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Learning about restoration of urban ecosystems: a case study integrating public participation, stormwater management, and ecological research

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Abstract Restoration of ecosystem functions in urban environments is made challenging by 1) a public that often lacks understanding of ecological principles, 2) inadequate evidence of the effectiveness of restoration practices, and 3) difficulty integrating social and biophysical factors in studies of urban ecosystems. This paper describes a case study in which potential solutions to these challenges were explored. We facilitated collaborative learning through public participation in the design and implementation of an urban riparian buffer along a headwater stream in a neighborhood park, a process that was informed by ecological research. Learning outcomes were evaluated using surveys and qualitative assessment of discussion. Results indicated that participants' knowledge about water quality problems associated with urbanization, stormwater, and nonpoint-source pollution increased, familiarity with stormwater management practices increased, and perceptions about the importance of stream ecosystem functions changed. In-stream monitoring of sediment delivery, as well as direct measurements of buffer infiltration capacity, provided early evidence of buffer effectiveness in prevention of sediment inputs to the stream and absorption of runoff from surrounding surfaces. This study provides a useful model for integration of collaborative learning through participation, ecological restoration, and ecological research in an urban setting. Elements deemed essential to success of this model included an opportunity for dialog focused on a specific natural feature, sustained interaction between participants and researchers, opportunities for hands-on participation by urban residents, and flexibility in restoration practice installation.

Keywords Urban ecology · Urban stream · Public participation · Urban riparian buffer

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Introduction

Urban ecologists have called for projects that better integrate social and biophysical factors in investigations of urban ecosystems (e.g., Grimm and Redman 2004; Young and Wolf 2006; Casagrande et al. 2007). The need for this integration arises from the powerful, complex, and inadequately understood human influences that affect ecological attributes of urban systems. Many urban ecological studies oversimplify these human effects, while many socioeconomic studies oversimplify ecological processes (Alberti et al. 2003). Thus, efforts to fully understand urban ecosystems as well as efforts to manage those systems to restore desired functions will not be as successful as those that more effectively integrate the human dimension in urban ecological research (Pickett et al. 1997).

Authors of United States and international policy have also attempted to incorporate the human dimension into natural resource policy. The United Nations (1992) formally stated that participation of concerned individuals should be considered a necessary aspect of sustainable natural resource development. Along the same lines, the National Pollutant Discharge Elimination System (NPDES) program of the Clean Water Act set forth minimum control measures requiring communities to conduct public education and invite public participation in stormwater management efforts (USEPA 2000). Although compliance with these measures is reportedly high (White and Boswell 2006), there is little direct evidence to indicate increased knowledge or changed human behavior regarding stormwater issues. Recent literature calls for researchers to become involved in efforts to engage humans in urban ecological restoration through public participation, with the goal of scientifically testing outcomes of these efforts to determine their effectiveness (Casagrande et al. 2007; Janse and Konijnendijk 2007; Selin et al. 2007).

In this study, we sought to achieve integration by investigating the results of public participation in an urban restoration project that was informed by ecological research. Specific objectives of this study were to 1) facilitate collaborative learning through public participation in implementing an urban ecological restoration project, 2) install a functioning restoration practice, and 3) conduct research to determine effectiveness of the restoration practice and to inform the collaborative learning process.

Participation in ecological restoration projects exposes participants to environmental issues and fosters learning; thus, public participation and collaborative learning can be closely linked (McDaniel and Alley 2005; Pahl-Wostl et al. 2007; Selin et al. 2007). Involving the public in ecological restoration projects has strong potential to enhance public awareness of local ecological problems. It has also been shown that ecological research can inform learning processes and enhance public awareness (e.g., Fenemor et al. 2008). Participation, learning, and enhanced awareness may in fact provide additional benefits for restoration efforts, such as increasing individual interest and involvement in environmental issues and activities (McDaniel and Alley 2005; Thompson et al. 2005), as well as contributing to social acceptance of specific restoration projects by providing opportunities for public input (Daniels and Walker 2001).

Nationwide, scientific monitoring of ecological restoration projects has been inadequate, leaving scientists, managers, and the public uncertain about the return on billions of dollars of investment in these projects (Bernhardt et al. 2005). Lack of adequate monitoring and uncertainty regarding effectiveness is of particular concern with respect to stormwater management practices. Communities regulated under NPDES authority are required to implement stormwater best management practices to reduce their contribution to stormwater-derived degradation of water resources (USEPA 2000). However, considerable doubt remains as to the efficacy of many of these practices (Pennington et al. 2003). Specifically, efforts to monitor effectiveness of preserved or restored riparian vegetation have produced conflicting results, with some studies suggesting positive effects on stream condition (Miltner et al. 2004; Muenz et al. 2006) and others revealing little or no benefit to streams (Roy et al. 2005; Walsh et al. 2007). Integration of research with ecological restoration is clearly needed to understand relationships between ecological restoration practices (such as riparian buffers), water quality, and stream condition.

Ecological research could also benefit from integrating public participation and restoration. In addition to the need for better scientific understanding of the human role in urban ecosystems, residents' knowledge about local landscapes and their interactions with them can improve researchers' understanding of urban ecosystems (Pickett et al. 2004). Finally, urban restoration projects can serve as experiments, where important research questions are answered through assessment of newly-installed practices (e.g. Felson and Pickett 2005).

A primary goal of this study was to develop a conceptual model for integrated urban ecology projects in which linkages among learning, restoration, and research are intentionally developed. Our initial conceptual model (Fig. 1) is intended to illustrate how these linkages could inform and improve the outcome of each of these individual project components. This paper reports results of a case study in which outcomes of learning, restoration, and research objectives were assessed both individually and in terms of their effect on one another. The ecological restoration project that served as the focus of this study was a constructed urban riparian buffer implemented to protect a stream channel by reducing the rate and quantity of overland stormwater flow to the stream. However, important elements of integration discussed in this paper are applicable to other ecological restoration projects that include both public participation and research.

Methods

Study area and project overview

This study was conducted in Ames, Iowa, a city with a population of 50,700 in the Des Moines Lobe ecoregion of central Iowa (Fig. 2a). College Creek, a first-order tributary of Squaw Creek, was the focus of this study, while data collected from Clear Creek, a neighboring tributary, was also used to inform understanding of local stream conditions (Fig. 2b). Ames is subject to stormwater permitting under the NPDES Phase II program,

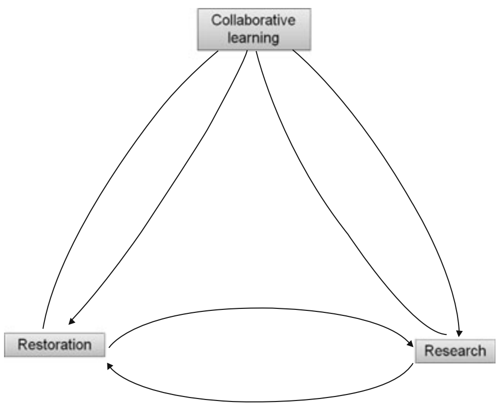

Fig. 1 Conceptual diagram showing integration among objectives of this study: collaborative learning, restoration, and research

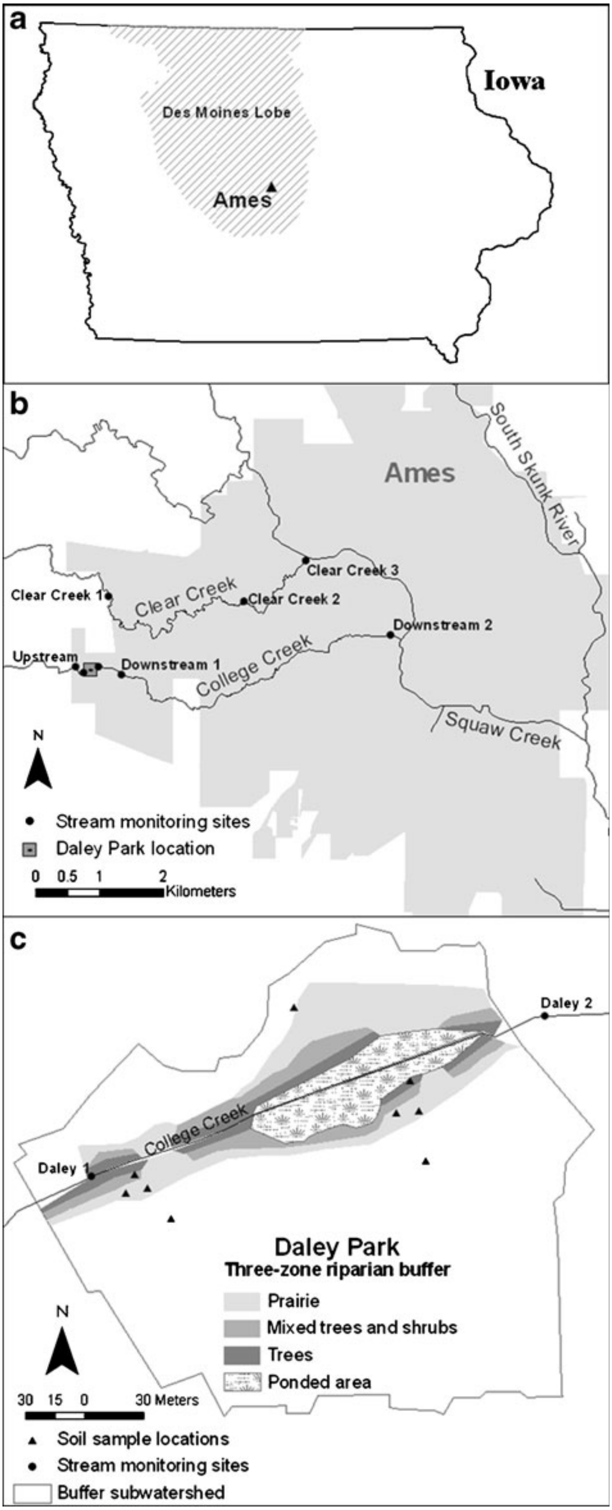

Fig. 2 Location of Ames within Iowa (**a**), map showing study streams, stream monitoring sites, and the location of Daley Park within Ames, IA (**b**), diagram of Daley Park showing the three-zone riparian buffer and soil core sampling locations (**c**)

and to the minimum control measures established by that regulation (USEPA 2000). To help meet these requirements, city officials, other government (Soil and Water Conservation Districts), and non-governmental organizations (Prairie Rivers Resource Conservation and Development) had been engaged with project personnel on preliminary efforts to examine land use and stream condition in the College Creek watershed.

Based on these interactions, we designed a research and demonstration project aimed at assessing different stormwater management practices: an infiltration practice, a stream channel protection practice, and a filtration practice. Work reported in this paper is focused on activities surrounding the largest of the three practices, an urban riparian buffer. Preliminary discussions with project partners were used to determine a suitable site for a riparian buffer. Daley Park, a city property in west Ames (Fig. 2c), was selected for the location of the riparian buffer because of its location near the headwaters of College Creek and because of evidence of stream bank erosion due to runoff from the surrounding landscape. This park is a 4.9-ha neighborhood park managed by the City of Ames Department of Parks and Recreation. A 267-m reach of College Creek runs through the northern edge of the park. The entire park and part of a subdivision surrounding the park (approximately 6.1 ha) drain to the stream corridor. The stream and associated riparian zone occupy just over 2 ha of the site, formerly an unmanaged area containing *Phalaris arundinacea* (reed canary grass), *Morus alba* (white mulberry), *Acer negundo* (boxelder), *Typha latifolia* (common cattail), and fewer representatives of other species including *Celtis occidentalis* (hackberry), *Juniperus virginiana* (eastern redcedar), *Populus deltoides* (eastern cottonwood), and some shrubs.

The buffer project served as the focus for participatory meetings to which neighborhood residents were invited, and a research project was designed to monitor water quality and provide direct measures of buffer effectiveness. All aspects of this project, including public participation activities, buffer design and installation, and ecological data collection and analysis were conducted by or directly managed by the authors.

Learning through public participation

Public participation involved group meetings (eight in 2007, five in 2008) held at or near Daley Park and other activities associated with the riparian buffer. Invitations were mailed or hand-delivered to each home (approximately 60 households) located adjacent to the park. Although census block data are not specific to these homes, an estimate based on a larger area surrounding the park indicated approximately 140 persons reside there (U.S. Census Bureau 2000). Outreach was focused on these households because of their proximity to the neighborhood park. In addition, many of these homes were adjacent to the site of the planned riparian buffer, so it was appropriate to notify these residents in particular about potential change in the landscape near their homes, and to provide opportunity for discussion and participation in further planning.

Each invitation included a brief explanation of project activities and information regarding discussion topics and activities planned for an upcoming meeting. Flyers were also posted in the park to invite other park users to the meetings. As participants arrived, they were asked to sign in to provide a record of their attendance and to facilitate subsequent communication. Regular attendees received e-mail communications that included meeting reminders and updates on activities.

Meeting structure, including discussion topics, sequence of events, and timing of activities, was determined by the authors prior to each meeting, documented in an outline, and followed closely. Meetings began with introductions of project personnel and community participants, a brief overview of the project and recent activities, followed by discussion of planned topics and question-and-answer discussion sessions. Hands-on activities, when they occurred, were introduced after discussion. All activities were conducted using a collaborative learning approach (e.g. Johnson et al. 1998; Daniels and Walker 2001), which facilitated integration of participants' prior knowledge, encouraged expression of diverse viewpoints, and equalized perceived power differentials (e.g, between community members and researchers, Thompson et al. 2005).

Topics were chosen to develop mutual understanding about urban water quality issues in general and local water quality issues specifically. Hands-on activities included a design workshop, in which participants were provided with schematic diagrams and explanations of functional characteristics associated with the components of riparian buffers, and invited to develop alternative buffer designs that incorporated their individual preferences. Small groups of participants were given an aerial photo of the park on which to create proposed layouts for the buffer. A city representative also attended and facilitated a question-and-answer session about this and other local stream projects.

Learning was assessed using pre- and post-participation surveys and qualitative assessment of dialog during discussions with residents. Participants at the first three meetings were provided a brief questionnaire (14 items) on-site at the first meeting they attended. Questions assessed participants' understanding and values related to watersheds, water quality, stream functions, typical urban pollutants, and their preferences for receiving information on these topics. Most questions were closed-ended items with a request for participants to "check all that apply", "check only one", choose yes or no, or choose a rating on an ordinal measurement scale (e.g. excellent to unacceptable). The same questionnaire was distributed as a mail-return survey at the conclusion of the project to assess changes in knowledge and perception following participation. Post-participation surveys were mailed to the 20 participants who attended multiple meetings during both years of the project (i.e. those with sustained participation and likely to have engaged in learning) following the procedure outlined in Dillman (2000). Pearson's Chi-square tests were used to identify significant differences ($p<0.05$) between pre- and post-participation survey responses (JMP, Version 7, SAS Institute, Cary, NC).

A note-taker attended all neighborhood meetings and recorded all presentation and discussion topics. To analyze discourse among participants, two researchers independently examined meeting notes to become familiar with all content, consider the meaning of statements, and organize statements into major themes (e.g., Colaizzi 1978). All public participation project components (public meetings, survey questionnaires) were conducted according to protocols approved by the Office for Responsible Research at Iowa State University. Items on survey questionnaires were also reviewed by personnel in the Center for Survey Statistics and Methodology at Iowa State University.

Assessment of stormwater management practice installation

To guide activities related to buffer design, installation, and maintenance, the buffer site was evaluated by project personnel, and activities were documented by the authors. Early site evaluation was conducted to inform design of the buffer, including overall size to maximize runoff capture, as well as the size and arrangement of each buffer zone, and to determine necessary quantities of plants, seed, and other materials. Installation work was largely done by project staff in May and June, 2007. Planting materials included municipal compost, 1-year-old tree seedlings, 2-year-old shrub seedlings, local ecotype prairie seed mix, and tree protectors. After plantings were completed, the site was evaluated regularly by project personnel to assess survival and determine maintenance needs. Maintenance was organized by project personnel and conducted by student employees and volunteers from among the neighborhood meeting participants.

Ecological research

Buffer capacity to infiltrate water Direct measurements of buffer capacity to infiltrate water were made by collecting soil cores extracted using a slide hammer soil corer (5.1-cm diameter; 15.2-cm length). Volumetric water content and soil bulk density were calculated for samples collected on four dates during June, July, and August (2008) within 24 h of a minimum 2-cm rain event. Soil cores were taken from four park areas with different soil characteristics: park lawn, planted prairie without compost application, planted prairie with compost application, and undisturbed areas closest to the stream (Fig. 2c). Two cores were extracted from each of two locations in the three buffer areas, and two cores were extracted from each of three locations on park lawn. Cores were kept in air-tight containers and processed immediately after sample collection. For each core, soil was weighed and dried at 60°C for 24 h or until constant weight was obtained. Soil samples were weighed again after drying to determine soil moisture content. Volumetric water content was calculated as soil moisture divided by soil core volume, and mean soil bulk density was calculated as soil dry weight divided by soil core volume. Infiltration rate in each area was calculated on two dates immediately following soil core extraction. Core holes were filled with water, and depth to the water's surface was measured every 30 min until either no water remained or after 3 h had elapsed. A mean value for each area was determined and used in analysis. Analysis of variance was used to determine the presence of significant differences ($p \leq 0.05$) across the dataset for all park areas, and pairwise multiple comparison tests (Tukey) were used to identify areas having different infiltration rates.

Runoff generation or capture for each of the four areas (lawn, prairie with or without compost, and riparian) was estimated for a rain event with 3.18-cm/h rainfall intensity (90% of Iowa storms; CTRE 2008). This value was calculated by subtracting the mean infiltration rate from precipitation rate (3.18 cm/h) and multiplying by the surface area to determine the volume of water generated or absorbed by each area (a positive number indicated runoff generation, while a negative number indicated excess capacity to absorb water).

Buffer effectiveness for stream water quality improvement In-stream grab samples (at 0.6 depth) for nutrient and sediment analyses were collected at two sites on College Creek in Daley Park: one directly upstream and one directly downstream of the installed riparian buffer (Fig. 2c). Sampling was conducted once every 2 weeks during spring and summer, and once every month during fall, for a total of 30 sample dates over a 3-year period (June to October, 2006; April to October, 2007; April to September, 2008), with both sites visited consecutively on the same day. Samples collected throughout 2006 and in early 2007 (through May 2007) represent conditions before buffer installation, samples collected from June 2007 through September 2008 represent those after buffer installation. Samples were placed in coolers and cold-stored until analysis. Nitrate samples were preserved with 5% sulfuric acid at the time of collection. Concentrations of nitrate-nitrogen (NO_3-N), total phosphorus (TP), and total suspended solids (TSS) were determined in the laboratory using standard methods (USEPA 1978, 1993a, b method 353.2 for nitrate and 365.1 and 365.3 for unfiltered phosphorus; and Eaton et al. 2005 for TSS). To measure discharge, we stretched a tape measure across the stream, divided the channel into five cells of equal width, and measured stream depth at the midpoint of each cell. We used a current meter to record four flow velocity readings per cell at six-tenths depth. We calculated an average value for each of the five cells from these four readings, multiplied this average velocity by the cross-sectional area of the cell, and summed the resulting five values (one per cell) to obtain total discharge for a sample site (Rantz 1982).

To determine delivery of NO_3-N, TP, and TSS for each sample date, parameter concentrations were multiplied by discharge, and the resulting value was divided by sub-basin area (the watershed area upstream of each sample site) to yield units of kg/ha/day. So that delivery rates before and after riparian buffer installation could be compared, we partitioned the 30 delivery values for each parameter into four seasons per year: spring (April to early June), early summer (mid-June to early July), late summer (early July to late August), and fall (mid-August to October). Dates included in each season during each year were determined by similarity of discharge (i.e., sample dates within overlapping seasonal ranges were placed with sample dates of similar discharge). Seasonal means were then calculated for each parameter, and the difference between delivery upstream and downstream of the buffer was determined. Analysis of variance and student's *t*-tests (each pair) were used to determine significant differences ($p \leq 0.05$) between delivery in each pair of seasons (e.g., early summer nitrate delivery in 2006 was compared to nitrate delivery in early summer, 2007 and early summer, 2008).

Assessment of stream ecological condition Macroinvertebrate and fish metrics were measured, and dissolved oxygen levels and *Escherichia coli* densities were determined. These assessments were conducted at five sites on College Creek (upstream of Daley Park, directly upstream of the buffer in Daley Park, directly downstream of the buffer, and two sites downstream of Daley Park) and three sites on Clear Creek (Fig. 2b and c).

Macroinvertebrates and fish were sampled in summer, 2007. At each site, macroinvertebrates were sampled from three plot locations (0.28-m^2 total benthic surface area sampled per site) within a 10-m stream reach by transferring benthic substrate to a D-frame net (Herringshaw 2009). All samples from a single site were combined to obtain one invertebrate sample per site. Benthic samples were analyzed in the laboratory by first comprehensively searching for and removing all large-bodied organisms (visible to the unaided eye, e.g., larger than approximately 0.5 cm). Subsequently, subsampling at 10x magnification was used to remove small-bodied organisms from samples. We identified insects and mollusks to family level and most other invertebrate groups to order or class. Fish were sampled from a stream reach 35 times mean stream width or 300 m, whichever was longer, using a backpack-mounted DC electrofisher (Smith-Root Model LR-20, Smith-Root Inc., Vancouver, WA) with two netters in a single upstream pass (Fischer et al. 2009). Macrohabitats in reaches were sampled individually. Prior to sampling, block nets were set when flows permitted to prevent movement of fishes among sampled macrohabitats. Fish were identified to species level. Standard metrics were used to quantify fish and invertebrate community structure, including abundance (for invertebrates, number of individuals/m^2; for fish, number of individuals/sample site) and taxa richness (number of taxa/sample site).

Dissolved oxygen concentrations were measured in-stream during daylight hours on five dates during June and July, 2007, using either the Winkler method or a portable electronic meter. *E. coli* densities were measured from samples taken monthly from May to October, 2007, and May to September, 2008. Grab samples (100 mL) were taken from the middle of the water column, chilled, and transported to the laboratory for analysis within 2 h of sample collection. Samples were analyzed using an Idexx Quanti-Tray/2000 and Colisure test kit (IDEXX Laboratories Inc., Westbrook, ME) to estimate the most probable number of colony-forming units per 100 mL.

Results

Three elements were integrated in this study: 1) collaborative learning among community residents, city partners charged with carrying out NPDES regulations, and ecological researchers, 2) urban ecological restoration (in particular, installation of a stormwater management practice), and 3) ecological research.

Collaborative learning

Levels of participation in neighborhood meetings, pre- and post-participation survey results, and themes emerging from discussions with residents and city partners provided evidence of collaborative learning. In 2007, neighborhood meeting discussion topics focused on general information about urban water quality issues and stormwater management practices (e.g., Arnold and Gibbons 1994; Schueler and Holland 2000; Klapproth and Johnson 2001), as well as discussion about the design, installation, and establishment of the riparian buffer in Daley Park (Table 1). In 2008, discussions were centered on information gathered from monitoring in the park and local streams, with data presented on water quality, buffer establishment and measures of buffer effectiveness, and aquatic ecology. Thirty-six individuals participated in one or more of the eight meetings held in 2007, and 30 individuals participated in at least one of the five meetings held in 2008. Twenty residents participated in multiple meetings during both years. In total, 46 different individuals participated in project activities over the 2-year period, with an average of seven residents participating at each meeting. Participants were also engaged in interactive buffer tours, where they assessed establishment of buffer plants, and several residents were involved in hands-on activities such as buffer design, buffer maintenance, and an aquatic ecology workshop, where participants were invited to view local invertebrate and fish specimens using microscopes. A few individuals with particular concerns about the buffer or interest in additional information requested one-on-one meetings with project staff (Table 1). In addition, other consultations with participants took place through e-mail and telephone conversations.

Table 1 Discussion topics and participation at meetings held with Daley Park neighbors concerning College Creek, urban water quality issues, and the installation of an urban riparian buffer on park property

	2007	2008
Discussion topics	Water quality, urban stream hydrology, stormwater and stormwater management, riparian buffers, succession, stream and water quality monitoring	College Creek water quality, buffer effectiveness, aquatic ecology, buffer establishment, succession
Number of participants	36	30
Number of group meetings	8	5
Average attendance: all group meetings	7	7
Average attendance: buffer tours	9	6
Number of participants at design workshop	10	NA
Number of participants engaged in hands-on installation and maintenance	2	12
Number of one-on-one meetings with project staff	4	2

Eleven of 14 pre-participation surveys were returned (78% return rate), while 10 out of 20 post-participation surveys were returned (50% return rate). Differences in pre- and post-participation response rates were most likely attributable to survey administration (the pre-survey was administered on-site as meetings began, whereas the post-survey was a mail-return questionnaire). Pre- and post-participation respondents were on average 45% and 55% male, 48 and 57 years old, and had resided in the community for an average of 23 (±5.3) and 21 (±4.3) years, respectively. These data indicate that survey respondents were older and had resided in the community longer than the overall population of Ames.

Comparison of pre- and post-participation survey responses provides evidence that participants learned basic principles of stormwater management and urban stream ecology, and that their attitudes concerning these issues changed (Tables 2 and 3). The number of respondents identifying non-point source pollutants as problems for urban streams, a common topic of discussion at our meetings, increased from pre- to post-participation surveys, and this difference was statistically significant (Table 2a). Industrial waste, which was not discussed in depth during our project, was also identified more often in post-participation surveys as a problem for urban streams. A higher proportion of respondents in post-participation surveys correctly identified pathways of stormwater movement in their neighborhood, although this difference was not statistically significant (Table 2b). Similarly, a higher (but not significantly different) proportion of residents agreed that there was a problem with stormwater in their community after participation (Table 2c). Participant familiarity with all stormwater management practices increased, and the number of respondents familiar with bioswales and riparian buffers as urban stormwater management practices increased significantly from pre- to post-participation surveys (Table 2d). In the case of riparian buffers, 100% of respondents taking the post-participation survey reported being familiar with this practice.

Survey responses also suggested changing values and perceptions about urban streams (Table 3), although pre- and post-participation responses were not statistically different. Most respondents did not think local stream quality was acceptable before or after participating in this project (Table 3a). After participation, all survey respondents viewed stream quality as unacceptable, whereas 9% thought it was acceptable before participating. Reasons for valuing streams also changed slightly; for example, fewer post-participation respondents indicated that streams “just are” important, and more of them indicated that they value streams for “visual enjoyment” (Table 3b). Perceptions regarding the functions that streams should perform also changed. In general, importance placed on providing habitat for aquatic organisms increased (Table 3c).

Several common themes emerged from participant comments in group meetings and individual discussions between researchers and residents over the 2-year timespan of the project. We organized these into three thematic categories: concern, affirmation, and interest (Table 4). Some concerns were raised at meetings that occurred during buffer design and installation phases. For example, some residents expressed concern that trees would block visual access to the park from their property, while others expressed concern that the buffer might reduce physical access to or visual connection with the stream. Potential landscape changes were also of concern to some residents. Growth of prairie grasses in the park adjacent to back yards of neighboring homes was perceived as undesirable by a few residents, while others expressed concern that rehabilitation of the stream channel itself might drain a ponded area of the stream that they valued for its wildlife viewing opportunities. Finally, participants expressed concern that the buffer would not be managed appropriately over the long term, and expressed relief that project personnel and city partners would be involved in on-going maintenance. In general, most concerns reflected

Table 2 Survey respondents' pre- and post-participation knowledge about urban stormwater and stormwater management practices. Numbers represent the percentage of respondents (n=11 and n=10, respectively) selecting each item in pre- and post-participation surveys

a) Which are problems in area urban streams? Check all that apply.	Industrial waste	Fertilizers	Sediment	Fallen trees, branches	Hazardous substances	Bacteria	Rocks, gravel	Non-point source pollutants
Pre-participation	27	100	64	64	55	91	18	27
Post-participation	90[a]	80	70	50	90	70	20	90[a]
b) What happens to water during heavy rain or rapid snowmelt in your neighborhood? Choose only one.	Most soaks into the ground		Some soaks in; most flows into a ditch		Some soaks in; most flows into a sewer system		Not sure	
Pre-participation	0		18		64		18	
Post-participation	0		10		90		0	
c) Is there a problem with stormwater in your community? Choose only one.	Yes		No		Don't know			
Pre-participation	45		9		45			
Post-participation	80		0		20			
d) Which stormwater management practices are you familiar with? Check all that apply.	Rain gardens	Detention ponds	Surface sand filters	Grass channels	Bioswales	Pervious pavers	Riparian buffers	
Pre-participation	36	82	36	73	18	27	55	
Post-participation	60	100	60	90	60[a]	60	100[a]	

[a] Difference between pre- and post-participation surveys significant ($p \leq 0.05$) based on Pearson's Chi-square test

Table 3 Survey respondents' pre- and post-participation values and perceptions about streams and water quality. Numbers represent the percentage of respondents (n=11 and n=10, respectively) selecting each item

a) How would you rank stream water quality in your community? Choose only one.	Excellent		Acceptable	Somewhat unacceptable	Unacceptable		Don't know
Pre-participation	0		9	36	36		18
Post-participation	0		0	60	40		0
b) If streams are important to you, why? Check all that apply.	Just are	Boating, fishing	Wading, swimming	Use nearby trails	Visual enjoyment	Live near stream	Education
Pre-participation	64	55	55	64	55	100	36
Post-participation	30	40	50	80	90	100	10
c) Which functions should be performed by area streams? Check all that apply.	Drain water from land	Safe water for swimming, skiing	Habitat for: Game fish for consumption	Other game fish	Small, non-game fish	Sensitive fish and other organisms	
Pre-participation	82	73	45	55	73	73	
Post-participation	80	80	80	80	100	70	

participant desires to improve the quality of the stream and riparian area while maintaining valued personal and social benefits offered by the stream and park.

A second theme, affirmation, reflected positive perceptions of the buffer by neighborhood residents (Table 4). Residents (with and without children) indicated that the stream buffer was an important opportunity for neighborhood children to learn about the environment. Several participants stated that they were glad for an opportunity to discuss the stream and were pleased that the city was engaged in stream improvement activities. Several participants also expressed enthusiasm about additional wildlife that native plantings might attract to the park. Others were optimistic that aquatic organism abundance would increase as well. Regular meeting participants, as well as other park users, frequently commented on the attractiveness of establishing prairie areas, and conveyed enthusiasm about anticipated growth of later-successional tree species added to the landscape.

The third thematic category, interest in water quality issues, reflected participant desires to improve local streams (Table 4). Beginning early in the project, participants noticed and reported physical stream characteristics that they found troubling, such as bank failures on College Creek. Several expressed interest in keeping the stream "clean" (free of debris and trash). Residents also expressed interest in water quality problems indicated by stream monitoring data from College Creek, particularly as it pertained to aquatic life. Early in the

Table 4 Themes emerging from group and individual discussions with Daley Park neighbors during design, installation, and establishment of an urban riparian buffer along College Creek on park property

Category	Emerging themes	Examples
Concern	Access to stream	Loss of views of the park, stream, and wildlife, enclosure of stream in trees, loss of physical access to stream
	Landscape change	Loss of ponded area in stream (wildlife value), growth of unmown prairie behind backyards
	Buffer management	Responsibility for management of the buffer in the future, continued involvement of project personnel
Affirmation	Learning opportunities	Focus for neighborhood discussions about the creek and water quality, place for children to learn about plants and wildlife
	Wildlife habitat	Improved stream and riparian area habitat, increased opportunities to see birds, butterflies, small mammals
	Aesthetics of buffer	Attractiveness of prairie plants, potential aesthetic benefits of mature trees on the landscape
Interest in stream improvement	Physical stream characteristics	Prevention of bank failures, removal of debris from stream
	Water quality	Prevention of damage from construction site runoff, sewage contamination, overuse of fertilizer on park lawn
	Best management practices	Consideration of information for managing stormwater on private properties, suggestions for further improving stormwater management in the park

project, residents stated that they seldom saw fish in the stream, and expressed interest in how water quality related to aquatic life. They were also interested in water quality problems based on other activities they observed, such as construction site runoff, overuse of fertilizer, and past sewage contamination. Because of historical water quality problems, residents expressed particular interest in information about bacteria in College Creek. Finally, several residents requested information about implementing stormwater management practices on their own properties (rain gardens, pervious pavers, organic pesticides), while others were interested in finding ways to further improve stormwater management in Daley Park.

Installation of a stormwater management practice

We conducted installation of the urban riparian buffer as a three-step process during spring 2007 that was coordinated with the neighborhood meetings previously described. Results described here include a description of that process, the plants and other materials used to install the three-zone buffer, and survival and establishment of plants over the 2 years since the project began (Table 5). The first step, prior to buffer installation, was removal of non-native and aggressive species of trees, shrubs, and other riparian plants by cutting, pulling, and spraying. After clearing undesirable vegetation, we planted approximately 210 trees and 100 shrubs in the buffer zones closest to the stream. We applied and incorporated compost along the southern outermost zone of the buffer and, following a 2-week resting period for the compost, drilled a 20-species prairie seed mix into the outer zone with a Brillion™ seed drill. The three zones of the buffer (Schueler 1995) were sized to fit the available space between a walking trail and the stream on the south side, and between private properties and the stream on the north side.

Five species of trees, five species of shrubs, and 20 species of grasses and forbs were planted in the three-zone buffer (Fig. 2c, Table 5). Trees were planted on 3-m centers in the area nearest the stream. Adjacent to the tree zone, a zone of mixed trees and shrubs was planted, also on 3-m centers. A zone of prairie grasses and forbs was planted farthest from the stream. However, in two areas on each side of the stream, prairie planting extended to the edge of the stream (trees and shrubs were omitted) to allow visual and physical access to the stream for residents, park users, and maintenance crews (Fig. 2c). We found a 91% survival rate for trees 2 years after planting, and were able to detect all but one prairie species, rattlesnake master (*Eryngium yuccifolium*), 2 years after planting (Table 5). There was considerable mortality among shrubs in the first year, necessitating replanting in 2008.

Ecological research

Buffer capacity to infiltrate water Analysis of soil cores revealed no statistically significant differences in volumetric water content or bulk density between park lawn, planted prairie, and undisturbed riparian soil areas (Table 6). However, infiltration rates were significantly higher in undisturbed riparian soil than all other areas. Although not statistically significant, infiltration rate in buffer prairie areas was, on average, slightly higher than in the park lawn, and composted areas of the planted prairie had slightly faster infiltration rates than prairie areas without compost. We used these mean infiltration rates to estimate the capacity of the buffer to capture inputs from a 3.18-cm/h rain event (90% of all rainfall events). This storm would result in 59.7 m^3/h of runoff from the park lawn area. Our estimates indicated that all three zones of the buffer would have the capacity to infiltrate directly incident precipitation, as well as part of the runoff from the contributing area.

Table 5 Information about buffer installation, materials used in the three zones of the buffer, and data reflecting establishment success after 2 years of growth. See Fig. 2c for zone locations

Installation process	
Removal of undesirable (non-natives or aggressive) species	
Tree and shrub planting	
Prairie seeding	
Plant materials	Surface area installed
Trees (1-0 and 2-0 bare-root stock)	Zone 1: 1,458 m^2 (trees only)
Quercus macrocarpa (bur oak), *Quercus bicolor* (swamp white oak), *Celtis occidentalis* (hackberry), *Platanus occidentalis* (sycamore), *Betula nigra* (river birch)	
Shrubs (1-0 bare-root stock)	Zone 2: 2,151 m^2 (trees and shrubs)
Prunus americana (American plum), Physocarpus opulifolius (ninebark), Amelanchier arborea (serviceberry), Sambucus canadensis (elderberry), Prunus tomentosa (Nanking cherry)	
Grasses (seed)	Zone 3: 4,781 m^2 (prairie grasses and forbs)
Andropogon gerardii (big bluestem), *Schizachyrium scoparium* (little bluestem), *Elymus canadensis* (Canada wild rye), *Sorghastrum nutans* (indiangrass), *Sporobolus clandestinus* (rough dropseed), *Bouteloua curtipendula* (side-oats grama), *Elymus virginicus* (Virginia wildrye)	
Forbs (seed)	
Rudbeckia hirta (black-eyed Susan), *Rudbeckia triloba* (brown-eyed Susan), *Rudbeckia subtomentosa* (sweet black-eyed Susan), *Echinacea pallida* (pale purple coneflower), *Ratibida pinnata* (yellow coneflower), *Heliopsis helianthoides* (early sunflower), *Desmanthus illinoensis* (Illinois bundleflower), *Cassia fasciculate* (partridge pea), *Petalostemum candidum* (white prairie clover), *Petalostemum purpureum* (purple prairie clover), *Eryngium yuccifolium* (rattlesnake master), *Asclepias incarnata* (rose milkweed), *Verbena hastata* (blue vervain)	
Soil amendments (compost; 5-cm depth; south side of stream only)	2,000-m^2 surface area
Buffer plant materials	Establishment success
Trees	91% survival
Shrubs	NA
Prairie grasses and forbs	19/20 species detected

Assuming that runoff from the lawn area would proceed from the outer edge of the buffer, flow first across the buffer's prairie, and then across the undisturbed riparian area, we estimated that the prairie could absorb an additional 34.5 m^3/h (prairie without compost) and 18.8 m^3/h (prairie with compost). The remaining 6.4 m^3/h likely to be contributed would be absorbed by the undisturbed riparian area, which has an estimated capacity to absorb 274.7 m^3/h (Table 6). Thus, the buffer's capacity to absorb runoff exceeds the rainfall contributions of 90% of storms from the contributing area.

Buffer effectiveness for stream water quality improvement Pre- and post-installation stream water quality data were used to determine change over time in relation to buffer installation. Delivery rates for all parameters were strongly influenced by discharge (Fig. 3). Nitrate delivery rates were generally below 0.20 kg/ha/day, except during late summer, 2008, when delivery just upstream of the buffer (Daley 1) exceeded 0.40 kg/ha/day (Fig. 3b). Sites just upstream (Daley 1) and just downstream (Daley 2) of the buffer generally had similar delivery rates, with the exception of late summer, 2008, when the upstream site had

Table 6 Mean (with standard error in parentheses) volumetric water content, soil bulk density, and infiltration rates in four zones of Daley Park (lawn, planted prairie with and without compost application, and undisturbed riparian soil with established vegetative cover) on four dates in summer 2008 following rain events of ≥2 cm/day. All data were collected at least 1 year after installation of the riparian buffer. Runoff/absorption calculated as remaining depth of 3.18-cm/h rainfall after infiltration, multiplied by surface area of each zone

Area	Volumetric water content (g/cm^2)	Mean soil bulk density (g/cm^3)	Mean infiltration rate (cm/hr)	Runoff generation (m^3/hr)	Total absorption capacity for each area (m^3/hr)
Park lawn	0.27 (0.01)	1.46 (0.03)	3.02[b] (0.32)	59.7	
Prairie without compost	0.31 (0.03)	1.64 (0.24)	4.24[b] (0.68)		−34.5
Prairie with compost	0.26 (0.01)	1.49 (0.03)	4.39[b] (0.59)		−18.8
Undisturbed riparian	0.28 (0.01)	1.41 (0.04)	7.48[a] (1.03)		−274.7

[a, b] a > b at p≤0.05 (Student's *t*-test, each pair)

substantially higher delivery than the downstream site. Phosphorus delivery rates varied from near zero to above 0.10 kg/ha/day during late summer, 2008 (Fig. 3c). Differences between phosphorus delivery upstream and downstream of the buffer were large during late summer, 2006, when delivery at the downstream site was considerably higher, and during

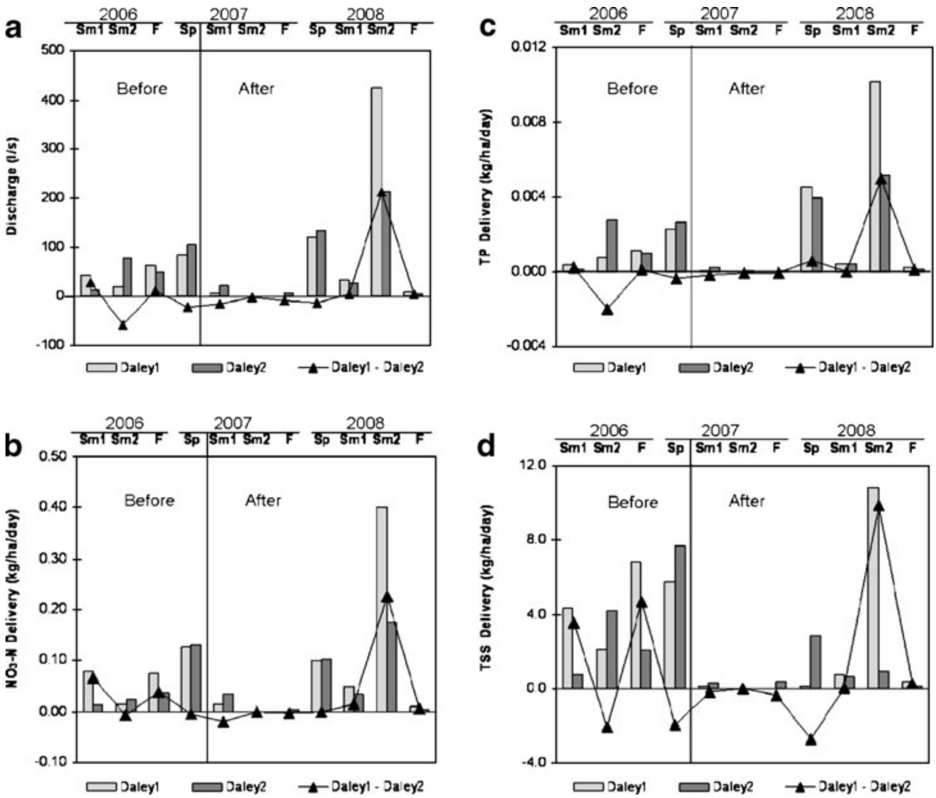

Fig. 3 Seasonal means for discharge (**a**) and delivery rates of nitrate (**b**), total phosphorus (**c**), and total suspended solids (**d**) at College Creek sites located directly upstream (Daley 1) and downstream (Daley 2) of the riparian buffer. For seasons, Sp = spring, Sm1 = early summer, Sm2 = late summer, and F = fall

late summer, 2008, when delivery at the upstream site was considerably higher. Total suspended solids delivery was lower after buffer installation, with the exception of late summer, 2008, when sediment delivery at the site upstream of the buffer, exceeded 11 kg/ha/day (Fig. 3d). Differences between upstream and downstream sediment delivery were variable, with the largest difference in late summer, 2008, when delivery upstream was considerably higher than delivery downstream. The difference between upstream and downstream delivery for all three parameters was significantly higher in late summer, 2008, than in the same season in earlier years (Table 7), although these differences were driven to some extent by greater differences in discharge (Fig. 3a).

Assessment of stream ecological condition Six invertebrate taxa and two fish species were found in Daley Park, and as many as 12 invertebrate taxa and nine fish species were identified in downstream reaches of College Creek (Table 8). Invertebrate densities in College Creek were higher on average than in Clear Creek (the nearby reference stream), although invertebrate taxa richness was similar across urban streams. Both fish abundance and fish species richness were considerably lower in College Creek sites than in Clear Creek sites (Table 8). Additional indicators of ecological condition in College Creek included dissolved oxygen concentrations and *E. coli* densities. Dissolved oxygen concentrations were stable across sites throughout spring and early summer sampling dates during both years, but were very low (less than 2 ppm) in late summer, 2007 (Fig. 4). *E. coli* levels ranged from 56 to greater than 4,000 colony-forming units/100 mL, with the majority of samples exceeding 200 colony-forming units/100 mL (Fig. 5). In 2007, *E. coli* density was consistently highest at the furthest downstream site, while in 2008 upstream to downstream patterns were more variable.

Discussion

Effective integration of collaborative learning with ecological research can improve social acceptance for and scientific soundness of efforts to restore urban streams, and improve public understanding of urban ecosystem structure, function, and health. However, there are few models in the literature describing successful integration of these elements. Using urban ecological research and public participation focused on an urban stormwater management practice, we conducted this study to create and examine linkages among learning, restoration, and research. We add these purposeful linkages to our initial conceptual model (Fig. 6), and describe the linkages in detail in the discussion that follows.

Table 7 Mean differences in nitrate, phosphorus, and total suspended solids delivery rates between samples taken upstream and downstream of the riparian buffer during the late summer sampling period before buffer installation (2006), 1 year after installation (2007), and 2 years after installation (2008)

Upstream — downstream delivery	Before (2006)	After (2007)	After (2008)
Nitrate (kg/ha/day)	−0.0068[b]	−0.00001[b]	0.2054[a]
Total phosphorus (kg/ha/day)	−0.0018[c]	−0.00003[b]	0.00454[a]
Total suspended solids (kg/ha/day)	−0.0008[b]	0.000005[b]	0.00471[a]

[a,b,c] Letters denote significant differences between years. a > b > c at $p \leq 0.05$ (Student's *t*-test, each pair)

Table 8 Macroinvertebrate and fish abundance and taxa richness for samples taken from three sites on College Creek (one near the riparian buffer in Daley Park and two sites downstream of Daley Park), and three sites on Clear Creek, a nearby urban stream with substantial natural riparian vegetation (see Fig. 2b for site locations)

Stream and sample site	Invertebrate density (individuals/m^2)	Invertebrate taxa richness (taxa/0.28 m^2)	Fish abundance (individuals/site)	Fish species richness (species/reach)
College Creek				
Daley Park 2 (on site)	1,652	6	27	2
Downstream site 1 (off site)	2,770	12	57	2
Downstream site 2 (off site)	11,923	8	121	9
Clear Creek (off-site reference stream)				
Clear Creek site 1	1,507	9	228	9
Clear Creek site 2	1,229	4	117	4
Clear Creek site 3	1,676	6	143	8

Collaborative learning and installation of a stormwater management practice

Intensive outreach to neighborhood residents about events related to the riparian buffer project, including door-to-door invitations and regular mailing of invitation letters, encouraged a high level of participation: out of 63 households invited (representing approximately 140 persons) 46 residents participated in at least one meeting. In addition, although small sample sizes limited statistical power of comparisons of pre- and post-participation survey results, there was evidence that regular participation in project meetings and activities increased knowledge about a range of stormwater management practices.

Relatively high levels of participation and successful learning outcomes were enhanced by two aspects of our project: a place-based focus and opportunities for hands-on participation. Since the riparian buffer was installed in a neighborhood park, and residents in surrounding homes were invited to participate, discussions about stormwater management in general, and riparian buffers specifically, had a focal point at this location. Levels of participation and interest were high at meetings during the design phase, when discussions were focused on Daley Park and the planned riparian buffer. Previous research suggests that communication among stakeholders in environmental projects can be improved by focusing dialogue on specific natural features, rather than only abstract concepts, so that experiences and values with unique local features can be shared (Cheng and Daniels 2003; Elmendorf 2008). In our study, the park, stream, and riparian buffer provided this source of common focus.

The riparian buffer project also provided opportunities to integrate hands-on and experiential activities. Buffer tours and buffer maintenance activities engaged participants in on-going assessment of the project site, and they allowed discussion of complex concepts, such as succession, movement of stormwater through the riparian zone, and ways in which the buffer could mitigate impacts of that flow. Attendance was higher at meetings for which hands-on and interactive activities were planned, suggesting that participants in environmental projects find these activities more appealing than meetings based solely on discussion. Hands-on and experiential activities are important factors that enhance environmental learning (Johnson and Catley 2009), and therefore affect attitudes and actions toward the environment (Rapport et al. 1998; McDaniel and Alley 2005).

Project personnel and 20 residents were regularly involved in activities in Daley Park over the 2-year period of the project. A sense of community developed from this sustained

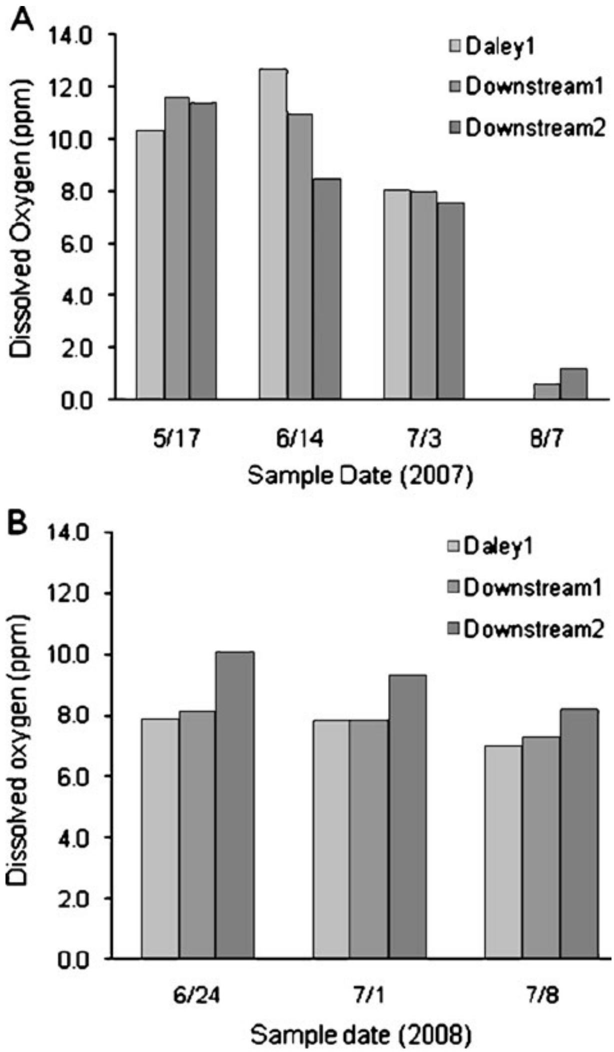

Fig. 4 Dissolved oxygen concentration measured at College Creek sample sites (one site in Daley Park and two downstream reference sites) during 2007 (**a**) and 2008 (**b**)

interaction between researchers and participants, as indicated by comments made throughout the project. Before the project, one resident said, "neighbors did not discuss the creek or water quality at all." Throughout the series of group meetings, several residents expressed enjoyment in regularly meeting with neighbors to discuss the stream. At one of the last meetings, a resident suggested we hold a "reunion" the following year for participants. Previous researchers have also found that both interaction over relatively long periods of time and participation in environmental projects build community (Cheng and Daniels 2003; Elmendorf 2008). A sense of community developed around an environmental issue can provide a number of environmental and social benefits to communities that are likely to be sustained over time (Elmendorf 2008).

In addition to facilitating learning and sense of community among residents, interaction between scientists and participants in the riparian buffer project also provided an avenue for residents' local knowledge, values, and concerns to inform design and installation of the buffer. This allowed us to conduct the project in a way that better suited neighborhood

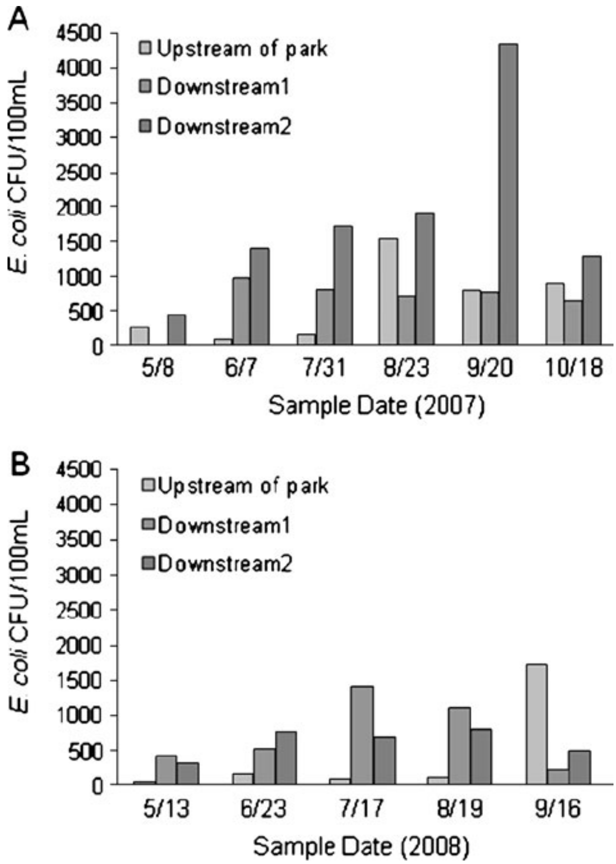

Fig. 5 *E. coli* densities in samples collected from College Creek sample sites (one site upstream of Daley Park and two downstream reference sites) during 2007 (**a**) and 2008 (**b**)

values, and also provided a venue for communications about project decisions. Previous researchers have found that involving residents in environmental projects increases acceptance of decisions (Stein et al. 1999; Selin et al. 2007). In addition, local knowledge can aid restoration projects to achieve maximum benefit for local communities (Small and Uttal 2005).

Indeed, the common themes emerging from discussions with residents suggested that participation improved both learning and restoration outcomes. Participant concerns reflected the importance of preserving social and personal benefits provided by the park. Urban green spaces are critical to the social well-being of communities because of these benefits (Elmendorf 2008), and so it was important to preserve these while maintaining critical aspects of the buffer as a functioning stormwater management practice. Residents especially valued physical and visual access to the stream, which they enjoyed while using the park and walking trail, and views across the stream, which residents of homes near the stream valued. For example, one resident did not “want a wall of trees blocking [his] view,” while another did not “want to live in a forest.” Through participation at the design workshop, residents helped form alternatives to standard riparian buffer designs in order to accommodate their concerns. For instance, two zones on each side of the stream were designated as treeless, thus preserving access points and views to and across the stream. A few participants were also concerned about inviting unwanted species of plants and animals into the neighborhood, and one resident preferred the riparian zone to be mowed regularly. Previous studies found similar concerns about riparian zone management, including

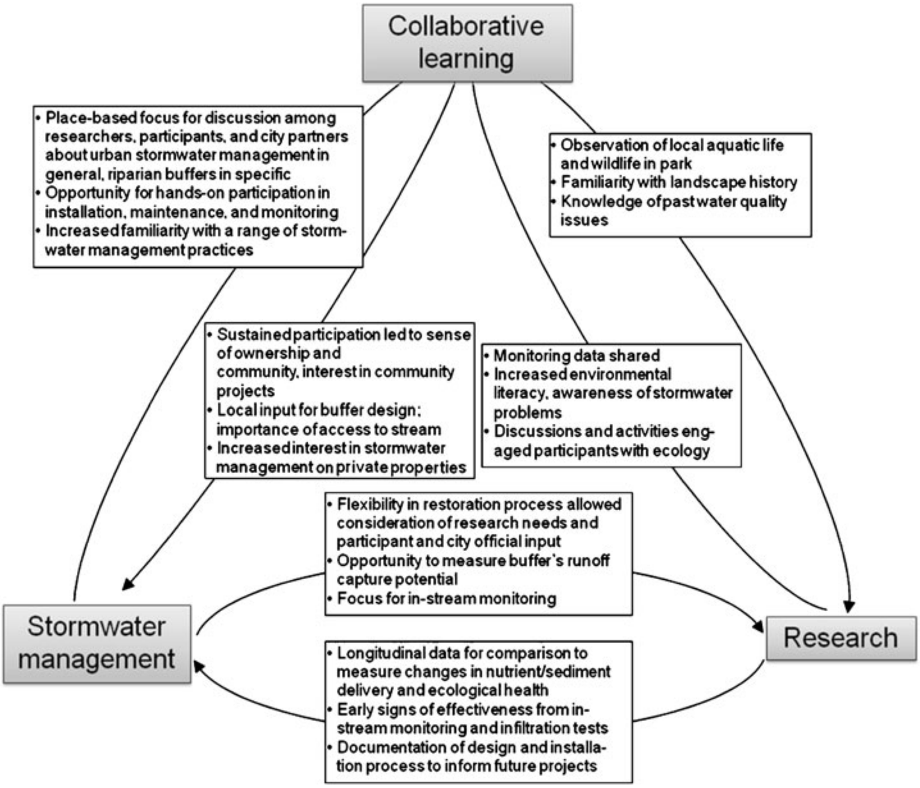

Fig. 6 Conceptual diagram showing linkages created and examined in this study among collaborative learning, installation of a stormwater management practice (urban riparian buffer), and urban ecological research (in-stream and direct monitoring of buffer)

interference with view-sheds and access, undesired wildlife, and importance of cared-for and traditional appearances in riparian landscapes (Towne 1998; Nassauer et al. 2001; Dutcher et al. 2004). By involving residents in the process, we provided an avenue for expression of those concerns, and were able to directly address many of them.

The participatory process also allowed residents to express affirmation and discuss positive aspects of the project. Many perceived it as beneficial for water quality, wildlife and aquatic organisms, and the neighborhood. As one resident stated, “it will be good for kids to see different trees, grasses, and wildlife in their own backyards.” Urban ecologists have pointed out this benefit as well, indicating that ecological restoration projects give urban dwellers the opportunity to see, appreciate, and work to protect natural communities (e.g. Heneghan et al. 2009).

We did not purposefully try to tie individual homeowner behaviors to stream water quality (see, for example legacy effects of homeowners’ landscape design in Boone et al. 2009, or direct effects of contemporary lawn care practices in Zhou et al. 2008), but we did discuss potential effects based on turf management in the park, such as increased N loading from fertilization (Law et al. 2004; Bernhardt et al. 2008). Interestingly, perceived benefits from buffer capture of park management inputs enhanced residents’ interest in site-level BMPs that they could implement on their own properties. Thus, the collaborative learning initiated by the riparian buffer project may have a ripple effect of increasing water quality benefits as residents become more involved in managing stormwater on their own properties.

In our study, installation of a riparian buffer provided a functional stormwater management practice as well as multiple opportunities for learning. This project provides additional empirical evidence for facilitation of collaborative learning among scientists and community members as a large potential benefit of inclusive urban ecological restoration projects (Pickett et al. 2004; Selin et al. 2007).

Collaborative learning and ecological research

Neighborhood meetings held to discuss the stream and riparian buffer in a city park also served as a venue for discussing issues related to stormwater and findings from local monitoring. Our results indicated that residents' knowledge of basic stormwater principles and problems in local streams associated with stormwater and nonpoint source pollutants increased during the project. The use of local monitoring data, including data about nutrient and sediment delivery, aquatic organisms, dissolved oxygen, and *E. coli,* aided this learning. For example, when asked about the source of knowledge about stormwater-related problems, one post-participation survey respondent answered that "sampling results indicated problems." Environmental knowledge is largely determined by exposure to environmental issues (McDaniel and Alley 2005), and in our study exposure to ecological data enhanced participants' knowledge about local water quality problems. In addition, participants' reasons for valuing streams became more specific, as indicated by fewer respondents answering that streams "just are" important. Thus, results of our study also support previous findings that environmental knowledge can determine attitudes toward the environment (Rapport et al. 1998; Stein et al. 1999).

Ongoing research also informed the collaborative learning process by engaging participants with ecology. Many residents had been observing wildlife in the park and aquatic life in College Creek for years, and participants at early meetings were convinced that there was very little aquatic life in the stream. Thus, ecological stream monitoring data were of particular interest to them. Hands-on interaction with aquatic organism specimens allowed participants to see aquatic organisms commonly used as indicators of ecological condition, and this activity was a helpful supplement to presentation of local fish and invertebrate data. In aquatic ecology discussions, we emphasized the role of aquatic organisms in stream ecosystems. For instance, fish and invertebrate taxa known to be sensitive to pollution and habitat disturbance were rarely encountered in local streams (Herringshaw 2009), and this finding provided opportunities for discussion about pollution tolerance and biodiversity. Dissolved oxygen concentrations fell below 5 ppm on one occasion, suggesting a possible reason for the absence of sensitive aquatic taxa (IDNR 2002). In addition, College Creek had higher invertebrate densities than Clear Creek but considerably lower fish abundance and diversity, a finding that we discussed in terms of aquatic food web concepts. We also discussed the role of woody debris in stream ecosystems, challenging the assumption held by some participants that streams should look "clean." Rapport et al. (1998) emphasized the role of scientists in helping the public understand and value the benefits of complex but natural ecosystem processes, and Stein et al. (1999) suggested that communities and individuals must perceive what a natural landscape *does* (what functions and services it provides) before they can perceive any benefit from protecting that landscape. By discussing information about aquatic ecology, participants learned the value of aquatic ecosystems, and survey results indicated an increasing perception that aquatic organisms are valued stream features.

Among participants, there was cumulative knowledge from decades of experience with the neighborhood landscape. Thus, participant knowledge of the park's history and past water quality issues in College Creek helped illuminate the local significance of certain findings from local stream monitoring. For example, a history of bacterial contamination in College Creek, as well as the understanding of bacterial contamination as a threat to human health, caused residents to be particularly interested in *E. coli* data. Although *E. coli* densities did not indicate on-going severe contamination, levels did regularly exceed standards for healthy human contact (235 cfu/100 mL; IDNR 2008), and this stimulated considerable discussion about residents' interest in protecting the stream from further contamination. In addition, after participation, the perception that local stream quality was unacceptable increased. As in other studies where immediate relevancy of topics improved information exchange (Shanley and Gaia 2002), the local significance of *E. coli* data helped residents understand the importance of monitoring water quality.

Stein et al. (1999) have called for identification of specific activities that can lead to increased knowledge about environmental issues. In our study, presenting place-based monitoring data, as well as engaging participants with aquatic organisms and ecology and inviting discussion about past water quality issues led to these outcomes.

Installation of a stormwater management practice and ecological research

One benefit of the integrated framework in which this project was conducted was that we had some degree of flexibility in placement, design, and installation of the riparian buffer, which allowed consideration of input from residents and city officials. The result, a three-zone buffer on 1.8 ha of public park property, was also a useful research tool as both an opportunity to measure runoff capture potential in different riparian zones and a focus for in-stream monitoring.

Documentation of installation provided evidence of factors that contributed to buffer establishment success. For example, buy-in from residents living near the buffer encouraged neighborhood support for the buffer during the establishment process. Both residents and project personnel were continually attentive to maintenance needs. In addition, tree protectors placed on trees prevented herbivory and contributed to high survival rates. When tree protectors were not used on shrubs during the first year, shrub survival was low, but improved after replanting and use of tree protectors during the second year. Incorporation of compost initially slowed establishment of prairie plants, but it also suppressed weedy species. During the second year of growth, prairie plants grew rapidly, and nearly all species were detected. Previous research has also found compost application to be ultimately beneficial to prairie establishment (Singer et al. 2006).

Buffer capacity to infiltrate water Direct measures of the potential of the buffer to absorb runoff from surrounding surfaces provided early evidence of the buffer's effectiveness. Although our results are very preliminary, infiltration tests point toward the potential for restored buffer zones to absorb runoff from surrounding areas. One year after the prairie was sown, this zone of the buffer, much of which had been mown turf previously, had somewhat faster infiltration rates than did park lawn. Compost application also increased the infiltration capacity of the establishing prairie, suggesting that using compost amendments during buffer installation can improve early buffer performance (increases in infiltration effectiveness over time for prairie established with compost amendments have also been documented by Singer et al. 2006). More rapid infiltration in the narrow zone of undisturbed riparian soil immediately adjacent to the creek also points toward the likelihood that, as trees, shrubs, and prairie vegetation become established in the place of mown turf, infiltration capacity is likely to increase in all areas of the buffer over time.

Given the close integration of restoration and research in this project, we were also able to make adjustments in the process to meet research goals. Site selection for buffer installation was determined in part by research needs. Because benefits of riparian vegetation maybe difficult to detect in urban streams, we chose to install the buffer in the headwater zone of a first-order stream, where watershed area was small and upstream effects would be less significant than in larger streams. In addition, previous studies relating urban riparian vegetation to stream condition have generally compared stream reaches with existing riparian vegetation to stream reaches without riparian vegetation (e.g., Miltner et al. 2004; Roy et al. 2005). In this study, our involvement with local partners over time allowed us to begin monitoring in-stream nutrient and sediment delivery before buffer installation, building the foundation for a longitudinal dataset for these parameters.

Buffer effectiveness for stream water quality improvement In-stream monitoring of nitrate, phosphorus, and sediment delivery indicated that, during a large rain event 14 months after installation, nutrient and sediment delivery decreased between the sites directly upstream and downstream of the riparian buffer. For nitrate and phosphorus delivery rates, these differences were strongly related to discharge differences. However, relative magnitude of sediment delivery downstream of the buffer provides evidence that, at minimum, little sediment was contributed to the stream in the area of the riparian buffer. Previous studies on riparian buffers have also demonstrated effectiveness in sediment interception (Matteo et al. 2006; Muenz et al. 2006). Monitoring also provided initial data for later comparisons of parameters important to the health of humans and aquatic life. For example, nitrate concentrations upstream and downstream of the riparian buffer (data not shown) generally did not exceed national standards for drinking water (10 mg/L; USEPA 2006). Although our data are preliminary, they do provide early evidence of the potential of the buffer to provide water quality benefits that are likely to increase over time.

Assessment of stream ecological condition E. coli densities regularly exceeded the state single-sample standard (235 CFU/100 mL) for safe human contact (IDNR 2008). Dissolved oxygen concentrations occasionally fell below 5 ppm, the level considered necessary to support aquatic life (IDNR 2002). These data provide baseline indicators of ecological health that can be compared to data in later years to assess improvements in stream health related to the riparian buffer.

There is considerable lack of consensus regarding the effectiveness of urban ecological restoration practices and stormwater best management practices (Pennington et al. 2003; Blakely and Harding 2005; Kaushal et al. 2008). This is particularly true for urban riparian buffers and the benefit of riparian vegetation in urban watersheds in general. There is ample evidence that natural riparian vegetation is a critical feature of a functioning stream (O'Driscoll et al. 2006; Reid et al. 2008), and some investigators have found that restored or preserved riparian vegetation is associated with improved ecological condition (Miltner et al. 2004; Moore and Palmer 2005). However, others have found that, particularly within urbanized watersheds, beneficial effects of riparian vegetation on stream ecological condition are minimal (Roy et al. 2005; Walsh et al. 2007). Due to inadequate monitoring of ecological restoration practices nationwide, it has been difficult to discern the reasons for these different results (Bernhardt et al. 2005; Alexander and Allan 2007). In our study, multiple forms of data collection provide early evidence (although preliminary and to be interpreted cautiously) that the riparian buffer is performing some functions effectively shortly after establishment. This study does show that tight coupling of urban ecological restoration with research provides findings can inform ongoing and future restoration efforts.

Conclusions

This paper describes a case study in which we developed a model for integrating collaborative learning through public participation, urban ecological restoration, and ecological research. The model was successful in producing three desired outcomes. First, learning occurred that improved residents' understanding of impacts of urbanization on streams, while researchers learned valuable information that guided restoration and research to better fit local needs and values. Second, a functional riparian buffer was installed that provides improved management of stormwater runoff in a public park, and that is perceived as an asset by neighborhood residents. Finally, a focused urban ecology research study was conducted that provided information about local stream conditions and effectiveness of riparian buffers, and informed local residents of problems in and benefits of local stream ecosystems. In the past, hindrances to successful urban ecological restoration have included a lack of public understanding of urban ecology and urban restoration needs, as well as insufficient monitoring data showing effectiveness of restoration practices (Bernhardt et al. 2005; Heneghan et al. 2009). The model described here addresses both of these needs, in addition to providing, albeit based on early evidence, a functioning stormwater management practice.

Several specific elements were essential to success of this project. First, sustained interaction between researchers and participants during the 2-year project period fostered a sense of trust and community that enhanced learning and increased interest in ecological improvement projects. When residents understood that project and city personnel were interested in long-term outcomes, their perceptions of the project as a whole were more positive. Second, hands-on and experiential activities were essential to knowledge building, particularly about complex concepts such as ecosystem processes (e.g., succession, trophic relationships). These activities also engaged residents in the restoration process in a way that encouraged greater participation and direct involvement in restoration outcomes. Finally, flexibility in the design and implementation process allowed us to conduct the project in a way that met both social and ecological goals. A working relationship with city partners was necessary to obtain this flexibility, and it also allowed us to help them meet their management goals. In particular, this project aided city partners in meeting NPDES Phase II minimum control measures, which require public participation, public education, and improved stormwater management. We contend that integration of the elements within our proposed conceptual model with specific linkages can be adapted and transferred for use broadly, both within and beyond the arena of urban ecological studies to generate similar outcomes.

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