.

Wetlands — Surveyed shorelines along the Indian River included fewer wetlands than control reaches in the Cedar River: wetlands composed 18 percent of the total length of Indian River shoreline, compared to 25 percent (upper reach) and 46 percent (lower reach) of the Cedar River shoreline. Although differences in wetland coverage between the two rivers may be partly related to the releases, the plausibility of both positive and negative effects of release flows on wetlands indicates that this issue is complicated. The Indian River may include fewer wetlands because of the decades-long presence of a major upstream dam. The flow releases scour fine sediments from the river bed and banks while the dam restricts the supply of upstream sediment; both act to reduce the sustainability of wetlands. The current release schedule, however, may also help to maintain wetlands in the Indian River by allowing periodic inundation of perched wetlands in backwater areas. Further research is needed to support these hypotheses.

Remote Thermal Imaging Study — Data from the three thermal imaging flights, with the release bubble covering different sections of the 27-km study reach, showed that few thermal refuges (waters at least 1°C colder than the main channel) occurred in the study area under normal summer base flows. Five cold-water tributaries entering the Hudson River downstream from the Boreas River contained most of the potential thermal refuge areas in the study area. The high-flow bubble (peak stage moving through study reaches) produced by flow releases from Lake Abanakee eliminated most main-channel refuges. In the lower Indian River (km 4–5), a water-surface area of 1,606 m^2 (4.24 percent) was at least 1°C colder than the main channel during base flows (third flight), but an area of only 56 m^2 (0.15 percent) was at least 1°C colder during release flows (second flight). In the Hudson River Gorge (km 6-15), a water-surface area of 529 m^2 (1.00 percent) was at least 1°C colder than the main channel during base flows (third flight), but an area of only 176 m^2 (0.34 percent) was at least 1°C colder during release flows (second flight). In the lower Hudson River (km 20–27), a water-surface area of 515 m^2 (0.68 percent) was at least 1°C colder during base flows (second flight), but an area of only 22 m^2 (0.03 percent) was at least 1°C colder than the main channel during release flows (third flight). Temperature data from the first flight were not included in this analysis because exposed rocks sometimes appeared to be thermal refuge; for instance, a surface area of 2,512 m^2 (7.56 percent) in the Indian River (km 1–5) appeared to be at least 1°C colder than the main channel during release flows, but an area of only 220 m^2 (1.25 percent) appeared to be at least 1°C colder when only the unshaded half of the river was considered. Analysis of temperature patterns at different spatial scales show different effects of release water on quality of fish habitat. Water temperatures in the middle of the reach (Hudson River Gorge) were consistently cooler than in the upper and lower study reaches of the river, and the high-flow bubble did not diminish thermal refuges in this reach to the same extent as in upper and lower reaches.

Thermal imaging offers an effective way to identify and characterize cold-water refuges in streams with poor access; however, two issues diminish the utility of Indian River data and analyses. First, boundaries between water and land were not always discernible and had to be delineated manually because overhanging vegetation on color images hid some shorelines, and surface temperatures of the river and the rocky shorelines could not be separated electronically on digital images. Second, the analyses and results could be limited by these technical difficulties and by the general inability to detect seeps on the river bed.

Fish Assemblages — Fish-population and community data were collected and summarized through electrofishing surveys at 12 sites in the Cedar, Indian, and Hudson Rivers during 2005 or 2006. Community indexes and density and biomass of individual fish populations were evaluated to test hypotheses that: (1) fish communities at all Indian River sites were negatively affected by the releases, and (2) fish communities at the four downstream sites on the Hudson River were moderately affected by the releases.

In the Indian River, fish communities appeared to be strongly affected by the releases at site IR01 and moderately affected at IR02 and IR03. Communities were slightly affected by the releases at the first study site in the Hudson River below the confluence with the Indian River (HR02) and either positively or not affected by releases at the remaining downstream Hudson

River sites (HR04 and HR05). Significant differences between estimates of community biomass and density at IR01 and at the most upstream Cedar River site (CR01) and the slight decrease in both estimates at HR02 indicate that fish communities at IR01 and HR02 were atypical. Community richness was consistently one to six species lower at the three Indian River sites than at all other study sites and three to six species lower than at the two downstream sites on the Cedar River. Community diversity, equitability, and dominance did not differ significantly among study sites in the three rivers. Significant differences in average community richness values at the three Indian River sites and at study sites in the Hudson River and in the Cedar River (aggregated by river) indicate that the releases may adversely affect the number of fish species in the Indian River. Species richness, diversity, and equitability were generally higher, and dominance at the three Hudson River sites downstream from the confluence with the Indian River (HR02, HR04, and HR05) was lower than at HR01, indicating that community function at the three affected Hudson River sites was altered slightly. Community structure at these three sites, however, was more balanced than the community at the control site HR01. The decreasing indexes with increasing drainage were opposite those observed in the Indian River and indicate either that natural variability in community indexes was high and the effects could not be quantified, or that the fishery was negatively affected when relative changes in flow were large and positively affected when relative changes in flow were moderate.

The changes in the density and biomass of individual fish populations as a result of flow releases were generally similar to changes in the community indexes. The releases had a strong effect on the densities of individual fish populations at the three Indian River study sites, whereas the effects of the releases on fish populations in the Hudson River were either less obvious, nonexistent, or contrary to what was expected. The releases appeared to reduce the number of fish species and slightly decrease the abundance of some endemic species in the Indian River. Flow releases may have also caused small changes in the densities of some species at several Hudson River sites, replacement of a few species at HR02 and HR04 (rather than species losses as noted for the Indian River), and little or no adverse effects at HR05. The total biomass of dominant species populations was severely affected by the releases only at IR01. The total biomass of species populations at Hudson River study sites reflected the addition of several species and small decreases or no change in species abundance. The balance of species populations generally increased as indicated by increases in community equitability at sites farther downstream; these trends appeared to be unrelated to the releases.

Biomass can be a better gauge of community disturbance than density because measures of biomass tend to fluctuate less widely than density when communities are affected by biotic, habitat, and water-quality stresses. Biomass data for species populations in this study were less variable (total biomass varied by a factor of 6) among sites than density (total density varied by a factor of 94). The biomasses of cutlips minnow, longnose dace, smallmouth bass, and rock bass populations at CR04, IR02, IR03, and possibly HR01 were relatively well balanced and similar to each other, but they generally differed from biomasses of species populations at sites farther upstream in the Cedar River. Biomasses of species populations at Indian River sites IR02 and IR03 were generally comparable to those observed at the two control sites, CR04 and HR01. Differences between the total biomass of populations at Indian River sites IR02 and IR03 and at the Cedar River sites CR01 and CR02 may be related to low densities of predator species at upstream Cedar River sites (above the Cedar Dam) or to different environmental conditions at the lower Indian River sites. The total community biomass at potentially affected Hudson River sites (HR02–HR05) was dominated by three to six species, including common shiner, fallfish, white sucker, cutlips minnow, smallmouth bass, and trout, whereas the total biomass at the control site (HR01) was dominated by smallmouth bass, rock bass, cutlips minnow, and central mudminnow. Except for sites HR01 and HR02, the biomass of fish populations was relatively well balanced in communities at most Hudson River study sites.

Other unmeasured factors may have also contributed to, or caused the observed differences in, population and community indexes among study sites in the three rivers. Additional replicated fish-community data, hydrologic data, and more detailed habitat information would be needed to fully document site-to-site similarities and differences and evaluate whether differences in population and community indexes were caused mainly by releases or by a combination of physical, chemical, and biological factors.

Macroinvertebrate Communities — Macroinvertebrate community data were summarized for surveys done at 12 study sites in the Cedar, Indian, and Hudson Rivers during 2005 and 2006; however, only results from 2006 were assessed to test hypotheses that macroinvertebrate communities at all Indian River sites were negatively affected by the releases, and that macroinvertebrate communities at the four downstream sites on the Hudson River were moderately affected by the releases.

Separate analyses of macroinvertebrate community indexes, functional feeding guilds, dominant species, and Bray-Curtis similarities provided complementary findings. Estimates of community richness were at or below the slightly affected (lower) threshold of 26 species only at CR01 and the three Indian River sites during 2005 and at two additional Cedar River and three Hudson River sites during 2006. The New York State Bioassessment Profile (NYSBAP) scores were below 7.5 only at CR01 and IR01 during 2005 and at all three Indian River sites and CR01 and CR04 during 2006. The factors that affect invertebrate communities in the Cedar and Indian Rivers appear to be analogous because NYSBAP scores (and most other metrics) were not significantly different between the sites immediately downstream from the dams in both rivers (IR01 and CR01). Analyses of feeding guilds and differences in dominant macroinvertebrate taxa generally confirm impoundment effects and indicate that macroinvertebrate communities at the study sites were similar during 2005 and 2006. The 2006 data indicate that 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 unaffected sites farther downstream from impoundments. No major differences were noted between the percentages of feeding guilds at HR01 and four other Hudson River sites. The composition of feeding guilds at CR01 and IR01, as well as those at IR02 and IR03, provide strong evidence for impoundment effects on food webs at riverine sites immediately downstream from both dams. A cluster analysis of Bray-Curtis similarities identified no unique effects in the Indian River caused by flow releases, but showed strong and similar impoundment effects at the two sites immediately downstream from the dams (IR01 and CR01), an undefined effect at CR04, diminishing effects at sites farther downstream in the Indian River (2 to 4 km below the dam), minor or no effects at downstream Cedar River sites (8 to 54 km below the dam), and no distinguishable effects at all Hudson River sites.

Overall, the results indicate that function and integrity (health) of macroinvertebrate communities at all Indian, Cedar, and Hudson Rivers were generally not affected by water quality, which ranged from very good to good. The strong effects on macroinvertebrate communities at sites immediately downstream from both dams could be attributed primarily to the comparable quality of waters discharged from respective impoundments. The near absence of scrapers at all Indian River sites and the presence of two unique species (blackflies and pea clams) at IR01 indicated there were some minor effects on benthic invertebrate assemblages by the releases. The lack of significantly different mean NYSBAP scores and other indexes between HR01 and the four other Hudson River sites downstream from its confluence with the Indian River during 2005 and 2006, and the fact that all Hudson River sites were classified as unaffected during both 2005 and 2006, indicates that the releases (and the impoundment) had few or no adverse effects on benthic macroinvertebrate communities in the Hudson River.

Trout Behavior — The use of thermal refuges by stocked brown trout varied among study reaches and ranged from low to moderate levels in the three rivers. Telemetry observations indicated that brown trout used thermal refuges to maintain body temperatures at least 1ºC cooler than the main-stem river (trout-body temperature differences (TDs) were at least 1ºC cooler than the river) 29 percent of the time in the Hudson River, 38 percent of the time in the Cedar River, and about 4 percent of the time in the Indian River. Observations when river temperatures were warmer than 20ºC and TDs were at least 1ºC cooler than river waters indicate that brown trout used thermal refuges 33 percent of the time in the Hudson River, 30 percent of the time in the Cedar River, and 4 percent of the time in the Indian River. Observations when river temperatures were warmer than 20ºC, trout temperatures were less than 20ºC, and TDs were at least 1ºC cooler than the river indicate that brown trout used thermal refuges 9 percent of the time in the Hudson River, 17 percent of the time in the Cedar River, and 1 percent of the time in the Indian River.

The releases generally decreased the ability of many trout to benefit from thermal refuges in the Indian and Hudson Rivers. Multilevel-effect analyses indicated that the releases had a significant negative effect on thermoregulation of trout in the Indian River and on trout within 50 m of a tributary in the Hudson River. When ambient river temperatures were thermally stressful, releases increased average temperatures of brown trout by less than 0.5ºC in the Indian River and by more than 1.0ºC in the Hudson River; however, the biological significance of this reduced ability to thermoregulate remains uncertain for several reasons. First, very few trout used thermal refuges in the Indian River. Brown trout near tributaries in the Hudson River occasionally maintained cooler temperatures or moved into cooler waters during releases. A limited number of observations before and during releases (span data) show that body temperatures did not change (80 percent) or increased (20 percent) in the Indian River and did not change (41 percent), increased (38 percent), or decreased (22 percent) in the Hudson River during releases. The releases, however, may have only a small effect on individual brown trout (and their populations) in the Indian and Hudson Rivers because few thermal refuges exist in both reaches, and relatively few study trout were found to exploit them. Although some naturalized brown trout may be present in the system, we assume that the behavior of telemetry (study) brown trout was comparable to the behavior of most resident brown trout because both groups originated from local hatcheries as 2-year olds and few generally overwintered.

Rates of trout movement and apparent survival during the telemetry study differed among study reaches and illustrate the different effects of unique thermal refuges and flow regimes on brown trout in the three river systems. The daily movement of trout was greater in study reaches in the Hudson River than in either the Indian or Cedar Rivers, and movement was generally unaffected by releases in the Indian and Hudson Rivers. In all study reaches, some trout dispersed from stocking locations within 24 to 48 hours. Over time, most trout tended to inhabit a few specific locations, usually in deep pools or runs or near tributary confluences. Different trout activity levels among the three study reaches may be related to variations in stream gradient and general habitat conditions. The apparent survival time for stocked trout was very low and similar in the Indian and Hudson Rivers during 2005 and 2006 but significantly higher in the Cedar River than in the other rivers during 2006. Fewer than 12 percent of trout stocked into affected reaches in the Indian and Hudson Rivers survived through both years, whereas 53 percent of trout in the Cedar River survived during 2006. More than 20 percent of dead trout and transmitters were found or inferred to be in the forest, sometimes in burrows or a rookery, indicating that predation was an important source of mortality. Other causes of mortality were likely angling, thermal stress, and starvation caused by the high metabolism rate required for survival.

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Effects of Recreational Flow Releases on Natural Resources of the Indian and Hudson Rivers in the Central Adirondack Mountains, New York, 2004–06

By B.P. Baldigo, C.I. Mulvihill, A.G. Ernst, and B.A. Boisvert[1]

Abstract

The U.S. Geological Survey (USGS), the New York State Department of Environmental Conservation (NYSDEC), and Cornell University carried out a cooperative 2-year study from the fall of 2004 through the fall of 2006 to characterize the potential effects of recreational-flow releases from Lake Abanakee on natural resources in the Indian and Hudson Rivers. Researchers gathered baseline information on hydrology, temperature, habitat, nearshore wetlands, and macroinvertebrate and fish communities and assessed the behavior and thermoregulation of stocked brown trout in study reaches from both rivers and from a control river. The effects of recreational-flow releases (releases) were assessed by comparing data from affected reaches with data from the same reaches during nonrelease days, control reaches in a nearby run-of-the-river system (the Cedar River), and one reach in the Hudson River upstream from the confluence with the Indian River.

A streamgage downstream from Lake Abanakee transmitted data by satellite from November 2004 to November 2006; these data were used as the basis for developing a rating curve that was used to estimate discharges for the study period. River habitat at most study reaches was delineated by using Global Positioning System and ArcMap software on a handheld computer, and wetlands were mapped by ground-based measurements of length, width, and areal density. River temperature in the Indian and Hudson Rivers was monitored continuously at eight sites during June through September of 2005 and 2006; temperature was mapped in 2005 by remote imaging made possible through collaboration with the Rochester Institute of Technology. Fish communities at all study reaches were surveyed and characterized through quantitative, nearshore electrofishing surveys. Macroinvertebrate communities in all study reaches were sampled using the traveling-kick method and characterized using standard indices. Radio telemetry was used to track the movement and persistence of stocked brown trout (implanted with temperature-sensitive transmitters) in the Indian and Hudson Rivers during the summer of 2005 and in all three rivers during the summer of 2006.

The releases had little effect on river temperatures, but increased discharges by about one order of magnitude. Regardless of the releases, river temperatures at all study sites commonly exceeded the threshold known to be stressful to brown trout. At most sites, mean and median water temperatures on release days were not significantly different, or slightly lower, than water temperatures on nonrelease days. Most differences were very small and, thus, were probably not biologically meaningful. The releases generally increased the total surface area of fast-water habitat (rapids, runs, and riffles) and decreased the total surface area of slow-water habitat (pools, glides, backwater areas, and side channels). The total surface areas of wetlands bordering the Indian River were substantially smaller than the surface areas bordering the Cedar River; however, no channel geomorphology or watershed soil and topographic data were assessed to determine whether the releases or other factors were mainly responsible for observed differences.

Results from surveys of resident biota indicate that the releases generally had a limited effect on fish and macroinvertebrate communities in the Indian River and had no effect on communities in the Hudson River. Compared to fish data from Cedar River control sites, the impoundment appeared to reduce total density, biomass, and richness in the Indian River at the first site downstream from Lake Abanakee, moderately reduce the indexes at the other two sites on the Indian River, and slightly reduce the indexes at the first Hudson River site downstream from the confluence with the Indian River. The densities of individual fish populations at all Indian River sites were also reduced, but related effects on fish populations in the Hudson River were less evident. Although statistical comparisons (and defensible conclusions) were not possible with the limited fishery data, the findings suggest that both the releases and the unique habitat (physical, chemical, and thermal features) of the lower

[1]Cornell University, USGS-NY Cooperative Fish & Wildlife Research Unit, 208 Fernow Hall, Ithaca, NY 14853-3001; Nov. 2010: AKRF, Inc., 307 Fellowship Road, Suite 214, Mt. Laurel , NJ 08054

Indian River are responsible, at least in part, for the character of the local fish populations and communities. The effects of both impoundments on macroinvertebrate communities in the Indian and Cedar Rivers were prominent and appear to overwhelm or mask possible effects related to the recreational releases. Compared to macroinvertebrate data from Cedar River control sites, the releases had small significant effects on macroinvertebrate assemblages and dominant species in the Indian River, and they occurred primarily downstream from the Lake Abanakee Dam. The macroinvertebrate communities at the Hudson River control site did not differ significantly from those at all other Hudson River sites and indicates that the effects of the impoundment and the releases did not extend much beyond its confluence with the Indian River.

The thermal-imaging and fish-telemetry results confirm that river temperatures in the Indian and Hudson study reaches were usually stressful to brown trout during the warm summer months. Few thermal refuges (defined as water at least 1°C cooler than the temperature in the main channel) were evident in both rivers during normal summer base flows, and use of these refuges by brown trout was typically low to moderate during 2005 and 2006. A few cold-water tributaries to the Hudson River provided limited areas of thermal refuges, but the releases from Lake Abanakee effectively eliminated these refuges by swamping them with warmer water. Multilevel-effect analyses indicate that the releases significantly reduced the ability of trout to thermoregulate themselves in the Indian and Hudson Rivers. The releases should ostensibly have only negligible effects on brown trout in the Indian and Hudson Rivers because few thermal refuges exist in both reaches, and relatively few study trout were found to exploit them. Trout movement was unaffected by the flow releases, but persistence of trout was low in the Indian and Hudson Rivers during 2005 and 2006 and higher in the Cedar River during 2006.

Introduction

The Hudson Gorge Primitive Area and the lower Indian River in the Adirondack Mountains of northeastern New York support small transient populations of native brook trout (*Salvelinus fontinalis*) and seasonal populations of hatchery (stocked) brown trout (*Salmo trutta*) and rainbow trout (*Oncorhynchus mykiss*). The river's extensive whitewater reaches also provide a setting for a commercial rafting industry that operates from April through October. The Town of Indian Lake owns and operates a raft-launching site on the Indian River about 5 km[1] above its confluence with the Hudson River and just downstream from the Lake Abanakee Dam. The town makes top-water releases from the dam 4 days each week during the spring, summer, and fall to increase river stages along a 17-mi reach of the Indian and Hudson Rivers. These 1.5-to-2 hour releases are vital to the rafting industry because they augment river stages and permit rafting during summer months when flows would normally be too low for rafters to easily navigate the river. Local anglers, however, are concerned that the releases decrease abundance of wild and stocked trout by directly or indirectly decreasing their growth, survival, or both. Anglers assume that high flows caused by the recreational flow releases (termed releases from here on) potentially increase thermal stresses, physically injure or kill trout, force trout to flee the area, decrease the quantity or quality of prey that trout prefer (minnow or benthic macroinvertebrate species), or potentially decrease the quality and quantity of suitable fish habitat or thermal refuges

Water temperature is a critical component of fish habitat in the lower Indian and the upper Hudson Rivers because it ranges near or above thresholds for survival of brook trout (24°C), brown trout (25°C), and rainbow trout (27°C) (Raleigh, 1982; Raleigh and others, 1984; Raleigh and others, 1986) for extended periods during summer months (Richard Preall, New York State Department of Environmental Conservation, written commun., 2003). Releases from Lake Abanakee during the warmest months of the year augment flows in downstream riverine reaches when water temperatures in both rivers, as well as in Lake Abanakee, are sometimes at or above thresholds lethal to salmonids and when combined inputs (volume) from cold-water tributaries and groundwater seeps along shorelines in both rivers are minimal. It is well known that trout often move to areas of their preferred temperatures to maximize growth, fitness, and survival (Power and others, 1999; Torgersen and others, 1999; Ebersole and others, 2003). Several studies found that salmonids actively or passively relocate to cool-water refuges, if present, to avoid lethal stresses as water temperatures approach the limits they can tolerate (Bermann and Quinn, 1991; Power, 1997; Baird and Krueger, 2003). Summer releases of water from Lake Abanakee may decrease the quality and number of cool-water habitats (thermal refuges) available to trout by overwhelming these areas, which are typically small, with high volumes of release water. No one, however, knows (1) how many areas of cooler water (thermal refuges) are in sections of both rivers, (2) whether the quality, numbers, or volumes of potential thermal refuges change during releases, (3) whether trout stocked into the lower Indian and upper Hudson Rivers in spring use thermal refuges during summer, and (4) whether trout can avoid thermal stresses during summer by finding and occupying thermal refuges during normal (base) flows as well as during higher release flows.

High velocities of river water during releases may injure and weaken trout or physically displace them farther downstream, subsequently eradicating them from stocked locations. Trout (and other fish species) may also become stranded, only to expire on shorelines after dam gates are

[1]Unit conversions are shown in the conversion tables at the front of the report.

closed and as elevated flows (or stage) recede throughout the system. Stocked trout that occupy shallow shoreline areas during flow releases may also be more susceptible to predation. Releases may also affect other fish species that trout prey upon, thereby disturbing the entire fish community in parts of each river. Aside from direct effects on fish species, the hydrologic properties of flow releases may also cause shifts in assemblages of macroinvertebrate species and may modify benthic communities that some fish species use as a primary food source. These factors, alone or in combination, could disrupt aquatic ecosystems, substantially alter normal fish communities, and yield lower numbers and biomass of fish in reaches throughout both rivers. Any disruptive effects of releases would be more obvious at upstream sites and less severe farther downstream because supplementary flows from existing sources attenuate hydrologic variations that releases may cause.

The U.S. Geological Survey (USGS), the New York State Department of Environmental Conservation (NYSDEC), and Cornell University began a cooperative 2-year study in late 2004 to generate baseline information on the behavior of stocked trout, hydrology, temperature, habitat, wetlands, resident fish, and macroinvertebrate communities in the Indian and the Hudson Rivers. The Rochester Institute of Technology (RIT) added a study component on the remote imaging of surface-water temperatures in 2005. Primary objectives of this study were to document and evaluate the potential effects of the releases on natural resources and on the survival of stocked trout within affected reaches of both rivers.

This report summarizes the baseline physical and biologic conditions at seven fixed sites downstream from Lake Abanakee in the Indian and the Hudson Rivers, variations in selected hydrologic and thermal regimes at these sites due to flow releases, temperature and biology data from four control sites in the Cedar River and one control site in the Hudson River, changes in surface-water elevation (lake stage) in Lake Abanakee due to releases, the quantity and quality of thermal refuges in the Indian and Hudson Rivers under normal and release flows, and the use of thermal refuges by trout under normal and release flows during 2004–06.

Effects of flow releases on fish and macroinvertebrate resources were qualified or quantified by comparing data from affected reaches with data from control reaches (physically similar, but unaffected by the releases) at nearby control sites in the Cedar River, a run-of-the-river system or at one reach in the Hudson River upstream from its confluence with the Indian River. Differences in trout behavior, survival, and body temperatures on release and nonrelease days between study reaches on the Indian and Hudson Rivers and control reaches on the Cedar River were used to assess potential effects of releases on the availability and use of thermal refuges by trout in the three rivers.

Measuring the Effects of Recreational Flow Releases on Habitat and Biological Communities

Point sampling and reach-wide assessments were used to characterize habitat, wetlands, temperatures, and trout behavior and evaluate the effects that releases from Lake Abanakee have on natural resources in the Indian and the Hudson Rivers. Detailed information on study reaches and sampling and analytical methods are provided below.

Study Sites

Fourteen sites were selected for study: two on Lake Abanakee, three on the Indian River, five on the Hudson River, and four on the Cedar River (fig. 1, table 1). Unlike the waters from Lake Abanakee, waters from Wakely Dam (fig. 1) flow freely into the Cedar River, thereby providing a run-of-the-river flow regime. Extensive sampling efforts in the Cedar River were not part of the initial study design; however, comparable biology and limited temperature data were collected from four sites in the system using identical sampling methods (fig. 1 and table 1).

Stage, Discharge, and Water Temperature

A USGS streamgage was constructed on the Indian River just downstream from Lake Abanakee (IR01, fig. 1). Discharge at this site was estimated from the stage-to-discharge relation, or rating curve, that was generated from periodic flow measurements made by USGS personnel. Pressure transducers were installed at two sites on Lake Abanakee (AB01 and AB02, fig. 1), two additional sites on the Indian River (IR02 and IR03, fig. 1), and five sites on the Hudson River (HR01–HR05, fig. 1). Dataloggers at all sites were programmed to measure stage and temperature at 15-minute intervals. Streamgage 01315081 (IR01) transmitted near-real-time data on stage and water temperature by satellite from November 2004 to November 2006. Daily data on stage, discharge, and water temperature for this gage are available at http://nwis.waterdata.usgs.gov/.

Pressure transducers, which were used to collect stage and water-temperature data at nine sites, were housed in weather-resistant cylindrical enclosures attached to a 25-ft cable with a sensor at its end. At each site, the sensor, cable, and transducer were placed inside a 2-in.-diameter steel pipe, which was securely anchored to trees, bridge abutments, or boulders. Investigators used a handheld computer to periodically download data..

Records— Stage and water-temperature data were collected at 15-minute intervals at all sites (table 2).

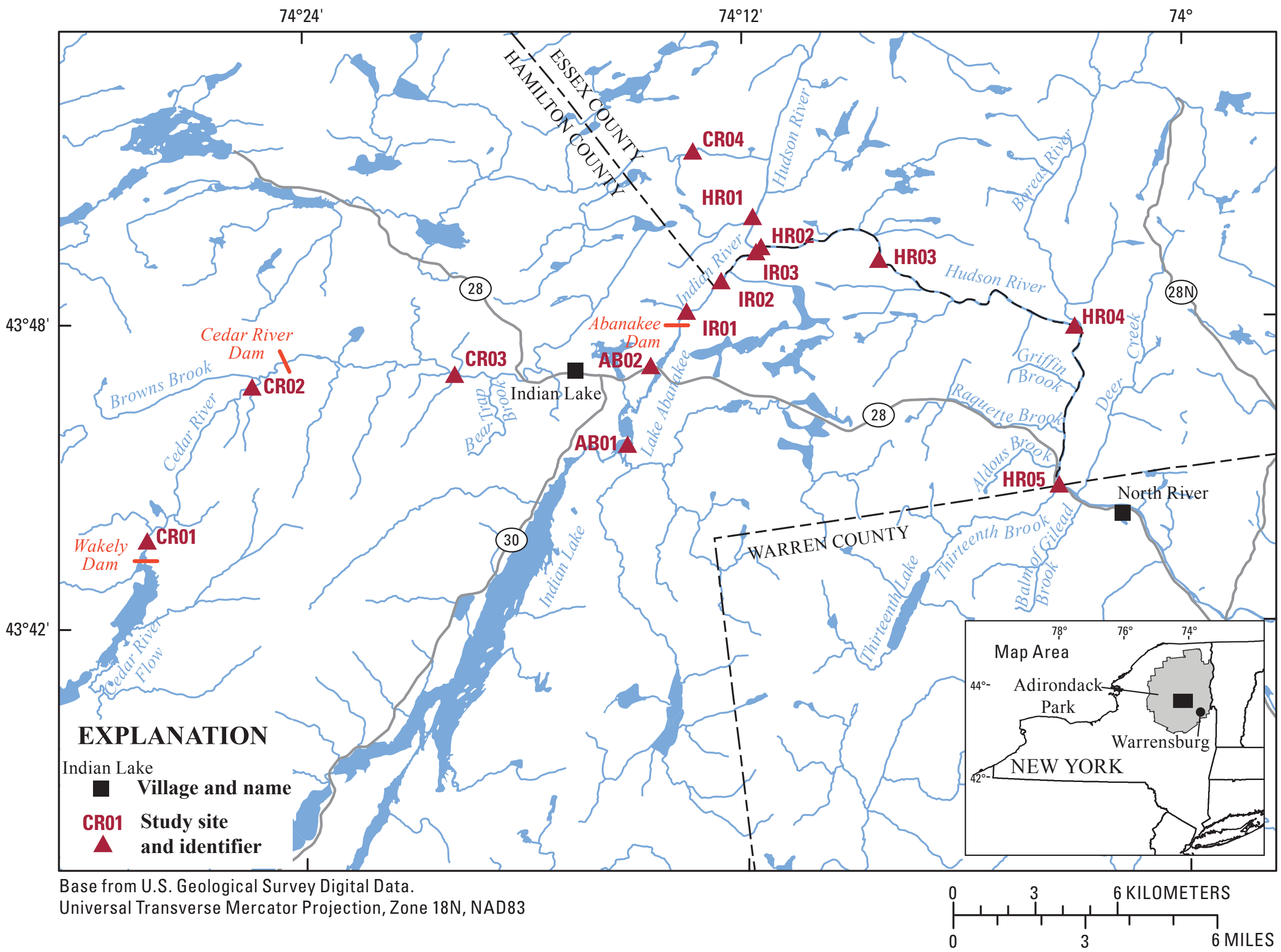

Figure 1. Map showing lLocations of study sites and dams on the Indian, Hudson, and Cedar Rivers, Adirondack Mountains, New York. Study-site codes are listed in table 1.

Equipment or battery failures led to gaps in continuous records at some sites. Missing temperature records at several sites were approximated from temperature data at the closest upstream site by using the average lag time between release stages and temperatures and the relation between water temperatures at both sites.

Data Analysis —The following procedures were used to analyze all stage and water-temperature data collected from the months of June to September in 2005 and in 2006 to determine whether stage and water temperature changed significantly during releases from Lake Abanakee.

- Water temperature and stage at the start and peak of each release were identified and used to calculate the total change in each of these variables at each site during release days.

- The same calculation was made on nonrelease days for the time interval between start and peak on the prior release day.

- The monthly mean change of each variable was calculated for release days and for nonrelease days.

- A t-test was used to determine whether mean changes in stage or temperature on release days differed significantly from mean changes in stage or temperature on nonrelease days

Stream Habitat

River-habitat features, in the form of geomorphic channel units (GCUs), were measured along the Indian River study section during August and September 2005 (fig. 2) and along four reaches of the Hudson River study section during August 2007. Seven GCUs were identified: riffle (turbulent white water), rapid (faster than a riffle, with greater changes in gradient), run (laminar flow that is faster along well defined thalweg), pool (deep, slow water along thalweg), glide (laminar flow with uniform channel depth), backwater (slow-velocity, protected water separated from main channel),

Table 1. Characteristics of 14 study sites at Lake Abanakee and on the Indian, Hudson, and Cedar Rivers in the Adirondack Mountains, New York, 2005 and 2006.

[Site locations are shown in figure 1; unit conversions are shown in the conversion tables at the front of the report. Latitude and longitude are in degrees, minutes, and seconds; km^2, square kilometers; USGS, U.S. Geological Survey]

Site code	Site name	Latitude	Longitude	Drainage area, square kilometers	USGS streamgage number	Characteristics observed or measured
			Lake Abanakee			
AB01	Lake Abanakee near Indian Lake	43 45 40.5	74 15 04.6	476	01315064	water temperature, stage
AB02	Lake Abanakee at Route 28 bridge near Indian Lake	43 47 05.1	74 14 22.8	487	01315072	water temperature, stage
			Indian River			
IR01	Indian River below Abanakee Dam near Indian Lake	43 47 55.4	74 13 46.3	505	01315081	water temperature, stage, discharge, fish communities, macroinvertebrate communities
IR02	Indian River above mouth near Indian Lake	43 48 47.6	74 12 37.5	513	01315083	water temperature, stage, fish communities, macroinvertebrate communities
IR03	Indian River at mouth near Indian Lake	43 49 21.4	74 11 40.0	518	0131508505	water temperature, stage, fish communities, macroinvertebrate communities
			Hudson River			
HR01	Hudson River at Gooley near Indian Lake	43 50 03.0	74 11 45.1	1,085	01314000	water temperature, stage, fish communities, macroinvertebrate communities
HR02	Hudson River below Indian River near Indian Lake	43 49 25.8	74 11 31.8	1,626	0131508508	water temperature, stage, fish communities, macroinvertebrate communities
HR03	Hudson River near North River	43 49 10.0	74 08 18.1	1,655	01315095	water temperature, stage, macroinvertebrate communities
HR04	Hudson River above Boreas River near North River	43 47 50.6	74 03 00.1	1,691	0131511503	water temperature, stage, fish communities, macroinvertebrate communities
HR05	Hudson River at North River	43 44 40.5	74 03 30.8	1,968	01315340	water temperature, stage, fish communities, macroinvertebrate communities
			Cedar River			
CR01	Cedar River below Wakely Dam near Indian Lake	43 43 38.9	74 28 18.5	117	01312710	fish communities, macroinvertebrate communities
CR02	Cedar River above Brown's Brook near Indian Lake	43 46 46.0	74 25 25.0	149	01312790	fish communities, macroinvertebrate communities
CR03	Cedar River above Bear Trap Brook near Indian Lake	43 46 59.0	74 19 55.0	213	01312925	fish communities, macroinvertebrate communities
CR04	Cedar River above mouth near Indian Lake	43 51 21.0	74 13 22.0	425	01313600	fish communities, macroinvertebrate communities

Table 2. Dates when data on river stage and temperature were collected at 10 study sites on Lake Abanakee and the Indian and Hudson Rivers in 2005 and 2006.

[Stage and discharge data for IR01, and temperature data for all other sites are available at http://nwis.waterdata.usgs.gov/. Locations of study sites are shown in figure 1; site codes are listed in table 1; na, no data available]

Site	2005		2006	
	River stage	River temperature	River stage	River temperature
AB01	6/25–7/23, 8/19–9/6	6/25–10/27	na	na
AB02	7/1–8/9, 8/20–9/29	6/30–10/27	3/30–9/28	3/30–9/28
IR01[1]	1/1–12/31	1/1–12/31	1/1–11/30	1/1–11/30
IR02	6/25–9/30	6/25–10/27	5/16–9/28	5/16–9/28
IR03	7/1–9/30	6/30–10/27	5/24–9/26	5/24–9/26
HR01	7/1–9/30	8/4–9/20	5/24–9/21	2/16–9/20
HR02	7/1–8/7, 8/30–9/30	6/30–8/25, 9/20–10/5	4/20–6/21	4/20–6/21
HR03	6/28–8/8, 8/20–9/30	6/28–11/14	4/20–5/26, 6/13–6/26	4/20–5/26, 6/13–6/26
HR04	6/28–9/30	6/28–10/27	4/20–9/26	4/20–9/26
HR05	6/25–8/13, 8/20–9/30	6/25–10/27	3/30–6/28	3/30–6/28, 8/14–9/26

[1] Discharge data are available only for this site in 2005 and 2006.

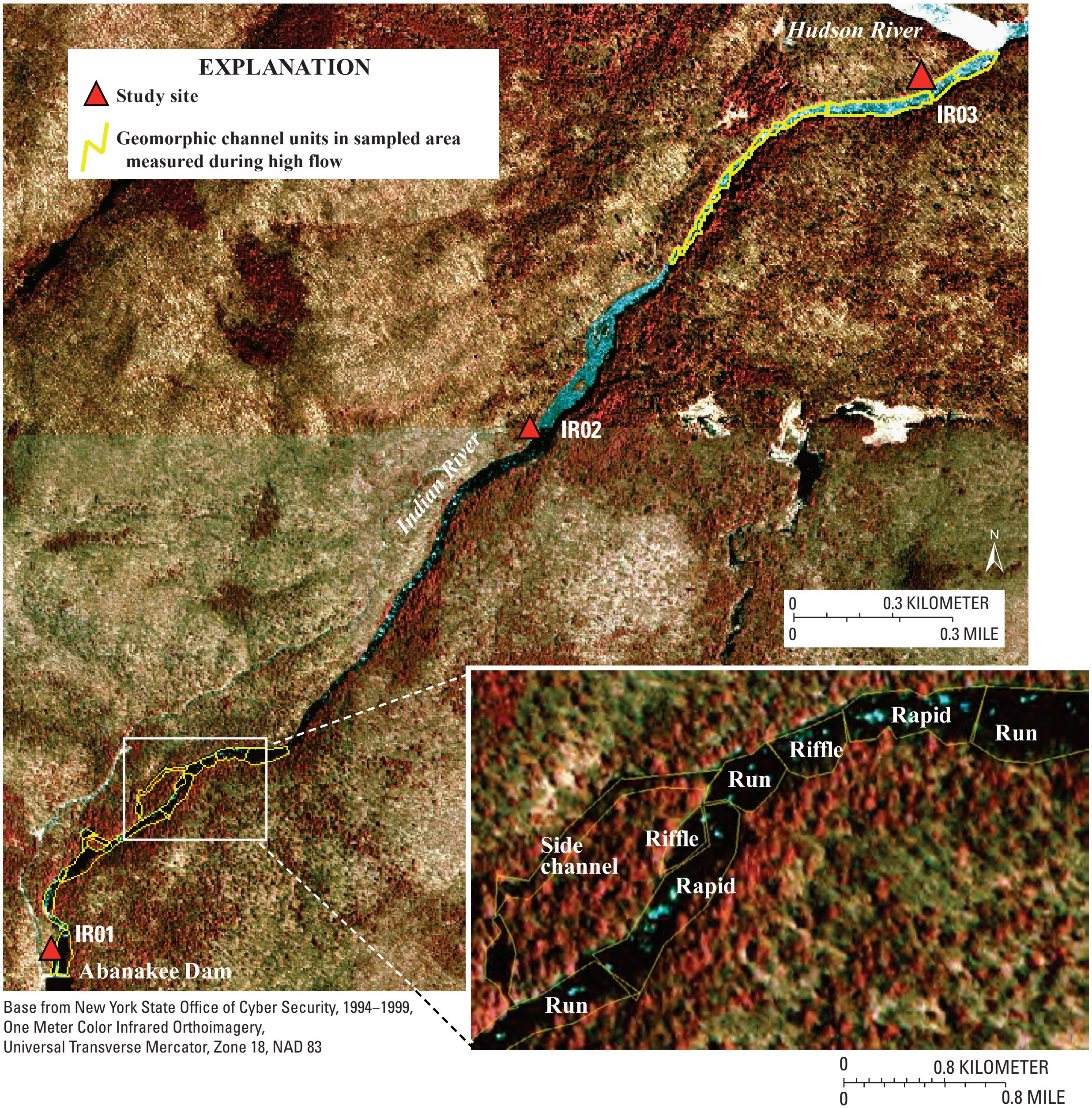

Figure 2. Aerial photograph of the Indian River from Abanakee Dam (lower left corner) to downstream confluence with the Hudson River (upper right corner), Adirondack Mountains, New York. Inset shows details of the sampled area, including labeled geomorphic channel units. Locations of the study sites are shown in figure 1; study-site codes are listed in table 1.

and side channel (channel that diverges from the main stem, then rejoins it). Indian River GCUs were mapped during base flow over the entire study segment and again at high flow over two shorter reaches that included three stage-depth dataloggers in the river segment (figs.1, 2). Hudson River GCUs were mapped during base flow and high flow along 400- to 1000-m reaches near each of the four stage-depth dataloggers (HR02–HR05). Each GCU was digitally traced into a handheld computer by using a global positioning system (GPS) and ArcMap 6.0 software. Water depth, velocity, and substrate size were measured at three points across a randomly selected transect within each GCU during base flow only.

Distribution of Wetlands

Wetlands were mapped along both banks of the entire Indian River during base flow in August and September 2005 and along one bank of two reaches of the Cedar River in September 2006 (fig. 3). Wetlands were identified by vegetation types and accumulations of soils. The area of each wetland was calculated by multiplying its length (along the edge of the river) by the average of three measurements of its width and by the areal density of the wetland patch. Area was not calculated for wetlands in the upper Cedar River reach because many of its wetlands lay on the narrow sides of steep

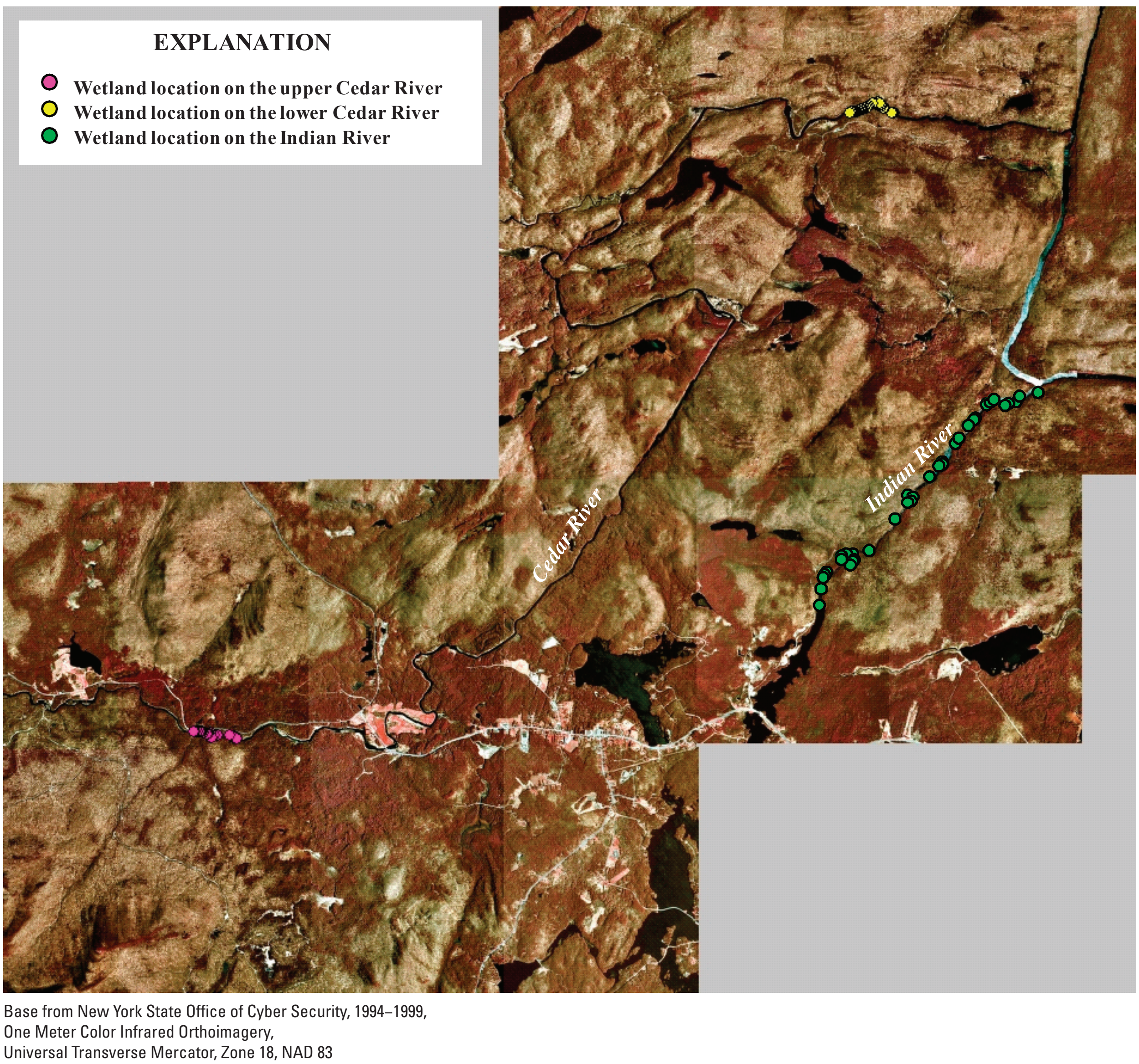

Figure 3. Map showing wWetlands on sections of the Indian and Cedar Rivers, Adirondack Mountains, New York. Locations of study sites are shown in figure 1. Grey color denotes areas where no data were collected.

banks. Only wetlands of area greater than 200 ft^2 or patchy wetlands that covered 200 ft^2 in a 600-ft^2 area were counted; however, all wetlands in the upper Cedar River were included (fig. 3).

Temporal and Spatial Patterns in River Temperature

Scientists from the Chester F. Carlson Center for Imaging Science at the Rochester Institute of Technology used airborne thermal remote sensing to map surface-water temperatures along the Indian and the Hudson Rivers downstream from Lake Abanakee to North Creek, NY. Sensors collected short-wave, medium-wave, and long-wave infrared and visible-spectrum data during three low-altitude flights in an airplane equipped with visible-light (red-green-blue band) and forward-looking infrared cameras. Digital temperature data were calibrated against data from the seven instream dataloggers, providing a resolution of less than 1ºC. Thermal imagery data were collected on August 25, 2005, a release day, during three flights that recorded data at most points along both rivers during low and high flows (before, during, and after a release). No single flight captured images of the entire reaches in both rivers during either low or high flow. IMAGINE image-processing software (ERDAS, 1995) and ArcGIS (ESRI, 1995) were used to process and analyze thermal imagery data.

Objectives of the thermal imagery surveys were to (1) document overall temperature patterns in the Indian and Hudson Rivers under base and release flows, (2) quantify the area and quality of thermal refuge available to resident trout during base flow, and (3) evaluate changes in thermal refuges in both rivers that were associated with the releases. Each of the three flights collected data from a different section of the 27-km reach during high flows. For this reason, data were processed along the whole river and in 1-km sections, in longitudinally split 0.5-km sections, and at cold-water tributary confluences to enable researchers to evaluate each section separately at low and at high flows. In addition, a longitudinal temperature profile along the whole river for each flight was generated by the investigators. A separate manuscript (Ernst and others, in press) provides further details outlining the collection and analysis of thermal-imagery data

Fish Communities

Near-bank fish communities along river margins at seven sites on the Indian and Hudson Rivers (IR01, IR02, IR03, HR01, HR02, HR04, and HR05; fig.1) and one site on the Cedar River below Wakely Dam (CR01; fig. 1) were characterized during July and August 2005 by electrofishing methods. Fish communities were surveyed at three additional sites on the Cedar River: above Browns Brook (CR02), above Bear Trap Brook (CR03), and above the mouth of the Cedar River (CR04) during August 2006 (fig. 1). Fish communities at HR03 were not surveyed because the site was too remote. At each study site, two or three near-bank locations (subreaches) were blocked off with a longitudinal 80-ft seine (placed parallel to shore) and lateral seines that extended from each end of the longitudinal seine to shore. All stunned fish were collected during three or four successive electroshocking passes, species were identified, and lengths and weights were recorded. Data from all locations at each site were combined, and proportional-reduction methods (Zippin, 1958) were used to calculate the numbers and biomass for each species population and the total fish community and the corresponding 95-percent confidence intervals. To standardize the measures for each species or for the entire fish community at each site, estimates of total density and biomass were divided by the total sampling area. Measures of community richness (number of species S), species diversity (d), equitability (Shannon-Weiner H′), and dominance (Simpson's C) at each site were calculated according to methods described by Whittaker (1975).

Potential effects of the releases on fish communities were assessed at three Indian River sites (IR01, IR02, and IR03) downstream from Lake Abanakee (where adverse effects from flow releases should be most evident) and at three Hudson River sites (HR02, HR04, and HR05). Any effects in the Hudson River should be less than conspicuous than the effects in the Indian River because changes in stage and flow associated with releases were proportionally smaller in the Hudson than in the Indian River; study sites in the Hudson River were typically wider than those in the Indian River and diluted by relatively large base flows originating in unaffected headwaters. Measures of community density, biomass, richness, diversity, equitability, and dominance, along with the density and biomass of individual species populations at the Indian River sites (IR01, IR02, and IR03), were compared to those at the Cedar River sites downstream of Wakely Dam (CR01, CR02, CR03, and CR04) to quantify the potential effects of the releases. Fish communities at several sites downstream from both impoundments should have been similar because they had comparable drainage areas, channel sizes, substrates, and gradients. The sites differed mainly with respect to distance downstream from each impoundment and river-flow regime: Cedar River sites were run-of-the-river, whereas Indian River sites were affected by recurring recreational flow releases from Lake Abanakee. Fish-community indexes at Hudson River sites HR02, HR04, and HR05 (downstream from its confluence with the Indian River) were compared with indexes at a control site (HR01) to evaluate the potential effects of the releases.

Macroinvertebrate Assemblages

Macroinvertebrates and debris were collected from nine sites (CR01, IR01–03, HR01–05) in early August 2005 (fig. 1) by using the standard traveling-kick method (Bode and others, 2002). These nine sites and three additional sites on the Cedar River (CR02, CR03, and CR04) were sampled during 2006.

At each site, single 5-min. samples were collected in riffles that covered a downstream distance of about 5 m. Collection nets were rectangular, 23 × 46 cm, with a mesh size of 0.8 × 0.9 mm. Samples were rinsed in a 500-µm (micrometer) mesh sieve and preserved in 95-percent ethanol. At the laboratory, 100 specimens were randomly sorted out from the debris three times, identified to the lowest possible taxonomic level (generally genus or species), and enumerated. This triplicate-sorting process generated data for 27 samples from 2005 and 36 samples from 2006.

Four general macroinvertebrate-community indexes or metrics were calculated from each 100-organism sample whose members had been identified to the lowest possible taxon. Indexes calculated for each site were defined by Novak and Bode (1992) and are listed below.

- Total community richness—a measure of the total number of macroinvertebrate taxa (generally species) found at each site.
- Ephemeroptera-Plecoptera-Trichoptera (EPT) richness—a measure of 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)—an indicator of tolerance to organic enrichment. Sensitive taxa have low HBI values, and tolerant taxa have high HBI values.
- Percent model affinity (PMA)—a measure of the biological effects of contaminants by comparing the benthic macroinvertebrate community at a given site to an ideal or model, benthic macroinvertebrate community. In riffles of New York streams, this ideal community consists of 20 percent Chironomidae, 10 percent Trichoptera, 40 percent Ephemeroptera, 5 percent Plecoptera, 10 percent Coleoptera, 5 percent Oligocheata, and 10 percent from other orders.

These four indexes were combined into the standard New York State Biological Assessment Profile (NYSBAP) following methods of Bode and others (2002).

All taxa were also categorized into various functional feeding guilds (feeding guilds) according to Merritt and Cummins (1996). Relations among macroinvertebrate indexes and the NYSBAP, and percentages of functional feeding guilds at each site, were evaluated through graphic comparisons and multiparametric (ANOVA) analyses to qualify and quantify site-to-site differences or similarities and characterize possible shifts in community function and overall ecosystem processes that might be caused by the releases. Spatial patterns in macroinvertebrate-community composition and classifications (grouping of sites with similar assemblages) were analyzed further by multidimensional scaling (MDS) ordination of relative abundance data (square-root transformed) for taxa (Shepard, 1962; Kruskal, 1964). The MDS ordination generates an arrangement of samples in what is termed "species-space," according to the nonparametric ranks of their Bray-Curtis similarities (Clarke and Warwick, 2001). Bray-Curtis similarities were estimated from the same data by using hierarchical cluster (group-average linking) analysis and permutation tests of similarity profiles (p less than 0.05) (Clarke and Warwick, 2001).

Monitoring Trout Behavior and Temperatures

The primary objectives of the trout-behavior study component were to determine whether the releases altered the behavior of trout with respect to their level of activity and their use of thermal refuges and whether these potential effects were biologically relevant in the Indian and Hudson Rivers. In addition, the possible effects of recreational releases on trout survival were assessed by using indirect data and plausible inferences. After the use of thermal refuges by stocked trout was confirmed, the effects of releases on usage were evaluated through two levels of analysis. For the first level, usage of thermal refuges was compared for release days and nonrelease days within the same river. If releases had an effect on trout behavior, differences in usage between release days and nonrelease days would be expected in the Indian and Hudson Rivers but not in the run-of-the-river Cedar River. Three analytical methods were used to determine if changes in trout body temperature were associated with recreational releases. For the second level of analysis, indirect effects of the releases were compared between the control (Cedar) river and each of the affected rivers. If the releases produced an effect, then differences in measures such as persistence, dispersal, and activity between trout would be expected between reference and affected river reaches; however, river-specific environmental factors, such as available refuge area, could confound these differences. To determine if the releases had biologically relevant effects on trout behavior, the percentage of trout that were using thermal refuges and also affected by the releases were quantified, and the magnitude of changes in body temperatures of trout using thermal refuges (and not using refuges) were contrasted. Data on trout movement and body temperature were collected by using radio telemetry with temperature-sensitive transmitters during summer field seasons in 2005 and 2006. Although some naturalized brown trout are present in the Indian and Hudson River study reaches, we assume that the behavior of telemetry (study) brown trout is comparable to the behavior of many resident brown trout because both groups originate from local hatcheries as 2-year olds.

Implanting Radio Transmitters— During both field seasons, the trout that were studied consisted of 2-year-old domestic-strain brown trout reared in the New York State hatchery system. These trout were transported to the Warren County Fish Hatchery in Warrensburg, New York, where Advanced Telemetry Systems (ATS) radio transmitters were surgically implanted. Mean trout length (± 2 standard errors (SE)) was 377.3 ± 6.1 mm in 2005 and 371.7 ± 3.4 mm in 2006. Implant surgery involved anesthetizing trout, inserting a transmitter into the abdominal cavity (using methods similar to the shielded-needle technique), and sealing the incision with sutures (Ross, 1982; Summerfelt and Smith, 1990). Recovering trout were held at the hatchery for 1 week in 2005 and 2 weeks in 2006 before they were released into study reaches. Transmitters were also implanted into control trout each season (5 in 2005 and 10 in 2006); these fish were held at a local hatchery to assess potential mortality or unusual behavior that surgeries may have caused and to assess the possibility that the transmitter might be expelled. All control trout in 2005 survived and exhibited normal behavior, and no trout expelled transmitters until after all field-tracking efforts for both years were completed. In 2006, five trout died within 96 hours of surgery; necropsies revealed punctured organs or hemorrhaging. The transmitters from these fish were implanted in new trout 1 to 7 days later. The 100-percent survival rate for control fish in both 2005 and 2006, and the fact that deaths during holding periods occurred within 96 hours of surgery, indicate that no surgery-related deaths occurred in stocked trout. Radio-tagged trout were stocked into the river on July 25, 2005, and on June 14, 2006. Two weeks after the initial stocking in 2006, two transmitters taken from trout that died in the Indian and Cedar Rivers were implanted into new trout from the remaining hatchery population. These newly implanted trout were held at the hatchery for 12 days, and then stocked into the Hudson River on July 10, 2006, to replenish study trout that were dying or disappearing more rapidly than those in either the Cedar River or Indian River.

Collection of Trout Temperature Data— The collection of multiple body temperatures simultaneously with the precise locations for each trout was attempted daily. The primary method used to collect data was either by walking or driving along banks of the study reaches with a three-element Yagi antenna and an ATS RS4500 datalogger (receiver) set to aerial-scan mode. The receiver cycled through all transmitter frequencies and recorded a temperature for any trout within range at a rate of approximately one observation per second. The second method (2006 only) was to install a fixed-location receiver on the shore of the Hudson River. The scan time and observation interval were set to continuously record the body temperature every 5 minutes when a trout was within range (roughly 1.2 km). For the first 10 days after stocking, the fixed receiver was positioned approximately 8 km downstream from the stocking location to identify any trout that exited the study reach in a nighttime rapid downstream movement, but no such actions were recorded. On June 24, 2006, the fixed receiver was moved approximately 0.8 km upstream from the stocking location and within range of one major and at least two minor tributaries. Data collection at the fixed receiver was discontinued on July 18, 2006.

Accuracy of Trout Observations—The accuracy of observations was subject to systematic and random error. Model F1815 and model F1820T radio transmitters were used in 2005 and 2006, respectively; these transmitters had factory-specified accuracy of ± 0.25ºC and precision of ± 0.5ºC. Laboratory tests were conducted on temperature measures from the model F1820T transmitter; the average difference (± 2 SE) in temperatures recorded by transmitters and a YSI (Yellow Springs Instrument Co.) meter was 0.01 ± 0.03ºC. The mean difference for any individual transmitter was always less than 0.2ºC, except for one transmitter, for which it was 0.34ºC. Transmitters were transferred from cool to warm water, and the time until temperature stabilized was recorded. On average, transmitters warmed to an accuracy of 0.04 ± 0.02ºC in 154 ± 6 seconds (N=21).

The internal Garmin GPS within each portable ATS 4500S receiver was reported to be accurate to 15 m (Advanced Telemetry Systems, written commun., 2005). Field accuracy tests were conducted in 2006 by placing a transmitter in the river and observing distances over which the receiver could detect the transmitter with only the coaxial cable (no antenna) attached. When collecting observations without the antenna, receivers could pick up signals from a transmitter at distances of 1 to approximately 100 m. By using the gain dial to adjust the sensitivity of the receiver, a general sense of distances between transmitter and observer was obtained. For example, at a gain setting of 3, a transmitter signal could not be detected at a distance beyond 30 m. Most observations of trout locations were made at gain settings between 1 and 6; therefore, the accuracy of monitored trout locations was considered to be 15 to 100 m. Although accuracies likely were similar during both years, transmitter (trout) location errors were not estimated in 2005.

Analysis of Trout Temperature Data— The effects of the releases on thermal behavior of tracked trout were characterized using three methods. One method, an analysis of observations that spanned flow releases (release spans),characterized changes in trout body temperature and tested whether such changes were associated with the releases. In the field, body temperatures for a few individual trout were logged by mobile and fixed receivers continuously from just before until just after a release event. These release-span observations of body temperature from individual trout were compiled for both release and nonrelease days. A total of 31 trout were observed on 38 days for a total of 108 fish-days; several trout were observed on more than one day. For each fish-day, trout body temperature was monitored 1.5 hours (h) prior to, 2 h during, and 1.5 h following the release at a trout's location; data were then extracted and plotted against time. Trout temperature records for nonrelease days were identified on the basis of average onset times and duration of release spans for each trout location. Plots of trout body temperatures were visually assessed and classified as displaying no change, an increase, or a decrease based on a 0.5ºC threshold. Four sets of release-span data were collected on the Cedar River, but analyses were omitted because only three individual trout were observed on 3 consecutive days. A second and third set of analyses (methods) were also used to evaluate the effects of the releases on thermal behavior of trout. Both compiled and analyzed temperature differences (TD, defined as the difference between the temperature of a trout and the temperature of the river) between fish and rivers (a) during release and nonrelease time blocks (TB) within each river and (b) at affected and control river reaches on the same days. In 2005 and 2006, all Indian and Hudson River trout body-temperature records collected before a release, during a release, during the same time periods on nonrelease days, and after a release (if daylight permitted—usually only in the Indian River) were assessed. Data were divided into six 4-hour time blocks (TB0 = 0100 – 0459, TB1 = 0500 – 0859, TB2 = 0900 – 1259, TB3 = 1300 –1659, TB4 = 1700 – 2059, TB5 = 2100 – 0059 Eastern Standard Time) so that most release-bubble (episode of peak stage moving through study reaches) observations fell within TB2 at the Indian River and within TB3 at the Hudson River. During 2006, trout were also tracked (observations made) in the Cedar River during time blocks TB1 (morning), TB2 (midday), and TB3 (afternoon), which correspond to unaffected and affected time blocks for study reaches in the other two rivers. All 2005 and 2006 observations were combined for both analyses.

For the second method, a set of multilevel models of trout and river TDs were assessed for each combination of river and time blocks. Repeated measures on the same trout and multiple measures on a single day were treated as random effects in the models. Fixed effects were incorporated into the model as follows: (1) daily variation in TDs, using river temperature at time of observation as the metric; (2) daily mean discharge, measured at USGS streamgage station 01315500 in North River, NY; (3) nearness of trout to a tributary (a trout within 50 m was consider near, otherwise it was not near); (4) release day, classified as either a release or nonrelease day; (5) distance of the trout from a river-temperature datalogger; and (6) interactions among all combinations of the first four variables. Determining interactions between nearness and other variables was not possible for the Indian River because it had few tributaries, and thus too few observations could be made. Aikaike's Information Criterion (AIC) (Burnham and Anderson, 2004) was used to determine which set of plausible models for each combination of river and time blocks was best supported by the data. This method also determined which parameters were most important (predictor weight closest to 1) in explaining variations in TD within each model and in the entire model set (see Boisvert, 2008, for details). It was hypothesized that if the releases had an effect on trout thermoregulation, then the variable "release day" would be included in the best supported model and would be an important parameter within the entire model set. In contrast, it was expected that "release day" would not be an important parameter for the unaffected Cedar River. Data gathered during extreme (flood) flows were excluded from this analysis. Multilevel models were analyzed by using the SAS MIXED procedure (Littell and others, 1996). A Bonferroni correction was used to make multiple comparisons of the least-square mean estimates and to examine the magnitudes and directions of significant effects.

The third procedure estimated the percentage of trout and the percentage of time that thermal refuges were utilized to qualify the potential effects (and the biological relevance) of the releases on trout behavior. The number of TDs that were at least -1ºC or -2ºC (cooler in trout than in the river) was compiled for trout with body temperatures less than 20ºC. The observed TDs represent the potential quality of thermal refuges in which a trout may be residing. Elliot (1994) concluded that 19ºC was the lowest temperature (upper critical range) at which normal brown trout behavior is disrupted as waters warm. Therefore, analyses herein considered temperatures of 20ºC and greater to be stressful to trout. Counts were grouped by time block and release condition for each river to estimate the percentage of trout that were using thermal refuges and either were affected or unaffected by the releases.

Analysis of Trout Movement— When possible, precise daily trout locations were recorded before release time blocks so that differences in daily movements on release and nonrelease days could be assessed. An internal GPS within each portable ATS 4500S receiver automatically logged all trout transmitters within range; thus, the coordinates represented the location of the observer, but not the trout. Observers moved along the river bank and logged the trout's location at a point where the transmitter signal was perpendicular to the observer. The observer recorded the lowest gain setting at which the signal was detected and, thus, the estimated accuracy of the trout's location. River-bank locations were transferred to corresponding midchannel locations by using GIS software (Manifold) that digitized and segmented a river centerline with nodes at 5-m increments. A nearest neighbor algorithm was used to translate each river-bank location to the nearest center-line node. Despite measurement error and data manipulations, the locations were sufficiently accurate to place a trout within geomorphic habitat units. Precise trout locations were not consistently recorded during 2005; therefore, daily trout movements were not calculated nor assessed for 2005 observations.

Trout positions relative to initial stocking location (meters upstream or downstream) were used to calculate the spatial characteristics of trout behavior during 2006. The 5th, 25th, 50th (median), 75th, and 95th quantiles of total travel distances and mean dispersion distances approximately 1 day, 1 week, 1 month, and 2 months after stocking were estimated. Activity was calculated as the average distance trout traveled between daily locations (Bettinger and Bettoli, 2002). Only observations from consecutive days were used because a Spearman's rank correlation revealed a temporal bias: longer movements were correlated with the number of days between observations. A Kruskal-Wallis test (Hatcher and Stepanski, 1994) was used to determine whether activity was different between rivers, and multiple comparisons were made using Dunn's test (Zar, 1996).

Analysis of Persistence and Fate— By definition, persistence is equivalent to neither survival nor mortality; however, persistence was considered a surrogate for mortality for the purposes of this investigation. It was calculated as the number of days that each trout remained alive and within respective study reaches (Bettinger and Bettoli, 2002). Mean persistence was estimated by using the SAS LIFETEST procedure, which allows for observations that were identified as "censored" (that is, trout that survived beyond the conclusion of the study). Mean persistence was compared among rivers within each year, and a Wilcoxon statistic was used to test homogeneity between survival curves (Allison, 1995). In this analysis, lost transmitters were treated as an outcome of mortality or emigration; that is, the trout were removed from the river system by some unknown means. Thus, mortality rates based on persistence were expected to be biased high and were used only to estimate potential mortality and assess relative differences among the three rivers and between study years.

Determining the fate of each trout indicates likely causes for trout mortality and the degree to which releases contribute directly or indirectly to possible morbidity. The fate of each trout can be estimated with some degree of confidence on the basis of final confirmed or inferred locations of transmitters. In many cases, no trout or their remains were ever found with the transmitters. Approximately 50 percent of all transmitters were recovered, and the final locations of remaining transmitters were inferred. The fate of each trout was assigned to one of the following categories: (1) "signal lost," which indicates that the signal for the transmitters was no longer detected; (2) "in woods," which describes locations beyond the width of the river at the highest summer flood (one trout in this category in 2006 had been taken by an angler); (3) "flood zone or shallow water," which describes locations with water depth not likely to be accessible to adult trout under base-flow conditions, but accessible when flooded during higher flows; (4) "midchannel," which describes locations in the river other than shallow water; and (5) "in living trout," which refers to a transmitter that showed evidence (either through its continuing activity or by visual observation) of remaining in a living trout at the end of the study.

Processing Telemetry Data— The receivers collected tens of thousands of records that subsequently required additional compilation or vetting to eliminate imprecise, duplicate, or spurious data. The first step in cleaning telemetry data was to determine the end dates, that is, the first day when a trout no longer persisted within a study reach. The 2006 transmitters were equipped with sensors that produced a mortality signal if a transmitter did not move for more than 8 hours. When a mortality signal was recorded, the end date was identified on the basis of prior and current temperature and location data. If the location of the transmitter had not changed for many days, the end date was the first day that the trout was observed at the same location. Similarly, if no mortality signal was emitted, and there was no change in trout movement from the final observed location, the first day at this location was the end date. If the signal indicated either by temperature or by location that the transmitter was out of the water, the end date was the day this condition was first observed. All data collected subsequent to the end date for a transmitter were excluded from analyses. Trout body temperatures and locations recorded during the 2006 floods (when daily discharge averaged more than 2,600 ft^3/s at USGS station 01315500) were also excluded from most analyses summarized herein.

River-temperature data were added; related calculations were completed; and time block and release codes were applied to the final telemetry dataset to categorize conditions and simplify analyses. A median body temperature was estimated for each trout during each time block and paired with a river temperature from the closest datalogger (at the time that the trout's temperature was logged); individual TDs were calculated as the differences between these values. For trout in the Indian and Hudson Rivers, body temperatures were measured and coded as being under either release or nonrelease condition on the basis of stages at the closest datalogger, which indicated the presence or absence of a release bubble when the trout's location was recorded. Observations were coded "release" only for TB2 on the Indian River and for TB3 on the Hudson River during release days. The Hudson River dataset also included observations recorded by the fixed receiver when manual-tracking data were not collected. The resulting file included the following data for each trout on a given day: day, river, trout identification (ID), time block (a new record for each different time block on the same day), time of measurement, trout temperature, corresponding river temperature, TD, and location coordinates (table 3).

Additional variables were added to this dataset (table 4) for analysis of mixed-effects models. These variables summarize the (1) total number of days that each trout was tracked in each river during each year, (2) percentage of tracking done on release days, (3) total trout-sampling events (observations of an individual trout temperature during a single time block on a given day), and (4) percentage of sampling events during a release. The "during release" category was not applicable for Cedar River observations because there were no flow releases

Effects of Recreational Flow Releases on Natural Resources of the Indian and Hudson Rivers

Summaries of riverine conditions and the relations between, and the differences among, key resources are provided in separate sections and in several related publications cited as follows.

Table 3. Examples of telemetry data logged for trout 151444 on given days and during selected time blocks under release or nonrelease conditions in the Hudson River in June 2006.

[EDT, Eastern daylight time; °C, degrees Celsius; release code 1, during release; release code 2, not during release]

Date	River	Trout identification	Time block	Time (EDT)	Release code	Trout temperature (°C)	River Temperature (°C)	Temperature difference (°C)	Position[1]	
									Easting (meters)	Northing (meters)
14–Jun–06	HR	151444	3	14:12:49	2	17.97	17.69	-0.28	576017.9	4845797
16–Jun–06	HR	151444	2	10:31:40	2	18.69	18.27	-0.42	576017.9	4845797
18–Jun–06	HR	151444	2	12:49:10	2	22.77	22.16	-0.61	576024.1	4845796
18–Jun–06	HR	151444	3	16:10:33	1	22.34	21.73	-0.61		
20–Jun–06	HR	151444	2	12:59:59	1	22.81	22.21	-0.6	575993.4	4845815
20–Jun–06	HR	151444	3	13:01:04	1	22.81	22.21	-0.6		
20–Jun–06	HR	151444	4	18:32:14	2	19.77	21.01	1.24		
21–Jun–06	HR	151444	2	12:37:54	2	22.61	21.99	-0.62	576018.0	4845810
21–Jun–06	HR	151444	3	15:19:00	2	23.19	22.62	-0.57		
22–Jun–06	HR	151444	2	12:14:01	2	21.02	20.38	-0.64	576507.2	4847487
22–Jun–06	HR	151444	3	13:58:33	1	21.65	20.82	-0.83		
23–Jun–06	HR	151444	3	15:19:58	2	23.94	23.01	-0.93	576013.8	4845796
24–Jun–06	HR	151444	4	17:21:00	2	21.51	19.49	-2.02	576012.4	4845822
25–Jun–06	HR	151444	4	17:18:26	2	23.57	22.36	-1.21	575960.8	4845903
26–Jun–06	HR	151444	4	17:15:32	2	20.92	19.49	-1.43	575960.7	4845920

[1]Position in Universal Transverse Mercator Zone 18 (U18).

Table 4. The scope of the trout telemetry sampling effort in 2005 and 2006.

[Individual trout were observed up to three times per day; releases did not occur during flood stages]

Study reach and reach number	Total number of observations	Total number of days trout were tracked	Percentage of days trout were tracked on release dates	Number (and percentage) of observations on release days
		2005		
Indian River IR01–IR03	200	17	47	83 (42)
Hudson River HR04–HR05	108	15	60	70 (65)
		2006		
Indian River IR01–IR03	870	45	47	393 (45)
Hudson River HR04–HR05	676	50	48	233 (34)
Cedar River CR01–CR03	1,045	46	46	329 (31)

Discharge of the Indian River Below Lake Abanakee

In November 2004, a near real-time streamgage (Indian River below Lake Abanakee near Indian Lake, USGS station 01315081) was installed on the Indian River immediately downstream from the Lake Abanakee Dam (IR01 in fig. 1). Daily mean discharge data during each month in 2005 and 2006 (tables 5 and 6) show that discharge at IR01 was usually high in summer 2006 compared to summer 2005; daily mean flows were 259 and 443 ft^3/s from June to September in 2005 and 2006, respectively. On release days during June–September 2005, discharge averaged 180 ft^3/s immediately before each release, peaked at 1,387 ft^3/s during releases, and decreased to 127 ft^3/s after the spillway gate closed. Discharge during the releases increased, usually within 30 minutes, by an average of 1,207 ft^3/s. On release days from June to September 2006, discharge averaged 349 ft^3/s immediately before each release, peaked at 1,410 ft^3/s during releases, and decreased to 263 ft^3/s after the spillway gate closed. Discharge after releases decreased by 65 to 70 ft^3/s (mean 66 ft^3/s) and by 63 to 96 ft^3/s (mean 80 ft^3/s) in 2005 and 2006, respectively. River discharge at IR01 did not recover to prerelease levels until the next release 60 percent of the time in 2005 and 46 percent of the time in 2006.

Indian and Hudson River Stages—Stage and water temperature were recorded every 15 minutes (except during equipment failures) at three sites on the Indian River, five sites on the Hudson River, and two sites on Lake Abanakee (fig. 1). Average increases in stage from start to peak of release on release days were compared to changes during the same time interval on nonrelease days to assess the magnitude and significance of changes at each site during June to September 2005 and during the same months in 2006 (tables 7 and 8). Monthly mean increases in stage during releases at the three Indian River sites ranged from 1.18 to 2.14 ft during 2005 and from 0.79 to 1.94 ft during 2006. Monthly mean changes in stage during releases at sites in the Hudson River ranged from 1.14 to 3.15 ft in 2005 and from 0.67 to 1.31 ft during 2006. Data in figures 4A and 5A depict changes in stage during release days on the two rivers, and figures 4B and 5B depict changes in stage on nonrelease days. The release effect among sites was relatively constant; exceptions occurred at IR01, which is directly below the dam, and at HR03, which is in a gorge (fig. 6). Significant changes in stage were observed at all sites downstream from the dam, but the control site HR01 (fig. 1) was not affected because it is upstream from the confluence of the Indian and the Hudson Rivers (fig. 6).

After the gate was closed and stage in the Indian River downstream of Lake Abanakee dropped below prerelease levels, it took 24 hours or more elapsed time before the stage returned to levels observed before the gate was first opened. In 2005, monthly mean river stages during June, July, August, and September decreased by 0.23 to 0.27 ft (mean 0.25 ft) below stages prior to the release after the gate was closed. In 2006, monthly mean river stages during June, July, August, and September at the Indian River below Lake Abanakee decreased by 0.13 to 0.33 ft (mean 0.23 ft) below stages prior to the release after the gate was closed.

Lake Abanakee Stage—The mean stage on release and on nonrelease days was calculated for AB01 and AB02 in 2005 and for AB02 in 2006 (table 9). Decreases in lake stage associated with releases at the dam were consistently about 0.30 ft. A drawdown of almost 2 ft occurred in October 2005 when the spillway gate reportedly failed in the open position (fig. 7). At the end of June and beginning of July 2006, the gate at Abanakee Dam was intentionally left open for several days to alleviate flooding (fig. 8). The lake did not fully rebound prior to the next release for several days during August 2006 (fig. 9). Between July 2 and October 2, 2005, the lake always recovered to at least 75 percent of the prerelease stage, had an average recovery before the next release of 91 percent of the prerelease stage, and fully recovered to 100 percent of the prerelease stage 50 percent

Table 5. Daily discharges in cubic feet per second on the Indian River below Lake Abanakee near Indian Lake (site IR01) for November 2004 through September 2005 and total monthly discharges with daily mean, maximum, and minimum for each month.

[Unit conversions are shown in the conversion tables at the front of the report. E, estimated; --, no measurement made; * denotes value calculated from the incomplete record for November 2004]

Day	November	December	January	February	March	April	May	June	July	August	September
1	---	544	612	173	174	785	1,340	234	170	143	391
2	---	644	617	242	171	430	1,230	235	314	218	280
3	---	589	630	259	166	1,380	1,120	251	373	145	312
4	---	566	635	262	164	1,090	985	245	297	245	258
5	194	655	622	261	162	606	951	214	236	170	242
6	205	704	609	261	162	416	592	183	193	241	208
7	E230	661	601	260	162	427	265	183	324	225	217
8	232	690	587	263	174	501	197	159	257	144	270
9	231	728	580	267	178	485	232	226	330	196	201
10	254	736	572	278	172	411	255	264	301	135	282
11	314	757	561	277	170	359	279	261	255	249	241
12	328	744	559	271	171	314	252	238	348	173	167
13	328	707	559	270	168	283	200	187	255	225	205
14	326	674	665	270	165	249	203	210	288	181	216
15	330	641	736	281	164	226	173	196	130	88	264
16	342	623	686	286	160	163	160	405	230	199	195
17	368	613	644	288	156	155	139	1,350	212	79	266
18	360	599	603	284	155	129	134	1,430	115	188	236
19	351	593	574	278	155	155	133	1,010	192	106	182
20	342	586	562	275	155	101	129	1,080	160	189	236
21	335	574	551	275	158	143	161	712	256	168	203
22	330	570	539	271	159	181	154	294	189	100	260
23	326	589	536	269	160	384	150	541	249	209	186
24	334	775	528	266	168	1,420	158	317	218	87	253
25	478	782	524	265	175	1,160	218	310	145	215	239
26	548	717	522	263	175	1,100	265	193	241	78	188
27	496	674	519	249	185	1,640	262	64	185	174	285
28	486	637	513	186	186	1,760	275	206	258	180	219
29	562	620	488	---	239	1,730	258	120	176	102	266
30	524	607	424	---	280	1,450	245	233	231	212	219
31	---	598	200	---	272	---	218	---	258	343	---
Total	9,154*	20,197	17,558	7,350	5,461	19,633	11,333	11,551	7,386	5,407	7,187
Mean	352*	652	566	262	176	654	366	385	238	174	240
Maximum	562*	782	736	288	280	1,760	1,340	1,430	373	343	391
Minimum	194*	544	200	173	155	101	129	64	115	78	167

Table 6. Daily discharges on the Indian River below Lake Abanakee near Indian Lake (site IR01) for October 2005 through September 2006 and total monthly mean discharges with daily mean, maximum, and minimum for each month.

[Unit conversions are shown in the conversion tables at the front of the report. --, no measurement made]

Day	October	November	December	January	February	March	April	May	June	July	August	September
1	283	749	935	563	813	648	270	365	491	1,840	653	383
2	252	813	751	541	792	640	302	288	382	1,460	341	453
3	191	770	677	526	824	638	300	271	674	896	626	414
4	255	702	629	514	951	630	335	312	1,030	1,390	438	391
5	195	656	601	509	1,210	624	358	351	954	1,170	373	358
6	284	627	577	502	1,210	619	308	240	756	913	290	286
7	292	631	556	492	1,050	614	305	270	558	718	242	245
8	687	609	537	488	931	608	253	281	726	811	303	147
9	742	618	533	485	862	605	256	597	479	804	233	210
10	669	926	529	480	634	609	215	794	578	754	286	196
11	255	811	518	477	701	637	199	754	637	756	212	138
12	298	673	514	497	740	652	167	245	571	850	224	238
13	490	646	509	511	729	689	179	332	540	1,080	162	161
14	545	617	501	540	719	856	235	572	536	853	66	222
15	1,080	617	492	636	708	599	208	808	458	858	156	147
16	1,170	993	506	608	701	296	163	1,140	381	852	95	220
17	773	1,020	502	577	740	246	186	1,200	258	724	146	205
18	701	731	495	980	766	229	174	1,100	209	783	43	150
19	661	684	492	1,550	737	204	129	1,130	192	742	131	238
20	615	651	488	1,340	716	181	119	1,060	269	610	206	200
21	583	617	484	1,150	699	135	138	977	234	256	171	261
22	563	598	481	1,080	723	136	136	714	342	277	293	189
23	597	586	477	998	703	137	695	380	340	354	232	255
24	640	565	475	926	681	134	1,890	433	392	329	263	231
25	750	553	480	885	675	137	1,760	424	281	406	202	177
26	989	542	563	712	671	144	1,400	410	188	588	275	250
27	894	533	588	749	662	144	1,220	343	704	607	279	171
28	784	529	565	778	654	147	922	280	2,160	478	226	211
29	712	573	549	775	---	156	943	252	3,200	779	279	212
30	678	843	579	785	---	170	904	272	2,500	729	215	270
31	700	---	571	807	---	185	---	735	---	590	298	---
Total	18,328	20,483	17,154	22,461	22,002	12,449	14,669	17,330	21,020	24,257	7,959	7,229
Mean	591	683	553	725	786	402	489	559	701	782	257	241
Maximum	1,170	1,020	935	1,550	1,210	856	1,890	1,200	3,200	1,840	653	453
Minimum	191	529	475	477	634	134	119	240	188	256	43	138

Table 7. Mean change in river stage from start of release to peak flow on release days and during the same interval on nonrelease days and number of release and nonrelease days at eight sites on the Indian and Hudson Rivers in the Adirondack Mountains, New York, for each month during June–September, 2005.

[Mean change in river stage, in feet, is the first number, and the number of observations is the second number (in parentheses). Locations of study sites are shown in figure 1; unit conversions are shown in the conversion tables at the front of the report. Site codes are listed in table 1. Mean monthly change in stage was significant (*p*-value < 0.001) at all sites except HR01. na, data not available]

Period	Flow condition	Study sites							
		IR01	IR02	IR03	HR01	HR02	HR03	HR04	HR05
June	release nonrelease	1.93 (20) -.01 (10)	1.26 (4) 0 (2)	na	na	na	na	na	na
July	release nonrelease	1.95 (18) 0 (13)	1.23 (18) 0 (13)	1.22 (17) 0 (12)	0 (18) 0 (13)	1.14 (18) .01 (13)	2.43 (18) 0 (13)	1.17 (18) 0 (13)	1.24 (18) 0 (13)
August	release nonrelease	2.14 (17) .01 (14)	1.39 (17) .01 (14)	1.33 (17) .01 (14)	0 (17) 0 (14)	1.45 (10) .01 (8)	3.15 (14) .01 (8)	1.58 (17) .01 (14)	1.57 (15) 0 (12)
September	release nonrelease	1.89 (17) 0 (13)	1.18 (17) 0 (13)	1.48 (17) .01 (13)	0 (17) 0 (13)	1.17 (16) .02 (14)	2.40 (17) .02 (13)	1.15 (17) 0 (13)	1.22 (17) .01 (13)
For all months	release nonrelease	1.98 (72) 0 (50)	1.27 (56) .01 (42)	1.34 (51) .01 (39)	0 (52) 0 (40)	1.22 (44) .01 (35)	2.63 (49) .01 (34)	1.30 (52) 0 (40)	1.33 (50) 0 (38)

Table 8. Mean change in river stage from start of release to peak flow on release days and during the same interval on nonrelease days and number of release and nonrelease days at eight sites on the Indian and Hudson Rivers in the Adirondack Mountains, New York, for each month during June–September, 2006.

[Mean change in river stage in feet is the first number, and the number of observations is the second number (in parentheses). Locations of study sites are shown in figure 1; unit conversions are shown in the conversion tables at the front of the report. Site codes are listed in table 1. Mean monthly change in stage was significant (*p*-value < 0.001) at all sites except HR01. na; data not available]

Period	Flow condition	Study site							
		IR01	IR02	IR03	HR01	HR02	HR03	HR04	HR05
June	release nonrelease	1.42 (23) .08 (7)	.79 (23) .02 (7)	1.12 (23) .07 (7)	0.0 (23) .02 (7)	.68 (19) .01 (2)	na	.76 (23) .02 (7)	.76 (23) .06 (5)
July	release nonrelease	1.28 (16) -.04 (15)	.79 (16) -.02 (15)	.94 (16) -.02 (15)	0.0 (16) -.01 (15)	na	na	.67 (16) -.02 (15)	na
August	release nonrelease	1.94 (18) .01 (13)	1.27 (18) .01 (13)	1.35 (18) .01 (13)	0.0 (18) 0.0 (13)	na	na	1.24 (18) .01 (13)	na
September	release nonrelease	1.88 (18) .01 (12)	1.23 (16) 0.0 (11)	1.30 (15) 0.00 (10)	0.0 (12) 0.0 (8)	na	na	1.31 (15) 0.0 (10)	na
Mean for all months	release nonrelease	1.63 (75) 0.0 (47)	1.00 (73) 0.0 (46)	1.18 (72) .01 (45)	0.0 (69) 0.0 (43)	na	na	.97 (72) 0.0 (45)	na

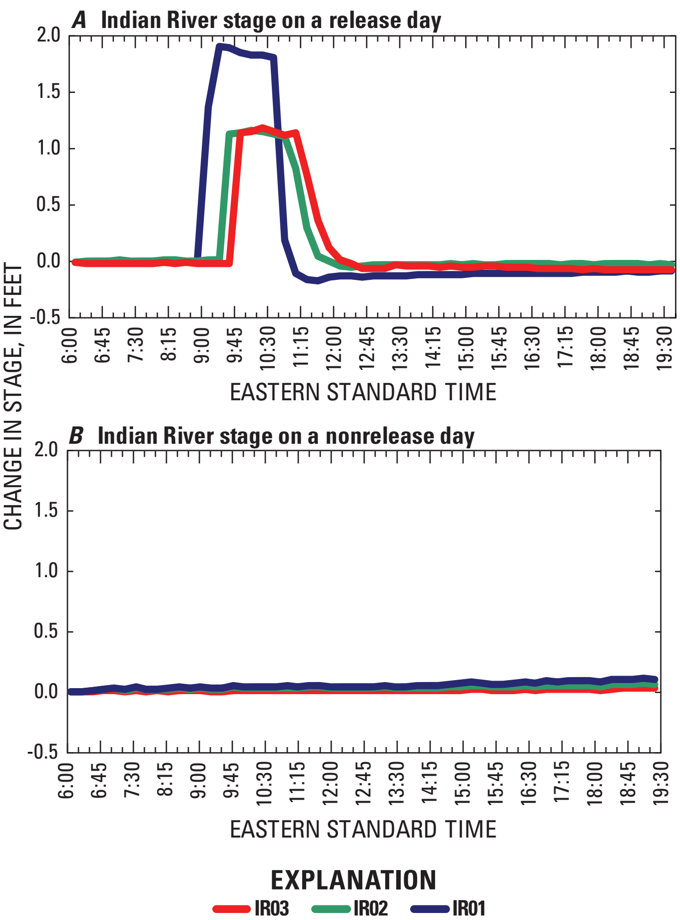

Figure 4. Graphs showing cChange in stage at three Indian River sites *A,* on July 7, 2005, a release day, and *B,* on July 8, 2005, a nonrelease day, Adirondack Mountains, New York. Locations of study sites are shown in figure 1; study-site codes are listed in table 1.

of the time; between July 6 and September 27, 2006, the lake always recovered to at least 84 percent of the prerelease stage, had an average recovery before the next release of 98 percent of the prerelease stage, and fully recovered to 100 percent of the prerelease stage 58 percent of the time. In 2005 recovery times ranged from 10 to 48 hours with an average recovery time of 31 hours, and in 2006 recovery times ranged from 6 to 48 hours with an average recovery time of 29 hours.

Recharge times in Lake Abanakee were initially hypothesized to depend mainly on inflows from Indian Lake. Stages at Indian Lake, Lake Abanakee, and IR01 between July 1 and August 1, 2005 (fig. 10A), and July 1 and August 1, 2006 (fig. 10B), however, indicate that precipitation and other inflows had a strong effect on stage-rebound times in Lake Abanakee. A more comprehensive analysis of gaged and ungaged inflows, precipitation, lake stage, and flow releases would be needed to fully characterize the effects of releases on recharge in Lake Abanakee.

River Temperatures

Temperature data were collected at three sites on the Indian River and at five sites on the Hudson River (fig. 1) to help quantify the thermal effects of the releases from Lake Abanakee. The mean changes in stream temperature from the start to the peak of releases on release days were compared to the mean changes for the same time period on nonrelease days to assess the magnitudes and significances of releases on thermal conditions at each study site during the months of June, July, August, and September in 2005 and 2006 (tables 10 and 11). Analysis of the pooled data for the 4 months in 2005 indicated that dam releases caused small but significant decreases in temperature at IR01 and IR02 and possibly reduced the rate of diel temperature increases at IR03, HR02, and HR04 (table 10). Analysis of the pooled 2006 data showed

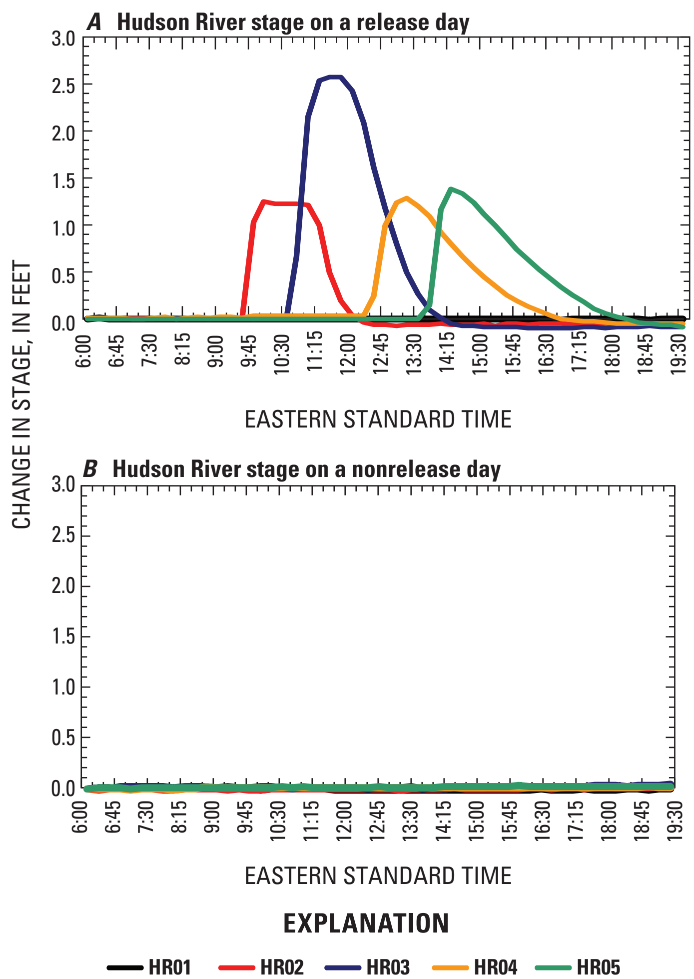

Figure 5. Graphs showing cChange in stage at five Hudson River sites *A,* on July 7, 2005, a release day, and *B,* on July 8, 2005, a nonrelease day, Adirondack Mountains, New York. Locations of study sites are shown in figure 1; study-site codes are listed in table 1.

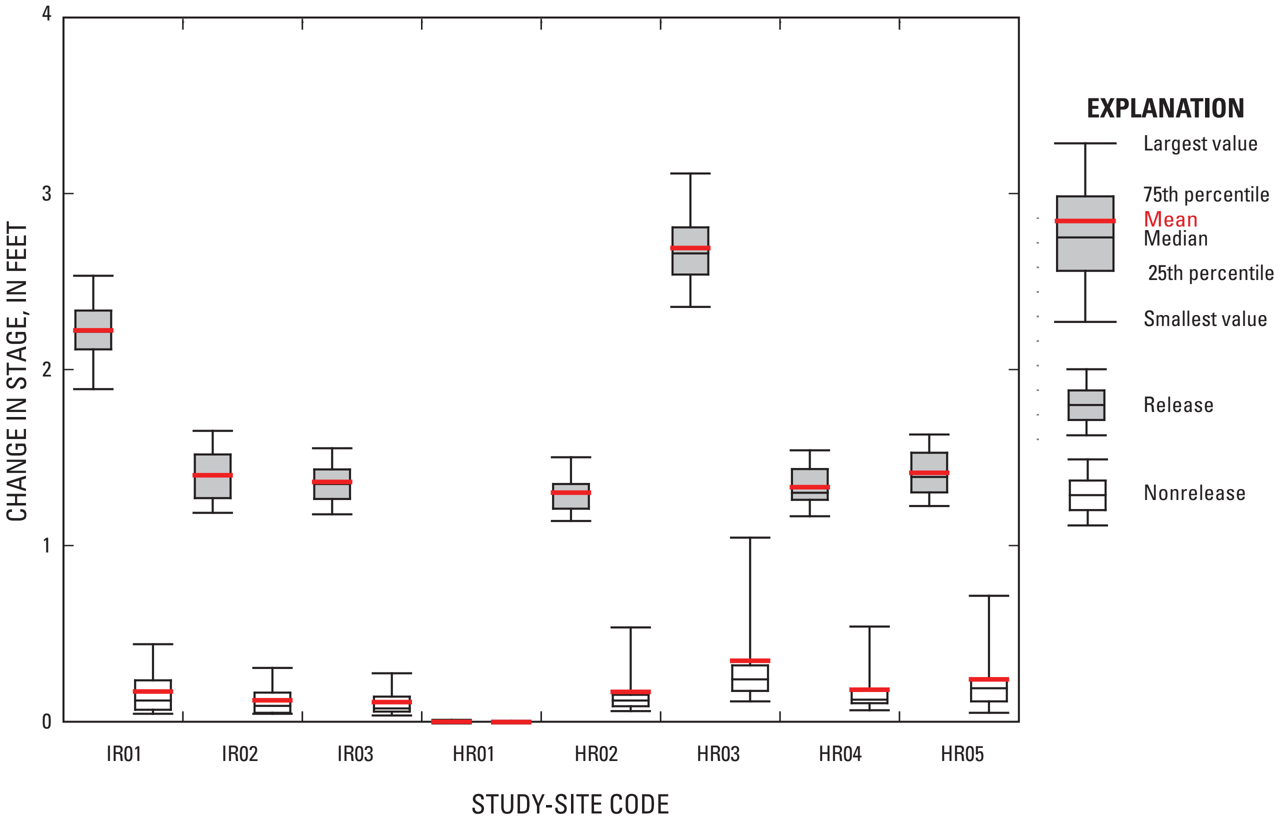

Figure 6. Graph showing cChange in stage at eight study sites on the Indian and Hudson Rivers, Adirondack Mountains, New York, on release and nonrelease days from July 1 to August 1, 2005. Locations of study sites are shown in figure 1; study-site codes are listed in table 1.

Table 9. Mean change in the stage of Lake Abanakee from start of release until closing of the spillway gate on release days and number of release and nonrelease days at two study sites in the Adirondack Mountains, New York, and during the same interval on nonrelease days during June–September 2005 and at one site during June–September 2006.

[Mean change in lake stage in feet is the first number, and the number of observations is the second number (in parentheses). Locations of study sites are shown in figure 1; unit conversions are shown in the conversion tables at the front of the report.. Site codes are listed in table 1. Mean monthly change in lake stage was significant (p-value < 0.001) at all sites except HR01. na, data not available]

Period	Flow condition	Study site and year		
		2005		2006
		AB01	AB02	AB02
June	release	-0.32 (4)	na	-0.26 (23)
	nonrelease	0.02 (2)		0.02 (7)
July	release	-0.30 (15)	-0.31 (18)	-0.23 (16)
	nonrelease	0.01 (12)	0.01 (13)	0.0 (15)
August	release	-0.32 (7)	-0.34 (12)	-0.32 (18)
	nonrelease	0.01 (7)	0.01 (10)	0.01 (13)
September	release	-0.29 (5)	-0.29 (17)	-0.32 (16)
	nonrelease	0.0 (1)	0.01 (13)	0.0 (11)
For all months	release	-0.31 (31)	-0.31 (47)	-0.28 (73)
	nonrelease	0.01 (22)	0.01 (36)	0.01 (46)

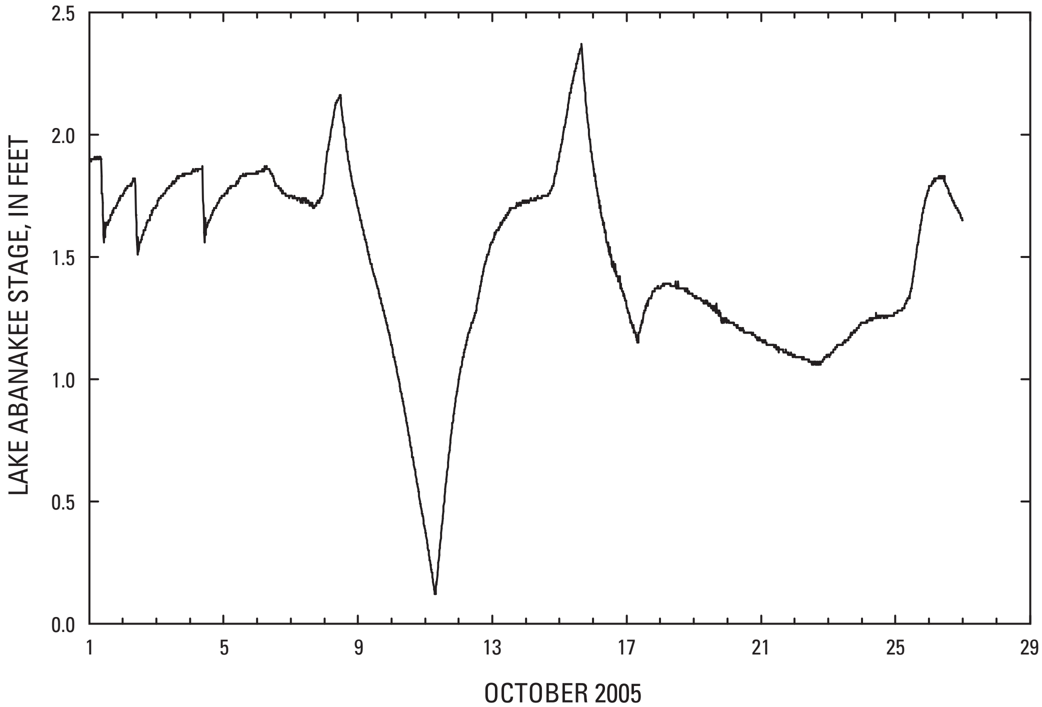

Figure 7. Graph showing lLake stage at Lake Abanakee at Route 28 bridge near Indian Lake (AB02), Adirondack Mountains, New York, during October 2005. Location of AB02 is shown in figure 1; study-site codes are listed in table 1.

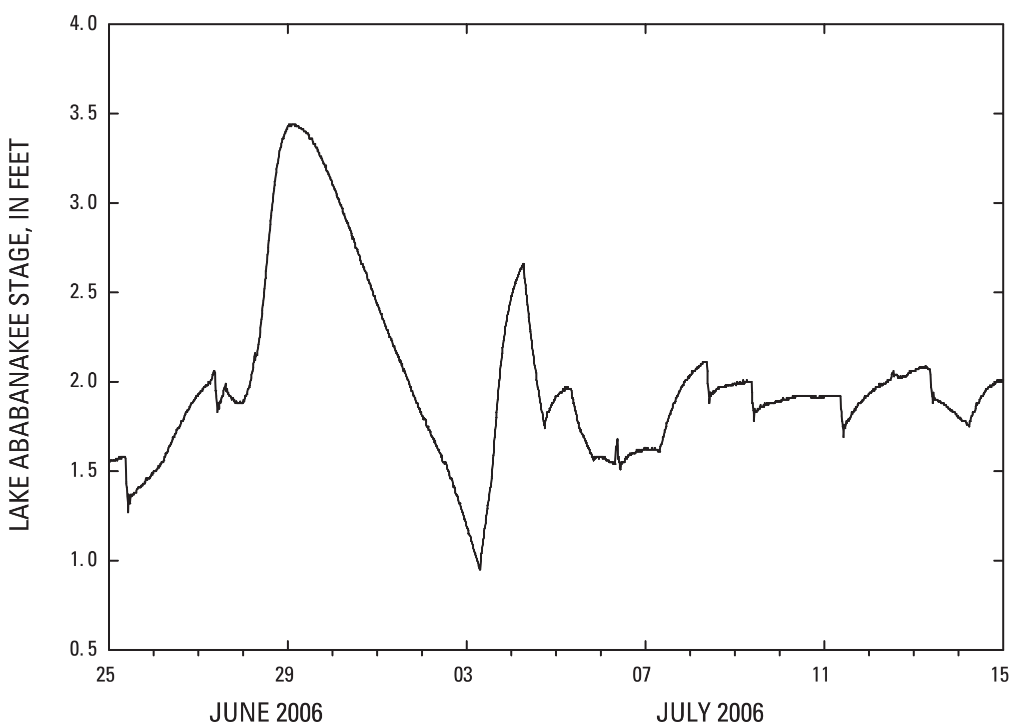

Figure 8. Graph showing lLake stage at Lake Abanakee at Route 28 bridge near Indian Lake (AB02), Adirondack Mountains, New York, during June and July 2006. Location of AB02 is shown in figure 1; study-site codes are listed in table 1.

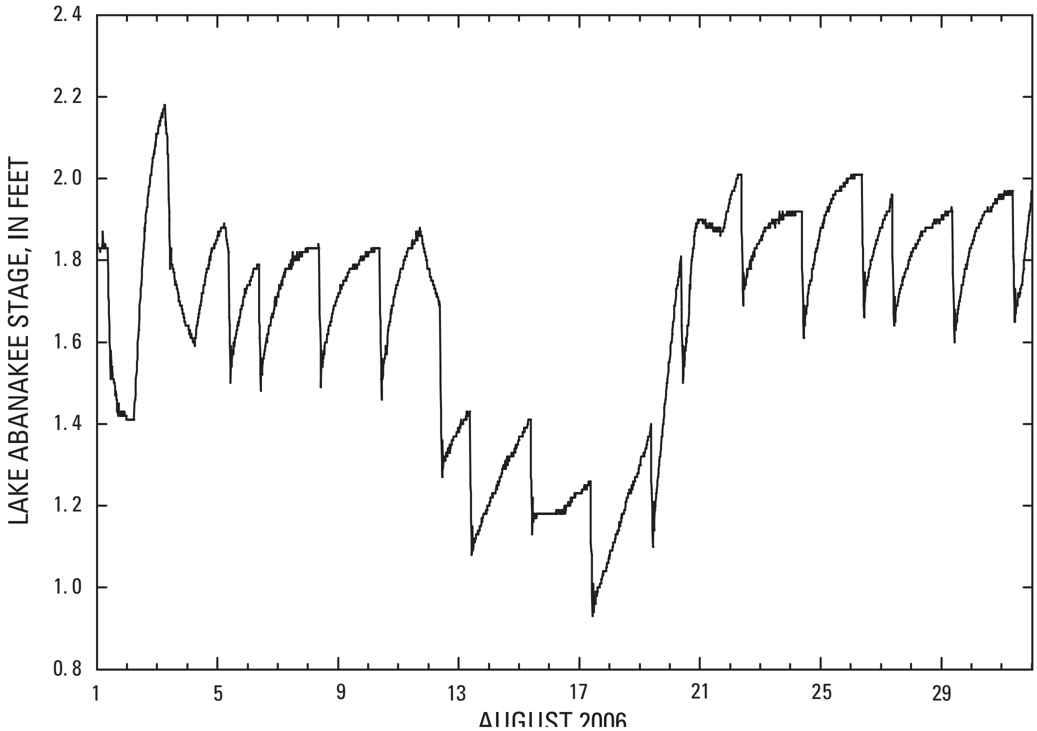

Figure 9. Graph showing lLake stage at Lake Abanakee at Route 28 bridge near Indian Lake (AB02), Adirondack Mountains, New York, during August 2006. Location of AB02 is shown in figure 1; study-site code is listed in table 1.

significant decreases in temperature during releases at IR01, significantly delayed diel temperature increases at IR02, and possibly moderated diel temperature increases at IR03 and HR04 (table 11). Examination of changes in water temperature over a 3-day period (2 nonrelease days and 1 release day) in the Indian and the Hudson Rivers showed that releases lowered temperature in the Indian River (fig. 11) and delayed and(or) reduced daily temperature increases in the Hudson River (fig. 12). Lower mean and median daily temperatures at all sites on release days than on nonrelease days between July 1 and August 1, 2005, (fig. 13) provide additional evidence for a cooling effect. The control site (HR01) exhibited no significant temperature differences between release days and nonrelease days. Decreases in temperature at several sites affected by releases were very small, indicating that the thermal changes would have no direct (positive or negative) effect on survival of resident trout. Regardless of releases, water temperatures at all study sites commonly exceeded the threshold (20°C) known to be stressful to brown trout. River-water temperatures were higher at all sites in summer 2005 than in summer 2006: monthly mean temperatures were 1.1, 1.6, and 2.8°C greater during July, August, and September 2005 than during the same periods in 2006. The maximum water temperature for the period of record at Indian River below Lake Abanakee was 26.5°C on July 18, August 9, and August 10, 2005. Daily maximum, minimum, and mean temperatures for each site are available in the 2005 and 2006 New York Annual Water-Data Reports for Eastern New York, excluding Long Island (http://ny.water.usgs.gov/htmls/pub/data.html).

Temporal and Spatial Patterns in Temperature of the Hudson River

Important temporal and spatial patterns in river temperatures from aerial infrared (IR) data are summarized below; more complete analyses of thermal-imaging results are provided in Ernst and others (in press). The longitudinal temperature profiles constructed for three periods over the course of a release day (fig. 14A) show that river temperatures increased unevenly during the day. During the first flight (10:12 Eastern Standard Time (EST)), when the high-water bubble covered the river between kilometers 1 and 5, most surface-water temperatures were below 22°C and generally decreased downstream (fig. 14A). During the second flight (12:39 EST), when the high-water bubble covered the river between kilometers 4 and 19, surface temperatures were near 22°C, although middle reaches between kilometers 6 and 18 containing the bubble were slightly cooler than the upper reaches between kilometers 1 and 4 and the lower reaches

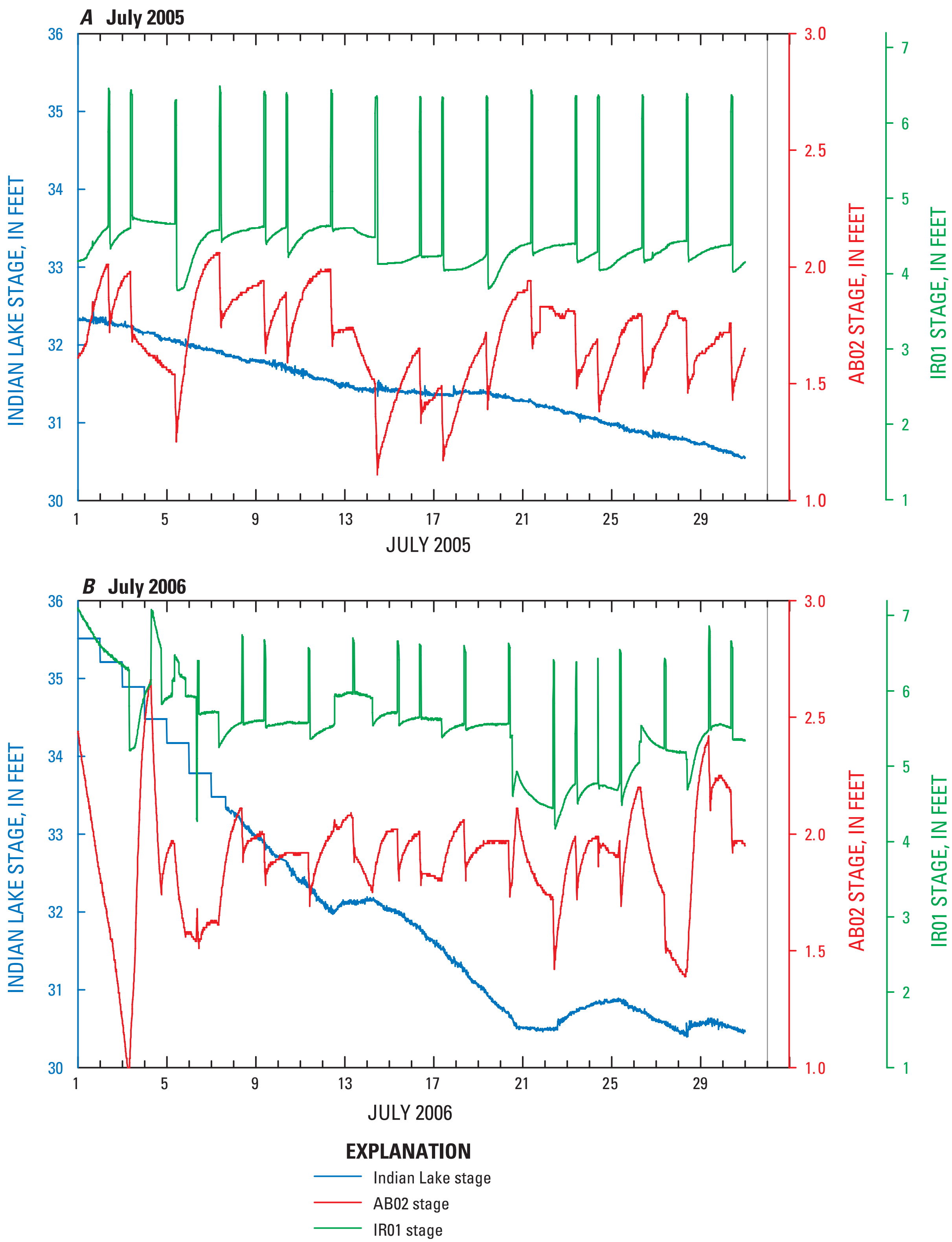

Figure 10. Graphs showing sStage at Indian Lake, Lake Abanakee (AB02), and Indian River (IR01), Adirondack Mountains, New York, during *A,* July 2005, and *B,* July 2006. Locations of study sites are shown in figure 1; study-site codes are listed in table 1.

Table 10. Mean change in temperature from start of release to peak flow on release days and during the same time period on nonrelease days and number of release and nonrelease days at eight sites on the Indian and Hudson Rivers in the Adirondack Mountains, New York, during June–September 2005.

[Mean change in temperature, in degrees Celsius, is the first number, and the number of observations in days, is the second number (in parentheses). Locations of study sites are shown in figure 1; study-site codes are listed in table 1. **Boldface** p-value (< 0.05) indicates significant changes in temperature. na, not available]

Period	Type of day	Study sites							
		IR01	IR02	IR03	HR01	HR02	HR03	HR04	HR05
June	release	**-0.60 (20)**	**-0.61 (4)**	na	na	na	na	na	na
	nonrelease	**0.16 (10)**	**0.22 (2)**						
		p<**0.001**	p = **0.022**						
July	release	**-0.40 (18)**	**-0.24 (18)**	**0.05 (17)**	na	0.17 (18)	0.64 (18)	0.08 (18)	0.18 (18)
	nonrelease	**0.12 (13)**	**0.15 (13)**	**0.20 (12)**		0.17 (13)	0.47 (13)	0.23 (13)	0.21 (13)
		p<**0.001**	p<**0.001**	p = **0.047**		p = 0.921	p = 0.097	p = 0.104	p = 0.819
August	release	**-0.21 (17)**	0.11 (17)	0.54 (17)	0.50 (15)	**0.18 (9)**	0.59 (14)	**0.01 (17)**	0.39 (15)
	nonrelease	**0.21 (14)**	0.20 (14)	0.75 (14)	0.42 (12)	**0.48 (7)**	0.49 (8)	**0.15 (14)**	0.08 (12)
		p<**0.001**	p = 0.065	p = 0.213	p = 0.411	p = **0.002**	p = 0.403	p = **0.029**	p = 0.078
September	release	**-0.04 (17)**	0.14 (17)	0.44 (17)	0.39 (12)	0.49 (4)	0.44 (17)	0.02 (17)	-0.05 (17)
	nonrelease	**0.19 (13)**	0.19 (13)	0.38 (13)	0.56 (8)	0.18 (6)	0.43 (13)	0.20 (13)	0.02 (13)
		p<**0.001**	p = 0.088	p = 0.577	p = 0.232	p = 0.014	p = 0.878	p = 0.007	p = 0.164
Mean for all months	release	**-0.33 (72)**	**-0.04 (56)**	0.34 (51)	0.45 (27)	0.21 (31)	0.56 (49)	**0.04 (52)**	0.16 (50)
	nonrelease	**0.17 (50)**	**0.18 (42)**	0.46 (39)	0.48 (20)	0.26 (26)	0.46 (34)	**0.19 (40)**	0.10 (38)
		p<**0.001**	p<**0.001**	p = 0.162	p = 0.757	p = 0.368	p = 0.096	p<**0.001**	p = 0.401

Table 11. Mean change in temperature from start of release to peak flow on release days and during the same time period on nonrelease days and number of release and nonrelease days at eight sites on the Hudson and Indian Rivers in the Adirondack Mountains, New York, during June–September 2006.

[Mean change in temperature, in degrees Celsius, is the first number, and the number of observations in days, is the second number (in parentheses). Locations of study sites are shown in figure 1; study-site codes are listed in table 1. **Boldface** *p*-value (< 0.05) indicates significant changes in temperature. na, not available]

Period	Type of day	Study sites							
		IR01	IR02	IR03	HR01	HR02	HR03	HR04	HR05
June	release	**-0.15 (23)**	**-0.06 (23)**	**0.02 (23)**	0.23 (23)	**0.22 (19)**	na	0.19 (23)	0.19 (23)
	nonrelease	**0.14 (7)**	**0.18 (7)**	**0.17 (7)**	0.18 (7)	**0.47 (2)**		0.09 (7)	0.14 (5)
		p = **0.001**	p = **0.008**	p = **0.019**	p = 0.716	p = **0.033**		p = 0.183	p = 0.568
July	release	**-0.05 (16)**	**0.03 (16)**	**0.04 (16)**	0.29 (16)	na	na	0.17 (16)	na
	nonrelease	**0.08 (15)**	**0.14 (15)**	**0.21 (15)**	0.30 (15)			0.32 (15)	
		p**<0.001**	p = **0.003**	p = **0.003**	p = 0.949			p = 0.064	
August	release	**-0.05 (18)**	0.20 (18)	0.44 (18)	0.20 (18)	na	na	**0.05 (18)**	0.38 (10)
	nonrelease	**0.18 (13)**	0.23 (13)	0.34 (13)	0.29 (13)			**0.37 (13)**	0.36 (7)
		p**<0.001**	p = 0.634	p = 0.281	p = 0.179			p**<0.001**	p = 0.946
September	release	**-0.05 (18)**	**0.04 (16)**	0.24 (15)	0.14 (17)	na	na	-0.02 (15)	0.27 (15)
	nonrelease	**0.15 (12)**	**0.25 (11)**	0.29 (10)	0.13 (11)			0.13 (10)	0.51 (10)
		p**<0.001**	p = **0.003**	p = 0.642	p = 0.686			p = 0.116	p = 0.155
Mean for all months	release	**-0.08 (75)**	**0.05 (73)**	0.17 (72)	0.22 (74)	na	na	**0.11 (72)**	0.25 (48)
	nonrelease	**0.14 (47)**	**0.20 (46)**	0.26 (45)	0.24 (46)			**0.26 (45)**	0.38 (22)
		p**<0.001**	p**<0.001**	p = 0.079	p = 0.616			p**<0.001**	p = 0.141

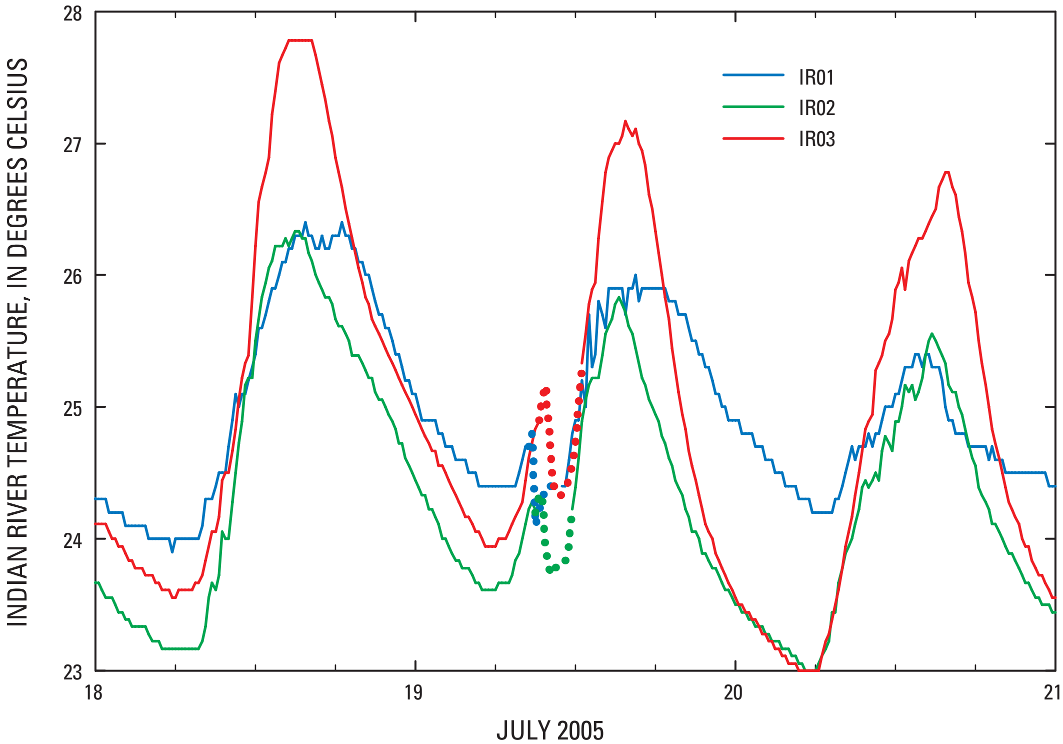

Figure 11. Graph showing cChange in temperature of the Indian River at three study sites in the Adirondack Mountains, New York, from July 18 to July 21, 2005. Dotted lines represent temperature recorded during a release. Locations of study sites are shown in figure 1; study-site codes are listed in table 1.

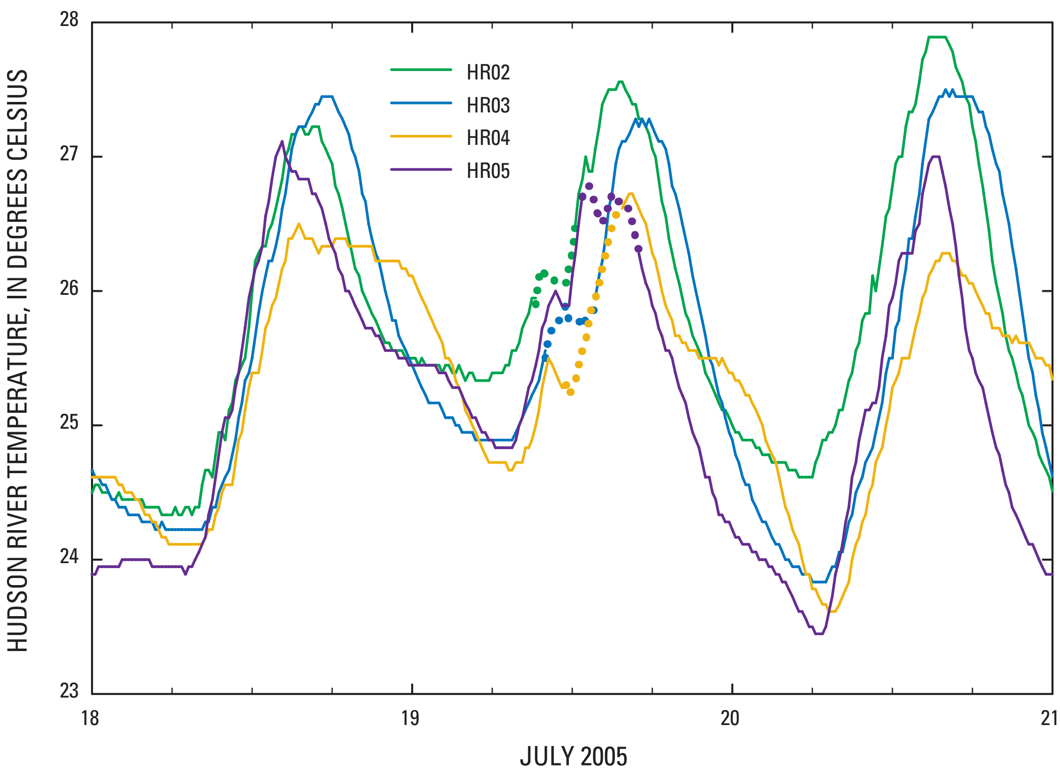

Figure 12. Graph showing cChange in temperature of the Hudson River at four sites, in the Adirondack Mountains, New York, from July 18 to July 21, 2005. Dotted lines represent temperatures recorded during a release. Locations of study sites are shown in figure 1; study-site codes are listed in table 1.

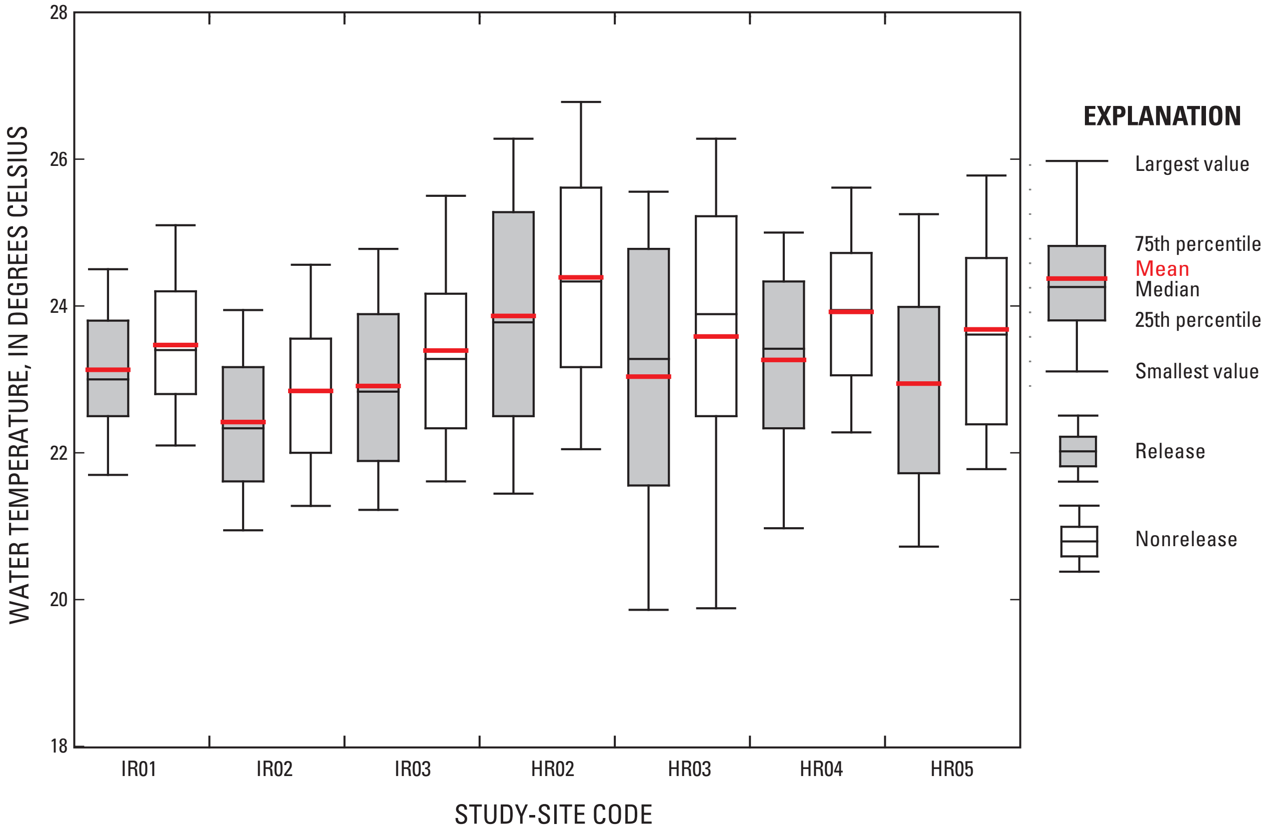

Figure 13. Graph showing cChange in temperature at eight study sites on the Indian and Hudson Rivers in the Adirondack Mountains, New York, on release and nonrelase days from July 1 to August 1, 2005. Locations of study sites are shown in figure 1; study-site codes are listed in table 1.

between kilometers 20 and 27 (fig. 14B). During the third flight (15:42 EST), most surface temperatures were above 22°C when the high-water bubble covered the river between kilometers 16 and 27. The middle reaches were cooler, and the upper reaches were much warmer than other reaches (fig. 14C). Thalweg temperatures, used for constructing the longitudinal temperature profiles, were generally lower than water temperatures along the stream bank during the first two flights, although thalweg temperatures and stream-bank temperatures were similar during the last flight. All three flights recorded many spikes and dips in temperature along the thalweg; although either type of change may reflect spurious data caused by such irregularities as exposed rocks, only the low dips that might indicate cold-water refuges for trout were assessed. No cool-water tributaries below the Boreas River affected the longitudinal temperature profile (fig. 14), probably because inflows along river banks were too small to affect temperatures near the thalweg.

An analysis of 1-km river sections showed that the largest areas of potential thermal refuge (areas where the water temperature was below the median for that section) were available to trout during the morning flight (10:12 EST); 4.1 percent (61,277 m^2) of surface water was at least 1ºC cooler than the median river temperature. Most of the coldest refuge area was in the first 4 km of the 27-km reach and was measured during passage of the high-water bubble (table 12); 0.7 percent (781 m^2) of surface water was at least 3°C cooler than the median temperature, but some rocky banks may have been misidentified because of shading. Water temperatures measured during the midday flight (12:39 EST) were warmer and offered fewer potential refuges along the river: only 0.4 percent (6,460 m^2) of surface water was at least 1ºC cooler than the median temperature, and no water was 3ºC cooler than the median (table 12). A few potential refuge areas were available in several 1-km sections: six of the eight 1-km sections had up to 30 m^2 of refuge area when the high-water bubble affected the reach. River temperatures measured during the afternoon flight (15:42 EST) were warmer still, but more refuge area was available than at midday. Areas of water that were at least 1ºC or cooler than the median temperature covered 0.9 percent (13,792 m^2) of the river surface. Most 1-km sections within the afternoon high-water bubble had little or no available refuge area when the high-water bubble affected the reach (table 12).

During the morning flight, the riparian vegetation on the east river bank of all 1-km river sections that ran north-south

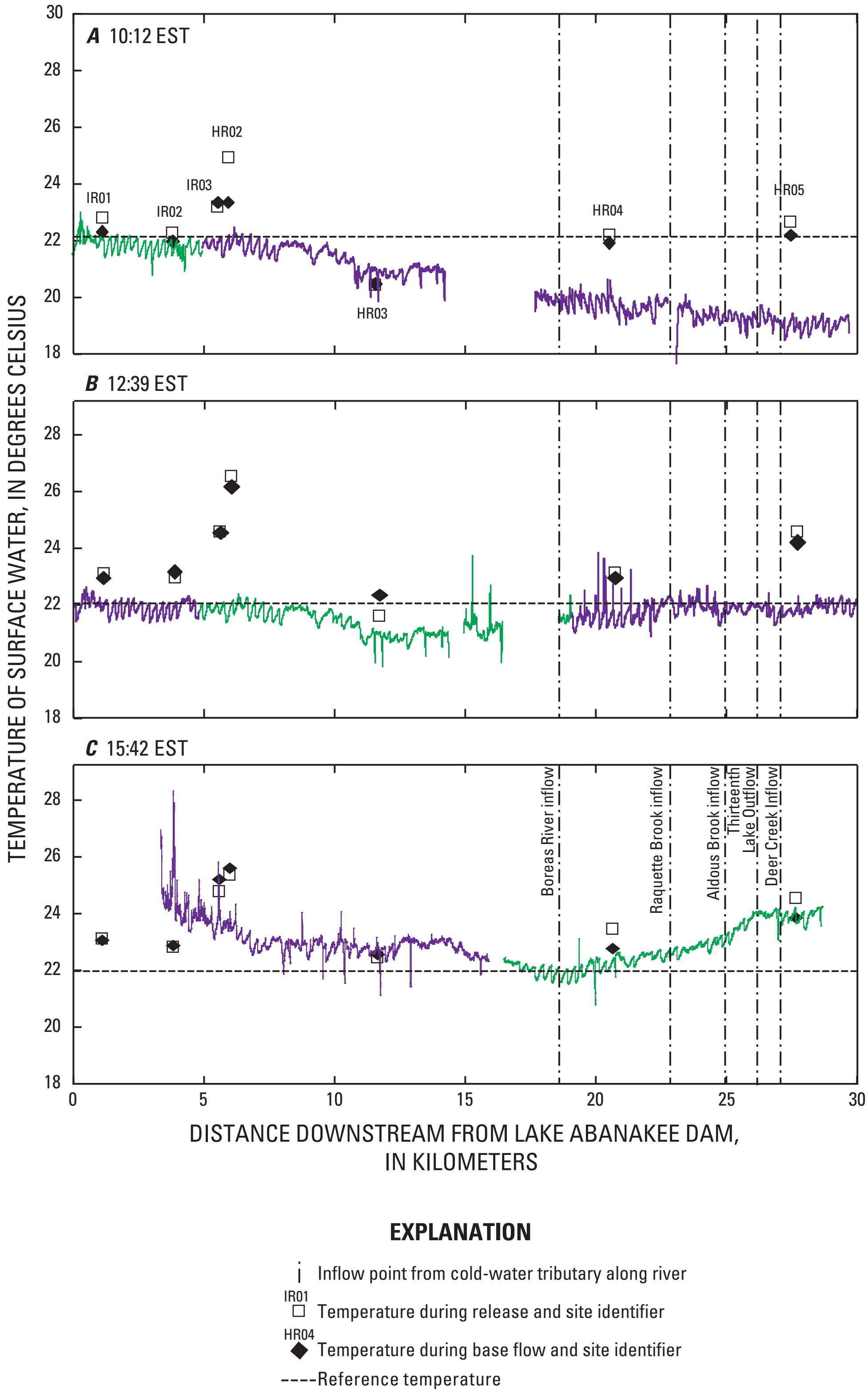

Figure 14. Graphs showing lLongitudinal temperature profiles of the three Indian Rivers study sites IR01–IR03 and Hudson River study sites HR02–HR05 in the Adirondack Mountains, New York, at *A,* 10:12, *B,* 12:39, and *C,* 15:42 Eastern Standard Time (EST) during release and nonrelease flows on July 25, 2005; mean temperature at the seven study sites from July 21, 2005 through September 21, 2005, on release and nonrelease days; and inflow points for five cool-water tributaries.

Table 12. Median temperature for each 1-kilometer section and refuge areas 1, 2., and 3ºC below the median temperature for that section during three flights along the 27-kilometer reach of the Indian and Hudson Rivers from the outflow point of the Abanakee Dam to North Creek, Adirondack Mountains, New York, July 25, 2005.

[Flight 1 aloft from 10:12 to 10:55 EDT; flight 2 aloft from 12:39 to 13:14 EST; flight 3 aloft from 15:42 to 16:05 EDT. Sections of the river under the high-water bubble are highlighted. Locations of study sites are shown in figure 1; unit conversions are shown in the conversion tables at the front of the report. Site codes are listed in table 1. ºC, degrees Celsius]

Flight 1					
Section (kilometers from outflow point)	Total area (square meters)	Median temperature (°C)	Refuge area below median temperature (square meters)		
			1ºC	2ºC	3ºC
1	23,843	20.7	2,169	808	73
2	22,343	19.9	2,871	1,162	4
3	44,379	20	3,170	1,033	457
4	25,053	20.6	3,069	850	247
5	50,744	20.6	1,291	124	0
6	60,802	20	946	253	0
7	57,194	19.6	2,284	579	1
8	61,213	19.6	2,027	379	1
9	61,091	19.8	166	15	0
10	52,149	19.5	3,508	507	1
11	43,962	19.4	868	51	0
12	49,621	19.5	354	49	0
13	44,774	19.7	580	32	0
14	47,229	19.7	3,075	901	28
15	58,242	19.6	2,951	1,285	50
16	5,557	20.1	344	177	6
17	56,832	20.1	116	6	0
18	62,941	19.9	846	118	0
19	69,630	19.8	2,134	397	2
20	77,170	19.7	9,383	442	7
21	63,808	19.7	2,797	599	11
22	71,964	19.7	4,937	576	5
23	95,715	19.4	2,920	121	0
24	86,914	19.2	2,922	103	0
25	77,398	19.4	4,260	223	0
26	74,663	19.2	570	2	0
27	53,488	19.1	719	93	0
Mean temperature		19.7			
Total area of the 27 sectors	1,498,719				
Total area 1–3°C below mean temperature (percentage of total 27-kilometer reach)			61,277 (4.09)	10,885 (0.72)	893 (0.060)

Table 12. Median temperature for each 1-kilometer section and refuge areas 1, 2, and 3°C below the median temperature for that section, during three flights along the 27-kilometer reach of the Indian and Hudson Rivers from the outflow point of the Abanakee Dam to North Creek, Adirondack Mountains, New York, July 25, 2005.—Continued

[Flight 1 aloft from 10:12 to 10:55 EDT; flight 2 aloft from 12:39 to 13:14 EST; flight 3 aloft from 15:42 to 16:05 EDT. Sections of the river under the high-water bubble are highlighted. Locations of study sites are shown in figure 1; unit conversions are shown in the conversion tables at the front of the report. Site codes are listed in table 1. ºC, degrees Celsius]

Flight 2					
Section (kilometers from outflow point)	Total area (square meters)	Median temperature (°C)	Refuge area below median temperature (square meters)		
			1ºC	2ºC	3ºC
1	24,314	22.1	89	0	0
2	22,327	21.9	57	0	0
3	44,380	21.8	4	0	0
4	25,025	21.9	12	0	0
5	50,741	21.9	100	0	0
6	60,772	22	94	0	0
7	57,199	21.7	386	50	0
8	61,185	21.8	288	13	0
9	60,983	21.6	113	25	0
10	52,040	21.4	71	2	0
11	43,962	21	120	0	0
12	49,535	20.8	14	0	0
13	44,699	21.1	0	0	0
14	26,955	21.2	469	0	0
15	58,122	21.1	209	7	0
16	5,519	21.5	0	0	0
17	56,731	21.6	4	0	0
18	62,817	21.7	30	0	0
19	69,512	21.8	283	0	0
20	77,139	21.9	383	0	0
21	63,825	22	11	0	0
22	71,899	22	688	34	0
23	95,774	22.1	718	11	0
24	86,927	21.9	853	0	0
25	77,373	21.9	1,067	0	0
26	74,649	22.2	187	53	0
27	53,456	22.1	210	16	0
Mean temperature		21.8			
Total area of the 27 sectors	1,477,860				
Total area 1–3°C below mean temperature (percentage of total 27-kilometer reach)			6,460 (0.44)	211 (0.014)	0 (0)

Table 12. Median temperature for each 1-kilometer section and refuge areas 1, 2, and 3ºC below the median temperature for that section, during three flights along the 27-kilometer reach of the Indian and Hudson Rivers from the outflow point of the Abanakee Dam to North Creek, Adirondack Mountains, New York, July 25, 2005.—Continued

[Flight 1 aloft from 10:12 to 10:55 EDT; flight 2 aloft from 12:39 to 13:14 EST; flight 3 aloft from 15:42 to 16:05 EDT. Sections of the river under the high-water bubble are highlighted. Locations of study sites are shown in figure 1; unit conversions are shown in the conversion tables at the front of the report. Site codes are listed in table 1. ºC, degrees Celsius]

Flight 3					
Section (kilometers from outflow point)	Total area (square meters)	Median temperature (°C)	Refuge area below median temperature (square meters)		
			1ºC	2ºC	3ºC
1	18,765	23.2	1,268	421	23
2	22,327	23.4	1,569	33	0
3	44,228	23.5	2,252	137	3
4	25,025	24.2	2,509	174	0
5	50,741	23.9	703	94	0
6	60,772	23.8	721	42	0
7	57,199	23.2	218	43	0
8	56,271	23.1	1,017	53	7
9	60,937	23	916	85	1
10	51,812	23	300	0	0
11	43,487	22.9	705	150	2
12	49,484	22.8	740	11	0
13	44,654	23.1	137	0	0
14	48,162	23.1	287	29	0
15	58,047	22.5	250	0	0
16	5,507	22.4	0	0	0
17	56,718	22.2	0	0	0
18	62,784	22	9	0	0
19	69,463	22.1	16	0	0
20	76,905	22.3	1	0	0
21	63,684	22.4	0	0	0
22	71,676	22.6	0	0	0
23	94,986	22.9	0	0	0
24	86,544	23.1	136	0	0
25	77,104	23.5	6	0	0
26	74,531	23.9	11	0	0
27	53,405	23.9	21	0	0
Mean temperature		23.1			
Total area of the 27 sections	1,485,218				
Total area 1–3°C below mean temperature (percentage of total 27-kilometer reach)			13,792 (0.92)	1,272 (0.09)	36 (0.002)

shaded some of the exposed rocks on the east bank and made them appear much cooler than the surrounding rocks and water; this created two potential problems. First, the shade made the rocks appear as though they were providing a thermal (wet) refuge, which disappeared once the shade was gone and the rocks warmed. Second, it biased or lowered all estimates of mean and median temperatures for the affected 1-km sections. This situation made delineations of actual refuges (which are defined relative to water temperature within the section) less accurate. To minimize this problem, each 1-km river section was divided in half along the thalweg, and then temperature data only for the half-section with the lesser amount of unshaded bank (that had been shaded in the morning) was summarized. This analysis produced results similar to those from the analysis of whole 1-km sections for the second and third flights but very different from the initial results for the first flight. During the first flight, only 0.7 percent (5,092 m^2) of unshaded water surface was 1 to 3ºC cooler than the median (table 13), whereas 4.1 percent of surface water reached those temperatures in the whole-river analysis (table 12). These contrasting results indicate that much of the area characterized initially as refuge in shaded half-sections may have actually been exposed rocks. During the second and third flights, the percentages of potential refuges based on either half or whole sections were comparable. Most river sections included little refuge area during the midday flight. During the afternoon flight, the lower half of the river provided little potential thermal refuge; the decrease in available refuge area became measureable 5 km upstream from the high-water bubble and continued through the end of the reach (table 13).

Five tributaries entering the river had localized cooling effects on river-water temperatures; all of these tributaries are in the lower third of the study reach at or below the confluence of the Hudson River and the Boreas River (fig. 15). The effects of cold-water tributaries on river temperatures are denoted by hand-drawn areas in figure 16. Cold tributary waters fill 15 to 25 percent of the hand-delineated area at low flow within each of these areas and provide most of the near-bank and off-channel thermal refuges in the study reach. The Boreas River at kilometer 19 and Deer Creek at kilometer 27 enter the Hudson River on its east bank (fig. 15); therefore, these tributaries appeared to provide more refuge for trout during the morning flight (table 14), probably because of spurious shading. The other three tributaries (Raquette Brook at kilometer 24, Aldous Brook at kilometer 25, and Thirteenth Lake Outlet at kilometer 26) enter the Hudson River on its west bank and provided more potential thermal refuge during the midday flight than during the morning flight (table 14). The Boreas tributary was warmer than the Hudson River at their confluence during the afternoon flights; the other four tributaries were cooler than the Hudson River at their confluence during the afternoon flights, but their effect on Hudson River temperatures was negligible (table 14, fig. 16).

River Habitat

River habitat was characterized by surveys of GCUs under base flow throughout the lower Indian River and at the four study reaches in the Hudson River. The effects of the releases on habitat were quantified by changes in the distribution of GCUs during high flows at seven sampled reaches in both rivers (fig. 2). Data from sampled reaches were compared to data from the same areas at base flow, even though the total lengths mapped at base flow and at high flow differed because GCUs did not always start and end in the same location under different flow regimes (for example, at HR02 and HR03). Runs and rapids were the dominant or sole GCUs at high (release) flows; however, although runs and riffles dominated the upstream portion of the Indian River during base flow, only riffles dominated the downstream portion (table 15). GCU composition of the Indian River during base flow changed at the river's confluence with the Hudson River. Riffles were still common, but glides and other fast-water GCUs (riffle, run, or rapids) dominated habitat during base flow at all four reaches of the Hudson River. Except for the Hudson River Gorge, most reaches of the Hudson River were wider and less steep than those in the Indian River, which probably allowed more slow-water habitat (glides) to dominate. Runs and rapids were the dominant GCUs along the Hudson River at high flows; glides were also a dominant GCU at the farthest downstream site (HR05).

Slow-water habitats (pool, glide, backwater, side channel) decreased from 31 percent during base flow to 7 percent during high (release) flow in the Indian River, from 45 percent during base flow to 21 percent during high flow in the Hudson River, and from 41 percent during base flow to 16 percent during high flow overall. Fast-water habitats (riffle, run, rapids) increased from 69 percent during base flow to 93 percent during release flow in the Indian River, from 55 percent during base flow to 79 percent during high flow in the Hudson River, and from 59 percent during base flow to 84 percent during high flow overall. Fewer GCUs were present during high flows than during base flows in all study reaches (table 15). Except for HR02 and HR03, where habitat surveys were shortened during high flows, total habitat areas of all study reaches were generally similar during base flow and high flow because both areas were mapped onto the same aerial photograph. Since the photograph was taken at low flow, it did not account for changes in stream width associated with high flow.

Distribution of Wetlands

Wetlands accounted for approximately 18 percent of the area along river banks in the Indian River, 25 percent near study reaches in the upper Cedar River, and 46 percent in the lower Cedar River (fig. 3, table 16). The average widths of

Table 13. Median temperature and refuge areas 1, 2, and 3°C below the median temperature for unshaded halves of each 1-kilometer section divided along the thalweg along the 27-kilometer reach of the Indian and Hudson Rivers from the outflow point of the Abanakee Dam to North Creek, Adirondack Mountains, New York.

[Halves are for the downstream view of each section. Sections under the high-water bubble are highlighted. Flight 1 aloft from 10:12 to 10:55 EST; flight 2 aloft from 12:39 to 13:13 EST; flight 3 aloft from 15:42 to 16:05 EST. Locations of study sites are shown in figure 1; unit conversions are shown in the conversion tables at the front of the report. Site codes are listed in table 1. ºC, degrees Celsius]

Flight 1						
Section (kilometers from outflow point)	Half	Total area (square meters)	Median temperature (°C)	Refuge area below median temperature (square meters)		
				1ºC	2ºC	3ºC
1	L	11,934	20.8	248	14	0
2	L	9,887	20	131	0	0
3	L	23,667	20.2	244	10	0
4	L	13,792	20.7	463	44	0
5	L	28,529	20.6	14	0	0
6	L	32,569	20.1	1	0	0
7	L	28,712	19.8	119	0	0
8	L	30,894	19.7	486	0	0
9	L	31,442	20	120	0	0
10	R	21,119	19.7	33	0	0
11	L	22,862	19.5	438	18	0
12	L	27,184	19.5	354	49	0
13	L	26,171	19.8	0	0	0
14	L	26,240	19.7	19	0	0
15	L	30,665	19.7	7	0	0
16	L	3,639	20.2	0	0	0
17	L	29,646	20.2	57	0	0
18	L	31,845	20	0	0	0
19	L	37,823	19.9	1,408	323	0
20	R	41,926	19.9	47	0	0
21	R	28,239	20	412	73	0
22	R	38,289	20	216	0	0
23	R	45,181	19.6	0	0	0
24	R	36,945	19.4	0	0	0
25	R	37,112	17.7	1	0	0
26	R	34,561	19.4	274	26	0
27	R	27,838	19.2	0	0	0
Mean temperature			19.9			
Total area of the 27 sections		758,711				
Total area 1–3°C below mean temperature (percentage of total 27-kilometer reach)				5,092 (0.7)	557 (0.1)	0 (0)

Table 13. Median temperature and refuge areas 1, 2, and 3°C below the median temperature for unshaded halves of each 1-kilometer section divided along the thalweg along the 27-kilometer reach of the Indian and Hudson Rivers from the outflow point of the Abanakee Dam to North Creek, Adirondack Mountains, New York.—Continued

[Halves are for the downstream view of each section. Sections under the high-water bubble are highlighted. Flight 1 aloft from 10:12 to 10:55 EST; flight 2 aloft from 12:39 to 13:13 EST; flight 3 aloft from 15:42 to 16:05 EST. Locations of study sites are shown in figure 1; unit conversions are shown in the conversion tables at the front of the report. Site codes are listed in table 1. ºC, degrees Celsius]

Flight 2					
Section (kilometers from outflow point)	Total area (square meters)	Median temperature (°C)	Refuge area below median temperature (square meters)		
			1ºC	2ºC	3ºC
1	12,244	22.3	20	0	0
2	10,143	22.1	2	0	0
3	23,947	21.9	4	0	0
4	13,971	22.1	2	0	0
5	28,649	21.9	0	0	0
6	32,567	22	1	0	0
7	28,785	21.8	0	0	0
8	31,025	21.9	6	0	0
9	31,414	21.7	3	0	0
10	21,556	21.4	0	0	0
11	22,833	21	0	0	0
12	27,170	20.9	1	0	0
13	26,149	21.2	0	0	0
14	16,614	21.3	364	0	0
15	30,755	21.3	2	0	0
16	3,676	21.5	0	0	0
17	29,613	22.2	1,949	0	0
18	31,772	21.8	6	0	0
19	37,778	21.9	301	0	0
20	42,312	22	7	0	0
21	28,590	22.1	8	0	0
22	38,624	22.2	52	0	0
23	45,660	22.3	1	0	0
24	37,407	22	10	0	0
25	37,590	22.1	0	0	0
26	34,898	22.4	173	66	0
27	28,087	22.2	1	0	0
Mean temperature		21.9			
Total area of the 27 sections	753,829				
Total area 1–3°C below mean temperature (percentage of total 27-kilometer reach)			2,913 (0.4)	66 (0)	0 (0)

Table 13. Median temperature and refuge areas 1, 2, and 3°C below the median temperature for unshaded halves of each 1-kilometer section divided along the thalweg along the 27-kilometer reach of the Indian and Hudson Rivers from the outflow point of the Abanakee Dam to North Creek, Adirondack Mountains, New York.—Continued

[Halves are for the downstream view of each section. Sections under the high-water bubble are highlighted. Flight 1 aloft from 10:12 to 10:55 EST; flight 2 aloft from 12:39 to 13:13 EST; flight 3 aloft from 15:42 to 16:05 EST. Locations of study sites are shown in figure 1; unit conversions are shown in the conversion tables at the front of the report. Site codes are listed in table 1. ºC, degrees Celsius]

Flight 3					
Section (kilometers from outflow point)	Total area (square meters)	Median temperature (°C)	Refuge area below median temperature (square meters)		
			1ºC	2ºC	3ºC
1	9,276	23.2	854	320	23
2	10,143	23.2	598	2	0
3	23,795	23.5	2,145	137	3
4	13,971	24.1	2,053	105	0
5	28,649	24	83	0	0
6	32,567	24.1	82	2	0
7	28,785	23.4	71	0	0
8	26,141	23.1	903	49	5
9	31,414	23.2	157	16	0
10	21,556	22.8	91	0	0
11	22,833	23.1	1	0	0
12	27,170	22.9	0	0	0
13	26,149	23.2	0	0	0
14	26,644	23.1	0	0	0
15	30,755	22.4	72	0	0
16	3,676	22.4	0	0	0
17	29,629	22.4	0	0	0
18	31,772	22.1	0	0	0
19	37,778	22.2	4	0	0
20	42,312	22.2	0	0	0
21	28,590	22.3	0	0	0
22	38,624	22.6	0	0	0
23	45,540	22.9	0	0	0
24	37,333	23.2	0	0	0
25	37,590	23.5	0	0	0
26	34,898	23.9	0	0	0
27	28,087	24	20	0	0
Mean temperature		23.1			
Total area of the 27 sections	755,677				
Total area 1–3°C below mean temperature (percentage of total 27-kilometer reach)			7,134 (0.9)	631 (0.1)	31 (0)

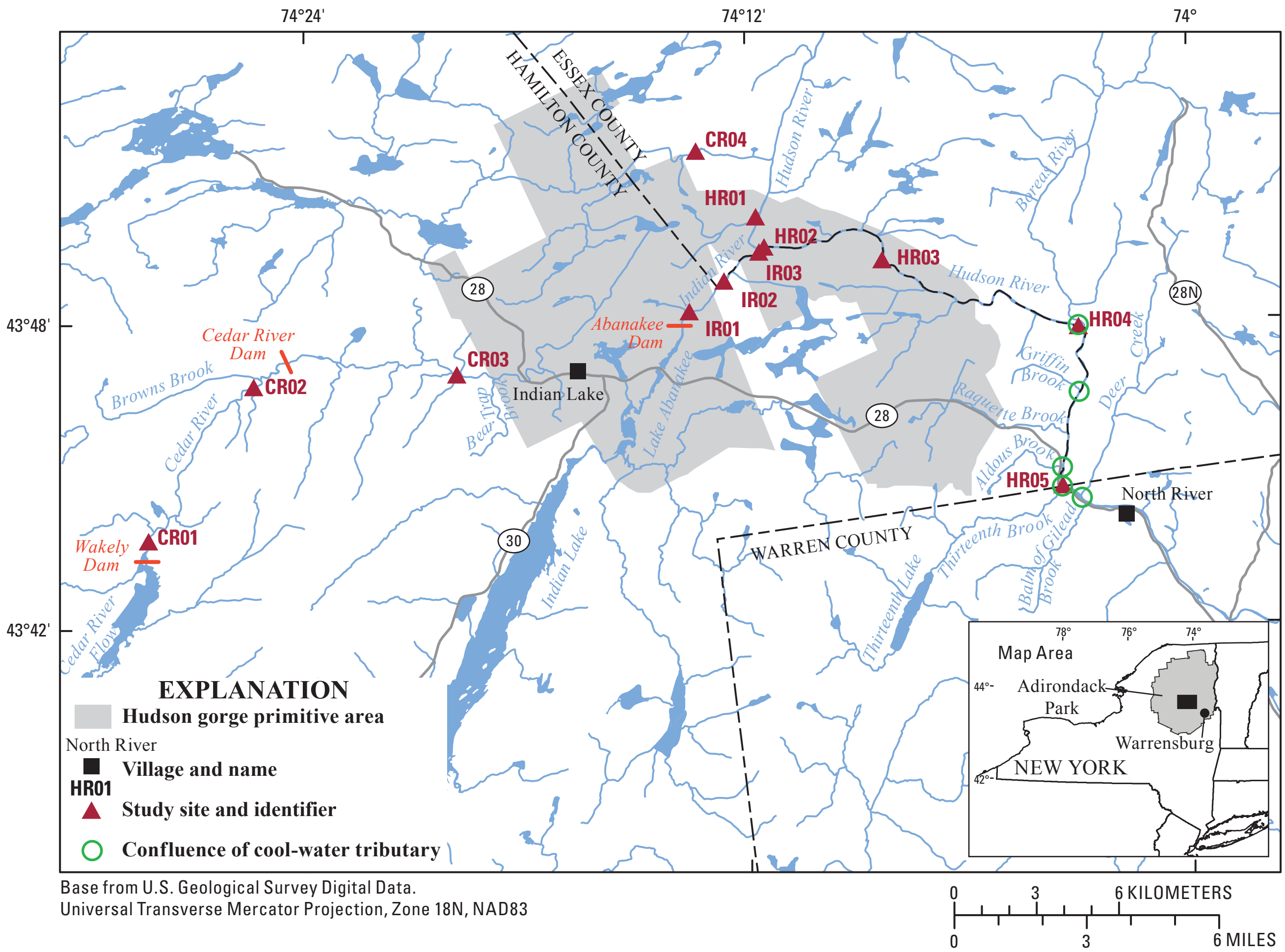

Figure 15. Map showing fFive tributaries entering the bottom third of the study reach at or below the confluence of the Hudson River with the Boreas River, Adirondack Mountains, New York. Study-site codes are listed in table 1.

wetlands were similar along both the Indian River and lower Cedar River. Wetland widths could not be measured in the upper Cedar River because access was restricted.

Fish Communities

Fish surveys were conducted at least once at four control sites in the Cedar River, three affected sites in the Indian River, one control site in the Hudson River, and three affected sites in the Hudson River during 2005 and 2006. Fish-community indexes and the density and biomass of individual fish populations were evaluated to test hypotheses that fish communities at the three Indian River sites (IR01, IR02, and IR03) were negatively affected by the releases, and fish communities at the three downstream sites on the Hudson River (H02, H04, and H05) were negatively affected by the releases. Because the Cedar River contains a run-of-the-river impoundment (Wakely Dam), comparison of fish indexes for Cedar River sites with those for Indian River sites was expected to illustrate the relative effects of frequent releases on biota in the Indian River. Comparison of community indexes for the three downstream Hudson River sites (HR02, HR04, and HR05) with indexes for the upstream control site (HR01) and with each other allows identification of the significant effects, possibly diminishing downstream, associated with releases. If releases are assumed to have only nominal effects on fish communities in the Hudson River, then comparison of community indexes from Hudson River and Indian River sites would be expected to reveal the combined effects of the impoundment and releases on fish communities at the three Indian River sites.

Community Indexes—The effects of releases on total density and biomass of fish communities differed among sites in the Indian River and the Hudson River, as expected. Total community density and biomass at the Indian River site immediately downstream from the dam (IR01) were on

Table 14. Median temperature and refuge areas .5, 1, 1.5, and 2°C below the median temperature for each 1-kilometer section along the 27-kilometer reach of the Indian and Hudson Rivers from the outflow point of the Abanakee Dam to North Creek, Adirondack Mountains, New York, 2005.

[Flight 1 aloft from 10:12 to 10:55 EST; Flight 2 aloft from 12:39 to 13:13 EST; Flight 3 aloft from 15:42 to 16:05 EST. Sections under the high-water bubble are highlighted Locations of study sites are shown in figure 1; unit conversions are shown in the conversion tables at the front of the report. Site codes are listed in table 1°C, degrees Celsius]

Section (kilometer from outflow point)	Tributary	Total area (square meters)	Median temperature (°C)	Refuge area below median temperature (square meters)			
				0.5°C	1.0°C	1.5°C	2.0°C
			Flight 1				
19	Boreas River	6,026	19.6	1,901	1,347	582	90
24	Raquette Brook	1,911	19.5	75	2	0	0
25	Aldous Brook	1,351	19.9	22	9	0	0
26	Thirteenth Lake Outlet	5,397	19.4	578	402	252	63
27	Deer Creek	2,590	18.8	554	362	139	14
			Flight 2				
19	Boreas River	6,026	21.9	977	296	11	0
24	Raquette Brook	1,911	22.3	256	93	22	8
25	Aldous Brook	1,351	22.3	977	296	11	0
26	Thirteenth Lake Outlet	5,397	22.4	707	281	212	136
27	Deer Creek	2,590	22.1	348	205	74	16
			Flight 3—passage of bubble				
19	Boreas River	6,026	22.4	9	0	0	0
24	Raquette Brook	1,911	23.4	84	47	15	0
25	Aldous Brook	1,351	23.5	35	0	0	0
26	Thirteenth Lake Outlet	5,397	24	13	0	0	0
27	Deer Creek	2,590	23.8	1	0	0	0

average between 10 and 45 percent of density and biomass estimates for other sites on the Indian River (table 17), and they were significantly lower than estimates for all other sites except HR04 in the three rivers (fig. 17). The differences between estimates of density and biomass at the next two downstream sites on the Indian River (IR02 and IR03) and at the two downstream sites on the Cedar River (CR03 and CR04, downstream from Wakely Dam) were generally minor. Density and biomass at IR02 and IR03, however, were similar to or somewhat higher than at most sites on the Hudson River. They were also similar to density and biomass estimates for most Cedar River sites, excluding CR02 (fig. 17). Except for IR01, community density and biomass at Indian River sites were comparable to the same indexes for most Cedar River and Hudson River sites. Total community density and biomass at the Hudson River sites downstream from its confluence with the Indian River (HR02, HR04, and HR05) were neither consistently lower nor higher than the same indexes at the control site (HR01) (table 17, fig. 17). Elevated (storm) flows during fish surveys may have affected sampling efficiencies at HR04, but the releases did not adversely affect total community biomass and density at most Hudson River sites. The significant difference between estimates of biomass and density at IR01 and at CR01 and the decrease in estimates of biomass and density at HR02 indicate that the releases slightly affected fish communities at IR01 and HR02. Many other physical, chemical, and biological factors would need to be quantified, however, to determine whether observed differences were caused solely by releases or by some combination of releases and related factors.

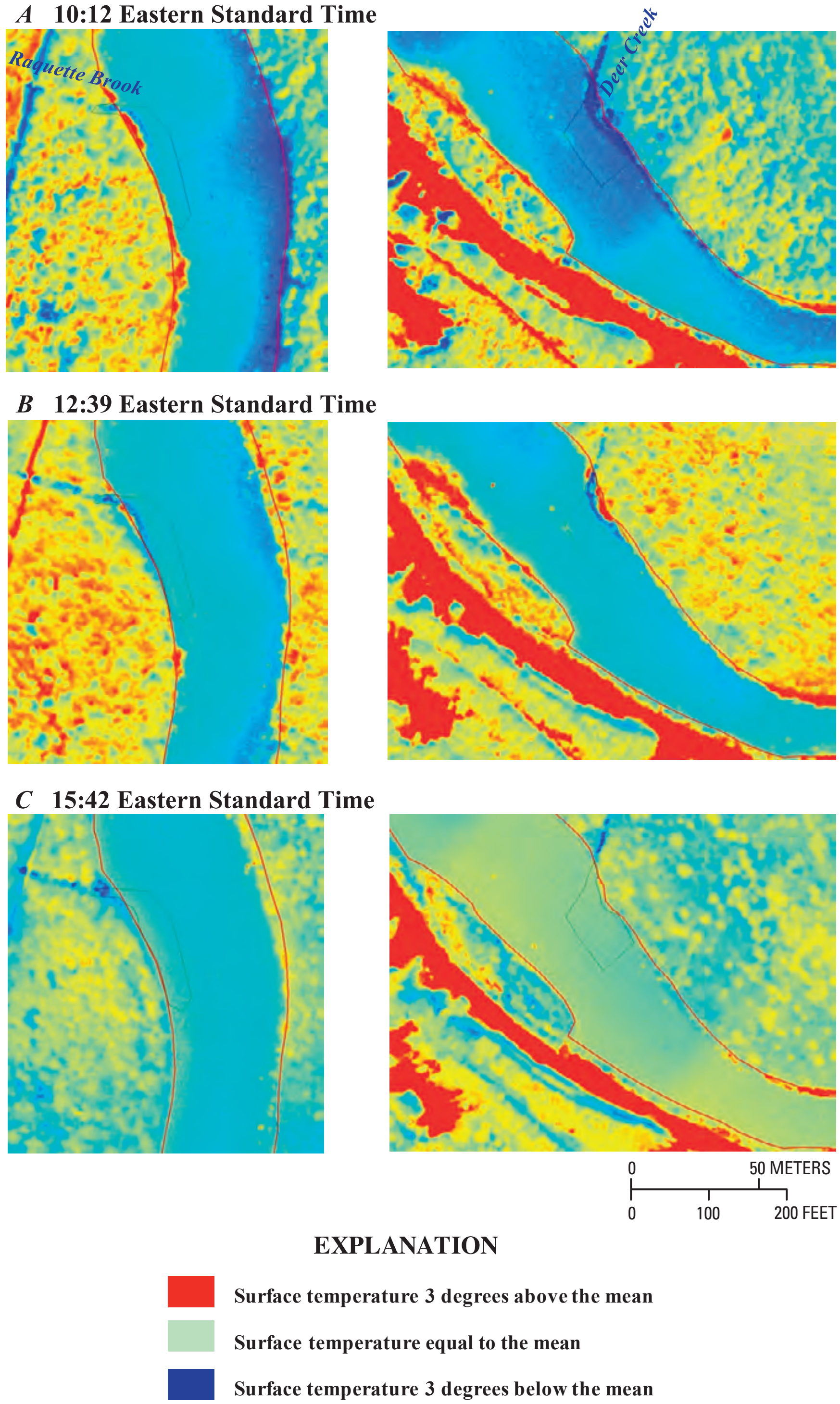

Figure 16. False-color images of the confluences of Raquette Brook at kilometer 24 and Deer Creek at kilometer 27 with the Hudson River during flights at *A*,10:12, *B*, 12:39, and *C*, 15:42 Eastern Standard Time in the Adirondack Mountains, New York. The release slug passed these tributaries during the third flight, reducing any cold-water effect.

Table 15. Areal percentage of seven types of geomorphic channel units (GCUs) in the Indian River, Adirondack Mountains, New York, at base and high flow on August 4, 17, and 18, 2005, and the total area and number of GCUs mapped.

[Locations of study sites are shown in figure 1; unit conversions are shown in the conversion tables at the front of the report. Site codes are listed in table 1.]

GCU type	Base flow	High flow
IR01		
Percentage of GCU area mapped		
Rapid	9.5	28.7
Riffle	21.5	1.3
Run	36.2	56.6
Glide	5.7	0
Pool	13.7	0
Backwater	6.1	6.7
Side channel	7.3	6.7
Number of GCUs		
	24	17
Total area, in square meters		
	42,262	42,198
IR03		
Percentage of GCU area mapped		
Rapid	5.6	32.8
Riffle	62.4	0
Run	2.2	67.2
Glide	14.5	0
Pool	0	0
Backwater	15.3	0
Side channel	0	0
Number of GCUs		
	10	6
Total area, in square meters		
	40,271	34,820

Table 15. Areal percentage of seven types of geomorphic channel units (GCUs) in the Indian River, Adirondack Mountains, New York, at base and high flow on August 4, 17, and 18, 2005, and the total area and number of GCUs mapped.—Continued

[Locations of study sites are shown in figure 1; unit conversions are shown in the conversion tables at the front of the report. Site codes are listed in table 1.]

GCU type	Base flow	High flow
HR02		
Percentage of GCU area mapped		
Rapid	3.9	0
Riffle	35.0	0
Run	9.4	94.7
Glide	47.5	0
Pool	0	0
Backwater	4.3	5.3
Side channel	0	0
Number of GCUs		
	14	5
Total area, in square meters		
	69,230	25,039
HR03		
Percentage of GCU area mapped		
Rapid	48.4	46.3
Riffle	0	0
Run	7.7	28.6
Glide	29.6	0
Pool	14.3	25.0
Backwater	0	0
Side channel	0	0
Number of GCUs		
	6	5
Total area, in square meters		
	64,512	35,435

Table 15. Areal percentage of seven types of geomorphic channel units (GCUs) in the Indian River, Adirondack Mountains, New York, at base and high flow on August 4, 17, and 18, 2005, and the total area and number of GCUs mapped.—Continued

[Locations of study sites are shown in figure 1; unit conversions are shown in the conversion tables at the front of the report. Site codes are listed in table 1.]

GCU type	Base flow	High flow
HR04		
Percentage of GCU area mapped		
Rapid	0	23.4
Riffle	41.3	25.4
Run	15.0	33.5
Glide	27.9	17.6
Pool	14.8	0
Backwater	1.0	0
Side channel	0	0
Number of GCUs		
	12	6
Total area, in square meters		
	81,488	93,146
HR05		
Percentage of GCU area mapped		
Rapid	11.4	8.7
Riffle	8.2	20.4
Run	38.3	35.3
Glide	37.2	32.9
Pool	0	0
Backwater	2.9	0.4
Side channel	2.0	2.3
Number of GCUs		
	12	8
Total area, in square meters		
	143,473	152,441

Though statistical analyses were not feasible with other standard indexes of community health (for example, richness, diversity, equitability, and dominance) at individual sites, several differences were apparent among sites in both affected rivers (and in the Cedar River) or when data from each site were pooled by river. Community richness (number of fish species) was consistently one to seven species lower at all Indian River sites than at all other study sites (table 17, fig. 18) and three to six species lower than at the two downstream sites on the Cedar River. Richness at HR01 was similar to that at HR02 and at HR04 but was four species lower than at HR05. Overall, mean richness at the three Indian River sites was significantly lower ($p < 0.05$) than at the four Hudson River sites or at the four Cedar River sites. Owing to high variability in most other indexes among study sites, no other indexes differed significantly among the three river systems. Species diversity and equitability values for IR01, IR02, and IR03 varied slightly, but on average they were similar to the same indexes at CR01, CR02, CR03, and CR04. Estimates of species diversity and equitability at CR03 and CR04 averaged almost twice as high as the same indexes at IR02 and IR03. These results indicate that fish communities at the Indian River sites functioned differently, and that their structure was less balanced than at communities at the Cedar River control sites. Community equitability was low and dominance was high immediately downstream from the Wakely Dam (CR01); both indexes also appeared to be affected at CR02 (compared to CR03 and CR04). No large predator species were present, and one or two minnow species dominated communities at CR01and CR02. Species richness, diversity, and equitability were generally higher, and dominance was lower, at the three Hudson River sites downstream from the confluence with the Indian River (HR02, HR04, and HR05) than at HR01, indicating that the function of fish communities at affected Hudson River sites was slightly different from, but more balanced than, the community at the control site (HR01).

Opposing downstream trends at affected sites in the Hudson and Indian Rivers indicate that either normal variability in fish indexes is high (and real effects cannot be quantified) or that there are negative effects when relative changes in flow are large and positive effects when relative changes in flow are small or moderate. The intermediate-disturbance theory may account for different community responses; it indicates that the most diverse communities develop in areas with intermediate levels of disturbance (Ward and Stanford, 1983; Death and Winterbourn, 1995; McCabe and Gotelli, 2000). Although reduced species richness, diversity, and equitability indicate that the integrity of fish communities at all Indian River sites may be adversely affected by releases, it is currently impossible to prove that other factors do not also contribute to observed differences among sites. Additional (replicated) fish-community data, hydrologic data, and more detailed habitat information would allow full characterization of site-to-site similarities and differences and a more complete assessment of the potential effects of the releases.

Table 16. Lengths and areas of wetlands along the Indian River and along surveyed sections of the upper and lower Cedar River, Adirondack Mountains, New York, 2005, and the percentages of river length bordered by wetlands.

[Length of wetlands includes banks and any islands having wetlands. Length of river includes length of islands, if any, (in parentheses); unit conversions are shown in the conversion tables at the front of the report. --, no data available]

River	Area of wetlands (square meters)	Length of wetlands (meters)	Percentage of river length bordered by wetlands	Length of river surveyed (kilometers)
Indian River	4,557	1,576	18	4.37
Upper Cedar River	--	219	25	0.62 (0.27)
Lower Cedar River	1,172	375	46	0.69 (0.13)

Table 17. Estimates of fish-community parameters for 11 study sites on the Indian, Hudson, and Cedar Rivers, Adirondack Mountains, New York, 2005 and 2006.

[Equitability was measured as Shannon-Weiner H′, dominance as Simpson's C, and diversity as the number of species divided by the number of individuals in the sample. Locations of study sites are shown in figure 1; unit conversions are shown in the conversion tables at the front of the report. Study-site codes are listed in table 1. m^2, square meters; ha, hectare; g, grams]

Study sites	Parameter						
	Sample area (square meter)	Richness (number of species)	Density (number of fish per 0.1 ha)	Biomass (g per 0.1 ha)	Diversity	Equitability	Dominance
CR01	305	6	1,382	1,542	2.34	0.35	0.58
CR02	432	7	2,265	3,489	2.35	0.51	0.38
CR03	468	8	276	1,758	3.82	0.71	0.25
CR04	427	10	234	1,264	5.08	0.83	0.20
IR01	803	5	24	560	3.91	0.66	0.24
IR02	237	5	241	1,594	2.85	0.54	0.34
IR03	252	4	159	1,244	2.50	0.48	0.40
HR01	352	7	233	1,159	3.68	0.51	0.47
HR02	311	6	112	770	3.89	0.61	0.30
HR04	197	7	168	226	4.61	0.67	0.27
HR05	378	11	872	1,282	4.38	0.76	0.21

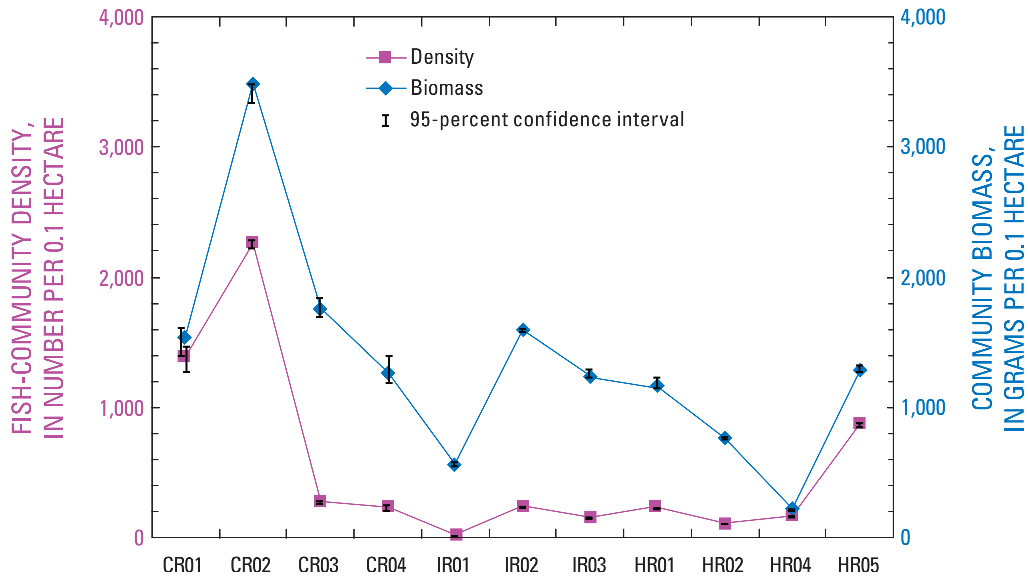

Figure 17. Graph showing eEstimates of density, biomass, and 95-percent confidence intervals for fish communities surveyed at 11 study sites on the Cedar, Indian, and Hudson Rivers, Adirondack Mountains, New York, 2005–06. Locations of study sites are shown in figure 1; study-site codes are listed in table 1.

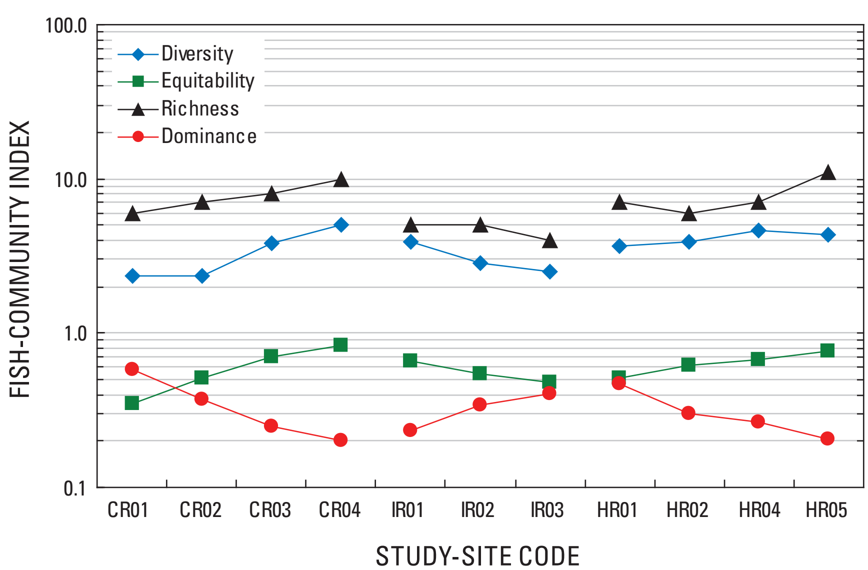

Figure 18. Graph showing dDiversity, equitability, richness, and dominance for fish communities at 11 study sites in the Cedar, Indian, and Hudson Rivers, Adirondack Mountains, New York, 2005–06. Locations of study sites are shown in figure 1; study-site codes are listed in table 1.

The general upward trend in several community indexes at Indian River sites (with increasing drainage area) tends to support the river-continuum concept (Montgomery, 1999; Power and others, 1999; Walters and others, 2003). Community richness, equitability, and diversity consistently increase, and dominance decreases, in the Cedar and the Hudson Rivers as fish communities acquire more species and become more diverse, complex, and balanced at downstream sites where drainage areas increase, and river reaches become more interconnected, warmer, larger, and generally more productive (Montgomery, 1999; Power and others, 1999; Walters and others, 2003; Robinson and Rand, 2005). Trends in these four indexes are clearly reversed between sites IR01 and IR03 in the Indian River (fig. 18). These unusual trends suggest either that site conditions may essentially be equivalent (for example, size and community health), so that the normal variability identifies false differences in indexes, or normal processes within and interactions among different levels of ecological organization (species assemblages) may have truly been disrupted. The similarity of the drainage areas of the three Indian River study sites (505 to 518 km^2) indicates that the first option is plausible. Additional evidence from the benthic macroinvertebrate communities may be useful in determining whether there is an alternative reason (other than the releases) for the trends noted in fish communities of the Indian River.

Density of Fish Populations—The density (and biomass) of individual species populations (table 18) show how fish communities and related indexes differ among sites and help qualify the effects of releases on fish communities. A few rock bass and rainbow trout and a small population of redbreast sunfish were most abundant and dominated the fish community at IR01. Dominant species differed at the Cedar River site immediately downstream from the unregulated Wakely Dam (CR01), where blacknose dace, common shiner, and white sucker were most abundant (table 18, fig. 19). Slimy sculpin, longnose dace, cutlips minnow, and smallmouth bass were most abundant and dominated communities at the other two Indian River sites (IR02 and IR03). Fallfish and many of the same species found at IR02 and IR03 dominated the fish community at HR02. The overall effect of the releases on fish communities in the Indian River appears to be caused by an actual loss of fish species rather than by species replacements or by small decreases in the numbers of endemic species. For example, 15 or 16 species, including blacknose dace, common shiner, creek chub, bluntnose minnow, central mudminnow, margined madtom, and white sucker were collected at Cedar River sites, whereas none of these species were found in the Indian River (table 18). Slimy sculpin also were present in the Indian River but not at any Cedar River site. Fish communities at the two upstream Cedar River sites (CR01 and CR02) were different from those at the downstream Cedar River sites (CR03 and CR04), possibly because no large piscivorous species (predators such as largemouth or smallmouth bass) were observed at the two upstream sites. The two upstream sites were situated between the Cedar River Dam and the Wakely Dam (fig. 1), which may have blocked both bass species from the intervening reach of the Cedar River. Populations of brook trout and brown trout have also been observed in the same river section, but their densities are low, and they appear to concentrate at river margins and in cooler tributaries during the warmer months.

The effects of the releases on fish communities of the Hudson River were less obvious than or contrary to the effects of releases observed in the Indian River. As with the Indian River sites, we did not collect common shiner and creek chub at the first potentially affected site on the Hudson River (HR02) or at the control site (HR01); however, both species were collected from sites farther downstream (table 18). Although four species (central mudminnow, stonecat, redbreast sunfish, and rock bass) were unique to the control site, eight more species (common shiner, creek chub, longnose dace, slimy sculpin, margined madtom, largemouth bass, brown trout, and rainbow trout) were observed at potentially affected sites but not at the control site (HR01) (table 18, fig. 19). Trout were collected only from sites where NYSDEC stocked 1- or 2-year-old trout (HR05 and IR01). In general, the releases appear to cause small changes in the densities of some fish species at several Hudson River sites, replacement of a few species at HR02 and HR04 (rather than potential loss of species as noted in the Indian River), and little or no adverse effect on fish populations at HR05. The overall effects of the releases on densities of fish communities in the Hudson River appeared to be nominal. Any effect of the releases on communities at HR05, however, would appear to be positive because community density, as well as biomass, richness, diversity, and equitability, were as high, or higher than, levels found at all other study sites in the Hudson River.

Biomass of Fish Populations—Biomass may be a better gage (of the effects of releases on fish communities) than density because biomass tends to fluctuate less widely than density (it is more conservative) when fish react to biotic, habitat, and water-quality stresses (Baldigo and Lawrence, 2001). Biomass data for species populations in this study were, in fact, much less variable among sites (total biomass varied 16-fold) than density (total density varied 103-fold) (tables 18, 19). Although biomass of rock bass, redbreast sunfish, and rainbow trout dominated the fish community at IR01 (like density), total biomass was about one-third of that estimated at CR01, where blacknose dace dominated the community (table 19, fig. 20). The biomass of slimy sculpin, cutlips minnow, rock bass, and smallmouth bass dominated fish communities at the other two Indian River sites (IR02 and IR03); except for sculpin, the same species dominated communities at the two upstream Hudson River sites (HR01 and HR02). The total biomass of fish communities at CR02 consisted mostly of blacknose dace and common shiner and was more than twice as large as the total biomass at CR01 (table 19, fig. 20). The biomass of cutlips minnows and either margined madtom or rock bass dominated the fish communities at both downstream Cedar River sites (CR03 and CR04) (fig. 20). The biomass of cutlips minnow, longnose

Table 18. Estimates of density for each fish species collected at each of 11 study sites on the Indian, Hudson, and Cedar Rivers, Adirondack Mountains, New York, 2005–2006.

[Densities measured in number of fish per 0.1 hectare. Locations of study sites are shown in figure 1; unit conversions are shown in the conversion tables at the front of the report. Study-site codes are listed in table 1.]

Common name	Study sites										
	CR01	CR02	CR03	CR04	IR01	IR02	IR03	HR01	HR02	HR04	HR05
Creek chub	7	167	9	5	0	0	0	0	0	20	0
Common shiner	233	914	47	112	0	0	0	0	0	0	238
Stonecat	0	0	0	0	0	0	0	6	0	0	0
Bluntnose minnow	0	37	0	21	0	0	0	0	0	0	0
Central mudminnow	0	0	0	7	0	0	0	14	0	0	0
Fallfish	0	0	0	0	0	0	0	150	48	71	206
Redbreast sunfish	0	0	0	9	6	0	0	3	0	0	0
White sucker	108	32	0	0	0	0	0	0	0	0	8
Cutlips minnow	0	0	58	87	0	110	20	14	6	25	190
Margined madtom	0	0	111	5	0	0	0	0	10	5	21
Brown bullhead	3	0	0	0	0	0	0	0	0	0	0
Brown trout	0	0	0	0	0	0	0	0	0	0	3
Rainbow trout	0	0	0	0	2	0	0	0	0	0	3
Northern redbelly dace	0	2	0	0	0	0	0	0	0	0	0
Blacknose dace	1,034	1,027	17	0	0	0	0	0	0	0	0
Longnose dace	0	79	19	16	0	84	91	0	10	5	137
Largemouth bass	0	0	0	0	7	0	0	0	3	0	0
Smallmouth bass	0	0	6	9	2	21	36	31	35	36	13
Rock bass	0	0	4	28	5	13	0	9	0	0	0
Slimy sculpin	0	0	0	0	0	13	12	0	0	0	11
Other minnows	3	0	0	0	0	0	0	0	0	5	42
Total	1,388	2,258	271	299	22	241	159	227	112	167	872

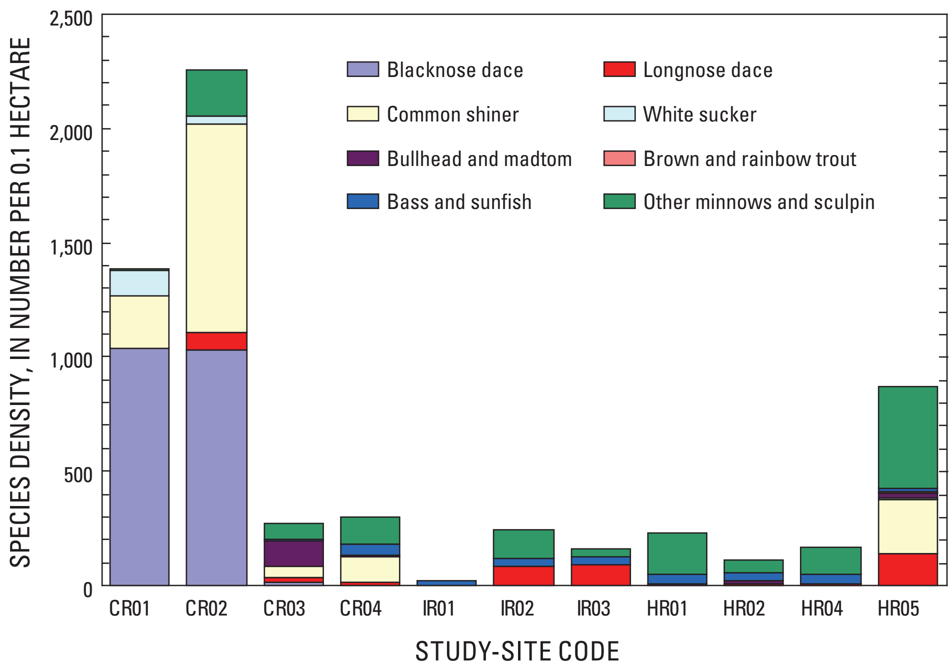

Figure 19. Graph showing dDensity (number of fish per 0.1 hectare) of each fish group or species at 11 study sites on the Indian, Hudson, and Cedar Rivers, Adirondack Mountains, New York, 2005–06. Locations of study sites are shown in figure 1; study-site codes are listed in table 1.

dace, smallmouth bass, and rock bass populations at CR04, IR02, IR03, and possibly at HR01 were relatively well balanced and generally alike, but the species (and biomass of each) differed from those at sites farther upstream in the Cedar River (table 19, fig. 20). The biomass of cutlips minnow, rock bass, smallmouth bass, or some combination of these three species dominated the total community biomass at CR04, IR02, IR03, and HR01. Differences between species and biomass at Indian River sites IR02 and IR03 and at Cedar River sites CR01 and CR02 could be related to the absence of predator species at the upstream Cedar River sites (as discussed earlier) or to the divergence in environmental conditions at the lower Indian River sites. Sites IR02 and IR03 have drainage areas of 513 to 518 km^2, and Cedar River sites have drainage areas that decrease from 425 km^2 at CR04 to 213 km^2 at CR03 to 149 km^2 at CR02 and to 117 km^2 at CR01. The biomasses of rainbow trout populations at IR01 and HR05 were relatively high (table 19, fig. 20) but much lower than would be expected shortly after springtime stocking. These findings suggest that, although community structure (species richness and densities of some species populations) was strongly affected at all three Indian River sites, community function (total biomass, and the biomasses and densities of dominant species populations) was severely affected by releases at only the first site downstream from Lake Abanakee (IR01).

The biomasses of species populations at most Hudson River study sites show no consistent trends that could be attributed to flow releases. Three to six species, including common shiner, cutlips minnow, fallfish, white sucker, smallmouth bass, and trout dominated the biomasses of communities at potentially affected Hudson River sites (HR02 through HR05), and the biomasses of cutlips minnow, central mudminnow, smallmouth bass, and rock bass dominated at the control site HR01 (table 19, fig. 20). The biomasses of fish communities at sites HR01 and HR02 were not well balanced but were well balanced among several species at HR04 and HR05 (table 19, fig. 20). The overall effects of releases on the biomasses, like the densities, of fish communities in the Hudson River, include the additions of a few species, small or no decreases in total biomass, and a general increase in the balance of species as community equitability increases at sites farther downstream (table 17).

Macroinvertebrate Assemblages

Although macroinvertebrate data were summarized for surveys done in 2005 and 2006, only the results from 2006 were interpreted because differences between data collected at the same sites in 2005 and 2006 were generally minor, and because the survey in 2006 included three additional sites in the Cedar River that were not sampled in 2005. Data

Table 19. Estimates of biomass for each fish species collected at each of 11 study sites on the Indian, Hudson, and Cedar Rivers, Adirondack Mountains, New York, 2005–06.

[Biomass measured in grams per 0.1 hectare. Locations of study sites are shown in figure 1. Unit conversions are shown in the conversion tables at the front of the report. Study-site codes are listed in table 1.]

Common name	Study sites										
	CR01	CR02	CR03	CR04	IR01	IR02	IR03	HR01	HR02	HR04	HR05
Creek chub	5	384	64	11	0	0	0	0	0	10	0
Common shiner	145	1,444	79	56	0	0	0	0	0	0	152
Stonecat	0	0	0	0	0	0	0	80	0	0	0
Bluntnose minnow	0	67	0	14	0	0	0	0	0	0	0
Central mudminnow	0	0	0	5	0	0	0	114	0	0	0
Fallfish	0	0	0	0	0	0	0	20	24	140	104
Redbreast sunfish	0	0	0	77	83	0	0	31	0	0	0
White sucker	48	17	0	0	0	0	0	0	0	0	129
Cutlips minnow	0	0	381	429	0	788	65	138	43	23	378
Margined madtom	0	0	1,037	2	0	0	0	0	80	3	11
Brown bullhead	3	0	0	0	0	0	0	0	0	0	0
Brown trout	0	0	0	0	0	0	0	0	0	0	106
Rainbow trout	0	0	0	0	330	0	0	0	0	0	304
Northern redbelly dace	0	1	0	0	0	0	0	0	0	0	0
Blacknose dace	1,337	1,363	26	0	0	0	0	0	0	0	0
Longnose dace	0	212	74	133	0	68	46	0	5	3	54
Largemouth bass	0	0	0	0	9	0	0	0	2	0	0
Smallmouth bass	0	0	3	126	5	165	1,033	612	615	46	20
Rock bass	0	0	94	410	132	448	0	165	0	0	0
Slimy sculpin	0	0	0	0	0	127	99	0	0	0	5
Other minows	3	0	0	0	0	0	0	0	0	3	20
Totals	1,541	3,488	1,758	1,263	559	1,596	1,243	1,160	769	228	1,283

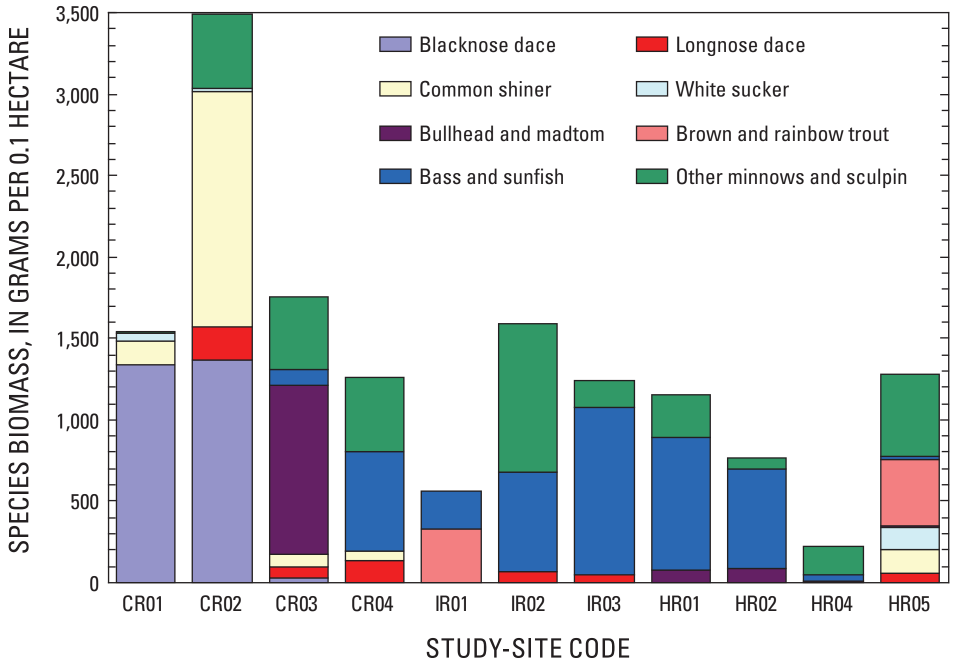

Figure 20. Graph showing bBiomass (grams per 0.1 hectare) of each fish or species at 11 study sites on the Cedar, Indian, and Hudson Rivers, Adirondack Mountains, New York, 2005–06. Locations of study sites are shown in figure 1; study-site codes are listed in table 1.

from 2006 on community indexes, functional feeding guilds, similarity of community assemblages, and dominant species were evaluated for 12 study sites in the Cedar, Indian, and Hudson Rivers to test hypotheses that the releases negatively affected macroinvertebrate communities at all Indian River sites and at the four downstream sites on the Hudson River. As in the fishery analyses, the four study sites in the Cedar River and HR01 in the Hudson River were used as controls. Because sites in the upper Cedar River were affected by a run-of-the-river impoundment, comparisons of macroinvertebrate indexes between Indian River and Cedar River sites illustrate the relative effects of the releases from Lake Abanakee on benthic macroinvertebrate communities in the Indian River. The comparison of community indexes at the four downstream Hudson River sites (HR02–HR05) to indexes at HR01 and among each other help define the significant and possibly diminishing downstream effects caused by both the impoundment and recreational releases. If the releases are assumed to have only nominal effects on macroinvertebrate communities in the Hudson River, then comparisons of community indexes from the Hudson River and the Indian River sites should illustrate the combined effects that the impoundment and the releases have on communities at all three Indian River sites.

Community Indexes—Summaries of mean indexes and the NYSBAP for macroinvertebrate communities surveyed in 2005 and 2006 at all study sites are listed in table 20. Community richness fell at or below the lower (slightly impacted) threshold of 26 species (Smith and Bode, 2004) only at CR01 and the three Indian River sites during 2005 and 2006, but low richness indicated slight effects at two additional Cedar River and three Hudson River sites sampled during 2006. The HBI upper threshold of 4.51 (Smith and Bode, 2004) was surpassed only at sites CR01 and IR01 during 2005 and 2006. Estimates of EPT richness were at or below the lower (slightly impacted) threshold of 10 species (Smith and Bode, 2004) at IR01 in 2005 and at all Indian River sites and at CR01 and CR04 in 2006. Estimates of PMA were below the lower (slightly impacted) threshold of 64 (Smith and Bode, 2004) at CR01, IR01, and IR02 in 2005 and remained so at these same sites and at CR04 and HR04 during 2006. Except for HBI, the metrics categorized IR01 and CR01 as moderately impacted (table 20). Because NYSBAP scores are derived from the four core metrics (above), the average scores at 12 sites indicate slight or no impacts (fig. 21). The NYSBAP scores below 7.5 indicate that macroinvertebrate communities were slightly impacted only at CR01 and IR01 during 2005, but all three Indian River sites and CR01 and CR04 were slightly impacted during 2006 (table 20, fig. 21).

To correctly assess the effects of the releases from Lake Abanakee on downstream macroinvertebrate communities, it is important to recognize that the assemblages at such sites exhibit certain patterns normally associated with upstream impoundments. Changes in water quality, food supplies, loads of nutrients and suspended sediment, and temperatures downstream from dams generally produce considerable shifts

Table 20. Mean estimates for macroinvertebrate community richness, Hilsenhoff's Biotic Index, Ephemeroptera-Plecoptera-Trichoptera (EPT) richness, Percent Model Affinity (PMA), and the New York State Bioassessment Profile (NYSBAP) for samples collected in riffles at 12 study sites in the Cedar, Indian, and Hudson Rivers, Adirondack Mountains, New York, 2005–06.

[HBI, Hilsenhoff's Biotic Index; EPT, Ephemeroptera-Plecoptera-Trichoptera; PMA, Percent Model Affinity; NYSBAP, New York State Bioassessment Profile. Locations of study sites are shown in figure 1; unit conversions are shown in the conversion tables at the front of the report. Study-site codes are listed in table 1.]

Study site	Richness (number of species)	HBI	EPT richness (number of species)	PMA (percent)	NYSBAP
			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

in species composition and resultant metrics (Bode and others, 2002). For this reason, the effects of releases on communities at Indian River sites need to be qualified and separated from general effects caused mainly by the impoundment. For instance, macroinvertebrate metrics at sites downstream from impoundments are typically corrected by shifting the impact-category cutoffs down by one category (Bode and others, 2002). For the systems used in this study, the NYSBAP threshold of 7.5 between slightly and nonimpacted sites would decrease to 5.0; thus, communities at all sites would be reclassified as nonimpacted. In addition, least-significant-difference (LSD) 95-percent confidence intervals for mean 2006 NYSBAP scores (fig. 21) and comparisons of homogeneous groups (table 21) indicate that communities at Indian River sites IR01, IR02, and IR03, and Cedar River sites CR01 and CR04 are relatively alike, but that they differ from communities at most Hudson River sites. Communities at these sites also differed from those at all Hudson River sites. The fact that mean NYSBAP scores at sites IR03, CR03, and HR04 in 2006 do not differ significantly from each other (table 21) may be related to a diminished impoundment effect at IR03 and a further diminished impoundment effect at CR03 and HR04. Both of these sites are situated downstream from long riverine pools, which in the case of CR04 resemble large bogs or marshes.

The lack of significantly different mean NYSBAP scores and other indexes between HR01 and the four other Hudson River sites downstream from its confluence with the Indian River during 2006 (table 21, fig. 21) and during 2005 (not shown) and the fact that all Hudson River sites were classified as nonimpacted during 2005 and 2006 (fig. 21) suggest that the releases and the impoundment had little or no negative effects on macroinvertebrate communities in the Hudson River. The fact that NYSBAP scores (and most other metrics) were not

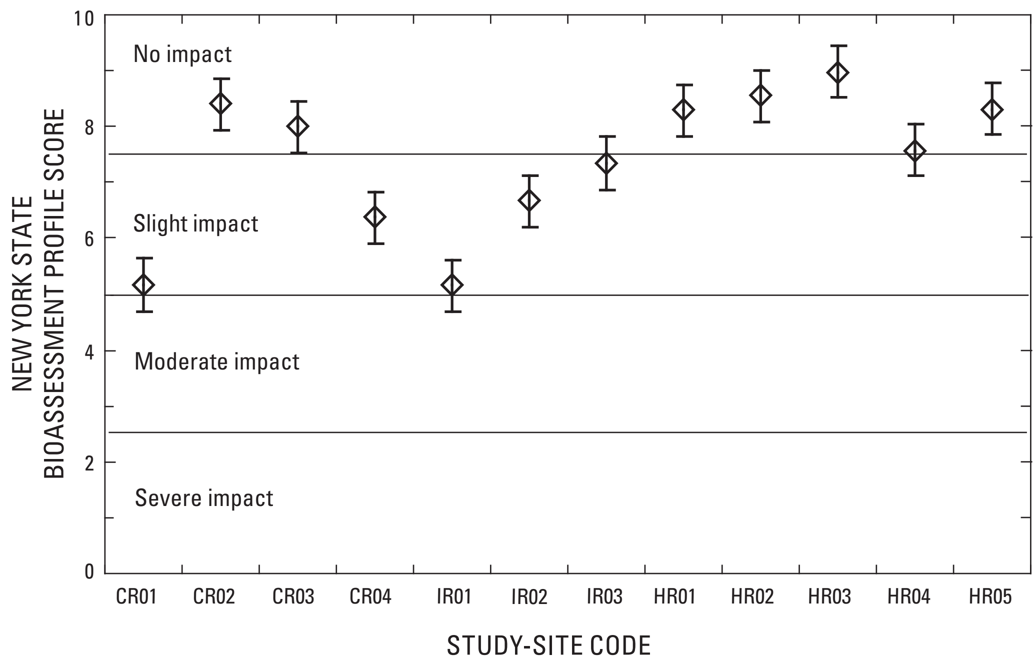

Figure 21. Graph showing Average New York State Bioassessment Profile scores and 95-percent confidence intervals for Fisher's least significant difference in relation to impact categories at 12 sites surveyed in the Cedar, Indian, and Hudson Rivers, Adirondack Mountains, New York, August 2006. Locations of study sites are shown in figure 1; study-site codes are listed in table 1.

significantly different between Cedar River and Indian River sites immediately downstream from their respective dams further indicates that the factors that affect macroinvertebrate communities in both rivers were similar. Therefore, these results indicate that the recreational releases did not contribute substantially to impacts on macroinvertebrate communities of the Indian River. Observed effects were caused mainly by impounded lake waters (continuously released into the Indian River) and that these impoundment effects did not extend to sites in the Hudson River. The absence of significant community impacts, however, does not entirely eliminate the possibility that releases could have adversely affected individual species populations 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 Guilds—Further analyses of feeding guilds and differences in the dominant macroinvertebrate taxa at each study site generally confirm impoundment effects but also help reveal subtle effects that the releases might have had at the trophic and species-population levels. Spatial trends in the percentages of the five functional feeding guilds at the study sites in each river were generally similar in 2005 and 2006 (table 22); thus, only the results from 2006 were examined in detail. Summaries of data in figure 22 show that percentages of collector-gathers and scrapers were lower at sites affected by impoundments (IR01, IR02, and CR01), and that percentages of collector-filterers at those sites were higher than at most unaffected sites farther downstream from both impoundments during 2006. The percentages of collector-filterers at the upper two sites in the Indian River (IR01 and IR02) were generally comparable to percentages at CR01, and they were higher than percentages at all sites in the Hudson River during 2006 (fig. 22, table 22). The percentages of predators at all sites in the Indian River were slightly lower than at several sites in the Hudson River and at CR01 and CR02, but differences were typically not significant during 2006 (table 23). The percentages of scrapers at all Indian River sites and at CR01 were 5.0 or less, lower than at CR02 (14.3), and significantly lower than at the five Hudson River sites during 2006 (table 23). The percentages of scrapers at the three Indian River sites generally ranged from 0.3 to 1.7 and from 5 to about 18 at the four Cedar River sites in 2006. There were no major differences in the percentages of shredders among all study sites; however, the percentages of collector-gatherers were significantly lower at IR01, CR01, and CR04 than at most other sites. Percentages of the five feeding guilds at HR01 did not differ significantly from those at the other four Hudson River sites.

Like the community indexes, the percentages of feeding guilds at CR01 and IR01, as well as those at IR02 and IR03, provide strong evidence that the impoundments heavily affected food webs at riverine sites immediately downstream from both dams. The main difference between macroinvertebrate assemblages in the Cedar and Indian Rivers was that scrapers were generally absent at all Indian River

Table 21. 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, Indian, and Hudson Rivers, Adirondack Mountains, New York, 2006.

[The columns of letters denote sites with homogeneous indexes (mean indexes were not significantly different ($p \leq 0.05$) among coindicated sites in the same vertical column) based on Fisher's least significant difference procedures. Locations of study sites are shown in figure 1. Study-site codes are listed in table 1]

Site code	Mean richness	Homogeneous richness	Mean HBI	Homogeneous HBI	Mean EPT	Homogeneous EPT	Mean PMA	Homogeneous PMA	Mean NYSBAP	Homogeneous NYSBAP
IR01	18.3	a b	5.3	f	5.3	a	44.0	a	5.2	a
IR02	18.7	a b c	4.3	e	10.0	c d e	59.0	b	6.7	b c
IR03	20.3	a b c d	3.7	b	9.7	b c d	71.3	d e f	7.3	c d
HR01	24.3	d e	3.7	b	16.7	h	69.3	c d e	8.3	e
HR02	29.7	f g	3.6	b	15.7	f g h	66.7	b c d	8.5	e f
HR03	32.3	g	3.8	b c	16.0	g h	76.7	e f	9.0	f
HR04	20.0	a b c d	3.1	a	12.7	d e f	62.7	b c	7.6	d
HR05	24.7	d e f	3.6	b	14.0	f g h	74.3	d e f	8.3	e f
CR01	15.3	a	5.5	g	7.3	a b c	46.0	a	5.2	a
CR02	29.3	e f g	4.3	e	13.0	e f g	75.0	d e f	8.4	e f
CR03	23.0	b c d	4.2	d e	12.7	d e f	78.3	f	8.0	d e
CR04	23.7	c d	4.0	c d	6.7	a b	49.3	a	6.4	b

Table 22. Percentage compositions of five functional feeding groups in macroinvertebrate communities at 12 study sites in the Cedar, Indian, and Hudson Rivers, Adirondack Mountains, New York, 2005–06.

[Locations of study sites are shown in figure 1; study-site codes are listed in table 1.]

Study code	Collector-filterer	Predator	Scraper	Shredder	Collector-gatherer
			2005		
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		
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

sites. Except for the near absence of scrapers, feeding-guild data provided little evidence that the releases had a significant and unique effect on macroinvertebrate communities in the Indian River or at any Hudson River site (downstream from the confluence with the Indian River).

The dominant and subdominant invertebrate species (the two to four species with the highest sample counts) shifted somewhat between affected and nonaffected sites, reflecting different physical conditions and food sources within riffles at study sites immediately downstream from impoundments on the Indian River and the Cedar River during 2005 and 2006. Collector-gatherers (for example, swimming mayflies—*Ameletus spp*. and *Acentrella spp*.), scrapers (for example, baetid mayflies such as *Heterocloeon sp*. and beetle larvae—*Oulimnius spp*. and *Stenelmis spp*.), predators (for example, Acariformes and Megalopterans such as *Climacia sp*.), and collector-filterers, such as fingernail and pea clams (*Musculium transversum* and *Pisidium compressum*) and the stonefly (*Hydropsyche spp*.), typically dominated macroinvertebrate communities at HR01, HR02, and HR03, even though flows at these sites fluctuated widely with releases. Collector-filterers including the pea clam *P. compressum*, blackflies (*Simulium gouldingi*), net-building chiromonids (*Microspectra polita*), and caddisflies (for example, *Hydropsyche spp*. and *Nyctiophylax sp*.) dominated local communities at CR01, IR01, and to some extent at CR04 (fig. 22). Although two species (*Pisidium compressum* and *Simulium gouldingi*) were abundant at IR01, they were almost entirely absent at CR01. Scrapers, such as *Stenelmis spp*., *Oulimnius spp*., *Phaenopsectra sp*., *Heterocloeon sp*., and *Stenonema spp*., were present at both sites, but they constituted only 5 percent of total counts at CR01 in 2006 and less than 2 percent of counts at IR01 during 2005 and 2006 (table 23). Communities at other Indian River and Cedar River sites (IR02, IR03, CR02, and CR03) were similar to each other and more similar to those at Hudson River sites than to communities at other affected sites within both rivers during 2006. The predominance of collector-filterers only at CR01 and IR01 confirms that the effects are spatially limited and directly related to conditions normally encountered below

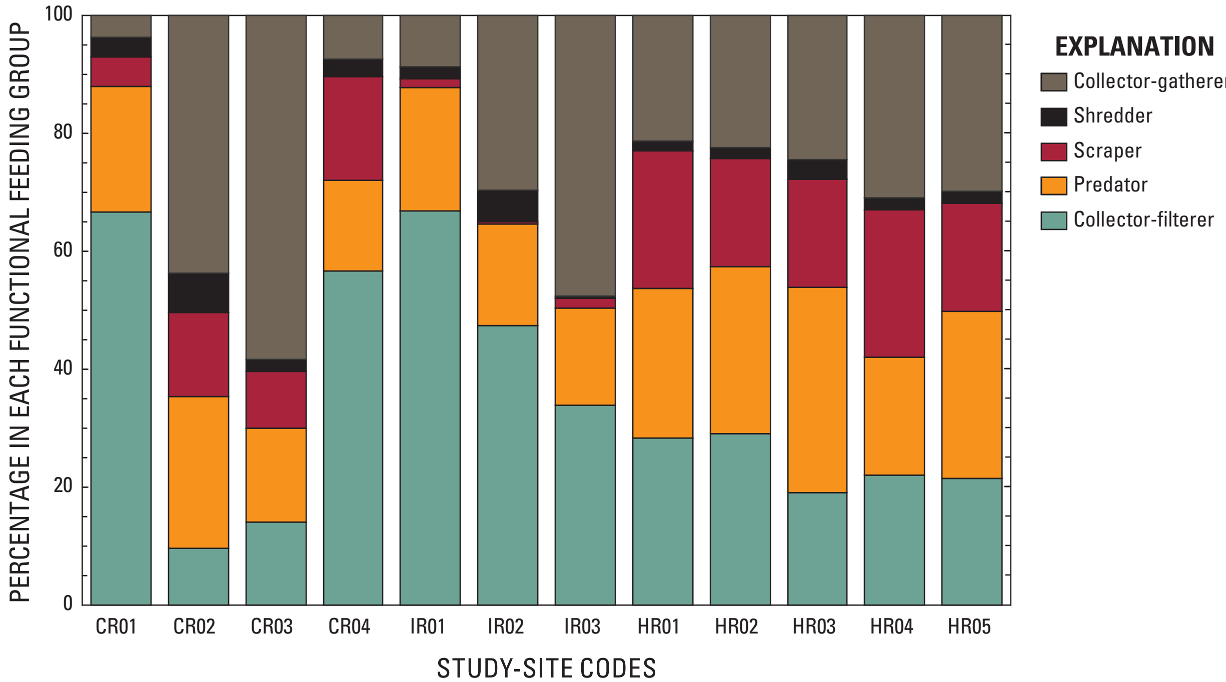

Figure 22. Graph showing tThe percentages of macroinvertebrates in each of five functional feeding groups at 12 sites surveyed in the Cedar, Indian, and Hudson Rivers, Adirondack Mountains, New York, August 2006. Locations of study sites are shown in figure 1; study-site codes are listed in table 1.

impoundments (Bode and others, 2002). The comparable and limited effects on communities in both the Indian and Cedar Rivers (within the first few hundred meters downstream from the respective dams) and the relatively similar communities at IR02–03, CR02–03, and all Hudson River sites indicate that the releases did not cause unique effects on macroinvertebrate communities in most of the lower Indian River or at any study site in the Hudson River. The larger percentage of scrapers at CR01 than at IR01, IR02, and IR03 and the occurrence of two collector-filterer species only at IR01 indicate, however, that the releases did have some effect on macroinvertebrate assemblages in the Indian River, primarily at the reach closest to the Abanakee Dam.

Community Similarity—A cluster analysis of Bray-Curtis similarities (fig. 23) for 2006 macroinvertebrate data generally supports prior findings from analyses of feeding guilds and dominant species. The macroinvertebrate assemblages at sites IR01 and CR01 did not differ significantly ($p < 0.05$) from one another and were more similar to each other (about 45 percent similar) than to assemblages at all other study sites (about 29 percent similar). Macroinvertebrate assemblages at IR02 and IR03 were about 54 percent similar to each other, 29 percent similar to those at CR01 and IR01, and about 32 percent similar to assemblages at the remaining study sites. Assemblages at CR02, CR03, and CR04 were 38 to 58 percent similar to each other and 43 percent similar to those at all Hudson River sites. Macroinvertebrate assemblages at all Hudson River sites were 53 to 65 percent similar to, and not significantly different from, assemblages at each site (fig. 23).

The 40-percent similarity bubbles in the two-dimensional ordination plot (fig. 24) graphically show how assemblages of macroinvertebrate species from sites that are affected, partly affected, or unaffected segregate into distinctive classes. These associations do not indicate any unique effects of the releases on communities the Indian River. They do, however, indicate strong and similar impoundment effects on communities at only two sites, IR01 and CR01 (each immediately downstream from a dam); an undefined effect at CR04 (54 km below the dam); similar and diminishing effects at Indian River sites IR02 and IR03 (2 to 4 km below the dam); minor or no effects at Cedar River sites CR02 and CR03 (8 to 54 km below the dam); and no distinguishable effects at all Hudson River sites.

In summary, the general function (integrity or health) of macroinvertebrate communities at all Indian, Cedar, and Hudson River sites was not seriously affected by water quality, which ranged from very good to good (Novak and Bode, 1992; Smith and Bode, 2004). Comparable effects on the structure of macroinvertebrate communities at sites immediately downstream from both dams (IR01 and CR01) could be attributed to the unique nature of impoundment waters. The near absence of scrapers at all Indian River sites and the presence of two species (blackflies and pea clams) only at IR01 indicate that the releases from Lake Abanakee had minor effects on the structure of macroinvertebrate communities only at IR01. The consequences that these minor effects could have on organisms at higher trophic levels, however, were not investigated in this study.

Table 23. Mean percentages of macroinvertebrate community feeding groups and similarities among 12 study sites in the Cedar, Indian, and Hudson Rivers, Adirondack Mountains, New York, 2006.

[The columns of letters denote sites with homogeneous feeding groups (mean indices were not significantly different ($p \leq 0.05$) among coindicated sites in the same vertical column) based on Fisher's least significant difference procedures. Locations of study sites are shown in figure 1; study-site codes are listed in table 1.]

Study site	Collector-filterer	Homogeneous collector-filterer	Predator	Homogeneous predator	Scraper	Homogeneous scraper	Shredder	Homogeneous shredder	Collector-gatherer	Homogeneous collector-gatherer
IR01	66.9	h	20.9	a b c	1.4	a b	2.0	a b	8.8	a
IR02	47.3	f	17.3	a b	0.3	a	5.3	c d	29.7	c
IR03	33.8	e	16.5	a b	1.7	a b	0.3	a	47.6	e
CR01	66.7	h	21.3	a b c	5.0	b	3.3	b c	3.7	a
CR02	9.7	a	25.7	b c d	14.3	d	6.7	d	43.7	e
CR03	14.0	a b	16.0	a b	9.7	c	2.0	a b	58.3	f
CR04	56.7	g	15.3	a	17.7	d	3.0	a b c	7.3	a
HR01	28.3	d e	25.3	a b c d	23.3	e	1.7	a b	21.3	b
HR02	29.0	e	28.3	c d	18.3	d	2.0	a b	22.3	b c d
HR03	19.1	b c	34.8	d	18.4	d	3.3	b c	24.4	b c d
HR04	22.0	c d	20.0	a b c	25.0	e	2.0	a b	31.0	d
HR05	21.4	c	28.4	c d	18.4	d	2.0	a b	29.8	d

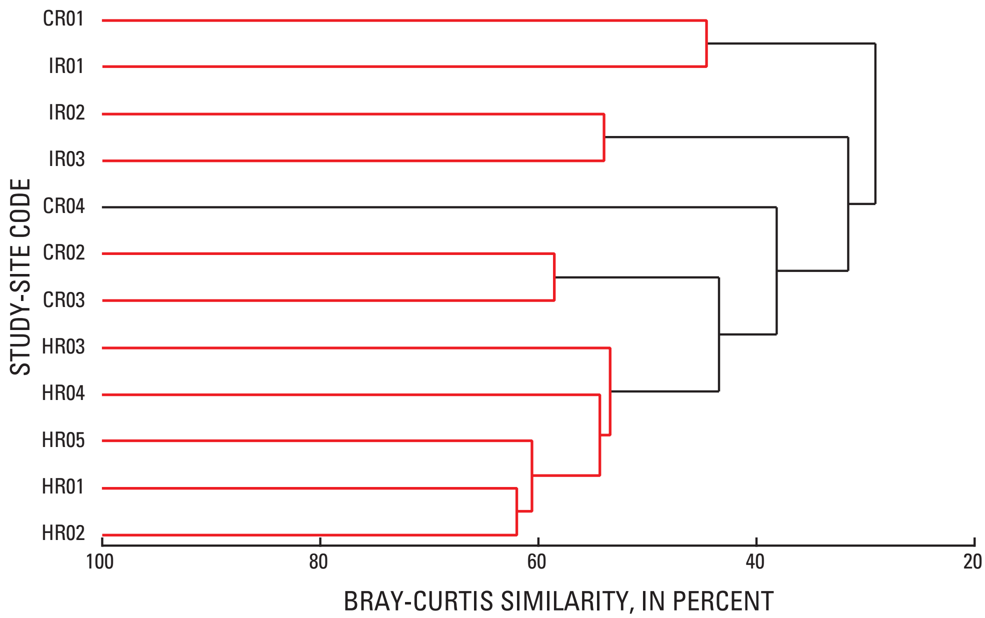

Figure 23. Graph showing cCluster analysis of Bray-Curtis similarities for macroinvertebrate assemblages based on square-root-transformed relative abundance data from 3 combined replicates collected at each of 12 sites in the Cedar, Indian, and Hudson Rivers, Adirondack Mountains, New York, August 2006. The red links identify sites at which replicates did not differ significantly ($p \leq 0.05$) from each other. Locations of study sites are shown in figure 1; study-site codes are listed in table 1.

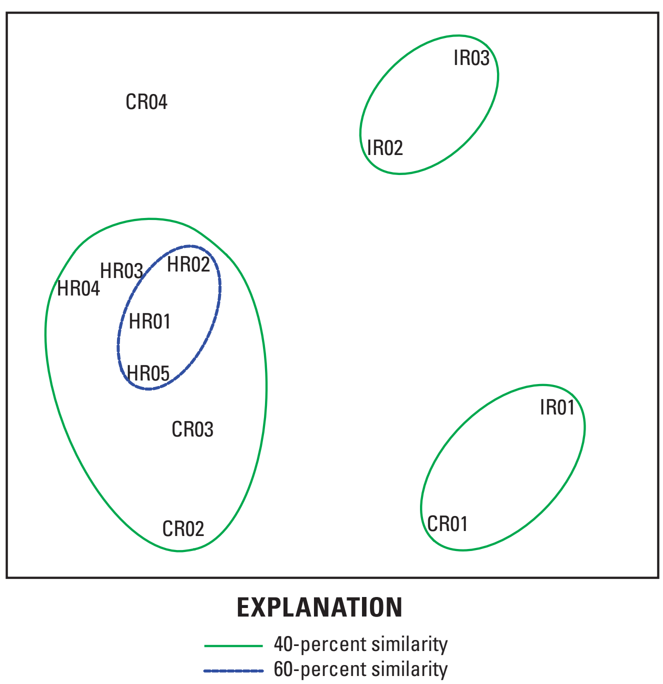

Figure 24. Diagram of oOrdination plot of macroinvertebrate assemblages based on square-root-transformed relative abundance data from 3 combined replicates at each of 12 sites in the Indian, Hudson, and Cedar Rivers, Adirondack Mountains, New York, August 2006. The bubbles denote significant group membership (40 and 60 percent Bray-Curtis

Trout Behavior

Results that summarize the use of thermal refuges, effects of the releases, movement behavior, persistence (apparent survival), and final location of transmitters for trout tracked during the telemetry study are listed and discussed separately below.

Use of Thermal Refuges—The percentage of transmitter observations of trout temperatures cooler than nearby main-stem river waters was used to approximate the percentage of time that trout used potential thermal refuges and the percentage of trout that used potential refuges at study reaches in the three rivers. Percentages generated on the basis of TDs of -1°C (trout were at least 1°C cooler than the main-stem river) were considered liberal estimates of refuge use, whereas percentages calculated on the basis of TDs of -2ºC (trout were at least 2°C cooler than the main-stem river) were treated as conservative estimates of refuge use. During 2005 and 2006, 21.7 percent of all trout-temperature observations were at least 1ºC cooler than water temperatures in the Cedar River, as were 3.9 percent of observations for the Indian River and 28.8 percent of observations for the Hudson River (table 24) (the percentages shown do not include data from time blocks during which temperatures might have been affected by releases). Using TDs that were at least 2ºC cooler than river temperatures for both years, mean percentages were found to decrease to about 11.3 percent of observations in the Cedar River, 2.7 percent in the Indian River, and 12.2 percent in the Hudson River (table 24). The percentages of TDs that were greater than or equal to -1ºC and -2ºC during the three time blocks on both nonrelease and release days for the three study reaches (rivers) are shown in figures 25 and 26, respectively. Interpreting the relations between TDs and releases (and assessing the effects of the releases) is problematic because the thresholds selected to indicate use of thermal refuges were somewhat subjective.

A comparison of mean TDs with Fisher's LSD 95-percent confidence intervals (CIs) for all trout tracked in each of the study reaches helped determine the appropriate TD cutoffs for refuge use and also showed how well the observations represented the actual percentage of time that trout used refuges (or the percentage of trout that appeared to be using refuges). Mean TDs and 95-percent LSD CIs for all telemetry trout tracked in the Hudson River during 2006 (fig. 27) showed that 5 out of 16 trout had TDs that were at least 1ºC cooler than the main-stem waters, and that the mean TD did not extend lower than -2ºC for all trout (trout number 51 was excluded because there were only two observations for it). The clear separation of TDs for the 5 (or 6) trout from the other 10 (TDs for which ranged around 0) indicates that the threshold of 1ºC TD may be appropriate to categorize the number and percentage of trout or the percentage of time that trout were using thermal refuges. Even though categories were more obvious in 2006 than in 2005, about 24 percent of telemetry trout in the Hudson River were classified as using thermal refuges during both years. Similar relations held for trout in the Cedar River, where 21.4 percent of telemetry trout (3 out of 14) during 2006 were classified as using thermal refuges (no tracking was done in 2005). In the Indian River, 8.3 percent of telemetry trout (2 out of 24) were at least 1ºC cooler than the river during 2005 and 2006 and were classified as using thermal refuges at least part of the time. The percentages of trout that were 1ºC (or more) cooler than main-stem rivers were similar to percentages of trout with TDs of -1ºC (and not -2ºC), which suggests that all observations may be used to evaluate the effects of the releases on the use of thermal refuges by brown trout in the three study reaches.

The benefit that thermal refuges potentially provide to resident and stocked trout differs among the three rivers and has some important implications. First, the percentage of trout using thermal refuges was very low in the Indian River (3.9 percent) and moderate (21.7 to 28.8 percent) in the Hudson and Cedar Rivers. Inequalities in the quantity, quality, or accessibility of thermal refuge areas and disparities in other environmental factors (for example, the presence of deep, slow-water habitat or the availability of prey) may account for differences in trout behavior between rivers. Comparable estimates of refuge usage in the Cedar and Hudson Rivers indicate that thermal refuges are widespread and available to trout in both study reaches. This study was not designed to directly quantify how low or moderate usage of thermal refuges might affect survival of individual trout in the three rivers. Potential refuge areas that are cooler than the main-stem river but remain warm enough to be stressful may be able to prolong the life of trout by reducing cumulative exposure; however, such refuges might not be able to sustain trout during prolonged periods of thermal stress.

Second, the percentages of all trout-temperature observations that were lower than 20ºC (fig. 28) on both release and nonrelease days confirm that thermal conditions were different within the three study reaches. These differences might affect trout survival and their need for and use of thermal refuges. On average, 45.7 percent of trout-temperature observations in the Cedar River in 2006 and 3.1 percent in the Indian River and 14.5 percent in the Hudson River were 20°C or cooler in 2005 and 2006 (fig. 28, table 24) during time blocks normally affected by the releases. Differences in the percentages of trout-temperature observations at (or warmer than) stressful temperatures reflect differences in the quality or quantity of thermal refuges and preferred physical habitat (in absolute values), the diurnal variation in ambient river temperatures, and (or) in the extent to which releases reduce the amount or availability of thermal refuges in the three rivers. The percentages of trout-temperature observations of river temperatures greater than 20ºC and trout temperatures cooler than the river by at least 1ºC decreased to 29.7 percent in the Cedar River and increased to 4.0 percent in the Indian River and to 33.0 percent in the Hudson River. These increases may indicate an increased use of thermal refuges in the Indian and Hudson Rivers when main-stem water temperatures become stressful. The percentages decreased to 17.1 percent in the

Table 24. Percentages of all morning, midday, and afternoon observations of trout body temperatures made in the Cedar River (2006) and the Indian and Hudson Rivers (2005–06) when trout body temperatures were less than 20°C, cooler than the main stem by at least 1°C, cooler than the main stem by at least 2°C, cooler than the main stem by at least 1°C when river temperatures were greater than 20°C, and less than 20°C and also cooler than the main stem by at least 1°C when river temperatures were greater than 20°C.

[Temperature difference (TD) data from release days (and time blocks) that could be affected by releases were not included in Hudson River or Indian River calculations. °C, degrees Celsius]

Study reach	Percentage of observed trout temperatures				
	All river temperatures			River temperatures greater than 20°C	
	Less than 20°C	At least 1°C cooler than main stem	At least 2°C cooler than main stem	At least 1°C cooler than main stem	Less than 20°C and at least 1°C cooler than main stem
Cedar River	45.7	21.7	11.3	29.7	17.1
Hudson River	14.5	28.8	12.2	33.0	8.9
Indian River	3.1	3.9	2.7	4.0	1.2

Cedar River, 1.2 percent in the Indian River, and 8.9 percent in the Hudson River when river temperatures were greater than 20ºC and trout were both cooler than 20ºC and cooler than the river by more than 1ºC (table 24). If the number of observations was assumed to be roughly comparable to the percentage of time trout spent in refuges or the percentage of trout that spent any time in refuges, the final estimates may represent the maximum percentage of trout that were able to maintain nonstressful body temperatures either by chance or by using thermal refuges in the three reaches. Thus, the actual percentages of trout that used and directly benefited from thermal refuges when river temperatures were stressful and body temperatures were within their preferred range appeared to be substantially lower than that indicated by analysis of observations of all TDs that were at least -1ºC cooler than main-stem waters. Differences in fish behavior or geographic or physical conditions in the Cedar and Hudson Rivers apparently enable a larger fraction of stocked trout (and probably resident trout) to effectively avoid thermal stresses (which should be reflected in better growth and survival rates) than was possible in the Indian River. Other factors, such as primary productivity, preferred habitat, and fishing pressure may also affect trout growth and survival but are beyond the scope of this investigation.

Effects of Recreational Releases—The effects of flow releases on the use of thermal refuges by trout were evaluated on the basis of (1) multilevel-effect models for a statistical analysis of the differences in TDs in the Cedar River and in the two rivers affected by releases, (2) a qualitative assessment of TDs during release and nonrelease days for each river, and (3) a qualitative assessment of trout body temperatures spanning the period before and during releases. Both qualitative analyses make no attempt to account for biases caused by repeated measures of individual trout or for sampling bias caused by the limited range of the fixed receiver for detecting transmitter signals.

Multilevel-effect models were used to provide a defensible quantitative analysis of the effects of releases on the use of refuges by trout, evaluate additional factors that may affect use of thermal refuges in all three study rivers, and confirm that stocked trout use thermal refuges. As originally hypothesized, release day was not as important as other variables for explaining variation in TDs in the Cedar River, but release day was important for the Indian and Hudson Rivers. Even so, release day had explanatory power only during time blocks when the release bubble passed through the reach: midday for the Indian River and afternoon for the Hudson River (table 24). Although most results from each study reach in each river were predictable, several important relations and deviations from expected results warranted more detailed analysis and explanation (Boisvert, 2008).

Telemetry-derived TDs for trout in the Cedar River provide a reference against which to compare and validate findings from the Indian and Hudson Rivers, which were affected by releases. The most important variable during all times of day (morning, midday, and afternoon) in the Cedar River was the interaction between ambient river temperature and whether a trout was near or not near a tributary (table 24). The interaction indicates that the correlation of TD with one of the interacted predictor variables varied based on the value of that variable in the interaction. Although the variable "release day" had one of the three highest parameter weights for each time block, that weight was minor relative to the other parameters with higher predictor weights. For example, during the afternoon (TB3), daily mean discharge and interaction between river temperature and nearness to a tributary were both more than twice as important for explaining variation in TDs than was release day.

During morning (TB1) and midday (TB2) time blocks in the Cedar River, variation in TDs was explained best by models that included interaction between river temperature and nearness of a trout to a tributary ($F_{1,170}$ = 48.76,

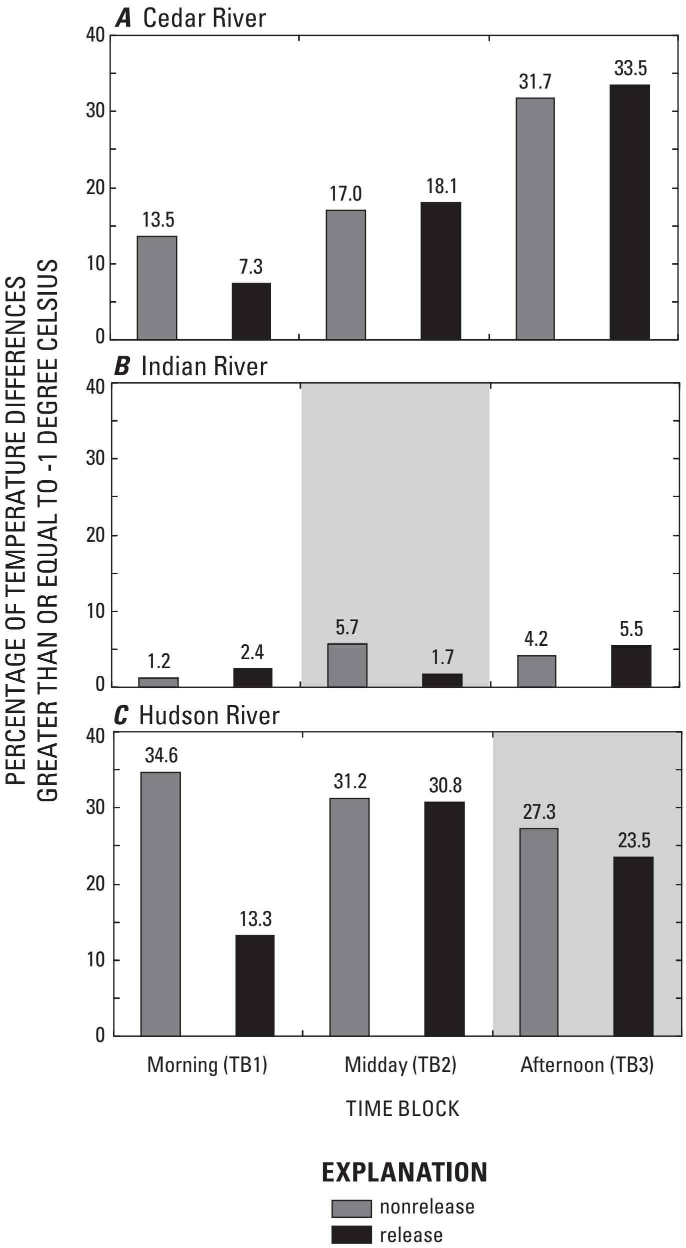

Figure 25. Graphs showing pPercentages of temperature differences that were greater than or equal to -1° Celsius on nonrelease days within time blocks TB1, TB2, and TB3 in the *A,* Cedar River (2006), *B,* Indian River (2005–06), and *C,* Hudson River (2005–06), Adirondack Mountains, New York. Gray backgrounds indicate time blocks when the release bubble passed through study reaches in the Indian River (TB2) and Hudson River (TB3) on release days.

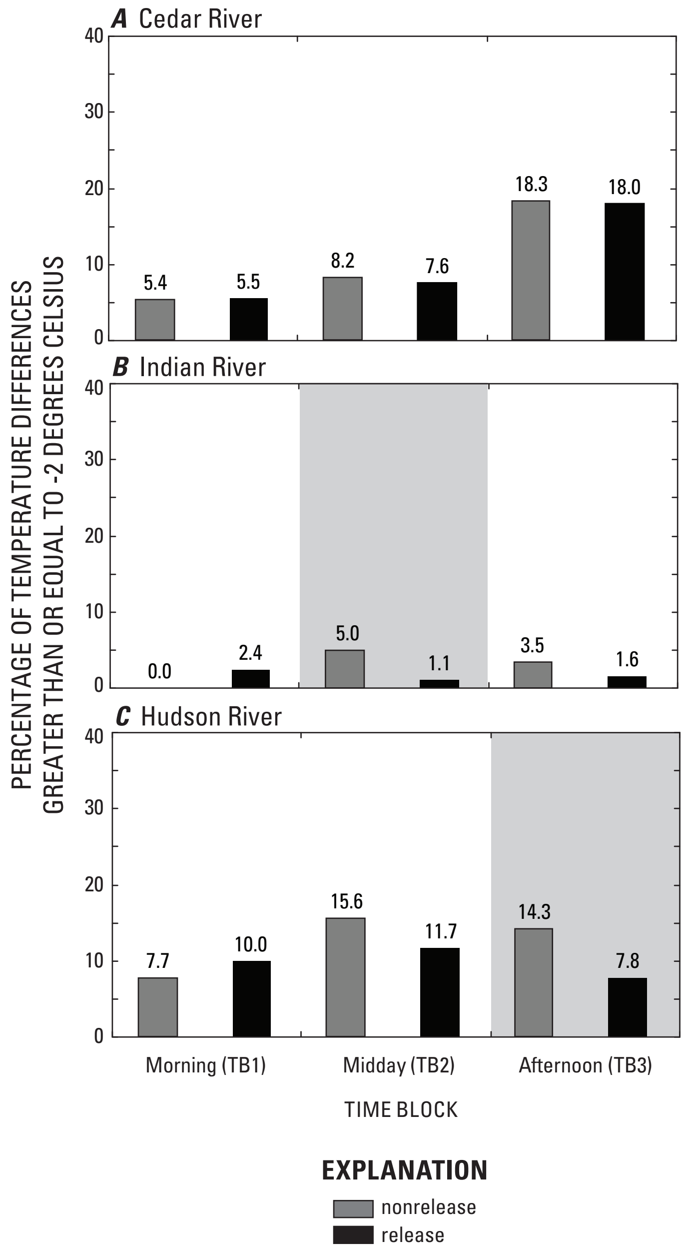

Figure 26. Graphs showing pPercentages of temperature differences that were greater than or equal to -2° Celsius on nonrelease and release days within time blocks TB1, TB2, and TB3 in the *A,* Cedar River (2006), *B,* Indian River (2005–06), and *C,* Hudson River (2005–06), Adirondack Mountains, New York. Gray backgrounds indicate time blocks when the release bubble passed through study reaches in the Indian River (TB2) and Hudson River (TB3) on release days.

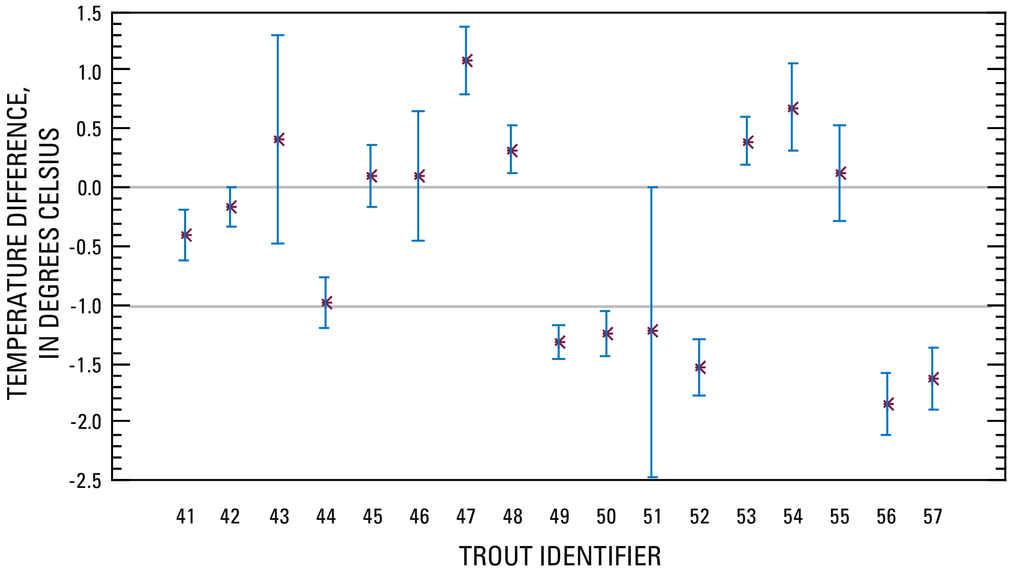

Figure 27. Graph showing aAverage differences between trout and river temperatures and standard errors for all observations of 17 trout tracked in the Hudson River, Adirondack Mountains, New York, during 2006. Trout identifier refers to the last two digits of the frequency of each implanted transmitter.

$p < 0.01$ for TB1 and $F_{1,287} = 14.27$, $p < 0.01$ for TB2). These models had almost 3–5 times more support than the next best model within each of the three model sets, and the fixed effect explained a significant amount of the variability. The best supported model for the afternoon in the Cedar River included the interaction between river temperature and nearness to a tributary and the variable mean daily discharge. This model was more than twice as well supported as the next best supported model. Both variables explained a significant amount of variation in TDs (daily mean discharge, $F_{1,18.7} = 13.32$, $p < 0.01$; interaction of river temperature with nearby tributary, $F_{1,275} = 12.29$, $p < 0.01$). Furthermore, differences between least-square mean (LSMean) estimates revealed that all of the less supported models that included release day were not significant for the Cedar River. Examination of LSMean estimates from the best supported model for TB3 (fig. 29A) reveals that, in general, trout temperatures were lower (trout were significantly cooler) than river temperatures that reached thermally stressful levels when the trout were within 50 m of a tributary. Although trout were probably using several types of thermal refuges, these findings indicate that tributary confluences are an important resource for trout. Results for morning and midday time blocks showed similar trends (Boisvert, 2008); however, the proximity of trout to a tributary did not strongly affect TDs when river temperatures were below 20ºC. These findings do not address the effects of releases, but they show that trout used thermal refuges mainly when river temperatures were elevated, tributaries were likely an important source of thermal refuges, and the study design successfully captured the effects of environmental variables with no biases for release-day type.

Recreational releases affected use of thermal refuges by trout in the Indian River as originally hypothesized (fig. 29B). Despite the relatively few tributaries and fewer observations of trout near tributaries in the Indian River, nearness to a tributary was more than five times more important than any other parameter during the time blocks before (TB1) and after (TB3) the release had passed through the reach (table 24). The best supported model during the morning and afternoon time blocks included only one fixed effect, nearness to a tributary ($F_{1,231} = -5.61$, $p = 0.02$ for TB1, and $F_{1,226} = 23.82$, $p < 0.01$ for TB3). Similarly, when much of the Indian River was inundated by high (release) flows during midday (TB2), the most important parameters (both had equal weights) were nearness to a tributary ($F_{1,282} = 8.43$, $p < 0.01$) and an interaction between river temperature and release day ($F_{1,273} = 12.07$, $p < 0.01$). These models had roughly 49 times more support than the second best supported model. Trout TDs varied little in the Indian River because thermoregulation (using thermal refuges) was rare, but trout near tributaries were cooler on average than the river during all time periods. Release day, during TB2, was correlated with reduced trout thermoregulation (TDs were more negative on release days) only when river temperatures were thermally stressful (fig. 29B); however, only about 1 percent of observations indicate that trout were in high-quality thermal refuges (trout temperatures < 20ºC) when Indian River temperatures were stressful (>20ºC) (table 24). These results indicate that tributary habitat is important for trout thermoregulation and that releases adversely affect the ability of trout to thermoregulate in the Indian River. These findings support the original hypotheses; however, the limited number or size of thermal refuges, small number of trout found in

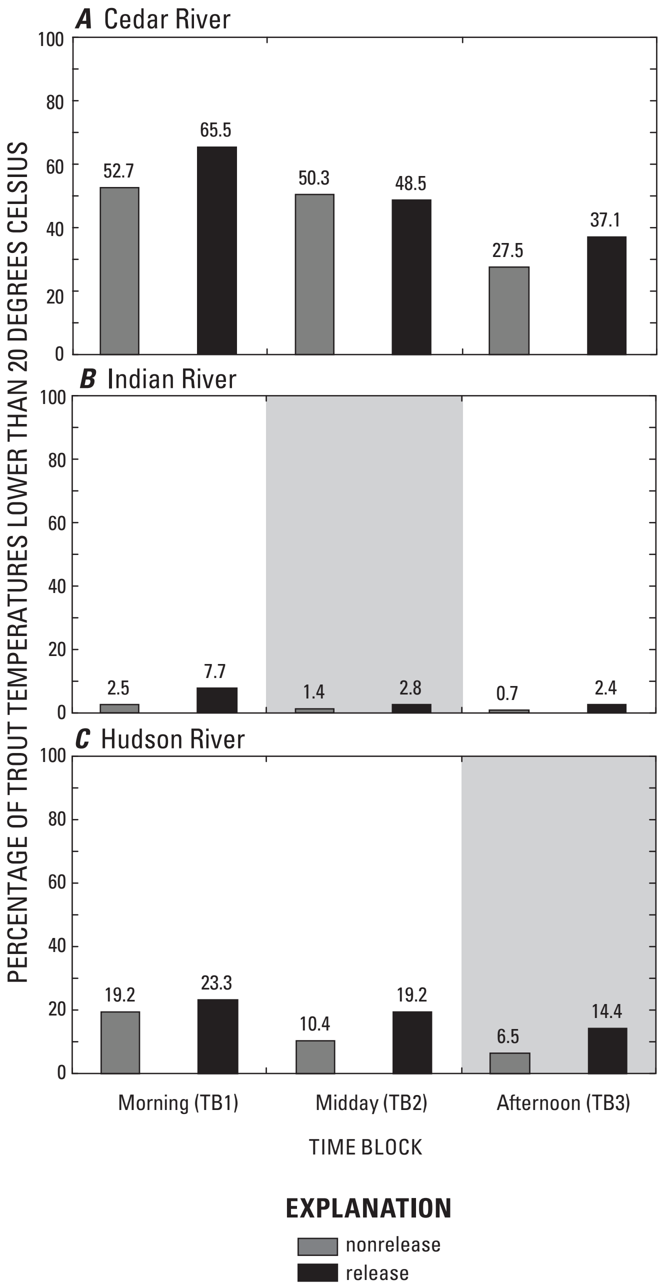

Figure 28. Graphs showing pPercentage of observations of trout temperature lower than 20ºCelsius on nonrelease and release days within time blocks TB1, TB2, and TB3 in the *A,* Cedar River (2006), *B,* Indian River (2005–06), and *C,* Hudson River (2005–06), Adirondack Mountains, New York. Gray backgrounds indicate time blocks when the release bubble passed through study reaches in the Indian River (TB2) and Hudson River (TB3) on release days.

refuges, and nominal trout TDs (generally less than -0.5ºC) within this study reach indicate that the releases have no clear effect on brown trout stocked into the lower Indian River.

In contrast to the Indian River, the releases had a moderate effect on use of thermal refuges by trout in the Hudson River (fig. 29C). Sufficient data were available for analysis of only the midday and afternoon time blocks. Like the Cedar River, the most important parameter during the midday time block (before the release bubble inundated Hudson River study reaches) was the interaction between river temperature and nearness (of trout) to a tributary (table 25). Although release day had the second greatest predictor weight, it did not explain a significant amount of the variation in TDs. As hypothesized, release day was included in the most important parameter (the interaction among river temperature, nearness to a tributary, and release day (F1,143 = 1.66, $p < 0.01$)) during the afternoon, when the release bubble affected the reach. Daily mean discharge (F1,275 = 12.12, $p < 0.01$) and distance (of trout) from a datalogger (F1,168 = 1.14, $p = 0.29$) also became important parameters during the afternoon as they did in the Cedar River. The model with the most support during midday included the interaction between release day and nearness to a tributary (F1,119 = 18.78, $p < 0.01$), and distance of trout to the nearest datalogger (F1,111 = 5.28, $p = 0.02$). The best supported model during the afternoon included an interaction among river temperature, nearness to a tributary, and release day (F1,143 = 1.66, $p < 0.01$); daily mean discharge (F1,275 = 12.12, $p < 0.01$); and distance to the nearest datalogger (F1,168 = 1.14, $p = 0.29$). Inspection of LSMean estimates from the best supported models for TB3 (fig. 29C) shows that trout temperatures were generally lower than river temperatures when the trout were thermally stressed. Under stressful river temperatures, trout were significantly cooler than the river when they were within 50 m of a tributary, but the magnitude of thermal relief was reduced (TDs were smaller) on release days. Nearness to a tributary generally did not affect trout TDs when river temperatures were close to 20ºC. Results for TB2 in the Hudson River were similar to those for TB2 in the Cedar River when trout were undergoing thermal stress, indicating that conditions were similar in the two rivers on nonrelease days. Results for TB3, when releases affected the Hudson River study reach, indicate that the releases adversely affected thermoregulation of individual trout even when they were near tributaries.

A qualitative analysis that compares the percentages of observations with TDs greater than -1ºC (trout were more than 1ºC cooler than the river) on release days to those on nonrelease days approximates the proportion of trout adversely affected by releases and confirms the findings of multilevel-effect models. This analysis also helps illustrate the biological relevance of the releases. Most of the following results are based on -1ºC TDs because prior analyses of the percentages of observations of TDs of at least -1ºC (and the mean TDs with their 95-percent LSD confidence intervals for individual trout) showed that the percentages of thermoregulating trout

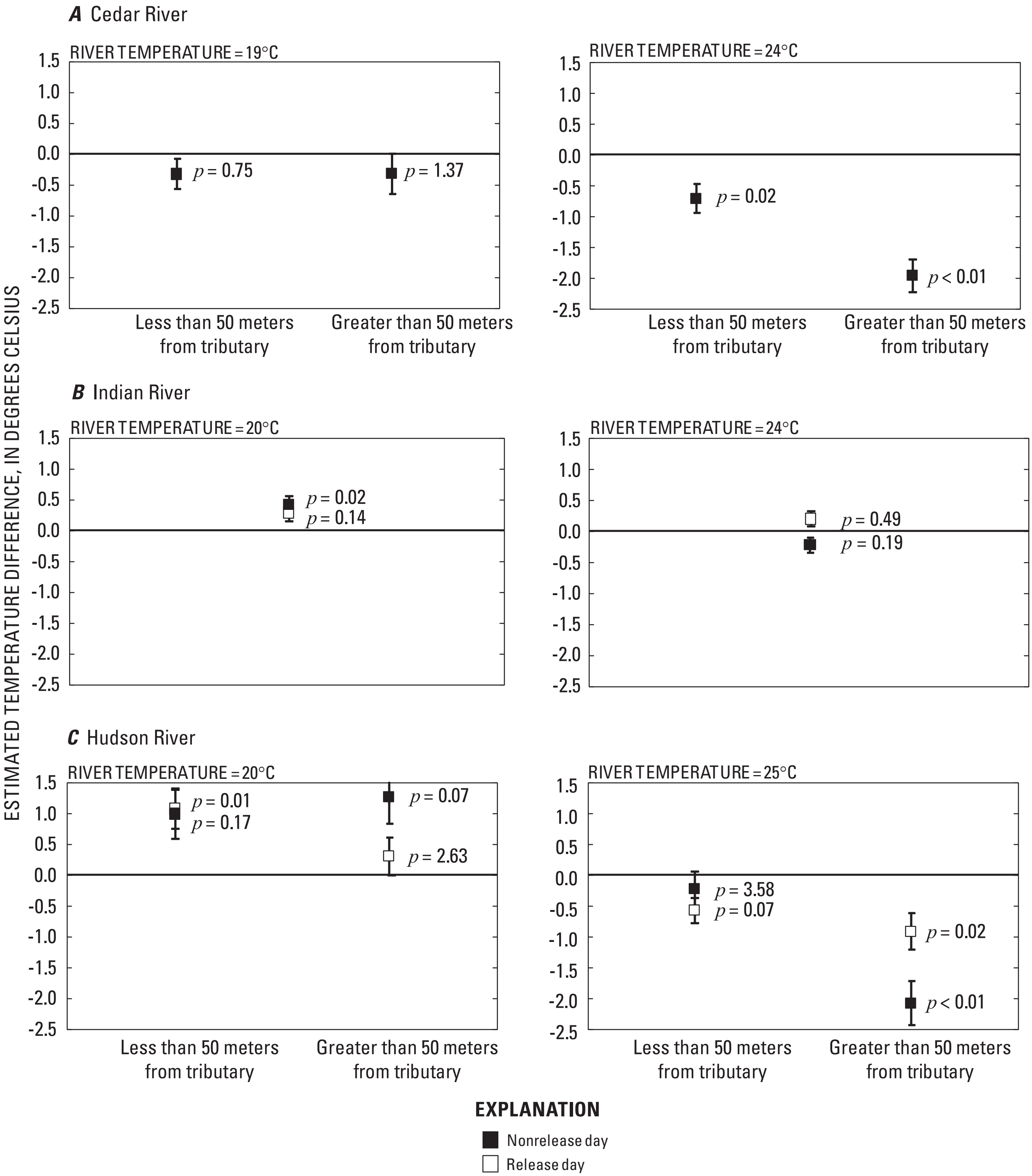

Figure 29. Graphs showing eEstimated least-square mean temperature differences and standard errors calculated from the best supported multilevel model for the *A,* Cedar and *B,* Indian Rivers, Adirondack Mountains, New York, during the afternoon time block (TB3), and the *C,* Hudson River during the midday time block (TB2) during 2006. Interactions terms, denoted by multiple estimates, included river temperature and (or) release day and proximity to tributaries. The results of

were roughly equivalent to the percentage of observations in which TDs were at least -1ºC. As part of the analysis, the number of observations indicating that trout were thermoregulating is assumed to represent the approximate percentage of trout that were using thermal refuges (fig. 25). In the unaffected Cedar River, the percentage of trout cooler than 20ºC was highest in the morning (TB1), and these percentages decreased throughout the later (warmer) parts of the day (fig. 28), even though the percentage of trout using thermal refuges increased throughout the day (fig. 25). These data largely support the statistical results from the multilevel-effect models. Trout TDs decreased during time blocks when the release bubble affected study reaches in the Indian and Hudson Rivers (fig. 25). Trout with TDs of at least -1ºC decreased from 5.7 percent on nonrelease days to 1.7 percent on release days during TB2 in the Indian River, and from 27.3 percent to 23.5 percent during TB3 in the Hudson River. These declines indicate that the releases decreased the utilization of thermal refuges by trout in both rivers. Such declines could be detrimental to trout survival when river temperatures are stressful. The small percentage (and number) of trout affected in the Indian River, however, indicates that few trout are using refuges under any thermal conditions. Therefore, adverse effects of the release on the sustainability of stocked trout in the Indian River are likely to be limited. The percentage of trout using refuges appears to be higher in the Hudson River than in the Indian River; however, the 3.8-percent decrease in usage during releases indicates that any effects of the releases on stocked trout (and possibly local trout populations) in the Hudson River should also be nominal (fig. 25C).

One apparent contradiction between the percentage analyses of TDs and the multilevel-model analysis emerges from TD data for the morning time block (TB1) in the Cedar and the Hudson Rivers. Unexpected differences between the percentages of trout using refuges on release days and on nonrelease days were found in both rivers; this indicates that behavioral thermoregulation decreased on release days (fig. 25), even though no releases occurred in the Cedar River, and releases occurred later in the day in the Hudson River. Results from the multilevel model, however, indicate that there were insufficient data for the TB1 in the Hudson River from which to draw statistically sound conclusions about release effects, and that TDs between release and nonrelease days during the morning in the Cedar River were accounted for by other more important variables (for example, river temperature and nearness to a tributary) (table 25). Release day was a relatively unimportant factor for the Cedar River models because it did not explain a significant amount of variability in thermoregulation. Although releases had the potential to strongly affect the use of thermal refuges and trout survival in the Hudson River and the Indian River, most findings indicated that trout generally utilized thermal refuges more frequently in the Hudson River than the Indian River but that the releases caused only small decreases in thermoregulation of trout in both rivers. Thus, the releases appeared to have no consequential effect on the use of thermal refuges by stocked trout in either the Hudson or Indian Rivers.

Changes in the body temperatures of several trout in the time spans before and during inundation by release bubbles in Hudson and Indian River study reaches (fig. 30) were also assessed qualitatively. This analysis focused only on changes

Table 25. The relative importance (indicated with a predictor weight between 0 and 1, representing the likelihood that a parameter is the most important for explaining variability in temperature differences) of the three most important parameters for each river and time-block combination.

[rivT, river temperature; ntrib, nearness to a tributary; rel, release day; dmd, daily mean discharge; * an interaction of variables, Shaded cells indicate the time period during which the release bubble passed through the river reach; parameters that include the variable release day are in **bold**]

Time block	Predictor weights and parameters		
	Cedar River	Indian River	Hudson River
Morning (TB1)	rivT*ntrib = 0.97 **rel = 0.18** rivT*ntrib*rel = 0.03	trib = 1.00 **rel = 0.18** rivT = 0.06	Insufficient data
Midday (TB2)	rivT*ntrib = 0.98 **rel = 0.22** dmd = 0.02	trib = 0.98r **rivT*rel = 0.98** **rel = 0.02**	rivT*ntrib = 0.86 **rel = 0.39** **rivT*ntrib*rel = 0.14**
Afternoon (TB3)	rivT*ntrib = 0.93n dmd = 0.76 **rel = 0.34**	trib = 1.00 rivT = 0.15 **rel = 0.15**	**rivT*ntrib*rel = 0.94** dmd = 0.88 rivT = 0.04

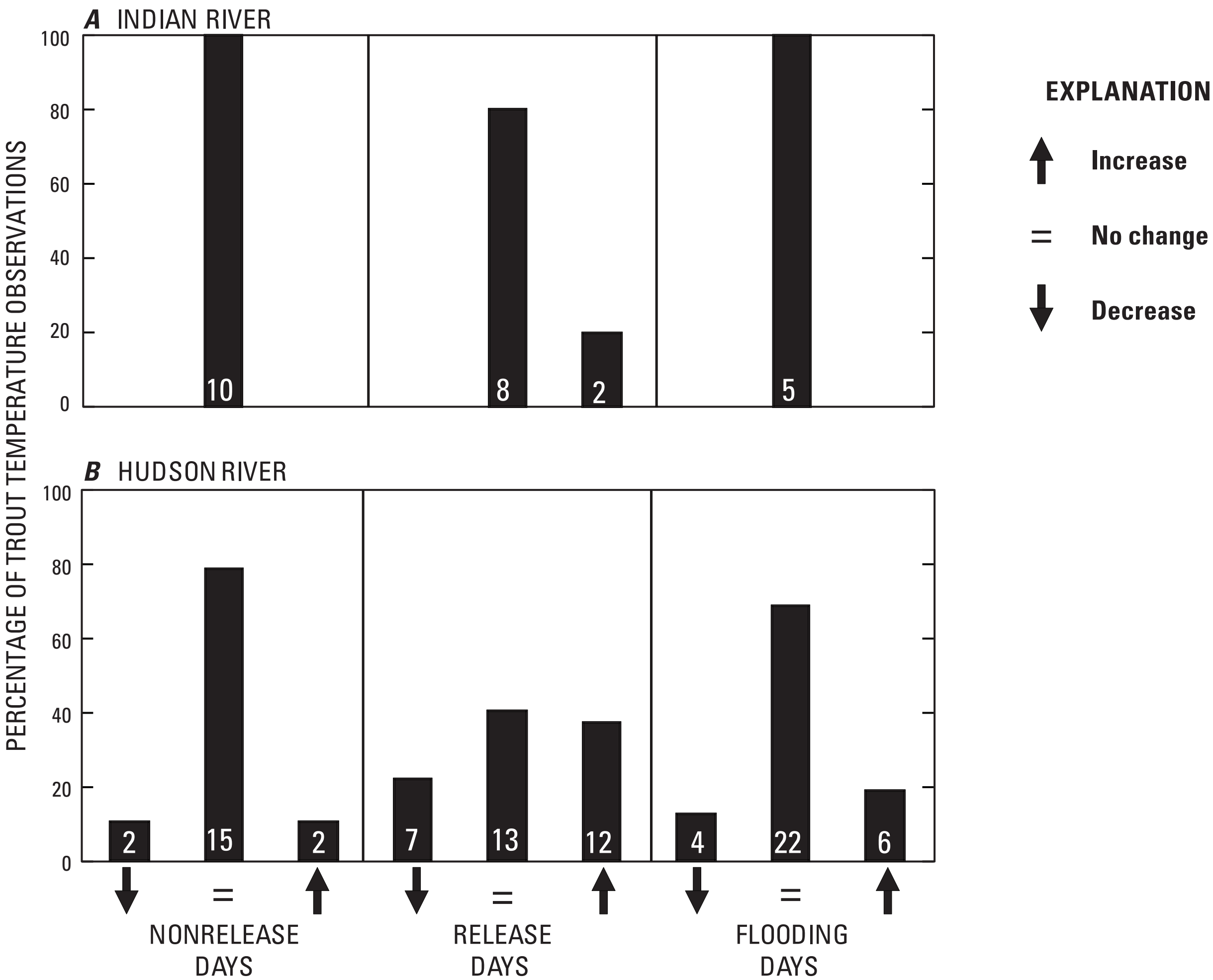

Figure 30. Graphs showing pPercentage (and number) of trout temperatures that increased, stayed the same, or decreased over the time span when release bubbles arrived at the trout's location on nonrelease, release, and flooding days in the *A,* Indian River and *B,* Hudson River, Adirondack Mountains, New York, during 2006.

in trout temperature over time; no direct comparisons to river temperatures were made. River temperatures reached at least 20ºC on all release and nonrelease days, however, and it was assumed that ambient river temperatures were not altered by release bubbles. Trout body temperatures in the Indian River did not change rapidly over time on nonrelease days, but increased abruptly on release days in 2 of 10 trout (fig. 30A), indicating that the release bubble reduced thermoregulation in at least two individuals. Although there appeared to be an effect, the number of trout affected by releases appears to be small. This view is supported by prior findings that indicate fewer than 6 percent of trout observations were in waters at least 1ºC cooler than the river (fig. 25B), fewer than 3 percent of trout observations were in waters cooler than 20ºC (fig. 28B), and only one of the five trout, occasionally observed in a thermal refuge, used it regularly (not shown). In the few cases where trout were in thermal refuges, increases in trout temperatures during releases were rare. Even though the releases did not appear to have biologically relevant effects on thermoregulatory behavior, brown trout in the Indian River probably grow slowly and have high mortality rates during summer months when they are thermally stressed for long periods.

In the Hudson River, trout temperatures changed (either decreased or increased) rapidly in roughly 20 percent of observations on nonrelease days and in 59 percent of observations on release days (fig. 30B). The observations for nonrelease days serve as a baseline and show that trout behavior in the Hudson River is more variable than in the Indian River (and is unrelated to the releases); Hudson River trout moved into and out of refuge areas, sometimes warming and sometimes cooling, even when unaffected by the release bubble. On release days, trout temperatures increased in 38 percent of observations and decreased in 22 percent of observations as the bubble passed through the study reach (fig. 30B). Increased temperatures indicate a dramatic reduction in thermoregulation (beyond the normal variability in behavior); however, decreased temperatures indicate that individual trout were sometimes able to avoid the adverse effects of releases by moving into even cooler thermal refuges. It is possible that increased river stages during releases enhance access of trout to tributaries with shallow confluences. These findings—and earlier observations indicating fewer than 28.8 percent of trout were at least 1ºC cooler than the river, fewer than 14.5 percent of trout were cooler than 20ºC (table 24), and 5–7 out of 16–17 trout often used a thermal refuge (fig. 27)—collectively illustrate that thermal refuge habitat is much more available and (or) accessible to trout in the Hudson River than in the Indian River.

Several observations suggest that the releases could be both detrimental and beneficial to brown trout in the Hudson River study reaches. In either case, the releases had a highly variable effect on trout in the Hudson; fewer trout were observed in thermal refuges during release days (23.5 percent) than during nonrelease days (27.3 percent) (fig. 25), and a greater percentage of trout exhibited temperature increases during release days (38 percent) than during nonrelease days (10 percent) (fig. 30B). These data indicate that stocked trout were using thermal refuges at low to moderate stages in the Hudson River, but that releases either decreased the amount and quality of thermal refuges or forced some trout from existing refuges. In contrast, temperatures of 7 trout (22 percent of release-day observations) decreased during releases in the Hudson River (presumably when trout entered a cooler tributary), which indicates that the releases could actually have benefited study trout (not reduce thermoregulation) in some cases. These trout avoided dilution of thermal refuges during releases, possibly by moving into normally shallow refuges that were inaccessible except when river stages were augmented by releases. On the other hand, any disturbance to a thermally stressed trout, by itself, could adversely affect their growth and survival. Overall, time-span observations for a small number of trout in the Hudson River showed that releases affected thermoregulatory behavior; temperatures changed in 59 percent of trout during release days but in only 21 percent of trout during nonrelease days. These data indicate that the releases may have slightly increased thermal stresses for trout in the Hudson River. Since most brown trout in the Hudson River were exposed to such thermal stresses for extended periods, they likely grew more slowly and exhibited higher rates of mortality during the warm summer months (regardless of the releases) than they would have in a comparable but unregulated system such as the Cedar River.

Movement Behavior—In 2006, about one-half of the 15 study trout in the Indian River remained at the stocking location (a large deep pool), and most others dispersed downstream over a 4-km-long river segment during the first 24 hours (fig. 31B). After 1 week, the location pattern remained similar to that for the first 24 hours after stocking. At 1 month, trout were spread over a smaller range (about 2.5 km), but many had moved upstream from the stocking location. Most trout occupied specific habitats: the stocking pool, a tributary 2 km downstream, a deep glide below rapids

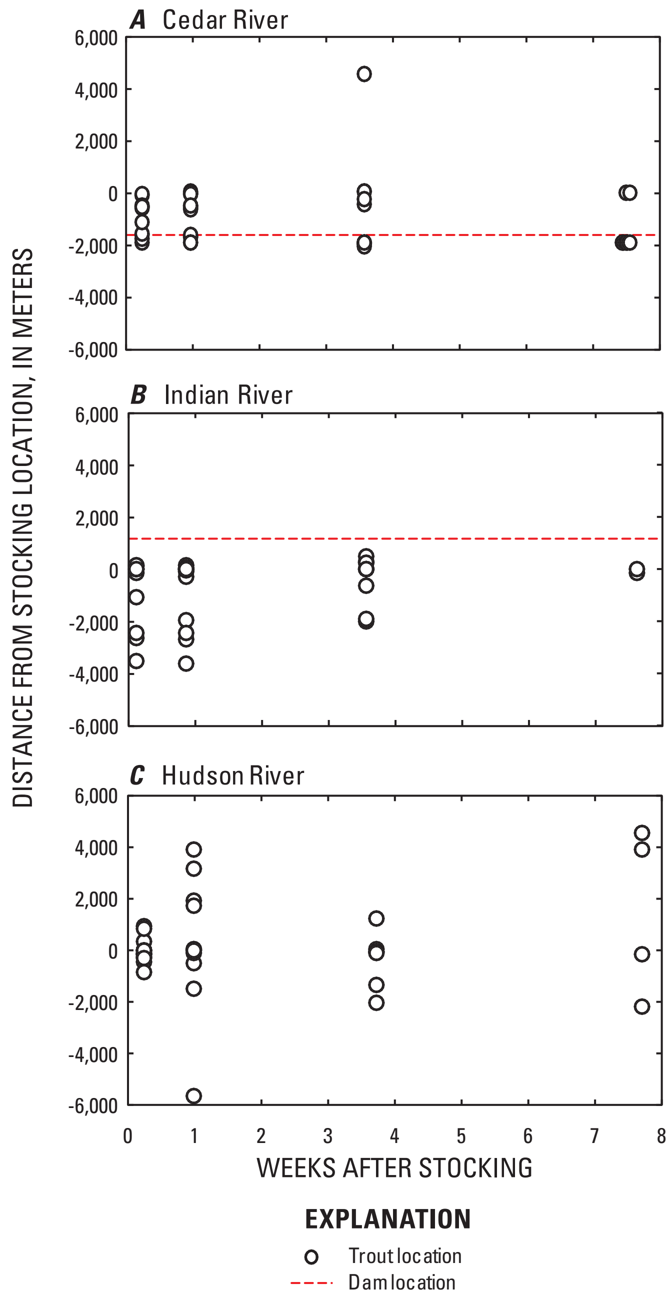

Figure 31. Graphs showing dDispersal of individual brown trout upstream (positive) and downstream (negative) from stocking locations in the *A,* Cedar, *B,* Indian, and *C,* Hudson Rivers, Adirondack Mountains, New York, at approximately 1, 7, 30, and 60 days after stocking during 2006.

(250 m upstream), and a deep pool at the base of rapids (500 m upstream). At 2 months, the only two persisting trout were in the stocking pool. No trout stocked into the Indian River were observed farther from the stocking area than the confluence of the Indian and Hudson Rivers; only 1 of the 15 study trout was not accounted for.

All but 4 of the 15 trout stocked into the Hudson River during 2006 dispersed from the general area of the stocking location (the mouth of Raquette Brook , a cold water tributary) within 48 hours (fig. 31C). Roughly equal numbers of trout moved in upstream and downstream directions, spreading out over a 2.7-km-long river segment. At 1 week, the trout had dispersed farther upstream and downstream, spreading out over 10 km, with four trout remaining close to the stocking location. At 1 month, the seven persisting trout were spread over a 3-km-long river segment. At 2 months, the four persisting trout were spread over a 6.5-km-long river segment. Trout dispersal was highly variable in the Hudson River and did not display an obvious pattern. Several locations were regularly inhabited by study trout: two cold-water plumes, near the stocking tributary (Raquette Brook) and at Aldous Brook; and a deep pool downstream from the Boreas River. Most trout were observed singularly, however, the few observed aggregations consisted of pairs.

Mean dispersion (absolute distance upstream or downstream from the stocking location) varied among the three rivers and over time. Mean dispersion (±2SE) for trout in the Cedar River was 934 m (±409, n = 11) after the first day, 834 m (±409, n = 14) after the second week, 1,622 m (±681, n = 13) after 1 month, and 1,386 m (±716, n = 7) after 2 months (fig. 32A). Trout in the Indian River were dispersed closer to the stocking location than they were in the other two rivers (fig. 32B). Dispersion in the Indian River averaged 692 m (±610, n = 15) after 1 day, 815 m (±683, n = 14) after 1 week, 544 m (±445, n = 11) after 1 month, and 80 m (±159, n = 2) after 2 months. Mean dispersion in the Hudson River was much narrower than in the Indian and Cedar Rivers after 1 day but much wider than in the other two rivers after 1 week (fig. 32C). Mean dispersion in the Hudson was 302 m (±163, n = 15) after 1 day, 1,535 m (±1064, n = 12) after 1 week, 703 m (±622, n = 7) after 1 month, and 2,681 m (±1984, n = 4) after 2 months.

Lastly, median trout locations, the interquartile range (middle 50 percent) of locations, and the middle 95 percent of locations from all observations are shown in figure 33 for each river during 2006. In the Cedar River, the median location was just upstream of the Cedar River Dam and the fifth percentile was a pool at the base of the Cedar River Dam (fig. 33A). Although trout moved downstream from this dam, they often returned and remained at its base there for long periods of time. The middle 50 percent of locations was 1,911 m long and was skewed upstream from the median. The middle 95 percent of locations was 2,193 m long (only slightly greater than the middle 50 percent) and similarly skewed upstream. In the Indian River, the median location was just downstream of the stocking pool (fig. 33B). The middle 50 percent of

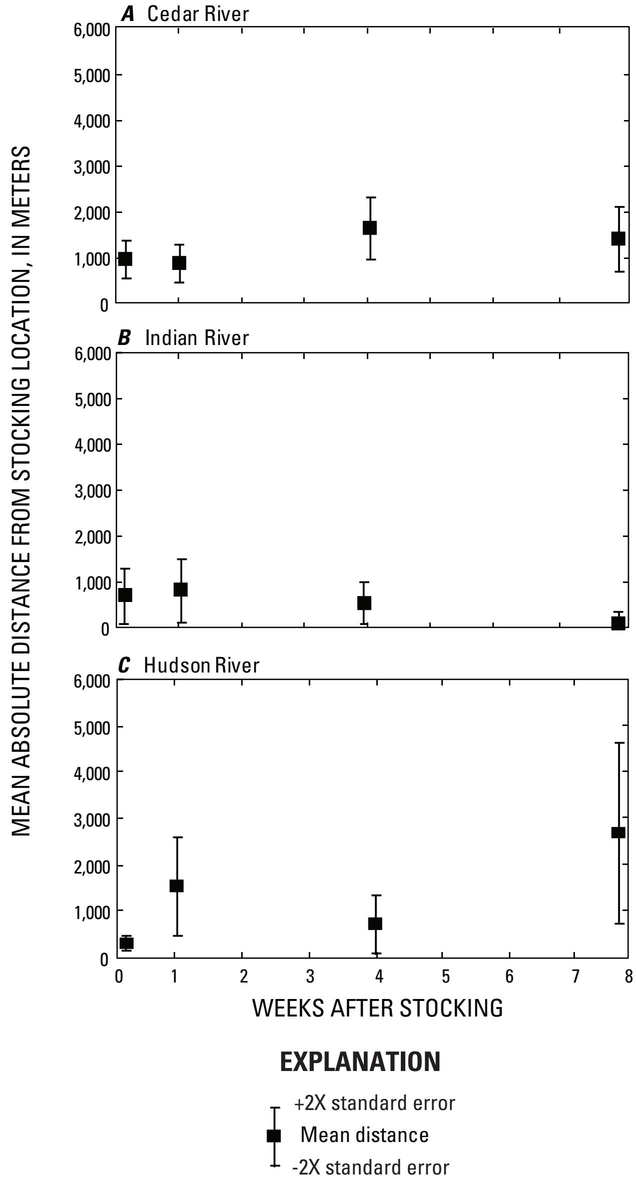

Figure 32. Graphs showing mMean absolute distance (±2 × standard error) of all brown trout from the stocking locations in the *A,* Cedar, *B,* Indian, and *C,* Hudson Rivers, Adirondack Mountains, New York, at approximately 1, 7, 30, and 60 days after stocking during 2006.

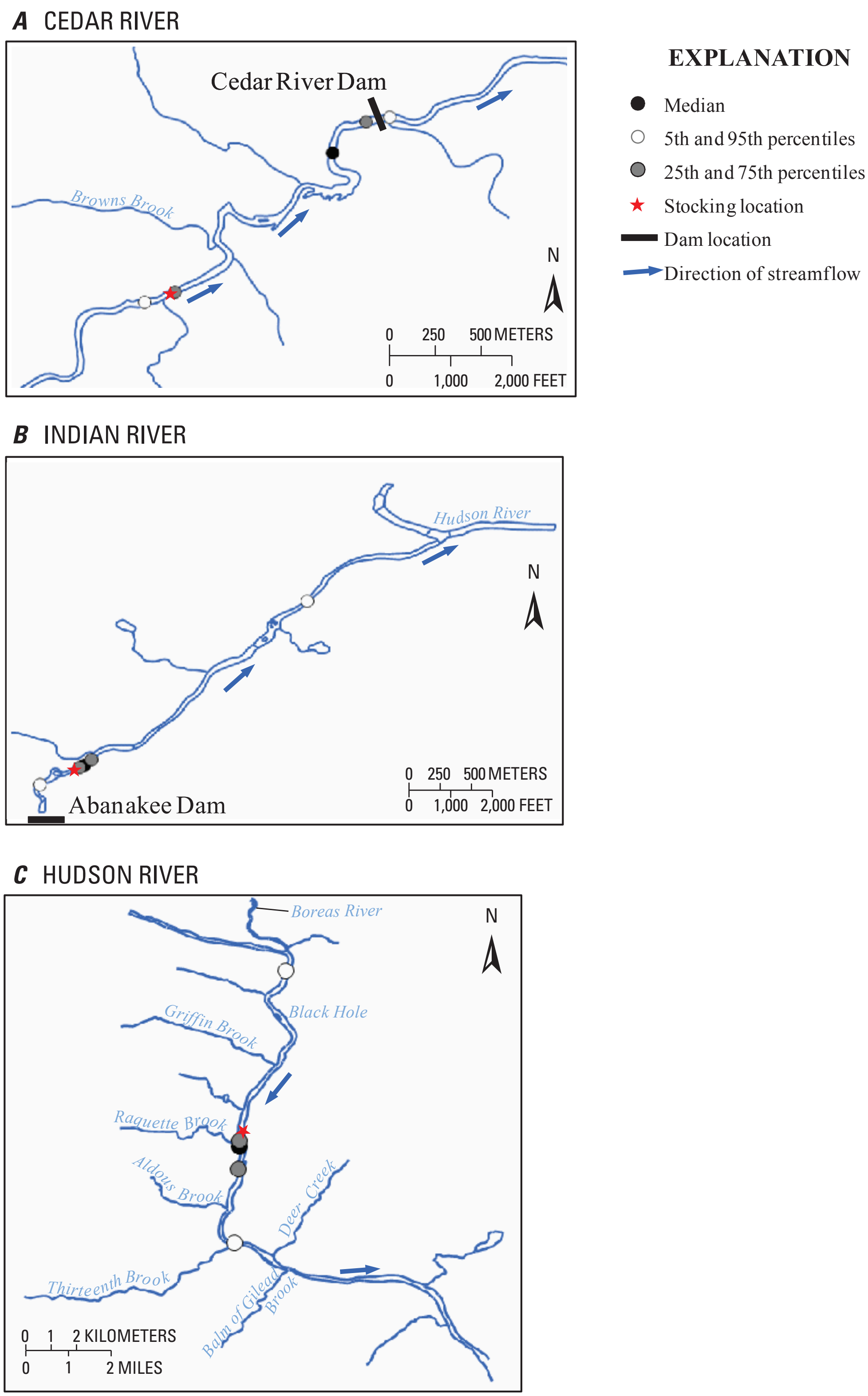

Figure 33. Maps showing dDistribution of brown-trout observations in generalized study reaches in the *A,* Cedar, *B,* Indian, and *C,* Hudson Rivers, Adirondack Mountains, New York, during 2006.

locations was only 120 m long and centered on the median. The middle 95 percent of locations was 2,838 m long and skewed downstream from the median. The median location in the Hudson River was also just downstream from the stocking tributary (fig. 33C). The middle 50 percent of locations was 569 m long and skewed downstream from the median. The middle 95 percent of locations (6,059 m) was longer than in the other two rivers and heavily skewed upstream from the median.

Trout activity level, defined as the distance moved between consecutive days, can partly explain differences in trout distribution and dispersion among the three rivers. Daily activity levels of trout in the Indian River indicate that trout moved shorter (median = 15 m) distances than in the Hudson River and less variable distances than in both other rivers (fig. 34). Activity levels of trout were similarly low (median = 15 m) in the Cedar River and higher (median = 45 m) in the Hudson River than in the Indian River. Trout activity levels were significantly different among the three rivers (Kruskal-Wallis $x^2 = 29.0015$, $p = <0.0001$). Results of Dunn's tests (Zar, 1996) show trout activity in the Hudson River as significantly different from activity in the Cedar River (Q = 4.63) or the Indian River (Q = 5.11) at $\alpha = 0.05$, although activity in the Indian River was not significantly different from that the Cedar River (Q = 0.74). Observations of trout locations made more than a day apart were not evaluated. In general, these findings indicate that trout moved more often (and farther) in the Hudson River than in either the Indian or Cedar Rivers. The metabolic cost of such movements would be high and could adversely affect growth and survival of stocked (and resident) trout because water temperatures in the Hudson River were near the upper critical range for brown trout (Elliot, 1994).

Persistence—Daily estimates of trout persistence (apparent survival) were determined by year and by river (fig. 35A–B) from July 25 to August 18 in 2005 and from June 14 to August 19 in 2006. During both years, trout in all rivers persisted for a minimum of 1 day and a maximum of 24 days in 2005 and 72 days in 2006 (durations for tracking operations each year). Seventy-five percent of the trout in the Indian and the Hudson Rivers no longer persisted after 13 to 20 days during 2005 (persistence in the Cedar River was not studied in 2005), whereas 75 percent of the trout in all rivers persisted at least 20 days during 2006. The middle 50 percent of persistence data for the Hudson and Indian Rivers showed similar trends between years, but trends varied considerably among the three rivers. Trout persisted in the Hudson River for the shortest time (median duration was 12 days in 2005 and 23 days in 2006), somewhat longer in the Indian River (median duration was 16 days in 2005 and 36 days in 2006), and for the longest time in the Cedar River (median duration was 67 days in 2006). The median durations of persistence in Hudson and Indian Rivers did not differ significantly in 2005 ($x^2 = 0.2312$, $p = 0.06306$) or in 2006 ($x^2 = 0.9669$, $p = 0.3255$). The median durations of persistence in the control, the Cedar River, differed significantly from values in the Hudson River ($x^2= 8.1059$, $p = 0.0044$) and in the Indian River ($x^2 = 4.1176$, $p = 0.0424$) during 2006. At the end of the 2005 effort, only one trout remained in the Hudson River, and no trout remained in the Indian River. At the end of the 2006 season, one trout remained in the Indian River, two remained in the Hudson River, and eight remained in the Cedar River. These observations indicate that average survival for stocked trout may be much lower in the Indian and Hudson Rivers than in the Cedar River (fig. 36). Given the limited physical habitat and stressful thermal conditions in the Indian River, low survival rates of stocked trout in this system could (hypothetically) be caused as much by the absence of thermal refuge areas as by the effects of flow releases. The percentage of trout using thermal refuges in the Hudson River was similar (when unaffected by releases) to that observed in the Cedar River; however, apparent trout survival in the Hudson River was poor and on a par with that in the Indian River. These results indicate that a combination of factors, such as poor physical habitat (for example, lack of deep slow water), low abundance of prey, or the releases affected trout mortality in the Hudson River. Collection of emaciated rainbow trout and brown trout (about 10 in. long) at two Indian River and Hudson River study sites during the summer of 2005 indicates that trout were generally unable to maintain their normal condition, even though anglers reported catching brook trout in the main-stem Cedar River and its tributaries.

Final Location of Transmitters—The large number of transmitters confirmed or inferred to be in nearby woods or exposed in the flood zone indicates that predation may have been an important cause of trout mortality in all study reaches. Losing transmitters or their signals was not a problem in either the Cedar or Indian Rivers, but approximately one-third of the 15 transmitters deployed in the Hudson River were lost during 2005 and 2006 (fig. 37). Apparently, differences in valley slope, riparian communities, or other factors not addressed by this study contributed to the high rate of loss for trout and transmitters, mainly in Hudson River study reaches.

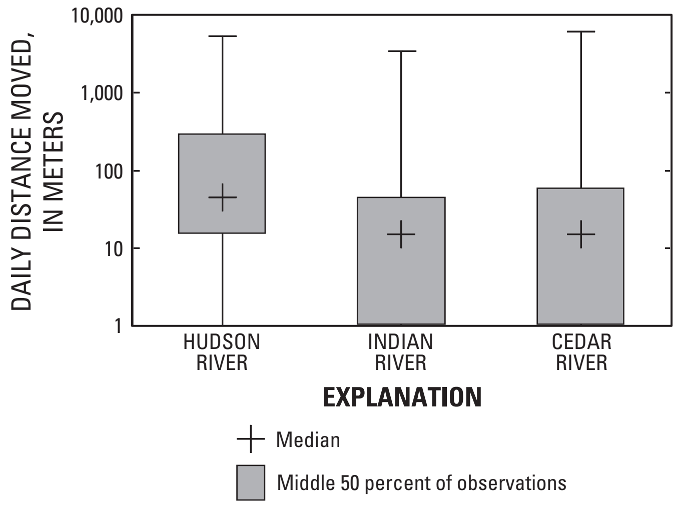

Figure 34. Graph showing sSummary of brown-trout activity (distance trout moved between consecutive days) in the Cedar, Indian, and Hudson Rivers, Adirondack Mountains, New York, during 2006.

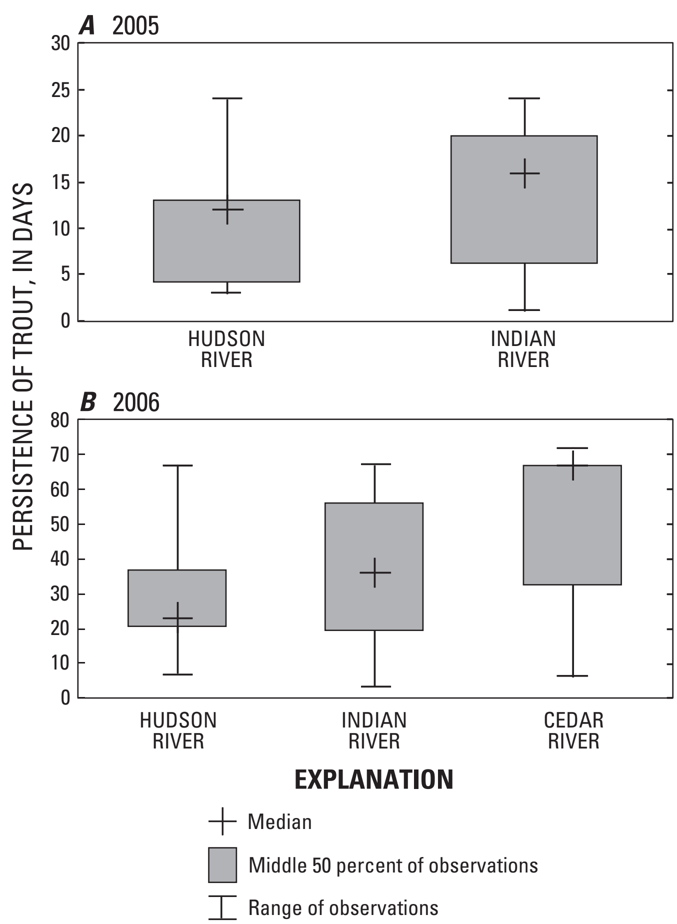

Figure 35. Graphs showing pPersistence of brown trout (number of days trout were apparently alive and within the study reach) in the Cedar, Indian, and Hudson Rivers, Adirondack Mountains, New York, during *A,* 2005, and *B,* 2006.

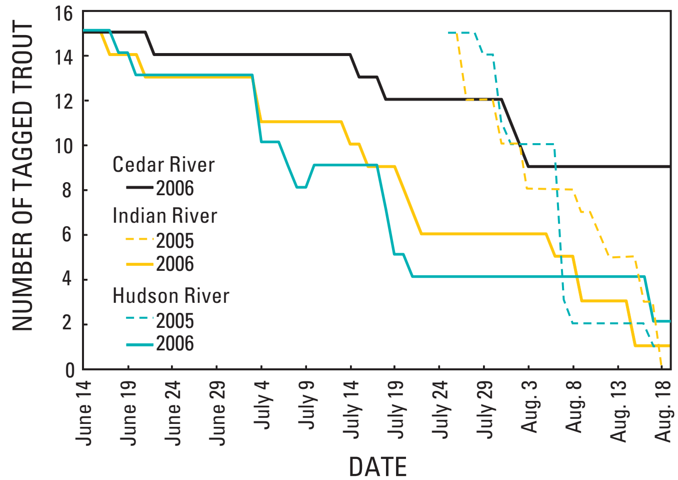

Figure 36. Graph showing tThe number of tagged trout apparently alive each day and with the study reach in the Indian and Hudson Rivers during 2005 and 2006 and in the Cedar River during 2006, Adirondack Mountains, New York.

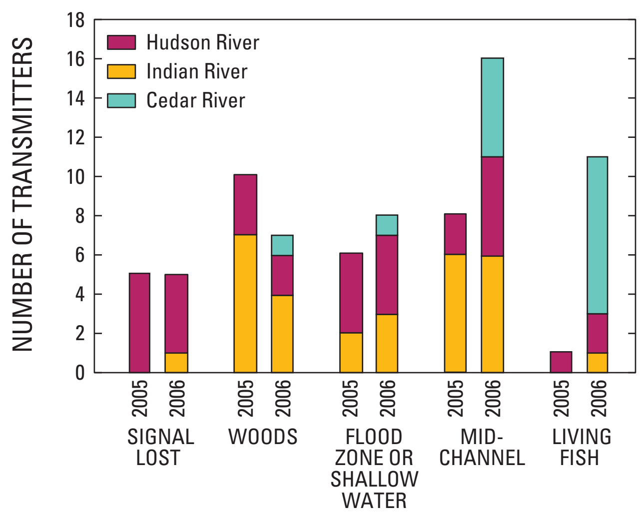

Figure 37. Graph showing cConfirmed or inferred final location of transmitters that had been implanted into 75 brown trout and stocked into the Indian and Hudson Rivers during 2005 and 2006 and into the Cedar River, Adirondack Mountains, New York, during 2006.

Summary

The water and biological resources in the lower Indian and upper Hudson Rivers were affected to different extents by the releases from Lake Abanakee. Some distinctive characteristics of these resources and measured or estimated effects that the releases may have on each are summarized by resource or by category below.

River Discharge and Stage

- Discharge at the Indian River below Lake Abanakee (IR01) increased on average by 1,207 ft^3/s during releases from June to September 2005 and by 1,410 ft^3/s from June to September 2006.
- Mean monthly increases in river stage during releases ranged from 0.79 to 2.14 ft at the three Indian River sites and from 0.67 to 3.15 ft at the four Hudson River sites downstream from the dam during June, July, August, and September of 2005 and 2006.
- River stage and flow in the Indian River below Lake Abanakee usually decreased after gate closure to levels lower than before the gate was opened, and they did not recover to prerelease levels roughly half of the time before the next release cycle began.

River Temperatures

- The recreational flow releases caused no significant or biologically relevant change in water temperatures at all fixed study sites in the Indian and the Hudson Rivers.
- Independently of releases, water temperatures at all study sites commonly exceeded the threshold (20ºC) known to be stressful to brown trout.
- Mean and median water temperatures on release days were slightly lower than mean and median water temperatures on nonrelease days.

Lake Stage (Surface-Water Elevation) in Lake Abanakee

- The releases caused Lake Abanakee stage to consistently decrease by about 0.3 ft on release days during June to September of 2005 and 2006.
- In 2005, lake stage fully rebounded between successive releases 50 percent of the time; recovery before the next release averaged 91 percent of the prerelease stage.
- In 2006, lake stage fully rebounded between successive releases 58 percent of the time; recovery before the next release averaged 98 percent of the prerelease stage.

Stream Habitat

- Short riffles dominated habitat at most Indian River and Hudson River study sites during base flows, and fewer but larger habitat units were evident during releases.
- Increased water velocities dramatically increased the amount of fast-water habitat (rapid, riffle, run) during releases. The releases also decreased the amount of slow-water habitat (pool, glide, backwater, side channel) in all study reaches.

Wetlands

- Surveyed shorelines of the Indian River contained fewer wetlands than did control reaches in the Cedar River.
- Although differences in the extent of wetlands bordering the Indian and Cedar Rivers may be attributed in part to the releases, both positive and negative effects on wetlands are conceivable and indicate that more research is needed to assess the net effect.

Temporal and Spatial Patterns in River Temperatures

- Few individual thermal refuges (waters at least 1ºC lower than the main channel) were evident in the 27-km study reach during normal summer base flows.
- Five cold-water tributaries that enter the Hudson River downstream from its confluence with the Boreas River provided most of the near-bank and off-channel thermal refuge areas in the study reach.
- The high-flow bubble produced by the releases from Lake Abanakee essentially eliminated all main-channel refuges by swamping inputs from the five cold-water tributaries.
- Analysis of temperature patterns at different spatial scales offers conflicting evidence of the effects on quality of fish habitat. Water temperatures in the middle of the reach (at Hudson Gorge) were consistently lower than those in the upper and lower reaches, and the high-flow bubble did not diminish the cooling effect.

- Remote imaging is an effective technique for identifying and characterizing certain cold-water (thermal) refuges in streams, but analyses and results can sometimes be limited by its inability to accurately separate water data from land-surface data or to detect seeps on the river bottom.

Fish Assemblages

- Fish-community biomass, density, and richness in the Indian River were strongly affected by releases at the first site below Lake Abanakee (IR01); these indexes were moderately affected at the two other sites (IR02 and IR03). Releases had a slight effect on community indexes at the first Hudson River site below its confluence with the Indian River (HR02); the effects of releases on community indexes at sites HR04 and HR05 were either positive or nonexistent.
- Releases had a strong effect on density of individual fish populations at all Indian River sites but the effects were less obvious, nonexistent, or contrary to those expected in the Hudson River.
- Releases severely affected the total biomass of populations of dominant species only at the first site downstream from Lake Abanakee (IR01). The total biomass of species populations at Hudson River study sites reflected the addition of several species, small or no decreases in the number of species, and a general increase in the balance of species populations at sites farther downstream; these trends appeared to be unrelated to the releases.
- There is no way to prove that other unmeasured factors did not contribute to the differences noted among fish communities at study sites in all three rivers. More precise information on fish communities, hydrology, and habitat would be needed to completely document site-to-site similarities and differences and determine whether the releases alone caused observed differences in population and community indexes, or whether some combination of physical, chemical, and biological factors caused them.

Macroinvertebrate Communities

- Macroinvertebrate community indexes indicate that the recreational-flow releases did not contribute substantially to the effects of the continuous releases of impounded waters from Lake Abanakee into the Indian River, and that any impoundment effect did not extend to study sites in the Hudson River.
- The larger percentage of scrapers at CR01 than at IR01, IR02, and IR03, and the occurrence of two collector-filterer species only at IR01, indicate that the releases had a minor effect on macroinvertebrate assemblages in the Indian River, primarily in the reach closest to the Lake Abanakee Dam. Comparable changes in feeding guilds or in dominant species were not evident at any Hudson River study site.

Trout Telemetry

- Use of thermal refuges by stocked brown trout varied among study reaches and ranged from low to moderate levels in the three rivers.
- The releases generally decreased the ability of many of the trout that were using thermal refuges in the Indian and Hudson Rivers to continue using them.
- Brown trout near tributaries in the Hudson River occasionally maintained lower temperatures than the river or moved into cooler tributary waters to avoid negative effects of releases.
- Multilevel effect analyses indicate the releases had a statistically significant negative effect on thermoregulation of study trout in the Indian and Hudson Rivers.
- Releases increased average temperatures of brown trout by 0.5°C in the Indian River and by 1.0°C in the Hudson River; however, the biological significance of their reduced ability to thermoregulate is uncertain.
- Daily movement of trout was significantly greater in study reaches of the Hudson River than in either the Indian or the Cedar Rivers, and movement was generally unaffected by the releases in the Indian and Hudson Rivers.
- Apparent survival for stocked trout was very low and similar in the Indian and Hudson Rivers during 2005 and 2006, but survival was higher in the Cedar River than in the other two rivers during 2006.

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