EXECUTIVE SUMMARY

Evaluating the Long-term Ecological Responses to Riparian Ecosystem Restoration at the Fort Benning, Georgia Military Installation

SERDP Project RC-2704

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ACRONYMS AND ABBREVIATIONS

µg/L	microgram(s) per liter
14-y PR	14-Years Post-Restoration
AIC	Army Infantry Center
BPOM	Benthic Particulate Organic Matter
CWD	Coarse Woody Debris
DOC	Dissolved Organic Carbon
DoD	Department of Defense
EPA	Environmental Protection Agency
ER	Ecosystem Respiration
FBMI	Fort Benning Military Installation
KM1	Kings Mill Creek (instream and ephemeral restoration site)
L	Liter(s)
LPK	Little Pine Knot (instream restoration site)
m	Meter(s)
mg	Milligram(s)
NH_4	ammonium
NO_3	nitrate
NRC	National Research Council
ORNL	Oak Ridge National Laboratory
PI	Primary Investigator
PR	Post-Restoration
SERDP	Strategic Environmental Research and Development Program
SRP	Soluble Reactive Phosphorus
TSS	Total Suspended Solids
US	United States
y	Year(s)

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1.0 INTRODUCTION

Streams and rivers provide numerous ecosystem services to humans. However, flowing waters can be impacted by a variety of anthropogenic activities because of the close proximity of humans to freshwater systems (i.e., 50% of the Earth's population live less than 3 kilometers from freshwater; Kummu et al. 2011). These perturbations can impair water quality, alter water quantity, and negatively impact freshwater biodiversity (National Research Council [NRC] 1992). In fact, almost half of small streams in the United States (US) are characterized as being in "poor condition" (United States Environmental Protection Agency [US EPA] 2006). Degraded environmental conditions often motivate stream and riparian restorations, with $14-15 billion spent on stream and river restorations in the US over a 15-year period (Bernhardt et al. 2005).

Ecological restorations aim to return ecosystem properties to pre-disturbance conditions (NRC 1992), with the restoration mission, goals, and objectives based on site-specific circumstances (NRC 1992, Palmer et al. 2005). Stream restorations are most often focused on improving water quality, managing riparian zones and stabilizing stream banks, improving instream habitat for aquatic organisms, and facilitating fish passage (Bernhardt et al. 2005). However, the efficacy of stream restorations is not well documented because only ~10% of restorations are monitored after implementation (Bond and Lake 2003, Roni et al. 2008, Bernhardt and Palmer 2011), and very few are monitored over long periods of time (i.e., >10 years; Roni et al. 2008, Tullos et al. 2009). Evaluation of stream restoration efficacy over both the short- and long-term is critical for assessing if stream restorations are effective at improving ecosystem conditions and are a worthwhile investment.

Numerous stream restoration techniques are implemented in practice, with the type of restoration selected based on the stressor(s), watershed characteristics, and restoration goals and objectives (NRC 1992, Bernhardt et al. 2005, Palmer et al. 2005). One commonly used stream restoration technique is instream habitat augmentation through the addition of large wood (i.e., coarse woody debris [CWD]) to stream channels. These CWD additions aim to provide habitat for benthic macroinvertebrates and fish, retain sediment, and create biogeochemical hotspots for a variety of ecosystem processes (e.g., nutrient cycling) (Bilby and Likens 1980, Smock et al. 1989, Bilby and Ward 1991, Roberts et al. 2007, Craig et al. 2008, Roni et al. 2015). Similar to most ecological restorations, the efficacy of CWD additions is not well established due to a lack of comprehensive evaluations (Roni et al. 2002, Thompson 2005).

2.0 OBJECTIVES

Various military training activities (e.g., dismounted infantry tactics, tracked vehicle maneuvers, heavy weapon use, airborne training drop zones) can have environmental impacts on Department of Defense (DoD) lands (United Stated Army Infantry Center [USAIC] 2001, Dale et al. 2002). At the DoD's Fort Benning Military Installation (FBMI) in Georgia, two experimental restoration projects were implemented ~14 years ago with the goal of reducing the effects of military activities on riparian and stream ecosystems. These restoration practices included ephemeral drainage revitalization and instream habitat augmentation (Figure ES.1). Ephemeral drainage restoration involved closing point-source inputs of sediment, stabilizing stream banks, and planting grasses and longleaf pine trees. Instream habitat restoration involved the addition of CWD dams along stream reaches.

A Strategic Environmental Research and Development Program (SERDP)-funded project measured the pre-treatment (2001-2003) and post-treatment (2003-2007) responses to restoration, and found that restoration improved some, but not all, aspects of ecosystem function and structure. Specifically, instream restoration increased ecosystem respiration (ER) rates, increased ammonium uptake rates, and changed some aspects of the macroinvertebrate communities. However, there were no effects on water quality and some other measures of macroinvertebrates possibly because these components of the stream ecosystems were slower to respond to CWD additions.

Figure ES.1. Ephemeral Drainage and Instream Restorations

Ephemeral drainage restoration (left) and instream habitat restoration through coarse woody debris additions (right). Photos are from original project files.

The objective of the current study was to re-evaluate the effects of two restoration practices on stream ecosystem processes ~14 years after implementation.

The specific objectives were to:

1) determine if the improvements to ecosystem condition that were observed immediately (1-3 years) after restoration were:
   a) still in an improved state ~14 years post-restoration (14-y PR), or
   b) were no longer showing improvements (i.e., return to pre-treatment conditions).

2) determine if the ecosystem parameters that did not change immediately (1-3 years) after restoration have:
   a) since responded to restoration, or
   b) still showed no change with restoration.

The current project was limited in scope compared to the original SERDP project. Thus, the project team focused on measuring a subset of environmental characteristics in this evaluation, some of which responded to initial restoration and others that did not. Further, the project team focused on quantifying instream responses to both restoration types as benefits observed from ephemeral restoration (e.g., decreased sedimentation rate) may be observed in the stream channels (e.g., decreased suspended solid concentrations). Studies that evaluate the long-term efficacy of ecological restorations are very rare. Thus, this project provides critical information on the longevity and efficacy of restorations. Further, these findings can be used to determine if these restoration technologies are worthwhile investments for DoD installations interested in restoring impaired watersheds.

3.0 TECHNICAL APPROACH

This study took place at seven sites at FBMI: four sites that received instream restorations in 2003-2004 and three sites that served as unrestored controls. Of these sites, two instream restoration sites received ephemeral drainage restoration, as did one unrestored control site. Pre-restoration conditions were monitored by the original SERDP project from 2001-2003, and post-restoration monitoring occurred from 2004-2007. The project team revisited these same seven streams ~14 years after restoration, from May 2017 to January 2019, and measured physical, chemical, and biological processes in all seven streams either monthly or seasonally. A subset of the environmental indicators measured in the original study were selected, and methodologies and sampling frequencies closely followed those in the original SERDP project so that pre- and immediate post-restoration data could be compared to data collected 14-y PR. Samples for water quality analyses were collected monthly, and ammonium uptake, stream metabolism metrics, benthic particulate organic matter (BPOM), and macroinvertebrate community metrics were measured seasonally (five seasons total). The project team also quantified CWD abundance in all seven streams.

4.0 RESULTS AND DISCUSSION

The overall conclusion from this study is that instream restorations (i.e., CWD additions that took place ~14 years ago) had minimal long-term effects on stream ecosystem structure (i.e., water quality, BPOM, macroinvertebrates) and function (i.e., nutrient uptake, stream metabolism). While CWD dams were still visible in restored streams (Figure ES.2), CWD abundance was not higher in restored vs unrestored streams 14-y PR.

In general, there were no long-term effects of restoration on water quality metrics (Figure ES.3). However, total suspended solid concentrations were higher and dissolved organic carbon concentrations were lower in restored vs unrestored streams, possibly because sampling sometimes occurred under variable flow conditions in a given month when access to some sites was restricted due to military training activities. There were also no long-term effects of CWD additions on stream ecosystem processes (i.e., ammonium uptake and stream metabolism metrics) despite these metrics increasing initially after CWD was added to streams (Figure ES.4). Finally, there were no consistent long-term effects of CWD additions on BPOM and macroinvertebrate community metrics (Figures ES.5 and ES.6). Most measured stream processes showed strong seasonal and interannual variation, and also varied across streams, possibly reflecting environmental and climatic drivers acting across multiple spatial and temporal scales (e.g., seasonality in light availability and temperature, wet vs dry years, etc.).

A primary motivation for these restorations at FBMI was a prior finding that stream ecosystem structure and function was impaired in watersheds with higher upland disturbance (Houser et al. 2005, Mulholland et al. 2005, Roberts et al. 2007a). An analysis of land cover data suggests that watershed disturbance has not changed substantially over the past ~14 years at FBMI, and some stream metrics were still negatively impacted by watershed disturbance (Figure ES.7); however, responses varied by ecosystem metric, season, and restoration period. Overall, watershed disturbance still appears to be an important driver of stream ecosystem condition at FBMI, suggesting that smaller-scale restorations such as CWD additions may not be effective in the long term if the larger-scale stressors are not also addressed (NRC 1992, Craig et al. 2008, Roni et al. 2008, Bernhardt and Palmer 2011).

Figure ES.2. Coarse Woody Debris Dam, Kings Mill Creek

Photo of a coarse woody debris dam in Kings Mill Creek, an instream restored site at Fort Benning Military Installation. The photo was taken ~14 years after instream restoration at this site.

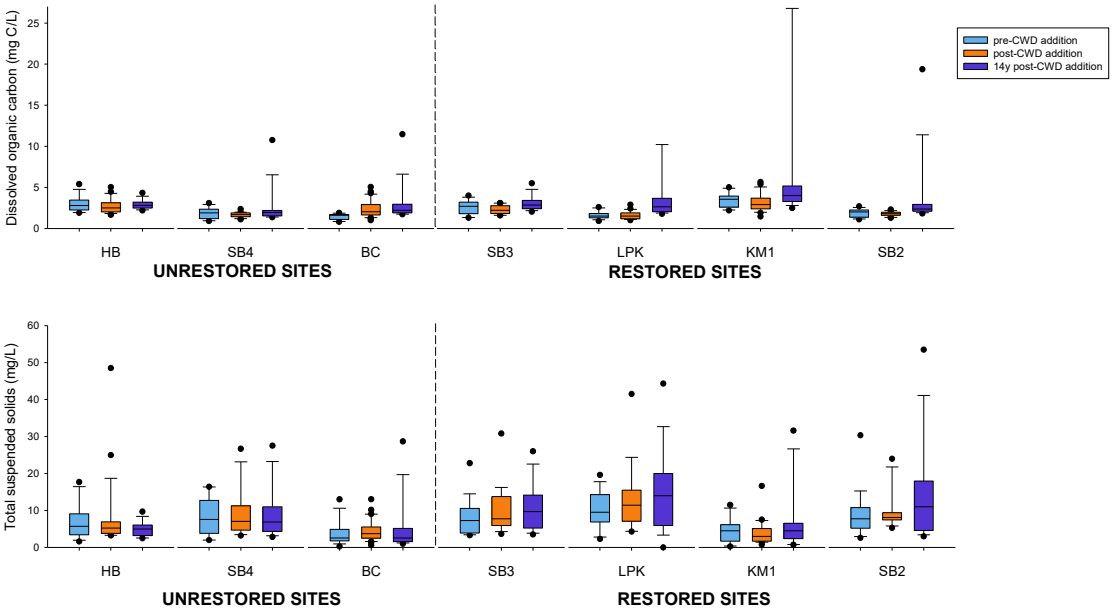

Figure ES.3. Dissolved Organic Carbon Concentrations and Total Suspended Solid Concentrations in Stream Water

Dissolved organic carbon (DOC) concentrations (milligrams carbon per liter [mg C/L]) [top panel] and total suspended solid concentrations (TSS; mg/L) [bottom panel] in stream water in the three unrestored streams and four restored streams in the pre-restoration period (2001-2003; blue boxes), immediately after restoration (2004-2007; orange boxes), and 14-y PR (2017-2018; purple boxes). Two DOC outliers, one at Little Pine Knot (LPK) (32 mg/L) and the other at Kings Mill Creek (KM1) (60.9 mg/L), were not included in the figure.

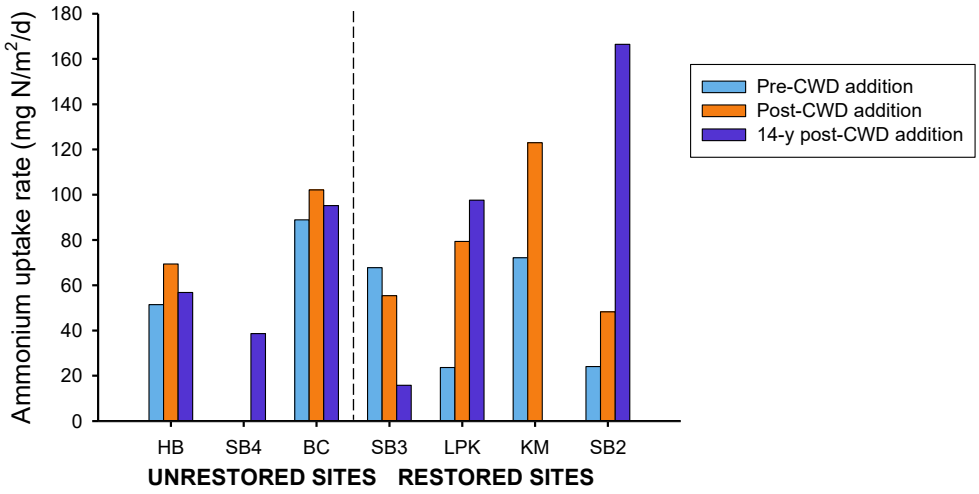

Figure ES.4. Ammonium Uptake Rate in Streams

Ammonium uptake rate (mg nitrogen per square meter per day [N/m^2/d]) in the three unrestored streams and four restored streams that received instream CWD restorations in the fall/early winter season in the pre-restoration period (immediately before restoration in October 2003; blue bars), immediately after restoration (2003-2005; orange bars), and 14-y PR (2017-2018; purple bars).

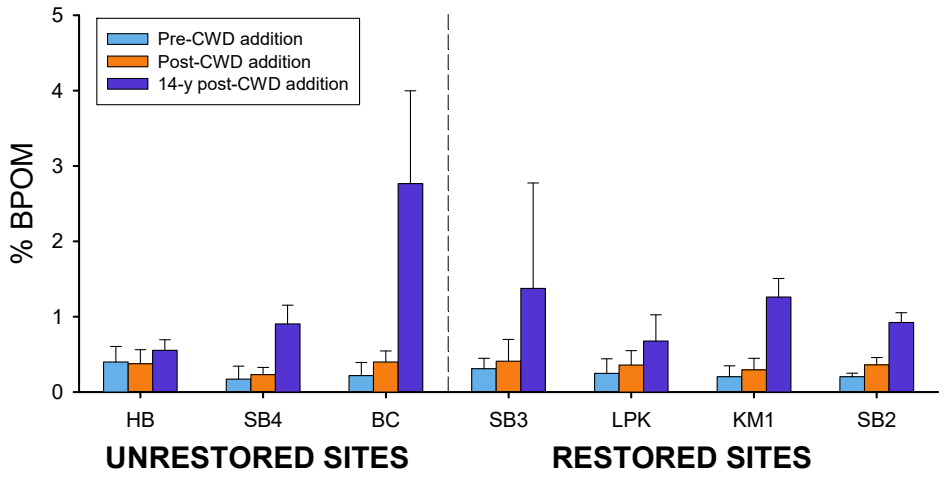

Figure ES.5. Mean Benthic Particulate Organic Matter in Stream Sediment

Mean (+ standard deviation) benthic particulate organic matter (%BPOM) in the sediment of three unrestored streams and four restored streams that received instream CWD restorations in the pre-restoration period (2001-2002; blue bars), immediately after restoration (2004-2007; orange bars), and 14-y PR (2017-2018; purple bars) across all seasons.

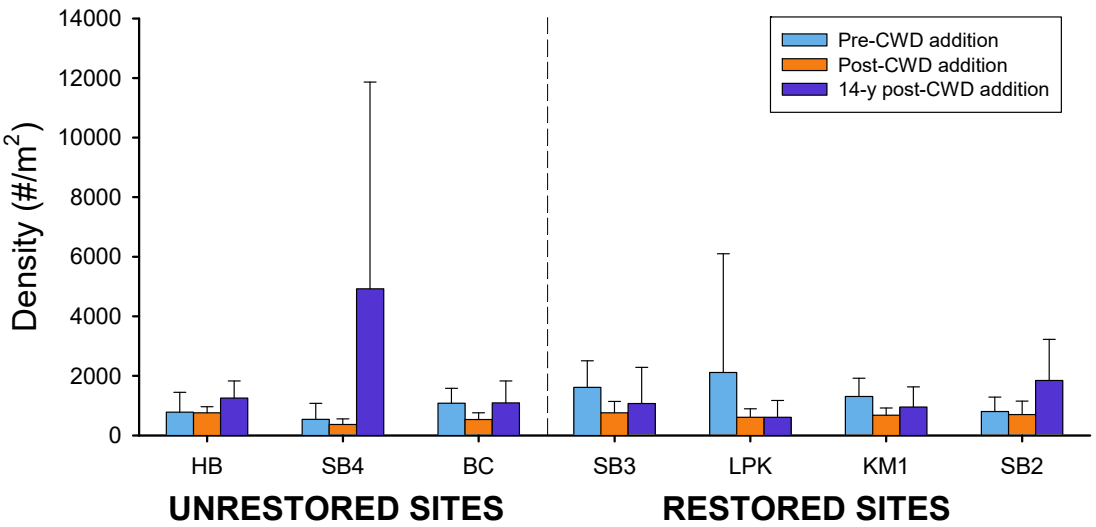

Figure ES.6. Mean Total Macroinvertebrate Density in Streams

Mean (+ standard deviation) total macroinvertebrate density (number of individuals/m^2) in the three unrestored streams and four restored streams that received instream CWD restorations in the pre-restoration period (2001-2002; blue bars), immediately after restoration (2004-2006; orange bars), and 14-y PR (2017-2018; purple bars) across all seasons.

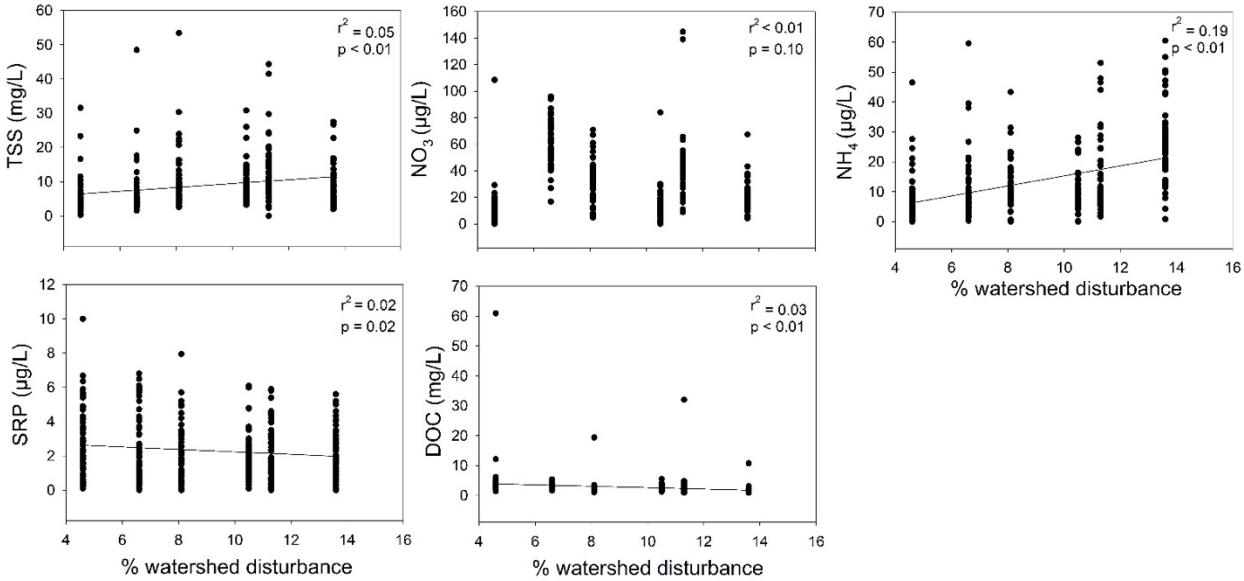

Figure ES.7. Relationships Between % Watershed Disturbance and Water Quality Metrics

Relationships between % watershed disturbance and water quality metrics (top left to bottom right panels: TSS, nitrate [NO_3], ammonium [NH_4], soluble reactive phosphorus [SRP], and DOC concentrations) for the entire 14 year dataset. Note: µg/L - micrograms per liter.

5.0 IMPLICATIONS FOR FUTURE RESEARCH AND BENEFITS

Measurement of select stream ecosystem structure and function metrics ~14 years after instream habitat augmentation suggests that there were minimal long-term benefits of these CWD installations as a restoration strategy. However, these findings may not be applicable to all stream ecosystems. Specifically, CWD additions to sandy-bottomed streams of the US Coastal Plain may be more susceptible to burial by sediments than in other ecoregions with more stable benthic substrates. Therefore, implementation of this restoration technology in Coastal Plain streams may require continual augmentation of CWD dams. Determining whether multiple additions of CWD to streams over time would be effective at improving stream condition is an important area for future research.

This study provided valuable information on the long-term efficacy of CWD additions; such evaluations are very rare in the field of restoration ecology. However, this evaluation was still limited as measurements only occurred over 1.5 years, and thus did not capture interannual variation in climatic and environmental factors that can be important drivers of stream ecosystem structure and function. For example, hydrologic flows during the 1.5-year measurement period ranged from historically high flows to historically low flows (United States Geological Survey stream gage 02341800, Upatoi Creek near Columbus, Georgia). It is not known if the lack of long-term response to CWD additions was masked by these hydrologically variable conditions. Overall, the paucity of studies that evaluate the long-term efficacy of restorations over several years highlights a future need in the field (Palmer et al. 2005, Bernhardt et al. 2005, Wohl et al. 2005, Lake et al. 2007).

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