Kenai River

Restoration Project Assessment

Provided for:

Kenai River Sportfishing Association
224 Kenai Ave., Ste. 102
Soldotna, AK 99669

March 18, 2010

KENAI RIVER
RESTORATION PROJECT ASSESSMENT

Prepared for

KENAI RIVER SPORTFISHING
ASSOCIATION

Kenai River Sportfishing Association
224 Kenai Ave., Suite 102
Soldotna AK 99669

Prepared by

inter·fluve inc.

Inter-Fluve, Inc.
1020 Wasco Street, Suite I
Hood River, OR 97031
(541) 386-9003
www.interfluve.com

With
Fish Metrics - Brian Pyper
Parkdale, OR

Primary authors:
Gardner Johnston (Inter-Fluve, Inc.)
Brian Pyper (Fish Metrics)

Date: March 18, 2010

This report was prepared by Inter-Fluve, Inc. under award #NA04NMF4380162 from the National Oceanic and Atmospheric Administration, U.S. Department of Commerce, administered by the Alaska Department of Fish and Game. The statements, findings, conclusions, and recommendations are those of the author(s) and do not necessarily reflect the views of the National Oceanic and Atmospheric Administration, the U.S. Department of Commerce, or the Alaska Department of Fish and Game.

Table of Contents

Appendices

Acknowledgments

We are grateful to the numerous individuals who provided technical support and field assistance for this effort. Ricky Gease, with the Kenai River Sportfishing Association (KRSA), provided the primary coordination and support for the project. Robert Ruffner, with the Kenai Watershed Forum (KWF), provided technical assistance, field gear, and field support. Mary King, with the Alaska Department of Fish & Game (ADFG), provided technical assistance and field support. The following individuals provided technical support: Dean Hughes and Bob Clark with ADFG, John Mohorich with the Kenai Peninsula Borough (KPB); Mike Edwards with U.S. Fish & Wildlife Service (USFWS), and Ray Beamesderfer with Cramer Fish Sciences. In addition, many private landowners along the Kenai River provided useful historical information and project observations.

Abstract

Considerable effort has been expended on streambank restoration measures on the lower Kenai River. Many of these projects utilize natural materials and bioengineering techniques to address streambank erosion and habitat conditions affected by shoreline development, shore angling, and boatwake erosion. This study involved two assessments: 1) Project Status Assessment – an inventory of the extent and type of restoration work that has been conducted between the mouth and Skilak Lake (river mile 50), and 2) Project Effectiveness Assessment – an evaluation of a sub-sample of projects with respect to their effectiveness in enhancing fish habitat.

The Project Status Assessment found that nearly 9 miles of streambanks have been treated with a total of 385 individual restoration projects, comprising approximately 9% of the total length of streambank in the lower 50 miles of the Kenai River. Techniques included cabled spruce trees (CSTs), bioengineered banks (BEBs), rootwad revetments, and combination projects. CST projects are the most common (57%), followed by combination approaches (21%), BEBs (16%), and other miscellaneous approaches (6%). Most projects (55%) were considered to be in good condition and received a "High Integrity" rating, with equal numbers of projects receiving Medium and Low Integrity ratings. Approximately 40% of the projects were constructed as part of the Kenai Peninsula Restoration Cost-Share Program, a landowner cost-share and technical assistance program run cooperatively by the Alaska Department of Fish & Game (ADFG) and the U.S. Fish & Wildlife Service (USFWS).

For the Project Effectiveness Assessment, seven CST projects were evaluated with respect to their effect on near-shore aquatic habitat and streambank vegetation. Each project was compared to nearby disturbed but untreated sites and also to natural (undisturbed) sites. Stream velocity varied by treatment type, with higher velocities found at untreated sites and lower velocities found at natural and treated sites. In addition, stream velocity as a function of distance from shore was significantly different among treatments. CST projects were effective at slowing velocity in near-shore areas (up to 3-4 ft), beyond which velocity increased dramatically and approached velocities at untreated sites by 6 ft from shore.

Treated sites had abundant habitat cover in the form of placed woody debris (i.e. spruce trees). For other cover types, including emergent vegetation, overhanging vegetation, undercut bank, and natural woody debris, treated sites had significantly less cover than natural banks. Untreated sites had the greatest amount of bank that was devoid of any cover. For the vegetation assessment, treated and untreated banks had significantly less vegetation cover in the form of trees and natural shrubs. Untreated banks had significantly greater bare ground than treated and natural sites.

Chapter 1. Introduction

Background

Considerable effort has been put towards streambank restoration projects on the lower Kenai River. Nearly nine miles of streambank between the mouth and Skilak Lake (river mile 50) have been treated with restoration projects over the last several years. The majority of these projects are designed to improve shoreline aquatic habitat and to control bank erosion using natural materials and "bioengineering" methods. This study quantifies and maps the extent of projects on the lower 50 miles of the Kenai River and evaluates the effectiveness of projects in providing fish habitat.

There has been extensive shoreline development along the banks of the Kenai River, primarily related to residential development and recreation access. Development-related activities, such as clearing of streambank vegetation and shoreline modifications, have impacted fish habitat (Liepitz 1994). The Kenai River also experiences tremendous angling activity during the summer months, exceeding 14% of the total fishing effort for Alaska (2006 data, Jennings et al 2009). This fishing pressure affects habitat through boat wake induced erosion (Maynord et al. 2007) and shore angling impacts (King and Clark 2004).

In response to the above factors, there has been a tremendous amount of effort put towards protecting and restoring streambank habitat. Many of the habitat restoration projects conducted on the Kenai River have been funded by the Kenai Peninsula Restoration Cost-Share Program (Cost-Share Program). Since 1995, the Alaska Department of Fish & Game (ADFG) and the U.S. Fish & Wildlife Service (USFWS) have provided funding assistance to streamside landowners on the Kenai River as part of this program. Applicants whose projects are accepted can receive reimbursement for up to 50% of the cost of their project. Since its inception, this program, and the associated outreach and technical assistance to landowners, has resulted in an enormous amount of restoration project implementation along the Kenai River.

Objectives

This study was conducted to characterize the current status and extent of streambank restoration work on the Kenai River between the mouth and Skilak Lake, and to evaluate the effectiveness of projects in enhancing fish habitat. The following objectives guided the assessment activities conducted in this study:

- Restoration Project Status
    - Map the location of restoration projects on the mainstem Kenai River and major side-channels between the mouth and Skilak Lake (river mile 50).
    - Quantify the amount of projects by type and compare conditions to past project inventories.
    - Document and compare the general physical condition of projects by project type.

- Restoration Project Effectiveness
    - Compare near-bank stream velocity at sites treated with CST projects to nearby untreated (but disturbed) sites and natural (undisturbed) sites.
    - Compare the availability of habitat cover types at CST projects to nearby untreated (but disturbed) sites and natural (undisturbed) sites.

The results of this study help to characterize the location, type, and condition of restoration projects on the Kenai River, and in comparison to past studies, help to define trends in restoration activity and progress towards mitigating human impacts. Assessing the effectiveness of projects in enhancing fish habitat will provide guidance for designing and implementing future restoration measures.

Previous Studies

Fish Habitat Associations

Past studies have looked at the associations between habitat and fish abundance/distribution in the Kenai River. These include Estes and Kuntz (1986), Burger et al. (1983), Bendock and Bingham (1988), and other previous ADF&G studies. These studies have demonstrated that most of the juvenile salmon rearing in the mainstem Kenai during the summer months occurs along bank margins where fish can access habitat cover and velocity refuge. Chinook make the most use of these habitats, although sockeye salmon, coho salmon, rainbow trout, Dolly Varden, and several non-salmonids also make use of mainstem bank habitats. Estes and Kuntz (1986) found that undercut banks with overhanging vegetation generally had the most fish. They concluded that velocity and cover appeared to be the most important variables influencing juvenile rearing. Bendock and Bingham (1988) found that Chinook salmon were positively correlated with cover, although the type of cover did not matter. They concluded that the specific type of cover may not be so important so long as stream velocity is within suitable ranges (i.e. less than ~30 cm/sec).

Streambank Conditions and Development Impacts

Scott (1982) identified the geomorphic conditions of Kenai River reaches and the physical processes affecting erosion and sedimentation. Scott noted that bank erosion conditions had remained relatively constant over the years but that human modifications related to fishing (i.e. boat wakes and bank trampling) and development (i.e. canals and bank structures) may create future bank instability. Inghram (1985), however, in a study of aerial photographs, could not relate bank erosion rates to human activities and speculated that human impacts were small and isolated.

The “309 Study” (Liepitz 1994) quantified and mapped (by parcel) the extent of streambank modifications throughout the Kenai River, including the section below Skilak Lake and the interlake reach between Skilak and Kenai Lakes. All streambank modifications were documented, including bank trampling, vegetation clearing, bank armoring, jetties, docks, and restoration projects. As many as 20.6 miles of streambank, out of 134 miles total, were impacted by human alteration. Approximately one mile of streambank was treated with restoration projects falling into one of the three following categories: 1) “cabled trees”, 2) “logs”, or 3) “soil bioengineering”. Habitat analysis indicated that 2.2% of habitat originally available for juvenile Chinook rearing had been lost as a result of human alteration to shoreline habitat. A development trends analysis found that 76% of modified banks and structures that were present in the 1993 surveys were put in place since 1963/64.

King and Clark (2004) mapped macrohabitat types along Kenai River shorelines using 1998 aerial photography. Between Warren Ames Bridge and Skilak Lake, a total of 13.4% of shorelines (including side-channels and back-channels) were classified as “disturbed”, which was defined as “50% or greater of the area is characterized by human perturbations (lawns, structures, land clearing activities, etc.)”.

Streambank Project Impacts and Effectiveness

There have been a number of studies looking at the impact of streambank projects on fish abundance, habitat conditions, or erosion. These include Dorava (1995), Dorava and Moore (1997), Dorava (1999), Hauser et al. (2000), and Karle (2003).

Dorava (1995) studied the hydraulic effects of various different structure types, including jetties, rock walls, docks, boat ramps, and a bioengineering project. He found that structures that protrude into the flow and reduce stream channel area (such as jetties) have the greatest influence on stream hydraulics. Measurements at the bioengineering project suggested that project elements (i.e. rootwads and boulders) were effective at slowing water velocities and keeping velocities within the suitable range for juvenile Chinook salmon.

Dorava and Moore (1997) found that CSTs, BEBs, rip-rap, and wooden retaining walls were all effective at controlling erosion, except in one case where a CST project washed away. Dorava (1999) found that CSTs and bio-logs reduced boat wake heights compared to sites with no bank protection. CSTs, bio-logs, and combination approaches (CSTs, bio-logs, and willow plantings) all provided erosion protection compared to an untreated natural bank. With respect to habitat cover, CSTs, bio-logs, and combination approaches all provided more cover than natural banks, with CSTs providing the most cover (Dorava 1999).

Hauser et al (2000) compared velocity and habitat cover conditions at treated, disturbed (untreated), and undisturbed (natural) sites. Treatment types included CSTs, bioengineered banks, and combination approaches (i.e. those including rootwads and/or CSTs in addition to brush layering). No significant differences were found for stream velocity, although CST projects and combination approaches had the greatest amount of “optimal” velocity for juvenile fish rearing. Fine woody debris was significantly more abundant at CST and combination projects. Overhanging vegetation was more abundant at CST projects, combination projects, and natural banks. The investigators concluded that CSTs and combination projects more closely resembled undisturbed banks, and bioengineering projects more closely resembled disturbed banks. They did not see an effect of streambank treatment on fish abundance, but attributed this, in part, to their sampling methods.

Karle (2003) evaluated two rootwad revetment projects on the Kenai River as part of an evaluation of the performance and stability of "bioengineered" erosion control structures on rivers throughout Alaska. Based on hydraulics analysis, the two Kenai River projects were determine to be in stable condition with little risk of failure; however, based on the results of the study as a whole, Karle recommended analysis methods and project techniques that could be used to improve upon the design of erosion control projects.

Sport Fishing Impacts

Studies were initiated in 1996 to evaluate angler use patterns and relationships among angler use, streambank vegetation, and streambank habitat conditions. Studies in 1996 and 1997 revealed few significant correlations (Larson and McCracken 1998, King and Hansen 1999); however, studies from 1998 to 2001 found that bank loss increased in areas of high angler use and that plant diversity and evenness was less in areas of high angler use. Bank loss was also found to be greater in areas of high powerboat activity (King and Hansen 2001-2002, King and Clark 2004).

The effect of boat-wakes on streambank erosion has received considerable attention on the Kenai River. Dorava and Moore (1997) characterized patterns and timing of boat use and bank erosion on the mainstem Kenai River in 1996. Bank loss in a non-motorized segment of river was about 75% less than in the highest boat-use area of the river, and 33% less than in the lowest boat-use area of the river.

A comprehensive study by Maynord et al. (2007) studied boat wake induced bank erosion between river miles 10 and 21. Boat wake induced erosion was found to vary depending on the timing of peak boat usage and stream flow, with greater erosion occurring at higher flows as a result of where on the bank the wave action occurs. They concluded that boat wake erosion may be a dominant factor during certain periods and may have ecological impacts, but that bank recession from flood and ice events likely overshadows the contribution from boat wakes.

Chapter 2. Project Status Assessment

Overview

The project status assessment was conducted along the mainstem Kenai River from the mouth to Skilak Lake (river mile 50). Field surveys were conducted in June 2008. The study recorded the types of streambank projects (i.e., techniques used), the spatial extent of projects, and the condition/integrity of projects. Projects included in the inventory are streambank protection or restoration projects that utilize "fish friendly" techniques that stabilize streambanks while also providing fish habitat benefit. The frequency and location of projects are presented and compared to previous studies. The longevity and integrity of the various restoration techniques are evaluated and compared.

Since 1995, ADFG and USFWS have provided funding assistance to streamside landowners on the Kenai River as part of the Cost-Share Program. Applicants whose projects are accepted can receive reimbursement for up to 50% of the cost of their project. This study quantifies the numbers and types of cost-share projects at the time of the survey. Non cost-share projects were included in the survey and comparisons are made between cost-share projects and non cost-share projects.

A companion study was also conducted during summer 2008 and is presented in Chapter 3 (Project Effectiveness Assessment). The companion study evaluates the fish habitat benefits provided by cabled spruce tree projects, which are the most commonly utilized projects on the Kenai River. Together, these two investigations help to characterize the current extent and effectiveness of streambank restoration projects along the Kenai River.

Methods

Project Mapping

Project inventory data was collected from June 16 to June 25, 2008 using a boat-based survey. Stream flows at the Soldotna Gage (USGS #15266300) ranged from 7,820 to 10,400 cubic feet per second during the survey. The entire 50 miles of the lower mainstem Kenai River from the mouth to Skilak Lake were included in the survey. Streambank protection and fish habitat enhancement projects located along the banks of the mainstem Kenai River and in major side-channels were inventoried. Projects consisting of rip-rap or other bank armoring (e.g. concrete retaining walls) were not included in the inventory unless they also included fish enhancement features. The location of each project was recorded by taking a GPS measurement at the upstream and downstream end of the project using a handheld Trimble GeoXT GPS. Contiguous treatments were considered separate projects if there was a change in treatment type or condition. Project type was recorded and a photograph was taken of each project.

Overview of Project Types

Project types included cabled spruce tree revetments, bioengineered banks, rootwad revetments, tethered logs, other miscellaneous treatment types, and combination approaches. Most of the projects generally conform to the project techniques described in the Alaska Streambank Revegetation and Protection Guidelines (Walter et al. 2005). Brief descriptions and example photographs of the primary project types are included below.

Cabled spruce trees

Cabled spruce tree revetments (CSTs) include the cabling of spruce trees to the streambank in order to provide streambank protection and erosion control. CSTs may include a single layer of spruce trees, multiple spruce trees bundled together, or stacked layers. Spruce trees are placed parallel to the streambank, oriented with their tops facing downstream and typically overlap 1/3 to 1/2 their length in a shingle fashion. The trees are secured to the bank with cables and earth anchors (e.g. duckbill anchors). CSTs limit streambank erosion and also provide velocity refuge and cover for juvenile salmonid rearing.

Typical cabled spruce tree revetment

Large cabled spruce tree revetment with multiple stacked layers

Bioengineered bank

For the purposes of this assessment, bioengineered bank treatments (BEBs) include a number of different restoration strategies including coir logs, live siltation, brush layering, and fabric-wrapped soil lifts. These techniques typically include the use of a coir log toe overlaid with fabric-encapsulated soil/gravel lifts that are layered with willow live stakes. The “brush layering” technique described in Walter et al. (2005) appears to be the most common design utilized on the Kenai River. Bioengineered banks are considered a fish-friendly method of bank stabilization.

Typical bioengineered bank

Bioengineered bank with coir log toe and good willow growth

Rootwad revetment

Rootwad revetments consist of logs with attached rootwads that are buried into the bank to provide streambank protection and fish habitat. The boles are buried perpendicular to the river with the rootwad fan facing the river and protecting the bank. The rootwads are placed close together or overlapped to ensure continuous bank protection. The rootwads are backfilled with soil or gravel. Biodegradable erosion control fabric (e.g. coir) is often used to reinforce the backfilled material or to construct fabric-wrapped lifts on top of the tree boles. Rootwad revetments reduce streambank erosion and provide juvenile fish habitat.

Typical rootwad revetment

Rootwad revetment with willow live staking

Tethered logs

Tethered logs include floating logs laid in the water parallel to the streambank and tethered to the bank with rope or cable. These treatments typically include logs in excess of 6 inches diameter and 15 feet long and may be single logs “shingled” along the bank or may consist of multiple logs extending out into the channel. Tethered logs reduce streambank erosion by dampening boat wake energy and by creating a velocity break along the shoreline. They also provide velocity refuge and cover for juvenile salmonid rearing.

Typical tethered log treatment

Typical tethered log treatment

Combination approaches

Many streambank treatments along the Kenai River include a combination of the above approaches. The most common combination projects incorporate BEBs and CSTs. For these techniques, a BEB is constructed first and CSTs are then installed along the bank in front of the structure. Combination approaches are common along the Kenai River. These treatments typically provide erosion control as well as fish habitat benefits.

Typical combination approach (cabled spruce trees and bioengineered bank)

Combination approach using cabled spruce trees and rootwad revetment

Project Condition and Integrity

The condition/integrity of each project was recorded. Projects were assigned to one of three "integrity" categories that were developed to characterize the condition and effectiveness of each project. The integrity categories are described in Table 1.

Table 1. Project integrity categories

High Integrity
• Project nearly 100% intact. Continuous treatment along length of project. • Project is accomplishing objectives of erosion protection and habitat protection/enhancement. • No significant erosion occurring on streambank. • Vigorous growth of planted vegetation is present along the majority of the project length. • High Integrity ratings were given to otherwise Medium Integrity projects where vigorous growth of planted vegetation was taking over and accomplishing project objectives despite the failure of other project elements.
Medium Integrity
• Project is 50% to 100% intact. Areas of discontinuous treatment along length of project. • Some erosion or signs of project disrepair, but nothing that compromises the integrity of more than half the project. • Some, but not all, objectives being accomplished. • Growth of planted vegetation is apparent but does not encompass the majority of the project. • Medium Integrity ratings were given to otherwise Low Integrity projects where growth of planted vegetation was taking over and accomplishing project objectives despite the failure of other project elements.
Low Integrity
• Project is 0% to 50% intact. Project is mostly discontinuous. • Significant signs of failure, complete failure of the majority of the project, or high risk of eminent failure. • Objectives of the project are no longer being met. Significant erosion and/or absence of fish habitat. • Little to no growth of planted vegetation.

Projects were assigned age classes for cases where project age could be reliably determined. The age of the project, or time since last maintenance, was determined through visual inspection of vegetation growth (for restoration plantings) or vegetation decay (for CSTs). In some cases, conversations with landowners assisted with determination of project age or the time since last maintenance. A system for determining the age of CSTs was developed by combining the observed decay of the spruce trees with project age obtained from landowners. Indicators of decay and corresponding age are included in Table 2. Example photos of spruce tree ages are included in Figure 1.

Table 2. Indicators used to determine age of cabled spruce tree revetment projects.

Indicator	Age
Green needles present	0-1 years old
Brown needles and/or cones present	1-2 years old
Needles absent but fine branches present	2-3 years old
No fine branches present	> 3 years old

Green needles present
(0-1 years old)

Brown needles and/or cones present
(1-2 years old)

Needles absent but fine branches present
(2-3 years old)

No fine branches present
(>3 years old)

Figure 1. Example photos of spruce tree age indicators used to determine age of CSTs during field surveys.

Identification of Cost-Share Projects

Projects were identified as to whether or not they were constructed as part of the Cost-Share Program. A working version of the restoration cost-share database from 2007 was obtained from ADFG. Property parcel numbers in the database were cross-referenced to a property ownership GIS layer obtained from the Kenai Peninsula Borough. Using this information, a GIS layer of cost-share parcels was developed. This layer was overlaid with the results of the project inventory to determine if projects were conducted as part of the Cost-Share Program.

Results

Frequency of Project Types

There were a total of 385 projects recorded during the survey, making up 45,284 lineal feet of streambank, or 8.6 miles. The most common project type is CSTs (Figure 2). A total of 57% of all projects are CST projects. CSTs are also a component in many of the combination approaches (Table 3). When combination approaches using CSTs are taken into account, projects with CSTs make up 73% of all projects on the Kenai River, equating to 6.0 miles of streambank. Combination approaches and BEBs make up the second and third most common project types, respectively. BEBs are also commonly incorporated into combination projects, and when taken in total, are a component of 35% of all projects. Tethered logs, rootwad revetments, and other miscellaneous approaches make up less than 10% of all projects. Rootwad revetments make up a very small portion of the projects; only 20 projects incorporate rootwad revetments, and there are only 3 projects that rely solely on rootwads.

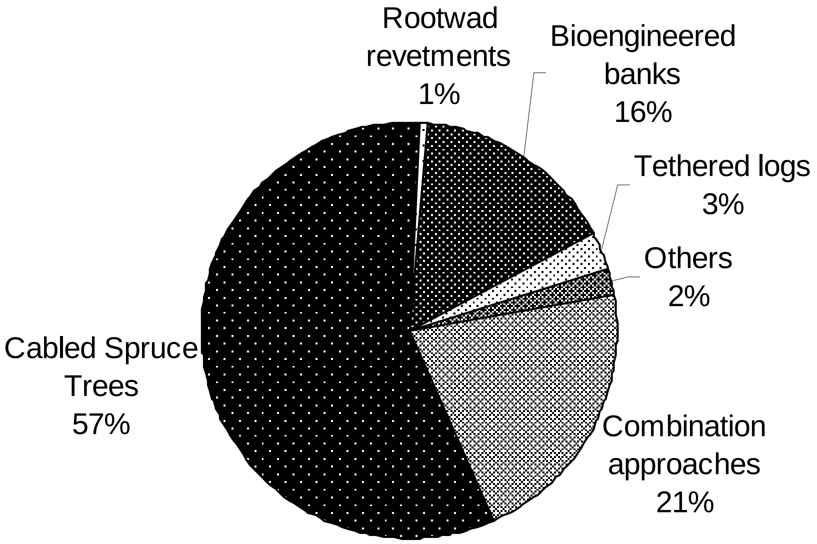


Figure 2. Total frequency of treatment types.

Table 3. Frequency of treatment types.

Restoration Technique	Number of projects	% of total projects	Total length of treatment (ft)	% of treatment lengths
Cabled Spruce Trees	221	57%	24,813	54%
Rootwad revetments	3	1%	609	1%
Bioengineered banks	60	15%	7,441	16%
Tethered logs	12	3%	2,264	5%
Others	8	2%	510	1%
Combination approaches	81	21%	9,648	21%
Bioengineered banks with cabled spruce trees	*57*	*15%*	*5,757*	*12%*
Bioengineered banks with rootwad revetments	*12*	*3%*	*2,256*	*5%*
Rootwads with cabled spruce trees	*1*	*0.3%*	*363*	*0.8%*
Bioengineered banks with rip-rap	*3*	*0.8%*	*583*	*1.3%*
Rootwads with rip-rap	*2*	*0.5%*	*132*	*0.3%*
Cabled spruce trees with rip-rap	*3*	*0.8%*	*197*	*0.4%*
Bioengineered bank, rootwad, & cabled spruce tree	*3*	*0.8%*	*360*	*0.8%*
Totals	**385**		**45,284** **(8.6 miles)**	

Spatial Distribution of Projects

Streambank restoration projects are located throughout the lower Kenai River from approximately river mile (RM) 10 to RM 45. There are no projects located downstream of RM 10 or upstream of river mile 45. There are also no projects located between RMs 25.5 and 30.3. The highest concentrations of streambank projects correspond to the areas of highest density residential development along the river. High density areas include the Soldotna, AK area (RM 14 – 25) and the areas just upstream and downstream of the Moose River confluence (RMs 32.5 to 37.6).

An overview of the entire study area is included in Plate 1 that shows the overall spatial distribution of projects by type. Plates 2 through 9 show the locations and types of projects at greater detail.

The number and type of projects per reach were compared to data obtained from the 309 Study (Liepitz 1994; surveys conducted in 1992-1993). Most of the projects recorded during the 309 Study were various types of bank armoring, including rip-rap, retaining walls, landing mats, and other miscellaneous approaches. However, the 309 Study also inventoried projects that used more natural materials, including “Cabled Trees”, “Logs”, and “Soil Bioengineering”, which are comparable to data collected as part of this study. These projects are compared in the following manner: cabled spruce trees are considered "Cabled Trees", rootwad revetments and tethered logs are considered "Logs", and bioengineered banks are considered "Soil Bioengineering". The data are included below in Table 4 and Figure 3.

In general, there has been a dramatic increase in implementation of “fish friendly” streambank protection measures since the early 1990s. For all reaches combined, there has been a 4.6 fold increase in project numbers (368 compared to 80) and an 8.8-fold increase in project length (8.5 miles compared to 1 mile). Reaches 1 and 4 have seen relatively modest changes, whereas reaches 2 and 3 have seen the greatest surge in restoration using these methods.

Table 4. Comparison of 2008 project inventory results with results from the 309 Study (Liepitz 1994). Units are lineal feet of streambank treated. Project categories are from Liepitz (1994). For purposes of this comparison, 2008 data is interpreted in the following manner: cabled spruce trees are considered "Cabled Trees", rootwad revetments and tethered logs are considered "Logs", and bioengineered banks are considered "Soil Bioengineering". Lengths of combination approaches were split among their component project types for this comparison.

	Reach 1			Reach 2			Reach 3			Reach 4		
Year	Cabled Trees	Logs	Bioeng	Cabled Trees	Logs	Bioeng	Cabled Trees	Logs	Bioeng	Cabled Trees	Logs	Bioeng
2008	0	441	0	4,464	147	3,194	20,238	2,853	7,873	3,084	2,331	453
1992-3 (309 Study)	300	205	0	820	320	279	215	272	0	2,389	212	110

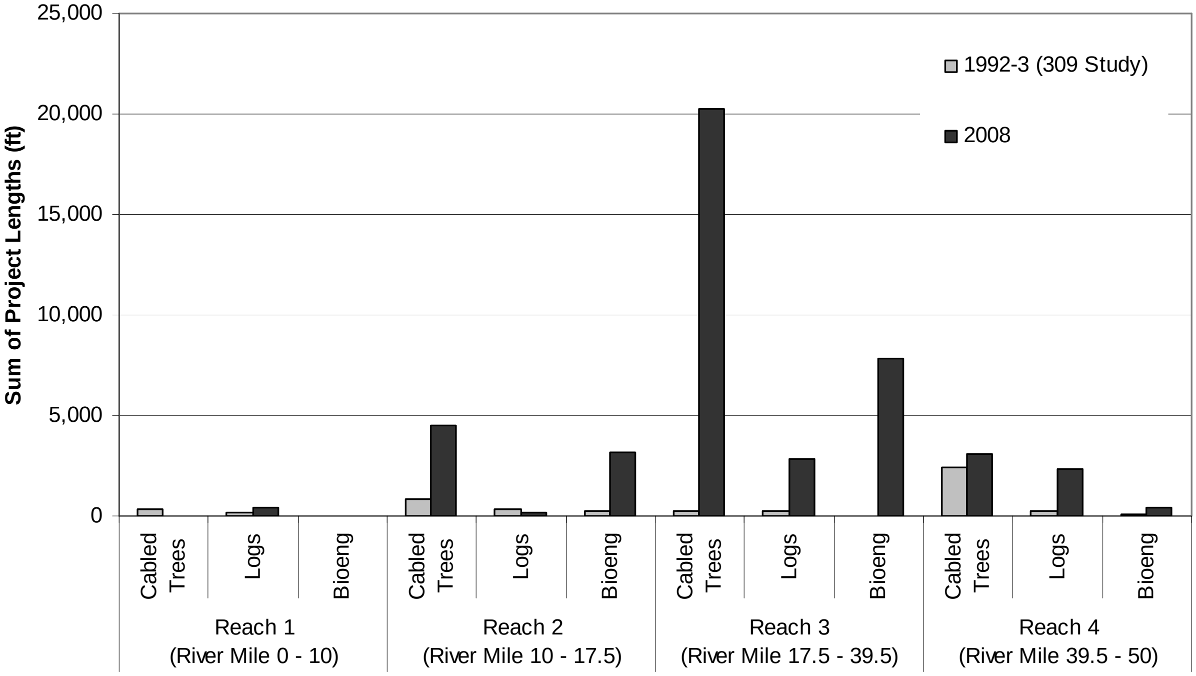


Figure 3. Comparison of 2008 project inventory results with results from the 309 Study (Liepitz 1994). Project categories are from Liepitz (1994). For purposes of this comparison, 2008 data is interpreted in the following manner: cabled spruce trees are considered "Cabled Trees", rootwad revetments and tethered logs are considered "Logs", and bioengineered banks are considered "Soil Bioengineering". Lengths of combination approaches were split among their component project types for this comparison.

Approximately 40% of all the projects have been constructed as part of the Cost-Share Program. There is a similar distribution of project types across project type categories for cost-share and non cost-share projects (Figure 4). Cost-share projects tend to be either CSTs, BEBs, or approaches that combine these two treatments. Tethered logs and other miscellaneous treatments have also been implemented, but have been constructed independent of the Cost-Share Program.

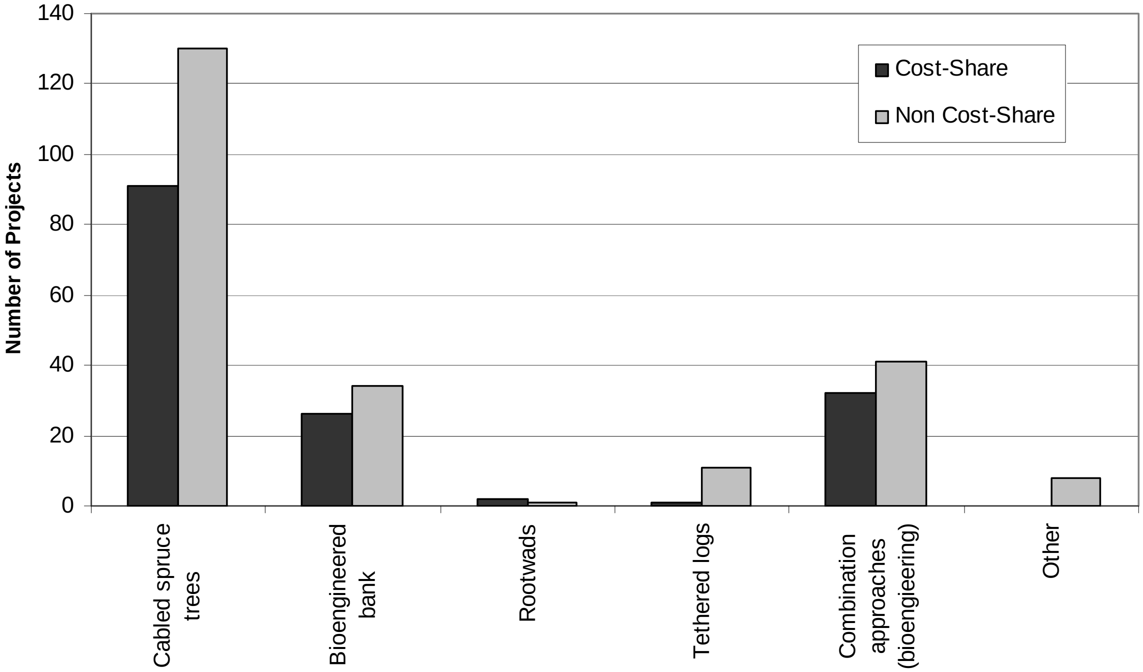


Figure 4. Project type for cost-share vs. non cost-share projects.

Project Condition and Integrity

More than half (55%) of the projects were identified as being in a High Integrity condition, with the remainder split evenly between Medium and Low Integrity (Figure 5). The integrity of projects varied by project type (Figure 6). All of the rootwad projects had High Integrity but the sample size is low. Greater than 70% of combination approaches were in the High Integrity category, with very few Low Integrity projects. Over half of CST projects had High Integrity with the remainder split evenly between Medium and Low Integrity. Bioengineered banks were mostly High or Low Integrity, with fewer projects of Medium Integrity. Tethered logs were mostly in the Medium Integrity category. Participation in the Cost-Share Program does not appear to influence project integrity (Figure 7).

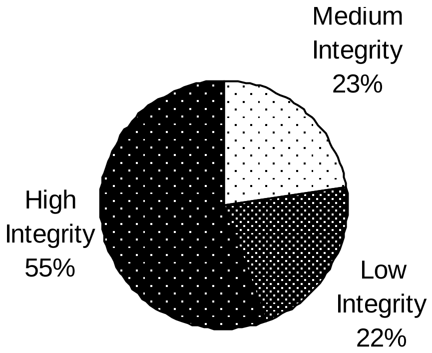


Figure 5. Results of project integrity/condition assessment for all projects.

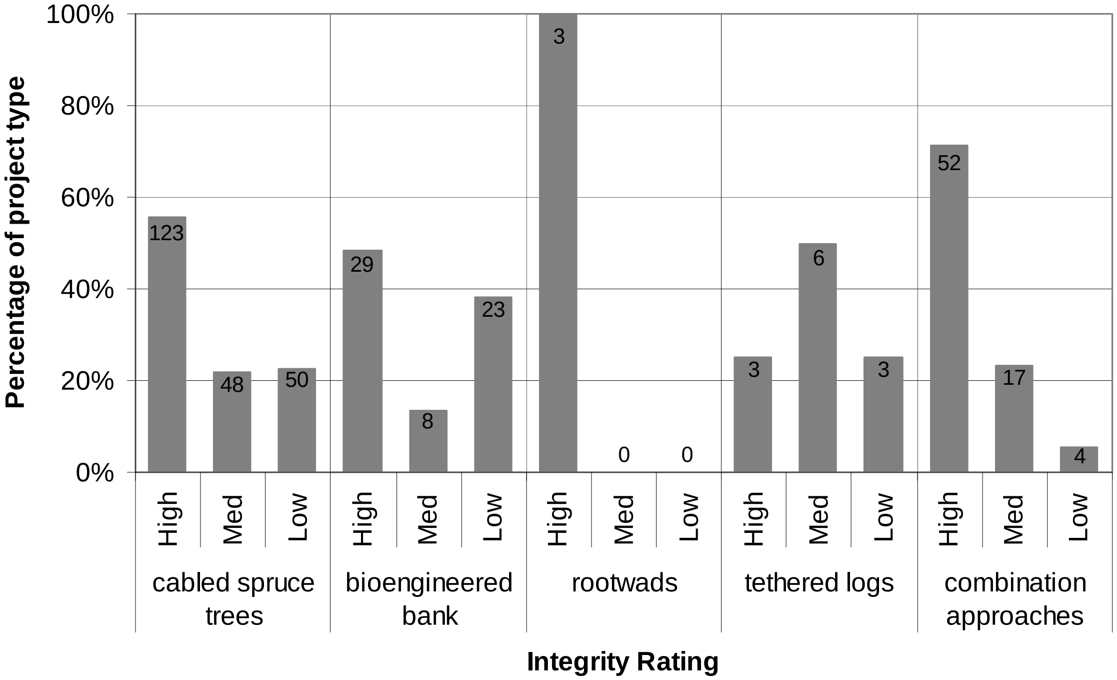


Figure 6. Integrity ratings by project type. The numbers of projects in each integrity rating category are provided on the bars. Combination approaches do not include those incorporating rip-rap.

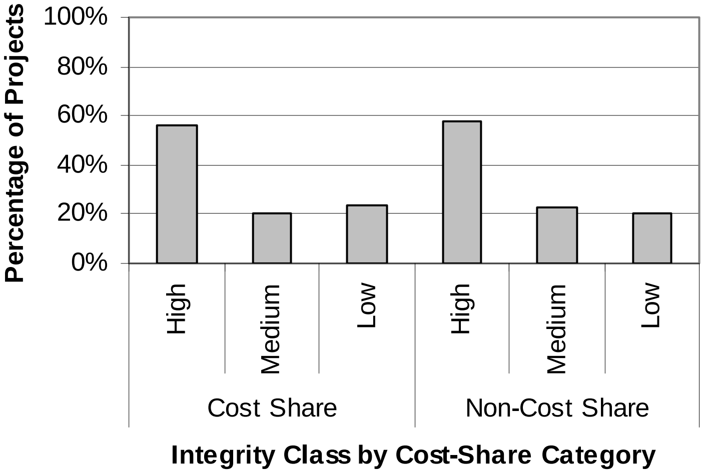


Figure 7. Effect of cost-share participation on project integrity. Participation in the Cost-Share Program does not appear to influence project integrity.

Discussion

Frequency of Projects

Erosion control and streambank restoration work along the Kenai River represents a tremendous effort that has resulted in 8.6 miles of restoration work. Approximately 9% of the streambanks between river miles 0 and 50 have been treated, although some areas contain a much higher density of projects. Near Soldotna, between river miles 20 and 21, as much as 37% of the streambanks have been treated. The highest concentrations of projects generally correspond with landownership patterns, parcel sizes, and bank angling access. Large blocks of public lands in the lower river (RM 0 to 14), middle river (RM 25 to 30), and in the upper river (RM 45 to 50) have very low densities of projects. These areas are in less need of streambank restoration because they retain native riparian forest vegetation, have difficult access for bank angling, and/or have legal restrictions on bank angling. The areas with the greatest concentrations of projects are those with small private parcels that have been developed for residential uses and that experience significant angler access to the banks. Many of these parcels have also been subjected to removal of streambank vegetation and historical removal of instream woody debris. These impacts have further contributed to bank de-stabilization and erosion.

CSTs are the most common type of project, and this is attributed to their low cost, ease of construction, and long-term effectiveness if maintained. BEBs, on the other hand, are less common, which is attributed to their greater cost and more difficult construction. BEBs require heavy machinery for bank excavation, and installing coir logs and fabric soil wraps is time consuming and labor intensive. Rootwad revetment projects are very uncommon; only 5% of all projects incorporate rootwads. Although rootwad projects are very effective at bank stabilization, few landowners are willing to put forth the expense and effort to construct them. Rootwad projects are expensive to install due to the excavation and re-filling of bank material required to bury/anchor the tree boles. Large wood materials can also be expensive to acquire and transport to the site. Projects that utilize a combination of approaches are relatively common (21% of all projects). Because these projects employ multiple techniques, they are more expensive to construct, but the added benefit provided to landowners in the form of bank protection and habitat enhancement may be worth the added effort and expense. Tethered logs and other miscellaneous approaches may be relatively inexpensive to construct, but these have uncertain effectiveness at erosion control and are not part of the Cost-Share Program and so are not frequently conducted on the Kenai River.

Historical Trends

Prior to the Cost-Share Program, most streambank protection projects were focused on halting erosion and the associated rapid loss of private lands. As the results of the 309 Study attest, in the early 1990s, most of the streambank protection projects involved bank armoring (e.g. rip-rap) or the use of non-native materials (e.g. landing pads). Although these efforts may have reduced erosion, they provide little in the way of fish habitat (Liepitz 1994). Since the early 1990s, there has been a dramatic increase in the implementation of “fish friendly” projects. By the late 1990s, contemporary techniques were seeing widespread use, and they are seeing even much greater use today. In total, there has been an 8.8-fold increase in projects that use natural materials, such as CSTs and BEBs that reduce erosion but also provide some fish habitat benefit (Figure 8).

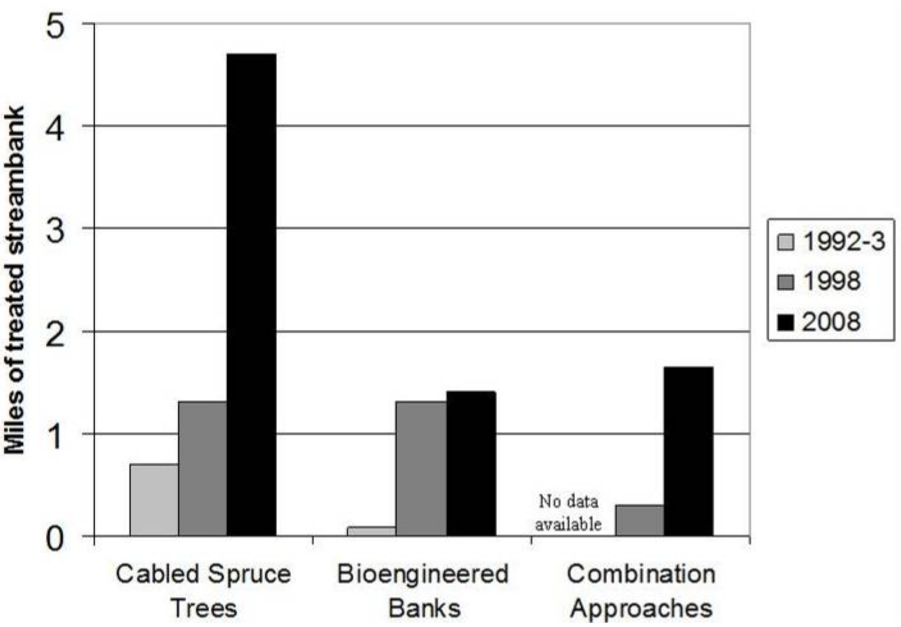


Figure 8. Change in frequency of projects since the early 1990s. 1992-3 data is from the 309 Study (Liepitz 1994); 1998 data is reported in Dorava (1999); and 2008 data is from the current study.

The increase in frequency of these newer techniques is likely due to a combination of factors: 1) the Cost-Share Program, 2) permit-related restrictions, and 3) greater education and outreach to landowners. The Cost-Share Program, which was initiated in 1995, requires application of CSTs, BEBs, rootwads, or combination approaches, and therefore has a strong influence on technique. Miscellaneous other techniques, including tethered logs, have not been conducted by cost-share participants. In total, 40% of all projects are conducted as part of the Cost-Share Program. Cost-share participants overwhelming implement cabled spruce tree projects (60%), although 26% and 32% implement BEBs and combination approaches, respectively.

Although many projects (40%) are conducted with funding assistance from the Cost-Share Program, there are still many projects conducted outside of the Cost-Share Program; and in general, these projects utilize similar techniques as cost-share projects and appear to perform similarly with respect to condition and longevity. Outreach and technical assistance has therefore been effective in promoting the use of habitat friendly techniques outside of the Cost-Share Program. Permitting requirements have also likely influenced the types of projects and implementation methods for projects conducted independent of the Cost-Share Program.

Project Condition and Integrity

The majority of projects (55%) received a High rating for project integrity, meaning they are nearly 100% intact and are accomplishing their intended objectives. An equal amount of Medium and Low Integrity projects make up the remainder. Medium and Low

Integrity projects show signs of failure and are not fully preventing erosion or creating beneficial habitat cover. In some cases, poor construction appeared to be responsible for project shortcomings, but in most cases, a lack of maintenance was the culprit.

When evaluating project success or failure, it is important to consider their location with respect to natural river erosion processes. Although bank type was not explicitly recorded as part of the survey, understanding the geomorphic setting helps to interpret why some projects fail and others persist. For instance, poor performance at several projects appeared to be related to their location at high energy, rapidly eroding banks. These locations include the tall eroding streambanks along outside meander bends that are a common feature of the Kenai River, and that represent natural erosion processes. Field observations revealed that projects at these locations had high failure rates and required aggressive techniques and routine maintenance in order to be successful. Projects located at inside meander bends, where sediment aggradation (as opposed to erosion) is the dominant process, appeared to have lower failure rates.

Except for rootwad projects, which may last a very long time and require little maintenance, the vast majority of projects use natural materials that are subject to fairly rapid decay and require regular maintenance to continue functioning as desired. Continued maintenance requirements underscore the importance of restoring natural streambank conditions (i.e. native vegetation communities) that will provide long-term bank protection and habitat value. Where feasible, projects should be viewed as interim measures to buy time until vegetative plantings can mature and provide long-term stability and habitat.

Participation in the Cost-Share Program does not appear to influence project integrity (Figure 7). The Cost-Share Program may increase the amount of people who implement streambank protection measures but it does not appear to influence how well they are constructed or maintained. It is assumed that in many cases the same contractors are used, which lends an element of quality control. Furthermore, the incentive to prevent erosion and bank retreat on private property exists regardless of whether or not folks participate in the Cost-Share Program.

A discussion of project conditions, maintenance requirements, and habitat functions of projects are provided below by project type.

Cabled spruce trees

CST projects were mostly in a High Integrity condition (56%), with an equal number of projects rated as Medium and Low Integrity. The preponderance of High Integrity projects is likely related to the relative low cost of construction and ease of regular maintenance. Most (54%) of CST projects were installed or had received maintenance within the past 2 years. As can be seen in Figure 9, the time since installation or maintenance has a large impact on project integrity. A project that goes three or more years without maintenance begins to lose integrity and effectiveness. This is due to the decay of the spruce trees over time and the eventual deterioration of the project.

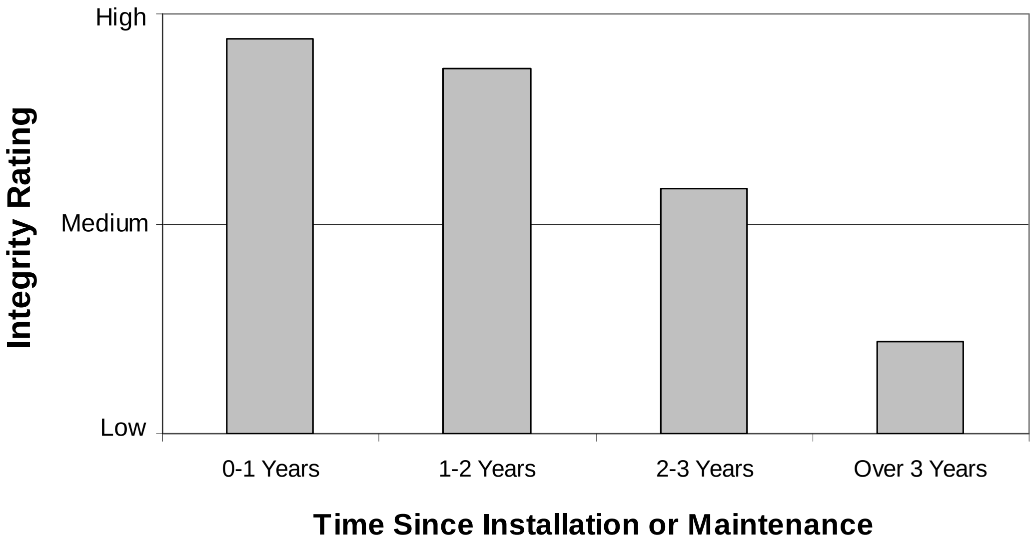


Figure 9. Effect of project age (time since last installation or maintenance) on the project integrity rating. Integrity ratings were converted to numerical ratings and were averaged by age class.

Based on these results, as well as conversations with landowners, it is evident that regular maintenance of CST projects is critical to ensure continued project effectiveness. Regular maintenance is required every 2 to 3 years and typically involves the replacement or addition of fresh spruce trees to the project. The short lifespan may be a drawback of CST projects, but the ease of maintenance makes up for this shortcoming. Some residents utilized a technique that makes maintenance very easy and avoids re-installation of the earth anchors. This is facilitated by the use of removable cable clamps at the front or top of the spruce bundles. When the spruce trees need replacement or supplementation with additional trees, the cable clamps can be unfastened and new trees can be added to the structure.

Field observations and data collected as part of the Project Effectiveness Assessment (Chapter 3) suggest that CSTs provide effective erosion control and fish habitat cover. Well-constructed CSTs reduce near-bank velocities and dampen boat wakes. This is consistent with the findings of Dorava (1999) and Dorava and Moore (1997), who found that banks protected with spruce trees were effective at attenuating boat wakes and protecting banks from flood-related erosion. Several residents encountered during the field survey said they have even noticed deposition of material behind CSTs and re-building of their banks.

CSTs provide cover habitat for juvenile salmon, which were regularly observed within CSTs during the field surveys. The habitat value provided by CSTs has been demonstrated by Hauser et al. (2000) and is evaluated in Chapter 3 of this report. Habitat availability varies depending on the age of the spruce trees and the means of construction. Newly constructed CSTs are often bundled very tightly together, which makes for effective erosion control but may limit access of juvenile salmon into the interiors of CSTs. Over time, the needles and fine branches fall off and access into the interior matrix of the spruce trees is improved. Most CST projects also provide overhanging cover because buoyant CSTs provide fish access to underneath the structure. This is especially the case with loosely bundled CSTs and less the case with CSTs packed and secured tightly against the bank. The above observations suggest that tighter packed CSTs may have greater erosion protection but less access by juveniles (both beneath and within the CSTs); and looser packed CSTs may have less erosion protection but greater habitat benefit.

The effect of CSTs on near-bank velocity and cover habitat for fish is addressed further in Chapter 3 of this report.

Bioengineered banks

As with CSTs, BEBs were observed to provide effective erosion control, provided they are constructed properly, have vigorous willow growth, and are maintained over time. This is consistent with the findings of Dorava (1999), who found that banks protected with bio-logs were effective at attenuating boat wake erosion. Figure 10 is a good demonstration of the effectiveness of BEB projects in providing erosion control. Karle (2003), however, found that bioengineering projects were not necessarily effective at preventing toe scour and bank erosion during flood events. He recommended that scour analysis be conducted as part of project design and that appropriate measures be taken to provide toe protection if necessary.

Figure 10. View looking upstream at BEB project near RM 31. Notice severe bank erosion and soil loss upstream of project (site of failed CST project) and effective bank protection provided by BEB.

Figure 11. BEB near RM 31. BEB is halting erosion; however, fabric wraps are beginning to fail. Even with vigorous willow growth (as on the left side in this photo), eventual collapse of the wraps will undermine the bank and create continued erosion and failure of the willows.

Most BEB projects were rated as either High Integrity (48%) or Low Integrity (38%), with few Medium Integrity (14%) projects. This suggests that when they fail, they fail quickly. Their construction makes them prone to this dynamic, where an unraveling of a soil wrap or collapse of a section of coir log provides an attack point for flow or wave erosion to quickly unravel the remainder of the project. BEB projects may also be vulnerable to icing events that may abrade the coir fabric or dislodge coir logs.

Based on field observations and conversations with landowners, well-constructed BEB projects have a useful lifespan of 5-10 years, depending on flow and icing conditions. Once they begin to fail, they are difficult to maintain, especially compared with CSTs, where one need only replace or supplement the project with new spruce trees. Maintenance of a failing BEB project may require replacing coir logs, replacing erosion control fabric, and rebuilding fabric wraps, which requires excavation and machinery work at the site – a costly measure that may justify complete re-building of the project. Proactive maintenance before failure, such as replacing or adding additional support stakes, may delay failure, but the eventual decay of the erosion control fabric is inevitable and will lead to eventual bank failure in most cases.

A major component of BEB projects is planting willow live stakes in order to enhance stability and presumably to provide long-term bank stability once the fabric wraps or coir logs deteriorate. Field observations indicate that vigorous willow growth may indeed enhance the erosion protection benefits of projects during summer high flows, but in very few instances were willows observed to provide bank stability once coir logs and fabric wraps deteriorated (Figure 11). Furthermore, willow mortality is common on BEBs, especially for lower tier plantings that are inundated during summer high flows. Grasses may grow better at this elevation and in some cases were observed to fold over the bank to provide a protective mat of vegetation.

Field observations and previous studies (Hauser et al. 2000) suggest that BEBs may provide less habitat cover due to their tendency to reduce near-bank complexity. This may be especially the case at lower river flows that do not inundate the willows. Stability of BEBs requires them to have little or no overhang that is accessible to juvenile fish. At high flows, willows will provide some overhanging cover but may not effectively reduce near-bank velocity. Furthermore, the smooth and linear nature of soil wraps and coir logs decreases the availability of velocity refuge, which on natural banks is provided by eddies, pocket water, alcoves, and the interstitial spaces within exposed tree roots or instream woody debris. Bank uniformity created by BEBs can be seen in Figure 12. This is typical of many of the BEB projects, where high velocities are present along the constructed bank and there is little in the way of bank overhang or instream wood cover.

Figure 12. Bioengineered banks provide good bank protection but create linear, uniform banks with little cover habitat for juvenile fish (left bank near river mile 31).

Figure 13. This combination project (rootwads plus cabled spruce trees) provides bank protection and a diversity of habitat cover along the bank (left bank near river mile 31).

Rootwad revetments

Projects using only rootwad revetments were all in the High Integrity condition, although the sample size is small (3 projects). When combination projects including rootwads are considered (17 projects), 90% of the projects rate as High Integrity, with only one Medium and one Low Integrity rootwad project. These results match observations that rootwad projects are generally intact and appear to be stable over long periods. Materials used in rootwad projects (i.e. logs with rootwads) are less prone to decay than CST or BEB projects. These projects also provide considerable stability to streambanks because of the strength of the material and the use of bole burial for ballast/anchoring.

Although the majority of rootwad projects on the Kenai River appeared to be in good condition, rootwad revetments may not be adequate to prevent bank erosion where scour potential is high. In a study of streambank protection projects throughout the Kenai Peninsula, Karle (2003) found that rootwad projects failed or suffered damage in areas where stream tractive forces (i.e. shear stress) were high. The two rootwad projects he evaluated on the Kenai River performed well, but hydraulic analysis showed low scour potential at these sites. Three other rootwad projects failed or were severely damaged, and these sites showed high scour potential. Karle (2003) concluded that erosion control projects should include shear stress and scour analysis, and that projects need to be properly designed to resist scour, which may include additional toe protection (e.g. rip-rap) to prevent damage to the structure.

Field observations suggest that rootwad revetments provide complex cover along the streambank that is accessible by juvenile salmon. The projection of the bole and rootwad into the channel mimics undercut bank conditions and the rootwads themselves provide a complex network of roots that provide cover, protection, and velocity refuge.

The drawback to using rootwads is the expense required to implement them, which is likely the reason for their infrequent use on the Kenai River. Considerable excavation is required and materials are expensive. However, due to their longevity and their habitat enhancement potential, rootwads may be an effective and economical streambank restoration technique over the long term.

Tethered logs

Only 3% of projects fall in this category and most of these projects were rated as being in a Medium Integrity condition (50%), with an equal amount of High and Low Integrity projects. Tethered log projects are not constructed as part of the Cost-Share Program and have been constructed in all manner of configurations. Most appear to have been constructed using little expense and very likely with logs cut from on-site. It is assumed these projects are effective at boat wake attenuation, similar to the wake-attenuation effect of bio-logs and spruce trees (Dorava 1999). Fish habitat cover may be provided under the structures but because tree boles without branches are typically used and they simply float on the surface, there may not be effective velocity reduction beneath the structures. However, velocity refuge is likely provided between the logs and the bank in places where space is available due to bank irregularities.

Combination approaches

Combination approaches reflect the benefits and drawbacks of their component techniques, which are described above. Hauser et al. (2000) found that projects using multiple techniques generally provided a greater diversity of habitat cover as a result of the different techniques and materials that are used. Many combination projects utilize a robust bank protection measure such as rootwads or BEBs and combine this with CSTs that provide added velocity refuge and habitat cover (see example combination project in Figure 13). In general, combination approaches rated as High Integrity (71%), with very few Low Integrity projects (5%). This might reflect a greater level of commitment and attention given by landowners who take on these larger and more complex projects.

Chapter 3. Project Effectiveness Assessment

Overview

This Project Effectiveness Study evaluates the effects of streambank restoration projects on fish habitat. The projects selected for evaluation used cabled spruce trees (CSTs) as the dominant treatment strategy. An original study objective was to evaluate multiple project types including bioengineered banks (BEBs) and rootwad revetments. However, due to limited resources and the preponderance of CST projects along the river (73% of projects incorporate CSTs), a decision was made to focus only on CST projects and use a higher sampling intensity at each site to improve inferences regarding effects of CST projects on habitat.

This study collected data for seven CST projects at seven distinct sites, and compared conditions to nearby untreated (disturbed) plots and natural (undisturbed) plots within each site. Three of the seven projects were combination projects that also utilized BEBs to some extent, including fabric encapsulated soil lifts or coir logs; however, bank conditions at these three sites were overwhelmingly governed by the presence of the CSTs and for the purposes of this study were considered CST projects. Although only one of the seven CST projects was conducted as part of the cost-share program, the objectives of all projects were assumed to be the same as those of the cost-share program. This is a reasonable approach given that the study projects represent CST treatments typical of those regularly conducted under the cost-share program.

The habitat variables used to evaluate CST projects were based in part on the objectives of the cost-share program, which are to protect and rehabilitate fish habitat, including (http://www.sf.adfg.state.ak.us/SARR/restoration/restor.cfm):

1) Overhanging vegetation for shade and source of terrestrial insects for food;
2) In-water debris, both natural woody debris and installed structures, that decrease water velocity along the bank, provide a media for benthic macroinvertebrates which are a food source, and provides in-water cover to escape from avian and piscine predators; and
3) Undercut banks that provide shade, slow velocity cells and protection from predators.

Study Hypotheses

Our hypothesis at the outset of this study was that banks treated with CST projects would have habitat conditions that better resembled natural banks than disturbed banks that had not received treatment.

We expected natural banks to have abundant and variable habitat cover. Natural banks provide a variety of cover types that support juvenile fish rearing. These include undercut banks stabilized by root masses, overhanging shrubs and grasses, instream woody material, and aquatic and emergent vegetation. Abundant and variable cover, combined with bank irregularities, would be expected to reduce near-bank velocity.

In contrast to natural sites, disturbed sites included in this study have been subjected to residential development, clearing of streamside vegetation, removal of instream woody debris, and bank trampling. These impacts would be expected to reduce the amount and the diversity of available habitat cover. Near-bank velocity would be expected to be higher than at natural or restored sites.

Sites treated with CSTs would be expected to have a high abundance of placed woody debris cover. However, other cover types, and the diversity of cover types, might be less than at natural sites due to the impact of CSTs on near-shore vegetation, undercut banks, and bank complexity. CSTs would be expected to reduce near-bank velocity compared to untreated sites. Velocity at CST projects would be expected to be similar to natural banks except that velocity reduction may not extend as far into the channel because CSTs are typically packed up against the bank and have a narrower, more uniform profile compared to complex natural banks.

With respect to streambank vegetation, natural banks would be expected to have a high incidence of tree cover, with shrubs and grasses also occurring along the bank. Disturbed sites would be expected to have infrequent tree cover and to be dominated by grasses and shrubs. Bare areas with active erosion would be expected in areas with high fishing use. Banks treated with CSTs would be expected to have sparse tree cover but may have planted shrub and/or grass cover. Bare areas may occasionally be present where residents access the streambank.

Study Design

The study used a post-treatment design or “retrospective” evaluation of CST projects that had already been implemented. At each of seven sites, data were collected at treated and untreated plots to evaluate how treatment with CSTs affects habitat in comparison to disturbed areas that have not received treatment. For comparison, a nearby “natural” plot that was relatively undisturbed by human alteration was also examined at each site. This sampling design allowed inferences to be drawn regarding the effectiveness of restoration measures to (1) improve conditions at disturbed sites, and (2) mimic “natural” habitat conditions.

Specifically, a total of seven sites were identified, each consisting of three nearby treatment plots that included the following: 1) a “treated” plot with CST project, 2) an untreated but disturbed plot (referred to as “untreated” throughout the remainder of this document), and 3) a “natural” (undisturbed) plot. This resulted in seven sites with three plots per site, for a total of 21 unique sample plots. Study sites were selected that had CST projects in close proximity to untreated and natural areas and that had similar bank morphology, sediment transport, and streamflow conditions. In essence, site selection focused on choosing sites that had similar treatment plots in all aspects except for human alteration and restoration treatment. The seven sites that best fit these criteria were used in the study.

Study Sites

The seven study sites were located on the banks of the lower Kenai River between river miles 15 and 42. All of the sites are located on straight segments or outside bends. The bank types are all low (2-8 ft tall) grassy or wooded banks. Under natural conditions, these banks would fall into the Type 4 or Type 7 bank-type categories described by Maynord et al. (2007), and would consist of forested conditions. An overview of the study site locations is included in Figure 14. Details for each study site are included in Appendix B.

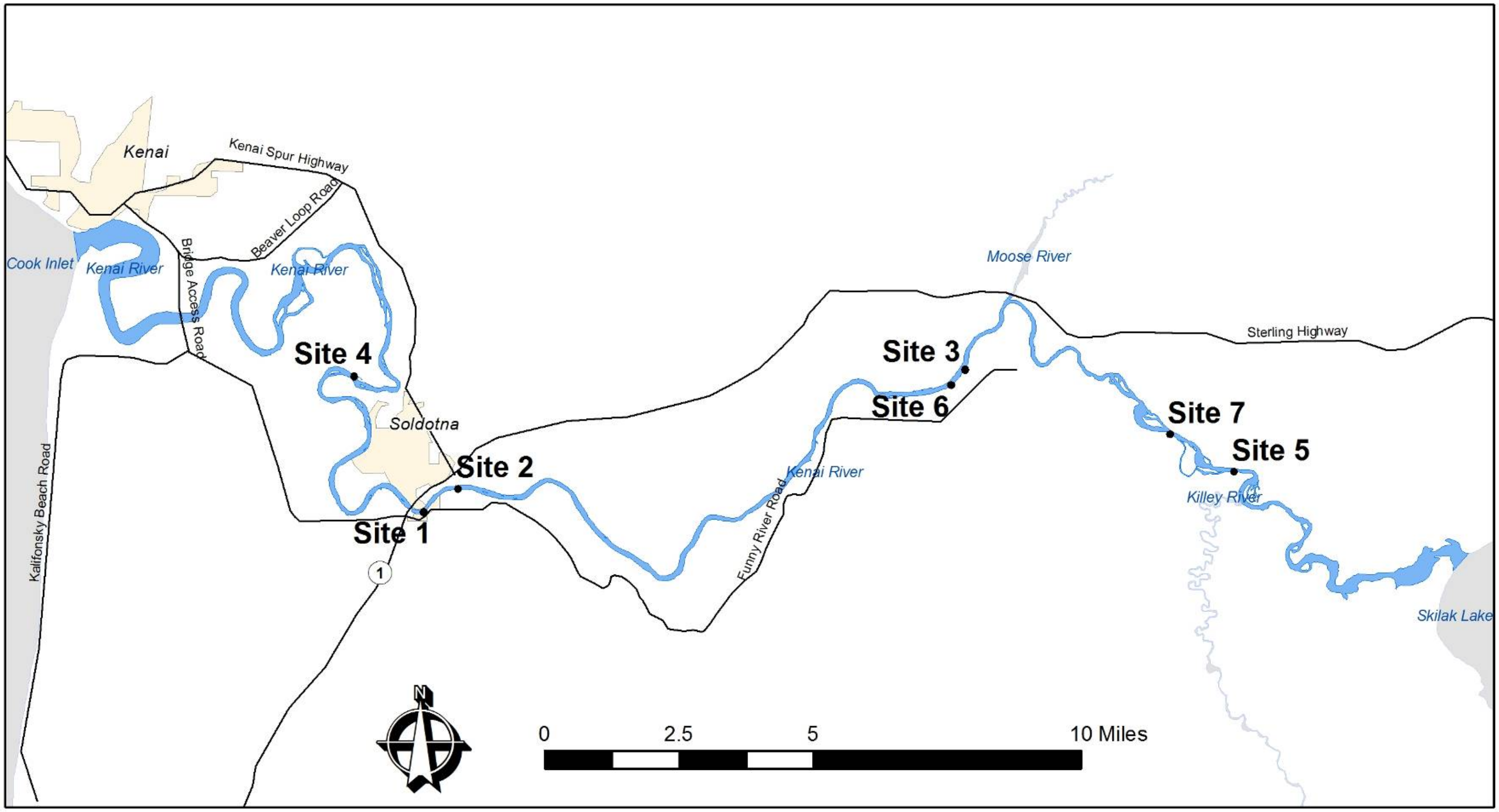


Figure 14. Overview of sample sites used for the Project Effectiveness Assessment. Numbering is based on the order in which the sites were sampled.

Field Sampling Methods

At each sample plot, a 60-foot section of bank was identified as the sampling segment for analysis. The segment was placed to capture a representative section of the bank. A survey tape was laid parallel to the bank and set back from the top of the bank enough to accommodate bank irregularities. A rebar stake with a metal label tag was pounded flush to the ground at each end of the tape, in order to monument the segment location but reduce tamper risk. The latitude and longitude of the upstream and downstream ends of the sample segment were recorded with a Trimble GeoXT handheld GPS unit. The segment was placed so that the upstream velocity transect (discussed below) was affected by conditions at the sampling plot, and not by different upstream bank conditions. At one sample plot (Site 7, treated), a 50-ft segment was used because of the short project length.

Velocity

Velocity was measured along a total of four equally-spaced transects at each sample segment. These transects were established perpendicular to the streambank at the 0-ft, 20-ft, 40-ft, and 60-ft intervals along the segment (see Figure 15). At the plot with the 50-ft segment length, the velocity transect typically located at the 60-ft interval was located at the 50-ft interval. Flagging was placed along the measuring tape at each transect location. A right-angle prism was used to place a 6" steel nail with flagging in the ground between the measuring tape and the streambank edge along each transect. The flagging on the measuring tape and the flagging on the nail were lined up as a visual cue for siting the velocity measurements along each transect. This technique ensured that transects were established perpendicular to the measuring tape. The nails also provide a reference point that could be found with a metal detector for future potential surveys at these same sites. At each transect, velocity and depth were measured at half-foot intervals extending out from the bank up to 4 feet, and then at the 5-ft and 6-ft intervals. In some cases, high velocities prevented the safe measurement of velocity and depth at the 5-ft and 6-ft intervals. Velocity was measured at the 0.6 depth for depths less than 2.5 feet and at the 0.2 and 0.8 depth for depths 2.5 feet and greater. Velocity was measured using a SonTek® FlowTracker handheld Acoustic Doppler Velocimeter (ADV).

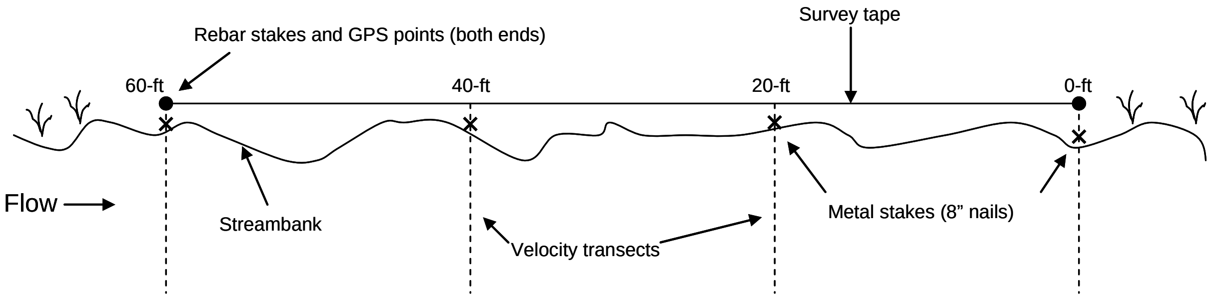


Figure 15. Example layout of plot segment and velocity transects.

Habitat Cover

Cover conditions were recorded at each treatment plot. The cover type categories are similar to those used in Estes and Kuntz (1986), Bendock and Bingham (1988), and

Hauser et al. (2001), and included woody debris, overhanging vegetation, emergent vegetation, aquatic vegetation, undercut banks, and cobble. The presence or absence of each cover type was recorded at 1-ft intervals for the entire 60-ft segment at each sample plot. This determination was made by moving along the survey tape and recording the cover types that were present on the bank along a transect extending from the tape at each 1 foot interval. Multiple cover types could be recorded for each interval. The cover type categories evaluated for this study are presented in Table 5.

Table 5. Cover type categories used for the habitat cover assessment.

Cover Category	Description
Emergent vegetation	Live plants that were rooted in the water but were standing upright and extended above the water surface at the time of the survey.
Aquatic vegetation	Live plants that were completely submerged at the time of the survey.
Overhanging vegetation	Live vegetation whose roots are submerged only at flood stage and which overhung the water by at least 0.5 ft and were within 1-foot elevation above the water surface during the survey.
Undercut bank	Bank that was undercut by at least 0.5 ft, measured with a yardstick.
Debris or deadfall	Woody debris (can still be attached by the roots) greater than 1 inch diameter that provided a velocity break within 3 feet of the edge of water at the time of the survey.
Placed woody debris	Woody debris material that has been placed along the streambank for erosion control or habitat enhancement (e.g. CSTs)
Cobble/boulder	Presence of streambed substrate greater than 5 inches median diameter.
No cover	Absence of any observable cover type

Vegetation

Vegetation was measured at the same 1-ft intervals used for the cover measurements. Vegetation type categories are presented in Table 6.

Table 6. Vegetation type categories used in the vegetation assessment.

Vegetation Category	Description
Bare	Denuded of vegetation that is necessary to provide stability to the bank.
Grass	Grass present along the bank.
Planted shrub	Planted shrub (e.g. willow stake) within three feet of the streambank edge.
Natural shrub	Natural (not planted) shrub within three feet of

Vegetation Category	Description
	the streambank.
Tree	Tree with a canopy that extends over the streambank edge at the sample location.

Data Analysis Methods

Velocity

The water-velocity dataset represents a highly structured sampling design. To reiterate, at each of seven sites *i*, three treatment plots *j* were identified (treated, untreated, and natural). At each plot, four transects *k* were established roughly 20 feet apart and perpendicular to the bank. At each transect, measurements of velocity and depth were taken at ten distance intervals *l* of 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 5.0, and 6.0 ft from water edge. Thus, a total of 840 measurements were possible for velocity and depth (i.e., 7 sites * 3 treatments * 4 transects * 10 distances = 840). Velocities could not be measured in 70 cases, and depth measurements were missing in another 17 cases. Thus, 753 complete records were available for analysis.

Ultimately, we are interested in describing and testing differences in velocity among treatments. More specifically, with the data at hand, we can examine *how velocity differs among treatments as a function of distance*. We began by conducting various exploratory analyses, some of which are presented below. These explorations suggested that the velocity data are well suited for comprehensive analyses using linear statistical models, as described next.

Mixed-effects models

To account for the spatial structure of the data when evaluating treatment effects, we used linear mixed-effects models (Pinheiro and Bates 2000). Such models are ideally suited for the multilevel or "hierarchal" nature of the dataset, in which transects are *nested* within treatment plots, which are nested within sites. In our models, we used the square root of velocity as the response variable. The rational for this transformation is discussed below. The basic form of the hypothesized relationship between square-root (velocity) and distance was linear, but different treatments could have different intercepts and/or slopes for the velocity-distance relationship (i.e., reflecting higher or lower velocities on average, depending on the treatment type and distance from water edge).

A model that can reasonably account for variation in velocity at all measurement levels (site, treatment plot, transect and distance interval) should provide reliable inferences regarding treatment effects. Thus, our goal was to be comprehensive in our assessment of key sources of variation. First, we expect depth to be an important determinant of velocity, and we need to ensure that estimates of treatment effects are not confounded by differences due largely to depth. We therefore included depth as a covariate, followed by terms for distance and treatment. An example model can be written as:

$$(1) \qquad y_{ijkl} = (B_0 + B_{0j}) + B_1 x_{ijkl} + (B_2 + B_{2j})\, d_{ijkl} + e_{ijkl}\,, \qquad e_{ijkl} \sim N(0,\ \sigma^2).$$

Here, y_{ijkl} denotes the square root of velocity measured at distance interval *l* of transect *k* within treatment *j* of site *i*. Coefficients include the overall intercept (B_0), the slope (B_1) for depth (*x*), and the slope (B_2) for the covariate distance (*d*). The treatment variable is a factor (categorical variable), with treatment effects modeled as treatment-specific intercepts (B_{0j}) and slopes for the distance relationship (B_{2j}). The errors (*e*) are assumed to be independent and normally distributed. All of the coefficients (*B*) in this model are fixed effects. Equation (1) is analogous to a classical analysis of covariance model with an interaction between treatment and distance (e.g., Neter et al. 1996).

While Equation (1) may be a useful descriptive model, it omits potential differences in velocity at the site level. For example, suppose velocities at one site are generally higher or lower across all distance intervals than at another site. This implies that sites have different intercepts for the distance-velocity relationship. We could model such differences as fixed effects, one for each site, but a preferable approach is to treat them as random effects. In essence, we view the sites as a "random" sample from a larger population of potential sites. As random effects, the site-specific differences would be modeled as a distribution, allowing inferences to be generalized to the population level (rather than being conditional only on the sites examined), and greatly reducing the number of parameters (fixed coefficients) in the model (Pinheiro and Bates 2000). Using the general notation of Pinheiro and Bates (2000), we add random effects for site-specific intercepts (b_{0i}) to Equation (1) as follows:

$$(2) \qquad y_{ijkl} = (B_0 + B_{0j} + b_{0i}) + B_1 x_{ijkl} + (B_2 + B_{2j})\, d_{ijkl} + e_{ijkl}$$

$$b_{0i} \sim N(0,\ \sigma_1^2),\ \ e_{ijkl} \sim N(0,\ \sigma^2)\ .$$

The random effects (b_{0i}) are assumed to be independent and normally distributed, and independent of the errors (e). Equation (2) is called a mixed-effects model because of the presence of both fixed and random effects.

At this stage, it is useful to reflect again on the detailed spatial structure of the data. Given the large distances separating sites, treatment plots, and even transects within plots (spaced 20 ft apart), we may expect velocities to differ somewhat at each of these levels. It is also conceivable that such differences would depend on the distance interval at which velocity was measured. This implies that both intercepts and slopes of the velocity-distance relationship could vary distinctly by site, treatment plot, or transect. In each case, it is appropriate to consider such differences as random effects. For the factor *treatment*, it is important to distinguish between treatment "types" and treatment "plots." In all models, we used fixed effects to represent systematic (mean) differences among treatment types that are observable across sites (i.e., the coefficients B_{0j} and B_{2j} in Equations 1 and 2). However, we may also expect plot-specific differences because each treatment plot is spatially distinct. This can be modeled with additional random effects for treatment. These are essentially "random" plot-specific effects distributed across sites and treatment types. For example, a given plot, regardless of treatment type, may exhibit low or high velocities because of its unique location and physical features.

The following model incorporates all of these potential sources of variation in velocity as function of distance:

(3) $y_{ijkl} = (B_0 + B_{0j} + b_{0i} + b_{0i,j} + b_{0i,j,k}) + B_1 x_{ijkl} + (B_2 + B_{2j} + b_{2i} + b_{2i,j} + b_{2i,j,k})\, d_{ijkl} + e_{ijkl}$

$\mathbf{b}_\mathrm{i} = \begin{bmatrix} b_{0i} \\ b_{2i} \end{bmatrix} \sim \mathrm{N}(\mathbf{0}, \mathbf{\Psi}_1)$, $\mathbf{b}_{ij} = \begin{bmatrix} b_{0i,j} \\ b_{2i,j} \end{bmatrix} \sim \mathrm{N}(\mathbf{0}, \mathbf{\Psi}_2)$, $\mathbf{b}_{ijk} = \begin{bmatrix} b_{0i,j,k} \\ b_{2i,j,k} \end{bmatrix} \sim \mathrm{N}(\mathbf{0}, \mathbf{\Psi}_3)$, $e_{ijkl} \sim \mathrm{N}(0, \sigma^2)$.

In this model, we have both fixed effects (B) and random effects (b) at various levels for intercepts (subscripts “0”) and slopes of the distance relationship (subscripts “2”). The random-effects terms correspond to sites (b_{0i}, b_{2i}), treatment plots ($b_{2i,j}$, $b_{2i,j}$), and transects ($b_{0i,j,k}$, $b_{2i,j,k}$). The subscripting for these terms indicates the hierarchy of the data – treatment plots are nested within sites (subscripted “*i, j*”), while transects are nested within treatment plots (“*i, j, k*”). In Equation (3), $\mathbf{b}_i$ denotes the random-effects vectors for sites with variance-covariance matrix $\mathbf{\Psi}_1$, and similarly for levels $\mathbf{b}_{i,j}$ and $\mathbf{b}_{i,j,k}$. All random effects are assumed to be independent within and among levels, and independent of e.

To summarize, this last model depicts (square root) velocity as a linear function of depth and distance, conditional on each treatment type, but also allows for differences at each factor level (i.e., differences in velocity that are site specific, plot specific, and transect specific). The model may appear overly complex, containing far more parameters than can be supported by the data. However, this is not the case. The structured sampling design for velocity can easily support such multilevel inferences (to the extent that clear differences exist at each level), and the use of random effects greatly reduces the number of “fixed” parameters that need to be estimated. For example, modeling differing intercepts and slopes for *transect* (with 84 levels) requires estimating only three variance-covariance terms in $\mathbf{\Psi}_3$ (the variances of $b_{0i,j,k}$ and $b_{2i,j,k}$, and their covariance).

Distance as a factor variable

In the models discussed above, distance was treated as a continuous covariate. However, distance could also be treated as a (categorical) factor with ten levels $l = 0.5, 1.0, 1.5, \ldots, 5.0, 6.0$. In brief, the advantage of modeling distance as a covariate (rather than a factor) is that it requires far fewer parameters, provides a simple description of the velocity-distance relationship, and facilitates comparisons (hypothesis tests) among treatment types. In contrast, treating distance as a factor provides greater flexibility – to the extent that relationships between velocity and distance vary considerably across treatments in complex (i.e., non-linear) ways, then modeling distance as a factor would better capture such variation.

For comparison, we examined the following mixed-effects model in which distance was treated as a factor variable:

$$(4) \qquad y_{ijkl} = (B_0 + B_{0j} + B_{0l} + b_{0i} + b_{0i,j} + b_{0i,j,k}) + B_1 x_{ijkl} + B_{jl} + e_{ijkl}$$

$$b_{0i} \sim N(0,\ \sigma_1^2),\ b_{0i,j} \sim N(0,\ \sigma_2^2),\ b_{0i,j,k} \sim N(0,\ \sigma_3^2),\ e_{ijkl} \sim N(0,\ \sigma^2)\ .$$

The new fixed-effect terms are B_{0l}, denoting interval-specific intercepts (or roughly speaking, mean velocities by interval across all data), and the interactions B_{jl}, allowing different means for each interval depending on the treatment type. Note that random effects for sites, plots, and transects are limited to intercept terms only (there is insufficient data to support meaningful interactions between these levels and distance intervals, except perhaps in the case of site).

Model selection

Many model specifications are possible for the velocity data. It was not our goal to evaluate all reasonable model structures and their individual components. Rather, we wanted to obtain accurate inferences regarding treatment effects after accounting for important auxiliary variables. Thus, our modeling approach was to begin with a simple structure and progressively add terms to investigate treatment effects. All models were fit by maximum likelihood using the methods described in Pinheiro and Bates (2000). To compare model fits, we used the AIC model-selection criterion, which provides a statistically rigorous balance between explanatory power and the number of parameters in a given model (Pinheiro and Bates 2000; Burnham and Anderson 2002).

Among candidate models, the model with the lowest AIC is the highest ranking or “best” model. For comparison, AIC of the best model was then subtracted from the AIC values of all other models. This measure is denoted Δ_i for the *i*th model, where $\Delta_i = 0$ for the best model and $\Delta_i > 0$ for all others. Burnham and Anderson (2002) suggest that models with values of Δ_i between 0 and 2 have “substantial” empirical support, while models with Δ_i between 4 and 7 have considerably less support, and essentially no support when $\Delta_i > 10$.

Velocity transformations

As shown below, the velocity data are heteroscedastic (variance increases as velocity increases), which violates the assumption of constant variance underlying the above models. We examined two approaches to account for heteroscedasticity. First, we examined several variance-stabilizing transformations including the square root, log, and Box-Cox transformations (Zar 1999; Venables and Ripley 2002), and found that the square root of velocity appeared most reasonable. In the second approach, we explicitly modeled the variance structure for velocity as a power function of a variance covariate (e.g., depth, distance or the fitted velocity itself) (Pinheiro and Bates 2000); however, use of the square-root transformation was more reliable at stabilizing variances and normalizing the data across potential covariates. Thus, for all model results presented below, we used the square root of velocity as the response variable (y).

Proportion of Velocity below Habitat Threshold

In our second approach to examining the velocity data, we quantified the proportion of near-bank habitat that had highly suitable velocities for juvenile Chinook salmon. We selected a velocity of 0.8 ft/sec to represent the upper end of juvenile rearing preference for the multiple species of salmon found in the Kenai River. This value was obtained based on the findings of past Kenai River studies including Burger et al. (1983), Estes and Kuntz (1986), and Bendock and Bingham (1988). We were primarily interested in comparisons among treatment types as a function of distance.

For these analyses, we began by estimating proportions (*p*) across transects for each combination of site *i*, treatment *j*, and distance interval *l*:

$$p_{ijl} = \frac{q_{ijl}}{n_{ijl}} , \tag{5}$$

where *q* was the number of velocity measurements less than or equal to the threshold (0.8 ft/sec), and *n* was the number of transects. Typically, *n* = 4 except in cases where depth or distance measurements were missing for one or more transects, in which case, *n* < 4. Because proportions were computed across transects, the total sample was reduced from 753 complete velocity records to 209 usable records for proportions.

The proportions (*p*) represent binomial probabilities, which can be analyzed using logistic regression models (McCullach and Nelder 1989; Dobson 2002). Our modeling approach was similar to that used above for raw velocity data – we began with a simple structure, progressively added terms, and compared model fits using AIC. We present results for the two highest-ranking models. The first model had the form:

$$y_{ijl} = (B_0 + B_{0i} + B_{0j}) + B_1 x_{ijl} + (B_2 + B_{2i} + B_{2j})\, d_{ijl} \tag{6}$$

where *y* is the “logit” transform of the observed proportions (*p*):

$$y = \text{logit}(p) = \log\left(\frac{p}{1-p}\right) . \tag{7}$$

In Equation 6, B_0 is the overall intercept, B_{0i} and B_{0j} respectively denote *site*-specific and *treatment*-specific differences in the intercept, B_1 and B_2 are the slopes for covariates *depth* (*x*) and *distance* (*d*); and B_{2i} and B_{2j} denote *site*-specific and *treatment*-specific slopes for the distance relationship. (In this analysis, values of depth x_{ijl} were the mean depths across transects.) The second model we discuss included a quadratic term for depth (i.e., adding $B_3 x_{ijl}^2$ to Equation 6).

For a given logistic model, coefficients (*B*) were estimated via maximum likelihood (Venables and Ripley 2002). Estimates of *B* provide predictions $\hat{y}$ (e.g., via Equation 6), and predicted proportions via the back-transformation of the logit function:

$$(8) \qquad \hat{p} = \frac{\exp(\hat{y})}{1 + \exp(\hat{y})} \; .$$

The statistical significance of each explanatory variable was tested using analysis of deviance (McCullach and Nelder 1989; Venables and Ripley 2002).

Note that all terms were treated as fixed effects. Although it is feasible to consider random effects for *site* within a logistic regression (McCulloch and Searle 2001; Gelman and Hill 2007), the procedure is complicated and not considered here. Using fixed effects for *site* is adequate. A key difference is that model estimates are conditional on the specific sites within the dataset, whereas with random effects, the estimates assume a distribution across the "population" of potential sites. In any case, because the sampling design is highly balanced, the choice of fixed or random effects for site will have very little influence on estimates of *treatment* effects (Pinheiro and Bates 2000).

Habitat and Vegetation

To summarize and compare habitat and vegetation cover data among treatment types, we first computed the proportion (*p*) of each type observed by plot. This was simply the number of "observed" cases divided by the total number of transects (n = 60 transects, except for the "Treated" plot of Site 7, where n = 50 transects). Thus, for each cover variable, there were a total of 21 observed proportions (7 sites * 3 treatments = 21).

We tested for differences in the mean proportion of each cover type among treatments using analysis of variance (ANOVA). The model design in each case was a two-factor ANOVA, with a single observation (*y*) for each combination of site *i* and treatment *j* (e.g., Neter et al. 1996):

$$(9) \qquad y_{ij} = \mu_{..} + \alpha_i + \beta_j + e_{ij}$$

where $\mu_{..}$ denotes the overall mean, α_i and β_j are *site*-specific and *treatment*-specific differences in mean, respectively, and errors *e* are assumed to be independently and normally distributed. In all cases, the factor *site* was included in the model when estimating and testing treatment effects (β_j). Note that with only one observation per stratum, it is not possible to estimate an interaction term between *treatment* and *site*. In addition, with only one observation and a balanced design, estimates and inferences regarding fixed treatment effects (β_j) will be the same regardless of whether *site* is assumed to have fixed or random effects, or if additional random plot effects are included.

For the observations *y*, we used the arcsine transformation to better normalize the proportions (i.e., y_{ij} = arcsine(square-root(p_{ij})). However, the arcsine transformation may be a poor choice in some cases, in particular when many proportions are near zero or one (Zar 1999). As an alternative approach, we also used logistic regression (where y = logit(p)) and assessed treatment effects using analysis of deviance (Venables and Ripley 2002). However, across comparisons, results of *F* tests and *t* tests were similar for both the arcsine ANOVA and logistic regression methods. We therefore limit our reporting to ANOVA results, which were slightly more conservative (i.e., had higher P-values for between-treatment *t* tests) and allowed for use of the Tukey test (Zar 1999) for comparing treatment types.

Results

Velocity

Graphical summaries illustrate several key features of the velocity dataset. As expected, velocities tended to increase as depth or distance increased, although these general relationships were highly variable (Figure 16). In addition, depth and distance were clearly correlated (r = 0.49 across all sample locations), but this relationship was also highly variable (Figure 16C).

Velocities appeared to differ considerably depending on treatment type. Across sites and distance intervals, velocities tended to be lowest for “treated” plots and highest for “untreated” plots (Figure 17A). In contrast, depths were quite similar on aggregate among the treatment types (Figure 17B). A more complicated pattern was evident for velocity as a function of distance (Figure 18A). Average velocities across sites were lowest for “treated” plots at distances up to 3.0 ft, after which velocities increased rapidly and generally exceed those of “natural” plots. Average velocities for “untreated” plots were consistently high across distance intervals (Figure 18A). Again, average depths were quite similar among treatment types regardless of distance (Figure 18B).

Patterns were much more variable at the site and transect levels. Among sites, the tendency toward low velocities for “treated” plots and high velocities for “untreated” plots was most evident for Sites 3, 5, and 6, either for pooled distances (Figure 19) or as a function of distance (Figure 20). Quite different velocity patterns were exhibited among the other sites, especially Sites 1 and 2. Distinct patterns among sites were also evident for depth (Figure 21). Finally, considerable variation in velocity and depth was observed at the transect level, even within treatment plots, as illustrated using data for Site 6 (Figure 22; a more extreme example than most sites).

In sum, velocities appeared to be strongly influenced by depth and/or distance, as well as conditions related to specific treatment types, sites, and transects. A priori, we expect depth to be an important determinant of velocity, and we need to ensure that estimates of treatment effects are not confounded by differences due solely to depth. Initial inspection of the aggregate data suggests that this is unlikely: velocities differed among treatments (Figure 17A and Figure 18A) whereas depths were similar (Figure 17B and Figure 18B). However, it is important to account for velocity-depth relationships explicitly when estimating potential treatment effects, as we did in our analyses below. In addition, relationships between velocity and distance are of central interest because of the nature of the treatments, specifically, the physical structure of the spruce tree revetments (the "Treated" category). Here, we need to be cautious of potential *colinearity* between distance and depth. However, as indicated in Figure 16C and in the results below, there was sufficient contrast to reliably estimate effects on velocity of both distance and depth. Finally, we observe considerable heteroscedasticity and skewness in the raw velocity data (Figure 16 and Figure 17). As noted in the Data Analysis Methods section above, using the square root transformation of velocity helped to stabilize variances and normalize the data.

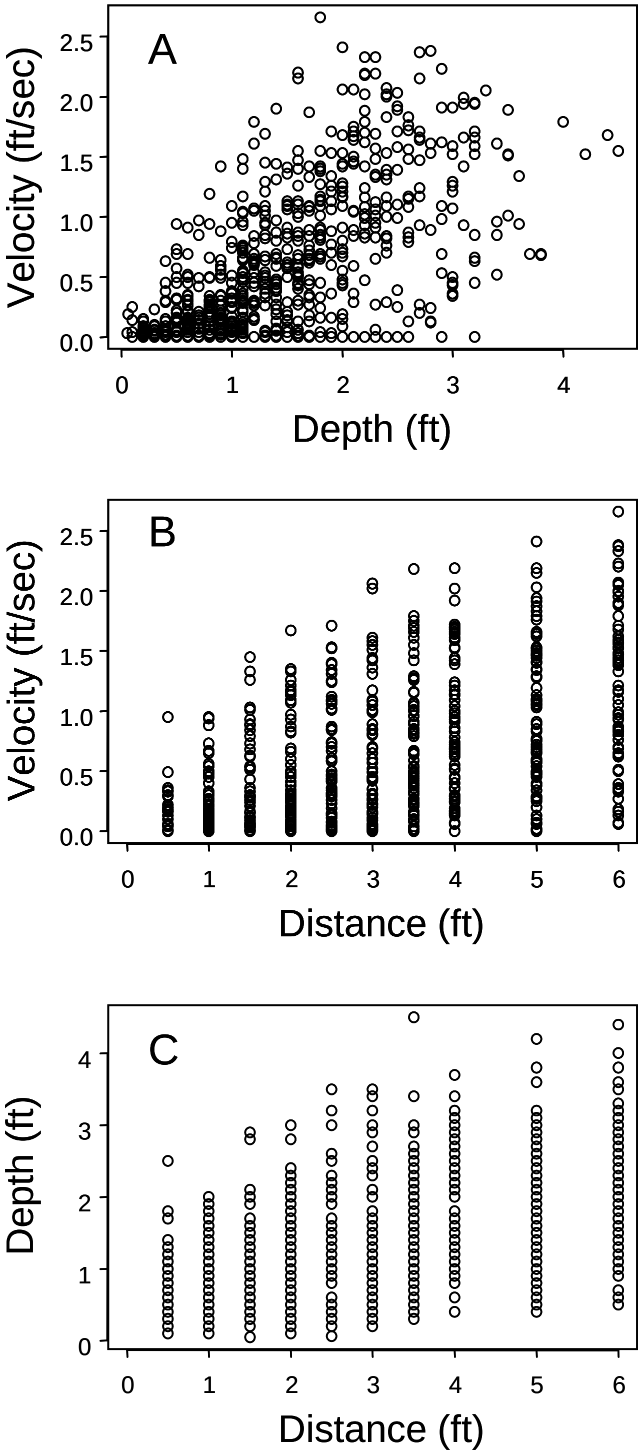


Figure 16. Scatter plots of (A) velocity versus depth, (B) velocity versus distance, and (C) depth versus distance. Data are pooled across all sites and treatments (*n* = 752).

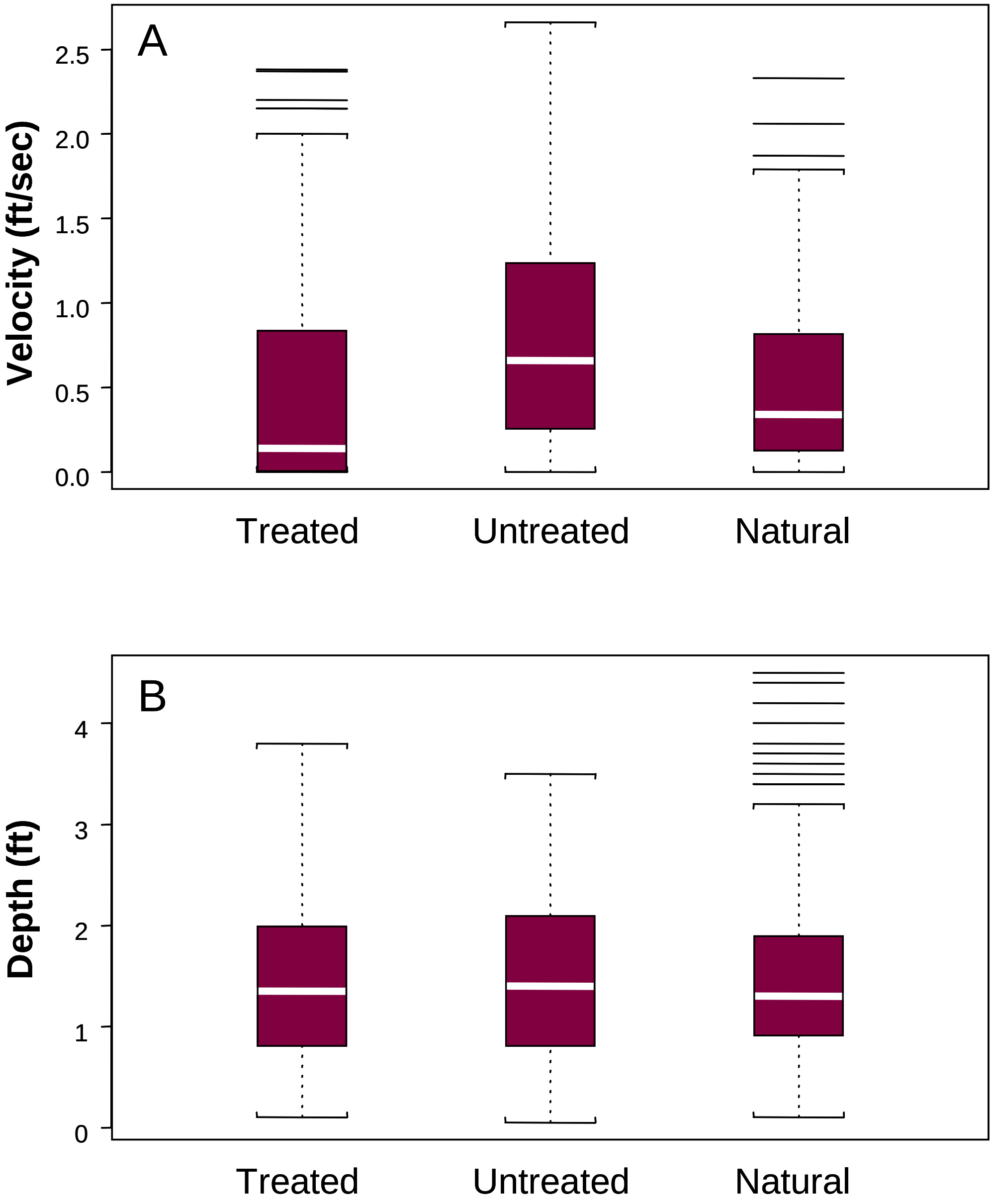


Figure 17. Box plots by treatment type for (A) velocity and (B) depth. Data are pooled across sites and distance intervals.

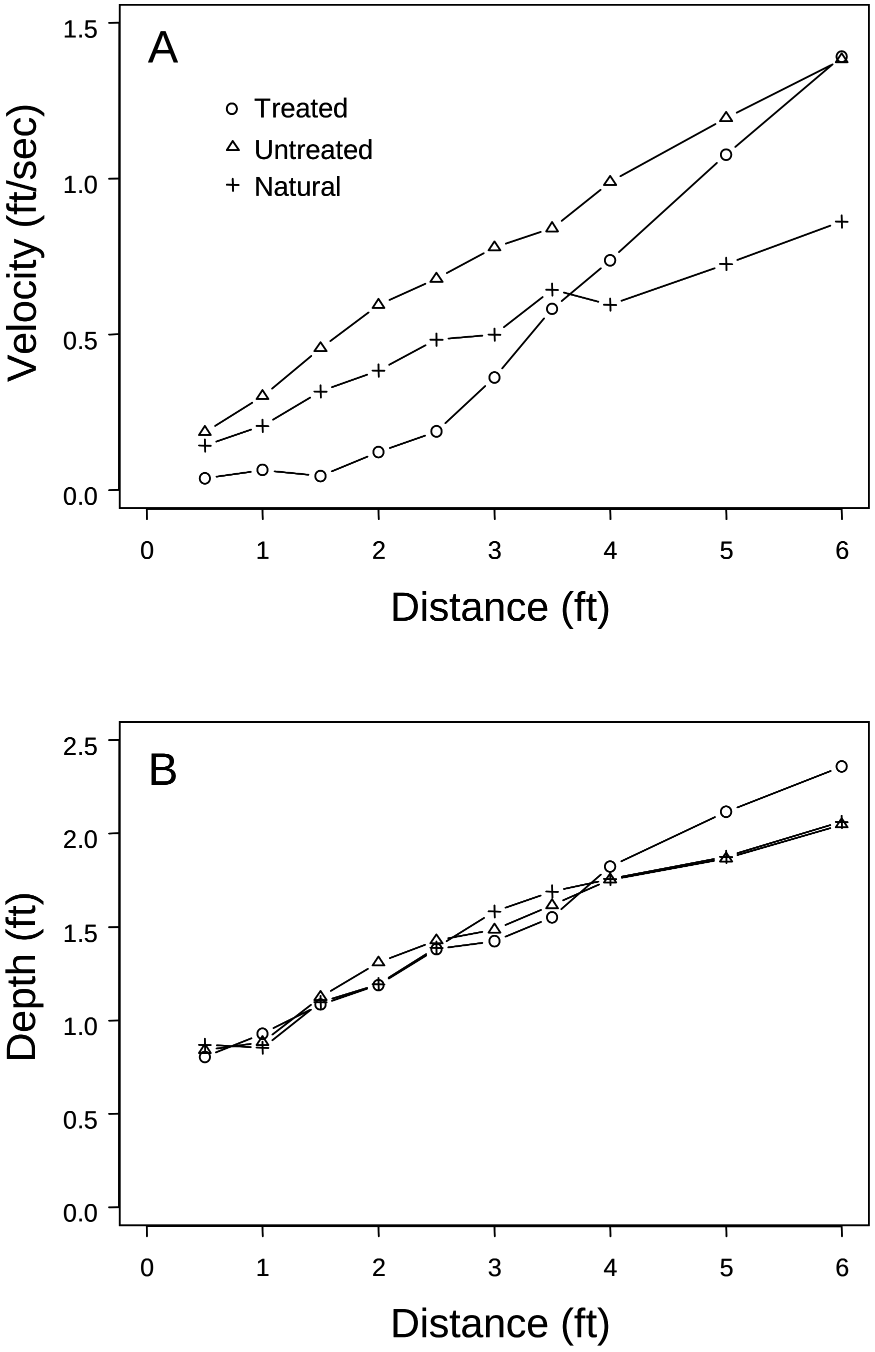


Figure 18. Mean values by treatment type and distance interval for (A) velocity and (B) depth. Means were computed across all sites.

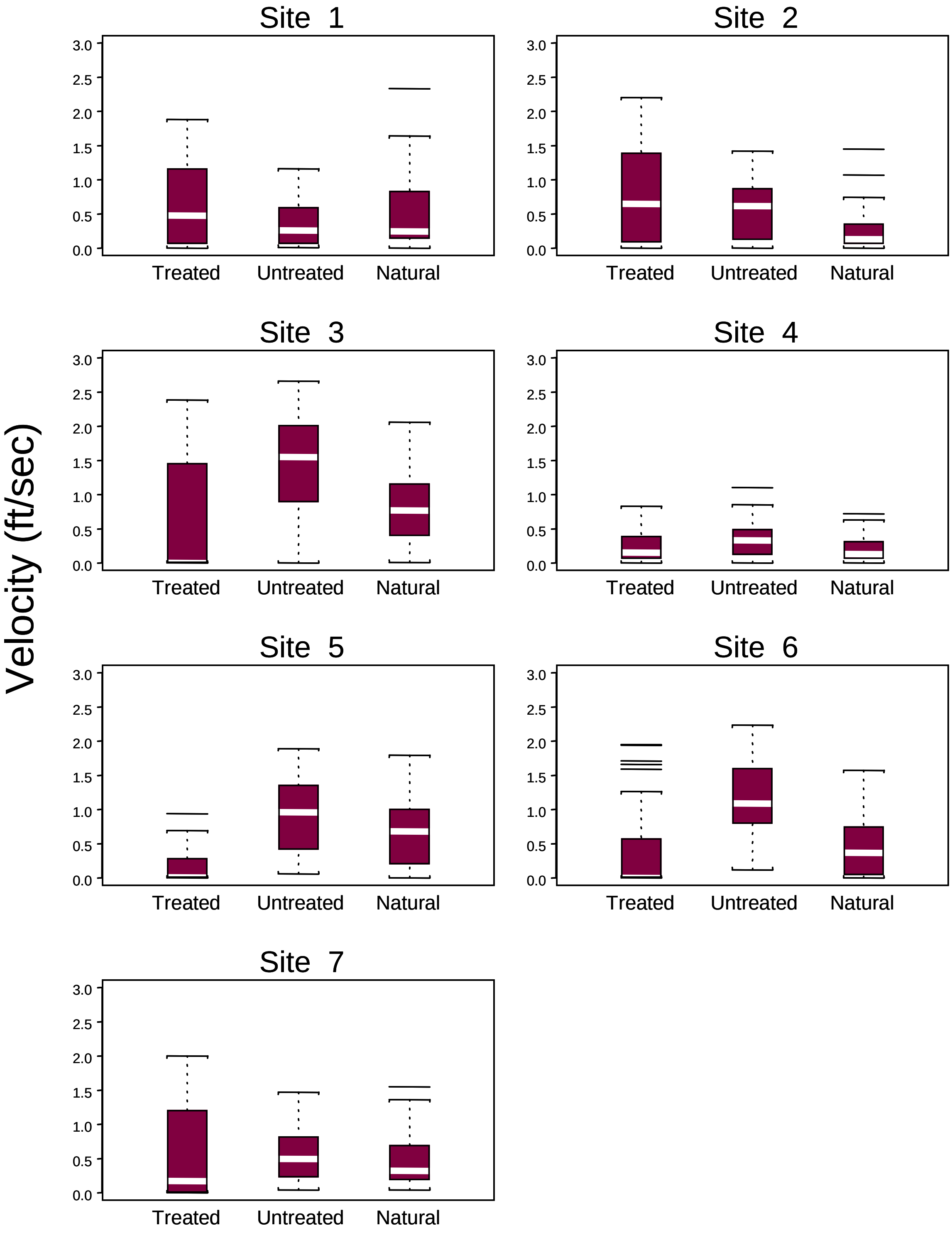


Figure 19. Box plots of velocity by site and treatment type (data pooled across transects and distance intervals).

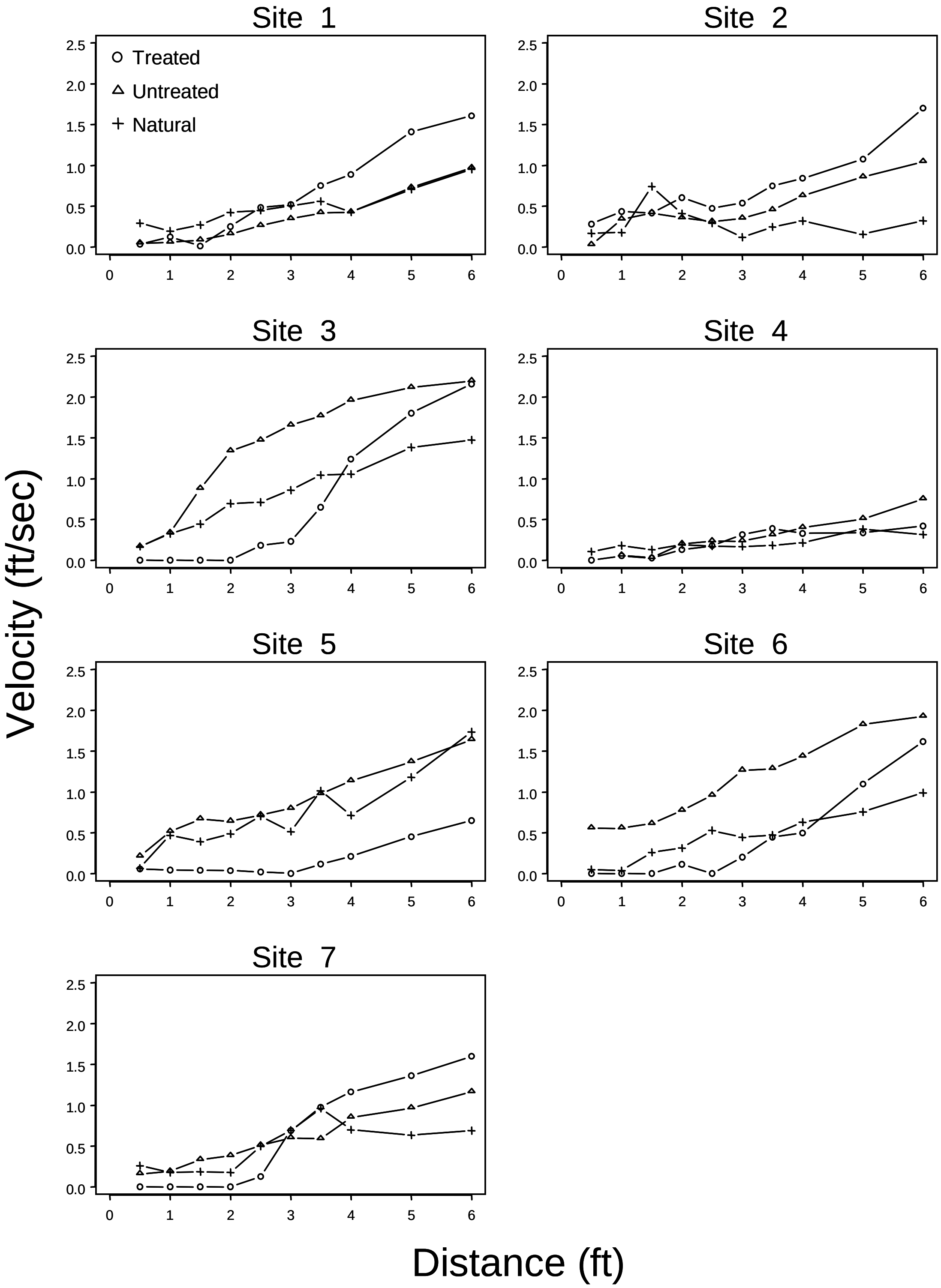


Figure 20. Mean values of velocity by site, treatment type and distance interval. Means were computed across transects.

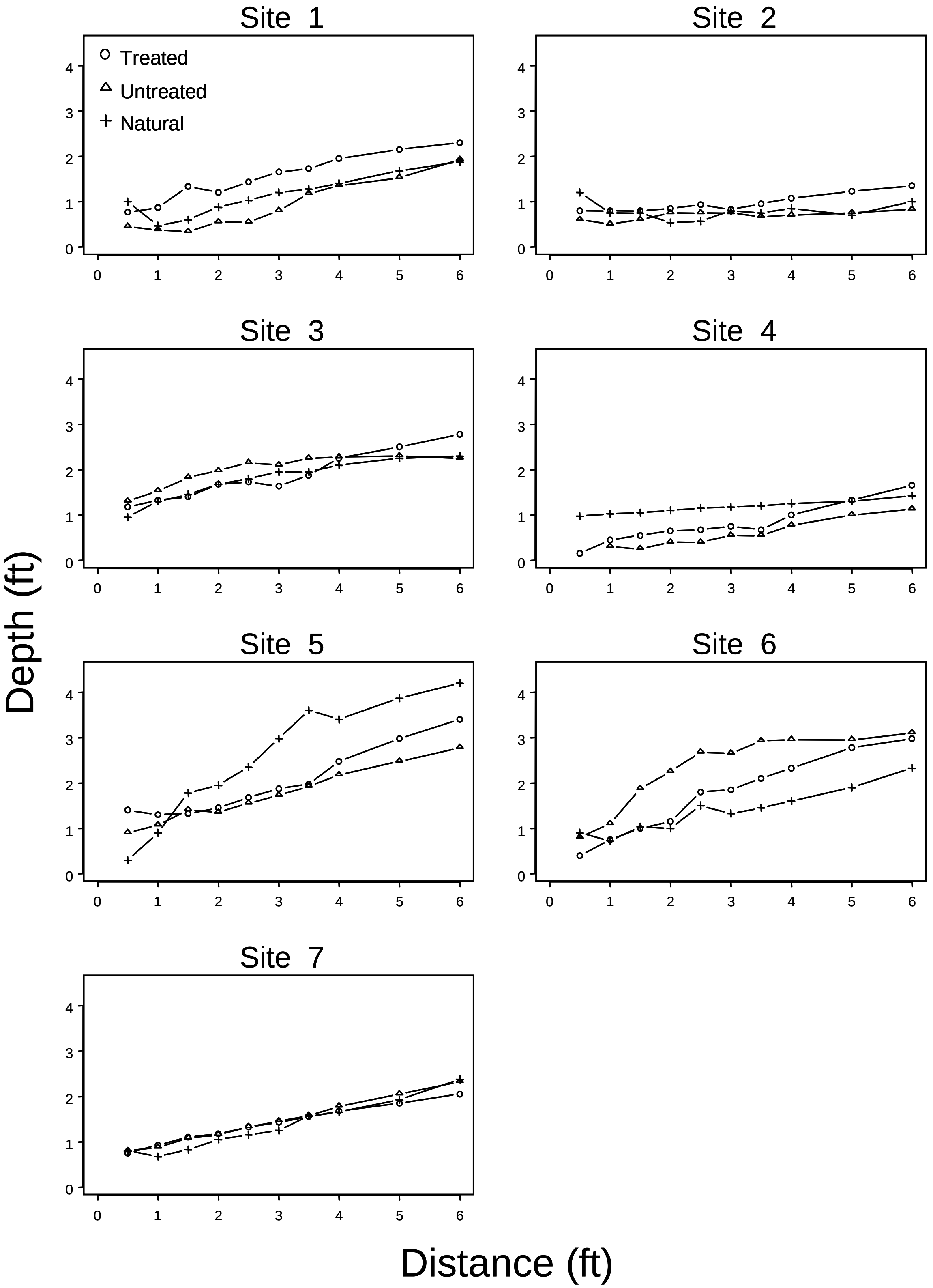


Figure 21. Mean values of depth by site, treatment type and distance interval. Means were computed across transects.

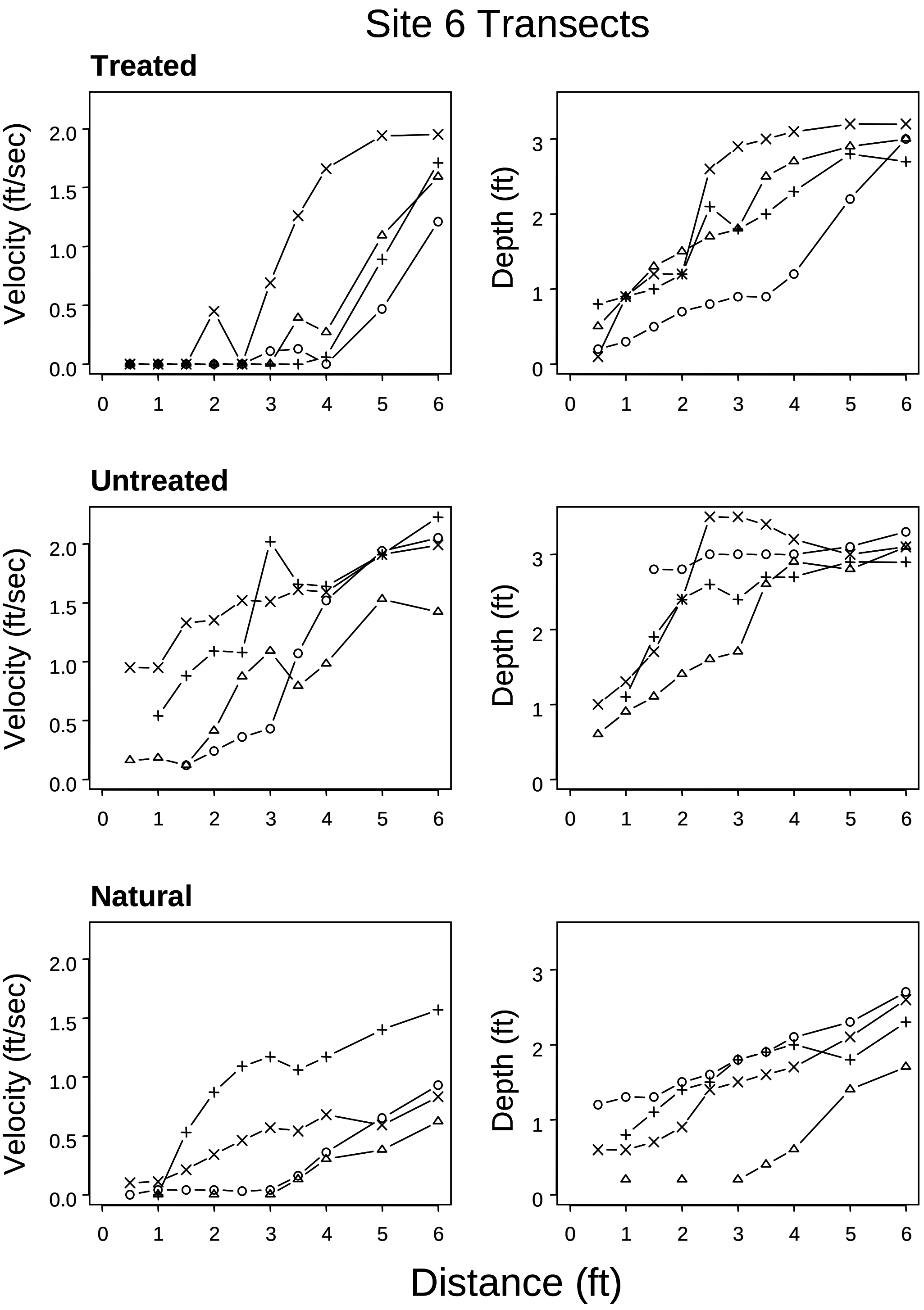


Figure 22. Velocity and depth for Site 6 by treatment, transect, and distance interval. Transects are distinguished by different markers and are only the same within a given treatment (e.g., triangles denote the same transect for velocity and depth within "Treated" plots in top panels).

Mixed-effects models

Analysis of velocity using mixed-effects models identified highly significant differences among treatments. For comparison, we report AIC results for eight models with increasing complexity (Table 7). We begin with models that had only fixed-effects terms. The first model included *depth* as a covariate, with AIC = 598.3 (Table 7, Model 1). Model fits were greatly improved by adding *distance* (Model 2) followed by *treatment*-specific intercepts (Model 3) (i.e., each term reduced AIC considerably; Table 7). Last, model fit was further improved by adding an interaction term between *distance* and *treatment* (i.e., allowing for treatment-specific slopes for the velocity-distance relationship) (Model 4; see also Equation 1).

The next four models retained the same fixed effects as in Model 4, but added random-effects components. First, site-specific intercepts were added (Model 5, Equation 2), followed by site-specific slopes for the velocity-distance relationship (Model 6). In both cases, model fit was greatly improved based on AIC (Table 7). Similar improvements were gained by adding random effects for plot-specific intercepts and slopes (Model 7). Note, we use the term "plot" here rather than "treatment" to distinguish between effects among treatment types (i.e., the fixed effects for treatment) and those among all treatment plots (the random effects). The final model included random effects for intercepts and slopes among transects (Model 8, Equation 3). These terms provided an even greater improvement in model fit (AIC reduced by 190.8) than did the previous additions for site and treatment plot (Table 7). Overall, Model 8 was clearly the preferred model in comparison to the simpler forms presented.

All fixed-effects terms in Model 8 were highly significant ($P < 0.001$; Table 8). The estimated coefficients reveal the nature of the significant differences among treatment types (Table 9). Note that treatment coefficients in Table 9 are defined as the difference between the "Treated" level and each of the two other treatments. Thus, both "Untreated" and "Natural" plots had significantly greater intercepts (B_{0j}) than "Treated" plots, but significantly lower slopes (B_{2j}) (Table 9). This implies that velocities at "Treated" plots were considerably lower on average at low distances, but increased at a much greater rate as distance increased. This is clearly depicted in the plot of predicted velocities for each treatment type (Figure 23A). It also appears that velocities at "Untreated" plots increased more rapidly with distance than at "Natural" plots (Figure 23A). To test this hypothesis, the model coefficients must be redefined to explicitly compare these two treatments; the subsequent results indicate that the intercepts were very similar (B_{0j}: Untreated – Natural = 0.032, SE = 0.080, $P = 0.69$), but the slope for "Untreated" plots was significantly greater (marginally) than for "Natural" plots (B_{2j}: Untreated – Natural = 0.046, SE = 0.024, $P = 0.052$).

In sum, Model 8 provides a simple description of treatment effects on velocity as a function of distance (Figure 23A). Standard diagnostics of the residuals and random effects of Model 8 suggested that error assumptions were reasonable. The linear relationships between square-root (velocity) and depth or distance also appeared reasonable. For example, model fit was not significantly improved by adding quadratic terms for either depth (B_3x^2; $P = 0.27$) or distance (B_3d^2; $P = 0.24$). However, a more refined description of the velocity-distance relationships can be achieved by treating distance as a factor, as in Equation (4). For comparison, we fit the model defined by Equation (4), which had a total of $K = 35$ (AIC = 20.0; $P < 0.001$ for all fixed-effects terms). Despite the far greater number of parameters available, the predictions for this model appear quite similar at first glance to those for Model 8 (Figure 23A). A key difference lies in the "Treated" predictions, which make a more rapid transition from low to higher velocities between distance intervals of 2.5 to 4.0 ft (Figure 23B). Nevertheless, the similarities between model predictions is reassuring, adding confidence to the treatment inferences based on the preferred (parsimonious) Model 8.

Finally, it is instructive to briefly examine the random-effects components of Model 8. These included distributions for intercepts and slopes that were specific to sites, plots, and transects (Table 7; Equation 3). Estimates of the standard deviation ($\hat{\sigma}$) of each component distribution are presented in Table 10. It is evident that a large source of variation in velocity was due to between-transect variability in intercepts (Table 7). The estimate $\hat{\sigma}$ for transects (0.233) was much greater than for plots (0.055) and sites (0.019) (the latter two estimates being highly uncertain, with broad confidence intervals – a common result for $\hat{\sigma}$ in mixed-effects models; Pinheiro and Bates 2000). In contrast, distributions for slopes had similar variation ($\hat{\sigma}$) among sites, plots, and transects (Table 10). This makes intuitive sense. At short distances, velocities generally approached zero, so at the plot and site levels we would expect little variation in the intercepts of the velocity-distance relationship (e.g., Figure 20). At the transect level, however, we observed much greater variation in velocity at short distances (e.g., Figure 22, Untreated plot). Alternatively, we would expect broader spatial patterns in near-bank physical conditions at the plot and site levels to similarly affect velocities across transects, that is, for there to be considerable between-plot and between-site variation in the slope of the velocity-distance relationship.

We can examine the influences of the site and plot random effects by comparing fixed-effects predictions with predictions that also incorporate random effects (Figure 24). As expected, predictions based solely on the fixed-effects terms of Model 8 (i.e., the across-site mean effects) often underestimate or overestimate velocities at a given site or plot. Predictions are greatly improved in some cases by the addition of random effects. For example, large *site*-specific effects improve predictions across treatment plots for Sites 3 and 4 (Figure 24). Large *plot*-specific effects are evident for the "Treated" plots of Sites 5 and 7. Knowledge of the potential magnitude of such site- and plot- specific effects, as provided by Model 8 results, would provide useful guidance in the development of future monitoring programs or experiments designed to assess the effects of restoration measures on nearshore velocities.

Table 7. Summary of AIC results for selected models fit to square-root (*velocity*). Models 1 through 4 contained only fixed effects (F). Models 5-8 contain the same fixed effects as Model 4, plus additional random effects (R) as described. *K* = number of parameters (fixed-effect coefficients and variance terms). Δ_i denotes the difference between the AIC value for the *i*th model and the AIC for Model 8 (the highest-ranking model).

Model	Fixed effects (F) and random (R) effects	*K*	AIC	Δ_i
1	F: depth	3	598.3	658.3
2	F: depth + distance	4	454.4	514.4
3	F: depth + distance + treatment	6	348.8	408.9
4	F: depth + distance + treatment + treatment*distance	8	305.1	365.2
5	R: site	9	261.0	321.1
6	R: site + site*distance	11	233.5	293.6
7	R: site + plot + (site + plot)*distance	14	130.8	190.8
8	R: site + plot + transect + (site + plot + transect)*distance	17	-60.0	0.0

Table 8. Analysis of covariance for the fixed-effects components of Model 8 (see Table 7). DF_1 denotes the numerator degrees of freedom (number of coefficients) and DF_2 denotes the denominator (residual) degrees of freedom.

Component	DF_1	DF_2	F-value	P-value
Intercept	1	665	149.9	< 0.001
Depth	1	665	93.9	< 0.001
Distance	1	665	61.4	< 0.001
Treatment	2	12	15.1	< 0.001
distance*treatment	2	665	11.1	< 0.001

Table 9. Estimated coefficients (fixed effects) for Model 8 fit to square-root(*velocity*) (see Table 7). Note that coefficients for *treatment* (B_{0j}) and *distance*treatment* (B_{2j}) are defined as the difference relative to the factor level "Treated" (i.e., the coefficients for "Treated" are equal to zero). SE = standard error. DF = degrees of freedom.

Coefficient	Estimate	SE	DF	t-value	P-value
B_0: intercept	-0.244	0.058	665	-4.24	< 0.001
B_1: depth	0.129	0.024	665	5.38	< 0.001
B_2: distance	0.181	0.021	665	8.67	< 0.001
B_{0j}: Untreated – Treated	0.473	0.079	12	5.96	< 0.001
B_{0j}: Natural – Treated	0.441	0.079	12	5.57	< 0.001
B_{2j}: distance * (Untreated – Treated)	-0.064	0.023	665	-2.73	0.007
B_{2j}: distance * (Natural – Treated)	-0.110	0.023	665	-4.68	< 0.001

Table 10. Estimates of the standard deviations ($\hat{\sigma}$) for the distributions of random-effects components in Model 8 (Table 7, Equation 3). Also shown are 95% confidence intervals (CI) and the residual standard error.

	Intercept		Slope for distance	
Variable	$\hat{\sigma}$	95% CI	$\hat{\sigma}$	95% CI
site	0.019	0.001 - 0.575	0.028	0.011 - 0.072
plot	0.055	0.004 - 0.725	0.035	0.020 - 0.061
transect	0.233	0.179 - 0.302	0.033	0.021 - 0.052
Residual	0.181	0.191 - 0.203		

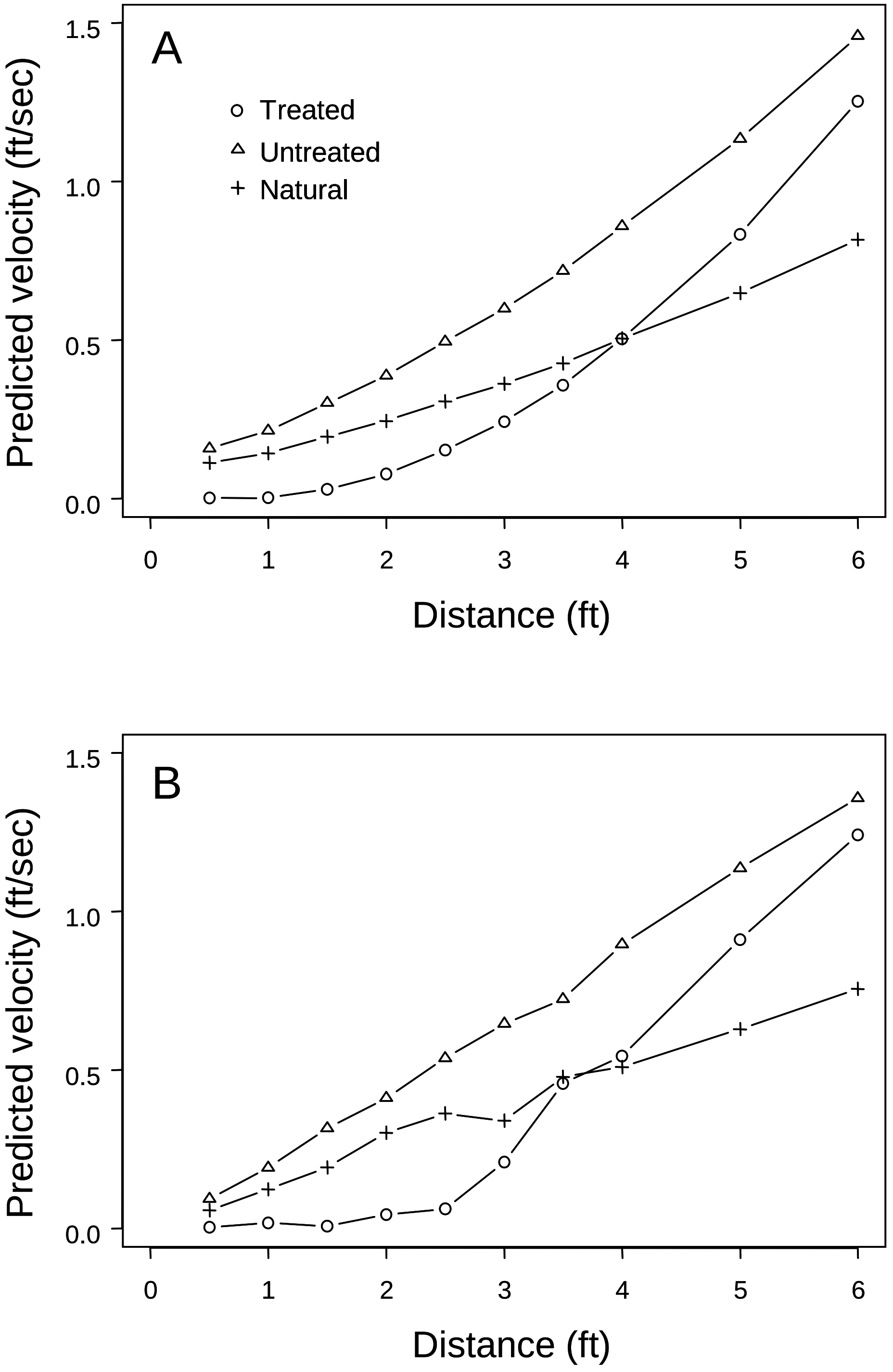


Figure 23. Predictions of velocity by treatment type and distance for (A) Model 8, in which distance was a covariate, and (B) the model defined by Equation (4), in which distance was a factor variable. For each distance interval, predictions were made with depth set equal to the mean depth across all sites, plots, and transects.

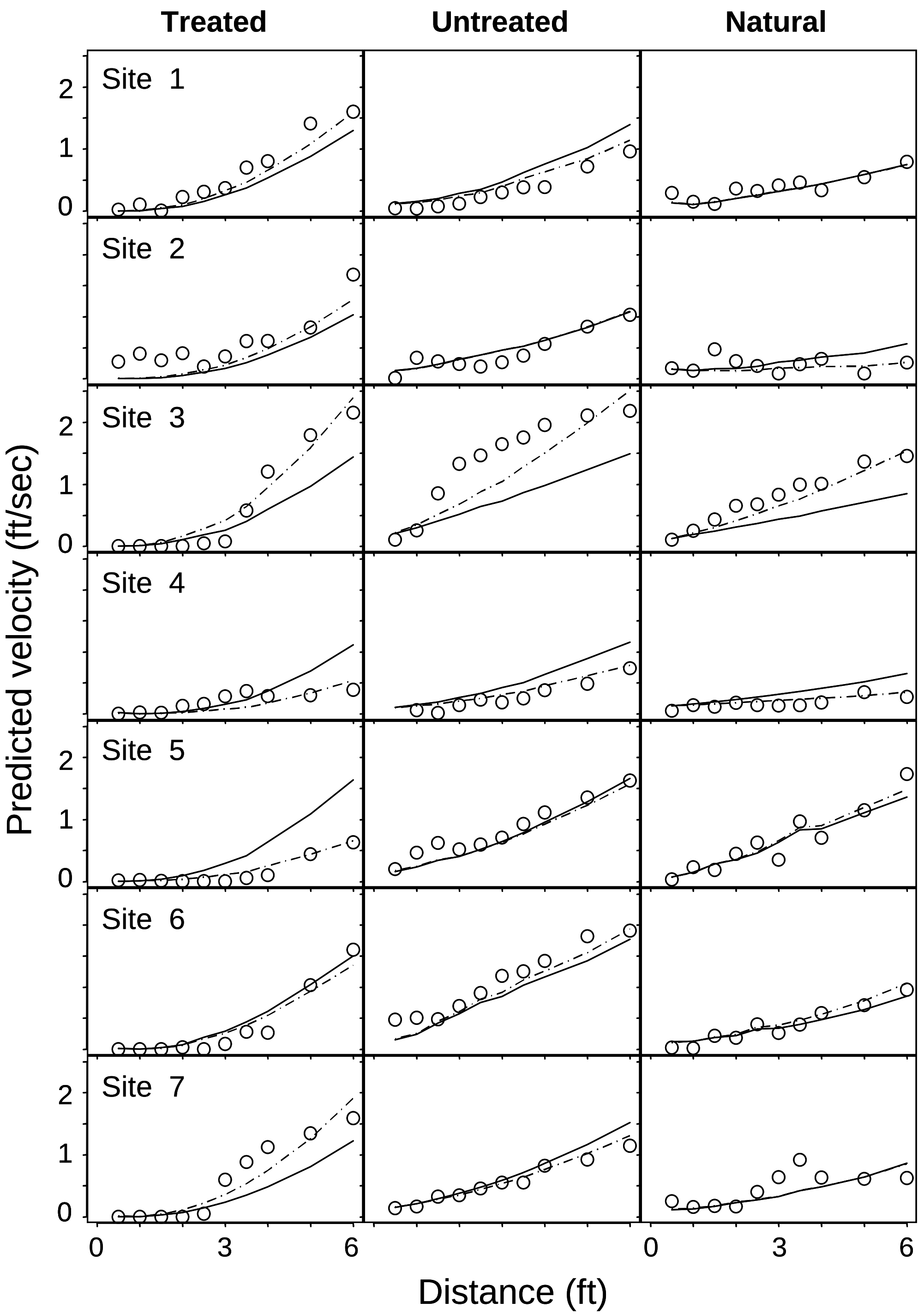


Figure 24. Predictions of mean velocity by site (rows) and treatment plot (columns) for Model 8. Solid lines are fixed-effects predictions; dashed lines are predictions incorporating site-specific and plot-specific random effects. Circles are mean velocities across transects for each distance interval. Note that transect-specific random effects are omitted in the dashed-line predictions.

Proportion of Velocity below Habitat Threshold

Not surprisingly, differences among treatments in the proportion of low velocities (less than or equal to 0.8 ft/sec) mimicked patterns found for raw velocities. Across sites, average proportions of low velocity declined rapidly as distance increased, with the highest proportions observed for “Treated” plots at low distance and for “Natural” plots at high distance (Figure 25). However, considerable variation in these patterns was observed among sites (Figure 26).

Logistic regression analysis identified highly significant effects of the variables *depth*, *distance*, *treatment* and *site* on the proportion (p) data ($n = 209$). We report results for the two highest-ranking models we examined (all simpler models had very little support based on AIC). The first model, defined by Equation (6), had an AIC value of 202.6. All model terms were highly significant (Table 11), implying that proportions of low velocity (in units logit(p)) declined linearly as a function of depth and distance, with clear differences among treatment types and among sites in the intercepts and slopes of the distance relationship (Table 12; Figure 27).

Model coefficients indicated that “Treated” plots had significantly higher intercepts, and lower slopes, than “Untreated” and “Natural” sites (Table 12). In other words, across sites, “Treated” plots had the highest proportions of low velocity at distances up to 3.0 ft, but the steepest decline in predicted proportions as distance increased beyond 3.0 ft (Figure 28A). There were also clear differences between predictions for “Untreated” and “Natural” plots, with the latter having increasingly greater proportions of low velocity as distance increased (Figure 28A). After redefining coefficients to compare these two treatment types, we found no difference in their intercepts (B_{0j}: Untreated – Natural = 0.28, SE = 0.61, P = 0.64) but significantly different slopes (B_{2j}: Untreated – Natural = -0.43, SE = 0.17, P = 0.012), which is consistent with the predictions in Figure 28A.

Basic diagnostics suggested that model fit for Equation (6) was reasonable; however, there was evidence of non-linearity for the depth relationship. Adding a quadratic term for *depth* (B_3d^2) to Equation (6) marginally improved model fit based on AIC (201.0), so we present results for this model as well. The estimated coefficient for the quadratic term ($B_3 = 0.40$, SE = 0.22, P = 0.065), in combination with the newly estimated linear term, indicated that proportions of low velocity declined more rapidly as depth increased but leveled out somewhat at higher depths (e.g., Figure 29). This had no influence on our conclusions regarding significant differences among *treatment* types; however, across-site predictions of low-velocity proportions were reduced slightly for all treatment types, in particular for “Natural” plots at large distances (Figure 28B).

Finally, we summarized the “total” proportions of low velocity across selected distance ranges (Table 13) by extrapolating predictions for each treatment type (i.e., we simply averaged the midpoints between distance intervals for prediction shown in Figure 28). For example, over the distance range from 0.5 to 4.0 ft, the proportion of velocity ≤ 0.8 ft/sec was roughly estimated to be 93% for “Treated” plots, 77% for “Untreated” plots, and 88% for “Natural” plots (Table 13, based on model Equation 6). In contrast, over distances from 4.0 to 6.0 ft, proportions were only 37% and 23% for “Treated” and

"Untreated" plots, but 63% for "Natural" plots. Predicted proportions were somewhat lower for the model with a quadratic term for depth (Table 13).

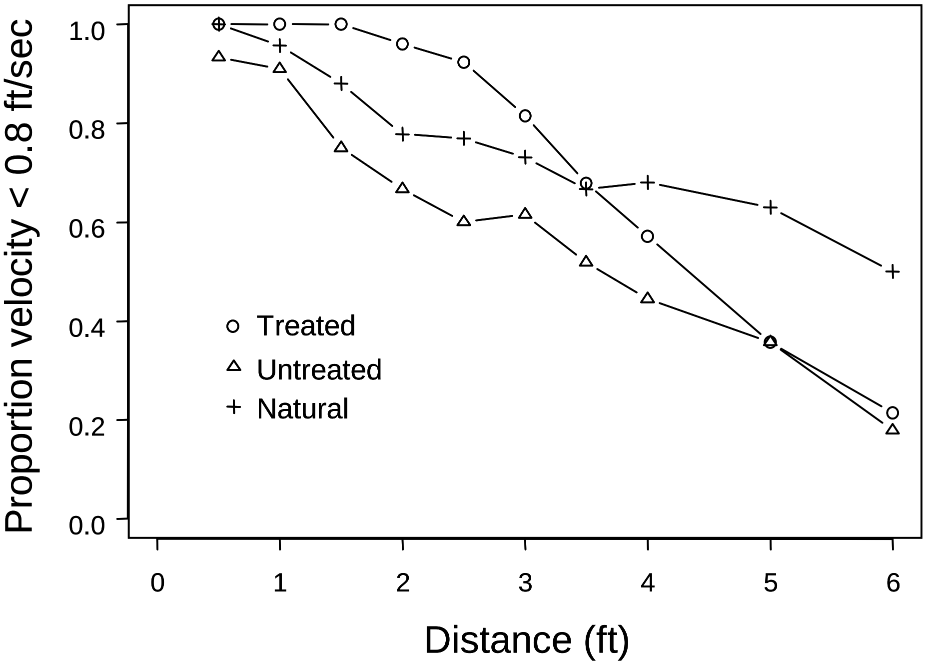


Figure 25. Mean proportions of low velocity values (≤ 0.8 ft/sec) by treatment type and distance interval. Means were computed across sites; initial proportions were computed across transects.

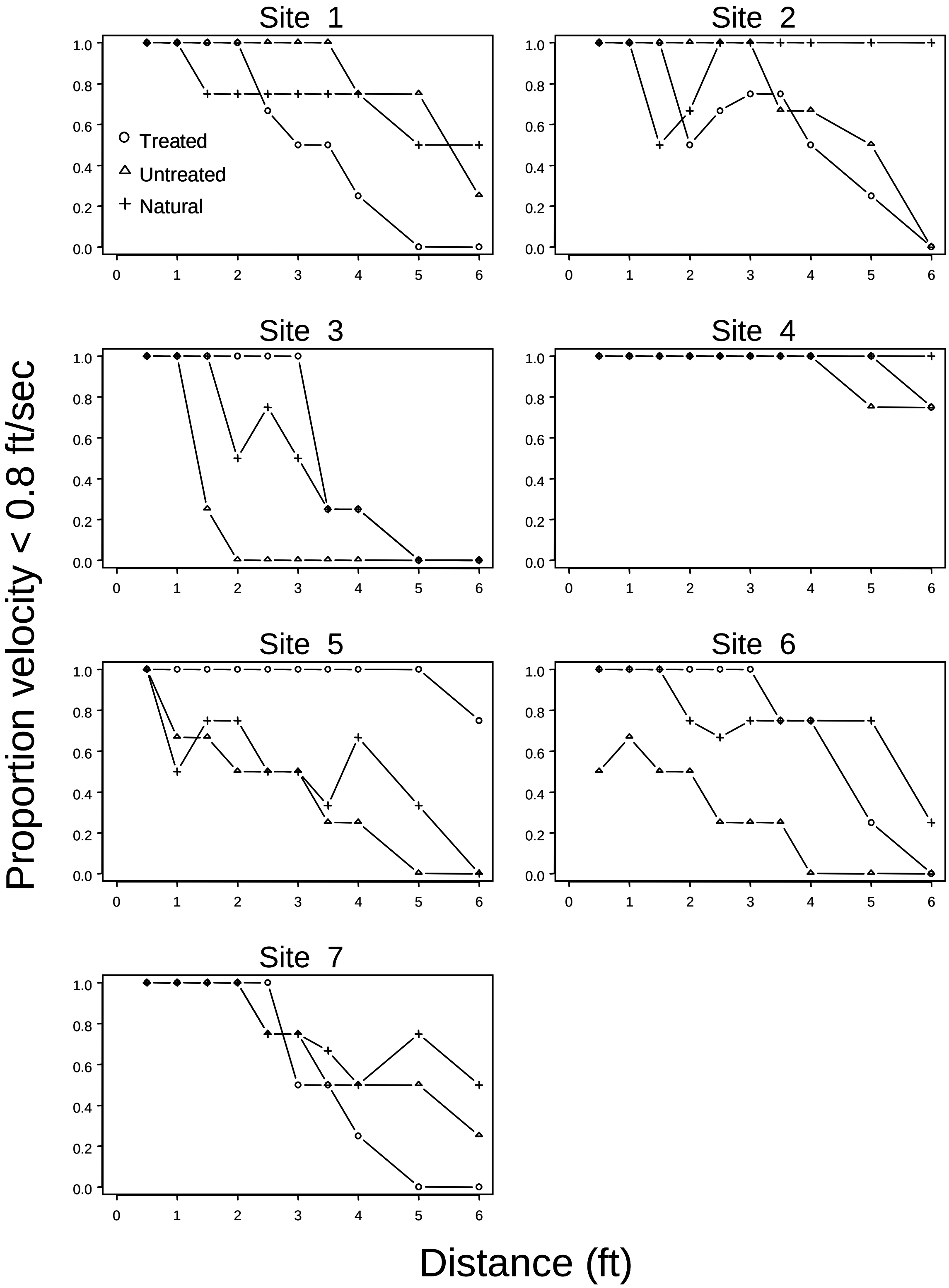


Figure 26. Proportions of low velocity values (≤ 0.8 ft/sec) by site, treatment type, and distance interval. Proportions were computed across transects.

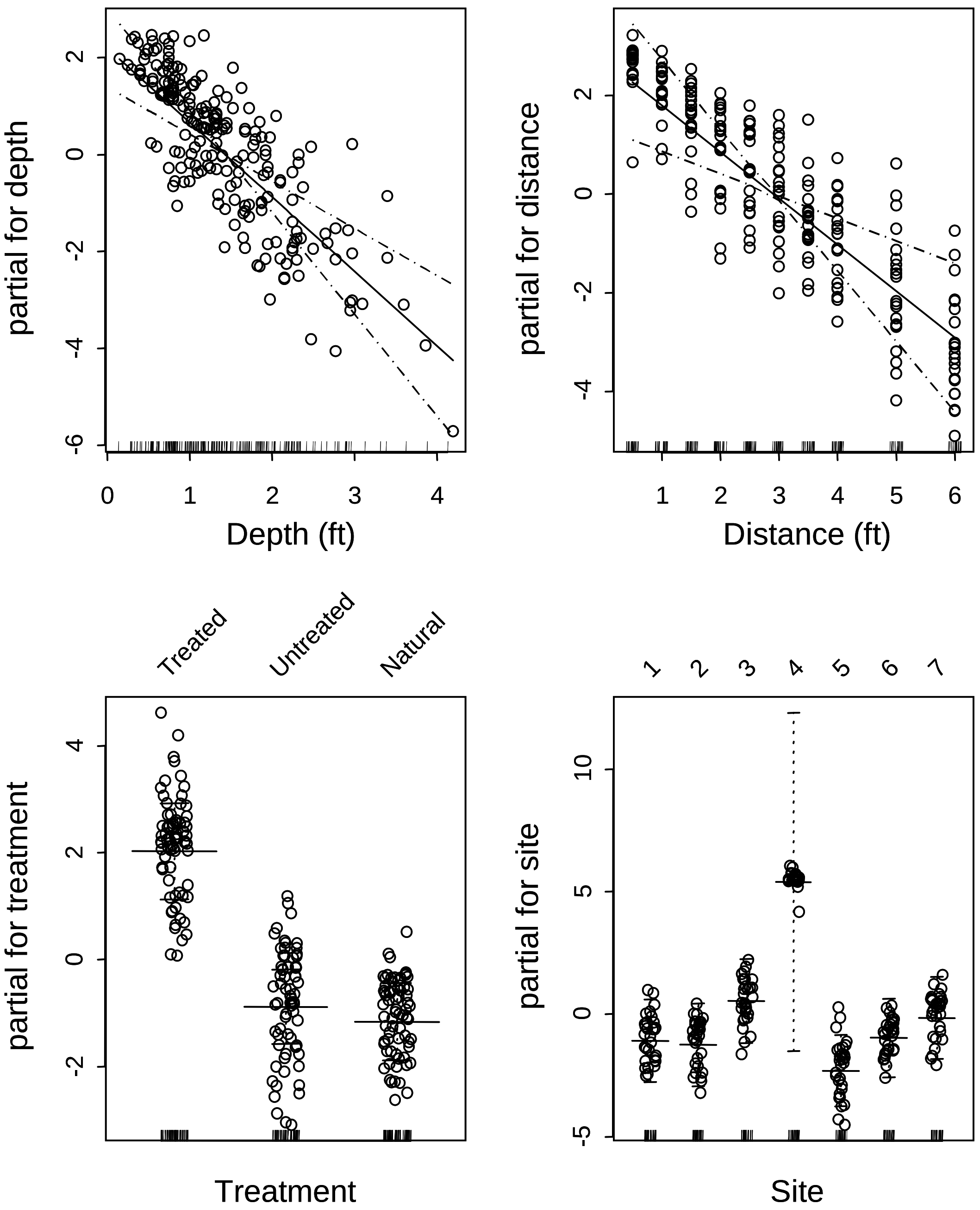
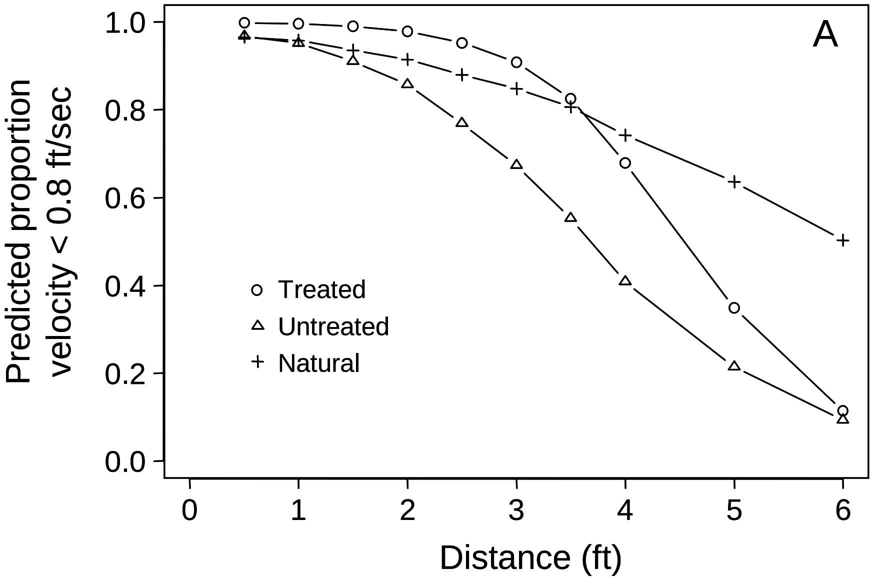


Figure 27. Partial effects of *depth*, *distance*, *treatment*, and *site* on deviance residuals of logit(*p*) for the logistic model defined by Equation (6) (where *p* = proportion of velocity ≤ 0.8 ft/sec). Dashed lines indicate approximate 95% confidence intervals for the fitted relationships; open circles are the observed data. Interactions terms for *distance*treatment* and *distance*site* are not shown.



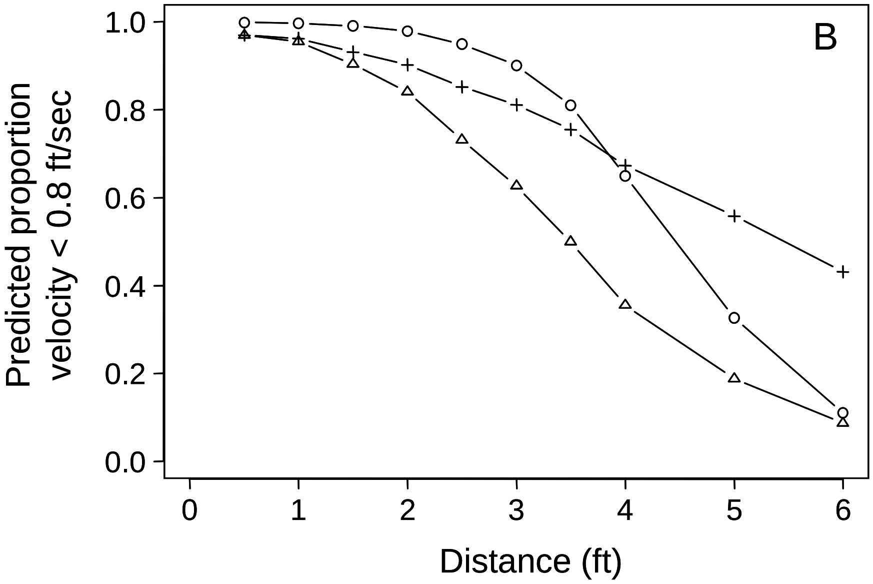


Figure 28. Across-site predictions of the proportion of low velocity (≤ 0.8 ft/sec) by treatment type and distance for (A) the logistic model defined by Equation (6), and (B) the same model with an added quadratic term for depth. For each distance interval, predictions were made with depth set equal to the mean depth across all sites, plots, and transects.

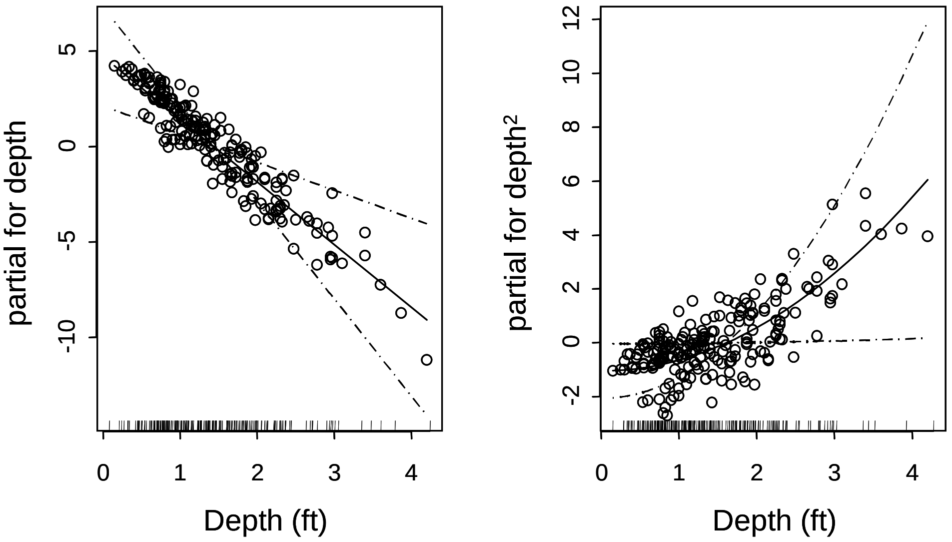


Figure 29. Partial effects of *depth* and *depth*^{2} on deviance residuals of logit(*p*) for the logistic model (Equation 6) with an added quadratic term for *depth* (where *p* = proportion of velocity ≤ 0.8 ft/sec). Dashed lines indicate approximate 95% confidence intervals for the fitted relationships; open circles are the observed data.

Table 11. Analysis of deviance for the logistic model (Equation 6) fit to proportions of low velocity (≤ 0.8 ft/sec). DF_1 is the number of coefficients and DF_2 is the residual degrees of freedom. P-values are based on Chi-squared tests where χ^2 = Deviance, with degrees of freedom = DF_1.

Component	DF_1	Deviance	DF_2	Residual deviance	P-value
intercept	1		208	548.3	
depth	1	213.2	207	335.1	< 0.001
distance	1	36.8	206	298.3	< 0.001
site	2	26.5	204	271.7	< 0.001
treatment	6	57.8	198	214.0	< 0.001
distance*treatment	2	18.3	196	195.7	< 0.001
distance*site	6	31.1	190	164.6	< 0.001

Table 12. Estimated coefficients for the logistic model (Equation 6) fit to proportions of low velocity (≤ 0.8 ft/sec). The twelve coefficients for *site* are not shown. Note that coefficients for *treatment* (B_{0j}) and *distance*treatment* (B_{2j}) are defined as the difference in logit(*p*) relative to the factor level "Treated" (i.e., the coefficients for "Treated" are equal to zero). SE = standard error. For all *t* tests, the degrees of freedom = 190.

Coefficient	Estimate	SE	t-value	P-value
B_0: intercept	6.80	0.98	6.93	< 0.001
B_1: depth	-1.54	0.31	-4.90	< 0.001
B_2: distance	-0.94	0.27	-3.48	< 0.001
B_{0j}: Untreated – Treated	-2.91	0.80	-3.64	< 0.001
B_{0j}: Natural – Treated	-3.19	0.82	-3.89	< 0.001
B_{2j}: distance * (Untreated – Treated)	0.45	0.21	2.15	0.033
B_{2j}: distance * (Natural – Treated)	0.87	0.21	4.19	< 0.001

Table 13. Predicted proportions (%) of low velocity (≤ 0.8 ft/sec) extrapolated across three distance ranges.

Model	Distance range (ft)	Treated	Untreated	Natural
Equation 6	0.5 to 4.0	93%	77%	88%
	4.0 to 6.0	37%	23%	63%
	0.5 to 6.0	73%	58%	79%
Equation 6	0.5 to 4.0	92%	75%	86%
+ $depth^2$	4.0 to 6.0	35%	20%	56%
	0.5 to 6.0	71%	55%	75%

Habitat and Vegetation

Across sites, large differences were observed in habitat-cover types among treatments (Figure 30A; Table 14). “Natural” plots tended to have more emergent vegetation, overhanging vegetation, undercut bank, and much more natural woody debris. “Treated” plots mostly had placed woody debris (i.e. CSTs) with lower relative amounts of other cover types except cobble. “Untreated” plots had the greatest amount of streambank with no cover present (11.4%) but were intermediate for most other cover types. The cover type “aquatic vegetation” was not included in the data analysis due to the infrequency of this cover type.

The ANOVA results for habitat cover (Table 15) indicated significant differences among treatments for all cover types except cobble. In particular, pairwise comparisons indicated that “Natural” plots had significantly greater proportions of emergent vegetation, overhang, and natural woody debris than either “Treated” or “Untreated” plots. In contrast, “Untreated” plots had greater proportions of the “no cover” category than the other treatments, while “Treated” plots had lower proportions of undercut banks (Table 15).

Clear differences among treatments were also evident for vegetation types (Figure 30B; Table 16). “Natural” plots had more vegetation composed of natural shrubs and trees. “Untreated” plots had the greatest amount of bare ground and the least amount of lawn, natural shrub, and tress. “Treated” plots had the greatest amount of lawn and planted shrubs, and intermediate amounts of natural shrubs and trees. The amount of grass was similar among treatment types.

Significant differences among treatments were found for several vegetation types (Table 15). (Note that reliable comparisons could not be made for the “lawn” and “planted shrub” categories, for which data were mostly limited to single high proportions in the “Treated” plot of Site 4). Specifically, “Untreated” plots had a significantly greater mean proportion of bare ground, while “Natural” plots had greater proportions of natural shrubs and trees than the other treatment types.

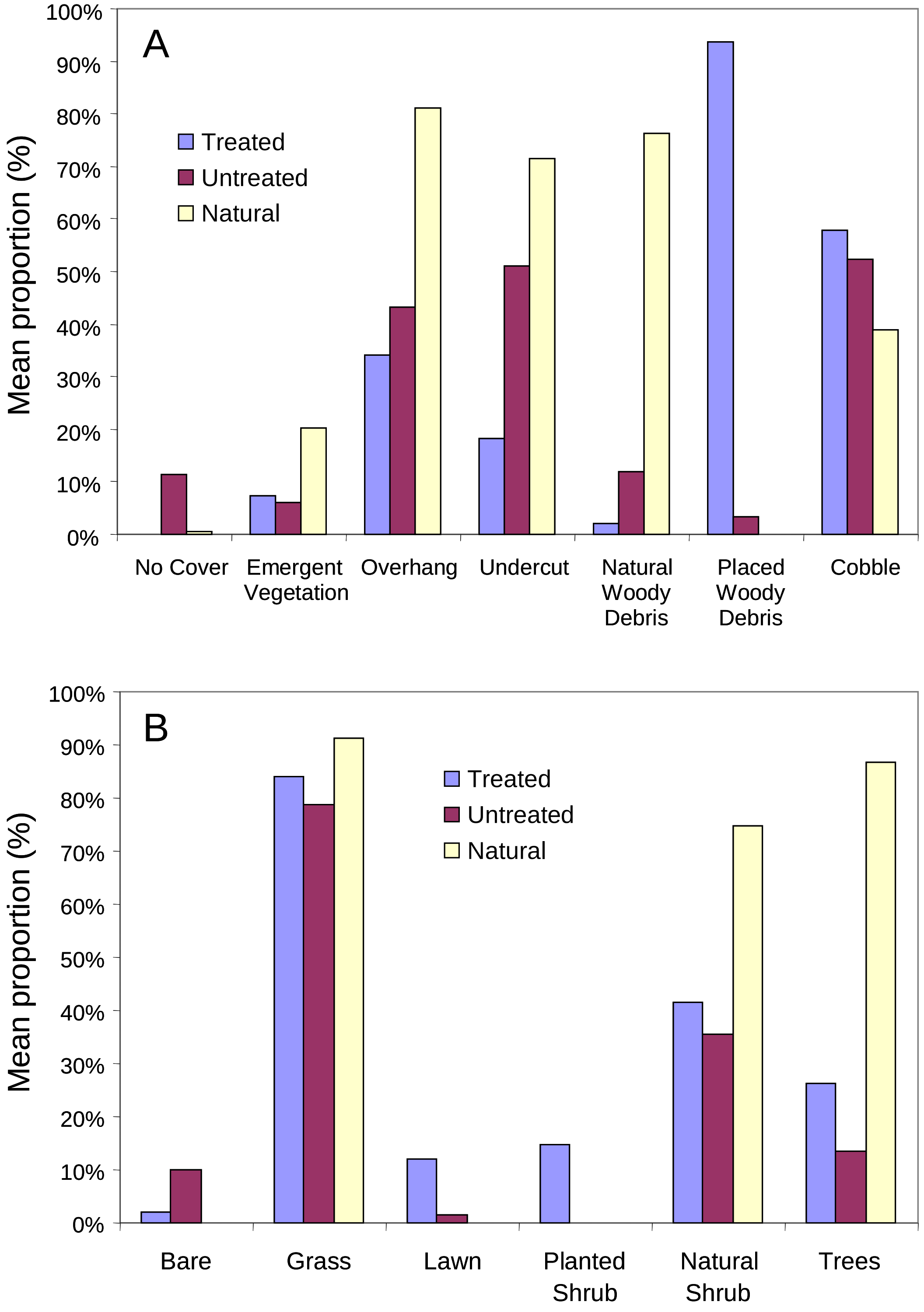


Figure 30. Mean proportion (%) across plots of (A) habitat-cover types, and (B) ground-cover (vegetation) types.

Table 14. Percent (%) habitat cover by site and treatment plot. SD = standard deviation.

Site	Treatment	No Cover	Emergent Vegetation	Overhang	Undercut	Natural Woody Debris	Placed Woody Debris	Cobble
Site 1	Treated	0.0	8.3	20.0	38.3	13.3	83.3	55.0
	Untreated	35.0	3.3	53.3	28.3	0.0	0.0	15.0
	Natural	0.0	18.3	78.3	55.0	56.7	0.0	43.3
Site 2	Treated	0.0	6.7	16.7	40.0	0.0	80.0	95.0
	Untreated	6.7	3.3	51.7	50.0	3.3	0.0	80.0
	Natural	1.7	5.0	95.0	58.3	16.7	0.0	76.7
Site 3	Treated	0.0	23.3	91.7	16.7	0.0	100.0	100.0
	Untreated	0.0	25.0	78.3	81.7	28.3	0.0	96.7
	Natural	0.0	23.3	86.7	61.7	95.0	0.0	80.0
Site 4	Treated	0.0	0.0	0.0	0.0	0.0	100.0	93.3
	Untreated	3.3	0.0	0.0	0.0	5.0	0.0	96.7
	Natural	1.7	35.0	85.0	75.0	68.3	0.0	8.3
Site 5	Treated	0.0	11.7	95.0	10.0	0.0	100.0	0.0
	Untreated	13.3	0.0	55.0	73.3	16.7	0.0	3.3
	Natural	0.0	50.0	83.3	78.3	100.0	0.0	0.0
Site 6	Treated	0.0	0.0	1.7	5.0	0.0	93.3	50.0
	Untreated	1.7	8.3	41.7	50.0	25.0	23.3	75.0
	Natural	0.0	5.0	61.7	80.0	98.3	0.0	63.3
Site 7	Treated	0.0	0.0	10.0	18.0	0.0	100.0	2.0
	Untreated	20.0	1.7	21.7	73.3	5.0	0.0	0.0
	Natural	0.0	5.0	76.7	91.7	98.3	0.0	0.0
Mean	Treated	0.0	7.3	34.1	18.3	2.0	93.7	57.8
	Untreated	11.4	6.0	43.1	51.0	11.9	3.3	52.4
	Natural	0.5	20.2	81.0	71.4	76.2	0.0	38.8
SD	Treated	0.0	7.9	38.4	14.4	4.7	8.1	39.5
	Untreated	11.6	8.2	23.5	26.9	10.5	8.2	41.0
	Natural	0.8	16.1	9.6	12.4	29.0	0.0	33.2

Table 15. Analysis of variance and pairwise comparisons of treatment means for proportion cover across sites. The "overall P-value" is from the ANOVA *F* test of the factor *treatment*, while pairwise P-values are based on individual *t* tests. Results are shown for models fit to arcsine-transformed proportions.

	Type	Overall P-value, H_0: T = U = N	Significant differences	P-values for pairwise comparisons, H_0: T = U	T = N	U = N
Habitat	No Cover	0.003	Untreated > Treated & Natural	0.001	0.613	0.004
	Emerg. Veg.	0.050	Natural > Treated & Untreated	0.895	0.037[a]	0.029[a]
	Overhang	0.009	Natural > Treated & Untreated	0.502	0.004	0.014
	Undercut	0.003	Treated < Untreated & Natural	0.022[a]	0.001	0.086
	NWD	0.000	Natural > Treated & Untreated	0.104	0.000	0.000
	PWD	0.000	Treated > Untreated & Natural	0.000	0.000	0.452
	Cobble	0.171	None	0.629	0.075	0.172
Vegetation	Bare	0.004	Untreated > Treated & Natural	0.016	0.168	0.001
	Grass	0.153	None	0.438	0.225	0.059
	Nat. Shrub	0.001	Natural > Treated & Untreated	0.835	0.001	0.000
	Trees	0.000	Natural > Treated & Untreated	0.283	0.000	0.000

[a] P-values slightly greater than 0.05 when Tukey test for multiple comparisons is used.

Table 16. Percent (%) ground cover (vegetation) by site and treatment plot. SD = standard deviation.

Site	Treatment	Bare	Grass	Lawn	Planted Shrub	Natural Shrub	Trees
Site 1	Treated	0.0	100.0	0.0	0.0	0.0	28.3
	Untreated	18.3	80.0	0.0	0.0	0.0	0.0
	Natural	0.0	100.0	0.0	0.0	28.3	76.7
Site 2	Treated	5.0	95.0	0.0	0.0	8.3	21.7
	Untreated	15.0	81.7	0.0	0.0	30.0	20.0

	Natural	0.0	100.0	0.0	0.0	50.0	86.7
Site 3	Treated	0.0	95.0	5.0	0.0	86.7	0.0
	Untreated	15.0	60.0	0.0	0.0	58.3	21.7
	Natural	0.0	38.3	0.0	0.0	100.0	85.0
Site 4	Treated	0.0	23.3	76.7	100.0	0.0	0.0
	Untreated	0.0	63.3	0.0	0.0	6.7	0.0
	Natural	0.0	100.0	0.0	0.0	45.0	80.0
Site 5	Treated	0.0	100.0	0.0	0.0	73.3	0.0
	Untreated	0.0	100.0	0.0	0.0	98.3	0.0
	Natural	0.0	100.0	0.0	0.0	100.0	83.3
Site 6	Treated	5.0	93.3	0.0	0.0	41.7	91.7
	Untreated	6.7	81.7	10.0	0.0	31.7	0.0
	Natural	0.0	100.0	0.0	0.0	100.0	100.0
Site 7	Treated	4.0	80.0	0.0	0.0	88.0	46.0
	Untreated	15.0	85.0	0.0	0.0	23.3	53.3
	Natural	0.0	100.0	0.0	0.0	100.0	95.0
Mean	Treated	2.0	83.9	12.0	14.6	41.5	26.3
	Untreated	10.0	78.8	1.4	0.0	35.5	13.6
	Natural	0.0	91.2	0.0	0.0	74.8	86.7
SD	Treated	2.3	25.5	26.6	35.0	37.3	31.1
	Untreated	7.1	12.5	3.5	0.0	31.1	18.6
	Natural	0.0	21.6	0.0	0.0	29.8	7.6

Discussion

Velocity

CST projects had a significant impact on nearshore stream velocity. In general, placing CSTs appears to bring plot-average velocities at disturbed sites closer to those found at natural (undisturbed) sites. The spatial distribution of velocity (i.e. the relationship between velocity and distance), however, is different between treated and natural sites. These findings suggest that CST projects have made significant progress in addressing degraded velocity refuge at disturbed streambanks, but that techniques could be improved to better mimic natural conditions.

Velocity is one of the most important factors in determining the amount of useable space for juvenile salmon during freshwater rearing (Bjornn and Reiser 1991). In large rivers, near-bank "edge" habitat, and the associated lower velocity in these areas, has been found to be important for juvenile salmonid rearing (Estes and Kuntz 1986, Murphy et al. 1989, Beechie et al. 2005). In the Kenai River, Bendock and Bingham (1988) captured juvenile Chinook in areas with velocities less than 100 cm/sec (3.3 ft/sec), with the highest densities in areas less than 20 cm/sec (0.7 ft/sec). Rearing density was positively associated with cover (versus no cover), and all areas with cover had mean velocities less than 30cm/sec (1ft/sec) (Bendock and Bingham 1988).

Our study found significant differences in velocity by treatment type for average velocity, proportion of velocity below 0.8 ft/sec, and changes in velocity with distance from shore. Overall, treated banks had average velocities that better resembled natural banks than untreated banks (Figure 17A). This pattern was evident for most but not all of the seven sites included in the study (Figure 19), indicating that site-specific conditions may add considerable variability.

Although CST installation tends to bring *average* velocities into line with natural banks, the *distribution* of this velocity is different than at natural banks. As can be seen in Figure 18A, CST treatment is quite effective at reducing velocity close to shore, but compared to natural banks, the benefit does not always extend very far out in the channel. The mixed-effects model fit to the data indicates that treated banks had considerably lower velocity on average at low distances, but velocity increased at a much greater rate as distance increased (Figure 23A). This dynamic is also evident when we look at the availability of velocity below 0.8 ft/sec, with treated banks providing more habitat than natural banks at close proximity to shore (<3-4 ft) but less habitat than natural banks farther (>3-4 ft) from shore (Figure 25).

Good summaries of the velocity-distance relationship are provided in Figure 28 and Table 13. For all distance ranges, untreated sites had the least amount of suitable velocity. For intervals less than 4 feet from shore, treated sites had the greatest availability of suitable velocity. From 4 to 6 feet, natural sites had the greatest amount of suitable velocity. When the entire distance range is considered, natural sites had the greatest amount of suitable velocity, although treated sites are similar. Untreated banks had the lowest velocities at all distances.

The specific effect of the velocity-distance relationship on juvenile rearing is unknown, but we can speculate on the impacts based on field observations. At treated banks, substantial benefit may be provided through the creation of an abrupt shear plane at the edge of the CST, allowing fish to rear in calm water adjacent to high velocity main channel flows where they can feed for drift organisms. Natural banks, on the other hand, may provide more variable and spatially distributed velocity refuge in the form of velocity breaks behind instream woody debris and other cover components. This diversity may actually increase the availability of feeding areas and likely represents the conditions to which Kenai River salmon have adapted to over time.

During the field surveys, qualitative observations were made with respect to the habitat benefits, erosion control benefits, and physical integrity of some CST projects versus others. In particular, looser packed (i.e. less dense) CSTs and CSTs that are not packed tightly up against the bank appear to provide greater access by juvenile salmon to within and behind the structures (Figure 31). In many cases, CSTs in this condition simply represent older or poorly maintained CSTs. Nevertheless, access to within and behind the structure provides abundant and complex velocity refuge and overhead cover, as well as greater access to overhanging vegetation, emergent vegetation, and undercut banks that lie behind the structure. In essence, loosely packed CSTs better resemble natural banks than their tightly packed counterparts. In contrast, tightly packed CSTs may limit the ability of juvenile salmon to access the interior matrix of the spruce trees or to access the bank behind the structure (Figure 32). Tightly packed CSTs, however, are likely to provide more effective bank protection and may last longer before deteriorating.

Figure 31. Loosely packed CSTs allow for juvenile salmon access to within and behind the structure, where there is good velocity refuge, overhanging vegetation, and access to undercut banks.

Figure 32. Tightly packed CSTs may provide more effective erosion control but may simplify the bank and limit access to within or behind the structure for juvenile salmon rearing.

Habitat

Untreated sites had the greatest proportion of bank with no cover, although the mean proportion in this cover type was quite low (11.4%) (Figure 30, Table 14). “No cover” conditions typically occur where banks have been cleared of vegetation and are heavily used for fishing or boat access, which results in vegetation trampling, bank collapse, and erosion. Bendock and Bingham (1988) found higher concentrations of juvenile Chinook and sockeye in areas with cover than areas without cover. Lack of cover is therefore likely to be detrimental to juvenile fish rearing, especially if “no cover” conditions make up a large proportion of a streambank.

Across all treatment types, there was a relatively small amount of emergent vegetation, and most of this was grass with the roots inundated at the time of the survey. In some cases, this was the result of clumps of grassy banks that had recently collapsed and settled lower on the streambank. As expected, natural banks had the greatest proportion of emergent vegetation cover. Based on field observations, the lack of emergent vegetation at treated and untreated banks is attributed to the presence of CSTs and bank trampling, respectively.

Natural banks had the greatest proportion of overhanging vegetation cover, which typically consisted of grasses, shrubs, and in some cases, trees. For untreated banks, overhanging vegetation usually consisted of only grasses because most of these sites had been cleared of woody vegetation. A low incidence of overhanging vegetation at treated banks may be a result of the treatment itself, especially for cases where streamside vegetation is removed to facilitate installation of CSTs. Our results differ from those of Hauser et al. (2000), who found that the amount of overhanging vegetation at CST projects closely approximated the amount at "undisturbed" (natural) banks, and these both had significantly greater overhanging vegetation than "disturbed" (untreated) sites. Their methods, however, included both live and dead vegetation, and so placed CSTs were included in the data, which may explain the discrepancy.

Natural banks also had the greatest amount of undercut bank, though differences were not statistically significant. Treated banks, however, had significantly less undercut bank than either untreated or natural banks. It is possible that CSTs are so effective at reducing erosion from scour and wave action that they inhibit the formation of undercut banks, a process that still occurs to some degree at untreated banks. An alternative explanation is that undercut banks may have been visually obscured by CSTs and escaped detection during field surveys. Although space beneath floating CSTs was not considered undercut bank, it could be argued that this condition mimics undercut banks and provides similar habitat benefits to juvenile fish. This condition was observed at several of the sites.

As expected, natural woody debris was most abundant along natural banks, whereas placed woody debris was most abundant along treated banks. At disturbed sites (both treated and untreated), removal of streamside trees has reduced the recruitment potential for woody debris. Direct removal of naturally-recruited instream woody debris has also likely occurred in some cases. Furthermore, at sites with CSTs, natural woody debris may have been removed in order to facilitate construction of the project. Due to these impacts, the presence of natural instream woody debris was very uncommon at the treated and untreated sites, a pattern that is seen throughout the lower Kenai River.

There was a greater standard deviation of natural woody debris at natural streambanks compared to disturbed streambanks (Table 14). Hauser et al. (2000) also found greater variation of wood debris values at undisturbed areas. Greater variability reflects the complex dynamics that produce natural wood cover. This variability likely provides a diverse array of habitat features that support multiple species and life-stages, and may be an indicator of overall habitat complexity.

Results indicated that natural banks had lower velocities at a greater distance (4 to 6 feet) from the bank than did treated or untreated banks. At most sites, this was likely due to the presence of instream woody debris that extended out from the bank 5 to 10 feet or more. Such woody material is sourced from the adjacent bank and has been recruited into the wetted channel but is still partially rooted to the shore. Results of the velocity analysis suggest that woody debris plays an important role in providing velocity refuge along bank margins. Woody debris provides many other important functions as well, including maintaining undercut banks, attenuating boat-wake erosion, providing overhead cover from avian predators, providing an invertebrate food source, and capturing organic matter.

There was no effect of treatment type on the abundance of cobble cover, which is not typically affected by disturbance or treatment of the bank itself. Although cobble may provide important cover for some species and life stages, this cover exists only on the bed of the channel and may not be as effective as other cover types that provide cover and velocity refuge closer to surface feeding areas. In some cases, such as Site 4, the inclusion of cobble in the analysis may actually obscure the dramatic lack of other, more beneficial cover types at the site (Table 14).

Vegetation

Vegetation composition varied by treatment type (Figure 30B). Vegetation cover is largely a function of land use activities and can have a strong influence on instream habitat conditions. The lack of abundant tree cover at treated and untreated sites was related to clearing of vegetation to maintain views, allow for landscaping, or to facilitate access to the streambank/river. Most mature trees have been cleared and new ones are prevented from becoming established. At treated sites, all or a portion of the bank has elevated, light-penetrating walkways that allow for grass and shrub growth. The untreated sites, however, do not have elevated walkways (except for Site 7), and the bank vegetation typically consists of small shrubs and grasses with impacts related to fishing access. Some portions of untreated banks have bare ground with no vegetation cover. Bare ground is typically located in areas of high fishing pressure or where footpaths access the shoreline. The impact of bank access on riparian vegetation and erosion has been thoroughly investigated over the past several years by ADFG (see King and Clark 2004).

The condition of riparian vegetation affects instream bank habitat. The absence of trees prevents the recruitment of large woody debris onto streambanks, and a lack of root masses reduces the presence of complex undercut banks. A lack of trees and shrubs decreases the amount of overhanging vegetation that can provide velocity refuge and a source of food organisms. Bare ground that is devoid of vegetation is subject to erosion from streamflow or rainfall, and likely contributes to rapid bank retreat.

Chapter 4: Conclusions and Recommendations

Conclusions

A tremendous amount of streambank restoration work has been conducted on the Kenai River in the last 15 years. Since the early 1990s, implementation of erosion control and fish habitat enhancement projects has increased almost 5-fold, with a current total of 385 projects covering nearly 9 miles of streambank between the mouth of the Kenai River and Skilak Lake. Most projects are geared towards protecting streambanks from bank erosion and improving degraded fish habitat. Unlike many older protection measures that did not adequately consider habitat impacts, these projects are built using techniques that reduce bank erosion while also protecting or restoring salmon habitat. These efforts, in combination with elevated light-penetrating walkways that are present in great abundance along the river, have served to reduce erosion, reduce bank trampling, and improve fish habitat.

Much of the recent streambank restoration work can be attributed to the Cost-Share Program, which has assisted landowners with implementing projects since 1995. It should be noted, however, that approximately 60% of projects are conducted without assistance from the Cost-Share Program, which indicates that outreach, education, and permitting requirements also influence the magnitude and type of projects that are constructed. In addition, the strong conservation ethic of Kenai River landowners and a genuine desire to improve fish habitat must not be discounted as important motivators for implementing habitat restoration projects.

The vast majority of projects implemented on the Kenai River are cabled spruce tree projects. CSTs appear to be effective at erosion control, and although they have a limited lifespan of only 2-4 years, their relative low cost of construction and maintenance make them a sensible approach for restoration. Compared with untreated (but disturbed) banks, CST projects reduce near-bank velocities and increase the amount of rearing cover for fish. However, compared with natural (undisturbed) banks, they do not provide velocity reduction as far out into the channel and they do not provide as diverse of an array of habitat cover. Nevertheless, CSTs have advantages over other techniques, and with creative modifications, future CST projects could be designed to better mimic natural streambank conditions.

Recommendations

Restore mature woody vegetation to streambanks. Mature trees provide erosion control, rootmasses that support undercut banks, and a source of woody debris recruitment to streambanks. Many of the developed parcels along the Kenai River have long been cleared of mature woody vegetation. Restoring mature, forested vegetation conditions will help to restore long-term streambank stability and habitat cover. The use of CSTs and other bank stabilization techniques can be effective at providing interim bank protection and habitat enhancement until mature woody vegetation becomes re-established.

Characterize the function and habitat benefits of natural streambanks. More investigation is needed into the benefits of natural banks (i.e. habitat and erosion control) and techniques that could be developed to mimic those functions. In particular, the functions and recruitment processes of natural woody debris warrants further study. Based on field observations, overhanging large woody debris, fallen but root-anchored woody debris, and tree roots provide stability and complexity to natural banks. Woody debris is recruited through natural processes such as bank erosion and icing. Whereas LWD dynamics are well-understood for streams in the conterminous US, there is less understanding of LWD dynamics in Alaskan rivers. Streambank and LWD dynamics, and their implications to restoration, warrant further investigation.

Develop new techniques that mimic natural bank conditions. Based on the above investigations of natural banks, new restoration measures should be explored that better represent the natural habitat conditions to which Kenai River salmon have adapted. For example, bank complexity could be enhanced through woody debris placements that extend further out into the channel than the typical CST or rootwad project. This may entail utilizing larger trees and extending them obliquely and perpendicularly into the flow and at a variety of depths. Interference with bank fishing and the availability of large wood material will be issues that need to be considered.

CSTs versus BEBs. Low construction cost, ease of maintenance, effective erosion control, and creation of cover habitat likely makes CST projects more economical and effective over the long term compared to BEBs. The Project Status Assessment also found that CSTs were in overall better condition than BEBs, and were therefore more likely to be accomplishing project objectives. Furthermore, observations during this and other studies (e.g. Hauser et al. 2000) suggest that BEBs tend to simplify the bank and may reduce rearing cover availability and complexity. Constructing CSTs instead of BEBs, or at least combining CSTs with BEBs, would enhance bank complexity.

Enhance CST project design. Whereas CSTs improve significantly upon conditions found at disturbed banks, they do not necessarily mimic the types and diversity of cover that is provided on natural banks. Techniques should be explored for enhancing CST projects through modifications or additions that add complexity. Adding larger trees or trees at oblique angles to the flow would enhance complexity and provide velocity refuge further out into the channel. Techniques should also be developed to increase juvenile access to within and behind spruce trees in order to increase available rearing cover. This might be accomplished by running cables only around tree trunks (not completely around the branches) and by tethering bundled trees at a short distance (i.e. 1-3 feet) from the shore.

Engineering analysis for projects. Karle (2003), in a study of restoration projects throughout Alaska, found that many "bioengineering" projects did not incorporate adequate bank toe protection and performed poorly. Even some rootwad projects were not adequate to resist shear stress at some sites. Karle recommended that erosion control projects should include shear stress and scour analysis, and that projects need to be properly designed to resist scour, which may include toe protection (e.g. rip-rap) to prevent damage to the structure. On the Kenai River, these design requirements may add considerable cost to landowners and may not necessarily be covered by the Cost-Share Program. An alternative approach for the Kenai River would be to conduct hydraulic and scour analysis at a sub-sample of projects in order to develop structural design criteria for a suite of project types and installation locations. These criteria could then be used as guidelines to assist landowners with designing restoration projects for their specific circumstances.

Additional areas for study. Extending this study to other treatment types, including BEBs and rootwad revetments, would enhance the applicability of the results. Other treatment types have been evaluated by Hauser et al. (2000) and Dorava (1999), and these studies should be built upon to further evaluate the effectiveness of a range of treatment types. Similar to Hauser et al. (2000), a suitable measure of bank complexity could not be devised within the scope of this study. The shear complexity of some banks, such as severe bank crenulations, small "islands" formed from collapsed banks, and instream large woody debris jams make complexity a difficult attribute to measure. Devising a reliable measure of complexity should be an objective for future project evaluations. A 3-dimensional measure of bathymetry, such as might be obtained with the use of an Acoustic Doppler Current Profiler (ADCP) would be a potential approach.

References

Beechie, T.J, M. Liermann, E.M. Beamer, and R. Henderson. 2005. A Classification of Habitat Types in a Large River and Their Use by Juvenile Salmonids. Transactions of the American Fisheries Society 134:717–729.

Bendock, T.N., and A.E. Bingham. 1988. Juvenile salmon seasonal abundance and habitat preference in selected reaches of the Kenai River, Alaska, 1987-1988. Fishery Manuscript No. 70. Alaska Department of Fish and Game, Division of Sport Fish, Juneau, AK.

Bjornn, T.C.; Reiser, D.W. 1991. Habitat requirements of salmonids in streams. In: Meehan, W.R. Influences of forest and rangeland management of salmonid fishes and their habitats. Bethesda, MD: American Fisheries Society: 83-138.Burger et al. (1983).

Burger, C.V., D.B. Wangaard, R.L. Wilmot, and A.N. Palmiso. 1983. Salmon investigations in the Kenai River, Alaska, 1979-1981. U.S. Fish and Wildlife Service, National Fisheries Research Center, Alaska Field Station, Anchorage, AK. 178pp.

Burnham, K.P. and Anderson, D.R., 2002. Model selection and multimodel inference: A practical information-theoretic approach (second edition). Springer-Verlag, New York.

Dobson, A.J. 2002. An Introduction to Generalized Linear Models (second edition). Chapman and Hall, London.

Dorava, J. 1999. Effectiveness of Streambank-Stabilization Techniques along the Kenai River, Alaska. USGS WRIR 99-4156

Dorava, J.M. 1995. Hydraulic Characteristics near Streamside Structures along the Kenai River, Alaska. U.S. Geological Survey - Water-Resources Investigations Report 95-4226.

Dorava, J.M. and G.W. Moore. 1997. Effects of boatwakes on streambank erosion, Kenai River, Alaska. U.S. Geological Survey. Water-Resources Investigations Report 97-4105. 92 pp.

Estes, C. and K. Kuntz. 1986. Kenai River habitat study. Alaska Department of Fish and Game, Federal Aid in Fish Restoration, Annual Performance Report, 1985-1986, Project F-10-1, Volume 27, Juneau, AK. 72 pp.

Gelman, A. and Hill, J. 2007. Data analysis using regression and multilevel/hierarchical models. Cambridge University Press, New York.

Hauser, W.J., M.J. Fink, D.W. Hughes, P.A. Hansen, and R.A. Clark. 2000. Kenai River Rehabilitation and Protection Program: Assessment of Streambank Habitat Treatments. ADFG Habitat Restoration Division, Technical Report No. 01-1.

Jennings, G.B., K. Sundet, and A.E. Bingham. 2009. Estimates of participation, catch, and harvest in Alaska sport fisheries during 2006. Alaska Department of Fish and Game, Division of Sport Fish and Commercial Fisheries. Fishery Data Series No. 09-54.

Karle, Kenneth F. 2003. Evaluation of Bioengineered Stream Bank Stabilization in Alaska. Prepared by Hydraulic Mapping and Modeling for Alaska Department of Transportation & Public Facilities – Research & Technology Transfer. FHWA-AK-RD-03-03.

King, M.A., and P. Hansen. 1999. Assessment of angler impacts to Kenai River riparian habitats during 1997. Alaska Department of Fish and Game, Division of Sport Fish. Fishery Data Series No. 99-9.

King, M.A., and P.A. Hansen. 2001. Assessment of shore angling impacts to Kenai River riparian habitats, 1998. Alaska Department of Fish and Game, Division of Sport Fish. Fishery Data Series No. 01-3.

King, M.A., and P.A. Hansen. 2002. Assessment of shore angling impacts to Kenai River riparian habitats, 1999. Alaska Department of Fish and Game, Division of Sport Fish. Fishery Data Series No. 02-19.

King, M.A., and R. Clark. 2004. Kenai River riparian habitat assessment. Alaska Department of Fish and Game. Report to the Alaska Board of Fisheries, 2005. 34 pp.

Larson, L.L., and B.W. McCracken. 1998. Assessment of angler impacts to Kenai River riparian habitats during 1996. Alaska Department of Fish and Game, Division of Sport Fish. Fishery Data Series No. 98-10.

Liepitz, G. S. 1994. An assessment of the cumulative impacts of development and human uses on fish habitat in the Kenai River. ADFG Tech report 94-6.

Maynord, S.T., D.S. Biedenharn, C.J. Fischenich and J.E. Zufelt. 2007. Boat wake induced bank erosion on the Kenai River, Alaska. Draft Report- 09 Jan 2007

McCullagh, P., and Nelder, J.A. 1989. Generalized Linear Models (second edition), Chapman and Hall, London.

McCulloch, C.E., and Searle, S.R. 2001. Generalized, linear, and mixed models. John Wiley and Sons, New York.

Murphy, M.L., J. Heifetz, J.F. Thedinga, S.W. Johnson, and K.V. Koski. 1989. Habitat Utilization by Juvenile Pacific Salmon (Onchorynchus) in the Glacial Taku River, Southeast Alaska. Can. J. Fish. Aquat. Sci. 46(10): 1677–1685.

Neter, K., Kutner, M. H., Nachtsheim, C. J., and Wasserman, W. 1996. Applied Linear Statistical Models (forth edition), McGraw-Hill, Boston.

Pinheiro, J. C. and Bates, D. M. 2000. Mixed-effects models in S and S-PLUS. Springer-Verlag, New York.

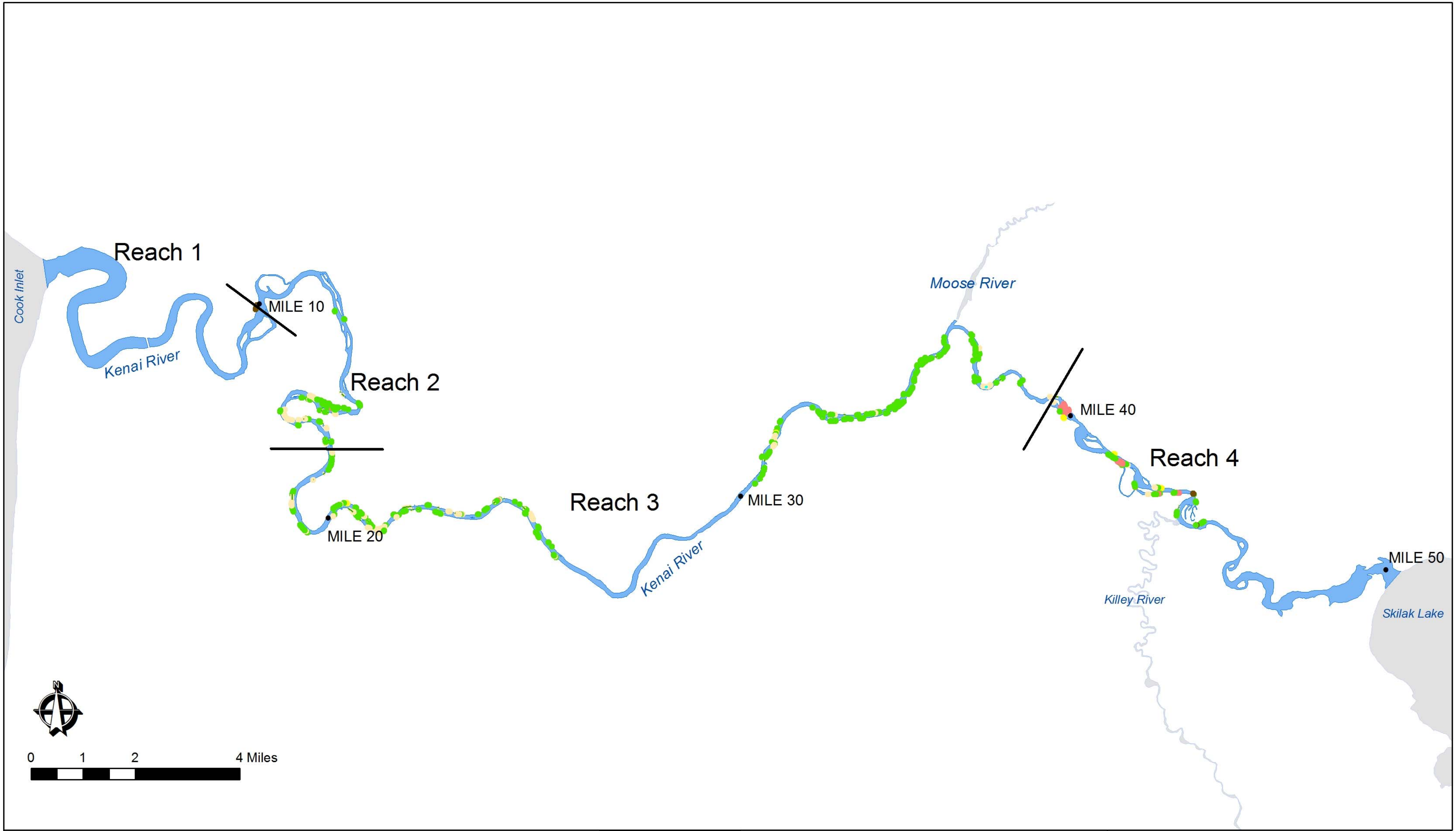
Venables, W.N. and Ripley, B.D. 2002. Modern Applied Statistics with S (fourth edition). Springer-Verlag, New York.

Walter, J., D. Hughes, N. Moore, F. Inoue, and G. Muhlberg. 2005. Streambank Revegetation and Protection – A Guide for Alaska, Revised 2005. Alaska Department of Fish and Game and Alaska Department of Natural Resources. Original Technical Report No. 98-3, March 1998.

Zar, J. 1999. Biostatistical analysis (fourth edition). Prentice-Hall, New Jersey.

Appendix A: Spatial Distribution of Projects Within Study Area

Appendix A: Table of Contents



Project Type

- Bioengineered Bank
- Combination Approaches
- Cabled Spruce Trees
- Other Misc Approaches
- Tethered Logs
- Rootwad Revetment
- / Reach Break

inter·fluve
1020 Wasco St, Suite 1
Hood River, OR 97031
www.interfluve.com

Kenai River Project Evaluation
Kenai River Sportfishing Association
2009

Plate 1

Spatial Distribution of Projects within Study Area OVERVIEW

Project Type

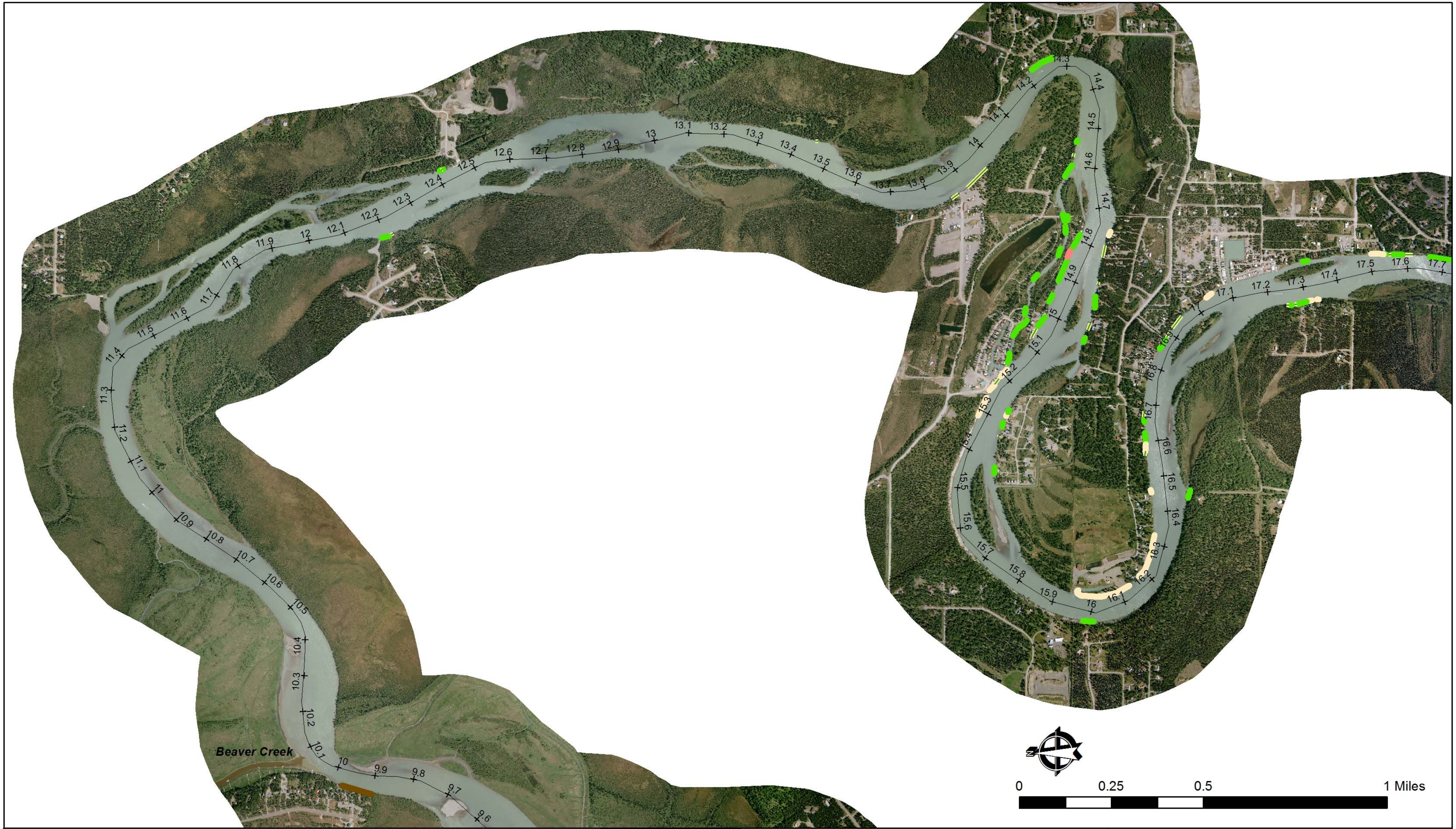
Bioengineered Bank	Other Misc Approaches	—+ Kenai River Mile
Combination Approaches	Tethered Logs	
Cabled Spruce Trees	Rootwad Revetment	

inter·fluve inc.
1020 Wasco St, Suite 1
Hood River, OR 97031
www.interfluve.com

Kenai River Project Evaluation
Kenai River Sportfishing Association
2009

Plate 2

Spatial Distribution of Projects within Study Area RIVER MILE 0 - 10



Project Type

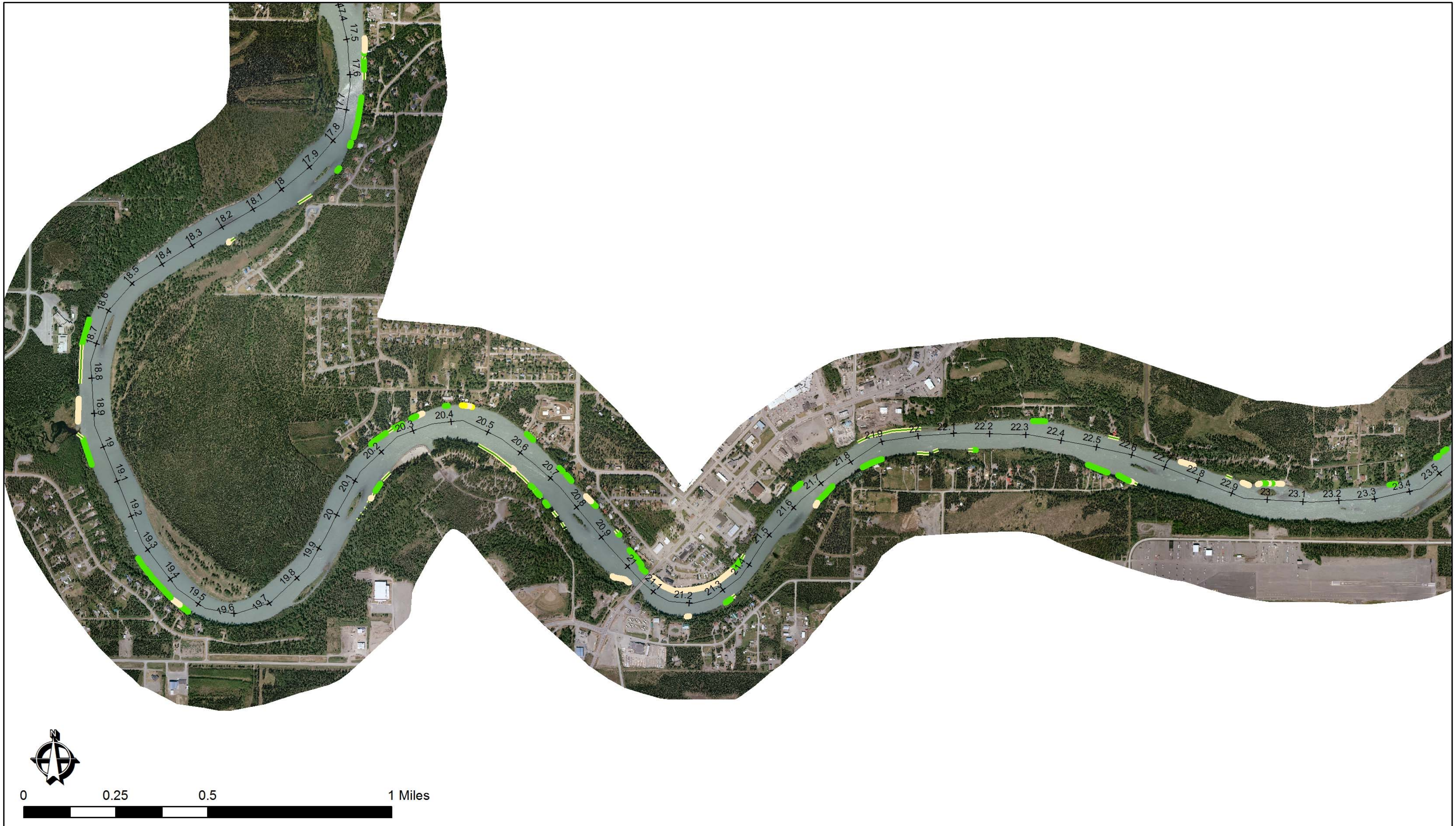
- ▬ Bioengineered Bank
- ─ Combination Approaches
- ▬ Cabled Spruce Trees
- ▬ Other Misc Approaches
- ▬ Tethered Logs
- ▬ Rootwad Revetment
- —+ Kenai River Mile

inter·fluve inc.
1020 Wasco St, Suite 1
Hood River, OR 97031
www.interfluve.com

Kenai River Project Evaluation
Kenai River Sportfishing Association
2009

Plate 3

Spatial Distribution of Projects within Study Area
RIVER MILE 10 - 17.5



Project Type

- ▬ Bioengineered Bank
- ▬ Combination Approaches
- ▬ Cabled Spruce Trees
- ▬ Other Misc Approaches
- ▬ Tethered Logs
- ▬ Rootwad Revetment
- —+ Kenai River Mile

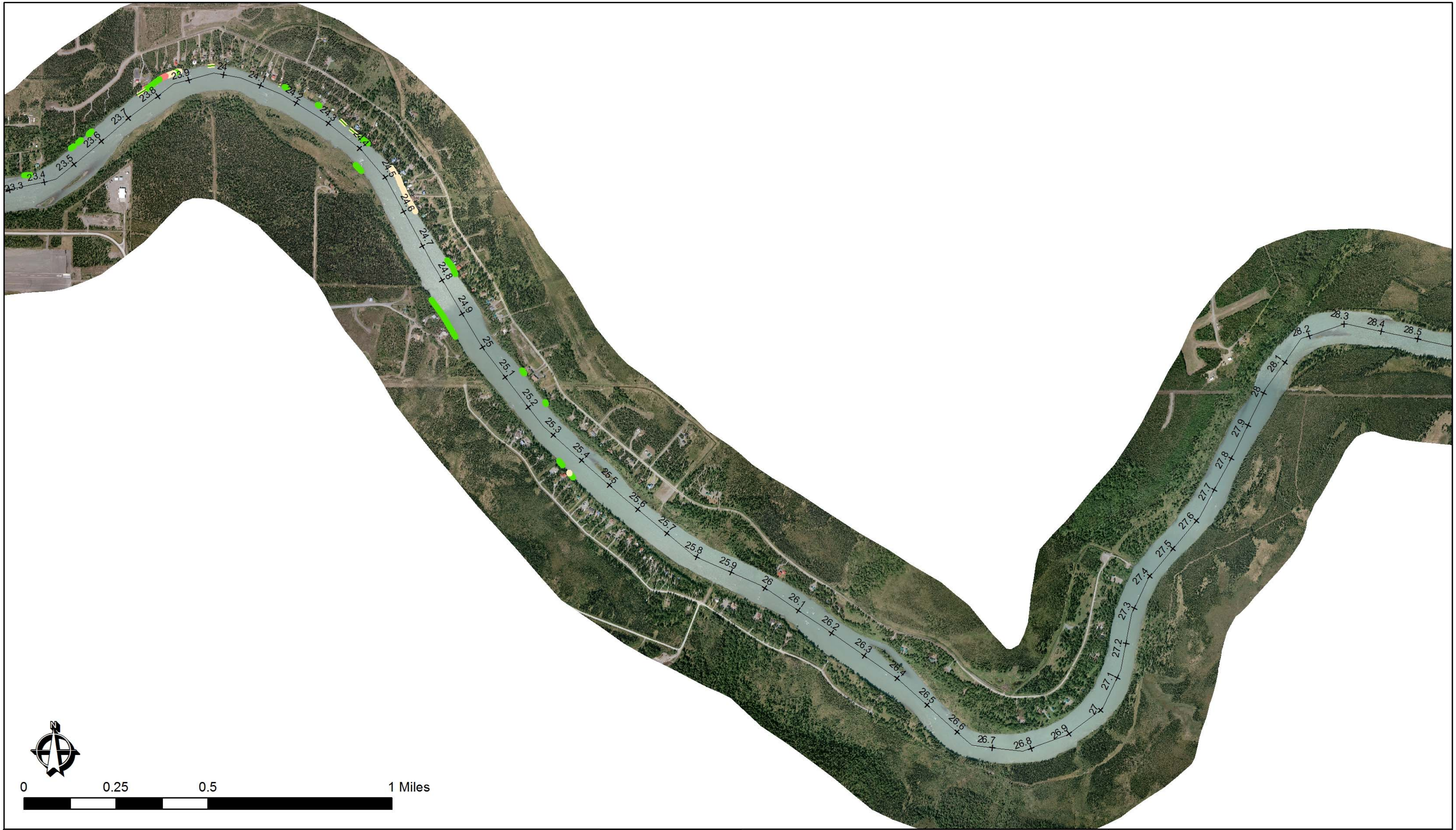
inter·fluve inc.
1020 Wasco St, Suite 1
Hood River, OR 97031
www.interfluve.com

Kenai River Project Evaluation
Kenai River Sportfishing Association
2009

Plate 4

Spatial Distribution of Projects within Study Area

RIVER MILE 17.5 - 23.5



Project Type

- Bioengineered Bank
- Combination Approaches
- Cabled Spruce Trees
- Other Misc Approaches
- Tethered Logs
- Rootwad Revetment
- Kenai River Mile

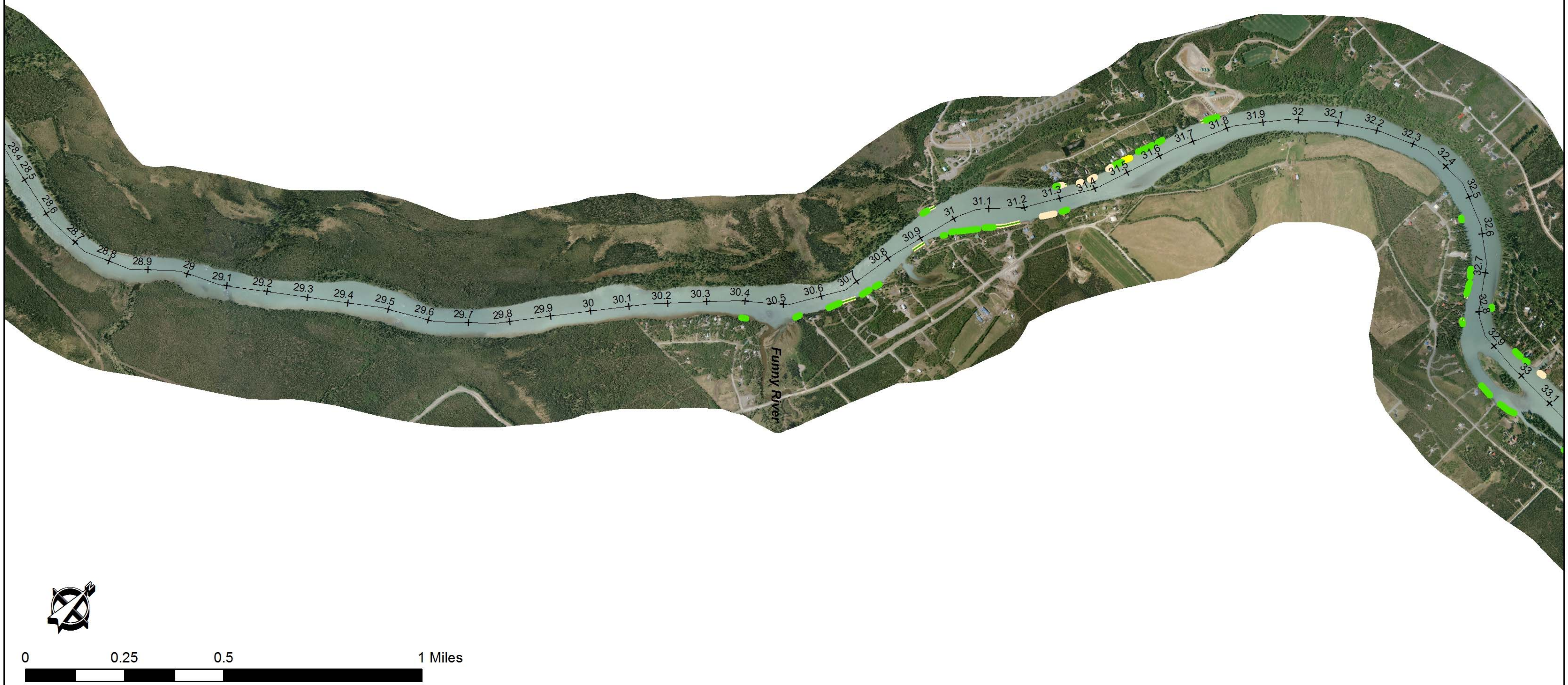
inter·fluve Inc.
1020 Wasco St, Suite 1
Hood River, OR 97031
www.interfluve.com

Kenai River Project Evaluation
Kenai River Sportfishing Association
2009

Plate 5

Spatial Distribution of Projects within Study Area

RIVER MILE 23.5 - 28.5



Project Type

- Bioengineered Bank
- Combination Approaches
- Cabled Spruce Trees
- Other Misc Approaches
- Tethered Logs
- Rootwad Revetment
- Kenai River Mile

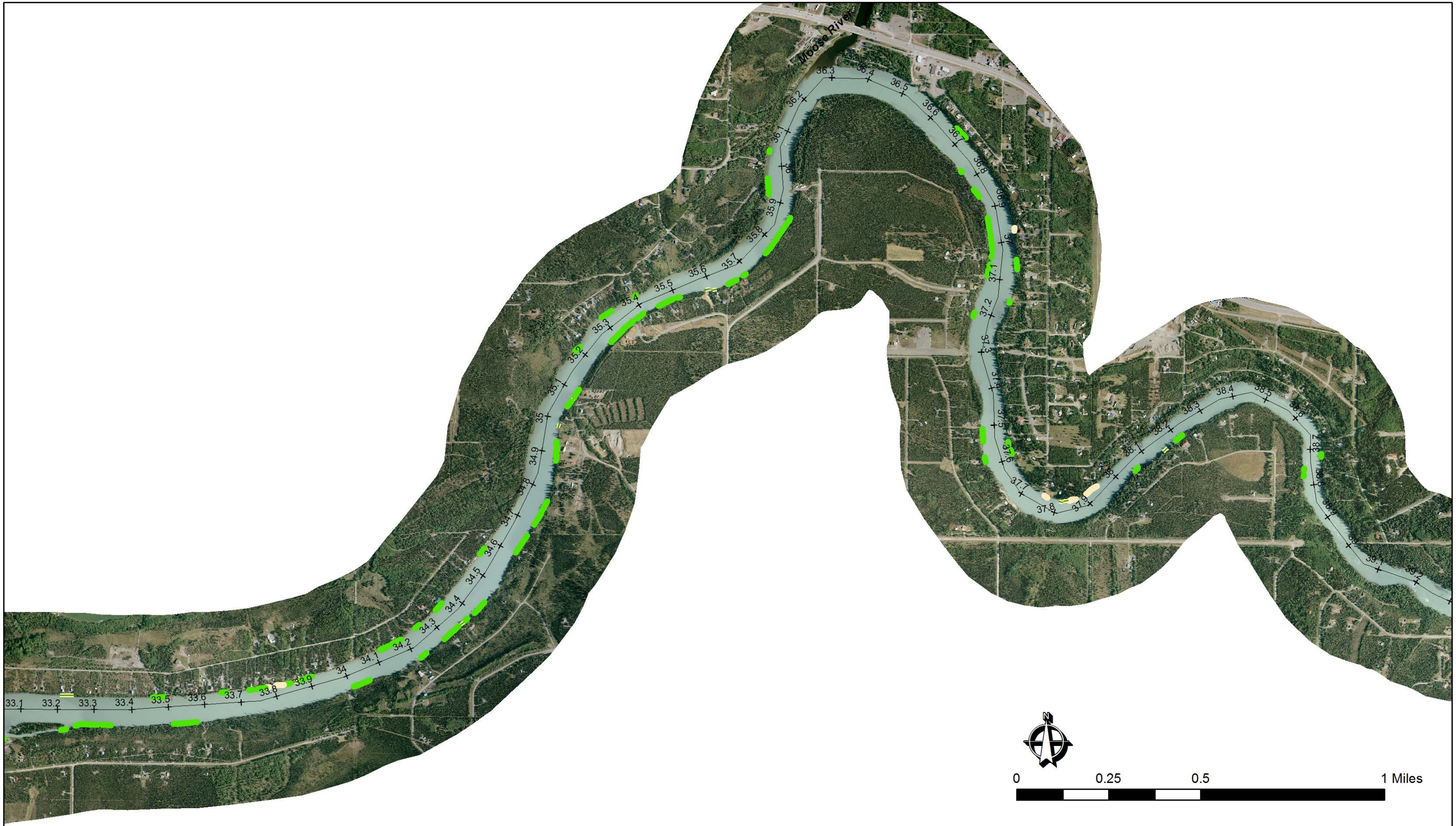
inter·fluve
1020 Wasco St, Suite 1
Hood River, OR 97031
www.interfluve.com

Kenai River Project Evaluation
Kenai River Sportfishing Association
2009

Plate 6

Spatial Distribution of Projects within Study Area

RIVER MILE 28.5 - 33



Project Type

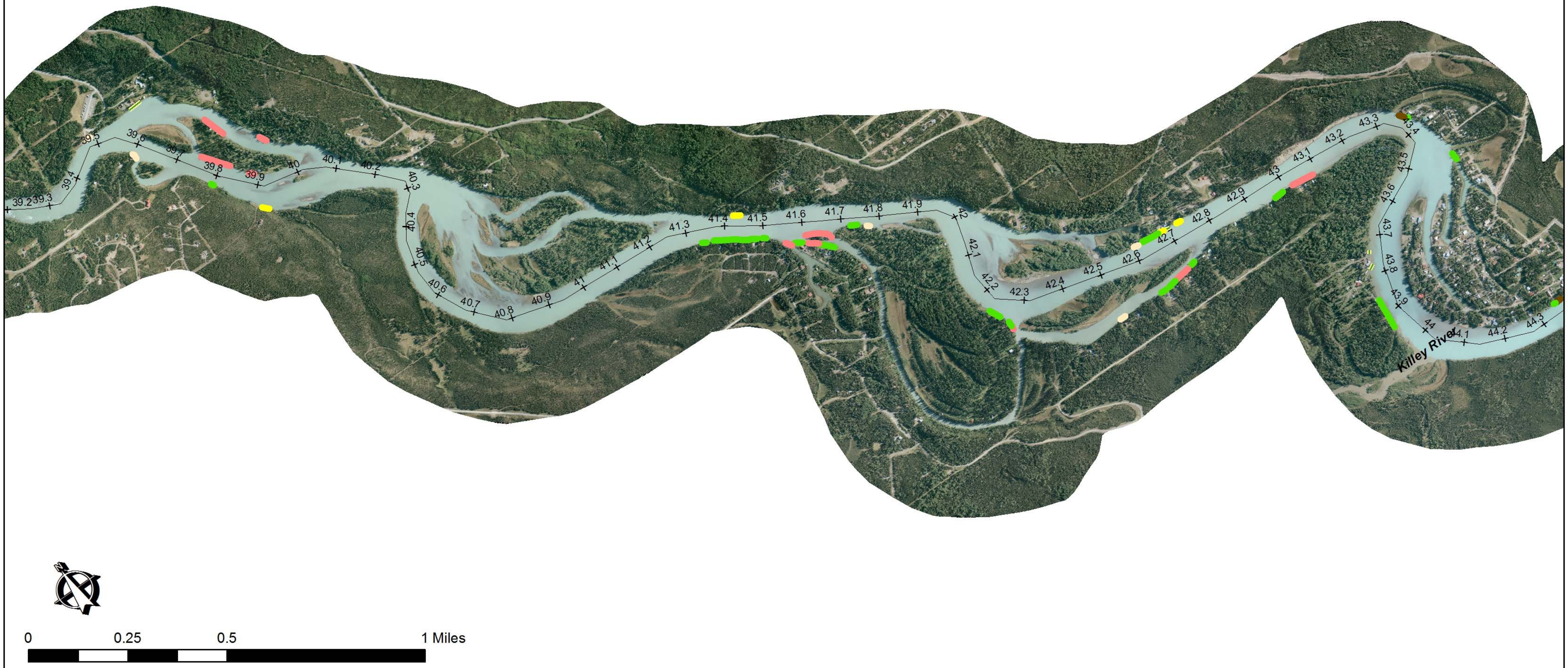
🟨 Bioengineered Bank	🟨 Other Misc Approaches
— Combination Approaches	🟥 Tethered Logs
🟩 Cabled Spruce Trees	🟫 Rootwad Revetment
—+ Kenai River Mile	

inter·fluve inc.
1020 Wasco St, Suite 1
Hood River, OR 97031
www.interfluve.com

Kenai River Project Evaluation
Kenai River Sportfishing Association
2009

Plate 7

Spatial Distribution of Projects within Study Area
RIVER MILE 33 - 39



Project Type

- ▬ Bioengineered Bank
- ▬ Combination Approaches
- ▬ Cabled Spruce Trees
- ▬ Other Misc Approaches
- ▬ Tethered Logs
- ▬ Rootwad Revetment
- —+ Kenai River Mile

inter-fluve inc.

1020 Wasco St, Suite 1
Hood River, OR 97031
www.interfluve.com

Kenai River Project Evaluation
Kenai River Sportfishing Association
2009

Plate 8

Spatial Distribution of Projects within Study Area

RIVER MILE 39 - 44

Project Type

- Bioengineered Bank
- Combination Approaches
- Cabled Spruce Trees
- Other Misc Approaches
- Tethered Logs
- Rootwad Revetment
- Kenai River Mile

inter·fluve

1020 Wasco St, Suite 1
Hood River, OR 97031
www.interfluve.com

Kenai River Project Evaluation
Kenai River Sportfishing Association
2009

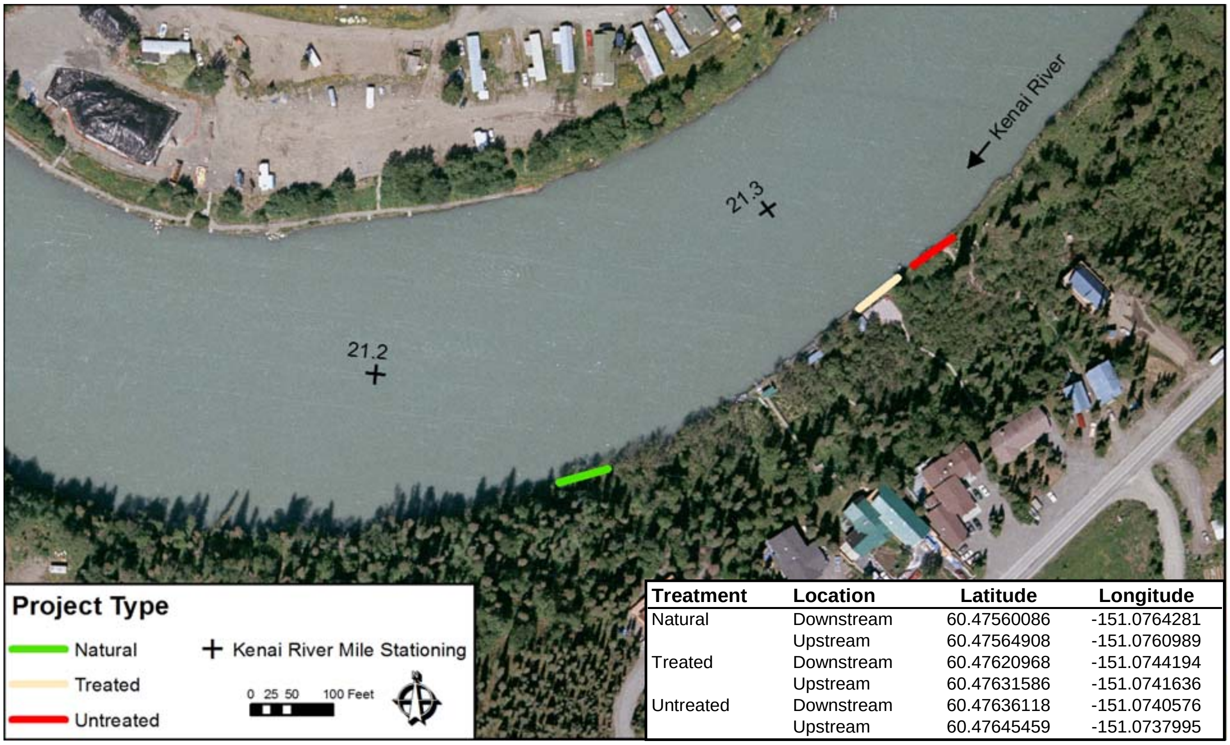
Plate 9

Spatial Distribution of Projects within Study Area

RIVER MILE 44 - 50

Appendix B: Site Details for Project Effectiveness Assessment

Site 1



Treatment	Location	Latitude	Longitude
Natural	Downstream	60.47560086	-151.0764281
	Upstream	60.47564908	-151.0760989
Treated	Downstream	60.47620968	-151.0744194
	Upstream	60.47631586	-151.0741636
Untreated	Downstream	60.47636118	-151.0740576
	Upstream	60.47645459	-151.0737995

Figure 1. Location of Site 1. Latitude and longitude (WGS 84) are given for the upstream and downstream ends of each sample segment.

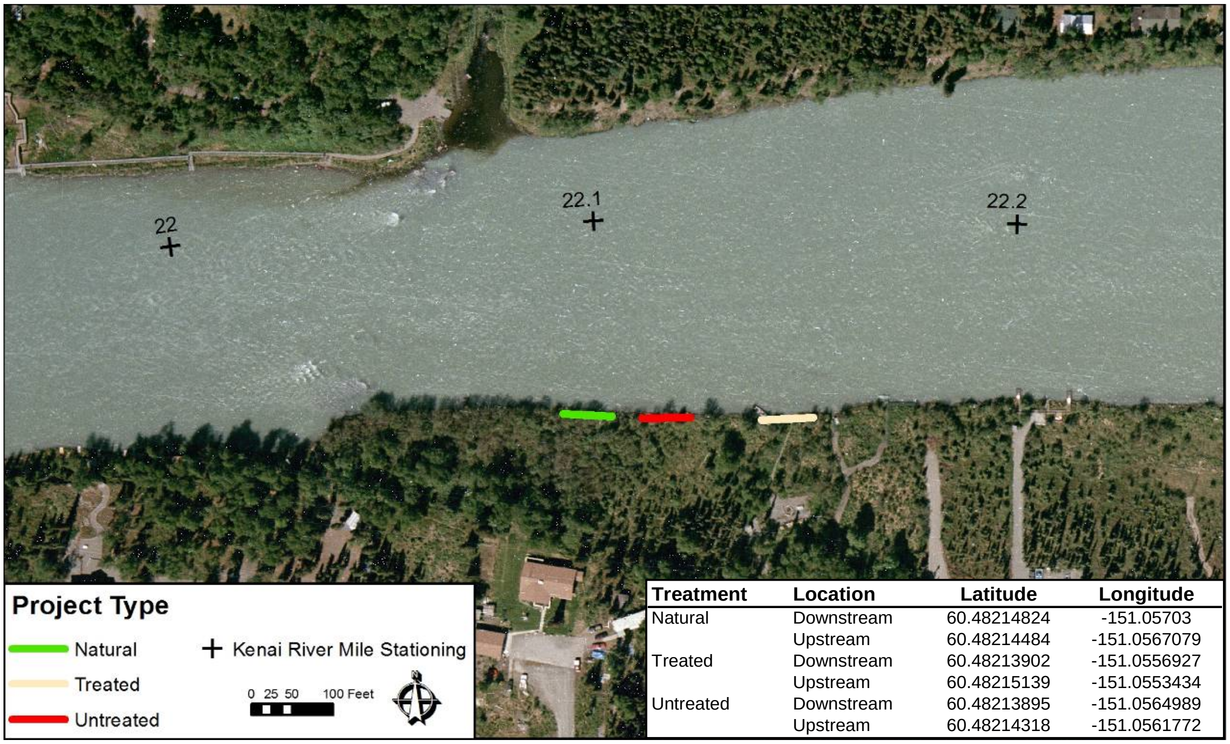
Site 1 - Untreated

Site 1 - Treated

Site 1 - Natural

Figure 2. Photos of Site 1 sample plots.

Site 2



Treatment	Location	Latitude	Longitude
Natural	Downstream	60.48214824	-151.05703
	Upstream	60.48214484	-151.0567079
Treated	Downstream	60.48213902	-151.0556927
	Upstream	60.48215139	-151.0553434
Untreated	Downstream	60.48213895	-151.0564989
	Upstream	60.48214318	-151.0561772

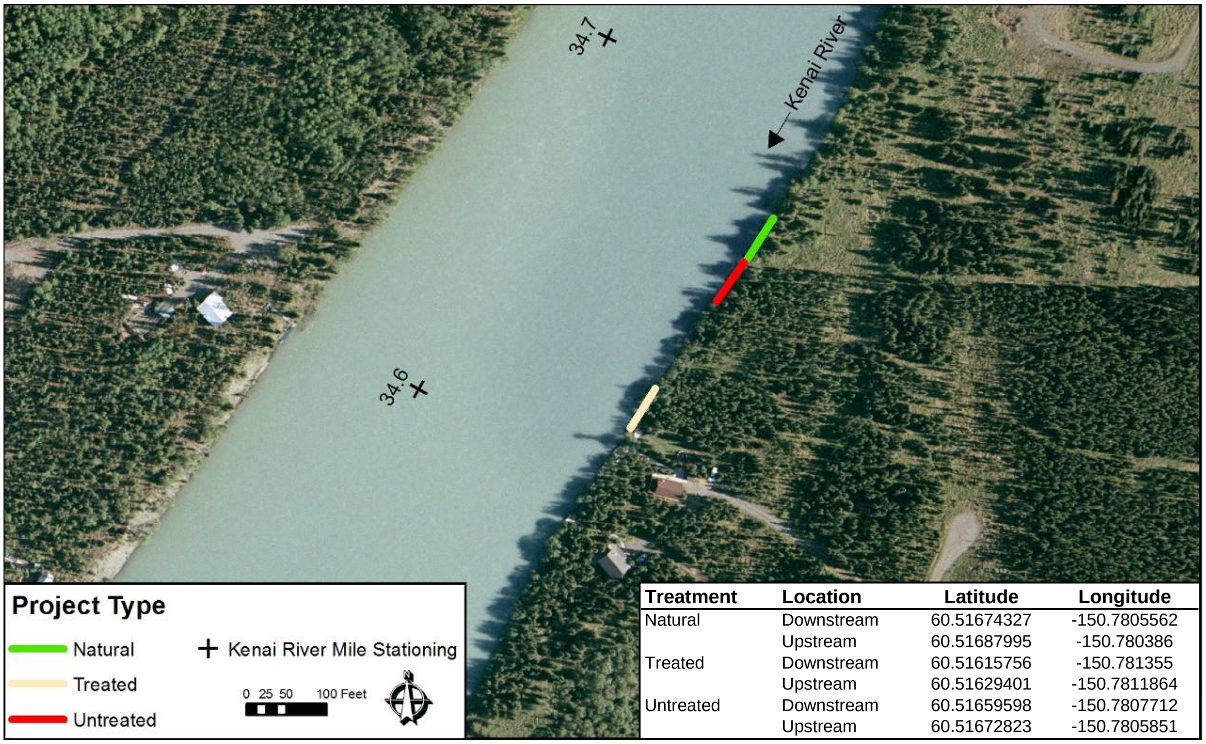
Figure 3. Location of Site 2. Latitude and longitude (WGS 84) are given for the upstream and downstream ends of each sample segment.

Site 2 - Untreated *Site 2 - Treated*

Site 2 - Natural

Figure 4. Photos of Site 2 sample plots.

Site 3



Treatment	Location	Latitude	Longitude
Natural	Downstream	60.51674327	-150.7805562
	Upstream	60.51687995	-150.780386
Treated	Downstream	60.51615756	-150.781355
	Upstream	60.51629401	-150.7811864
Untreated	Downstream	60.51659598	-150.7807712
	Upstream	60.51672823	-150.7805851

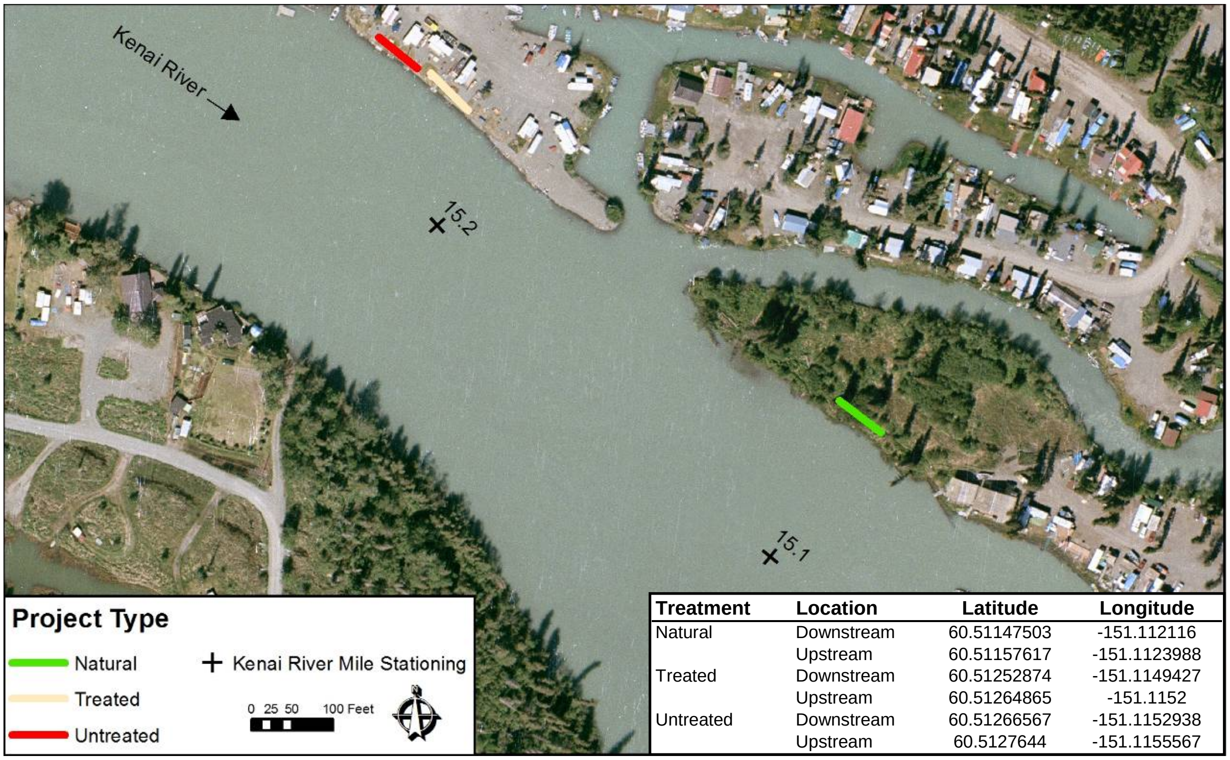
Figure 5. Location of Site 3. Latitude and longitude (WGS 84) are given for the upstream and downstream ends of each sample segment.

Site 3 - Untreated *Site 3 - Treated*

Site 3 - Natural

Figure 6. Photos of Site 3 sample plots.

Site 4



Treatment	Location	Latitude	Longitude
Natural	Downstream	60.51147503	-151.112116
	Upstream	60.51157617	-151.1123988
Treated	Downstream	60.51252874	-151.1149427
	Upstream	60.51264865	-151.1152
Untreated	Downstream	60.51266567	-151.1152938
	Upstream	60.5127644	-151.1155567

Figure 7. Location of Site 4. Latitude and longitude (WGS 84) are given for the upstream and downstream ends of each sample segment.

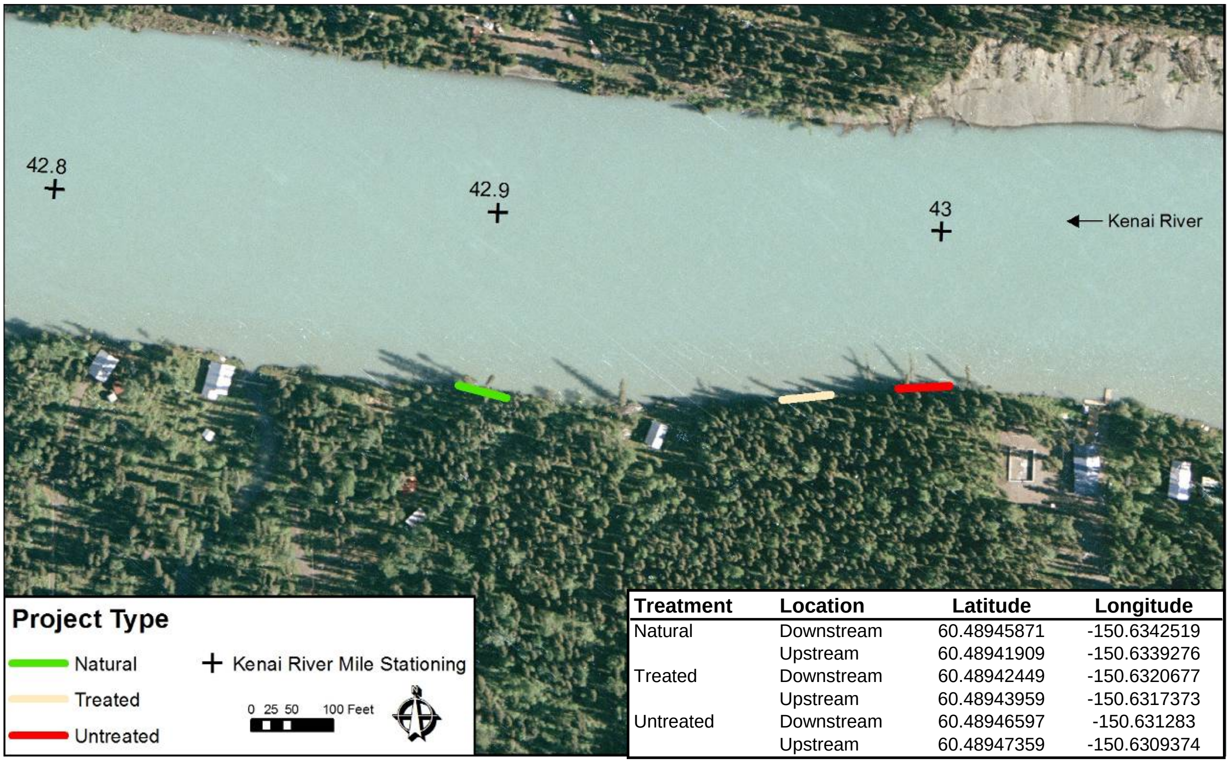
Site 4 - Untreated

Site 4 - Treated

Site 4 - Natural

Figure 8. Photos of Site 4 sample plots.

Site 5



Treatment	Location	Latitude	Longitude
Natural	Downstream	60.48945871	-150.6342519
	Upstream	60.48941909	-150.6339276
Treated	Downstream	60.48942449	-150.6320677
	Upstream	60.48943959	-150.6317373
Untreated	Downstream	60.48946597	-150.631283
	Upstream	60.48947359	-150.6309374

Figure 9. Location of Site 5. Latitude and longitude (WGS 84) are given for the upstream and downstream ends of each sample segment.

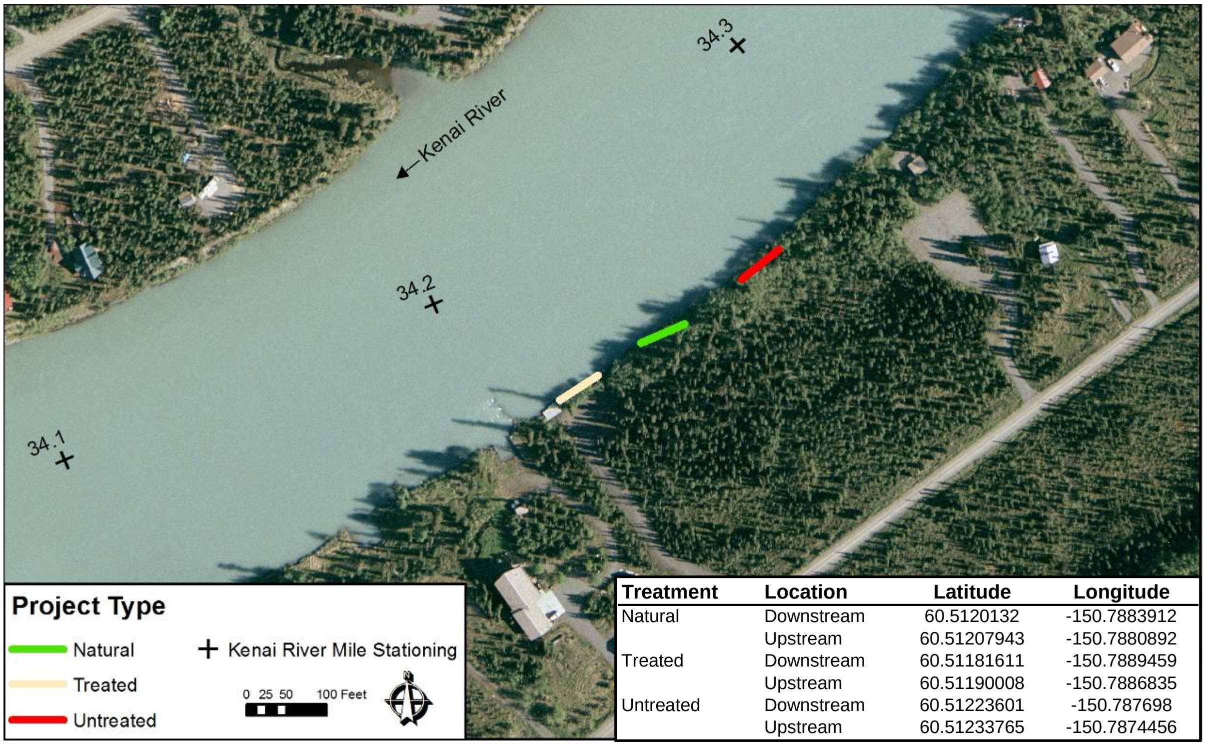

Site 5 - Untreated


Site 5 - Treated


Site 5 - Natural

Figure 10. Photos of Site 5 sample plots.

Site 6



Treatment	Location	Latitude	Longitude
Natural	Downstream	60.5120132	-150.7883912
	Upstream	60.51207943	-150.7880892
Treated	Downstream	60.51181611	-150.7889459
	Upstream	60.51190008	-150.7886835
Untreated	Downstream	60.51223601	-150.787698
	Upstream	60.51233765	-150.7874456

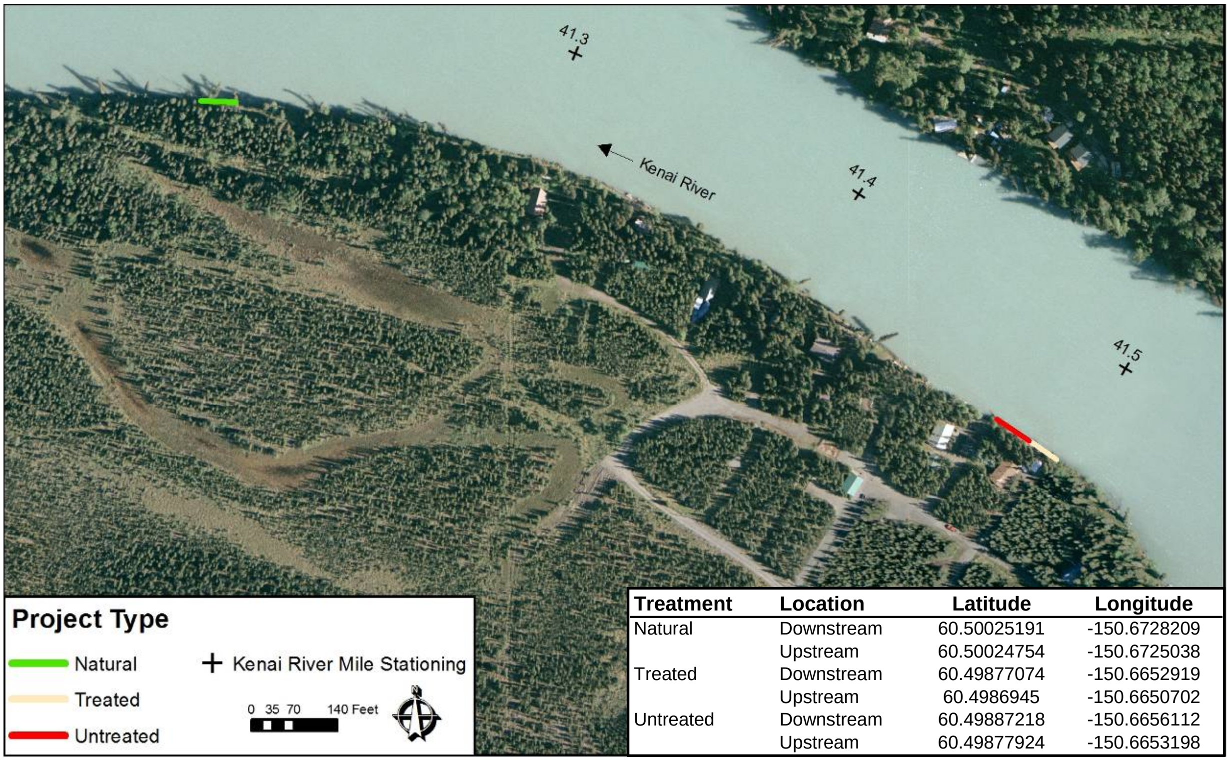
Figure 11. Location of Site 6. Latitude and longitude (WGS 84) are given for the upstream and downstream ends of each sample segment.

Site 6 - Untreated *Site 6 - Treated*

Site 6 - Natural

Figure 12. Photos of Site 6 sample plots.

Site 7



Treatment	Location	Latitude	Longitude
Natural	Downstream	60.50025191	-150.6728209
	Upstream	60.50024754	-150.6725038
Treated	Downstream	60.49877074	-150.6652919
	Upstream	60.4986945	-150.6650702
Untreated	Downstream	60.49887218	-150.6656112
	Upstream	60.49877924	-150.6653198

Figure 13. Location of Site 7. Latitude and longitude (WGS 84) are given for the upstream and downstream ends of each sample segment.

Site 7 - Untreated

Site 7 - Treated

Site 7 - Natural

Figure 14. Photos of Site 7 sample plots.